The Estimation of Greenhouse Gases Emission of Peat Fire[1]

Lailan Syaufina, Bambang Hero Saharjo and Tatang Tiryana[2]

ABSTRAK

Kebakaran gambut merupakan masalah serius yang menimbulkan permasalahan lingkungan di kawasan Asia Tenggara dalam lima tahun terakhir. Masalah kabut asap yang banyak menimbulkan kerugian merupakan dampak yang nyata dari kebakaran gambut. Untuk melihat sejauh mana kontribusi kebakaran gambut terhadap emisi gas rumah kaca, sebuah penelitian dilakukan di Desa Kuala Dua, Kotamadya Pontianak, Kalimantan Barat. Penelitian ini bertujuan untuk mengkaji 1) perilaku kebakaran gambut, 2) emisi gas rumah kaca dari kebakaran gambut pada berbagai kadar air gambut, 3) hubungan antara kadar air gambut dengan laju pembakaran. Penelitian dilakukan dengan uji pembakaran baik dalam skala laboratorium maupun lapangan dan analisis gas rumah kaca, serta uji statistik. Hasil penelitian menunjukkan: 1) emisi gas rumah kaca yang dominan dari kebakaran gambut adalah: CO_2, CO dan NO_x. 2) Kadar air gambut berpengaruh positif nyata terhadap emisi gas rumah kaca, 3) Laju pembakaran berpengaruh negatif nyata terhadap emisi gas rumah kaca, 4) Berdasarkan probabilitas penyalaan, kadar air kritis gambut untuk terbakar adalah 117.39 %.

Keywords: kebakaran gambut, emisi gas rumah kaca, kadar air kritis gambut

1. INTRODUCTION

Peatland plays a very important role in maintaining environmental balance. Peat prevents flooding by absorbing heavy rainfall during wet season as behaving like a sponge. During dry season, peat releases the moisture back into the atmosphere slowly. When the forest is cleared, the exposes peat will dry out quickly and catch fire easily. Once this happens, the fire smoulders deep in the earth for a long period. It is nearly impossible to extinguish.

Undoubtedly, the 1997/1998-fire episode in South East Asian region was worsened by the occurrence of peat fires. The transboundary haze pollution was mainly contributed by some clusters of peat fires in Indonesia particularly in Sumatra and Kalimantan. The transboundary haze pollution was basically contributed by the particulate matter from peat fires which is the major pollutant in the haze. During the thick haze episode in 1997, the Pollution Standard Index (PSI) in Indonesia reached of above 2000 which was categorized as hazardous. The highest pollution levels recorded in Malaysia and Singapore were equivalent to a PSI of 900 and 226 respectively.

Moreover, the emission of carbon in the form of CO_2 and CO as a result of incomplete burning in smoldering process in peat fire has a great contribution to the greenhouse gases emission. According to Ward (1990), biomass burning contribute 88 % of carbon dioxide emission. Carbon dioxide is not toxic, though, it causes a problem in

---

[1] Portion of final report of the study funded by Osaka Gas Foundation of International Cultural Exchange, Research Grant Fiscal Year 2002/2003
[2] Lecturers of Department of Forest Management, Faculty of Forestry, Bogor Agricultural University, PO Box 168, Bogor 16001, Tel./Fax. 0251-621244, E-mail: lailans@hotmail.com

which 'blanket' will contribute the greenhouse effect that warms the earth. Besides, other trace elements such as sulfur, nitrogen oxides and methane also support to the emission.

In contrast to the importance of peatland and the dangerous impacts of peat fire, there were few studies on peat fire conducted in the region. There are also insufficient knowledge and technology on environmentally safe burning in peatland and on Greenhouse gases emission contributed by peat fire. A previous study conducted in Peninsular Malaysia revealed several models for estimation of peat moisture content by rainfall and water level and of peat combustion rate by moisture content (Syaufina 2002). Therefore, further study on the estimation of greenhouse gases emission caused by peat fire need to be conducted in order to benefit on peatland management.

The objectives of the study are to determine: 1) Peat fire behaviour, 2) Greenhouse gases emission of peat fire at various peat moisture content, and 3) Relationship of peat moisture content and combustion rate. The expected outcomes of the study are: 1) Model of estimation of greenhouse gases emission at various moisture content, 2) Threshold of peat combustibility, and 3) Recommendation for peatland management.

2. METHODOLOGY

The study was conducted in Kuala Dua Village, Sungai Raya sub-district, Pontianak district, West Kalimantan province. It is the important location in contributing smoke and haze problem in Kalimantan which is very close to Supadio Airport. The field study was conducted in two periods, namely: wet season in April 2003 and dry season in July 2003.

3.1. Establishment of burning plots

Four burning plots sized 3 x 3 m^2 were established in the study area to study fire behaviour and gas emission. The plots located on the preparation land for agriculture belongs to a local farmer.

3.2. Measurement of fuel load

To know fuel potency and availability in each plot, fuel load was measured by establishing 1 x 1 m^2 plot size. Surface fuel which consist of shrubs were cut and surface litter were taken. Both kind of fuels were then weighed to obtain fresh weight or fuel load in ton/ha.

3.3. Measurement of fire behaviour

Field burning test was conducted by using ring fire technique in each plot. Fire behaviour was measured in term of: flame height, burning time, burning rate and smoke condition.

3.4. Measurement of fire severity

Fire severity was assessed by measuring soil temperature on the soil surface, 1 cm depth and 5 cm depth.

3.5. Peat ignition test

Peat ignition test was conducted by using ignition box and burner. About 18 peat samples in various moisture content were burned in the box individually. Burning rate and percentage of burned peat were measured and calculated. Greenhouse gases emission from each sample of ignition test were also analysed.

3.6. Gas analyses

The origin of emission gas for the analyses purpose was from different phases of combustion process, namely: smoldering, flaming and glowing. The gas was respired using special apparatus and was transferred into bottle glasses which are ready for analyses. The greenhouse gases which will be analysed including: CO, CO_2, NO, SO, CH_4 .

3.7. Statistical analyses

Estimation model of greenhouse gases emission in various moisture content and ignition probability were established by using SPSS and curve expert computer softwares.

3. RESULTS AND DISCUSSION

3.1. Fuel types

Vegetation dominated on the peatland in the study area were fern species consist of 4 species, namely: Pakis Hutan (*Stenochlaena palustris* (Burm.f.)Bedd), Pakis Lembiding , Pakis Resam (*Gleichenia macrophylla* RB. Br. Var Vulcanica), Pakis Rawa (*Nephrolepis radicans* (Burm.f.)Kuhn. These species grows specifically on the opened peatland area (Sastrapraja and Afriastini 1985; Istomo 2002). So far, these species are used by local people as vegetables and also as composting materials. However, the use of the vegetation as compost has not been well socialized yet. From forest fire point of view, these species are good fuels of which they can be easily burned.

3.2. Fire behavior in ground cover vegetation burning in peatland

Fire behaviour is simply defined as the manner in which a wildland fire develops: how fuel ignite, flame development and fire spread (Perry 1990) and how a fire reacts to the variables of fuel, weather or climate and topography (Chandler et al. 1983) as influencing factors.

Fuel condition varied with season. In wet season (April 2003) mean moisture content was 135 % with fuel load ranged from 16 to 45 ton/ha. Whereas, in dry season (July 2003) mean moisture content was 29.6 % with fuel load ranged from 22 to 32 ton/ha.

Field burning test for ground cover vegetation in peatland in the study area is shown in Table 1. It indicates that environmental factors influence fire behaviour, i. e: flame height, fire temperature, burning time, fire intensity, surface temperature and burning peat temperature in 5 cm deep.

Flame height ranged from 80 to 150 cm in wet season and from 200 to 250 cm in dry season. Burning increased fuel temperature of 35 – 400 °C in wet season and of 50 – 472 °C in dry season. Moreover, fire intensity also varied with season. It ranged from 61 to 658 kW/m and from 273 to 1586 kW/m in wet and dry season respectively. It is influenced by flame height in which flame height in dry season was higher than that of in wet season.

No doubt, ground vegetation is strongly involved with all fire behaviour. Ground vegetation of ferns in the study area is classified as grassland ecosystem of which the vegetation types is influenced strongly by climate condition. Since this ecosystem is dominated by small sized foliage, it responses quickly to the changing of weather condition (Schroeder and Buck 1970). Moreover, it is explained that if moisture content of this type of vegetation drop to 30 or 40 %, it can be easily burning. Therefore, the vegetation has higher flammability in dry season when compared to that of in wet season. The study shows that lowering of fuel moisture in dry season may lead to the decreasing of burning time, the increasing of flame height, fire intensity and burning temperature. However, based on ash color and temperature in the soil, fire severity in the burned area is classified as low.

3.3. Ignition probability

Peat fire is dominated by smoldering process which is slow in spread. The ignition test for 18 peat samples in the laboratory scale indicated that 100 % of the peat samples burned completely. Peat moisture content ranged from 0 to 117.39 %. The highest peat moisture content that can burn was 117.39 % (Figure 1). It means that 117.39 % is the critical moisture content for the peat which is close to the value found by Frandsen (1997) of 110 %. *Peat ignition probability is influenced by several factors,* namely: moisture content, bulk density, and inorganic content. The higher the bulk density the lower the *ignition probability* (Frandsen 1997). Inorganic content may retard the ignition process. The higher the inorganic content the lower the ignition probability. Obviously, moisture content also has negative correlation with ignition probability. However, all the factors work together on influencing the ignition probability. Besides, peat texture may also affect the probability (Syaufina 2002).

3.4. Relationship between peat moisture content and burning rate

One of the important peat fire behaviour is burning rate. As peat fire smolders underground slowly, it is difficult to detect and control. Therefore, it is important to study the relationship between peat moisture content and burning rate. Table 2 shows the burning rate at various peat moisture content. Burning rate ranged from 0.33 g/min at 117.39 % moisture content to 1.09 g/min at 4.17 % moisture content.

Statistically, burning rate (Y) and peat moisture content (X) has linear correlation with equation as follows:

[illegible]

the burner was not able to evaporate all the water and volatile material contents that leads to the decreasing of peat heat conductivity and heat transfer will stop.

Burning process in peat is strongly involved with the ability of heat transfer which is influenced by soil humidity, physical and chemical peat properties (deBano et al. 1998). Soil humidity is affected by soil moisture in which the higher the soil moisture the lower the ignition probability. Physical and chemical soil properties include organic content, bulk density, soil bedrock material, porosity, moisture content, soil temperature, and hydraulic conductivity (Frandsen 1997). Moreover, these soil properties may influence oxygen supply and soil heat conductivity (deBano et al. 1998) which influence on heat penetration and ignition continuity.

3.5. Greenhouse gases emission

3.5.1. Greenhouse gases emission from ground vegetation burning

This study revealed that greenhouse gases emission concentration varies with combustion phase. Dominant greenhouse gases produced by the combustion process were CO_2, CO and NO_x. Among the three greenhouse gases measured in this study, NO_x concentration is the highest (Figure 3). This is relevant with the research of Luberst et al. (1991) in Levine (1994) that NO_x concentration tend to be higher than CO_2 concentration. Moreover, there is a trend of decreasing in greenhouse gases emission from flaming to smoldering or glowing phases (Figure 3). Obviously, gas emission in flaming phase is higher than that of on other combustion phases.

Since flaming phase is a complete burning process, the highest concentration of CO_2 and NO_x produced in flaming phase (Table 3). Maximum temperature reached in the field burning test was above 600°C in all plots that may contribute to the complete burning. Tsai (2000) explained that complete burning resulted in heat reaction above 900° K (627°C) to 950°K (657°C), whereas at temperature below 850°K (557°C) the reaction will produce more carbon monoxide and lower CO_2. Moreover, Levine (1994) describe that flaming phase produce higher CO_2 and NO_x than that of smoldering phase. However, all the phases occur in simultaneously process. It may difficult to separate each phases strictly. Hence, it is necessary to have further study and observe more intense phenomenon on each phase. DeBano et al. (1998) indicated that Nitrogen in fuel will break down at 200°C into gas form. This may explain the high production of NO_x in the ground vegetation burning in peatland.

Comparison of detail greenhouse gases emission is shown in Table 4. Greenhouse gases emission from peat ignition test are shown in Table 5. Statistically, gas emission increases with moisture content. The trend is shown in Figure 4. All regression models show a trend of positive correlation between greenhouse gases emission and moisture content.(X) Regression model for CO_2(Y1), CO (Y2) and NO_x (Y3) respectively are as follows:

$Y1 = 46536.1 + 364.13\,X$
[redacted] $+ 554.806\,X$ and
$Y3 = 87055.1 + 563.301\,X$

Furthermore, all the models have coefficient of determination (R^2) above 78 % which means that the models can explain the relationship between the two variables well. Differences of gas emission between smoldering and flaming phases can be explained by oxygen supply. The high oxygen supply in flaming phases causes the increasing of gas emission and explosive burning. Whereas, oxygen supply is relatively constant or even decreased in smoldering phase. Ohlemiller (2003) explained that the increasing of oxygen supply may lead to the transition from smoldering to flaming causing the acceleration in pyrolysis process. Moreover, the increasing of temperature around burning process may have similar effect. Besides, the increasing of burning temperature influence gas emission in burning process.

The study shows that peat fire is dominated by smoldering process with temperature maybe started at 300-500°C (deBano et al. 1998). It is known that flaming phase is dominated by CO_2 emission of 63 %, whereas smoldering phase produce about 37 % CO_2 (Lubert et al. 1991) in Levine (1994). Therefore, it is clear that smoldering phase also contribute to the high CO_2. The study observed that temperature increased during the ignition test until the end of the test. The result is supported by Babrauskas and Krasny (1997) in Ohlemiller (2003) that there was a transition from smoldering to flaming when burning time reached 22-306 minutes.

4. CONCLUSIONS

1. Dominant greenhouse gases emission detected from peat fire were CO_2, CO, and NO_x
2. Burning rate affected greenhouse gases emission significantly in which the increasing of burning rate leads to the decreasing of greenhouse gases emission
3. Peat moisture content affected greenhouse gases emission significantly in which the higher the moisture content the higher the greenhouse emission
4. Several linear regresion models between moisture content of peat and greenhouse gases emission have been developed in this study
5. Based on the ignition probability, the critical moisture content of the peat is 117.39 %

ACKNOWLEDGEMENTS

The authors express their sincere gratitude to the Environmental Research Center, Bogor Agricultural University for its support and encouragement, the Osaka Gas Foundation of International Cultural Exchange Research Grant Fiscal Year 2002/2003 for its financial support, and Nana S. S. for his help in the study.

REFERENCES

Andriesse, J. P. 1988. Nature and Management of Tropical peat Soils. Food and Agriculture Organization od the United Nation. Rome. 165 pp.

Artsybashev, E. S. 1983. Forest fires and Their Control. K. Badaya trans., V. Pandit ed., Oxonian Press Pvt., New. Delhi, India. 160 pp.

Chandler, C., P. Cheney, P. Thomas, L. Trabaud, D. Williams. 1983a. fire in Forestry vol. I. John Wiley and Sons. Canada. 450 pp.

DeBano, L. F., D. G. Neary and P. F. Fpolliot. 1998. Fire'sEffects on Ecosystems. John Wiley and Sons. Inc. New York. 333pp.

Frandsen, W. H. 1991b. Heat evolved from smoldering peat. Int. J. Wildland Fire I (3): 197-204.

Levine, J. S. 1994. Biomass Burning and the Production of the Greenhouse Gases. http://asd-www.larc.nasa.gov/biomass_burn/bimass.html . [3 May 2003].

Levine, J. S. 1999. Gaseous and particulate emissions released to the atmosphere from vegetation fires. Health Guidelines for Vegetation Fire Events, Lima. Peru, 6-9 October 1999. WHO.

Ohlemiller, T.J. 2003. Smoldering Combustion. http://fire.nist.gov/bfrlpubs/bfrl02/f0273.html. [2 Agustus 2003].

Syaufina, L. 2002. The effects of climatic variations on peat swamp forest condition and peat combustibility. Doctoral Thesis of Faculty of Forestry Universiti Putra Malaysia. Malaysia. 258 pp.

Ward, D. E. 1990. Factors influencing the emissions of gases and particulate matter from biomass burning. In. J. G. Goldammer ed., fire in the Tropical Biota. Ecosystem Processes and Global Challenges Ecological Studies 84. Springer-Verlag. Berlin. Germany. pp. 418-436.

Table 1. Fire behaviour and the influencing environmental factors

Parameter	Wet Season				Dry Season		
	Plot 1	Plot 2	Plot 3	Plot 4	Plot 1	Plot 2	Plot 3
Weather condition							
- Temperature (°C)	33	41.3	39	40	39	37	37
- Relative humidity (%)	60	50	48	49	52	55	55
- Wind speed (m/sec)	0,41	0,9	1,07	1,07	0,9	1,.07	1,07
- Wind direction	T-B	T-B	T-B	T-B	T-B	T-B	T-B
- Cloud condition	clean	cloudy	cloudy	cloudy	clean	cloudy	cloudy
Fuel Characteristic							
- Surface fuel load (ton/ha)	16	42	44	45	22	24	32
- Surface fuel depth (cm)	10-30	10-30	10-30	10-30	37.75	36.75	37
- Ground cover moisture (%)	136	134	-	-	22.12	27.12	39.61
- Peat moisture (%)	426.32	354.55	354.55	270.37	525	556.4	859.97
Burning Time (WIB)	14.00	10.00	.11.20	13.00	12.15	13.05	13.37
Fire behavior							
- Maximum flame height (m)	0.5-1.0	0.5-0.8	0.75-1.0	1.0-1.5	1.0-2.0	1.0-2.25	1.0-2.25
- Flame temperature (°C)							
Maximum temperature	380	350	395	400	649	843	843
Ground temperature	35	40.3	41.3	59	50.0-183.0	50.0-472	50.0-308
5 cm below ground	-	-	-	-	37.0	50.0	43.0
10 cm below ground	-	-	-	-	30.0	35.0	36.2
- Fire severity	low	low	low	low	low	low	low
- Duration (minute)	6.30'	4.56'	7.20'	2.25'	5.15'	8.25'	6.35'
- Burning percentage (%)	76	76	90	100	95	100	100
- Fire Intensity (kW/m)	61-273	61-168	169-273	273-658	273-1229	273-1586	273-1587
- Ash color	Black-white	Black-white	Black-white	Black-white	Black-white	Black-white	Black-white

Table 2. Burning rate at various peat moisture content

No	Moisture content (%)	Burning rate (gr/min)
1.	0.00	0.94
2.	2.04	0.92
3.	3.09	1.01
4.	4.17	1.09
5.	8.70	0.84
6.	8.70	0.89
7.	12.36	0.91
8.	26.58	0.71
9.	44.93	0.51
10.	51.52	0.80
11.	56.25	0.72
12.	66.67	0.68
13.	85.19	0.60
14.	88.68	0.50
15.	92.31	0.41
16.	96.08	0.47
17.	100.00	0.52
18.	117.39	0.33

Table 3. Greenhouse gases emission at various combustion phases

Combustion phase	Greenhouse gases emission (ppm)			
	CO_2	CO	NO_x	Total
Flaming	68.403	100.990	126.932	296.325
Smoldering	59.943	113.336	113.336	257.327
Glowing	62.435	118.229	118.229	268.718
Total	190.781	273.093	358.497	822.371

Table 4. Comparison between greenhouse gases percentage at various combustion phases from this study and the study of Lubert, et.al. (1991) *in* Levine (1994)

Greenhouse gases	Gas percentage forming during combustion process			
	Flaming		Smoldering	
CO_2	53.30	63	46.70	37
CO	54.58	16	45.42	84
NO_x	52.86	66	47.17	34

Table 5. Greenhouse gases emission from peat ignition

No.	Moisture content (%)	Greenhouse gases (ppm)			
		CO_2	CO	NOx	Total
1	2,04	49.578,71	67.369,60	90.013,26	206.961,57
2	25,00	48.739,09	65.909,91	88.430,42	203.079,42
3	44,93	591.157,6	78.401,59	110.366,42	247.925,61
4	51,52	60.670,24	88.054,05	113.395,06	262.119,36
5	56,25	70.755,56	91.599,60	121.481,51	383.836,67
6	66,67	84.369,25	122.920,7	146.622,16	353,912,11
7	88,68	81.680,49	100.661,8	133.436,43	315.778,75
8	92,31	83.527,98	125.088,1	142.929,70	351.545,80
9	96,08	76.637,83	112.865,9	142.929,70	332.433,53
10	100,00	81.175,73	115.631,9	141.700,14	338.507,81
11	117,39	66.973,98	96.623,50	119.899,93	283.497,40

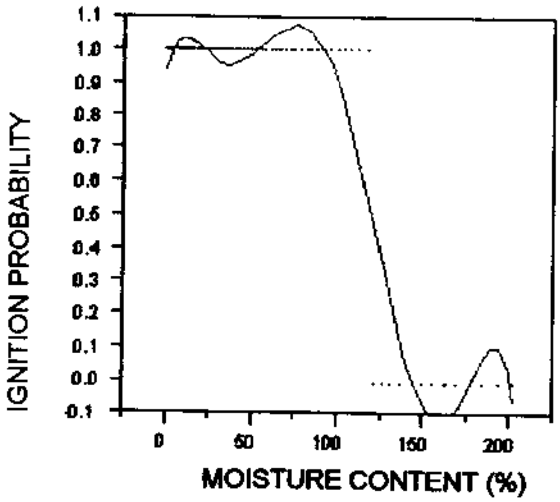


Figure 1. Ignition probability of peat

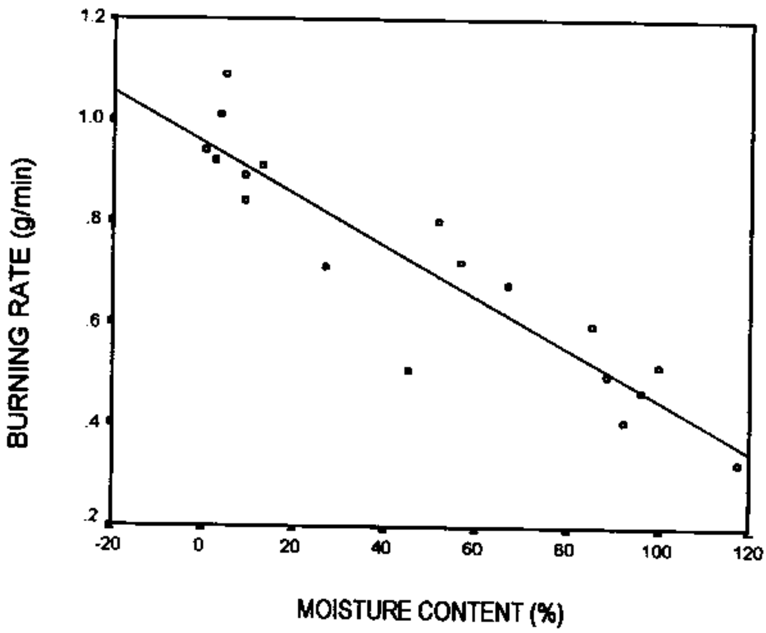
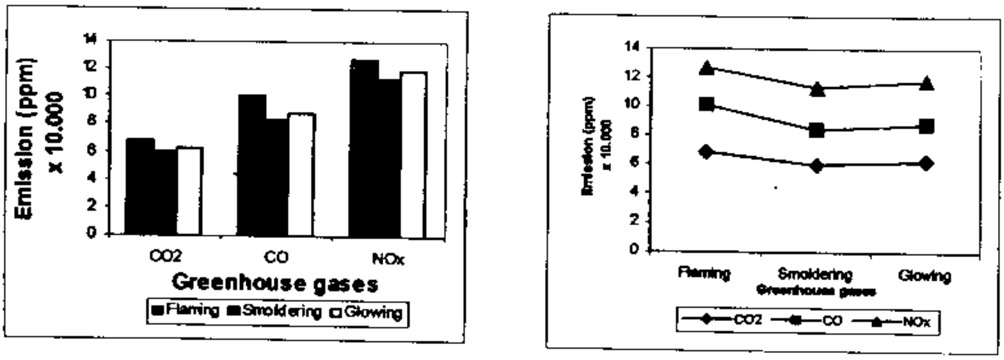
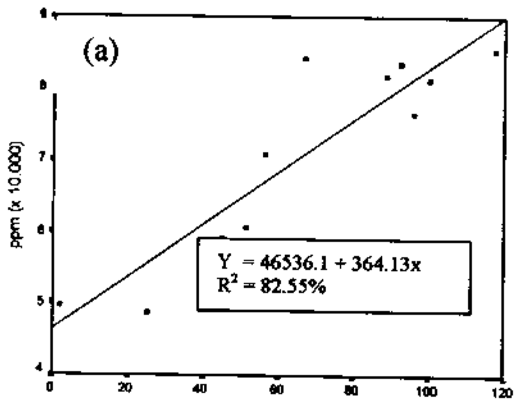


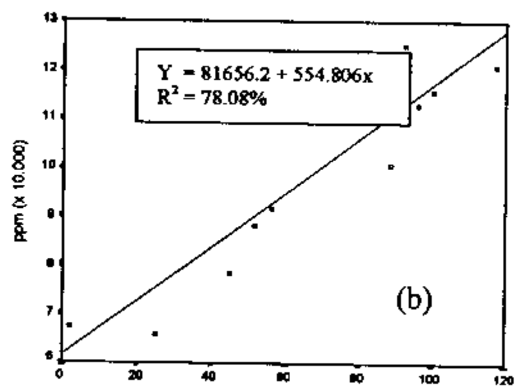
Figure 2. Linear regression of peat moisture content and burning rate

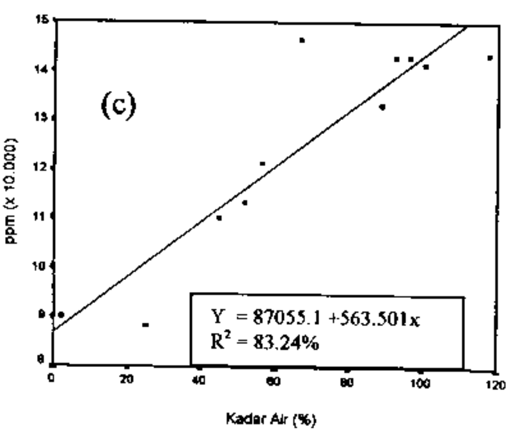


a b

Figure 3. Greenhouse gases emission from ground vegetation burning in peatland (a) gas emission based on types; (b) gas emission based on combustion phases







MOISTURE CONTENT (%)

Figure 4.
Regression models of greenhouse gases emission at various moisture content (a) CO_2 (b) CO, (c) NO_x