Characteristics of Carbon-containing Gases Release during Combustion of Main Arbor in Heilongjiang Province of China

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Abstract

Based on the study on spatiotemporal pattern of fires in forestry areas in Heilongjiang Province of China, outside field investigation is combined with indoor experiment to calculate the emission amount of carbon-containing gases and emission factors when combustible material coming from fourteen main arbor trees combust via emission factor method in forestry areas in Heilongjiang Province. The results showed that CO\textsubscript{2} is the main components generated by combustible material of trees when they burn. The emission amount of carbon-containing gases remain diverse when different tree species combust but to varying degrees. The average value is 54531.82 g, 14612.08 g, 1269.27 g respectively. The CO\textsubscript{2} emission factors of each tree species are significantly higher than other gases. The average value of CO\textsubscript{2}, CO, C\textsubscript{2}H\textsubscript{6} factors are 2.6827 g·kg\textsuperscript{-1}, 0.5800 g·kg\textsuperscript{-1}, 0.0264 g·kg\textsuperscript{-1} respectively. The average value of emission amount given off by five kilogram test sample is 5802.54 mg, 1398.18 mg, 82.06 mg. The average total emission amount of carbon-containing gases is 7282.78 mg.

Keywords: arbor; carbon-containing gases; emission

\textbf{Nomenclature}

\begin{align*}
C_i & \quad \text{full-carbon} \text{ (%)} \\
EF_i & \quad \text{emission factor} \ (\text{g·kg}^{-1}) \\
m_{\text{fuel}} & \quad \text{carbon content of fuel} \ (\text{g}) \\
M_i & \quad \text{gas emissions in different arbores} \ (\text{g}) \\
M_{i_1} & \quad \text{oven-dry moisture content} \ (\text{%}) \\
MC_i & \quad \text{oven-dry moisture content} \ (\text{%}) \\
MC_{i_1} & \quad \text{Air-dry moisture content} \ (\text{%}) \\
W_1 & \quad \text{fresh weight} \ (\text{g}) \\
W_2 & \quad \text{oven-dry weight} \ (\text{g}) \\
W_3 & \quad \text{air-dry weight} \ (\text{g})
\end{align*}

1. Introduction

Forest is the main terrestrial ecosystems and plays an important role in the global carbon balance. The results showed that the stability of forest carbon pool, the increase or the release had an important relationship with changes in atmospheric carbon pool. The storage of forest carbon is the key in the net carbon sink saturation of terrestrial ecosystems related to of the key. It has become a forest ecosystem and global change researches the focus and hot scientific issues. The frequent
occurrence of forest fires, especially major forest fires, had not only destructed the natural ecosystems, but also caused a massive release of carbon-containing greenhouse gases, and ulterior affects the global environment. In the late 1970s, Crutzen, et al. (1979), Olson (1981) and Seiler et al (1980) have proposed the greenhouse gases that forest fires released would have an important impact on global change. In 1990s, Goldammer (1990) successfully estimated the tropical forest carbon emissions due to forest fires. Amiro et al (1999) used remote sensing techniques to estimate the CO2 flux of western Canadian boreal forest after fire. Isaev et al (2002) evaluated the Russian carbon emissions after fire by high-resolution multi-spectral satellite imagery, large-scale aerial photography and the decrypted image obtained from national security system. Zhang et al (2003) applied the SPOT satellite data to estimate monthly carbon combustion zone and forest fires carbon release. Wang XK, et al (2001) obtained the mean annual of CO, CO2 and CH4 released from forest fires in China by the emission ratio method, Cao Guo-liang et al (2005) calculated the SO2, NH3, CH4, CO, CO2 and other pollutants in the total emitted by biomass burning in mainland China. As the main carbon-containing trace gases, CO2, CO and CH4 influenced atmospheric chemic environment and the greenhouse effect badly (Cruzten et al., 1979; Levine et al., 1995), besides CO and CH4 affected many atmospheric chemical reactions, in some areas, affected the ozone concentration in tropospheric (Goldammer & Cruzten, 1993). It is estimated that total global amount of CO2, CO CH4 released from forest fires were 3135Tg C / a, 228 Tg C / a and 167 Tg C / a (Levine et al., 1995). And CO2, CO and CH4 emissions from forest fire in China were 45%, 21% and 44% of global emission from forest fires.

Accounting to 45%, 21% and 44% from the total global emissions (Wang XK et al, 1998), Above researches and data obtained by using more than the method of remote sensing technology, combined with emissions raised from forest fire to estimate smoke emission, through indoor tests to determine the gas emission factors and application of large-scale estimation study carried out very little. Therefore, 14 major arbors in Heilongjiang Province were studied in this paper. The field investigation and indoor control test were combined to measure the carbon gases released during the combustion, and calculate the emission and the emission factors of different gases. The aim is to provide theoretical basis for calculation the smoke emissions from forest fire, estimation the impact forest on the environmental of the atmosphere.

2. Survey of the research area

Heilongjiang province is located in China's northermost (121°11'-135°05"N; 43°25'-53°33'E), area of 460,000 square kilometers. Its west is Songnen Plain, northeast is the Sanjiang Plain, the northern and southeast is mountain. The climate is cold temperate -humid temperate- half a humid monsoon climate. The average temperature on January was -31 °C to -15 °C, extreme minimum temperature was -52.3 °C (Mohe February 13, 1969). The average temperature on July was 18 - 23 °C, frost-free period was only 3-4 months, and the average annual precipitation was 300-700 mm.

There are 183 families, 737 genera and 2400 species. Higher plants in the province, which 1763 species are seed plants, accounting for 7.2% of seed plants in our country, belonged to 642 genera and 110 families. Thereinto, the angiosperm has 107 families, 636 genera, 642 species, and the gymnosperms have 3 families, 6 genera and 17 species. The primary arbor are Pinus koraiensis Pinus sylvestris L. var. mongolica Picea koraensis Larix gmellinii Fraxinus mandshurica Phelodendron amurensic Juglans mongolica Alnus hirsute Tilia amuresnis Betula fruticosa Populus davidiana Acer mono Populus ussuriensis, and so on. The province was the high incidence of forest fires, the average annual forest area burned ranked first in our country. It is the most serious provinces, hazarded by forest fires.

3. Research methods

3.1. Sample cllollection

The major forest tree species of Maoer Mountains, Daxing’ anMountains and Xiaoxing’ an Mountains were studied. Based on forest fire statistics, the field investigation carried out in May and October 2009 for the month of twice. The larger diameter classes trees stand were selected and 20 quadrates, which were 20 m × 20 m set up by using mechanical distribution method. The species composition, height and diameter in quadrates were recorded. The standard wood sample for every species was collected, and repeated three times for each kind of wood. The trunk bark of tree and the bark in the outside diameter and high department were taken mainly. The collecting fields samples were weighed fresh mass. In the end the samples enveloped and labeled were taken back to laboratory in order to analyze.

According to the site of burning, forest fire can be divided into surface fire, crown fire and ground fire 3 types; by the intensity fire can be divided into high intensity fire, medium fire and low fire. Different types of fire hazarded in forests different levels; different fire intensity forest fires in different diameter classes of trees there were differences in the damage. Due to thickening of bark, the larger diameter class trees had a certain tolerance to the medium and low fires, and the effect on the tree cadres was smaller, the burning part focused on the bark (Hu Hai-qing, 2005). Therefore, the bark of larger diameter class trees was selected as the burning of test materials in this study.
3.2. Calculation method of moisture content

Oven-dry moisture content: the samples were enveloped, weighed them together with the envelope, and put into the oven at 85 °C drying to oven dry weight, lastly weighed immediately after cooling. The calculation was as follows:

$$M_i = \frac{(W_i - W_2)}{W_2} \times 100\% \quad (1)$$

Air-dry moisture content: the sample was kept in a cool and dry place indoors, weighed them after 30 days of air-dried. The calculation as follows:

$$MC_i = \frac{(W_i - W_2)}{W_2} \times 100\% \quad (2)$$

3.3. Determination method of emissions

Combustion test system control environment was produced by the British KANE, composed with KM-9106E-based integrated gas analyzer, automatic constant temperature heating system, electronic scales, gas collection system, data acquisition and computer. In this study, the combustion chamber was the vertical device of 2.0m³, and the laboratory temperature and humidity was relatively constant. In order to prevent smoke drift arising from errors, controlled personnel move and closed doors and windows to reduce air convection when the flue gas were measured. Sample quality was 5.0g, the heating temperature was set at 480 °C-500 °C, and the time of combustion was between the 20-25min. The CO₂, CO and CₓHᵧ were collected by flue gas analyzer probe, and the different fuel combustion gas emissions volume fraction were recorded through Fire Works software, one time every 10s. Repeated three times for each sample were tested. The data average was selected for the same gas emissions, and the data were saved and sorted.

3.4. Calculation method of the emission factor

The volume fraction of gas emission of different fuel once every 10s was exported by Fire Works software, using the software to fit the gas emission curves, calculates the integral area, and obtains the proportional relationship of volume between the different gases. Then multiplied by the corresponding carbon fraction and the emission factors of different gas were reckoned. The different gases emission factors were calculated using the following formula (EF):

$$EF_i = \frac{M_i}{m_{fuel}} \quad (3)$$

3.5. Calculation method of gas release amount

Using the different gas emission factors, combined with the moisture content of dried specimens and full-carbon (total carbon content of each species were used internationally 0.5), the amount of CO₂, CO and CₓHᵧ (of CH₄ meter) released in the test were calculated. The formula was as follows:

$$m_i = M_i \times C_i \times \frac{(100 - MC_i)}{100} \times EF_i \quad (4)$$

4. Results and analysis

4.1. The moisture content of bark

The fuel moisture had different impact mechanism on combustion efficiency. The water burning reduced the circular heat; furthermore water evaporation absorbed the latent heat. The changes of moisture leaded to different combustion states, and there were also significant differences in the combustion products. With the increasing of using of biomass fuels and the biomass combustion technology development and utilization, the influencing mechanism of water in the combustion process
will be lucubrated. Studies have shown that the water in combustible substance could play a role in promoting combustion a certain range, the combustion reaction were more full, complete, and the combustion emissions of CO$_2$ increased significantly. However, the increase in moisture would make the ignition time delayed. In the condition of absolute dry, the duration of fuel combustion and emissions of various gases were the lowest. When the air-dried moisture content was 10% - 20%, the fuel combustion reaction would be intense, full and complete (Deng Guang-rui, 2006).

Table 1 showed that oven dry moisture content of Alnus hirsute was the highest (102.83%), but there were no significant difference with Tilia amurensis(101.49%), at the same time Pinus sylvesstris was the lowest (29.11%), oven dry moisture content of bark of other species all was 29.11 % and 102.83% for. The air-dry of Alnus hirsute was the highest (50.69%), but there was no significant difference with Tilia amurensis, Pinus sylvesstris was the lowest (22.55%), other species were between 22.55% and 50.69%. The average oven dry moisture content of 14 kinds of tree species in bark was 63.79%, and the air-dried moisture content was 37.57%.

Table 1. The moisture of different barks

<table>
<thead>
<tr>
<th>Tree Spieces</th>
<th>oven dry moisture content /%</th>
<th>air-dried moisture content /%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alnus hirsute</td>
<td>102.83</td>
<td>50.69</td>
</tr>
<tr>
<td>Betula fruticosa</td>
<td>61.67</td>
<td>38.14</td>
</tr>
<tr>
<td>Pinus koraensis</td>
<td>63.12</td>
<td>38.69</td>
</tr>
<tr>
<td>Populus ussuriensis</td>
<td>89.81</td>
<td>47.31</td>
</tr>
<tr>
<td>Acer mono</td>
<td>49.42</td>
<td>33.07</td>
</tr>
<tr>
<td>Tilia amurensis</td>
<td>101.49</td>
<td>50.37</td>
</tr>
<tr>
<td>Phellodendron amurense</td>
<td>49.21</td>
<td>32.98</td>
</tr>
<tr>
<td>Fraxinus mandshurica</td>
<td>88.57</td>
<td>46.97</td>
</tr>
<tr>
<td>Populus davidiana</td>
<td>47.48</td>
<td>32.33</td>
</tr>
<tr>
<td>Juglans mandshurica</td>
<td>42.21</td>
<td>29.68</td>
</tr>
<tr>
<td>Quercus mongolica</td>
<td>47.51</td>
<td>32.21</td>
</tr>
<tr>
<td>Pinus sylvesstris L. var.</td>
<td>29.11</td>
<td>22.55</td>
</tr>
<tr>
<td>Picea koraensis</td>
<td>30.91</td>
<td>23.61</td>
</tr>
<tr>
<td>Larix gmelinii</td>
<td>89.76</td>
<td>47.31</td>
</tr>
<tr>
<td>average</td>
<td>63.79</td>
<td>37.57</td>
</tr>
</tbody>
</table>

4.2. Analysis of gas-emission

As could be seen from Fig.1, Alnus hirsute released the most CO$_2$ emission, the smallest was Larix gmelinii. There were no significant difference between Betula fruticosa and Pinus koraensis , Birch, pine, between Tilia amurensis, Phellodendron amurense and Fraxinus mandshurica , and between Populus davidiana , Quercus mongolica and Pinus sylvesstris. CO$_2$ emissions from Alnus hirsute was significantly greater than the other species, but Larix gmelinii was significantly less than other species. CO$_2$ emission of Alnus hirsute was 28.93 times of Larix gmelinii. Average emissions from large Small order of Larix gmelinii > Alnus hirsute > Betula fruticosa > Pinus koraensis > Populus ussuriensis > Acer mono > Tilia amurensis > Phellodendron amurense > Fraxinus mandshurica > Populus davidiana > Juglans mandshurica > Quercus mongolica > Pinus sylvesstris > Picea koraensis > Larix gmelinii. CO emissions average in descending order of Pinus koraensis > Alnus hirsute > Populus ussuriensis > Tilia amurensis > Pinus sylvesstris > Quercus mongolica > Acer mono Phellodendron amurense > Picea koraensis > Populus davidiana > Juglans mandshurica > Fraxinus mandshurica > Larix gmelinii, the smallest was Betula fruticosa. There was no significant difference in CO emission between Populus ussuriensis and Tilia amurensis, between Larix gmelinii and Betula fruticosa. Larix gmelinii and Betula fruticosa was significantly less than other tree species, pine birch CO emissions is 3.73 times.

Compared with CO$_2$ and CO emissions C$_3$H$_8$ emissions was small, flat Average in descending order of gross Alnus hirsute > Pinus koraensis > Populus ussuriensis > Acer mono > Pinus sylvesstris > Phellodendron amurense > Populus davidiana > Quercus mongolica > Juglans mandshurica > Tilia amurensis > Picea koraensis > Betula fruticosa > Fraxinus mandshurica > Larix gmelinii. C$_3$H$_8$ emission of Alnus hirsute was 5.18 times of Larix gmelinii.
Thus, C\textsubscript{x}H\textsubscript{y} and CO\textsubscript{2} emissions of Larix gmelinii were the smallest. There was no significant difference in the total gas emissions between Tilia amurensis and Picea koraiensis. The total gas emissions of Alnus hirsute was the biggest, and the smallest was Larix gmelinii.

4.3. Emission factors of different tree species

As Tab.2 showed, CO\textsubscript{2} emission factor was significantly larger than the other gases; the biggest was Betula fruticosa, and the smallest was Larix and gmelinii. Contrary to CO\textsubscript{2} emission factor, CO and C\textsubscript{x}H\textsubscript{y} emission factors of Larix gmelinii was the biggest, and the smallest was Betula fruticosa. The total carbon gas emissions showed the same trend as CO\textsubscript{2}. Clements and McMahon (1984) applied the indoor micro-environment test, sieved the dry powder of pine by the 10 mg, 60 meshes, and made them combust in the conditions of oxygen and nitrogen. And CO\textsubscript{2}, CO and C\textsubscript{x}H\textsubscript{y} (total of CH\textsubscript{4}) emission factors (2.9624 g \cdot kg\textsuperscript{-1}, 0.4261 g \cdot kg\textsuperscript{-1}, 0.0126 g \cdot kg\textsuperscript{-1}) that they measured were similar with the three kinds of carbon gas emission factors in this paper.

Table 2. Emission factors of different arbor

<table>
<thead>
<tr>
<th>Tree Spices</th>
<th>CO\textsubscript{2}</th>
<th>CO</th>
<th>C\textsubscript{x}H\textsubscript{y}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alnus hirsute</td>
<td>3.0713</td>
<td>0.3323</td>
<td>0.0266</td>
</tr>
<tr>
<td>Betula fruticosa</td>
<td>3.3892</td>
<td>0.1604</td>
<td>0.0092</td>
</tr>
<tr>
<td>Pinus koraiensis</td>
<td>2.7993</td>
<td>0.4959</td>
<td>0.0321</td>
</tr>
<tr>
<td>Populus ussuriensis</td>
<td>2.8948</td>
<td>0.4446</td>
<td>0.0266</td>
</tr>
<tr>
<td>Acer mono</td>
<td>2.9214</td>
<td>0.4198</td>
<td>0.0311</td>
</tr>
<tr>
<td>Tilia amurensis</td>
<td>2.7428</td>
<td>0.5645</td>
<td>0.0134</td>
</tr>
<tr>
<td>Phellodendron amurense</td>
<td>2.8389</td>
<td>0.4794</td>
<td>0.0271</td>
</tr>
<tr>
<td>Fraxinus mandshurica</td>
<td>3.0294</td>
<td>0.3850</td>
<td>0.0118</td>
</tr>
<tr>
<td>Populus davidiana</td>
<td>2.9005</td>
<td>0.4488</td>
<td>0.0222</td>
</tr>
<tr>
<td>Juglans mandshurica</td>
<td>2.9027</td>
<td>0.4502</td>
<td>0.0206</td>
</tr>
<tr>
<td>Quercus mongolica</td>
<td>2.6517</td>
<td>0.6095</td>
<td>0.0208</td>
</tr>
<tr>
<td>Pinus sylvestris L. var.</td>
<td>2.3828</td>
<td>0.7492</td>
<td>0.0387</td>
</tr>
<tr>
<td>Picea koraiensis</td>
<td>1.8419</td>
<td>1.1052</td>
<td>0.0320</td>
</tr>
<tr>
<td>Larix gmelinii</td>
<td>1.1913</td>
<td>1.4757</td>
<td>0.0573</td>
</tr>
</tbody>
</table>
4.4. The amounts of gas emissions

Fig.2 showed that in the gas release test, CO$_2$ released from combustion every 5g sample of Betula fruticosa was the largest (7625.68mg), the smallest was Larix gmelinii (2677.60mg). And CO$_2$ emission released from Betula fruticosa was 2.85 times of Larix gmelinii. CO emission from Larix gmelinii was maximum (3320.35mg), and the smallest was the Betula fruticosa (360.88mg). CO emission from Larix gmelinii was 9.2 times from Betula fruticosa. C$_x$H$_y$ emission from Larix gmelinii. Was maximum (128.98 mg), and the smallest was Betula fruticosa (20.81mg). C$_x$H$_y$ emission from Larix gmelinii was 6.20 times of Betula fruticosa released. The total of carbon emission released from Alnus hirsute was the biggest (9290.62mg), and Fraxinus mandshurica was the smallest (5603.46mg). The total of carbon emission released from Alnus hirsute was 1.66 times of Fraxinus mandshurica.

5. Conclusion and discussion

CO$_2$, CO, C$_x$H$_y$ emissions released from 14 major forest trees in Heilongjiang combustion were determined through field investigation and laboratory testing combined. The differences significance of different types of forest fuel gas emissions were tested by the lowest significant difference method (LSD). Studies showed that CO$_2$ was the main emission released form forest fires. There were differences in the amount of each emission between different tree species, but the difference was significant degree of inconsistency. The amount of CO$_2$, CO and CH$_4$ released from 14 kinds of trees combustion were (ppm) 54531.82, 14612.08, 1269.27 respectively. The amount of CO$_2$, CO and CH$_4$ released from every 5g sample were (mg) 5802.54mg, 1398.18mg, and 82.06mg. The average total carbon emission from 14 species of trees was 7282.78mg.

The emission factors of 14 kinds of tree species were calculated in this study, there into CO$_2$ emission factor was significantly greater than other gases, CO$_2$, CO and C$_x$H$_y$ emission factors were 2.6827, 0.58, 0.0264 respectively, which had some differences with the other foreign scholars. In overseas studies about trace gases released from forest fires of, the determination test of carbon gases and other trace gases emission factor have turned indoor microenvironment into sampling directly in air or measuring data in the fire. Ward et al (1992) and Ferek et al (1998) determined that CO$_2$ and CO emission factor from forest fires in Brazilian were 1700, 140 g • kg$^{-1}$ and 1600, 125 g • kg$^{-1}$ by air sampling tests and the BASE-B test method, and. Sinha et al (2003) measured the emission factors for trace gases were CO$_2$ (1700 ± 60) g • kg$^{-1}$, CO (68 ± 30) g • kg$^{-1}$, CH$_4$ (1.70 ± 0.98) g • kg$^{-1}$. Which were released from forest fires in southern African countries, by collecting samples in the air of fires and measuring the data. These dates were less than the results in this study. The reason is that fuel is not completely burned on the ground in the field in forest fires; the combustion efficiency of fuel is far lower than the indoor test, so the measured emission factor is lower than the result measured in laboratory.

In this study, there were a variety of differences in emission factors of different tree species. The main reasons were their different physical and chemical properties and different C content, resulting in a variety of amount of different trace gases released in combustion reaction. As the indoor environmental conditions, resulting in the concentration of oxygen in
combustion, flaming combustion duration and combustion efficiency factors such as differences. When calculation the amount of gases released from forest fires by indoor combustion test to the emission factor, the combustion efficiency is an important matter.

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