Fuel Properties of Slab Wastes from Sengon Sawmills: A Case Study in Sleman and Wonosobo Regencies

Joko Sulistyo, Binsar Edward Sianturi, and Raditya Ananta Rustantoputro

Abstract

Sengon (*Paraserianthes falcataria* (L.) Nielsen) is a fast-growing and versatile species that has been established in community forests. Many sawmills utilize sengon wood as a raw material which generates wastes in the form of sawdust and slab consisting of a mixture of bark and wood. Those wastes are widely used by communities and home industries as fuel. The objective of this study was to characterize the energy properties of slab wastes from sengon sawmills in Wonosobo dan Sleman Regencies. The results showed that the calorific value and fuelwood value index (FVI) ranges were 4,089 to 4,749 cal/g and 2.71 to 18.74, respectively. The values of density ranged from 0.23 to 0.94 g/cm^3. The proximate analysis showed that the values of moisture and ash contents ranged from 13.90 to 20.03% and from 0.30 to 4.59%, respectively, whereas volatile matter and fixed carbon contents ranged from 75.84 to 88.94% and from 10.23 to 20.62%, respectively. In general, the slab samples from Wonosobo gave higher values in fixed carbon content and FVI but smaller values in density, moisture content, volatile matter content, and ash content than those of the samples in Sleman. The bark part showed higher amounts in density, moisture content, fixed carbon content, and ash content but lower in volatile matter content, calorific value, and FVI than the wood part. Based on the wood consumption, sawmill recovery, calorific value, and dry weight biomass value, the potential annual energy from slab wastes in Sleman and Wonosobo reached 1,374 × 10^{13} cal (equivalent to 1,525,222 L of kerosene) and 1.521 × 10^{14} cal (equivalent to 16,884,016 L of kerosene), respectively.

Keywords: falcata wood, sawn wood, biomass energy, calorific value, community forest

Introduction

Sengon (*Paraserianthes falcataria* (L.) Nielsen syn *Albizzia falcataria*) is a fast-growing species and has various benefits in all parts of the tree, from leaves to roots. The characteristics and potentials of sengon wood are in accordance with industrial demands. This makes more and more industries, such as the sawmill and plywood industries, use sengon wood as raw material.

The abundance of sengon wood utilized by the industry, of course, generates a lot of residual processing wastes in the form of slab and sawdust. The slab wastes generated by the sawmill industry consist of bark and wood. The percentage of the bark was found to be about 10~20% of the stem depending on the species and growing conditions (Fengel and Wagener 1984). In another study it was found that the percentage of bark on sengon stems was 6.26% (Chin *et al.* 2013). It is assumed that the portion of the bark on the slab is higher than that of the stem. This large amount of wastes is widely used as firewood by the people surrounding community forests such as those in Wonosobo, Temanggung, Magelang, and Yogyakarta. In Yogyakarta, especially the Godean area, people use sengon wood as energy for the production of bricks and tiles. From field observations, one of the roof tile business owners stated that the consumption of sengon firewood in each industry reached 20~30 m^3/year.

Although it has been widely used as fuel, research on the properties of sengon as energy wood is still limited, especially when it is in the form of slab waste. Previously, the effects of bark, species, tree age, and tree position on energy characteristics have been observed in sengon and other species (Kumar *et al.* 2010; Kumar *et al.* 2011; Chin *et al.* 2013; Nasser and Arif 2014). Therefore, this study aimed to explore the characteristics of the slab waste fuelwood generated from sawmills located in two sengon producing centers, namely Sleman and Wonosobo Regencies.

Sleman Regency had the potential for sengon logs to reach 3,662 m^3 spread over 11 sub-districts in 14 villages (Dinas Kehutanan Provinsi D.I.Yogyakarta 2011a). Meanwhile, community forests in Wonosobo in 2011 covered an area of about 18,982 ha, which was dominated by sengon plants with the potential for sengon production reaching 200,000 m^3 per year (Kabupaten Wonosobo 2011). The importance of this research is to provide information on the influence of the site of the waste and plant parts on the calorific value produced in order to increase the economic value of the material as well as to estimate the potential biomass energy produced by sengon slab wastes as a substitute for fossil fuels such as kerosene.

Materials and Methods

Field Sampling

Samples were taken from the slab wastes of industrial center sengon sawmills. The collection was carried out in Kepil and Kaliwiro Sub-districts for Wonosobo Regency and in the Sub-districts of Tempel, Kalasan, and Cangkringan for Sleman Regency (Figure 1). In Wonoboso sawmills, the materials were divided into large-diameter (more than 15 cm) and small-diameter (less than 8 cm) logs.

Sample Preparation

The slab wastes were collected from freshly sawn logs to prevent mixture with previous sawing wastes (Figures 2 and 3). Then, the obtained slabs were air-dried to ease the bark separation. After that, the bark was carefully separated from the wood. A huge variation was observed in bark thickness from Sleman samples. The bark thickness of slabs from Cangkringan, Tempel, and Kalasan was about 0.47 cm, 0.13 cm, and 0.09 cm, respectively. From each part, 2 g specimens were taken for moisture content, specific gravity, ash content, and volatile matter content tests and 1 g specimens were taken for calorific value test.

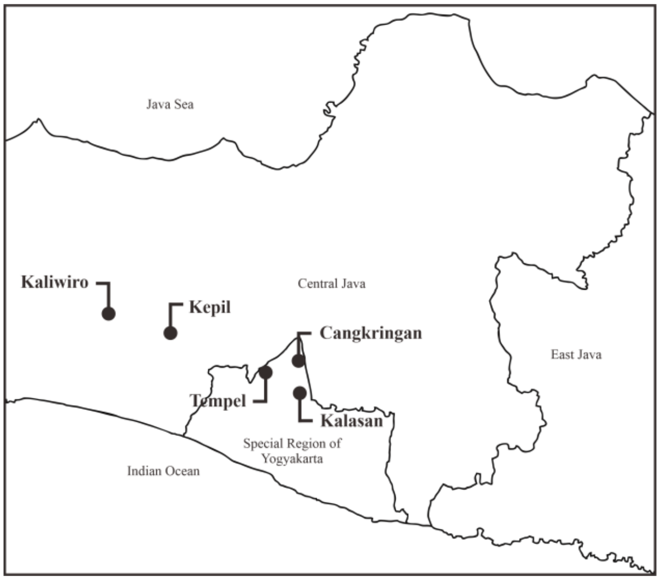

Figure 1. Geographic distribution of sampling sites.

Figure 2. Slab wastes from a sengon sawmill in Wonosobo Sleman.

Figure 3. Slab wastes from a sengon sawmill in Wonosobo.

Determination of Density (g/cm^3)

Volumes of oven-dried samples were determined by water displacement method (ASTM D 2395-02, 2006). The densities of the samples (d) were determined using eqn. (1),

$D = W_{OD}/V_{OD}$ .... (1),

where W_{OD} is the oven-dry mass of wood and V_{OD} is the oven-dry volume of wood.

Determination of Calorific Value (cal/g)

The one-gram wood specimens were burned in an oxygen bomb calorimeter (Parr Instrument Company Inc, no. 1341 series 3403) for determining the calorific value. The testing referred to ASTM 5865-04.

Proximate Analysis

The air-dry weights (W_A) of the samples were recorded. These specimen blocks were oven-dried at (103 ± 2) °C until they achieved constant mass (Wo). The moisture content (MC) was determined using eqn. (2),

$MC (\%) = [(W_A - Wo) / (Wo)] \times 100$ .... (2).

The ash and volatile matter contents were determined according to ASTM D1102-84 and ASTM D3175-02, using a muffle furnace. The fixed carbon content (FCC) was estimated using eqn. (3),

FCC (%) = [100 - (% ash content + % volatile matter content)] .... (3).

The testing for each characteristic was repeated three times.

Fuel Value Index

The fuel value index (FVI) was calculated using eqn. (4) (Purohit and Nautiyal 1987),

$FVI = CV \times D / AC$ .... (4),

where CV is the calorific value (kJ/g), AC is the ash content (g/g), and D is the density (g/cm^3) of biomass.

Estimation of Sawmill Recovery

Recovery data was obtained through secondary data and direct observation in March 2011. The data were provided by the Industry and Trade Service of Sleman Regency and the Forestry Service of the Special Region of Yogyakarta. For primary data collection, several sawmills were selected in each of these areas. The selected sawmills consumed a minimum of 250 m^3 of sengon raw material per month. Recovery calculation was performed with eqn. (5),

Recovery (%) = (Output / Input) × 100 .... (5),

where input is the volume of round logs before conversion with Smalian's formula (m^3) and output is the volume of lumber obtained after conversion (m^3).

Estimation of Potential Slab Waste Energy

Potential annual energy estimation was carried out after calculating the wood consumption of the sengon processing industry, the waste potential, and the dry weight of the slab wastes. The wood consumption can be seen from the secondary data from the Forestry Service of Yogyakarta Special Region and the Forestry Service of Wonosobo Regency in 2011.

Based on the calculation of the recovery data, the potential for sengon sawmill wastes could be estimated. The waste potential was estimated with eqn. (6),

Waste potential (m^3) = WC – (WC × R) .... (6),

where WC is the wood consumption (m^3) and R is the sawn recovery (%).

Biomass in energy production refers to living or recently dead biological material that can be used as a fuel source. This dry biomass can be expressed in units of kilograms or tons. The content of biomass in wood can be calculated using eqn. 7 (Brown 1997),

Dry weight = $D_O \times V_O$ .... (7),

where W_O is the oven-dry density (gr/cm^3) and V_O is the oven-dry volume (cm^3).

The potential energy estimation from slab wastes from sengon sawmills can be calculated using eqn. 7 eqn. 8 (Brown 1997),

Estimated Energi (cal) = DW × CV .... (8),

where DW is the dry weight (kg) and CV is the calorific value (kcal/kg).

Results and Discussion

Based on the proximate analysis, technically, a good fuelwood is to have a high level of fixed carbon content while other parameters are at low levels. Proximate measurements for sengon slabs from two sites are presented in Table 1. The moisture content was slightly wetter in the bark, while the moisture content in the wood was still in the range of air-dry moisture content (13~18%). The bark part showed higher values in fixed carbon and ash contents but lower in volatile matter content than did the wood part. In general, the samples from Wonosobo gave higher values in fixed carbon content but smaller in moisture, volatile matter, and ash contents than the samples in Sleman. The difference between large- and small-diameter logs can be seen in the Kepil sample. It was measured that big logs gave lower fixed carbon content values, but their ash and volatile matter content values were larger compared to those of small-diameter logs.

The results of measurement of density, calorific value, and FVI are presented in Table 2. The the bark had higher values than the wood in density. A reverse trend was observed in the calorific value and FVI parameters. The samples from Sleman gave higher density values, especially in the bark part, than the Wonosobo samples. On the other hand, the calorific values of the bark of the Sleman samples showed lower levels than the Wonosobo samples. For the FVI, the wood samples in Sleman showed lower values than those in Wonosobo. Large-size logs (Wonosobo samples) showed higher values in density and calorific values than of small logs.

The specific gravity value range of sengon wood was found to be 0.24~0.49, the calorific value 4,664 cal/g, and the ash content 0.6% (Martawijaya *et al*. 2005). Research on sengon wood from Malaysia (Chin *et al.* 2013) showed specific gravity of 0.50, calorific value of 4,294 cal/g (high heating value), and ash content of 1.46%. The highest calorific value was observed in a Wonosobo sample (Kepil/big log, 4,749 cal/g), and so was the highest FVI value (Kepil/small log, 18.74). This variation in calorific value or FVI is thought to be due to the influence of the chemical properties of the material that were not measured in this study, such as the extractive and lignin contents. Previous studies have shown a significant correlation between calorific value and extractive content as well as between calorific value and moisture content in sengon wood (Chin *et al.* 2013). In other species, the contents of lignin, ash, and extractives were found to affect the calorific value (White 1987; Fuwape 1991; Nasser and Arif 2014). While the high values of density, lignin content, and extractive content in the bark would increase the calorific value, the comparatively high value of ash content and moisture content might decrease the calorific value and FVI levels. The average FVI of wood samples from Wonosobo shows a value of > 10, implying that slabs from the regency are more profitable as a fuel (Kataki and Konwer 2001) than those from Sleman. Although their FVI values were relatively low, in the future, sengon wood wastes will still be the main choice as biomass fuel due to their abundance.

Samples with large diameters in Wonosobo showed higher densities and calorific values than small-diameter logs. It is assumed that the large-diameter logs were from older wood or from the bottom parts of the trees as characterized by low percentages of juvenile wood and high extractive contents. A study on Eucalyptus hybrids showed that the calorific values of mature trees were higher than those of lower-age trees, but the ash content values were much higher in lower-age trees compared to mature trees (Kumar *et al.* 2010). The calorific values were found to decrease along the stem length towards the tree-top in *A. auriculiformis* and *C. equisetifolia* (Kumar *et al.* 2011). Furthermore, it was noticed that the ash content values in general were found to be higher in the top portions of the trees, and, similarly, they were found significantly higher in the case of *A. auriculiformis*. Thus, further research on the effects of age and position in the sengon tree is important. It was also noticed that some samples showed comparatively high ash content values. This has necessitated a study on the relation with toxic metals in sengon wood. Research on South African fuelwood showed that the calorific value should not be the only factor to be taken into account when evaluating fuelwood; negative environmental impact should also be considered (Manalula and Meincken 2009).

Table 1. Proximate analysis of of slab waste from sengon sawmills (average of three replications with standard deviation in parentheses)

Location	Parts	Moisture content (%)	Volatile matters content (%)	Fixed carbon content (%)	Ash content (%)
Sleman					
Kalasan	Wood	17.28 (0.66)	88.94 (0.31)	10.23 (0.35)	0.83 (0.05)
	Bark	20.03 (0.45)	83.94 (1.26)	11.47 (1.33)	4.59 (0.22)
Cangkringan	Wood	16.79 (1.08)	88.50 (0.99)	10.68 (0.87)	0.82 (0.05)
	Bark	19.50 (0.38)	83.58 (1.04)	12.65 (1.19)	3.77 (0.13)
Tempel	Wood	15.07 (0.23)	88.37 (0.55)	10.81 (0.59)	0.81 (0.03)
	Bark	19.82 (0.46)	84.64 (0.75)	12.21 (1.69)	3.40 (0.21)
Wonosobo					
Kepil	Big log	16.32 (0.25)	82.89 (0.55)	16.50 (0.45)	0.60 (0.11)
	Small log	13.90 (0.78)	85.65 (0.74)	13.96 (0.77)	0.30 (0.09)
	Bark	17.59 (0.45)	75.84 (2.38)	20.62 (2.32)	3.53 (0.07)
Kaliwiro	Big log	15.65 (0.26)	83.17 (0.80)	16.14 (0.79)	0.68 (0.60)
	Small log	15.82 (0.56)	83.71 (0.52)	15.98 (0.54)	0.38 (0.10)
	Bark	17.37 (0.55)	76.90 (0.65)	19.18 (0.73)	3.91 (0.18)

Sawmilling is the process of converting logs into lumber by using a variety of machines. The measurement of recovery (yield or conversion efficiency) showed the range of 45~71% (Table 3). Previous research on sengon wood sawing in a flat-sawn pattern (diameter of 24~50 cm) obtained a recovery of 45% with a productivity of 0.66 m^3/hour (Rachman 1991). The recovery in Wonosobo site showed a smaller variation in value than that in Sleman site. This might be due to the various types and conditions of bandmills used, worker experiences (years), and sizes of logs converted.

Wood biomass is an important resource for generating energy with both environmental and economic benefits. The estimation of potential energy showed a large difference between Sleman and Wonosobo sites (Table 4). This can be seen from the potential area and larger volume of timber in Wonosobo Regency. Although the average density of slab wastes was higher for the Sleman samples when compared to the Wonosobo samples (0.59 vs 0.38 g/cm^3), the slab wastes in Wonosobo produced 11 times greater energy (1,521 × 10^{14} cal) than those in Sleman (1,374 × 10^{13} cal). Furthermore, if we assume that fuel wood substitutes domestic heating oil (kerosene), then the amount will equal to about 1.52 million litres in Sleman or 16.8 million litres in Wonosobo.

Table 2. Density, calorific, and fuelwood value index of slab waste from sengon sawmills (average of three replications with standard deviation in parentheses).

Sawn industry	Parts	Density (g/cm^3)	Calorific value (cal/g)	Fuelwood Value Index
Sleman				
Kalasan	Wood	0.23	4,546	5.34
	Bark	0.94	4,089	3.52
Cangkringan	Wood	0.34	4,720	8.16
	Bark	0.84	4,215	3.94
Tempel	Wood	0.31	4,697	7.46
	Bark	0.89	4,274	4.69
	Average	0.59 (0.33)	4,423 (266)	5.51 (2.06)
Wonosobo				
Kepil	Big log	0.30	4,749	10.22
	Small log	0.25	4,645	18.74
	Bark	0.52	4,524	2.71
Kaliwiro	Big log	0.36	4,690	15.65
	Small log	0.26	4,581	15.82
	Bark	0.59	4,474	2.90
	Average	0.38 (0.11)	4,637 (88)	11.00 (6.34)

Remark : big log = diameter >15 cm, small = log diameter < 8 cm

Table 3. Recovery assesment of sengon sawmills in Wonosobo and Sleman Regencies

No	Name of sawn industry	Input/month (m^3)	Output/month (m^3)	Recovery (%)
	Wonosobo - Kepil			
1	Mitra Abadi	270.0	159.30	59.0
2	Rizquan Abadi	500.0	300.0	60.0
3	Eka Abadi	350.0	201.25	57.5
	Wonosobo - Kaliwiro			
1	Karunia Abadi	380.0	228.0	60.0
2	Maju Makmur	400.0	246.0	61.5
3	Kambium Prima	600.0	360.0	60.0
			Average	59.70
	Sleman			
1	CV Sinar Albasia**	985.15	616.43	62.57
2	Remaja Sejahtera*	233.0	125.0	53.64
3	PT Citra Raharja Utama*	2450.0	1740.0	71.02
4	PT Perwira Karya**	211.40	91.98	45.31
5	UD Sengkati Bersaudara	270.0	157.0	58.0

Remark: * Source = Dinas Perindustrian dan Perdagangan Kabupaten Sleman (2011), ** Source = Dinas Kehutanan D.I.Yogyakarta (2011a).

To safely use wood biomass for energy, the available wood biomass should be estimated from an economic perspective. A previous study on some small- and medium-scale enterprises in the food and beverage industry in Wonosobo showed that the fuel cost of using wood pellets was smaller than the fuel cost of using other fuels, such as firewood, gas, and sawdust (Sylviani *et al.* 2013). Despite some weaknesses that exist in the use of wood or bark materials, using them as substitutes for fossil materials such as kerosene in a year can save up to about Rp102.5 billion for Wonosobo and Rp 9.2 billion for Sleman (Table 4). The assumption is that kerosene sold for Rp 6,071/L (in 2011) with a calorific value of 10,986 cal/g and specific gravity of 0.82 (Staffel 2011). Another scheme is that the enormous amount of sengon wood wastes is converted into briquettes (Saputro & Widayat 2016) and carbonized into charcoal, rocket stove fuel (Wibowo 2020), as well as wood activated charcoal on solid propellants for rocket fuel (Manistatho *et al.* 2021). It will be more advantageous for megawatt electricities as charcoal has a higher calorific value than that of wood itself.

Table 4. Energy estimation of slab waste potential from sengon sawmills per year

No	Characteristics	Equation	Sleman	Wonosobo
1	Wood consumption (m^3)		12,406*	213,715 **
2	Recovery (%)		57.75	59.70
3	Waste potential (m^3)	WC-(WC × Recovery)	5,247.738	86,127.145
4	Density (g/cm^3)		0.592	0.383
5	Dry weight(kg)	density × waste potential	3,106,660	32,986,641
6	Calorific value (kcal/kg)		4,424	4,610
7	Energy estimation (cal)	dry weight × calorific value	1.374×10^{13}	1.521×10^{14}
8	Kerosene equivalent (L) [a]	energy estimation/(10.986 × 0.82)	1,525,222	16,884,016
9	Economical value (Rp) [b]	(× Rp 6,071)	9,259,627,552	102,502,861

Remark: * Source= Dinas Kehutanan Provinsi D.I.Yogyakarta (2011b); ** Source = Kabupaten Wonosobo (2011), WC = wood consumption; a = kerosene's calorific value of 10,986 cal/g and specific gravity of 0,82; kerosene price (2011) = Rp 6,071.

Conclusions

The understanding of fuel properties is very important in the utilization of any material as fuel. The energy properties of slab wastes generated by sawmills in Sleman and Wonosobo Regencies were determined. Besides the sawmill location, the stem part (wood and bark) and log size factors were also indicated to affect the energy characterisctis of the slabs. The highest calorific value (Kepil/big log, 4,749 cal/g) and FVI (Kepil/small log, 18.74) were observed in the Wonosobo samples. The sawmill recovery value ranged from 45 to 71%. Based on secondary data, the wood consumption in Wonosobo was considerably higher than that in Sleman. It was calculated that the estimated potential energy produced by sawnmill slab wastes in Sleman and Wonosobo reached 1,374 × 10^{13}

calories (equivalent to 1,525,222 L of kerosene) and 1.521 × 10^{14} calories (equivalent to 16,884,016 L of kerosene) a year, respectively. In addition, the effect of log diameter on calorific value have been observed in this experiment. Due to huge variations of log diameter in sawmill from both sites, therefore, the relationship between the two should be determined in the future works.

References

Annual Book of ASTM Standards. 1984. ASTM D 1102-84, Test Method for Ash in Wood. American Society for Testing and Materials.

ASTM International. 2002. ASTM D3175-02. Standard Test Method for Volatile Matter in the Analysis Sample of Coal and Coke. American Society for Testing and Materials.

ASTM International. 2004. ASTM D 5865 : 2004 Standard Test Method for Gross Calorific Value of Coal and Coke. American Society for Testing and Materials.

ASTM International. 2006. ASTM D 2395 : 2006 Standard Test Methods for Specific Gravity of Wood and Wood-Based. American Society for Testing and Materials.

Brown, S. 1997. Estimating Biomass and Biomass Change of Tropical Forests: A Primer. FAO Forestry Paper Vol. 134. Food and Agriculture Organization of the United Nations, Rome.

Chin, K.L.; P.S. H'ng; E.W. Chai; B.T. Tey; M.J. Chin; M.T. Paridah; A.C. Luqman; M. Maminski. 2013. Fuel characteristics of solid biofuel derived from oil palm biomass and fast growing timber species in Malaysia. Bioenergy Research 6: 75–82.

Dinas Kehutanan Provinsi D.I.Yogyakarta. 2011a. Laporan Mutasi Kayu (LMK) oleh Industri Primer Hasil Hutan. Laporan Dinas Kehutanan Provinsi D.I.Yogyakarta.

Dinas Kehutanan Provinsi D.I.Yogyakarta. 2011b. Surat Keterangan Asal Usul (SKAU). Laporan Dinas Pertanian dan Kehutanan Kabupaten Sleman.

Dinas Perindustrian dan Perdagangan Kabupaten Sleman. 2011. Data Izin Usaha Industri (IUI). Laporan Dinas Perindustrian dan Perdagangan Kabupaten Sleman.

Fengel, D.; G. Wegener. 1984. Wood: Chemistry, Ultrastructure, Reactions. Walter de Gruyter, Berlin.

Fuwape, J. A. 1991. Effect of extractives on heating value of *Gmelina arborea*. Journal of Tropical Forest Science 4(4): 281-28.

Kabupaten Wonosobo. 2011. Potensi Kayu Bulat. www.kabupatenwonosobo.com. Retrieved at 5 April 2014.

Kataki, R.; D. Konwer. 2001. Fuelwood characteristics of indigenous tree species of North-East India. Biomass and Bioenergy 22: 433-473.

Kumar, R.; K.K. Pandey; N. Chandrashekar; S. Mohan. 2010. Effect of tree-age on calorific value and other fuel properties of Eucalyptus hybrid. Journal of Forestry Research 21(4): 514-516.

Kumar, R.; K.K. Pandey; N. Chandrashekar; S. Mohan. 2011. Study of age and height wise variability on calorific value and other fuel properties of Eucalyptus hybrid, *Acacia auriculaeformis*, and *Casuarina equisetifolia*. Biomass and Bioenergy 35: 1339-1344.

Manistatho, F.A.;Y.E. Prawatya, R.A. Wicaksono. 2021. Analisa Pengaruh Arang Aktif Kayu Sengon (*Paraserianthes falcataria* (L.) Nielsen) Sebagai Komposisi Fuel Propelan Padat pada Bahan Bakar Roket. Jurnal Teknologi Rekayasa Teknik Mesin 2(2): 62-67.

Martawijaya, A.; I. Kartasujana, K. Kadir, Y.I. Mandang. 2005. Atlas Kayu Indonesia Jilid II. Badan Penelitian dan Pengembangan Kehutanan Bogor

Munalula, F.; M. Meincken. 2009. An evaluation of South African fuelwood with regards to calorific value and environmental impact. Biomass and Bioenergy 33: 415-420.

Nasser, R; I. Aref. 2014. Fuelwood characteristics of six acacia species growing wild in the Southwest of Saudi Arabia as affected by geographical location. BioResources 9(1): 1212-1224.

Purohit, A.N.; A.R. Nautiyal. 1987. Fuelwood value index of Indian mountain tree species. The International Tree Crops Journal 4: 177-182.

Rachman, O. 1991. Pengaruh pengerasan mata gergaji dan pola penggergajian terbadap. karakteristik penggergajian kayu sengon (*Paraserianthes falcataria*). Jurnal Penelitian Hasil Hutan 9(4): 163-169.

Saputro, D.D.; W. Widayat. 2016. Karakterisasi Limbah Pengolahan Kayu Sengon Sebagai Bahan Bakar Alternatif. Jurnal Sain dan Teknologi 14(1): 21-29.

Staffell, I. 2011. The Energy and Fuel Data Sheet. University of Birmingham, UK.

Sylviani; H. Dwiprabowo; E. Y. Suryandari. 2013. Analisis biaya penggunaan berbagai energi biomassa untuk IKM (Studi Kasus di Kabupaten Wonosobo). Jurnal Penelitian Sosial dan Ekonomi Kehutanan 10(1): 48-60.

White, R.E. 1987. Effect of lignin content and extractives on the higher heating value of wood. Wood and Fiber Science 19(4): 446-452.

Wibowo, N.I. 2020. Pemanfaatan Teknologi Tepat Guna Kompor Roket dengan Formulasi Bahan Bakar Pelet Kayu dan Kayu Sengon. Agroscience 10(2): 136-147.

Joko Sulistyo, Binsar Edward Sianturi, and Raditya Ananta Rustantoputro
Department of Forest Products Technology,
Faculty of Forestry, Universitas Gadjah Mada,
Jl. Agro No.1, Bulaksumur, Yogyakarta 55281, Indonesia
Tel. and Fax.: +6274 550541
E-mail : jsulistyo@ugm.ac.id