CO_2 Emissions from the Combustion of Native Australian Trees

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Abstract- Carbon dioxide (CO_2), as a primary product of combustion, is a known factor affecting climate change and global warming. In Australia, CO_2 emissions from biomass burning are a significant contributor to total carbon in the atmosphere and therefore, it is important to quantify the CO_2 emission factors from biomass burning in order to estimate their magnitude and impact on the Australian atmosphere. This paper presents the quantification of CO_2 emission factors for five common tree species found in South East Queensland forests, as well as several grasses taken from savannah lands in the Northern Territory of Australia, under controlled 'fast burning' and 'slow burning' laboratory conditions. The results showed that CO_2 emission factors varied according to the type of vegetation and burning conditions, with emission factors for fast burning being 2574 ± 254 g/kg for wood, 394 ± 40 g/kg for branches and leaves, and 2181 ± 120 g/kg for grass. Under slow burning conditions, the CO_2 emission factors were 218 ± 20 g/kg for wood, 392± 80 g/kg for branches and leaves, and 2027 ± 809 g/kg for grass.

Keywords: *CO_2, Emission factors, vegetation burning, Australia.*

I. INTRODUCTION

Biomass burning, including vegetation (savannah, forest and agricultural residues) fires and burning for cooking and heating, has been identified as an important source of atmospheric particles and gases [1-6]. Their emissions have had a significant impact on both air pollution and climate [7], due to the acidification of clouds, rain, and fog [8]; their light-scattering and absorption effects [9]; and their influence on cloud formation [10] and cloud microphysical processes [11].

Around 40-130 million hectares of land are burned in Australia annually [12] and of the 21 million hectares of forest fires burning from July 2002 to February 2003 across Australia, nearly 15 million hectares was located in the savannahs of the Northern Territory of Australia [13]. In the preceding years, from 1980-1995, more than 1 million hectares of the Kakadu National Park in the Northern Territory of Australia were destroyed by fires [14], and from 1997-2001, biomass burning in the savannahs of the Northern Territory of Australia was estimated to affect an area of 30 million hectares [15, 16]. The state of Queensland also experiences biomass burning every year, with over 37,000 hectares of forest burned in 1991 [17] and over 1 million hectares of forest burned from July 2002 to June 2003 [13].

Of the greenhouse gasses emitted by these fires, the release of carbon dioxide (CO_2) is considered to have the most significant impact on global warming due to the large quantities that are released into the atmosphere [18]. In Europe, 5-year data showed that approximately 11 million tonnes of CO_2 were released from wildfires each year [19], while in Finland, it was estimated that 134 million tonnes of CO_2 were released by wood burning from 2005-2007 [20]. Similarly, the deforestation of the Amazon across two states in Brazil produced 56.9 x 10^6 tonnes of CO_2 from 2006-2007 [2], while in Asia, the annual contribution of biomass burning and crop residue burning to CO_2 emissions is estimated to be around 1.1 x 10^9 and 37.9 x 10^7 tonnes, respectively [21]. In Australia, biomass burning resulting from wild fires and prescribed fires in the savannah regions of northern Australia is recognised to contribute around 6-8 % to global carbon emissions [22, 23], with the total carbon emitted by biomass burning estimated to be around 67.6 x 10^6 tonnes in 2004 [24].

The quantification of CO_2 emission factors from biomass burning is important to help estimate how much of the gas is released during burning. For example, in the agricultural fields of India, the burning of wheat straw was reported to emit 1787 ± 36 g of CO_2 per kg of wheat straw burned [25], while the average CO_2 emission factor from an Amazonian forest clearing fire was 1599 g/kg of dry biomass burned [26] and the CO_2 emissions from burning various types of garden biomass ranged from 897-1423 g/kg [27]. In Australia, the CO_2 emission factor for biomass burning has yet to be quantified and therefore, this study aimed to quantify the CO_2 emission factors from the burning of vegetation typically found in the open forests of South East Queensland and the savannahs of the Northern Territory of Australia – areas in which the states experience large fires every year [13, 16, 17]. The factors influencing these emission factors were also investigated in this study.

II. METHODOLOGY

Experimental Setup

The CO_2 measurement system was part of a larger system designed to characterize and quantify the emission factors of biomass burning (particles and gasses) under controlled laboratory conditions.

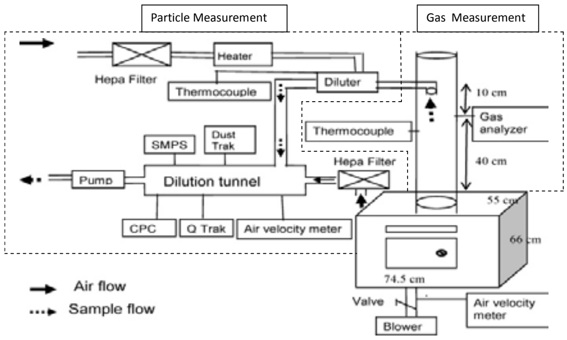

Figure 1. Experimental setup consisting of the burning system (modified stove), a dilution and sampling system, a particle measurement system, and a gas measurement system [4-6].

As shown in Figure 1, the experimental setup consisted of a burning system (modified stove), a dilution and sampling system and a particle measurement system [4, 5]. A modified commercial stove (66 x 74.5 x $55cm^3$), fitted with a ventilation system to enable the introduction of a controlled amount of air into the stove, was used to simulate different burning rates. In order to obtain a homogeneous rate of air flow, the outlet of the ventilation system was connected to a rectangular hood, which was connected to a blower with a maximum capacity of 14 L/s, by a pipe 30 mm in diameter. The flow rate of the air was adjusted by a valve located at this connection.

CO_2 Measurements

The CO_2 measurements were carried out using an Andros Gas Bench gas analyser. The smoke samples were taken from the flue through a conductive tube (0.1cm in diameter) which was placed 40 cm above the stove. The samples were then introduced into the gas analyser and the CO_2 concentrations during the burning process were measured continuously, at a sampling interval of 20s.

Sample Material and Preparation

The samples consisted of different species of vegetation taken from Queensland and Northern Territory of Australia. In Queensland, samples were collected from trees growing in open forests at Mount Samson, located about 40 km west from the city of Brisbane. Five hard wood species of Eucalyptus were selected according to their prevalence in the forest, including: Spotted Gum (Eucalyptus citriodora), Blue Gum (Eucalyptus tereticornis), Bloodwood (Eucalyptus intermedia), Iron Bark (Eucalyptus crebra) and Stringybark (Eucalyptus umbra). Large sections of the trunk of each species were placed in an open area of the laboratory for several months to obtain homogeneous moisture contents within the optimum range (20-30%) for burning [28]. In order to measure the moisture content of the wood, the logs were cut into pieces 15-25 cm in length, with diameters of 5-12 cm and measurements were conducted by measuring the dry (outer) part and wet (inner) part of the trunk several times. For example, the moisture content of 15-26 % for Blue Gum means that the moisture content was 15% in the outer part of the wood and 26% in the inner part of the wood. The measured moisture content of the other samples ranged from 18-26 % for Spotted Gum, 14-24 % for Bloodwood and 17-25 % for Iron Bark. The moisture content of the branches was also measured and ranged from 16-18 % for Spotted Gum, 18-22 % for Iron Bark and 18-20 % for Stringybark.

In the Northern Territory of Australia, three species of grasses were collected from the savannahs in the Jabiru region in August 2005, according to their prevalence in the area [29, 30], along with litter samples containing a mixture of grass, leaves and branches. The grass species sampled were *Shorgum intrans*, *Aristida holothera* and *Eulalia mackinlayi*. The moisture content for each species was measured according to the difference between the sample weight before and after drying. The moisture content of the samples ranged from 6-9% for *Aristida holothera*, 7-10% for *Eulalia mackinlayi*, 6-11% for *Shorgum intrans* and 8-15% for litter, and were similar to those reported for grasses growing in the savannahs of Northern Australia during the early and the late dry season, being 19% and 11%, respectively [31].

Burning Conditions

The samples were burned in the stove under ‘fast burning’ and ‘slow burning’ conditions. During fast burning, the stove was connected to a blower that introduced fresh air with maximum velocity 14 L/s. Under slow burning conditions, the blower was not connected to the ventilation system during the burning process. Burning of the samples was repeated three times for each of the burning conditions.

For fast burning, the air velocity at the base of the stove was measured at several points using an air velocity meter, while the door of the stove was closed. The air velocity across horizontal cross section was relatively homogeneous within 15 cm from the middle of the stove base with a speed of 1.8-2.0 m/s. Therefore, the samples for emission characterisation during burning were placed in the centre of the stove’s base.

Burning of the wood samples was repeated 5 times for fast burning and 3 times for slow burning, in order to confirm the reproducibility of the results for the same wood species. Newspaper and small pieces of the same wood types were used as a starter and kindling for the burning of the first sample, and pieces of the same wood were used as kindling for burning the following samples [5].

Emission Factor Calculation

Emission factors of gaseous species were calculated according to the following equation, which is similar to that described by Jenkins et al. [32]:

$$E_i = \frac{10^{-3}}{m_{fd}} \int_{t_o}^{t_f} A_s v C_i \frac{w_i}{22.4} dt \qquad (1)$$

where, Ei is the emission factor of species i, m_{fd} is the mass of vegetation consumed during burning, t_0 is the starting time of each test, t_f is the finishing time, A_s is the stack area (0.03 m^2), v is the average stack gas velocity, C_i is the sampling concentration of species i, and W_i is the molecular weight of species i.

III. RESULTS AND DISCUSSION

CO_2 Concentration

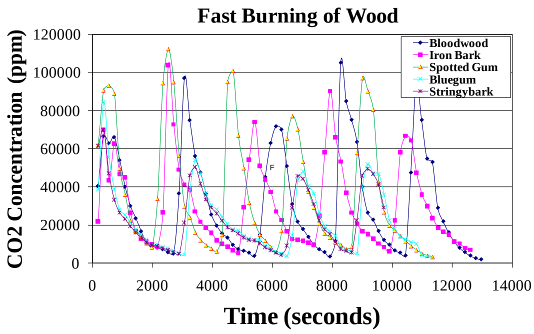

Figure 2. CO_2 concentrations measured during the fast burning

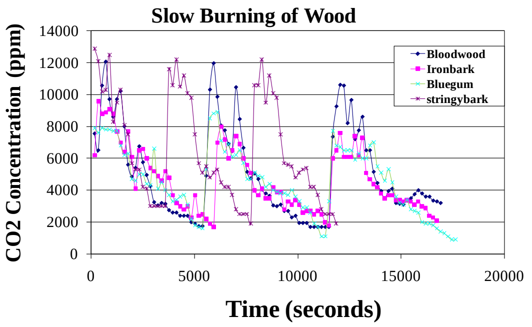

Figure 3. CO_2 concentrations measured during the slow burning of different wood species.

Figure 2 and 3 show time series of CO_2 concentrations measured during the fast burning and slow burning of different wood species. In general, it can be seen that the CO_2 concentration produced by fast burning showed a similar pattern for each species burned, while the emission behavior of different species varied somewhat during slow burning. Similar CO_2 concentrations were observed for the fast and slow burning of branches and leaves, as well as the fast and slow burning of grass.

The average CO_2 concentration was calculated by dividing the total concentration during one run by the burning time and the standard deviation calculated using the 5 repeated runs for fast burning and 3 repeated runs for slow burning. The results showed that fast burning generates higher average CO_2 concentrations than slow burning, with Spotted Gum producing the highest CO_2 concentration of 35904 ± 5298 ppm during fast burning. Having relatively the same hardness, Bloodwood, Stringybark and Blue Gum generated CO_2 concentrations of 29960 ± 2380 ppm, 29390 ± 1190 ppm and 23525 ± 5660 ppm during fast burning, respectively. During slow burning, Stringybark produced the highest concentrations of CO_2 being 6280 ± 547 ppm, compared to 5407 ± 299 ppm, 4938 ± 347 ppm, 4496 ± 345 ppm and 4495 ± 525 ppm for Spotted Gum, Bloodwood, Blue Gum and Iron Bark, respectively.

No significant difference in the CO_2 emitted from the leaves and branches were found between fast burning and slow burning, with average concentrations of 4584 ± 103 and 3977 ± 205 ppm for Stringybark, 4189 ± 154 and 7665 ± 220 ppm for Spottedgum, and 3837 ± 330 and 6740 ± 580 ppm for Ironbark, during fast and slow burning, respectively. It can be seen that Stringybark produced the highest CO_2 concentration during fast burning, but the lowest CO_2 concentration during slow burning.

The trends in CO_2 concentration produced by grass were similar to those generated by the wood samples for both fast and slow burning, however fast burning produced higher CO_2 concentrations than slow burning for all grass samples burned. The average CO_2 concentrations were 86667 ± 1320 and 59619 ± 3540 for *Aristida*, 90667 ± 2150 and 61642 ± 5135 ppm for *Eulalia* and 134286 ± 3560 and 60667 ± 4260 ppm for *Intrans*, for fast and slow burning, respectively, with an average CO_2 concentration ratio for fast burning compared to slow burning of 1.45 for *Aristida*, 1.47 for *Eulalia* and 2.2 for *Intrans*. No significant differences in CO_2 concentration were observed between each species under the same burning conditions.

Emission Factors

Figure 4 presents the average particle number emission factors and the standard deviations for the fast burning and slow burning of the different wood species. In general, fast burning produced significantly more CO_2, with emission factors around 20 times higher than for slow burning. The CO_2 emission factors for the fast burning of woods were 953 ± 39 g/kg for Spotted Gum, 919 ± 39 g/kg for Blue Gum, 989 ± 67 g/kg for Blood Wood, 945 ± 93 g/kg for Iron Bark and 747 ± 120 g/kg for Stringybark. Overall, Blue Gum and Stringybark produced the highest and lowest CO_2 emission factors, respectively, however no statistically significant difference in CO_2 emission factors was observed during fast burning. For all samples, the average CO_2 emission factor for fast burning was 911 ± 34 g/kg.

Under slow burning conditions, the CO_2 emission factors of Spotted Gum, Blue Gum, Blood Wood, Iron Bark and Stringybark were 29 ± 4 g/kg, 36 ± 1 g/kg, 40 ± 1 g/kg, 35 ± 7 g/kg and 32 ± 1 g/kg, respectively. Like fast burning, no statistically significant difference in CO_2 emission factors was observed during slow burning. For all samples, the average CO_2 emission factor for fast burning was 34 ± 3 g/kg.

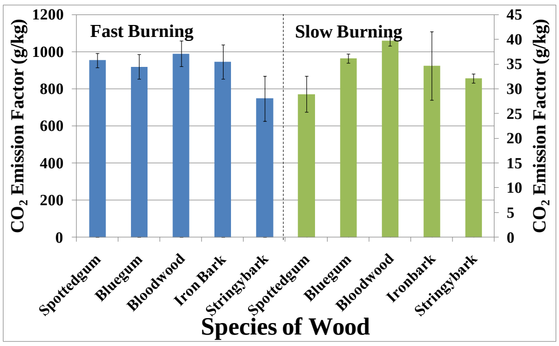

Figure 4. Emission factors for the burning of different wood species.

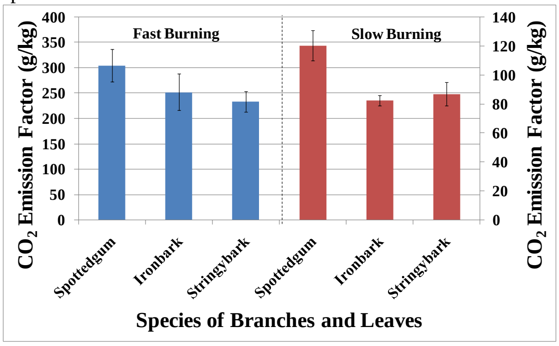

Figure 5. Emission factors for burning different branch and leaf species.

As shown in Figure 5, the CO_2 emission factors for branch and leaf samples were similar during fast burning and slow burning, with emissions factors of 305 ± 32 and 121 ± 10 g/kg for Spotted Gum, 252 ± 36 and 83 ± 4 g/kg for Iron Bark and 264 ± 29 and 87 ± 8 g/kg for Stringybark, during fast and slow burning, respectively. Overall, Iron Bark had the lowest CO_2 emission factor, while Spotted Gum had the highest CO_2 emission factor. For all samples during fast and slow burning, the average CO_2 emission factor was 97± 7 g/kg. Similarly, Figure 5 shows that the fast burning of grass produced CO_2 emission factors of 5107 ± 570 and 1192 ± 382 g/kg for *Aristida*, 4360 ± 393 and 1485 ± 259 g/kg for *Eulalia*, and 4284 ± 209 and 1072 ± 202 g/kg for *Intrans*, during fast and slow burning, respectively. For all samples, the average CO_2 emission factor for fast burning and slow burning were 4584 ± 390 and 1250 ± 280 g/kg, respectively.

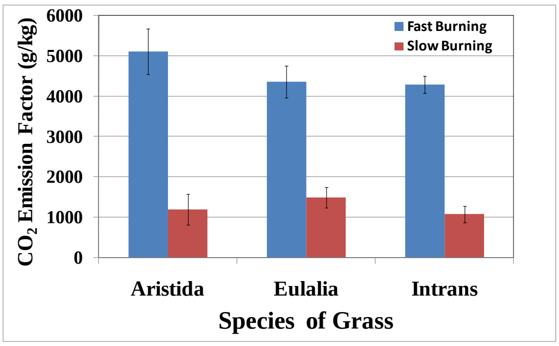

Figure 6. Emission factors for burning different grass species.

In general, the CO_2 emission factors for wood, branches and leaves, and grass varied according to the different species, as well as the different burning conditions. Fast burning resulted in an average CO_2 emission factor of 911 ± 34 g/kg for wood, 264 ± 29 g/kg for branches and leaves, and 4584 ± 390 g/kg for grass, while slow burning CO_2 emission factors were 34 ± 3 g/kg for wood, 97± 7 g/kg for branches and leaves, and 1250 ± 280 g/kg for grass. Overall, fast burning produced ten times more CO_2 than during slow burning, however burning condition was found to have no significant impact on the CO_2 emission factors for the branches and leaves or grass.

Comparison to Other Studies

To date, the CO_2 emission factors from different types of vegetation have been reported in a number of studies (see Figure 7). For example, a study of the greenhouse gasses emitted from cooking stoves in Mexico found that the CO_2 emission factors from wood burning ranged from 7-35 g/kg depending on the type of stove [33]. Another study characterised the gaseous pollutants emitted from stoves in rural China and reported that the CO_2 emission factors ranged from 1148-1172 g/kg for Brushwood, 704-1500 g/kg for Maize Straw, 676-1148 g/kg for Wheat Straw, 977 g/kg for Rice Straw, and 1439-1600 g/kg for Shorghum [34]. The CO_2 emission factors from the burning of rice, wheat and corn straws (i.e. three major agricultural crop residues in China) using a self-built burning stove and an aerosol chamber were reported in a similar study, being 791.3 g/kg for Rice Straw, 1557.9 g/kg for Wheat Straw and 1261.5 g/kg for Corn Straw. [35]. A further study aimed to estimate the emission factors from various types of garden biomass, such grass, leaves, twigs and a mixture of the three, in a controlled SIFT chamber, and reported emission factors of 320 g/kg, 1064.6 g/kg 897.3 g/kg and 1423 g/kg from grass, leaves, twigs and mixture, respectively [27].

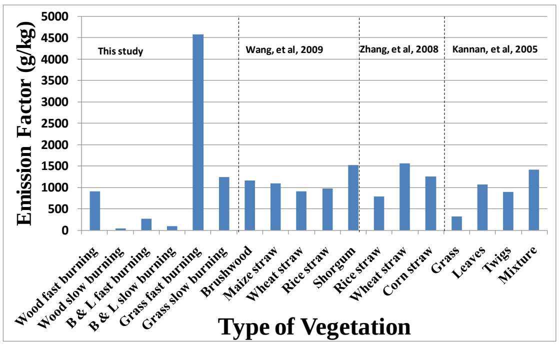

Figure 7. CO_2 emission factor from several studies

In this study, the CO_2 emission factors from wood burning were 911 ± 34 g/kg for fast burning and 34 ± 3 g/kg for slow burning, which indicates that the CO_2 emission factors obtained from burning wood in cooking stoves in Mexico (7-35 g/kg) were likely to be obtained under conditions similar to slow burning [33], while the CO_2 emission factors from burning wood in stoves (1148-1172 g/kg) were likely to be obtained under conditions similar to fast burning [34]. In terms of grass, this study obtained the a CO_2 emission factor of 4584 ± 390 g/kg for fast burning and 1250 ± 280 g/kg for slow burning, while the emission factors reported by other studies ranged from 1439- 1600 g/kg [34] and 320 g/kg [27]. In contrast to laboratory studies, field measurements of the CO_2 emission factors were also reported and ranged from 1787 ± 37 g/kg for wheat straw burning [25] and 1599 g/kg for forest burning [26]. The variations in CO_2 emission factors across the above-mentioned studies are most likely to be the result of differences in the burning system, burning conditions and the species of vegetation used.

IV. CONCLUSION

In summary, the type of vegetation and burning conditions were found to significantly affect the CO_2 emission factors of the species investigated, with grass demonstrating a significantly higher CO_2 emission factor than wood and fast burning demonstrating a significantly higher CO_2 emission factor than slow burning. The quantification of the CO_2 emission factors for biomass burning is very important, in order to estimate the amount of CO_2 released into the atmosphere, as well as its potential impact on the environment. By knowing the CO_2 emission factor for each species, as well as the quantity and density of the burnt biomass, CO_2 emissions can be calculated accurately.

The CO_2 emission factors of the native Australian trees were comparable to the emission factors of the other vegetation around the world. The different type of vegetation and burning conditions caused the variation.

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