Atmos. Chem. Phys. Discuss., 8, S5710–S5715, 2008
www.atmos-chem-phys-discuss.net/8/S5710/2008/

Atmospheric Chemistry and Physics Discussions

Interactive comment on "Water vapor release from biofuel combustion" *by* R. S. Parmar et al.

R. S. Parmar et al.

Received and published: 7 August 2008

We thank the reviewer for the thoughtful comments on our manuscript. Especially we are grateful for making the publication of Clements et al. (2007) known to us. Our replies to the comments (in italics) are given below. Text changes compared to the ACPD version are also indicated.

However, given the references in the paper to the impact of "other carbon compounds" and their potential impact on the ratios observed (p.4490, lines 25-28) the authors should explicitly include some of their original aerosol results to further constrain the carbon budget.

Response: This comment was brought up by reviewer 1 as well so we refer to our response to comment 4 of reviewer 1 and copy this text here: Response: This paragraph was added to give the reader a feeling that the resulting fuel moisture content estimates remain distinctly visible, even if we missed carbon in the balance. The de-

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crease is different depending on the assumed fuel composition. We use cellulose and lignin as borderline cases. The value of 10% missing carbon was given as an upper limit. The other forms can include gases, aerosols and ashes. Prominent among the gases would be methane (<1%), nonmethane hydrocarbons (<1%) and partially oxidized hydrocarbons as alcohols, carbonyl compounds and organic acids (in sum <1%, Andreae and Merlet, 2001). Both water-soluble and water-insoluble organic carbon as well as elemental carbon is found in aerosols emitted from vegetation fires (˜3%, Lobert, our results: ˜3%, in one case max. 5%, details see Iinuma et al., 2007). Ashes from open biomass fires usually are assumed to amount to ˜10% and contain ˜ 10% carbon (Lobert, 1989).

We change the text (If the fuel carbon.. , line 26) accordingly to: Even if the fuel carbon not assessed as CO and CO2 and thus escaping in other forms as gases (<3%, Andreae and Merlet, 2001), aerosols (˜ 1%, Merlet and Andreae, 2001; in our experiments ˜3%, Iinuma et al., 2007 for details) or ashes (˜1%,Lobert, 1989) would come up to 10%, the ratio delta H2O/(delta CO+delta CO2+delta C(additional)) would still remain above unity and the estimated fuel moisture contents would be reduced by 11 to 25% depending on the assumed fuel composition, with cellulose or lignin as borderline cases.

The conventional wisdom in wildland fire fighting is that combustion is not sustained when fuel moisture exceeds about 30%, and while conventional wisdom can easily be wrong, I am inclined to believe that it has some value. Early work on forest fires and relationship of fuel moisture to fire danger also supports a value of "moisture of extinction" somewhere near 25-40%.

Response: We do agree that fuel too wet will not sustain a self-propagating combustion. However, we would like to stress that a wind driven fire-line of a natural fire dries out its own prospective fuel. It is then basically a distillation process in which radiant heat drives out the water by vaporization and thus prepares the fuel for combustion. Water in the effluents comes from both processes. Our reloading of fuel during the

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combustion session basically imitates a progressing fire line.

Added text (after page 4490, line 10, see also response to reviewer 1): .. Indeed, in most of our experiments, this threshold was surpassed. (new text to follow) Much higher fuel moisture contents of 70 to 200% for instance are given by Van Wagner (1977) for crown fires, and moisture in the litter layer may exceed 200% (de Ronde et al., 1990). Combustion of such fuel indirectly will contribute to the effluents of the burns. As our reloading of fuel during the combustion session imitates a progressing fire line, higher fuel moisture contents obviously can be sustained.

de Ronde, C., J. G. Goldammer, D. D. Wade, and R. Soares. 1990. Prescribed burning in industrial pine plantations. In: Fire in the tropical biota. Ecosystem processes and global challenges (J.G. Goldammer, ed.), 216-272. Ecological Studies 84, Springer-Verlag, Berlin-Heidelberg-New York, 497 p.

There is one other quantity that I would like to see discussed, the air temperature in the samples entering the sampling container. (and how it relates to the air entering the combustion chamber).

Response: There is a temperature rise of approximately 10 °C in the smoke entering the chimney duct versus ambient. The air temperature in the sampling container then is lower again. On days with strong insolation the air temperature inside the storage container was influenced by solar heating of the container walls. The seemingly small temperature rise has to be related to the rate of fuel combusted; in our experiments usually between 10 and 30 gram per minute, while the air flow rate was ˜3.8 m3 per minute.

Text change added to the following response.

The discussion of experimental design would be much better with a diagram illustrating the apparatus (i. e., the fuel bed, the ducting and the sample chamber).

Response: The set-up for the fuel combustion is identical to that described by Lobert

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et al. (1990) and (1991), in which Figure 1, and Figure 36.1 respectively give details. The position of the additional container for mixing and storing the effluent gases will best be described by the added photographs.

Text change (page 4486, line 22) It consists of a chamber for burning biomass (Lobert, 1989; Lobert et al., 1990 (Figure 1); Lobert et al., 1991 (Figure 36,1)) and a container for smoke dilution, mixing and aging, which are depicted in Figure x. The fires were sustained on a fuel bed housed in a facility open to ambient air (Fig. x, left). In the burning chamber (Fig. x, middle), an inverted stainless steel funnel funnel with a 1.2 m diameter opening was positioned 0.5 m above the fuel bed. The smoke was lifted up via this funnel into the steel sampling container (32 m3) (Fig. x, right) at a typical flow rate of about 63 dm3 s-1 (min-max: 53.3 - 68.3 dm3 s-1) provided by a fan at the end of the sampling line. Temperatures in the chimney usually were approximately 10 K above ambient and lower again in the storage container. The temperature rise is related to the the rate of fuel consumption, in our experiments between 10 and 30 g min-1.

Lobert, J. M., Scharffe, D. H., Hao, W. M., and Crutzen, P. J., Importance of biomass burning in the atmospheric budgets of nitrogen-containing gases, Nature 364, 552 - 554, 1990.

It should also explain the method of ignition and sustaining combustion in the tests. Any sort of fueled ignition using propane, methane, etc. would bias the carbon hydrogen budget of the fuel combustion, while a purely heat-ignition would bias any temperature data.

Response: The fuel combustion was started with butane and during this stage the emissions were sent vertically up to the chimney and discarded. When combustion conditions stabilized and were self-propagating without further support, usually after a minute or so, a switch in the chimney was used to redirect the effluents through a steel pipe of ˜20 cm diameter and 500 cm length into the sampling container. The

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combustion was maintained by reloading when necessary and by this also guiding the combustion more to a flaming or smoldering combustion as needed. We consider the reloading during the combustion process as being similar to the propagation of a flame front in a wild fire.

Text change (page 4487, line 6)

.. downwards. The fires were started by a butane torch. A switch in the exhaust stack above the funnel was used to vent the emissions at the beginning vertically out through the chimney and thus discarded. When combustion conditions stabilized and were self-propagating without further support, usually after a minute or so, the switch in the chimney was used to redirect the effluents through a steel pipe of ˜20 cm diameter and 500 cm length into the sampling container. Assuming ... And after page 4488, line 1. .. natural fires. We consider the reloading, which basically is a moving of fresh fuel from the sides to the center of the combustion table where the fire is, as being similar to the propagation of a flame front in a wild fire. This includes that radiating heat already initiates vaporization of low volatile compounds, which may boost the fire in case of light hydrocarbons or attenuate it in case of water vapor by being a heat sink.

The authors' analysis of Clements et al. (2006) could be further expanded, including revision to include Clements et al. (2007). Even without the latter reference, the '06 discussion should note two additional points. First, Clements et al. (2006) noted that there was standing water in the fields during their fire, and this may bias the moisture observations. Second, those authors also estimated their fuel moisture at 8%, well below the value calculated by the present authors.

Response: We thank the reviewer for guiding our interest to the Clements et al. (2007) paper. As mentioned by himself, unfortunately this publication does not contain CO2 mixing ratios, although these data obviously have been obtained. The lack of this information prevents us from making use of that paper. The reviewer correctly points out that standing water was in the field during the fire and this certainly will have biased

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the delta H2O/delta CO2 ratio. We should have mentioned this as well as the much lower fuel moisture content mentioned in that paper. We thank the reviewer for pointing to that value. We checked and indeed found a transcription error. It should have read 44%. Nevertheless, our fuel moisture content was much higher. We expand our text by combining this information and assessing how large the contribution from the biomass combustion alone could be.

Changed text (same as given in the response to reviewer 1): For an assumed delta CO/delta CO2 emission ratio of 8%, the amount of released water to released carbon oxides would be 1.49, resulting in a fuel moisture content of approximately 44% with cellulose as reference. The large difference to the 8% fuel moisture mentioned by Clements et al. (2006) make the influence of an additional source as standing water and/or soil moisture very likely. Nevertheless, this water vapor still would have been inside the biomass burning plume, i.e., have been lofted together with the combustion emissions. Reverting our arguments, we would conclude from an 8% fuel moisture content of cellulose and also 8% delta CO/delta CO2 in the emissions an increase of only 2240 ppm water vapor or 1.4 g kg-1, that is the rise would have been from 6.9 to 8.3 instead of 9.1 g kg-1. The difference would have to stem from additional sources. This estimate would hold only, of course, directly at the source. The ratio of water vapor to CO2 in ambient air is so large, that the initially diagnostic ratio of delta H2O/(delta CO+delta CO2) soon is concealed, when the mixing ratios are getting close to background values.

(Figure X is with the editor and can be requested, of course. This comment replaces the previous one, in which special characters incidentally were not converted).

Interactive comment on Atmos. Chem. Phys. Discuss., 8, 4483, 2008.

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Interactive Comment