Journal of Engineering and Applied Sciences 11 (9): 2054-2058, 2016
ISSN: 1816-949X

Value-Added Products from Kenaf and Hemp Core Residue

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Abstract: Wood core of kenaf and hemp are the residue from bast fibre production. This research aims to find opportunities of turning these raw materials into wood pellets and particleboard for value-added products. Hemp and kenaf core residue from mechanical decortication and stem retting were grouped sorted according to their 5 different treatments: kenaf core residue from retting process (KeR); kenaf core residue from mechanical decortication (KeM); hemp core residue from mechanical decortication (HeM); kenaf core residue from mechanical decortication and hemp core residue from mechanical decortication ratio 1:1 by weight (HKM) and hemp core residue from mechanical decortication and sawdust ratio 1:1 by weight (HSD). The result showed that chemical properties of raw materials KeR, KeM and HeM were 75.06, 73.54 and 70.69% of holocellulose, respectively. Alphacellulose was at 60.46, 69.00 and 57.49%, respectively. Lignin was at 34.43, 35.14 and 30.49%, respectively. Wood pellets from all treatment perform gross heating value of 4,220-4,140 kcal $kg^{-1}$with a net heating value of 3,890-3,810 kcal kg^{-1}. The pellets were luster and strong in all treatments except KeR. After producing the particleboard, all samples performed modulus of rupture (MOR) at 13.67-12.20 MPa. Modulus of Elasticity (MOE) was 1,640.3-1,010.9 MPa and Internal Bonding (IB) was 0.63-0.42 MPa. The core residue was not at the standard of particleboard (flat press medium density) but passes the insulation board standard. Acoustic absorption of KeR, KeM and HeM were 22.63, 22.34 and 23.56%, respectively. The core residue from kenaf and hemp were able to form wood pellet and insulation board for value-added products. Furthermore, the economic evaluation of products from core residue should be investigated for actual industrial production.

Key words: Kenaf, core residue, chemical properties, wood pellet, particleboard

INTRODUCTION

Bast fibre is a plant fibre resource obtained from the bark of some herbaceous plants. After bark is removed from the stem, core residue remains, leaving a huge amount of agricultural waste. There are lignocellulosic material and biomass member. In northern Thailand, hemp (*Cannabis sativa* L.) core residue is left over from hemp cultivation by strictly contact farming while kenaf (*Hibiscus cannabinus* L.) is cultivated and harvested widely in North-East Thailand. While hemp was less insecticide need, kenaf is one of an alternative plant for less irrigation demand. The climate change affect to agricultural system. Thus, bast fibre that needs less irrigation might be alternative plants to replace rice cultivation. To complete the value chain of bast fibre promotion of country, the applications of them should be revealed. Bast fibre is usually used in textiles (Sengloung *et al*., 2008), composite materials (Mussig, 2010) and fibre cement (Elsaid *et al*., 2011). Fibre length is one of the main characteristics that define the potential for applications. Hemp bast fibre is 20-25 mm length while core fibre is 0.6 mm length (Sengloung, 2009). Thus, the bast fibre has opportunity to use as a long fibre more than core fibre. Hemp wood core residue was 75-78% of stem yield (Sengloung, 2009). The product from core residue were previously in the forms of animal beds, dirt absorbent (Anonymous, 2015) and insulation board (Fernando, 2013). In Thailand, farmers use the core residue of kenaf as household fuel in rural areas and supply for the export market. The low demand and low value of bast fibre plants made them less interesting until climate change and irrigation supply problems of the country in 2015. The planting area of bast fibre in Thailand has declined since 1986 due to the promotion of other agricultural plants. The statistics recorded on the

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planting area of bast fibre was 241.6 ha with a yield of 512 tons in 2015. The demand for energy increases continuously. The alternative and renewable energy are interested for replacing fossil fuel (Alamsyah *et al*., 2015). Wood pellets are one of the alternative energy sources from lignocellulose biomass which is from various types of organic residue such as sawdust, bamboo, rice husk, palm trunk and other agricultural waste (Bergstrom *et al*., 2008.). Wood pellets are high density and easy to transport (Bergstrom *et al*., 2008; Giacomo and Taglieri 2009; Liu *et al*., 2013). The quality of wood pellet terms to pellet length, heating value and fewer residues after burn. The pellet length affects from the ability of pellet formation. The good formation allows the pellet tolerance against breaking during transport. Cellulose is a functional carbohydrate. The other product of core residue may rely on the material products. Wood with short fibres may be used in particleboard production which has specific physical properties each type of them. The enormous amount of agricultural waste in bast fibre production can be used as raw material in wood pellet production and board production. To fulfill the value chain of this plant from farm to end products, the core residue of these crops needs to be developed into value-added products that will generate more income for farmers.

MATERILAS AND METHODS

Preparation of raw materials: Hemp and kenaf core residue from different treatments were used as raw materials for this research. The hemp core residue came from Chiang Mai province with mechanical decortications process (HeM). The kenaf core residue was obtained from Ubon Rachathani province. It was from mechanical decortications (KeM) and from stem water-retting processes (KeR). Then, hemp and kenaf was mixed in portion 1:1 by weight (HKM) and kenaf combined with saw dust (HSD) as showed in Table 1. Moisture content was reduced from HeM, KeM and KeR by drying in the sun to avoid the uneven moisture content. The raw materials were broken into small pieces by hammer mill and the bark removed using a sieve shaker. Sieve pore was 3 mm diameter with 25 meshes. The sample above the sieve was use for particleboard and insulation board formation, sample pass the sieve shaker was used for pellet formation.

Chemical properties of raw materials: The samples KeR, KeM and HeM were milled into powdery form. Chemical properties of core residues were analyzed according to TAPPI standard as follows: extractive; TAPPI T204cm-97, TAPPI T264-cm97 and TAPPI T207-cm93 (Anonymous, 1997, 1999). Holocellulose according to Browning (Anonymous, 1999), alphacellulose: TAPPI T203-cm88. Lignin TAPPI T222 om-98 (Anonymous, 1993a); Ash: TAPPI T211-cm97 (Anonymous, 1993b; Browing, 1963; TAPPI, 2002) and Moisture Content (MC). Each treatment was analyzed with 3 replications. Pellet formation and testing: The samples in Table 1 were formed using a pellet formation machine. The sample size measured from 100 pellets. The proximate analysis, moisture content, volatile matter, ash and fixed carbon were analyzed. High heating value of all treatments was determined using bomb calorimeter (ASTM D7582 and ASTM D5865 (Anonymous, 2015).

Table 1: Abbreviation of treatments in the experiment

Abbreviations	Sources of core residue
KeR	Kenaf from water-retting
KeM	Kenaf from mechanical decortication
HeM	Hemp from mechanical decortication
HKM	Hemp:kenaf core residue from mechanical decortication; ratio 1:1
HSD	Hemp from mechanical core residue: saw dust; ratio 1:1

Particleboard formation and testing: The sample in Table 1 was used to form particleboard. The mixture of core wood with Urea-Formaldehyde (UF) at portion 10 g UF with 100 g of core wood was pressed in a 140°C hot press with 30×30 cm size and 12 mm thick. Then leaf at least 7 days before a properties test. The properties tested were density, Moisture Content (MC), Thickness Swelling (TS), Modulus Of Rupture (MOR), Modulus Of Elasticity (MOE) and Internal Bonding (IB) with TIS 876-2547 standard (Thai Industrial Standard, 2004).

Insulation board formation and testing: The same process of sample and UF was done with lower density 10 mm thick board. This insulation board was tested for density, MC, TS, MOR, MOE, IB (Thai Industrial Standard, 2004) and acoustic absorption.

RESULTS AND DISCUSSION

Chemical properties of materials: The examined chemical properties of KeR, KeM and HeM were holocellulose, alphacellulose, extractive, lignin, ash and moisture content. Hollocellulose of KeR, KeM and HeM were 75.06, 73.54 and 70.69%, respectively. The extractive of HeM was 24.49%, higher than kenaf KeR (18.96%) and KeM (18.55%). Lignin content of raw materials was 34.43, 35.14 and 30.49%, respectively. The lignin content in hemp was lower than in kenaf. According to sundried KeR, the ash

Table 2: Chemical properties of raw materials

Chemical properties (%)	KeR	KeM	HeM
Holocellulose	75.06	73.54	70.69
Alphacellulose	60.46	69.00	57.49
Extractive	18.96	18.55	24.49
Lignin	34.43	35.14	30.49
Ash	1.44	2.12	2.72
Moisture content	5.60	7.50	6.52

content was 1.44%, lower than KeM (2.12%) and HeM (2.72%). This may be caused by retting process that may affect to inorganic materials in the kenaf core residue. Due to water retting process of bast fibre, the core residue can sometimes be influenced by mechanical decortication or stem water-retting. Thus, the quality of core residue may vary according to their previous process and the storage condition after. The result from chemical properties showed the effect of different processes on chemical properties of the sample (Table 2).

Pellet characteristics and properties: The wood pellet from mechanical decortication performed the proper form. KeM, HeM, HKM and HSD were 3.28, 4.26, 4.22 and 3.98 mm long, respectively. The KeR was 1.61mm long with a fragile form. All wood pellets were 7 mm in diameter, within the industrial standard range of 6-8 mm. The length of wood pellet, KeM was in range of grade C while HeM, HKM and HSD were in grade D. The density of KeM and HKM were in grade B while HeM and HSD were in grade D. Ash content of all samples was classified in grade B. The heating value properties of all samples was lower than the heating value obtained from sawdust. Thus, the core residue wood pellet had the proper shape of pellets, but produced less energy compared to sawdust, but the overall quality is remained in criteria of industrial use (Toscano *et al*., 2013; Vinterback, 2004; Stahl and Berghel, 2011).

KeR was not a good performer in terms of fragile wood pellets. This may cause intolerant and the damage of wood pellet during transportation. To use KeR, the material needs to mix with other lignocellulose biomass for better formation of wood pellet. The mechanical decortication core residue was able to produce wood pellets. Thus the mechanical decortication should be considered to replace the stem water retting process. Mechanical decortication was more environmentally friendly than stem water retting process with its effect on water pollution (Akin, 2010). The raw materials from various sources are mixed to produce the pellet in industrial production. Those are mainly from saw mills. Thus, core residue may combine with others lignocellulosic materials for improving the properties according to the market demand (Fig. 1 and 2 and Table 3).

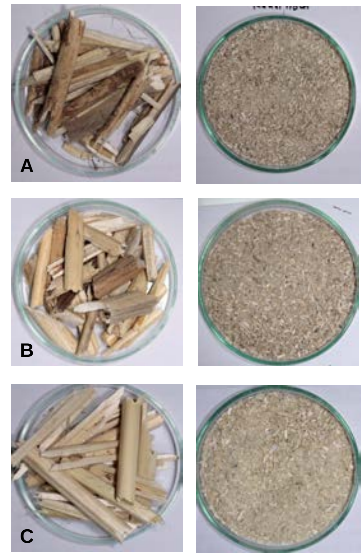

Fig. 1: Raw material and sample preparation of wood core residue A: KeR; B: KeM; C: HeM

Fig. 2: Raw material and sample of wood core residue A: KeR; B: KeM; C: HeM; D: HKM; E: HSD

Particleboard properties: The density, MC and IB of KeM, HeM, HKM and HSD were within the criteria of TIS 876-2547 standard. The TS and MOR of all treatments were lower than the standard at 12 and 14%, respectively. According to Thai Industrial Standard Institute, all samples did not meet the criteria of flat pressed particleboard: medium density (TIS 876-2547) (Table 4 and 5). Thus, the treatment was not suitable for making particleboard but the mixture of core wood with others wood may perform with different results.

Insulation board properties: Insulation board is mostly vertically attached to walls and needs a lighter weight than particleboard. The density of insulation board was between 0.16-0.48 g cm^{-3} (Hoadley, 2000). The KeR, KeM and HeM were in the criteria of density and MOE standard of insulation board. The MOR of all treatments

Table 3: Properties of wood pellet

Type of materials	Pellet morphology: Color	Luster	Strongness	Length (cm)	Properties: Density (g L^{-1})	MC (%)	Volatile (%)	Fixe carbon (%)	Ash (%)	Heating value (kcal kg^{-1}): Gloss	Net
KeR	Pale	Less-luster	Fragile	1.61±0.22	483.32	7.1	76.7	14.4	1.8	4,220	3,890
KeM	Pale while andbrown	Luster	Strong	3.28±0.36	632.95	7.9	73.4	16.5	2.2	4,160	3,840
HeM	Yellowish andbrown	Luster	Strong	4.26±0.13	591.36	7.1	74.0	16.5	2.4	4,170	3,850
HKM	Pale and yellowish	Luster	Strong	4.22±0.17	600.23	7.5	72.6	17.7	2.2	4,180	3,860
HSD	Dark brown	Luster	Strong	3.98±0.27	551.69	8.0	73.0	16.8	2.2	4,140	3,810
Sawdust[a]	-	-	-	-	-	-	-	27.2	1.5	4,990	-
Tipawat	Grad B	N/A	N/A	≤32	≥600	≤10	N/A	N/A	≤1.5	N/A	≥4,200
Wood	Grad C			≤32	≥600	≤10			≤3.0		≥4,040
pellet[b]	Grad D			≤40	≥550	≤15			≤6.0		≥3,940

[a]Energy Technology Laboratory, Thailand Institute of Scientific and Technology Research, Thailand; [b]Tipawat Corporation Ltd

Table 4: Properties of particleboard

Type of materials	Particleboard: Density (g cm^{-3})	MC (%)	TS (%)	MOR (MPa)	MOE (MPa)	IB (MPa)
KeR	0.60	9.46	5.65	13.67	1640.3	0.63
KeM	0.61	9.04	8.73	12.02	1465.3	0.60
HeM	0.62	8.63	9.69	12.04	1229.6	0.42
HKM	0.64	8.87	6.30	10.20	1064.4	0.51
HSD	0.66	8.15	6.39	10.98	1010.9	0.49
TIS 876-2547[a]	≥0.4-0.8	4-13	≥12.00	≥14.00	≥1800.0	≥0.45

Table 5: Properties of insulation board

Type of materials	Density (g cm^{-3})	MC (%)	TS (%)	MOR (MPa)	MOE (MPa)	IB (MPa)	Acoustic absorption (%)
KeR	0.43	7.25	7.89	6.41	620.27	0.58	22.63
KeM	0.45	5.98	6.85	6.08	614.17	0.59	22.34
HeM	0.40	5.54	7.85	6.38	676.63	0.48	23.56
Hoadley[a]	0.16-0.48	-	-	1.38-5.52	172-867	-	N/A

[a]Thai Industrial Standard Institute (Thai Industrial Standard, 2002)

Fig. 3: Particleboard from core residue after testing A: KeR; B: KeM; C: HeM; D: HKM; E: HSD

in this experiment was between 6.08-6.41 MPa while the standard was 1.38-5.52 MPa. The MOR of all treatments was higher than the standard. The acoustic absorption of KeR, KeM and HeM were 22.63, 22.34 and 23.56% which achieves the criteria of ≥15% for the insulation properties

Fig. 4: Insulation board from core residue A: KeR; B: KeM; C: HeM

(Hoadley, 2000). More standard specification for cellulosic fibre insulating board tests need to be intensively investigated according to ASTM C208-12. The density of insulation board was high which may improve for light weight insulation board by mix with other low density materials.

CONCLUSION

The core residues from kenaf and hemp chemical properties were 70.69-75.06% holocellulose and 57.49-69.00% of alphacellulose. The extractive of core residue from kenaf was lower than hemp. The lignin content of core residue were 30.49-34.43%. Particleboard made from kenaf and hemp core residue did not meet TIS 876-2547 particleboard standard. The possibility of value-added products from core residue should focus on wood pellets and insulation board rather than particleboard. The acoustic absorption of core residue was between 22.34-23.56%.

ACKNOWLEDGEMENTS

Researchers would like to thank the Botany Section, Faculty of Liberal Arts and Sciences, Kasetsart

University, Kamphaeng Saen Campus and Plants Fibre Resources and Applications Research Unit for chemical analysis lab equipment. We thank the Royal Project foundation for supplying the hemp wood core residue. We express our thanks to the Department of Forest Products, Faculty of Forestry, Kasetsart Unversity. This project was funded by Kasetsart University Research Institute (KURDI).

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