CHAPTER 5

Factor affecting to densified pellet

5.1 Introduction

Experiment results of the Densified pellet are discussed in this chapter which including to the characteristic of plastic waste and cornstover, the characteristics of pellet from corn stover (less than 3 mm in overall size), the characteristic of mixed plastic waste and corn stover, constitution model, and specific energy requirement. The parameter are preheating temperature, compression pressure, grinding size, moisture content, plastic waste and corn stover ratio.

5.2 Experimental methodology

This research was carried out for pelletization of mixed plastic waste and corn stover. The moisture content, mixed plastic and corn stover ratio, preheating temperature and pressure are the parameters which were investigated. The methodology of this research are described in Chapter 3.

Plastic waste and corn stover are mixed and compressed for pellet densification.

Various parameters which affect chemical characterization and physical properties of the pellet are studied

5.3 Result and discussion

5.3.1 Chemical characteristic of mixed plastic waste and corn stover.

The composition and calorific value of plastic wastes and corn Stover before compaction are listed in Table 5.1. It is found that plastic wastes appeared to have lower moisture and ash content than corn stover. However, calorific value of the waste is significantly higher value than that of biomass.

Table 5.1: Characteristics of plastic waste and corn stover.

Material	Moisture (%)	Ash (%)	Sulfur (%)	Chlorine (%)	Calorific value (MJ/kg)
Plastic wastes	0.35	0.22	0.17	0.15	58.0
Corn stover	8.47	8.62	0.08	0.11	15.4

Table 5.1 presents the characteristics of the pelletized fuels that is made from corn stover under 150 MPa compression. Preheat temperature of 25°C, 75°C and 100°C and moisture content of 5%, 10%, 15% and 20% were studied. The particle size of corn stover before pellietization is less than 3 mm.

Table 5.2: Characteristics of pellet which is made from corn stover.

Preheating temperature (°C)	Moisture content of material (%)	Pellet characteristics								
		Moisture content (%)	Ash (%)	Durability index (%)	Density (g/cm^3)	Sulfur (%)	Chlorine (%)	Carbon (%)	Oxygen (%)	Calorific value (MJ/kg)
25	5	2.17 ± 0.12	8.92 ± 0.63	86.4 ± 0.54	0.94 ± 0.01	0.08 ± 0.01	0.11±0.03	53.19±0.23	43.79±0.51	15.83 ± 0.13
25	10	3.62 ± 0.07	8.26 ± 0.08	72.73 ± 0.36	1.01 ± 0.01	0.09 ± 0.01	0.13±0.03	52.17±0.13	44.81±0.42	17.95 ± 0.17
25	15	5.36 ± 0.1	9.36 ± 0.08	89.74 ± 0.53	1.01 ± 0.01	0.08 ± 0.01	0.11±0.04	53.04±0.25	43.94±0.23	16.22 ± 0.13
25	20	7.3 ± 0.08	8.49 ± 0.05	82.22 ± 0.68	1.03 ± 0.08	0.08 ± 0.01	0.12±0.03	53.77±0.33	43.21±0.21	16.05 ± 0.44
75	5	3.95 ± 0.07	8.39 ± 0.16	85 ± 1	1.12 ± 0.01	0.08 ± 0.01	0.11±0.03	53.19±0.23	43.79±0.51	16.32 ± 0.11
75	10	4.43 ± 0.07	8.63 ± 0.07	86.96 ± 0.17	1.15 ± 0.03	0.09 ± 0.01	0.13±0.03	52.17±0.13	44.81±0.42	15.64 ± 0.29
75	15	6.53 ± 0.09	8.41 ± 0.08	81.4 ± 0.56	1.12 ± 0.01	0.08 ± 0.01	0.11±0.04	53.04±0.25	43.94±0.23	16.6 ± 0.24
75	20	7.26 ± 0.08	8.11 ± 0.11	80 ± 0.14	1.11 ± 0.1	0.08 ± 0.02	0.12±0.03	53.77±0.33	43.21±0.21	16.36 ± 0.15
100	5	0.96 ± 0.07	9.12 ± 0.13	86.21 ± 0.31	1.11 ± 0.01	0.08 ± 0.01	0.11±0.03	53.19±0.23	43.79±0.51	16.07 ± 0.12
100	10	1.05 ± 0.05	8.02 ± 0.1	99.15 ± 0.3	1.22 ± 0.08	0.08 ± 0.01	0.13±0.03	52.17±0.13	44.81±0.42	16.26 ± 0.21
100	15	2.37 ± 0.07	8.52 ± 0.15	98.32 ± 0.42	1.17 ± 0.01	0.08 ± 0.01	0.11±0.04	53.04±0.25	43.94±0.23	16.42 ± 0.31
100	20	5.5 ± 0.11	8.65 ± 0.12	97.1 ± 0.24	1.79 ± 0.01	0.08 ± 0.02	0.12±0.03	53.77±0.33	43.21±0.21	16.28 ± 0.45

As seen Table 5.2, densities of corn-stover pellet are between 0.94 g/cm^3 and 1.22 g/cm^3. Density of the pellet depends on preheating temperature and moisture content in the raw material as shown. Calorific values of the pellet are between 15.8 and 16.6 MJ/kg. The other objective of this research is to study pellet fuels which is called RDF-5. Table 5.1 shows that the calorific value of plastic waste is 4 times higher than corn stover’s (see Table 5.2). Therefore, it is possibility to use the mixed plastic waste and corn stoverrof as RDF-5. The quantity of corn stover in this study is 25, 35 and 45% by weight.

Table 5.3 to Table 5.5 lists the characteristics of pelletized fuels, that are made from mixed plastic waste and corn stover by 55:45%wt., 65:35%wt., and 75:25%wt., under 150 MPa compression. Preheat temperature of 25°C, 75°C and 100°C and moisture content of 5%, 10%, 15% and 20% were studied. Particle size of corn stover is between 0.5 - 1 mm. The result found that the mixed plastic waste and corn stover pellet has calorific value between 26 and 29 MJ/kg which is higher than corn stover pellet (see Table 5.2). Moreover, the mixed pellet has ash content and moisture content lower than the corn stover pellet. Therefore, properties of the mixed pellet could be improved by changing the ratio of mixtures and conditions of pelletization.

Table 5.3 Characteristic of mixed plastic waste and cornstover at 55:45%wt.

Preheating temperature (°C)	Moisture content of material (%)	Pellet characteristics								
		Moisture content (%)	Ash (%)	Durability index (%)	Density (g/cm^3)	Sulfur (%)	Chlorine (%)	Carbon (%)	Oxygen (%)	Calorific value (MJ/kg)
25	5	2.42 ± 0.39	6.76 ± 0.19	81.62 ± 0.12	0.8746 ± 0.0088	0.1194 ± 0.0014	0.12 ± 0.03	64.56 ± 7.3	21.38 ± 7.11	26.65 ± 0.86
25	10	3.37 ± 0.15	6.10 ± 0.10	78.86 ± 0.66	0.9526 ± 0.0093	0.1205 ± 0.0011	0.19 ± 0.03	67.9 ± 0.11	18.68 ± 0.49	27.53 ± 0.53
25	15	4.19 ± 0.23	6.34 ± 0.15	72.58 ± 0.12	0.6453 ± 0.0094	0.1303 ± 0.0008	0.08 ± 0.03	66.25 ± 0.11	20.12 ± 0.04	28.22 ± 0.2
25	20	6.3 ± 0.19	6.00 ± 0.13	90.7 ± 0.9	0.5779 ± 0.0065	0.1212 ± 0.0011	0.12 ± 0.04	66.22 ± 0.25	20.15 ± 0.13	27.15 ± 0.13
75	5	2.36 ± 0.14	5.46 ± 0.14	98.57 ± 0.13	0.8779 ± 0.0106	0.1194 ± 0.0014	0.12 ± 0.03	64.56 ± 7.3	21.38 ± 7.11	26.65 ± 0.86
75	10	3.23 ± 0.22	6.24 ± 0.14	93.83 ± 0.1	1.0231 ± 0.0082	0.1205 ± 0.0011	0.19 ± 0.03	67.9 ± 0.11	18.68 ± 0.49	27.53 ± 0.53
75	15	3.81 ± 0.31	6.12 ± 0.13	90.7 ± 0.12	0.8012 ± 0.0086	0.1303 ± 0.0008	0.08 ± 0.03	66.25 ± 0.11	20.12 ± 0.04	28.22 ± 0.2
75	20	6.05 ± 0.18	6.38 ± 0.15	95.48 ± 0.12	0.7734 ± 0.0082	0.1212 ± 0.0011	0.12 ± 0.04	66.22 ± 0.25	20.15 ± 0.13	27.15 ± 0.13
100	5	2.21 ± 0.24	6.77 ± 0.10	98.62 ± 0.1	0.9444 ± 0.0093	0.1194 ± 0.0014	0.12 ± 0.03	64.56 ± 7.3	21.38 ± 7.11	26.65 ± 0.86
100	10	3.07 ± 0.21	6.29 ± 0.12	96.85 ± 0.13	1.0319 ± 0.0094	0.1205 ± 0.0011	0.19 ± 0.03	67.9 ± 0.11	18.68 ± 0.49	27.53 ± 0.53
100	15	3.77 ± 0.22	6.42 ± 0.13	93.21 ± 0.1	0.8669 ± 0.0088	0.1303 ± 0.0008	0.08 ± 0.03	66.25 ± 0.11	20.12 ± 0.04	28.22 ± 0.2
100	20	5.97 ± 0.23	6.57 ± 0.16	81.62 ± 0.12	0.6191 ± 0.6129	0.1212 ± 0.0011	0.12 ± 0.04	66.22 ± 0.25	20.15 ± 0.13	27.15 ± 0.13

Table 5.4 Characteristic of mixed plastic waste and cornstover at 65:35%wt.

Preheating temperature (°C)	Moisture content of material (%)	Pellet characteristics								
		Moisture content (%)	Ash (%)	Durability index (%)	Density (g/cm^3)	Sulfur (%)	Chlorine (%)	Carbon (%)	Oxygen (%)	Calorific value (MJ/kg)
25	5	1.77 ± 0.06	3.42 ± 0.03	76.53 ± 0.1	0.6048 ± 0.0088	0.144 ± 0.0008	0.14 ± 0.01	73.43 ± 0.27	12.39 ± 0.11	36.42 ± 0.12
25	10	1.98 ± 0.17	3.23 ± 0.02	74.32 ± 0.9	0.7953 ± 0.0093	0.1403 ± 0.0007	0.13 ± 0.02	69.14 ± 0.16	17.4 ± 0.01	35.17 ± 0.77
25	15	2.97 ± 0.12	3.42 ± 0.03	73.21 ± 0.1	0.5917 ± 0.0086	0.1498 ± 0.0006	0.14 ± 0.01	67.9 ± 0.13	17.48 ± 0.19	36.22 ± 0.73
25	20	1.34 ± 0.14	3.57 ± 0.04	70.28 ± 0.11	0.5646 ± 0.0088	0.1424 ± 0.0006	0.13 ± 0.01	70.54 ± 0.19	13.98 ± 0.22	34.9 ± 0.58
75	5	1.61 ± 0.02	3.29 ± 0.03	88.46 ± 0.11	0.6722 ± 0.0086	0.144 ± 0.0008	0.14 ± 0.01	73.43 ± 0.27	12.39 ± 0.11	36.42 ± 0.12
75	10	1.87 ± 0.03	3.77 ± 0.02	96.21 ± 0.9	0.8919 ± 0.0088	0.1403 ± 0.0007	0.13 ± 0.02	69.14 ± 0.16	17.4 ± 0.01	35.17 ± 0.77
75	15	2.52 ± 0.03	3.43 ± 0.02	88.03 ± 0.1	0.6644 ± 0.0093	0.1498 ± 0.0006	0.14 ± 0.01	67.9 ± 0.13	17.48 ± 0.19	36.22 ± 0.73
75	20	3.08 ± 0.03	3.12 ± 0.03	86.44 ± 0.12	0.6022 ± 0.0094	0.1424 ± 0.0006	0.13 ± 0.01	70.54 ± 0.19	13.98 ± 0.22	34.9 ± 0.58
100	5	0.68 ± 0.06	3.24 ± 0.03	86.08 ± 0.1	0.6862 ± 0.0088	0.144 ± 0.0008	0.14 ± 0.01	73.43 ± 0.27	12.39 ± 0.11	36.42 ± 0.12
100	10	0.89 ± 0.1	3.46 ± 0.03	96.97 ± 0.21	0.6961 ± 0.0086	0.1403 ± 0.0007	0.13 ± 0.02	69.14 ± 0.16	17.4 ± 0.01	35.17 ± 0.77
100	15	2.28 ± 0.1	3.30 ± 0.03	86.65 ± 0.1	0.6876 ± 0.0065	0.1498 ± 0.0006	0.14 ± 0.01	67.9 ± 0.13	17.48 ± 0.19	36.22 ± 0.73
100	20	2.86 ± 0.03	3.38 ± 0.03	84.23 ± 0.11	0.6156 ± 0.0094	0.1424 ± 0.0006	0.13 ± 0.01	70.54 ± 0.19	13.98 ± 0.22	34.9 ± 0.58

Table 5.5 Characteristic of mixed plastic waste and cornstover at 75:25%wt.

Preheating temperature (°C)	Moisture content of material (%)	Pellet characteristics								
		Moisture content (%)	Ash (%)	Durability index (%)	Density (g/cm^3)	Sulfur (%)	Chlorine (%)	Carbon (%)	Oxygen (%)	Calorific value (MJ/kg)
25	5	1.25 ± 0.04	1.26 ± 0.05	74.02 ± 0.11	0.5812 ± 0.0093	0.163 ± 0.0008	0.16 ± 0.01	79.38 ± 0.13	5.34 ± 0.31	40.52 ± 0.08
25	10	2.43 ± 0.04	1.23 ± 0.04	74.64 ± 0.9	0.6349 ± 0.0065	0.1603 ± 0.0011	0.16 ± 0.01	76.65 ± 0.4	7.41 ± 0.6	39.99 ± 0.12
25	15	2.43 ± 0.03	1.34 ± 0.03	72.34 ± 0.12	0.4303 ± 0.0093	0.1611 ± 0.0008	0.16 ± 0.01	75.22 ± 0.04	9.5 ± 0.33	39.86 ± 0.09
25	20	3.22 ± 0.05	1.42 ± 0.04	70.53 ± 0.9	0.3912 ± 0.0082	0.1642 ± 0.001	0.16 ± 0.01	74.58 ± 0.18	9.62 ± 0.25	39.17 ± 0.14
75	5	1.13 ± 0.02	1.22 ± 0.04	80.23 ± 0.1	0.6023 ± 0.0094	0.163 ± 0.0008	0.16 ± 0.01	79.38 ± 0.13	5.34 ± 0.31	40.52 ± 0.08
75	10	1.44 ± 0.02	1.38 ± 0.04	96.08 ± 0.1	0.6823 ± 0.0082	0.1603 ± 0.0011	0.16 ± 0.01	76.65 ± 0.4	7.41 ± 0.6	39.99 ± 0.12
75	15	1.99 ± 0.03	1.29 ± 0.02	86.78 ± 0.98	0.5738 ± 0.0093	0.1611 ± 0.0008	0.16 ± 0.01	75.22 ± 0.04	9.5 ± 0.33	39.86 ± 0.09
75	20	2.81 ± 0.04	1.31 ± 0.05	85.42 ± 0.1	0.5571 ± 0.0093	0.1642 ± 0.001	0.16 ± 0.01	74.58 ± 0.18	9.62 ± 0.25	39.17 ± 0.14
100	5	0.94 ± 0.03	1.38 ± 0.04	90.83 ± 0.12	0.6185 ± 0.0082	0.163 ± 0.0008	0.16 ± 0.01	79.38 ± 0.13	5.34 ± 0.31	40.52 ± 0.08
100	10	1.01 ± 0.02	1.22 ± 0.04	87.56 ± 0.1	0.6281 ± 0.0007	0.1603 ± 0.0011	0.16 ± 0.01	76.65 ± 0.4	7.41 ± 0.6	39.99 ± 0.12
100	15	1.46 ± 0.01	1.33 ± 0.02	85.12 ± 0.11	0.617 ± 0.0093	0.1611 ± 0.0008	0.16 ± 0.01	75.22 ± 0.04	9.5 ± 0.33	39.86 ± 0.09
100	20	N	N	N	N	0.1642 ± 0.001	0.16 ± 0.01	74.58 ± 0.18	9.62 ± 0.25	39.17 ± 0.14

*Remark : N = not detected

5.3.2 Chemical characteristic and properties of mixed plastic waste and corn stover.

Several parameters affect chemical characteristics and physical properties of mixed plastic waste and corn stover pellet. Chemical characteristic and properties of mixed pellet are density, moisture content of pellet, durability, stability and ash content. Parameters, i.e. preheating temperature, compression pressure, grinding size, moisture content, mixed plastic waste and corn stover ratio, are investigated in this study. ANOVA test is used for surveying that which parameter is the most effect to pellet's properties. Table 5.6 to Table 5.10 shows results of ANOVA analysis of moisture content, pellet density, durability, ash content, pellet stability, calorific value and the contents of sulfur chlorine carbon hydrogen nitrogen and oxygen. The result found that the moisture content of pellet and pellet durability were significantly affected by main effect and the interaction of all 2 way, 3 way, 4 way and 5 way at the 5% level. Pellet density was significantly affected by main effect and the interaction of all 2 way, 3 way, 4 way and 5 way at the 5% level. But, the interaction of mixed plastic waste and corn stover ratio x compression pressure x preheating temperature was not significant ($P>0.05$). The effects of grinding size and moisture content, and mixed plastic waste and corn stover ratio x grinding size, mixed plastic waste and corn stover ratio x compression pressure, and grinding size x preheating temperature were not significant on ash content of pellet. The interaction of all 3 way, 4 way and 5 way of pellet stability can not predicted. Because, the experimental of pellet stability is tested for only one trial. The stability of pellet was significantly affected by compression pressure, temperature and moisture content. The interaction of compression pressure x moisture content, preheating temperature x moisture content, and compression pressure x preheating temperature were significant on the pellet stability. The result of mains effect and interactions effect on the physical characteristics (calorific value, and the content of sulfur, chlorine, carbon, hydrogen, nitrogen, and oxygen) were the same. All main effects were not significant on chemical characteristics, except mixed plastic waste and corn stover ratio, and moisture content. All the interaction of 2 way, 3 way, 4 way and 5 way at 5% level were not significant on chemical characteristics except mixed plastic waste and corn stover ratio x moisture content. The densification process variables for ANOVA analysis on table 5.6 – 5.10 are mixed plastic waste and corn stover ratio (R), grinding size (S), compression pressure (P), preheating temperature (T), and moisture content (M).

Table 5.6 : The ANOVA test result of pellet moisture content.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1589.859[a]	316	5.031	218.871	.000
Intercept	5907.472	1	5907.472	256991.127	.000
R	277.126	2	138.563	6027.858	.000
S	1.385	2	.692	30.122	.000
P	7.020	2	3.510	152.705	.000
T	188.200	2	94.100	4093.605	.000
M	495.999	3	165.333	7192.442	.000
R * S	81.646	4	20.412	887.961	.000
R * P	16.572	4	4.143	180.229	.000
R * T	3.611	4	.903	39.275	.000
R * M	62.624	6	10.437	454.055	.000
S * P	14.259	4	3.565	155.072	.000
S * T	5.403	4	1.351	58.765	.000
S * M	14.783	6	2.464	107.185	.000
P * T	3.105	4	.776	33.770	.000
P * M	10.519	6	1.753	76.268	.000
T * M	25.504	6	4.251	184.914	.000
R * S * P	40.031	8	5.004	217.680	.000
R * S * T	27.748	8	3.468	150.889	.000
R * S * M	21.346	12	1.779	77.383	.000
R * P * T	4.897	8	.612	26.628	.000
R * P * M	20.151	12	1.679	73.053	.000
R * T * M	26.179	12	2.182	94.905	.000
S * P * T	5.686	8	.711	30.919	.000
S * P * M	9.072	12	.756	32.889	.000
S * T * M	7.187	12	.599	26.055	.000
P * T * M	8.182	12	.682	29.662	.000
R * S * P * T	17.378	16	1.086	47.250	.000
R * S * P * M	22.402	24	.933	40.607	.000
R * S * T * M	14.287	22	.649	28.250	.000
R * P * T * M	8.091	23	.352	15.303	.000
S * P * T * M	10.229	24	.426	18.542	.000
R * S * P * T * M	18.714	44	.425	18.502	.000
Error	14.574	634	.023		
Total	7931.109	951			
Corrected Total	1604.433	950			

a. R Squared = .991 (Adjusted R Squared = .986)

Table 5.7 : The ANOVA test result of pellet density.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	20.079[a]	314	.064	30.398	.000
Intercept	361.201	1	361.201	171709.097	.000
R	4.559	2	2.279	1083.590	.000
S	1.775	2	.888	422.010	.000
P	3.790	2	1.895	900.868	.000
T	2.535	2	1.267	602.436	.000
M	3.903	3	1.301	618.506	.000
R * S	.223	4	.056	26.546	.000
R * P	.056	4	.014	6.635	.000
R * T	.064	4	.016	7.658	.000
R * M	.059	6	.010	4.703	.000
S * P	.059	4	.015	7.019	.000
S * T	.073	4	.018	8.734	.000
S * M	.175	6	.029	13.871	.000
P * T	.129	4	.032	15.343	.000
P * M	.105	6	.017	8.313	.000
T * M	.057	6	.009	4.490	.000
R * S * P	.070	8	.009	4.181	.000
R * S * T	.076	8	.010	4.529	.000
R * S * M	.132	12	.011	5.245	.000
R * P * T	.030	8	.004	1.779	.078
R * P * M	.073	12	.006	2.874	.001
R * T * M	.119	11	.011	5.153	.000
S * P * T	.216	8	.027	12.821	.000
S * P * M	.113	12	.009	4.475	.000
S * T * M	.094	12	.008	3.730	.000
P * T * M	.048	12	.004	1.920	.029
R * S * P * T	.085	16	.005	2.512	.001
R * S * P * M	.138	24	.006	2.728	.000
R * S * T * M	.116	22	.005	2.515	.000
R * P * T * M	.139	22	.006	3.011	.000
S * P * T * M	.184	24	.008	3.650	.000
R * S * P * T * M	.208	44	.005	2.244	.000
Error	1.325	630	.002		
Total	393.655	945			
Corrected Total	21.404	944			

a. R Squared = .938 (Adjusted R Squared = .907)

Table 5.8 : The ANOVA test result of pellet durability.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	122831.490[a]	314	391.183	348.329	.000
Intercept	6149069.403	1	6149069.403	5475437.612	.000
R	17283.306	2	8641.653	7694.958	.000
S	2920.577	2	1460.288	1300.313	.000
P	12128.016	2	6064.008	5399.695	.000
T	66047.121	2	33023.561	29405.823	.000
M	7980.977	3	2660.326	2368.886	.000
R * S	407.096	4	101.774	90.625	.000
R * P	1008.804	4	252.201	224.572	.000
R * T	212.126	4	53.031	47.222	.000
R * M	226.801	6	37.800	33.659	.000
S * P	503.199	4	125.800	112.018	.000
S * T	764.272	4	191.068	170.137	.000
S * M	311.084	6	51.847	46.167	.000
P * T	202.884	4	50.721	45.164	.000
P * M	503.825	6	83.971	74.772	.000
T * M	499.879	6	83.313	74.186	.000
R * S * P	376.935	8	47.117	41.955	.000
R * S * T	393.043	8	49.130	43.748	.000
R * S * M	271.974	12	22.665	20.182	.000
R * P * T	555.507	8	69.438	61.831	.000
R * P * M	301.813	12	25.151	22.396	.000
R * T * M	196.161	11	17.833	15.879	.000
S * P * T	430.663	8	53.833	47.935	.000
S * P * M	328.086	12	27.340	24.345	.000
S * T * M	662.355	12	55.196	49.149	.000
P * T * M	546.131	12	45.511	40.525	.000
R * S * P * T	629.695	16	39.356	35.044	.000
R * S * P * M	381.872	24	15.911	14.168	.000
R * S * T * M	470.822	22	21.401	19.057	.000
R * P * T * M	510.330	22	23.197	20.656	.000
S * P * T * M	453.117	24	18.880	16.812	.000
R * S * P * T * M	653.186	44	14.845	13.219	.000
Error	707.508	630	1.123		
Total	6408766.320	945			
Corrected Total	123538.997	944			

a. R Squared = .994 (Adjusted R Squared = .991)

Table 5.9 : The ANOVA test result of pellet ash content.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4026.491[a]	314	12.823	572.576	.000
Intercept	12560.972	1	12560.972	560866.320	.000
R	3838.429	2	1919.214	85695.816	.000
S	.038	2	.019	.852	.427
P	.202	2	.101	4.513	.011
T	.345	2	.172	7.701	.000
M	.099	3	.033	1.468	.222
R * S	.121	4	.030	1.354	.249
R * P	.137	4	.034	1.524	.193
R * T	.253	4	.063	2.829	.024
R * M	.817	6	.136	6.080	.000
S * P	1.313	4	.328	14.658	.000
S * T	.066	4	.017	.741	.565
S * M	.676	6	.113	5.033	.000
P * T	.578	4	.144	6.448	.000
P * M	1.037	6	.173	7.715	.000
T * M	.432	6	.072	3.212	.004
R * S * P	1.683	8	.210	9.394	.000
R * S * T	1.075	8	.134	5.999	.000
R * S * M	1.168	12	.097	4.347	.000
R * P * T	2.893	8	.362	16.148	.000
R * P * M	1.686	12	.140	6.273	.000
R * T * M	1.896	11	.172	7.696	.000
S * P * T	.754	8	.094	4.206	.000
S * P * M	.931	12	.078	3.465	.000
S * T * M	2.135	12	.178	7.944	.000
P * T * M	2.303	12	.192	8.570	.000
R * S * P * T	2.495	16	.156	6.964	.000
R * S * P * M	1.621	24	.068	3.017	.000
R * S * T * M	3.818	22	.174	7.748	.000
R * P * T * M	2.270	22	.103	4.608	.000
S * P * T * M	4.815	24	.201	8.958	.000
R * S * P * T * M	7.106	44	.161	7.211	.000
Error	14.109	630	.022		
Total	17272.425	945			
Corrected Total	4040.600	944			

a. R Squared = .997 (Adjusted R Squared = .995)

Table 5.10 : The ANOVA test result of pellet stability.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2777043.825[a]	59	47068.539	294.421	.000
Intercept	107619939.692	1	107619939.692	673179.069	.000
R	.000	2	.000	.000	1.000
S	.000	2	.000	.000	1.000
P	68985.815	2	34492.907	215.758	.000
T	653184.000	2	326592.000	2042.883	.000
M	494773.200	3	164924.400	1031.627	.000
P * M	72478.125	6	12079.688	75.560	.000
R * M	.000	6	.000	.000	1.000
S * M	.000	6	.000	.000	1.000
T * M	1125030.000	6	187505.000	1172.872	.000
R * P	77.175	4	19.294	.121	.975
S * P	.000	4	.000	.000	1.000
P * T	130784.625	4	32696.156	204.519	.000
R * S	.000	4	.000	.000	1.000
R * T	.000	4	.000	.000	1.000
S * T	.000	4	.000	.000	1.000
Error	141483.375	885	159.868		
Total	115919397.000	945			
Corrected Total	2918527.200	944			

a. R Squared = .952 (Adjusted R Squared = .948)

Table 5.11 : The ANOVA test result of calorific value.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	26524.719[a]	323	82.120	436.730	.000
Intercept	1146179.916	1	1146179.916	6095620.899	.000
R	26216.910	2	13108.455	69713.464	.000
S	.000	2	.000	.000	1.000
P	.000	2	.000	.000	1.000
T	.000	2	.000	.000	1.000
M	133.323	3	44.441	236.347	.000
R * S	.000	4	.000	.000	1.000
R * P	.000	4	.000	.000	1.000
R * T	.000	4	.000	.000	1.000
R * M	174.485	6	29.081	154.658	.000
S * P	.000	4	.000	.000	1.000
S * T	.000	4	.000	.000	1.000
S * M	.000	6	.000	.000	1.000
P * T	.000	4	.000	.000	1.000
P * M	.000	6	.000	.000	1.000
T * M	.000	6	.000	.000	1.000
R * S * P	.000	8	.000	.000	1.000
R * S * T	.000	8	.000	.000	1.000
R * S * M	.000	12	.000	.000	1.000
R * P * T	.000	8	.000	.000	1.000
R * P * M	.000	12	.000	.000	1.000
R * T * M	.000	12	.000	.000	1.000
S * P * T	.000	8	.000	.000	1.000
S * P * M	.000	12	.000	.000	1.000
S * T * M	.000	12	.000	.000	1.000
P * T * M	.000	12	.000	.000	1.000
R * S * P * T	.000	16	.000	.000	1.000
R * S * P * M	.000	24	.000	.000	1.000
R * S * T * M	.000	24	.000	.000	1.000
R * P * T * M	.000	24	.000	.000	1.000
S * P * T * M	.000	24	.000	.000	1.000
R * S * P * T * M	.000	48	.000	.000	1.000
Error	121.846	648	.188		
Total	1172826.481	972			
Corrected Total	26646.564	971			

a. R Squared = .995 (Adjusted R Squared = .993)

Table 5.12 : The ANOVA test result of sulfur.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.262[a]	323	.001	929.527	.000
Intercept	19.888	1	19.888	22816075.741	.000
R	.251	2	.125	143849.573	.000
S	.000	2	.000	.000	1.000
P	.000	2	.000	.000	1.000
T	.000	2	.000	.000	1.000
M	.006	3	.002	2265.186	.000
R * S	.000	4	.000	.000	1.000
R * P	.000	4	.000	.000	1.000
R * T	.000	4	.000	.000	1.000
R * M	.005	6	.001	957.106	.000
S * P	.000	4	.000	.000	1.000
S * T	.000	4	.000	.000	1.000
S * M	.000	6	.000	.000	1.000
P * T	.000	4	.000	.000	1.000
P * M	.000	6	.000	.000	1.000
T * M	.000	6	.000	.000	1.000
R * S * P	.000	8	.000	.000	1.000
R * S * T	.000	8	.000	.000	1.000
R * S * M	.000	12	.000	.000	1.000
R * P * T	.000	8	.000	.000	1.000
R * P * M	.000	12	.000	.000	1.000
R * T * M	.000	12	.000	.000	1.000
S * P * T	.000	8	.000	.000	1.000
S * P * M	.000	12	.000	.000	1.000
S * T * M	.000	12	.000	.000	1.000
P * T * M	.000	12	.000	.000	1.000
R * S * P * T	.000	16	.000	.000	1.000
R * S * P * M	.000	24	.000	.000	1.000
R * S * T * M	.000	24	.000	.000	1.000
R * P * T * M	.000	24	.000	.000	1.000
S * P * T * M	.000	24	.000	.000	1.000
R * S * P * T * M	.000	48	.000	.000	1.000
Error	.001	648	8.717E-7		
Total	20.150	972			
Corrected Total	.262	971			

a. R Squared = .998 (Adjusted R Squared = .997)

Table 5.13 : The ANOVA test result of chlorine.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	.738[a]	323	.002	6.325	.000
Intercept	19.203	1	19.203	53176.708	.000
R	.195	2	.098	270.000	.000
S	.000	2	.000	.000	1.000
P	.000	2	.000	.000	1.000
T	.000	2	.000	.000	1.000
M	.150	3	.050	138.738	.000
R * S	.000	4	.000	.000	1.000
R * P	.000	4	.000	.000	1.000
R * T	.000	4	.000	.000	1.000
R * M	.392	6	.065	181.108	.000
S * P	.000	4	.000	.000	1.000
S * T	.000	4	.000	.000	1.000
S * M	.000	6	.000	.000	1.000
P * T	.000	4	.000	.000	1.000
P * M	.000	6	.000	.000	1.000
T * M	.000	6	.000	.000	1.000
R * S * P	.000	8	.000	.000	1.000
R * S * T	.000	8	.000	.000	1.000
R * S * M	.000	12	.000	.000	1.000
R * P * T	.000	8	.000	.000	1.000
R * P * M	.000	12	.000	.000	1.000
R * T * M	.000	12	.000	.000	1.000
S * P * T	.000	8	.000	.000	1.000
S * P * M	.000	12	.000	.000	1.000
S * T * M	.000	12	.000	.000	1.000
P * T * M	.000	12	.000	.000	1.000
R * S * P * T	.000	16	.000	.000	1.000
R * S * P * M	.000	24	.000	.000	1.000
R * S * T * M	.000	24	.000	.000	1.000
R * P * T * M	.000	24	.000	.000	1.000
S * P * T * M	.000	24	.000	.000	1.000
R * S * P * T * M	.000	48	.000	.000	1.000
Error	.234	648	.000		
Total	20.174	972			
Corrected Total	.972	971			

a. R Squared = .759 (Adjusted R Squared = .639)

Table 5.14 : The ANOVA test result of carbon.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	13419.615[a]	323	41.547	9.267	.000
Intercept	3264651.281	1	3264651.281	728196.663	.000
R	11465.904	2	5732.952	1278.763	.000
S	.000	2	.000	.000	1.000
P	.000	2	.000	.000	1.000
T	.000	2	.000	.000	1.000
M	638.507	3	212.836	47.474	.000
R * S	.000	4	.000	.000	1.000
R * P	.000	4	.000	.000	1.000
R * T	.000	4	.000	.000	1.000
R * M	1315.204	6	219.201	48.894	.000
S * P	.000	4	.000	.000	1.000
S * T	.000	4	.000	.000	1.000
S * M	.000	6	.000	.000	1.000
P * T	.000	4	.000	.000	1.000
P * M	.000	6	.000	.000	1.000
T * M	.000	6	.000	.000	1.000
R * S * P	.000	8	.000	.000	1.000
R * S * T	.000	8	.000	.000	1.000
R * S * M	.000	12	.000	.000	1.000
R * P * T	.000	8	.000	.000	1.000
R * P * M	.000	12	.000	.000	1.000
R * T * M	.000	12	.000	.000	1.000
S * P * T	.000	8	.000	.000	1.000
S * P * M	.000	12	.000	.000	1.000
S * T * M	.000	12	.000	.000	1.000
P * T * M	.000	12	.000	.000	1.000
R * S * P * T	.000	16	.000	.000	1.000
R * S * P * M	.000	24	.000	.000	1.000
R * S * T * M	.000	24	.000	.000	1.000
R * P * T * M	.000	24	.000	.000	1.000
S * P * T * M	.000	24	.000	.000	1.000
R * S * P * T* M	.000	48	.000	.000	1.000
Error	1452.557	324	4.483		
Total	3279523.453	648			
Corrected Total	14872.172	647			

a. R Squared = .902 (Adjusted R Squared = .805)

Table 5.15 : The ANOVA test result of hydrogen.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	507.404[a]	323	1.571	20.711	.000
Intercept	132262.531	1	132262.531	1743738.051	.000
R	359.995	2	179.998	2373.074	.000
S	.000	2	.000	.000	1.000
P	.000	2	.000	.000	1.000
T	.000	2	.000	.000	1.000
M	43.743	3	14.581	192.233	.000
R * S	.000	4	.000	.000	1.000
R * P	.000	4	.000	.000	1.000
R* T	.000	4	.000	.000	1.000
R * M	103.666	6	17.278	227.787	.000
S * P	.000	4	.000	.000	1.000
S * T	.000	4	.000	.000	1.000
S * M	.000	6	.000	.000	1.000
P * T	.000	4	.000	.000	1.000
P * M	.000	6	.000	.000	1.000
T * M	.000	6	.000	.000	1.000
R * S * P	.000	8	.000	.000	1.000
R * S * T	.000	8	.000	.000	1.000
R * S * M	.000	12	.000	.000	1.000
R * P * T	.000	8	.000	.000	1.000
R * P * M	.000	12	.000	.000	1.000
R * T * M	.000	12	.000	.000	1.000
S * P * T	.000	8	.000	.000	1.000
S * P * M	.000	12	.000	.000	1.000
S * T * M	.000	12	.000	.000	1.000
P * T * M	.000	12	.000	.000	1.000
R * S * P * T	.000	16	.000	.000	1.000
R * S * P * M	.000	24	.000	.000	1.000
R * S * T * M	.000	24	.000	.000	1.000
R * P * T * M	.000	24	.000	.000	1.000
S * P * T * M	.000	24	.000	.000	1.000
R * S * P * T* M	.000	48	.000	.000	1.000
Error	24.575	324	.076		
Total	132794.510	648			
Corrected Total	531.979	647			

a. R Squared = .954 (Adjusted R Squared = .908)

Table 5.16 : The ANOVA test result of nitrogen.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4.603[a]	323	.014	5.758	.000
Intercept	11.664	1	11.664	4712.909	.000
R	3.930	2	1.965	793.955	.000
S	.000	2	.000	.000	1.000
P	.000	2	.000	.000	1.000
T	.000	2	.000	.000	1.000
M	.484	3	.161	65.152	.000
R * S	.000	4	.000	.000	1.000
R * P	.000	4	.000	.000	1.000
R * T	.000	4	.000	.000	1.000
R * M	.189	6	.032	12.742	.000
S * P	.000	4	.000	.000	1.000
S * T	.000	4	.000	.000	1.000
S * M	.000	6	.000	.000	1.000
P * T	.000	4	.000	.000	1.000
P * M	.000	6	.000	.000	1.000
T * M	.000	6	.000	.000	1.000
R * S * P	.000	8	.000	.000	1.000
R * S * T	.000	8	.000	.000	1.000
R * S * M	.000	12	.000	.000	1.000
R * P * T	.000	8	.000	.000	1.000
R * P * M	.000	12	.000	.000	1.000
R * T * M	.000	12	.000	.000	1.000
S * P * T	.000	8	.000	.000	1.000
S * P * M	.000	12	.000	.000	1.000
S * T * M	.000	12	.000	.000	1.000
P * T * M	.000	12	.000	.000	1.000
R * S * P * T	.000	16	.000	.000	1.000
R * S * P * M	.000	24	.000	.000	1.000
R * S * T * M	.000	24	.000	.000	1.000
R * P * T * M	.000	24	.000	.000	1.000
S * P * T * M	.000	24	.000	.000	1.000
R * S * P * T * M	.000	48	.000	.000	1.000
Error	.802	324	.002		
Total	17.069	648			
Corrected Total	5.405	647			

a. R Squared = .852 (Adjusted R Squared = .704)

Table 5.17 : The ANOVA test result of oxygen.

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	17992.450[a]	323	55.704	12.984	.000
Intercept	135405.478	1	135405.478	31560.749	.000
R	16090.211	2	8045.105	1875.179	.000
S	.000	2	.000	.000	1.000
P	.000	2	.000	.000	1.000
T	.000	2	.000	.000	1.000
M	579.459	3	193.153	45.021	.000
R * S	.000	4	.000	.000	1.000
R * P	.000	4	.000	.000	1.000
R * T	.000	4	.000	.000	1.000
R * M	1322.780	6	220.463	51.386	.000
S * P	.000	4	.000	.000	1.000
S * T	.000	4	.000	.000	1.000
S * M	.000	6	.000	.000	1.000
P * T	.000	4	.000	.000	1.000
P * M	.000	6	.000	.000	1.000
T * M	.000	6	.000	.000	1.000
R * S * P	.000	8	.000	.000	1.000
R * S * T	.000	8	.000	.000	1.000
R * S * M	.000	12	.000	.000	1.000
R * P * T	.000	8	.000	.000	1.000
R * P * M	.000	12	.000	.000	1.000
R * T * M	.000	12	.000	.000	1.000
S * P * T	.000	8	.000	.000	1.000
S * P * M	.000	12	.000	.000	1.000
S * T * M	.000	12	.000	.000	1.000
P * T * M	.000	12	.000	.000	1.000
R * S * P * T	.000	16	.000	.000	1.000
R * S * P * M	.000	24	.000	.000	1.000
R * S * T * M	.000	24	.000	.000	1.000
R * P * T * M	.000	24	.000	.000	1.000
S * P * T * M	.000	24	.000	.000	1.000
R * S * P * T* M	.000	48	.000	.000	1.000
Error	1390.061	324	4.290		
Total	154787.990	648			
Corrected Total	19382.511	647			

a. R Squared = .928 (Adjusted R Squared = .857)

From factors analysis, the effect on pellet properties are as follows:

1) The effect of mixed plastic waste and corn stover ratio

Table 5.18 shows the characteristics of pellet from various ratio of mixed plastic waste and corn stover under 150 MPa compression and preheating temperature of 75°C. Moisture contents of the material are 5%, 10%, 15% and 20%. It is found that the lowest heating value is at 55:45 of mixed plastic waste and corn stover ratio while the highest on is at 75:25 because plastic has higher heating value and carbon than corn stover. Therefore, high amount of plastic waste in the mixed pellet leaded to high heating value. In addition, sulfur and chlorine are rised as plastic waste content increases. Figure 5.1 and Figure 5.2 present pellet density and durability index, respectively, of the mixed pellet with 55:45, 65:35 and 75:25 PL:C ratio. It is found that density and durability index are decreased as increasing plastic volume.

Table 5.18 Characteristics of pellet from mixed plastic waste and corn stover at different ratio.

No.	PL:C ratio	P	T	H	HV	S	Cl	C	H	N	O
1	55:45	150	75	5	26.65 ± 0.86	0.1194 ± 0.0014	0.12 ± 0.03	64.56 ± 7.3	13.82 ± 0.23	0.2 ± 0.04	21.38 ± 7.11
				10	27.53 ± 0.53	0.1205 ± 0.0011	0.19 ± 0.03	67.9 ± 0.11	13.13 ± 0.39	0.22 ± 0.06	18.68 ± 0.49
				15	28.22 ± 0.2	0.1303 ± 0.0008	0.08 ± 0.03	66.25 ± 0.11	13.43 ± 0.04	0.25 ± 0.13	20.12 ± 0.04
				20	27.15 ± 0.13	0.1212 ± 0.0011	0.12 ± 0.04	66.22 ± 0.25	13.41 ± 0.37	0.19 ± 0.05	20.15 ± 0.13
2	65:35	150	75	5	36.42 ± 0.12	0.144 ± 0.0008	0.14 ± 0.01	73.43 ± 0.27	13.9 ± 0.15	0.15 ± 0.06	12.39 ± 0.11
				10	35.17 ± 0.77	0.1403 ± 0.0007	0.13 ± 0.02	69.14 ± 0.16	13.2 ± 0.19	0.2 ± 0	17.4 ± 0.01
				15	36.22 ± 0.73	0.1498 ± 0.0006	0.14 ± 0.01	67.9 ± 0.13	14.34 ± 0.06	0.21 ± 0	17.48 ± 0.19
				20	34.9 ± 0.58	0.1424 ± 0.0006	0.13 ± 0.01	70.54 ± 0.19	15.21 ± 0.4	0.1 ± 0.02	13.98 ± 0.22
3	75:25	150	75	5	40.52 ± 0.08	0.163 ± 0.0008	0.16 ± 0.01	79.38 ± 0.13	14.97 ± 0.18	0.02 ± 0.01	5.34 ± 0.31
				10	39.99 ± 0.12	0.1603 ± 0.0011	0.16 ± 0.01	76.65 ± 0.4	15.62 ± 0.22	0.01 ± 0.01	7.41 ± 0.6
				15	39.86 ± 0.09	0.1611 ± 0.0008	0.16 ± 0.01	75.22 ± 0.04	14.97 ± 0.28	0.07 ± 0.01	9.5 ± 0.33
				20	39.17 ± 0.14	0.1642 ± 0.0010	0.16 ± 0.01	74.58 ± 0.18	15.48 ± 0.44	0.02 ± 0.03	9.62 ± 0.25

The calorific heating value of mixed plastic waste and corn stover pellet was between 26 and 41 MJ/kg. The heating value of the pellet is higher than that is defined by the European RDF standard (Gendebien, 2003) (15 MJ/kg). In addition, sulfur was about 0.11 – 0.17% and chlorine was 0.12 – 0.16% which were less than the limitation of the European

RDF standard. The standard limits sulfur and chlorine contents of 0.4% and 0.5%, respectively.

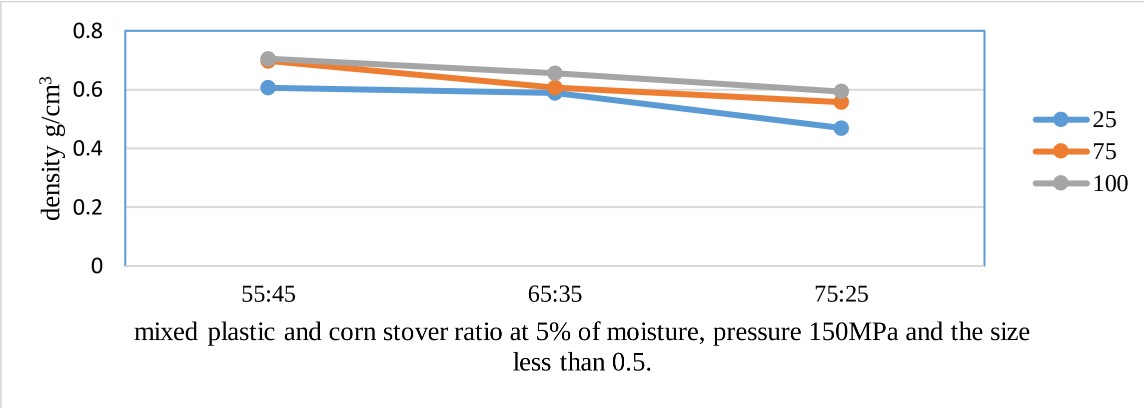

Figure 5.1 : Relation of density and mixed plastic and corn stover ratio.

Figure 5.1 shows that density is reduce to the increasing of plastic volume. The lowest density found at 75:25 of mixed plastic and corn stover ratio. While the highest density is found at 55:45 of mixed plastic and corn stover ratio. At the same condition, it can be explained that more plastic content lets decrease the pellet density.

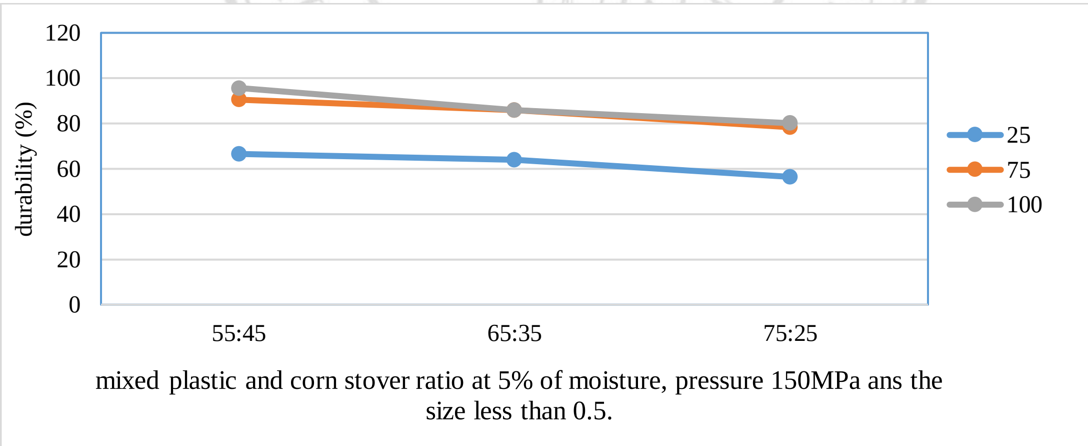

Figure 5.2 : Relation of durability index and mixed plastic and corn stover ratio.

Figure 5.2 shows that durability index is reduced as the plastic volume is increased. Pellet with plastic waste and corn stover ratio of 75:25 provides the lowest durability, while the highest durability index is found at 55:45 of mixed plastic and corn stover ratio. It can be explained that more plastic content lets to decrease durability index at the same condition. In addition, corn stover has fiber, protein and lignin which can improve pellet durability. This means that pellet with high content of corn stover should have high durability index.

2) The effect of preheating temperature

Preheating temperature has an effect on the pellet properties, which are density, moisture content, durability index and stability. From the statistical test, preheating temperature is the most effect to durability. At 150 MPa compression, 10% of moisture and the 0.5 to 1.0 mm in size of corn stover, it is found that density and durability index are increasd as the temperature increased as shown in Figure 5.3 and Figure 5.4.

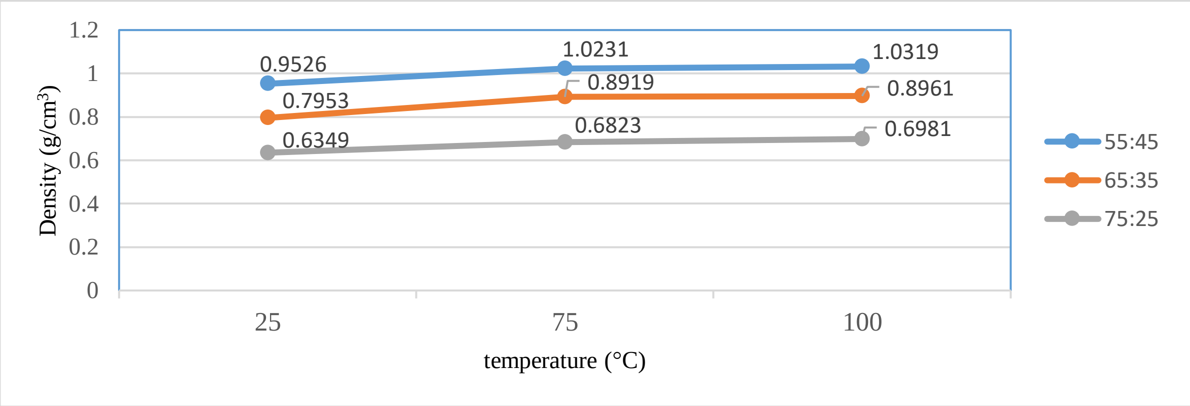

Figure 5.3: Pellet density at 150 MPa compression, 10% of moisture, 0.5 – 1 mm. of corn stover size and 25°C, 75°C and 100°C of preheating temperature.

Figure 5.3 shows that density is increased as the temperature rised at 55:45, 65:35 and 75:25 ratios. Material is softer in case of production under high preheating temperature, especially for corn stover which has natural binders (lignin and protein). The binder provides easy particle bonding during the densification process. Density is increased about 7 - 12% when the temperature is rised from 25 to 75°C. In the same way density is increased about 0.5 – 3% when the temperature is rised from 75 to 100°C.

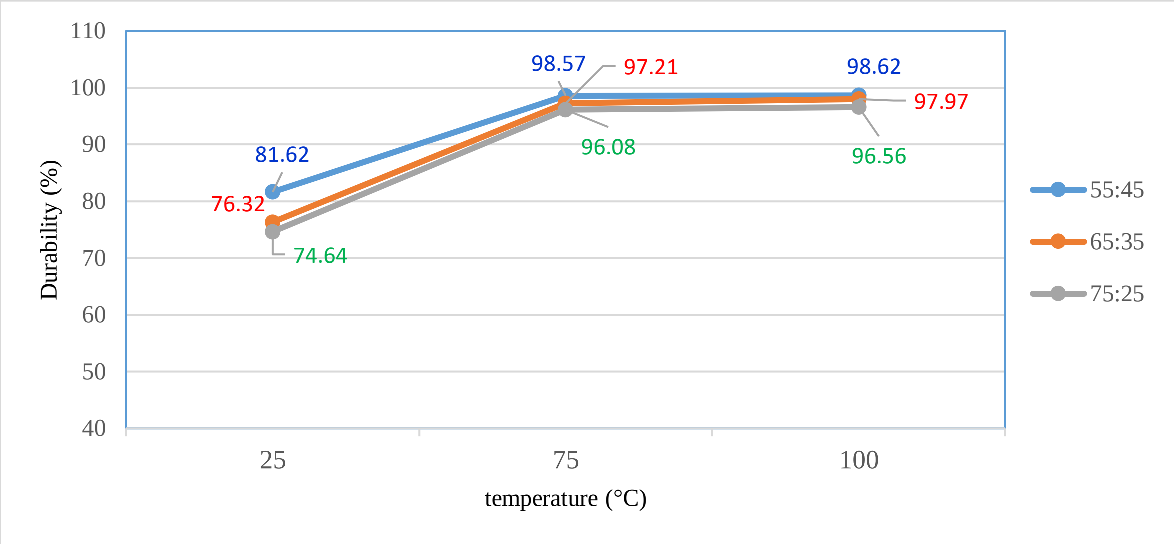

Figure 5.4: The durability at the condition of 150 MPa, 10% of moisture, 0.5 – 1 of corn stover size and 25°C, 75°C and 100°C of preheating temperature.

Figure 5.4 shows that durability is increased as the temperature increases at 55:45, 65:35 and 75:25 ratios. Pellet with the highest content of corn stover (PL:C ratio of 55:45) has the highest durability because high content of corn stover provides a large amount of natural binding components, i.e. fiber, lignin and protein. Preheating corn stover to 75 to 100°C makes reduce air void between particles. Natural binding components are changed into crystallization of soluble which is called “solid bridge”. It is also occurred during densification process. After pelletization, the pellet should be stronger after cooling. Therefore, pelletization at higher temperature (75°C to 100°C) let the pellet has higher durability. Durability is increased about 20 – 32% when the temperature is rised from 25 to 75°C. In the same way, durability is increased about 0.05 – 0.5% when the temperature is rised from 75 to 100°C.

At 100 MPa compression, density and stability of pellet can be high if high preheating temperature is used (see Figure 5.5). This is in an agreement with the work of Glen (1968). Densities of the pellet with

PL:C ratio of 55:45, 65:35 and 75:25 are increased as the preheating temperature is rised as shown.

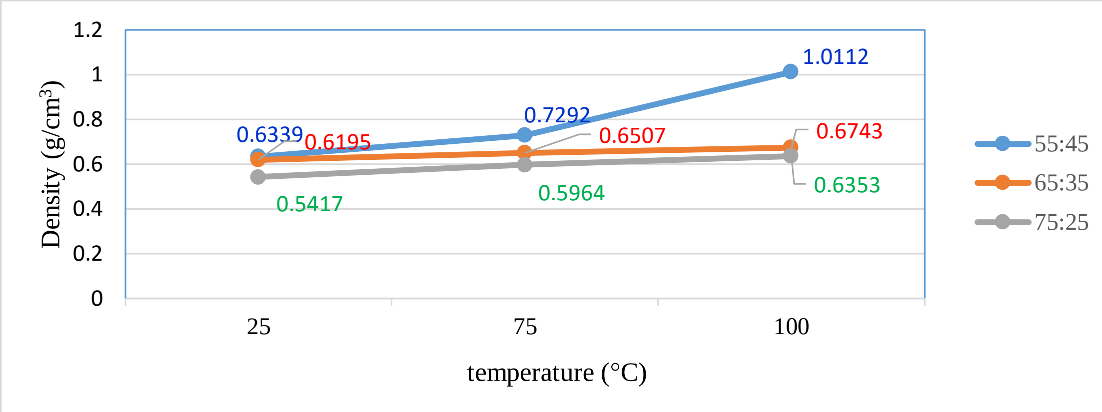

Figure 5.5: The density at the condition of 100 MPa, 10% of moisture, 0.5 – 1 of corn stover size and 25°C, 75°C and 100°C of preheating temperature.

Figure 5.5 presents that high density of 1.0112 g/cm^3 can be found at 100°C preheating temperature and low pressure (100 MPa). Pellet with PL:C ratio of 55:45 provides the highest density because of high content of plastic waste. Pellet with PL:C ratio of 65:35 and 75:25 provide lower density than that of the pellet with PL:C ratio of 55:45.

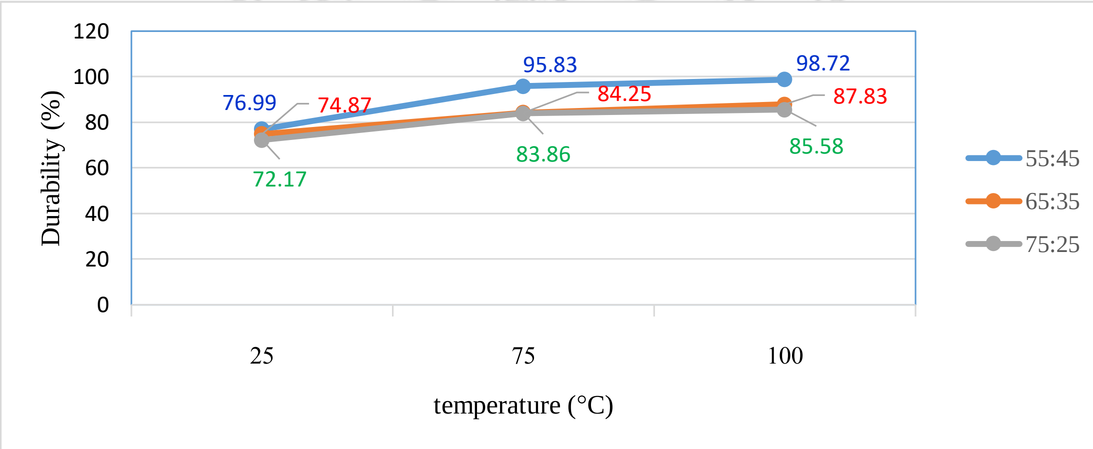

Figure 5.6: The durability at the condition of 100 MPa, 10% of moisture, 0.5 – 1 mm. of corn stover size and 25°C, 75°C and 100°C of preheating temperature.

Figure 5.6 shows that durability can be improved by increasing temperature. High preheating temperature lets the pellet has high durability.

3) The effect of pressure

Pressure also affects the properties of pellet as same as preheating temperature. The result of this study found that, pressure has effects on pellet density, durability index and stability. Compaction a high pressure lets the pellet has higher density, durability index and stability. Compation with pressure of 100 MPa, 150 MPa and 200 MPa at the condition of 10% of moisture, 0.5 – 1 mm. of corn stover size and 25°C, 75°C and 100°C preheating temperature could increase the pellet density to 54%, 45% and 6%, respectively (see Figure 5.7).

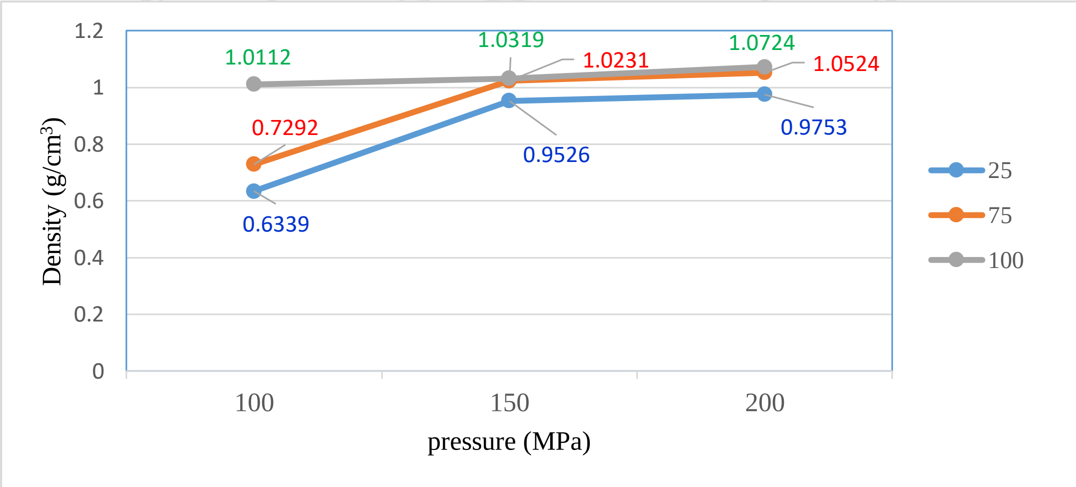

Figure 5.7 : The density at the condition of 55:45 ratio of mixed plastic waste and corn stover, 10% of moisture, 0.5 – 1 of corn stover size and 25°C, 75°C and 100°C of preheating temperature.

Increasing pressure of compaction gives higher density of pellet because air void between particles are squeezed out. Also, natural binder components that are in corn stover, e.g. protein, starch, lignin and pectin are closer and makes the pellet stronger. At 200 MPa compaction, the pellet has the highest density at the PL:C ratio of 55: 45 because of high content of corn stover.

In the same way, durability is also increased as the pressure is increased. Compaction with pressure of 100 MPa, 150 MPa and 200 MPa could increase the pellet durability to 54%, 45% and 6%, respectively (see Figure 5.8). The conditions of compaction are 10% of moisture, 0.5 – 1 mm of corn stover size and 25°C, 75°C and 100°C preheating temperature.

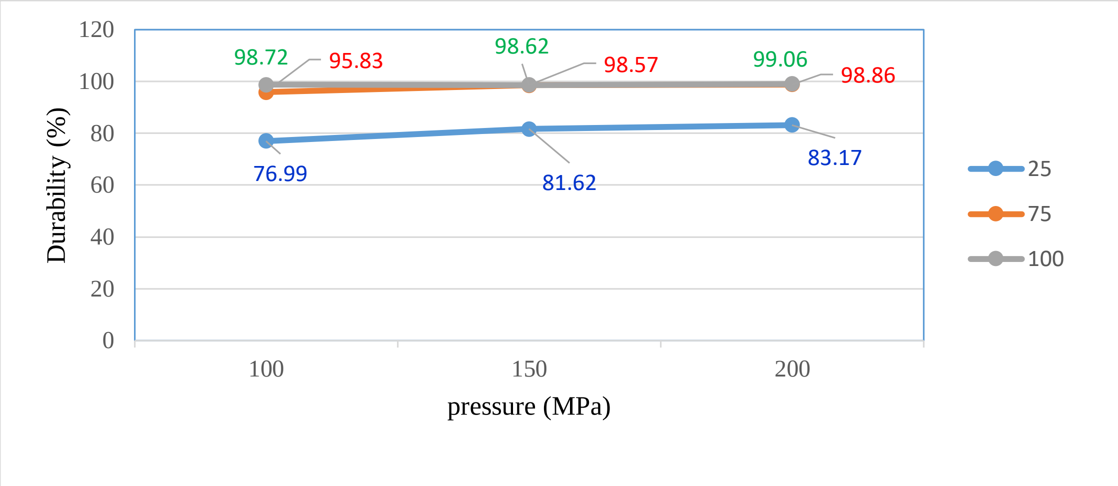

Figure 5.8 : The durability at the condition of 55:45 ratio of mixed plastic waste and corn stover, 10% of moisture, 0.5 – 1 of corn stover size and 25°C, 75°C and 100°C of preheating temperature.

4) The effect of moisture content of material

Moisture content also affects the properties of pellet. The result of this study found that it has effects on pellet density, durability index and stability. Increasing moisture content lets the pellet has high density, and stability. The optimum moisture content is 10%. Over the optimum point, the density is decreased. The same result are found for the PL:C ratio of 55:45, 65:35 and 75:25. Figure 5.9 presents the relation of density and moisture content at the condition of 150 MPa, 0.5 – 1 of corn stover size and 75°C of preheating temperature.

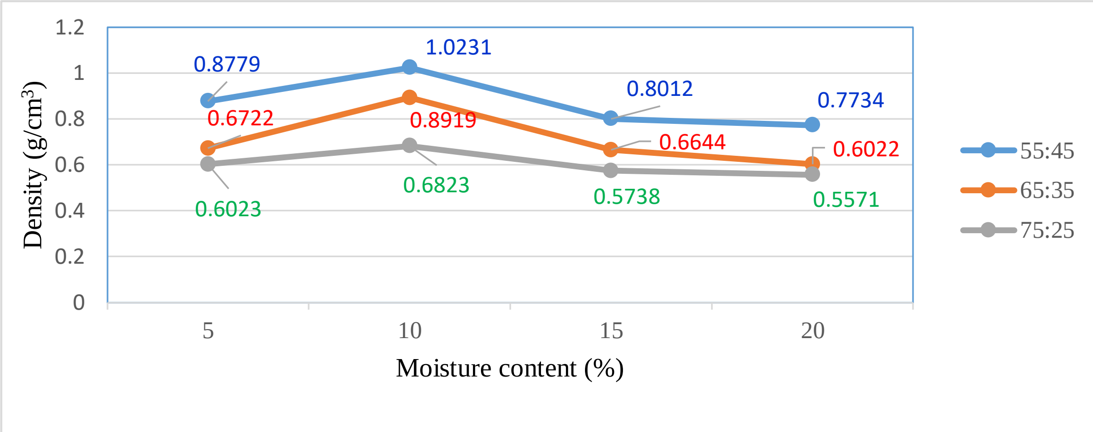

Figure 5.9 : The relation of density and moisture content at the condition of 150 MPa, 0.5 – 1 of corn stover size and 75°C of preheating temperature.

Figure 5.9 shows the relation of durability and moisture content at the condition of 150 MPa, 0.5 – 1 of corn stover size and 75°C of preheating temperature. By the way, durability is also increased as moisture content is increased. The maximum density is provided at moisture content of 10%. Density is decreased in case of using moisture content over or less than the optimum point.

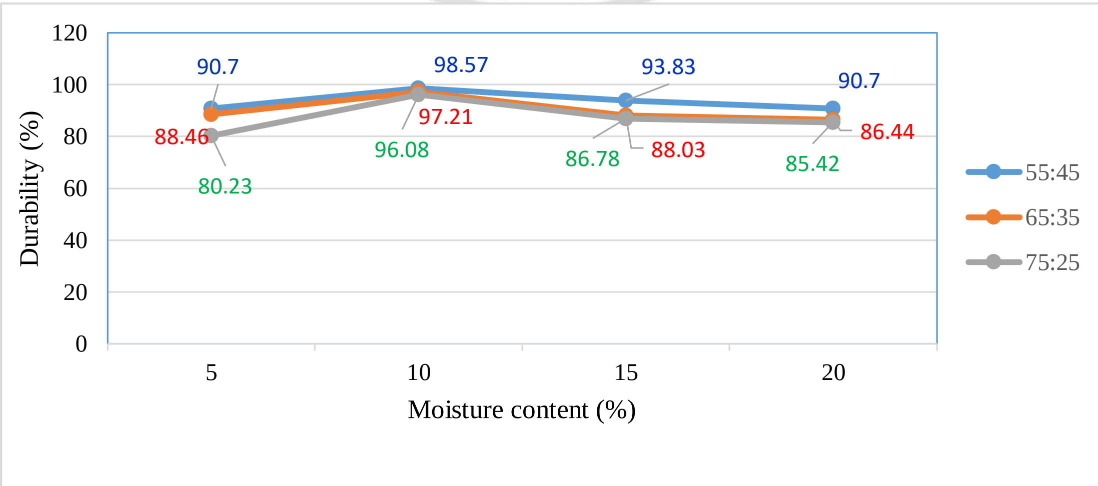

Figure 5.10 : The relation of durability and moisture content at the condition of 150 MPa, 0.5 – 1 of corn stover size and 75°C of preheating temperature.

5) The effect of particle size.

The result of this research found that the optimum particle size is between 0.5 – 1 mm which provides the maximum density. Smaller particle size (less than 0.5 mm) or larger particle size (over 1mm) are not appropriate for palletization. Figure 5.11 shows the relation of density and particle size at the condition of 150 MPa of compression, 10% of moisture content and 75°C of preheating temperature. It is found that pellets with particle size between 0.5 – 1 mm have the highest density for all PL:C ratio.

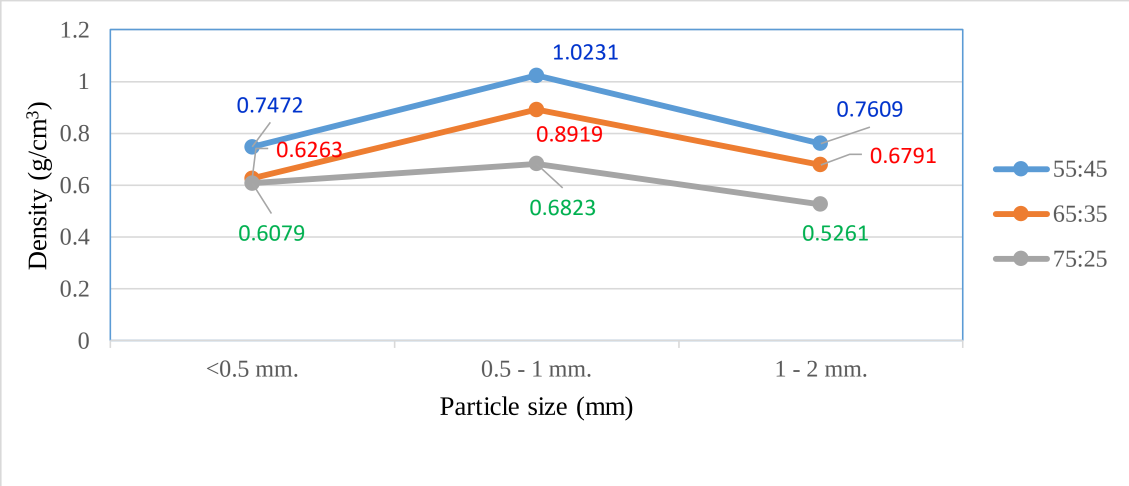

Figure 5.11: The relation of density and particle size at the condition of 150 MPa of compression, 10% of moisture content and 75°C of preheating temperature.

The properties of RDF in this study are compared with the results of Chiemchaisri (2010). It is noted that pellets which are produced with the same condition, but different in biomass, as Chiemchaisri did are compared. It is found that either mixing plastic waste with corn stover in this study or cassava root at 55% in Chiemchaisri's work are quite similar. Comparation results of pellets which are made from mixed mixed plastic waste and corn stover and mixed plastic waste and cassava root are shown in Table 5.19 and Table 5.20.

Table 5.19: RDF properties of mixed plastic waste and cassava root (Chiemchaisri, 2010) by 5 hp hydraulic compression. The experiment condition is at room temperature compression, 7% of moisture content of material and the particle size about 10 mm. And, the size of RDF briquette was 40 x 40 mm.

Properties	Mixed plastic waste and cassava root ratio (Chiemchaisri, 2010)				
	55.56:44.44	50:50	45.45:54.55	41.67:58.33	38.46:61.54
Density (g/cm^3)	0.595	0.674	0.676	0.613	0.587
Moisture(%)	2.95	3.46	3.54	3.94	5.50
Ash(%)	14.5	15.9	13.6	12.6	10.3
S(%)	0.19	0.16	0.16	0.14	0.14
Cl(%)	0.85	0.99	0.97	0.44	0.61
HV (MJ/kg)	26.0	23.8	21.9	22.8	23.2

Table 5.20: RDF properties of mixed plastic waste and corn stover. The experiment condition is at room temperature compression, 10% of moisture content of material, 150MPa of compression pressure and the particle size between 1 – 2 mm. And, the size of RDF pellet was 20 mm. length and 8 mm. diameter.

Properties	Mixed plastic waste and corn stover		
	55:45	65:35	75:25
Density (g/cm^3)	0.6513	0.5191	0.4788
Moisture(%)	3.09	3.27	2.31
Ash(%)	6.38	3.38	1.46
S(%)	0.12	0.14	0.16
Cl(%)	0.12	0.13	0.16
HV (MJ/kg)	27.53	35.17	39.99

5.3.4 The result of specific energy consumption

Table 5.21 lists the density, energy consumption, heating value and energy ratio of pellets under compaction pressure of 100 MPa, 150 MPa and 200 MPa and preheating temperature of 75°C and 100 °C. Energy ratio is calculated using Equation 5.1.

$$\text{Energy ratio} = \frac{\text{energy of pellet (heating value)}}{\text{energy consumption of pelletization}} \quad (5.1)$$

The energy consumption of this research is considered to the energy of densification process only as show in figure 5.27.

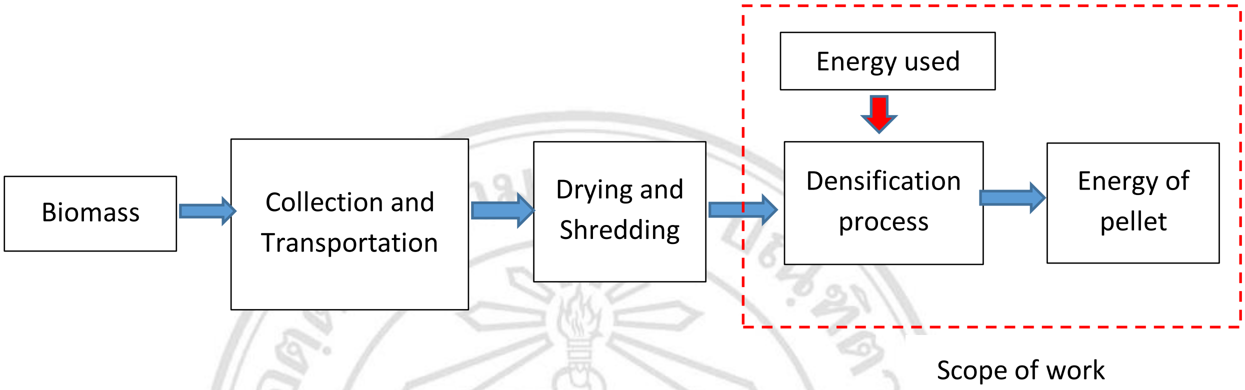

Figure 5.27: Diagram of biomass conversion.

Table 5.21 Energy consumption and energy ratio of palletization at each condition.

Pressure (MPa)	Temperature (°C)	Density (g/cm^3)	Production rate (kg/hr))	Electric power (kW)	Energy use (kWh)/kg	Energy use (MJ/kg)	Heating value (MJ/kg)	Energy ratio	Remark
100	75	0.7292	0.084	1	11.90	42.86	26.65	0.62	1 pellet/mold
			0.84	1	1.19	4.29		6.21	10 pellet/mold
100	100	1.0112	0.056	1	17.86	64.30	27.53	0.43	1 pellet/mold
			0.56	1	1.78	6.41		4.29	10 pellet/mold
150	75	1.0231	0.084	1	11.90	42.86	26.65	0.62	1 pellet/mold
			0.84	1	1.19	4.29		6.21	10 pellet/mold
150	100	1.0319	0.056	1	17.86	64.30	26.65	0.41	1 pellet/mold
			0.56	1	1.78	6.41		4.16	10 pellet/mold
200	75	1.0524	0.07	1	14.29	51.44	26.65	0.52	1 pellet/mold
			0.7	1	1.43	5.15		5.17	10 pellet/mold
200	100	1.0724	0.049	1	20.41	73.48	26.65	0.36	1 pellet/mold
			0.49	1	2.04	7.34		3.63	10 pellet/mold

Energy ratio was calculated in two cases of 1 pellet/mold (design mold) and 10 pellet/mold (suppose mold) as showed in table 5.14. The 1 kW of heater is used for heating of material before compaction. And the electric power of 1 kW is 3.6 MJ. The result found that, the energy ratio was increase to production rate and the highest energy ratio was at two conditions of palletization, which are pellet made from 100 MPa and 75 °C and pellet made from 150 MPa and 75 °C. Pellet at compaction pressure of 150 MPa provides higher density than that is produced at compaction pressure of 100 MPa.

5.4 Conclusion

Various pelletizations have effects on the properties of mixed plastic waste and corn stover pellet. In this study, the parameters include 1) 55:45, 65:35, and 75:25%wt. of mixed plastic waste and corn stover ratio, 2) 25°C, 75°C and 100°C of preheating temperature of material, 3) 100, 150 and 200 MPa of compression pressure, 4) particle size which is less than 0.5 mm, between 0.5 - 1.0 mm and between 1.0 – 2.0 mm, and 5) moisture content of material of 5, 10, 15 and 20%wt. The pellets of this research are tested for calorific heating value, S, Cl, C, H, N and O contents, density, moisture content of pellet, ash content, pellet durability index and pellet stability.

The result found that mixed plastic waste has higher calorific heating value than corn stover for 4 times. Furthermore, it has less ash, but more moisture content than corn stover. Corn stover has sulfur and chlorine less than mixed plastic waste and corn stover, but the the calorific heating value of corn stover pellet is between 15 and18 MJ/kg. Pellet’s properties including the calorific heating value, ash content, moisture content, etc. can be improved by mixing plastic waste into its composition. The mixed plastic waste and corn stover pellet has the calorific heating value between 26 and 40 MJ/kg and has less content of ash.

Using the statistical test for the properties of mixed plastic waste and corn stover pellet, it is found that:

Moisture content of pellet and pellet durability were significantly affected by mains effect and all of interactions effect way at the 5% level. Pellet density was significantly affected by main effect and the interaction of all 2 way, 3 way, 4 way and 5 way at the 5% level. But, the interaction of mixed plastic waste and corn stover ratio x compression pressure x preheating temperature was not significant ($P>0.05$). The effects of grinding size and moisture content, and mixed plastic waste and corn stover ratio x grinding size, mixed plastic waste and corn stover ratio x compression pressure, and grinding size x preheating temperature were not significant on ash content of pellet. The stability of pellet was significantly affected by compression pressure, temperature and moisture content. The interaction of compression pressure x moisture content, preheating temperature x moisture content, and compression pressure x preheating temperature were significant on the pellet stability. The result of mains effect and interactions effect on the physical characteristics (calorific value, and the content of sulfur, chlorine, carbon, hydrogen, nitrogen, and oxygen) were the same. All main effects were not significant on chemical characteristics, except mixed plastic waste and corn stover ratio, and moisture content. All the interaction of 2 way, 3 way, 4 way and 5 way at 5% level were not significant on chemical characteristics except mixed plastic waste and corn stover ratio x moisture content.

The result of factors analysis found that:

- Mixed plastic waste and corn stover ratio affects calorific heating value, density, ash content, and moisture content of pellet. Pellet has the highest calorific heating value and element composition at the ratio of 75:25%. The least calorific heating value and element composition is occured at the ratio of 55:45%. The highest calorific heating value is 39 – 40 MJ/kg and the least calorific heating value is 26 – 29 MJ/kg. As recommended by the European standards, the specific heating value of RDF should more than 15 MJ / kg. The standard recommends that sulfur content and chlorine content must be less than 0.4% and less than 0.5%, respectively. In this research, mixed plastic waste and corn stover pellet has sulfur between 0.11 and 0.16% and has chlorine content between 0.12% and 0.16%. The result found that sulfur and chlorine content of mixed plastic waste can be reduced by mixing the corn stover with plastic waste. Furthermore, mixed plastic waste and corn stover ratio affects density and durability index. Higher ratio of plastic content lets provides low density and durability index. The reason is that corn stover has natural binder (include protein, lignin, starch, etc.) and fiber which could improve the strength of pellet. Therefore, the lower corn stover lets to decrease strength and density of pellet.

- Preheating temperature of material affects pellet properties including density, moisture content of material, durability index and stability. For example, the higher preheating temperature lets the pellet has high density, durability index and stability at the compression pressure of 150 MPa. The reason is that natural binders (include lignin, protein etc.) are soften and easy squeezed out of particle at the higher preheating temperature. They are being around particle and also being instead of air and void between particles. After that they are in crystal form and changed to solid bridge after cooling. These processes occurs during the compression process. The pellet after cooling has high density, durability index and stability. From results of pellet at condition of 25 and 75°C, it is found that durability index is increased about 20 to 30% at the ratio of 75:25, 65:35 and 55:45%wt. At the condition of 75 - 100°C, durability index is also increased about 0.05 to 0.5% at the ratio of 75:25, 65:35 and 55:45%wt. It is found that mechanical properties are improved when the preheating temperature is increased. However, mechanical properties are insignificant changed at high preheating temperature. At 100°C preheating temperature and 100 MPa compaction pressure, the pellet provides the density and durability index closed to the density at the compression pressure of 150 MPa. It is also found that pellet with high density can be produced at low compression pressure with high preheating temperature. This result is the as same as the work of Glenn (1968). The pellet density at compression pressure of 150 MPa, preheating temperature of 75 and 100°C is 1.0231 and 1.0319 g/cm^3, respectively. Moreover, at the same compression pressure of 100 MPa, it is found that the ratio of 55:45%wt. gives the highest density and durability index since at this ratio the pellet has the highest content corn stover which has a lot of natural binder.
- Compression pressure affects pellet properties. It can improve density, durability index and stability. The reason is that the natural binders (include protein, starch, lignin, pactin) are easy to squeeze from particle and lets the

pellet to be performed under compaction mechanism. The highest density and durability are at the compression pressure of 200 MPa. Compaction with low pressure of 100 MPa can provide higher pellet density if the preheating temperature is increased. It can give pellet density higher than 1 g/cm^3. At the temperature of 25°C, pellet density is increased by 54% if compression pressure is risked from 100 MPa to 200 MPa. At the temperature of 75°C, pellet density is increased by 45% if compression pressure is risked from 100 MPa to 200 MPa. At the temperature of 100°C, pellet density is increased by 6% if compression pressure is increased from 100 MPa to 200 MPa. It is also found that pellet density which is produced at low compression pressure and high preheating temperature is closed to that which is made under at high compression pressure. At higher preheating temperature, although under the different compression pressure, the pellet densities do not changed significantly.

- Moisture content of material affects pellet properties including density and durability. Higher moisture content lets the pellet has higher density and durability index. The pellet density and durability either low or high content of plastic waste are to be high if it is compacted under the appropriate moisture content as did by. Li & Liu (2000). The research found that the appropriate moisture content of material is 10% which give the highest pellet density and stability.
- Particle size affects the pellet properties including density and durability index. The result found that using either too small particle size (less than 0.5 mm.) or too large particle size (over 1 mm.) can not produce pellet with high density and durability index. The appropriate particle size is between 0.5 and 1 mm for all ratio of mixed plastic waste and corn stover.

The result of energy consumption found that pellet which is produced at the 150 MPa of compaction pressure and 75 °C of temperature gives the highest energy ratio. Its density of this condition is 1.0301 g/cm^3.

5.5 References

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