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The environmental impact on air quality and exposure to carbon monoxide from charcoal production in southern Brazil

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ABSTRACT

Black wattle silviculture is an important activity in southern Brazil. Much of the wood is used in the production of charcoal and the pyrolysis products impacts on air quality. This paper estimates the level of atmospheric contamination from the production of charcoal in one region of Brazil. We describe a low-cost charcoal kiln that can capture condensable gases and we estimate the levels of exposure of kiln workers to carbon monoxide. The latter results indicated that exposure to carbon monoxide can be reduced from an average of 950 ppm to 907 ppm and the mass of gases reduced by 16.8%.

1. Introduction

Black wattle (*Acacia mollissima Willd.*) is a leguminous species of tree found in the State of Rio Grande do Sul, the southernmost state of Brazil (located between 27° and 34°S and between 50° and 57°W). In one part of this state, thousands of small producers make charcoal from black wattle on traditional brick kilns that do not have any environmental emission controls.

Charcoal is produced in kilns by a process called pyrolysis: breaking down the chemical structure of wood under high temperature in the absence of air. The amount of solid (charcoal), liquid (pyroligneous extract) and gaseous (flue gas) depends on various process parameters, including temperature, time, pressure and kiln design, the amount of the pyrolysis products (Syred et al., 2006; Malimbwi and Zahabu, 2008; Panwar et al., 2012).

The carbonization process for the charcoal generation uses, in general, small-scale technologies that are difficult to control and that have low gravimetric yields (Rousset et al., 2011). In Brazil, charcoal production takes place primarily in the same way as it did a century ago, with 95% of the kilns constructed from a basic brick design (Campos, 2008). According to Brito (1990), the efficiency of these kilns in producing charcoal is very low (approximately 30% by weight of the raw materials). Consequently, there are releases into the atmosphere of high volumes of gases and other by-products. Workers and general population in these regions have been exposed to the pollutants from these kilns and have been annoyed from inhaling these contaminants (Encarnação, 2001; Pimenta et al., 2006; Rohde, 2011).

In order to reduce the environmental impact of charcoal using these traditional kilns, an alternative and low-cost model has been developed in the Regions of Lajeado/Estrela and Montenegro (State of Rio Grande do Sul). This type of kiln captures part of the condensable gases generated by the pyrolysis process and also produces a pyroligneous extract as a byproduct.

Given the environmental and occupational problems caused by charcoal production, the purpose of this study was to estimate the amount of gases emitted from these traditional kilns located in the Regions of Lajeado/Estrela and Montenegro. As well, we have studied the possibility of decreasing gases emissions by using a low-cost condensable gas kiln. Finally, we estimated the levels of exposure of workers to carbon monoxide from the kilns.

2. Materials and methods

2.1. Estimation of emissions of combustion products

Official Brazilian data (IBGE, 2009) was used to estimate charcoal production in the Regions of Lajeado/Estrela and Montenegro. From these data, we estimated that every ton of charcoal produced by wood carbonization through slow pyrolysis released 0.69 t of emissions that comprised 0.5 t of pyroligneous extract and 0.19 t of non-condensable gases (Brito, 1990).

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2.2. Experiments on charcoal kilns

We compared two 7.5 m^3 charcoal kilns, one based on the traditional design, made of bricks, in which the pyrolysis gases were released through holes located in the sides of the kiln, and the other one was modified with pipes to conduct and condense part of the smoke, very similar to the experimental scale system conducted by Balat and Demirbas (2009). The kilns were co-located 300 m from the house where a family of producers lived and we fired them at the same time, with the same raw materials and thus with the same climatic conditions.

In order to compare the traditional kilns and the ones with the condensable gases abatement system, the experiment was done by using both charcoal kilns at the same time, with the same raw material and subjected to the same climate conditions during the pyrolysis.

2.3. Occupational exposure assessment

We used a portable gas detector (Multipro Biosystems) to measure exposure of workers to carbon monoxide (CO) at two points located 0.5 m to the kilns and at the same height to simulate what a worker would inhale. An average of three measurements, after the gas detector stabilized, was obtained. Such stabilization occurs when the gas detector measures a continuous value. We did not measure any other compounds but made use of Brazilian occupational regulations for exposure to polycyclic aromatic hydrocarbons (PAH) and other chemical agents (BRASIL, 1978) to identify chemical agents present in the environment as well as potential health hazards.

3. Results

3.1. Production of charcoal in the Lajeado/Estrela and Montenegro Regions

Due to the high levels of black wattle silviculture in the Regions of Lajeado/Estrela and Montenegro, there are a large number of small rural producers. There is no reporting on quantities produced, but estimates of average production of charcoal have been made (SPG, 2011) and these are shown in Fig. 1 by municipality of Rio Grande do Sul for the years 2004–2006.

It has been estimated that the non-condensable gases generated during the wood pyrolysis are composed, by weight, of approximately 52.0% of CO_2, 37.0% of CO, and 11.0% of hydrocarbons (Brito, 1990). From this average composition, and using official charcoal production data (IBGE, 2011), we show in Table 1 the annual emissions of pyrolysis gases in the Regions of Lajeado/Estrela and Montenegro.

3.2. Chemical agents released to the atmosphere from charcoal production

Based on the average composition of the pyroligneous extract (Barbosa et al., 2009; Demirbas 2007; Balat et al., 2009), which is a byproduct of charcoal production when condensing the gases (Brito, 1990), we estimated the annual emissions of organic compounds present in the gases in some of the municipalities in the region (Table 2). The emissions were determined from the annual charcoal production in each municipality and by applying charcoal:emissions relationships and the concentration of the condensable gases taken from literature (Brito, 1990). The table shows that annual emissions were quite high in the municipalities of Brochier and Paverama, and in the territorial unit of Poço das Antas.

The number of workers exposed to these emissions is also difficult to estimate. However, using official data (IBGE, 2011), we estimated that the number of kilns is 6423 and the average number of workers is about 12,846. Most of these workers do not possess any

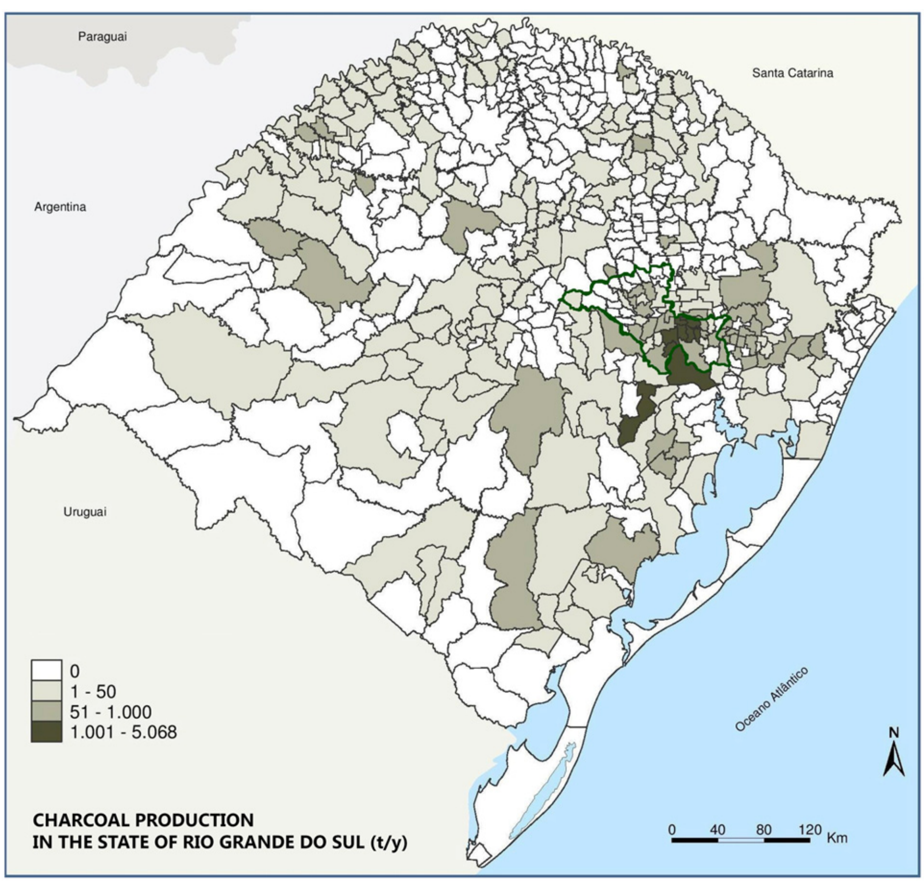

Fig. 1. Average production of charcoal in the State of Rio Grande do Sul, 2004–2006.

Table 1
Estimated atmospheric emissions (tonnes per year) from charcoal production.

Municipality	Area (km^2)	Total emissions (t/y)	Condensable (t/y)	Non-condensable (t/y)	Carbon monoxide (t/y)	Emissions in the territorial unit (t/y km^2)
Brochier	109.7	11,207	8121	3086	1604	102.2
Maratá	80.4	6159	4463	1696	882	76.6
Paverama	171.6	14,245	10,323	3923	2040	83.0
Poço das Antas	62.1	7790	5645	2145	1115	125.4
Salvador do Sul	99.2	9402	6813	2589	1346	94.8
São José do Sul	60.1	1396	1011	384	199	23.2
São Pedro da Serra	35.4	3555	2576	979	509	100.4
Total	618.5	53,753	38,952	14,802	7697	605.6

Table 2
Annual emissions from organic compounds present in the condensable gases.

Compound		Acetic acid	Methanol	Aromatics	Phenolics	Aldehydes	Tar	Total
Composition		0.06	0.025	0.035	0.03	0.01	0.06	0.22
Brochier	t/y	487.3	203.0	284.2	243.6	81.2	487.3	1786.6
	t/y km^2	4.4	1.9	2.6	2.2	0.7	4.4	16.3
Maratá	t/y	267.8	111.6	156.2	133.9	44.6	267.8	981.8
	t/y km^2	3.3	1.4	1.9	1.7	0.6	3.3	12.2
Paverama	t/y	619.4	258.1	361.3	309.7	103.2	619.4	2271
	t/y km^2	3.6	1.5	2.1	1.8	0.6	3.6	13.2
Poço das Antas	t/y	338.7	141.1	197.6	169.4	56.5	338.7	1241.9
	t/y km^2	5.5	2.3	3.2	2.7	0.9	5.5	20
Salvador do Sul	t/y	408.8	170.3	238.5	204.4	68.1	408.8	1498.8
	t/y km^2	4.1	1.7	2.4	2.1	0.7	4.1	15.1
São José do Sul	t/y	60.7	25.3	35.4	30.3	10.1	60.7	222.5
	t/y km^2	1.0	0.4	0.6	0.5	0.2	1.0	3.7
São Pedro da Serra	t/y	154.5	64.4	90.2	77.3	25.8	154.5	566.7
	t/y km^2	4.4	1.8	2.5	2.2	0.7	4.4	16

information about the possible health problems related to the chemicals generated from charcoal production and almost no respiratory protection equipment is used.

3.3. Reduction of atmospheric emissions

Low-cost condensers for the gases generated from pyrolysis have been developed for small-scale charcoal producers (Fig. 2). These condensers collect part of the pyroligneous extract during the production process, decrease gas emissions and provide a byproduct which has some commercial value. The system works by means of the insertion of pipes into the lower part of the kiln in order to conduct the gases to a post-pyrolysis chamber where the temperature of the gases decreases. This is known as the Brochier Model for the collection of pyroligneous extract (Brochier is the name of the town where the local government first gave support to the introduction of this new model in some kilns).

By applying a mass balance approach, we calculated the gaseous and charcoal production of each of the two kilns that we used. The traditional charcoal kiln yielded, by weight, 21% charcoal and the Brochier Model yielded 28.9%. In addition, in the conventional kiln, we found emissions of gases of 0.786 kg/kg of wood burned and the Brochier Model produced emissions of 0.664 kg/kg of wood burned, a reduction of 16.8%. The Brochier Model also generated 5.7% of pyroligneous extract and 65.4% of gaseous compounds, while the traditional kiln generated 78.1% of gaseous compounds instead of charcoal only as this model does not have the option for condensing part of the gases. These results indicate that the use of the Brochier Model increases the efficiency of the kiln, while achieving the main objective of condensing a considerable part of the gas emissions.

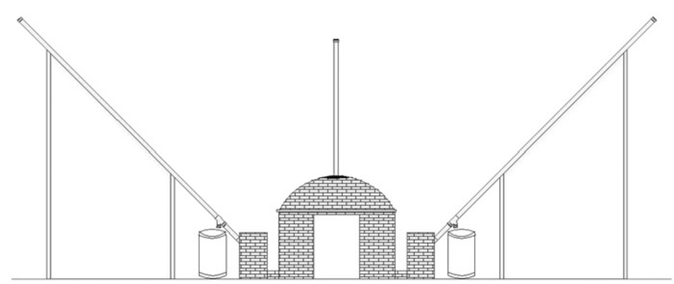

Fig. 2. Brochier Model scheme. The system works by means of the insertion of pipes into the lower part of the kiln in order to conduct the gases to a post-pyrolysis chamber where the temperature of the gases decreases.

3.4. Carbon monoxide exposure

Concentrations of CO near the ventilation holes were 950 ppm and 907 ppm for the traditional charcoal kiln and the Brochier kiln, respectively. Workers who monitor the kiln, which occurs about 6–10 times per day for a 10–15 min period, would be exposed to these levels. Such concentrations of CO corresponds roughly to a total annual emission of 7697 t/y in the region (Table 1). As a consequence, each kiln is responsible for the emission of approximately 1.19 t CO/y.

4. Discussion

4.1. Potential health hazards from exposure to polycyclic aromatic hydrocarbons

The regions studied consist of a hilly area, and much of the land has been subject to erosion. Also, as it is largely unsuitable for farming, many producers have found an alternative livelihood in the production of black wattle (Encarnação, 2001). These hilly areas, connected to the high density of the condensable gases compounds, interfere in the dispersion of the emitted gases.

The main non-condensable gases produced are carbon monoxide, carbon dioxide, methane and hydrogen (Demirbas, 2007). In addition, the carbonization of biomass also emits a range of carbon compounds, including PAHs in the liquid and gaseous phases, which are highly toxic and require careful attention. Barbosa et al. (2009), for example, detected 16 PAHs associated with the particulate matter from the slow pyrolysis of *Eucalyptus sp*. From the PAHs analyzed in this paper, the results included seven carcinogens, three co-carcinogens, phenols, levoglucosan, of which naphthalene, phenanthrene and fluorene were the most abundant. Genotoxic emissions accounted for 11% of the total of 16 PAHs.

Because all of the charcoal producers are located near workers' homes, their families can be exposed, depending on wind direction and meteorological conditions, to smoke from the charcoal kilns. As charcoal is produced on an average of 20 day per month, exposures of these rural families is essentially continuous.

Singh et al. (2008) evaluated concentrations of the levels of PAHs in the blood of children in India from charcoal emissions for which they are exposed through inhalation, in their diet and in the soil. The compound naphthalene had the highest average concentrations and displayed a significant correlation between wood-burning ovens and total non-carcinogenic PAHs.

From the relation of the activity characteristics and the frequency of contact with toxic compounds estimated by Ribeiro and Wünsch Filho (2004), a toxicological classification of charcoal activity could be made. Given the toxicology of the chemicals generated and the description of the exposure characteristics, we expect that frequent contact could lead to certain chronic health problems and chronic poisoning if the worker does not use respiratory protection, which is rather infrequent.

4.2. Potential health hazards from exposure to carbon monoxide

Workers who do not use any respiratory protection equipment are exposed when they control the air intakes of the kiln. The Limits of Tolerance, as stated in Brazilian Regulatory Norm NR 15, state that the highest tolerable level of carbon monoxide for continuous exposure in a 48 h working week is 39 ppm. Despite the short period of daily exposure to this gas for charcoal kiln workers, concentrations are very high when comparing with the limits of exposure. Given that workers generally do not appreciate the risks, the development of an educational program would be an important first step towards prevention of chronic health problems associated with high exposure to the emitted chemical agents.

4.3. Process improvement

The average distribution of products and by-products generated by carbonization showed that liquid and gaseous by-products accounted for almost 70% of the initial mass of wood (Rousset et al., 2011). Efficiencies of 27%–35% have already been reported in other countries from carbonization in similar brick kilns without proper control of the process and emissions treatment. (Malimbwi and Zahabu, 2008).

Results from pyrolysis experiments demonstrated that a moderate temperature ($<400\,^{\circ}C$) greatly favors the production of charcoal and moisture content of the wood does not have a major effect on the efficiency of the kilns (Rousset et al., 2011). Balat and Demirbas (2009) reported that conversion to charcoal from 10 to 20 min increased from approximately 23.1% to 66.4%, respectively.

These findings show the strong influence of some pyrolysis parameters, such as temperature and time to charcoal production (Panwar et al., 2012), where time to production appears to be the most important factor (Balat et al., 2009). Also, increasing temperature causes an increase in the gas products and, therefore, a corresponding decrease in solid products (Syred et al., 2006).

Although the Brochier Model increases carbon yield and reduces emissions, the carbonization process can still be improved. The parameters described in the literature that have a direct consequence on carbon yield—temperature and time—are not monitored currently by the producers but can be monitored easily and optimized in order to increase charcoal production and, as a consequence, decrease the gaseous emissions and exposure.

5. Conclusions

The traditional kilns used for charcoal production in Brazil emit highly toxic compounds, such as carbon monoxide and PAHs. In the region studied, although dispersion of the gases is attenuated because of the topography the general population is nonetheless exposed. The Brochier kiln is a first step towards the achievement of improved air quality, but further modification are needed to reduce emissions and increase efficiency.

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