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An Experimental Study on Autoignition of Wood

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***Abstract*—**Experiments were conducted to characterize fire properties of wood exposed to the certain external heat flux and under variety of wood moisture content. Six kinds of Indonesian wood: *keruing*, *sono*, *cemara*, *kamper*, *pinus*, and *mahoni* were exposed to radiant heat from a conical heater, result in appearance of a stable flame on the wood surface caused by spontaneous ignition. A thermocouple K-type was used to measure the wood surface temperature. Temperature histories were recorded throughout each experiment at 1 s intervals using a TC-08. Data of first ignition time and temperature, end ignition time and temperature, and charring rate have been successfully collected. It was found that the ignition temperature and charring rate depend on moisture content of wood.

***Keywords*—**Fire properties, moisture content, wood, charring rate.

I. Introduction

EVERY long dry season, serious forest fires periodically occur at several islands in Indonesia such as Kalimantan Island, result in loss of natural resources and smoke that disturb the air and marine traffic. Auto ignition on solid fuel such as wood often across the forest without any source of fire. This spontaneous ignition is a complex interplay of chemistry, heat transfer, and mass transfer, which is caused by the heat radiation around the wood object. Because of the hazardous and complexity of auto ignition, the process of this auto ignition needs to be confirmed by experiments.

Recently Poespowati [7], [8] conducted an experimental study on re-ignition characteristics of Australian wood-based materials in order to investigate the role of wood porosity on its re-ignition characteristics. Their experiments were carried out on a set of wood samples with various levels of porosity at heat flux level between 40 – 60 $kW.m^{-2}$ by using a modified mass-loss cone calorimeter. Results of the study were consistent with their previous experimental data on surrogate ceramic samples revealing that the effect of porosity on the re-ignition delay time was significant at all heat flux levels particularly those in excess of 50 $kW.m^{-2}$.

Later on, Poespowati [9] carried out an experimentally study on fire properties of eight kinds of Indonesian wood (*akasia*, *sengon*, *bangkirai*, *waru*, *kempas*, *meranti*, *gelam*, and *ulin)* exposed to the irradiance heat flux between 17-41 $kW.m\text{-}^{2}$. It was found that low density wood will burn faster than the high density wood and the higher the incident heat flux, the quicker the ignition time, inversely, the lower the ignition temperature.

The results for auto ignition time was between 100-200 second, and the auto ignition temperature was between 350-600°C.

Experiment on three kinds refuse derived fuel fire inception by spontaneous ignition by using TG-DTA has been conducted by Lijing Gao et.al [4]. The range of pyrolysis temperature was 150-550°C, and the activation energy was 89.82 kJ/mol.

The main objective of the study is to gain a more fundamental insight into the role of wood moisture content on its ignition characteristics under fire conditions. This study concerns with the effect of wood moisture content on spontaneous ignition behavior of six kinds of Indonesian wood in order to provide a data base of fire characteristic i.e. ignition time, ignition temperature, end ignition time, end ignition temperature, and charring rate.

II. Experimental Method

The experimental apparatus used in this study was a non-standard truncated heater. Fig. 1 shows the schematic layout of the apparatus. This particular instrument was designed in accordance with capable of accommodating samples of up to 25 mm thick if horizontally placed.

It must be pointed out that the studies were mainly concern with the spontaneous ignition of samples. Therefore the spark igniter was not used. A thermocouple on the surface of the sample was used for measurements of temperature history within the test samples. For this study, stainless steel, sheathed, ungrounded junction chromel-alumel thermocouples (0.003 inch out side diameter) were used. The type of thermocouple used for this purpose was *K*-type made for the temperature range of 95-1260°C. Temperature histories were recorded throughout each experiment at 1 s intervals using a digital data acquisition system (TC-08).

To examine the autoignition of wood, six different species of Indonesian wood (*keruing*, *sono*, *cemara*, *kamper*, *pinus*, and *mahoni*) were tested with a truncated conical under irradiance heat flux of 22 $kW.m^{-2}$. The wood samples were made into wood blocks with a dimension of 5 cm long, 5 cm wide and 2.5 cm thick, and they were oven dried due to obtain the moisture content variety (0%, 50% and 100%). The experimental procedure consisted of the following steps. Firstly, the sides of the sample except its surface was wrapped in a single layer of aluminium foil in order to minimize the edge

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effects and to simulate a one-dimensional heat transfer situation. Then, the sample was instrumented with a thermocouple on its surface and then placed horizontally in the sample holder assembly. The samples sitting in the open air and ready to be heated by irradiance heat flux.

The radiant heater was then set to 22 kW.m^{-2}, which is relevant with temperature of 500^{o}C. When subjected to external heating, wood starts to decompose, giving a mixture of volatile species and a carbonaceous residual / char as products. Flame could be seen to appear in the volatile stream and then flash down to the wood where it persisted on the surface. The ignition time and temperature were recorded as the first appearance of flame and the time of end-ignition was recorded as the disappearance of flame. Meanwhile, the char layer was observed by measuring the thickness of char. The experimental procedures outlined above were systematically repeated for various combinations of wood moisture content, and they were tested three times at per level of moisture content.

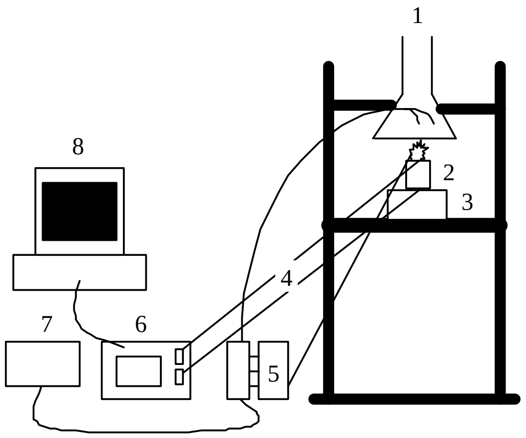

Fig. 1 Schematic layout of non-standard truncated cone

1. Cone heater
2. Wood sample
3. Sample holder
4. Thermocouple
5. Temperature digital
6. Data Taker (TC 08)
7. Electricity
8. PC

III. Results and Discussions

The results of the experimentally study are presented as histories of fire properties of wood (Ignition temperature, ignition time, end-ignition temperature, end-ignition time, and charring rate) that are illustrated in Fig. 2 to Fig. 6 and tabulated in Table I to Table V.

Ignition temperature is the temperature of the wood surface at the time of ignition. Fig. 2 and Table I show the behaviour of ignition temperature of woods under three different moisture content.

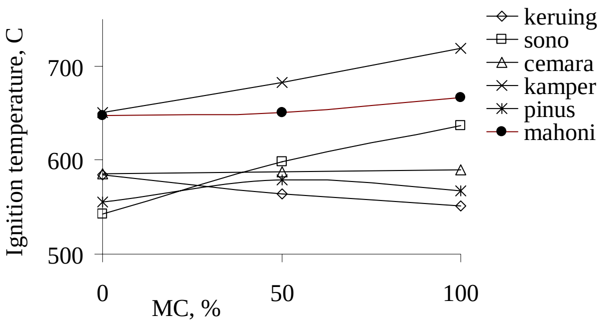

Fig. 2 Ignition Temperature of woods as functions of Moisture Content

TABLE I
Ignition Temperature of Woods as Functions of Moisture Content

MC %	Ignition Temperature, C					
	keruing	*sono*	*cemara*	*kamper*	*pinus*	*mahoni*
0	584.76	542.3	585.59	650.9	555.9	646.91
50	564	598.0	587.74	682.72	579.2	650.23
100	551.2	637.1	589.8	719.5	566.9	667.19

As can be seen from Fig. 2, most of the curves have linear relationship between ignition temperature and moisture content. It shows that the higher the moisture content, the higher the ignition temperature. *Kamper* wood has the highest ignition temperature for every percent of moisture content. Meanwhile, for 50% of moisture content, the sequences of ignition temperature from the highest to the lowest show the same sequences for 100% of moisture content, as follow: *kamper*, *mahoni*, *sono*, *cemara*, *pinus*, and keruing. This ignition temperature sequences also occurred for 0% of moisture content, except for *sono* wood that shows the lowest ignition temperature. Characteristics of wood ignition temperature depend on the species of wood that consist of different percentage of cellulose, hemicellulose, and lignin. These chemical components might affect the behaviour of ignition temperature.

The effect of moisture content and the kind of wood on end-ignition temperature illustrates in Fig. 3 and tabulated in Table II. End-ignition temperature or extinguish temperature is the temperature when the fire disappear from the sample surface.

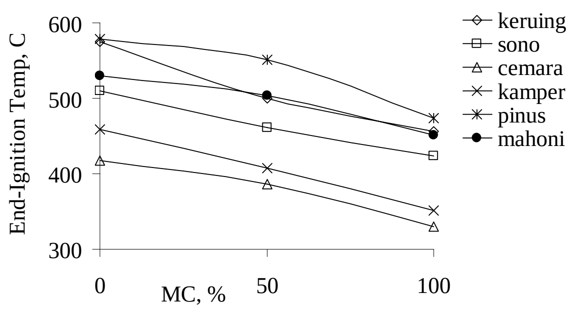

Fig. 3 End-Ignition Temperature of woods as functions of Moisture Content

TABLE II
END-IGNITION TEMPERATURE OF WOODS AS FUNCTIONS OF MOISTURE CONTENT

MC, %	End-Ignition Temperature, C					
	keruing	*sono*	*cemara*	*kamper*	*pinus*	*mahoni*
0	575.14	510.6	417.05	458.9	578.2	529.88
50	500.05	460.7	386.39	407.82	551.1	503.5
100	456.03	423.3	329.74	351.25	473.2	451

Fig. 3 and Table II indicate the effects of moisture content of woods on end-ignition temperature. Ignition process of wood is glowing ignition followed by visible fire on the wood surface, and finished by the end of visible fire. In general, *pinus* wood has the highest end-ignition temperature, on the other hand, *cemara* wood has the lowest one. Moreover, the curves indicate that the end-ignition temperature decrease as the increase of moisture content.

The Fig. 4 and the Table III bellow show the performance of ignition time of woods as a function of moisture content.

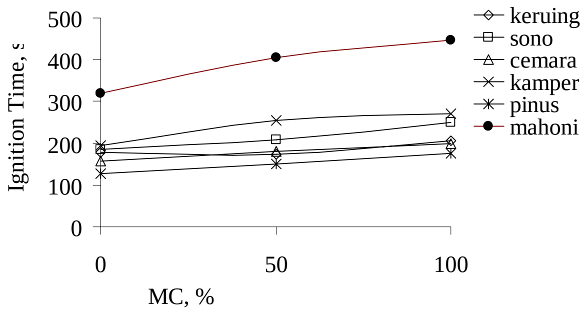

Fig. 4 Ignition Time of woods as functions of Moisture Content

TABLE III
IGNITION TIME OF WOODS AS FUNCTIONS OF MOISTURE CONTENT

MC, %	Ignition Time, s					
	keruing	*sono*	*cemara*	*kamper*	*pinus*	*mahoni*
0	179.33	185.7	157.2	193.67	127.3	319
50	174	208.7	180.2	254	151.3	405
100	205	250.3	198.7	270	176.7	445.67

As can be seen from Table III, all specimens tested needed at least about 2 minutes to catch fire at 0% Moisture Content, the longest time to have fire was *mahoni* wood with moisture content of 100%. Ignition time is the minimum time when sample tend to ignite and generate a visible flame or fire under a certain irradiance heat flux. The ignition time increases with the increase of moisture content. This is simply due to the higher the moisture content the more water inside the wood structure, as such, more time to evaporate the water prior ignition process. *Pinus* woods need the shortest time to ignite, it is because *pinus* wood consist more lignin than the other woods, result in the quicker ignition time.

The next Fig. 5 and Table IV provide data of end-ignition time under variety of moisture content and wood types.

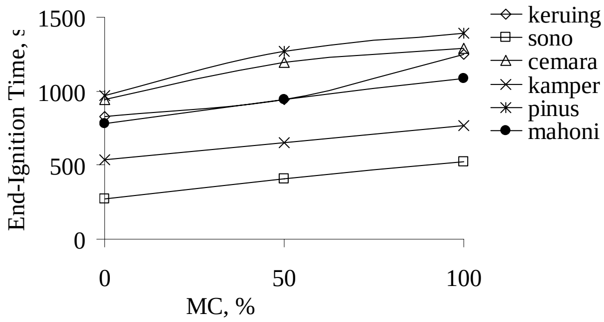

Fig. 5 End-Ignition Time of woods as functions of Moisture Content

TABLE IV
END-IGNITION TIME OF WOODS AS FUNCTIONS OF MOISTURE CONTENT

MC, %	End-Ignition Time, s					
	keruing	*sono*	*cemara*	*kamper*	*pinus*	*mahoni*
0	831.33	272	943.33	538	970	779
50	942.67	404	1191.34	652.3	1268	943
100	1252	523	1288.67	766.7	1394	1086.7

Fig. 5 and Table IV indicate the end-ignition time influenced by moisture content and the kinds of wood. In general the higher the moisture content, the longer the end-ignition time. *Pinus* has the longest time to extinguish, followed by *cemara*, *keruing*, *mahoni*, *kamper*, and *sono*. End-ignition time or extinguish time is the endurance of wood sample under fire condition. This fire endurance depends on the charring rate of wood. It can be noted that the longer the charring rate, the longer the end-ignition time. The endurance of fire on the sample surface also influenced by the oxygen availability, both oxygen in the sample structure and oxygen from environment. It means that the more the oxygen, the longer the fire on the sample. The more oxygen in the sample structure, the more porous the sample, as such the lower the sample density.

Fig. 6 and Table V give the charring rate occurrence under different moisture content and wood species.

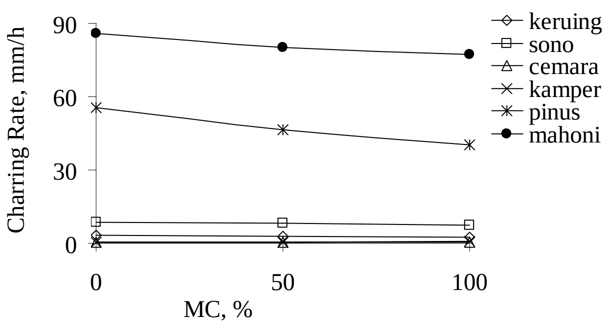

Fig. 6 Charring Rate of woods as functions of Moisture Content

TABLE V
CHARRING RATE OF WOODS AS FUNCTIONS OF MOISTURE CONTENT

MC, %	Charring Rate, mm/h					
	keruing	*sono*	*cemara*	*kamper*	*pinus*	*mahoni*
0	3.21	8.7	0.32	0.41	55.4	85.72
50	3	8.09	0.31	0.55	46.4	80
100	2.62	7.27	0.32	0.66	40.2	77.34

Fig. 6 and Table V show the charring rate of all kinds of wood under various level of moisture content. The charring rate of wood refers to the dimensional rate (mm/h), at which wood change to char. The pyrolysis behaviour of wood as a charring fuel leaves relatively significant amounts of carbonaceous residue (char) when it burns. The porous residue, in turn, alters the heat and mass transfer processes within the solid. For every value of moisture content, *mahoni* wood has the highest rate of char formation; followed by *pinus* wood, *sono* wood, and *keruing* wood. On the other hand *kamper wood and cemara* wood have the lowest charring rate. The differences of wood charring rate are affected by the differences of wood characteristics such as density, permeability, anatomy, and chemical composition. Compared with Fig. 5, Fig. 6 gives inconsistent results; the sequence of charring rate should be relevant with the sequence of end-ignition time. The only consistent result was found for *keruing* wood and *kamper* wood.

IV. CONCLUSION

In the present paper, the fire properties of autoignition of wood samples have been experimentally conducted. The results of the present study indicate that in general ignition temperature, ignition time, end-ignition temperature, end-ignition time, and charring rate of wood based materials are functions of their moisture content and their chemical composition. In general, it can be indicate that fire properties of wood are affected by moisture content, chemical components, and density. More properly experimental equipment such as cone calorimeter should be applied in order to get the consistent results.

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