Estimation of volume emissions at burning of some forest materials

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The emissions are calculated from burning forest materials of some types. It is shown that the amounts of emitted CO and CO_2 are smaller at a highly intense forest fire. Similar results were obtained for other carbonic components of gaseous emissions as well. The volume of disperse carbon (C_{disp}) emitted from burning of Shreber's Feathermoss is larger at a low-intensity fire. At burning of lichen, the amount of C_{disp} in emissions is larger at a highly intense fire.

Biomass burning is one of the global sources of gas and aerosol emissions into the Earth's atmosphere.[1] It is known that more than 200 000 forest fires destroying about 0.5% of the total forest cover arise every year. Burning of vegetation, substrate, and soil humus is accompanied by the emission of various compounds, whose chemical composition is poorly studied yet.[2]

The problem of forest fires is especially urgent for boreal forests. Every year a great deal of effort goes into the fire control. Nevertheless, we still have no any definite answer to the question "Are the forest fires good or a disaster?" There are few papers devoted to the study of emissions from forest fires in Siberian boreal forests[3–9] and very deficient information about their composition.[10]

In this paper we evaluate the volume and chemical composition of the main components of gas emission, as well as the elemental composition of aerosols and burning products of different forest materials in laboratory and field experiments.

Experimental and computational methods

For experiments we took the most abundant forest materials: Shreber's Feathermoss, lichen, sedge, cowberry, birch leaves, pine needles, and the litter. The water content of these materials was predetermined. As they were burnt, aerosols were sampled onto filters of AFA-KhA-20 fibrous polymer material and Glass Fiber Pre-filters 50 mm in diameter with the use of a pump and specialized equipment.

The emission volume was calculated by Belov's method[10] with the Konev's data on the content of such chemical elements as carbon, oxygen, hydrogen, and nitrogen in forest materials[4] (Table 1).

Table 1. Chemical composition of some forest materials[4]

Material	Element, % (of mass)			
	C	H	O	N
Sedge	47.9	5.51	39.37	1.64
Birch leaves	49.36	6.28	42.59	1.6
Shreber's Feathermoss	50.11	5.77	39.69	1.43
Cowberry	52.7	6.1	36.71	0.89
Pine needles (perennial)	53.1	5.9	34.47	1.03
Pine needles (annual)	53.1	5.9	34.33	1.17
Lichen	45.4	6.0	45.8	0.3
Wild rosemary	54.7	6.8	34.86	0.94
Litter	49.6	5.2	33.88	0.92

Calculation of volume emission from burning of some forest materials

The consumption of air and the amount of burning products were calculated using Shreber's Feathermoss as an example (the chemical composition of Shreber's Feathermoss is demonstrated in Table 1):

$$K = \frac{8}{3}\text{C} + 8\text{H} - \text{O} = \frac{8}{3}\,0.502 + 8{\cdot}0.058 - 0.4 = 1.43 \text{ kg},$$

where K is the amount of oxygen, kg; C is the carbon, kg; H is the hydrogen, kg; and O is the oxygen, kg.

The calculations showed that for the complete oxidation of carbon and hydrogen to CO_2 and water, 1.43 kg oxygen is needed for 1 kg of absolutely dry combustible material. By definition, it is the oxygen coefficient.

The oxygen coefficient is the mass ratio of O_2 to that of the material under condition that carbon and hydrogen oxidize completely to CO_2 and H_2O in the burning process without the excess of oxygen. In the atmosphere, oxygen is in a mixture with nitrogen and other gases, which do not take part in burning. Thus, the gaseous oxidizer in the burning process is the

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mixture of oxygen and nitrogen; therefore, the amount of air needed to provide for material burning is much larger than the amount of pure oxygen. At the 60% humidity, the air contains 22.85% (by mass) of O_2, 75.3% of N_2, 1.29% of argon, 0.53% of water vapor, and 0.046% of CO_2.

Having known the needed amount of oxygen and its mass percentage in the air, we can calculate the amount of air needed for burning of 1 kg of Shreber's Feathermoss:

$$B = \frac{K}{0.23} = \frac{1.43}{0.23} = 6.26 \text{ kg},$$

where B is the amount of air, in kg.

Thus, 6.26 kg of air is needed for complete burning of Shreber's Feathermoss. In laboratory experiments it was found that underburning (UB) for Shreber's Feathermoss is, on the average, 20%.

Then, based on the initial composition of the material, we calculated the yield of carbon dioxide, nitrogen, argon, and C_{disp}:

$$CO_2 = (O + \frac{8}{3}O) \times 0.8 + B \times 0.00046 =$$

$$= (0.5011 + \frac{8}{3} \times 0.5011) \times 0.8 + 6.2626 \times 0.00046 = 1.47 \text{ kg};$$

$$N_2 = B \times 0.7528 + N = 6.2626 \times 0.7528 + 0.0143 = 4.73 \text{ kg};$$

$$Ar = B \times Ar = 6.2626 \times 0.0129 = 0.08 \text{ kg};$$

$$C_{disp} = C \times UB = 0.5011 \times 0.2 = 0.10 \text{ kg}.$$

The air consumption and the amount of carbon dioxide emitted at burning of other forest materials were calculated in a similar way (Table 2).

Table 2. Volume emissions at burning of forest materials

Material	Consumption at burning of 1 kg of dry material, kg		Burning product, kg		Inert gas	
	in oxygen	in air	CO_2	C_{disp}	Ar	N_2
Sedge	1.32	5.80	1.41	0.10	0.08	4.38
Birch leaves	1.39	6.10	1.45	0.10	0.08	4.61
Shreber's Feathermoss	1.43	6.26	1.47	0.10	0.08	4.73
Cowberry	1.53	6.66	1.55	0.11	0.09	5.03
Pine needles (perennial)	1.54	6.75	1.56	0.11	0.09	5.10
Pine needles (annual)	1.54	6.76	1.56	0.11	0.09	5.10
Lichen	1.23	5.39	1.33	0.09	0.07	4.06
Wild rosemary	1.60	6.99	1.61	0.11	0.09	5.27
Litter	1.40	6.13	1.46	0.10	0.08	4.62

Underburning of forest materials means incomplete burning of carbon, and some its part in this case is emitted in the form of aerosol. The amount of underburnt material at forest fires was estimated by the researchers from the V.N. Sukachev Institute of Forest and Wood SB RAS.[4,11] It was found that about 10–20% of carbon in forest materials is usually underburnt. In our case the amount of the underburnt material was 20%.

The available data on water content in the forest materials allowed us to calculate the amount of emitted water vapor. Thus, burning of 1 kg of Shreber's Feathermoss in the absolutely dry state emits 7.092 kg of burning products (CO_2, N_2, Ar, C_{disp}) and 0.047 kg of ash.

Our results agree with the results of foreign scientists. According to these data, in particular, the amount of carbon dioxide gas produced at burning of 1 kg of a dry material is equal to 1.6 kg (Ref. 12).

Analysis of chemical composition of aerosol deposited onto the fiberglass filter allowed us to find the ratio between the organic and inorganic carbon produced at burning of some kinds of the forest material (Table 3).

Table 3. Ratio of organic and inorganic carbon in aerosols

Material	Amount of carbon in the aerosol form		
	C_{org}/C_{inorg}	Organic carbon, kg	Inorganic carbon, kg
Sedge	4.1	0.08	0.02
Birch leaves	18.2	0.09	0.005
Shreber's Feathermoss	4.95	0.08	0.02
Pine needles (perennial)	7.7	0.09	0.01
Pine needles (annual)	2.6	0.08	0.03

It is seen from Table 3 that the amount of organic carbon in aerosols is larger than that of inorganic carbon. Their ratio ranges from 2.6 (pine needles) to 18.2 (birch leaves).

Within the framework of the Russian–American Project "Forest Fire Effect on Eurasian Boreal Forests," two experiments were conducted in summer 2000 in order to model fires of different intensity in lichen-moss pine forests. Each experimental fire had the area of 4 ha. Various specialists took part in this field experiment. In particular, it involved estimation of the stock and amount of burnt forest materials of different kinds (Table 4).

Table 4. Amount of burnt forest materials and oxidizer demand at their burning

Fire intensity	Material	Material stock, kg	Demand, kg	
			in oxygen	in air
Low	Lichen	3022	3725	16301
	Shreber's Feathermoss	11853	16962	74230
High	Lichen	2396	2954	12925
	Shreber's Feathermoss	12591	18017	78850

Using the data obtained on the amount of burnt forest material and on the gas emission composition (analysis of the composition of gas emissions was carried out and kindly presented at our disposal by Steve Baker, US Forest Service, Missoula, who took part in the experiment), we calculated the volume emissions by the above methods for these experimental fires, and the results of these calculations are given in Table 5.

Table 5. Emissions at experimental fires of different intensity in lichen-moss pine forest, kg/ha

Fire intensity		Emission										Inert gases	
		CO	CO_2	CH_4	C_2H_4	C_2H_2	C_2H_6	C_3H_6	C_3H_7	H_2O	C_{disp}	Ar	N_2
Low	Lichen	1014	3177	83	12	2	6	4	3	1578	218	167	9731
	Shreber's Feathermoss	4391	13757	361	51	7	24	16	12	8215	1262	1017	59539
High	Lichen	709	2325	52	6	0.5	4	3	1	2265	274	210	12272
	Shreber's Feathermoss	4112	13487	303	34	3	21	15	7	8208	1188	958	56050

Calculations of carbon emission at forest fires usually involve the total stock of ground forest material. In our opinion, such an approach is not fully correct. To estimate the emissions at forest fires, one should take into account that the material stock is not burnt completely, and the amount of underburnt materials depends on the intensity of burning.

Conclusion

Based on the results of the experiments conducted, possible volume emissions have been calculated for fires of different intensity. It was found that the volumes of emitted CO and CO_2 are smaller at a highly intense fire. Similar results were obtained for other carbon-containing components of gaseous emissions as well.

The volume of disperse carbon (C_{disp}), Ar, and N_2 produced at burning of Shreber's Feathermoss is also larger for low-intense fire. At burning of lichen, the content of this components (C_{disp}, Ar, N_2) in emissions is higher at a high-intensity fire. For in-depth knowledge of volume gaseous and aerosol emissions, further investigations are needed, which would help to refine the volume and composition of emissions at forest fires of different intensity and to assess their effect on the carbon balance and change of the chemical composition of the atmosphere in a smoke plume.

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