Peat fire characteristics of tropical peatland in Central Kalimantan, Indonesia

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Chapter 1. Background
General view of tropical peatland

Importance of tropical peatland
- Stores significantly large amount of carbon
- Conservation of natural ecosystem
- Climate regulation
- Hydrological system
- Natural resources

Problems in tropical peatland
- Logging
- Settlements
- Farmland
- Canal

Burning every year not only in El Nino event

Kalimantan 8.6 M ha
(44% of Indonesian peatland)

Peat fire 2004 in Palangka Raya
Chapter 1. Background

Total burned area in Indonesia from 1984 to 2001

Burned area, ha

Years


El Nino
Oil Palm
Rice plantation
Transmigration

Even in C. Kalimantan

Source: Department of Forestry, Indonesia, 2002.
Chapter 1. Background

Bad effects of tropical peatland fire on environment in case 1997

1. Damage on peatland: 0.73 M ha of peatland in Central Kalimantan*

2. Carbon emission from Central Kalimantan: 0.19 – 0.23 Gt of carbon release to the atmosphere through peat combustion*

3. Damage on natural ecosystem: 9 National Parks in Indonesia were damaged

4. Damage on social activity and human health in Southeast Asia

(*Page et al, 2002)
Chapter 1. Background
Review of previous study

Boreal peat

1. Fire Behavior: Ignition process, smoldering front, spread rate and peat fire temperature
Miyanishi (2000) and others

2. Fuel composition: Crown, Surface and Ground

3. Combustion characteristics of fuels: Flammability and calorific value

4. Fire ecology, carbon released, and Social economic

Tropical peat

No data

No data

No data

The objectives of this study are:

1. To clarify the peat fire behavior in tropical peatland
2. To examine the fuel composition, and
3. To evaluate combustion characteristic of fuel materials in the laboratory
Peatland fire

Laboratory Analysis
- Combustion characteristics of peat
  - Preheating
  - Ignition, flaming & glowing temperature
  - Volatile matter
  - Degradation rate
  - Calorific values
  - TG-DTA & Bomb Calorimeter

Field Observation
- 9 study sites
- 1 study site
- Monitoring climate & hydrology
  - Rainfall
  - Temperature
  - Humidity
  - S. radiation
  - Wind speed/direction

Peat fire characteristics
- Fuels in peatland
- Peat fire behavior
- Damage level
  - Crown
  - Surface
  - Ground
  - Front type
  - Spread rate
  - Temperature
  - Fuel loss
  - Fire depth
  - Carbon loss

Proposal on peat fire control
Contents of thesis

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1. Fire propagation regimes in tropical peatland
2. Horizontal and vertical peat fire front
3. Spread rate of peat fire
4. Peat moisture near smoldering zone
5. Temperature in peat layer during a fire event
6. Peat fire damage
3.1. Fire propagation regimes in tropical peatland

- Peat fire
- Surface fire
- Crown fire
- Spotting
- Brands
3.2. Horizontal and vertical fire line of peat burning

1. Horizontal fire line

Method
3m by 3m quadrate
75 cm length iron sticks
50 cm intervals
Place: plot 3, 5, and 7
Observation: 1-14 August 2002

Peat fire line in plot 3
Six days observation

Wind direction

Cross section
3.2. Horizontal and vertical fire line of peat burning

2. Vertical fire line
   a. Surface peat fire
   b. Subsurface peat fire
### Spread rate of tropical peat fire

#### Spread rate

<table>
<thead>
<tr>
<th>Location: Plot 3,5 and 7</th>
<th>Surface peat (cm/day)</th>
<th>Subsurface peat (cm/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Kalimantan Peat fires (20 cases)</td>
<td>42 – 155</td>
<td>12 – 60</td>
</tr>
</tbody>
</table>

#### Case of boreal peat fires

<table>
<thead>
<tr>
<th>Peat type</th>
<th>Spread rate</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russian peat</td>
<td>12-240</td>
<td>Chistjakov, 1983</td>
</tr>
<tr>
<td>Canadian peat</td>
<td>72-288</td>
<td>Wein, 1983</td>
</tr>
<tr>
<td>Australian peat</td>
<td>100</td>
<td>Wein, 1983</td>
</tr>
</tbody>
</table>
3.4. Peat moisture near smoldering zone

Peat moisture near smoldering zone at plot 3 and 5

Peat moisture near smoldering zone in Seney NWR Michigan USA (Hungerford, 1996)
3.5. Temperature in peat layer during a fire event

Temperature distribution in a peat fire

Recorded by Thermal video system (TVS 600) Avio Neo Thermal, on 15 September 2004.
3.5. Temperature in peat layer during a fire event
3.5. Temperature in peat layer during a fire event

Front temperature of surface peat fire

Fire temperatures measurement

Tool: Chromel alumel thermocouples of 0.5 mm, with stainless steel sheath in a 6 channel data logger (KADEC-US Kona System Co. Ltd. Japan)

Date: 20 – 27 August 2002.

The temperature above 250°C persisted about 30 minutes
3.5. Temperature in peat layer during a fire event

Slash and burn experiment on peat ignition

1-2 minutes heating by high temperature of surface fire was not enough to ignite peat layer

275°C (≈ignition temperature)

Location: University site
Date: 16 September 2002
3.5. Temperature in peat layer during a fire event

Woods burning experiment on peat ignition

![Graph showing temperature changes over time during a fire event. The graph indicates that peat ignites at a temperature of approximately 275°C.](image-url)
3.6. Fire damage

Change of micro topography

University site

Peat loss by fire:

- Maximum = 80 cm
- Averages = 56 cm
- Measured at 1 m interval
### 3.6. Fire damage

Burned area and mean depth of peat fire penetration of each plot study

<table>
<thead>
<tr>
<th>Plot</th>
<th>Burned area (ha)</th>
<th>Depth (cm)</th>
<th>Forest damage level*)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>2.0</td>
<td>46</td>
<td>Heavy</td>
</tr>
<tr>
<td>P2</td>
<td>3.0</td>
<td>38</td>
<td>Heavy</td>
</tr>
<tr>
<td>P3</td>
<td>1.2</td>
<td>30</td>
<td>Heavy</td>
</tr>
<tr>
<td>P4</td>
<td>2.6</td>
<td>53</td>
<td>Heavy</td>
</tr>
<tr>
<td>P5</td>
<td>1.4</td>
<td>33</td>
<td>Heavy</td>
</tr>
<tr>
<td>P6</td>
<td>5.0</td>
<td>38</td>
<td>Heavy</td>
</tr>
<tr>
<td>P7</td>
<td>1.2</td>
<td>40</td>
<td>Heavy</td>
</tr>
<tr>
<td>P8</td>
<td>0.9</td>
<td>20</td>
<td>Medium</td>
</tr>
<tr>
<td>P9</td>
<td>1.2</td>
<td>32</td>
<td>Heavy</td>
</tr>
<tr>
<td>University</td>
<td>3.0</td>
<td>56</td>
<td>Heavy</td>
</tr>
<tr>
<td>Mean</td>
<td>2.15</td>
<td>39</td>
<td>Heavy</td>
</tr>
</tbody>
</table>

*) ITTO, 1994  
Forest damage level: Dead of trees caused by fire (%)  
Light damage < 20%; medium; heavy > 60%
Peat fire characteristics in the field:

Peat Ignition
Smoldering temperature: 125-500°C
Duration of heating >20 minutes
Dry wood on the peat surface: necessary for long heating
Peat moisture < 40 % db
Fire in the slash and burn area: rarely ignite peat

Fire Expansion
Flaming temperature: around 300-400°C
Type and spread rate of fire front expansion:
  Surface :42-155 cm/day
  Subsurface :12-60 cm/day

Damage Level
Maximum depth of peat loss: 80 cm
Average depth of peat loss : 39 cm
Subsurface peat fire : heavy forest damage level
Chapter-4 Fuel materials in tropical peatland

1. Fuel composition in secondary peatland forest
2. Fuels composition in the ground
3. Distribution of wood in the ground
4. Fuel loss by fire
5. Carbon loss by fire
4.1. Fuels in secondary peatland forest

Observation methods

1. Crown fuels
   Location : University plot
   Selection : Live and standing dead trees
   Size : 20m x 20m (4 plots)
   Weight : 2 trunks of 5, 10 and 20 cm in diameter (fresh weight) and 5 pcs (each) for oven dry 80°C for 24 hrs

2. Surface fuels
   Location : University plot
   Selection : Grass, litter, wood debris, and fallen wood
   Size : 20m x 20m (4 plots)
   Weight : before and after 80°C oven dry for 24 hrs

3. Ground fuels
   Location : University, plot 3, 5 and 7
   Selection : grass root, wood and Coarse peat >2 mm mesh size
               Fine peat <2 mm mesh size
   Size : 1m x 1m x 1m (3 plots each)
   Weight : Before and after 120°C oven dry for 24 hrs
4.1. Fuels composition in secondary peatland forest

Fuels in Secondary peatland forest (This study)

<table>
<thead>
<tr>
<th>Fuel Components</th>
<th>ton/ha</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Crown fuels</td>
<td>29.7</td>
<td>8.0</td>
</tr>
<tr>
<td>(Leafs and trunk)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Surface fuels</td>
<td>43.1</td>
<td>11.6</td>
</tr>
<tr>
<td>(Grass, litter, wood debris, fallen wood)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Ground fuels *)</td>
<td>300.0</td>
<td>80.4</td>
</tr>
<tr>
<td>(Grass root, wood, coarse and fine peat)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total 372.8 ton/ha

Fuels in another region
(In tropical forest of Para Brazil)

<table>
<thead>
<tr>
<th>Fuel Components</th>
<th>ton/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Crown fuels</td>
<td>188.7</td>
</tr>
<tr>
<td>(Leafs and trunk)</td>
<td></td>
</tr>
<tr>
<td>2. Surface fuel</td>
<td>45.0</td>
</tr>
<tr>
<td>(Litter and Fallen trunk)</td>
<td></td>
</tr>
</tbody>
</table>

Total 233.7 ton/ha

*) Calculated for 1 m in depth

The fuel composition about 80% in the ground
4.2. Fuels composition in the ground

Legend
- Grass root
- Wood
- Coarse peat
- Fine peat

<table>
<thead>
<tr>
<th>Depth (cm)</th>
<th>Coarse peat</th>
<th>Fine peat</th>
<th>Wood</th>
<th>Grass root</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-15</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15-30</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30-50</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Dry weight (%)
4.3. Distribution of wood in the ground

These big woods are distributed in deeper layer.
4.4. Fuel loss by fire

Observation methods

Mass loss caused by fire:

\[
M = M_b - M_a
\]

- \(M_b\): Fuel dry weight of unburned area
- \(M_a\): Fuel dry weight of burned area

Method to calculate of fuel loss by fire

an example of Plot 5
Mean mass loss from 9 plots: 109 ton/ha

4.4. Fuel loss by fire

Percentage of fuel loss by fire

Ground fuel loss by fire (%)

<table>
<thead>
<tr>
<th>Ground component</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass root</td>
<td>8.0</td>
</tr>
<tr>
<td>Wood</td>
<td>9.2</td>
</tr>
<tr>
<td>Coarse peat</td>
<td>27.9</td>
</tr>
<tr>
<td>Fine peat</td>
<td>30.7</td>
</tr>
</tbody>
</table>
4.5. Carbon release

Carbon release from peatland fire

\[ M_b = A \times B \times E \]

\( M_b \) = Biomass loss by fire
\( A \) = Burned area
\( B \) = Biomass loading
\( E \) = Burning efficiency (%)

Surface fuels
10.6 t CO\(_2\)/ha
(25%)

Ground fuels
31.8 ton CO\(_2\)/ha
(75%)

Total = 42 ton CO\(_2\)/ha

- Biomass \( \rightarrow \) 45% of C, and 90% of CO\(_2\) (Seiler & Crutzen, 1980)
- Peat \( \rightarrow \) 50% of C, and 77% of CO\(_2\) (Yakelson, et al 1997)

The case of 1997 fires in Indonesia

C. Kalimantan: 350 ton CO\(_2\)/ha
(Page et al, 2002)

Sumatera: 42 ton CO\(_2\)/ha
(Murdiyarso et al, 2002)

Boreal forest

Russia
Surface fuel: 8.6 ton CO\(_2\)/ha

North America
Surface fuel: 7.0 ton CO\(_2\)/ha
(Conard et al, 2002)
Fuel composition of secondary peatland forest

Ground fuels : 80% of total dry weight
Surface and crown fuels : 20% of total dry weight

Ground fuels composition:
Grass root : 8%, decreased with depth
Wood : 9%, increased in deeper layer
Coarse peat : 38%, decreased with depth
Fine peat : 45%, distributed in all layers

Fuel loss and carbon release:
Average of fuel loss : 109 ton/ha
Carbon release : 42.38 ton CO$_2$/ha
(75%) from ground fuels
Chapter 5. Combustion characteristics of peat

1. Thermogravimetry (TG) analysis
2. Differential Thermal Analysis (DTA)
3. Derivative Thermogravimetry (DTG) analysis
4. Calorific value of peat combustion
Chapter 5. Combustion characteristics of peat

Apparatus

1. TG-DTA: Thermogravimetry and Differential Thermal Analysis

2. Bomb Calorimeter

TG DTA Seiko 3600

Bomb Calorimeter, IKA C7000
Chapter 5. Combustion characteristics on peat

TG DTA curves of fine peat at 20-40 cm in depth
Chapter 5. Combustion characteristics of peat

Peat sample and preparation

Sieve: 2 mm mesh

- 0 - 20 cm
  - Fine peat
  - Coarse peat

- 20–40 cm
  - Fine peat
  - Coarse peat

- 40-60 cm
  - Fine peat
  - Coarse peat

Dried air for 2 weeks

Sampling: at University plot
Date: 18 August 2002
The composition of the basic materials of peat*}

Coarse peat

Fine peat

*) From TG curves, in percentage
5. 2. Differential Thermal Analysis (DTA)

Temperature characteristics of peat combustion

Coarse peat

Legend
- Green: Preheating
- Red: Ignition
- Yellow: Flaming
- Dark Brown: Glowing

Fine peat

Peat depth, cm

- 0 - 20 cm
- 20 - 40 cm
- 40 - 60 cm

Temp, C
5.2. DTA curve analysis

Pattern of DTA curves on peat combustion

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Coarse peat 0-20 cm</th>
<th>Wood (Shorea, spp)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ignition temperature (°C)</td>
<td>256</td>
<td>259</td>
</tr>
<tr>
<td>Flamming temperature (°C)</td>
<td>330</td>
<td>339</td>
</tr>
<tr>
<td>Glowing temperature (°C)</td>
<td>432</td>
<td>477</td>
</tr>
<tr>
<td>Moisture content (%)</td>
<td>20.44</td>
<td>8.30</td>
</tr>
<tr>
<td>Volatile matter (%)</td>
<td>52.43</td>
<td>66.00</td>
</tr>
<tr>
<td>Max. degradation rate (mg/min)</td>
<td>3.87</td>
<td>2.22</td>
</tr>
<tr>
<td>Calorific value (kJ/g)</td>
<td>18.90</td>
<td>18.87</td>
</tr>
</tbody>
</table>
5.3. Derivative Thermogravimetry (DTG) analysis

Volatile matter release rate $= \frac{dTG}{dt}$

DTG curve of coarse peat at 0-20 cm in depth
5.3. Derivative Thermogravimetry (DTG) analysis

Volatile matter release rate of peat combustion

![Bar chart showing release rates of coarse and fine peat across different depth ranges.]

- **Coarse peat**
  - 0-20 cm: High release rate (≈ 4 mg/min)
  - 20-40 cm: Moderate release rate (≈ 1 mg/min)
  - 40-60 cm: Low release rate (≈ 0.5 mg/min)

- **Fine peat**
  - 0-20 cm: Moderate release rate (≈ 1 mg/min)
  - 20-40 cm: Low release rate (≈ 0.5 mg/min)
  - 40-60 cm: Very low release rate (≈ 0.1 mg/min)
5.3. Calorific value
Bomb calorimeter analysis

Calorific values of peat

<table>
<thead>
<tr>
<th>Peat depth, cm</th>
<th>Calorific value, kJ g⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20 cm</td>
<td>Fine peat: 19.3</td>
</tr>
<tr>
<td></td>
<td>Coarse peat: 18.8</td>
</tr>
<tr>
<td>20-40 cm</td>
<td>Fine peat: 19.2</td>
</tr>
<tr>
<td></td>
<td>Coarse peat: 19.0</td>
</tr>
<tr>
<td>40-60 cm</td>
<td>Fine peat: 19.5</td>
</tr>
<tr>
<td></td>
<td>Coarse peat: 18.9</td>
</tr>
</tbody>
</table>
The combustion characteristics of peat:

1. 57% non ignitable materials and 43% ignitable materials
2. Various combustion temperatures:
   - Preheating temperature:
     - Surface peat: 96 - 103°C
     - Subsurface peat: 141 - 151°C
   - Ignition temperature: 256 - 277°C
   - Flaming temperature: 310 - 330°C
   - Glowing temperature: 411 - 438°C
3. Volatile matter loss rate: 1.12 mg/min
   (Coarse peat in the surface: 3.87 mg/min)
4. Calorific value: 18-19 kJ/g
6. General Discussion

Schematic diagram of peatland fire dynamics

Forest damaged by fire in Central Kalimantan

- Surface peat fire
  - Moved 3 times faster than subsurface peat fire
  - Surface peat contain many coarse peat.

- Subsurface peat fire
  - Penetrated

Initial condition of peat for ignition
- Peat MC ≤ 40%
- Heating duration > 20 min
- Ignition temperature ≥ 275°C

Damage levels
- Wood burning
  - Long burning time
  - Higher temperature >700°C

Fuel types
- Light
- Medium
- Heavy

Crown, Surface & Ground fuels

Forest damaged by fire in Central Kalimantan
1. Important combustion parameters of tropical peat were clarified and the understanding of fire behavior in the field:

- Smoldering zone temperature
- Fire spread rate on surface and subsurface peat fire
- Peat moisture, duration of heating and forest damage level
- Volatile matter and char content of peat
- Flaming and glowing temperature
- Volatile matter release rate
- Calorific values of peat
2. Fuel composition of secondary peatland forest: 80% are stored on the ground.

3. Two types of peat fire expansion: surface peat fire and subsurface peat fire.

4. Dry wood on the ground and coarse peat in the surface layers: important for peat ignition.

5. Subsurface peat fire: heavy damage on peatland forest.
Subsurface peat fire was recognized as a key of tropical peat fire.

Save our peatland from fire

Thank you