How big is small?

Enough to not breathe oil!

The Peruvian case of diesel-fuelled wick lamps for lighting

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Health risks due to indoor air pollution (IAP) from inefficient domestic burning processes for cooking or lighting are not breaking news. The presence of high levels of sulfur dioxide in burnt wood emissions from traditional cookstoves; its remaining high levels in the air after two hours from turning off the source; and the fact that this gets even worse with an oil-fuelled wick lamp that pollutes almost the same as a second traditional cookstove in the same room for at least one hour each day for 20% of the world´s population, maybe are. This paper shows first evidence from Peru´s rural context in the simultaneous lack of modern energy devices for lighting and cooking.

Keywords: sulfur dioxide; indoor air pollution; diesel wick lamp;

Introduction

Worldwide there are about 1,400 million people without access to electricity (OECD, 2010). Of these, it is estimated that 500 million people still use fossil fuels, among them mainly kerosene, to produce light (Lam et al. 2012).

In Peru, about three million people lack access to electricity (MEM, 2013). Unlike in other countries, in Peru no one is using kerosene-fuelled wick lamps because kerosene has been banned by law since 2010, since it is used in the production of illegal drugs (narcotics). However, there are many families in rural areas of the rainforest which have replaced kerosene with diesel, using it as fuel for wick lamps.

In addition, almost all families using wick lamps cook in open fires (traditional stoves). The negative impact of traditional stoves in open fires has long been researched (Fullerton, et.al 2008; Smith, et.al 2004); however, there is no evidence about the exposure to both indoor air pollutants at the same time.

The smoke from diesel combustion contains lots of chemical components as gas or ultrafine particle emissions (particulate matter, black carbon, etc).

Resulting products from these emissions are carbon dioxide CO_2, carbon monoxide CO, sulfur dioxide SO_2 and mono nitrogen oxides NOx (Morawska, et.al 2004). The International Agency for Research on Cancer (WHO, 2012) classified engine diesel exhaust as carcinogenic to humans.

The risk is much higher with fuel combustion in wick lamps, since one tenth of the fuel burned is converted to black carbon compared to a diesel engine, where this relation represents only one-thousandth (Jacobson, et.al 2013). In addition there is some evidence that indoor pollutants from fuel-based lamps may have correlation with cataract and tuberculosis, but this requires further study (Mills, 2012).

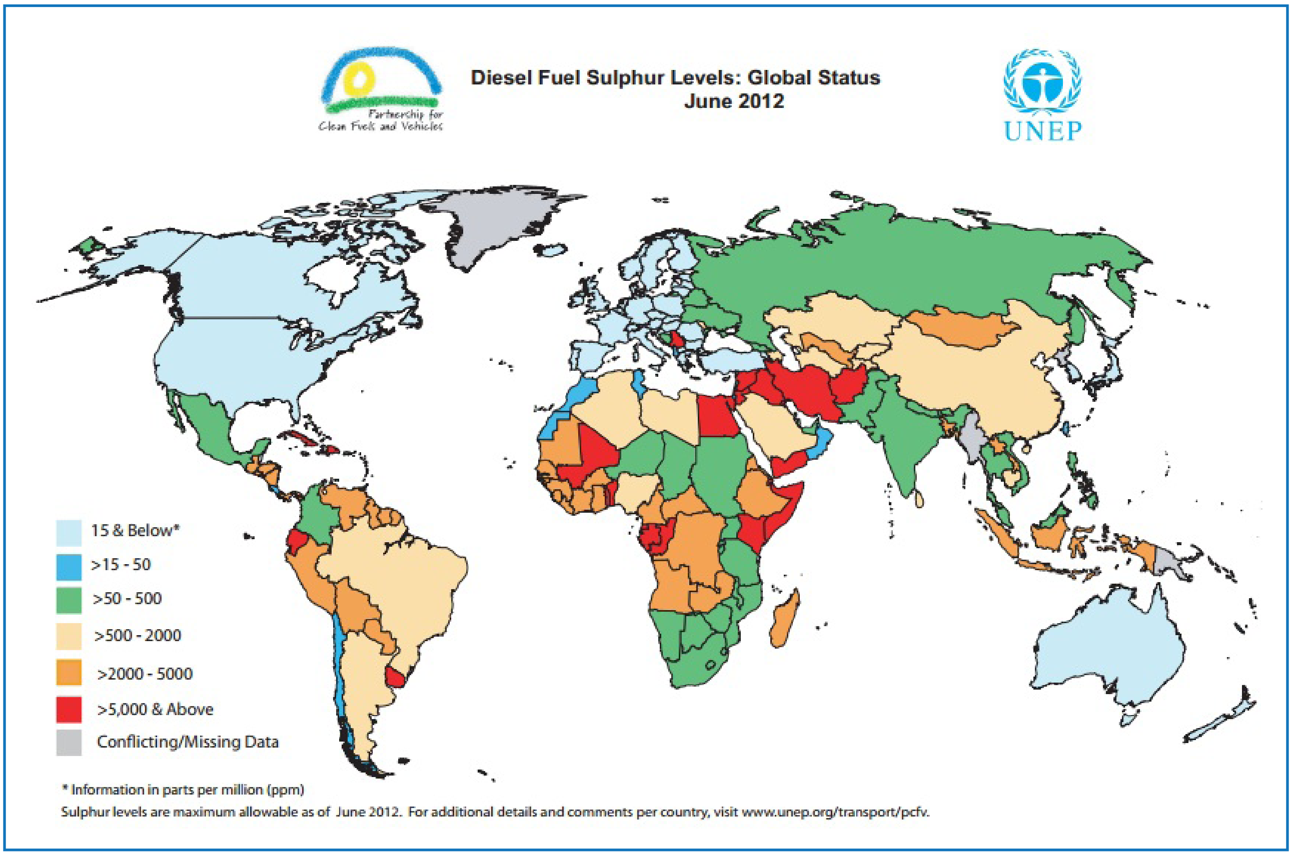
I. Research Objectives

This paper aims to study exposure levels to the polluting gases produced by diesel-fuelled wick lamps (DFWL), and to the levels from its simultaneous use with wood burning traditional cooking stoves. The first research question was to discover if the use of DFWL results in dangerous exposure levels of the same dangerous gases that traditional cookstoves produce, mainly particular matter 2.5 ($PM_{2.5}$) and carbon monoxide (CO).

In addition, it was tested if the concentration´s levels of sulfur dioxide (SO_2) are higher than those recommended by the World Health Organization (WHO) as the highest exposure limits. The focus on sulfur dioxide responds to the concerning about the high level of sulfur that Peruvian diesel has, one of the highest in Latin America as figure 1 shows.

Figure 1

Diesel Fuel Sulfur Levels: Global Status (UNEP, 2012)



According to the Peruvian Environment Ministry (MINAM, 2013), the high content of sulfur in diesel is responsible for an increase in the last three years of SO_2 levels in the air by nearly 500% in the Peruvian capital Lima. The last occurred by stable levels of nitrogen dioxide NO_2 and ozone O_3 in the same time period.

The last research question was to measure the emission´s levels of these three gases from DFWL in simultaneous use with a traditional cookstove (3-stone-fire), and to evaluate its remaining levels over time after turning off the sources.

The measure of carbon dioxide (CO_2) was only for discovering if there are any health implications regarding its emissions levels in the discussion around IAP, since it wasn´t recorded in Peruvian traditional stove tests.

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[1] SO_2 is one of the most common air pollutants according to the WHO beneath $PM_{2.5}$, nitrogen dioxide (NO_2) and ozone (O_3).

II. Methods

Two DFWL with different types of wick (Type A: cotton and Type B: old cloth) were collected from households in two different towns in the Amazon area (the provinces San Martín and Amazonas, respectively) and used as polluting sources. Tests were conducted on indoor air pollutant concentration levels of dangerous gases ($PM_{2.5}$, CO, SO_2 and carbon dioxide CO_2), resulting from the burning of these two types of DFWL with diesel fuel.

The equipment used for measuring $PM_{2.5}$ and CO was the Aprovecho IAP-Meter with resolutions of 0-60,000 $\mu g/m_3$ (red laser scattering photometer) and 0-1,000 ppm (electrochemical cell) respectively. For SO_2 and CO_2 it was used Aeroqual with resolutions of 0-15 ppm (Gas Sensitive Electrochemical – GSE Sensor) and 0-5,000 ppm (Non dispersive Infra Red – NDIR Sensor) respectively. Both devices were calibrated in December 2011 for the last time.

The equipment belongs to Housing Ministry´s improved cookstove certification laboratory in Lima, where these tests were conducted. The equipment was located in the room in a simulating position of a regular nose of a typical user, following conventional protocols used for testing cookstoves (Aprovecho, 2014).

The environment chosen had a ventilation rate of 4.29 h^{-1}, which was determined with the window and door closed, as recommended by the new protocol for IWA (International Workshop Agreement, GACC 2012) on improved stoves.

During the trials for each type of test, it was intended to homogenize some variables such as:

- Initial background measure of all tested gases (30 min.) for setting a baseline of concentrations in the room.
- Length of the DFWL test; both types of DFWL A and B were evaluated for 3.5 hours burning time each day on 3 consecutive days during similar hours respectively (D1-D6 for days 1 until 6).
- Similarly, during days D7-D9, the exposure levels of the traditional stove were evaluated in the mornings alone, and, in the afternoons, simultaneous with the burning of the most polluting DFWL according to the results of tests on D1-D6 (type A). The duration of both tests was 1 hour.
- After turning off the sources, measure equipment remained recording concentration levels for two hours to evaluate the dispersion speed of the gases.
- Infrastructure: the laboratory for IAP imitates a rural house made of typical material and dimensions for walls and roof (mud bricks and corrugated iron).
- Same characteristics of diesel and firewood for all tests: the laboratory´s firewood is standardized for stove tests regarding humidity, wood type and origin.
- Technical evaluator: same person for all tests with prior experience in stove evaluations.
- The approximate level of light emitted by the DFWL: the lighting level should remain constant durant the tests, so the evaluator pulled the wick during the tests for keeping its light constant

To control the environmental variables that could influence the results of the tests, the Davis Vantage Pro Weather Station was used. This equipment took values for inner temperature of the room (°C), relative humidity (%), wind speed (m/s) and solar radiation (W/m^2). Average values of these units during the evaluation days can be seen on Table 1:

Table 1

Average values of environmental variables during evaluation days.

Average values	**D1-D3**	**D4-D6**	**D7-D9**
Inner temperature (°C)	32.9 ± 0.4	32.5 ± 1	41.9 ± 1.8
Relative humidity (%)	56 ± 0.6	54.7 ± 2.1	42.7 ± 2.0
Wind speed (m/s)	1.2 ± 0.3	1.3 ± 0.1	1.2 ± 0.2
Solar radiation (W/$m^{2)}$	578.9 ± 53.9	593.3 ± 56.5	476.4 ± 49.5

The results on concentrations levels of these gases should be compared to the recommended highest exposure levels made by WHO ($PM_{2.5}$, SO_2 and CO) and by the Occupational Safety and Health Administration (OSHA, CO_2) respectively. These levels can be seen on table 2.

Table 2

Recommended exposure levels

Air pollutant	**Exposure time**	**Recommended level (ppm)**	**Institution**
SO_2	10 minutes	0.17 ppm	WHO
	24 hours	0.007 ppm	WHO
$PM_{2.5}$	24 hours	25 µg/m^3	WHO
	365 days	10 µg/m^3	WHO
CO	30 minutes	50 ppm	WHO
	1 hour	25 ppm	WHO
CO_2	15 minutes	30,000 ppm	OSHA
	8 hours	1,000 ppm	OSHA

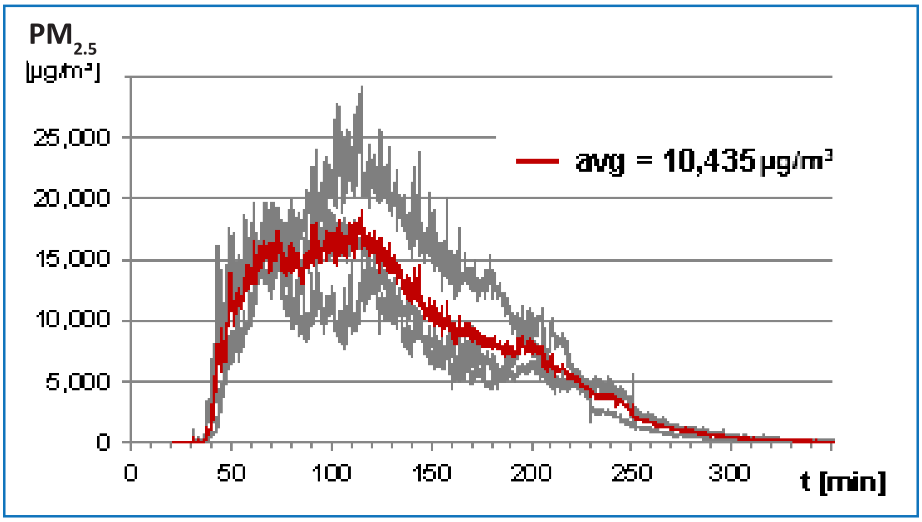
III. Results

The DFWL type A showed in all tests the highest concentration of gases. This DFWL showed the highest fuel consumption with an average of 101 g of diesel versus 55 g for 3.5 hours burning with DFWL type B respectively. All the results listed below are taken from the tests conducted with DFWL type A.

The average $PM_{2.5}$ levels of the most polluting DFWL was around 10,435 µg/m³ with peaks nearly 30,000 µg/m³. Figure 2 shows $PM_{2.5}$ concentration levels for the three days of measurement and its average for DFWL A.

Figure 2

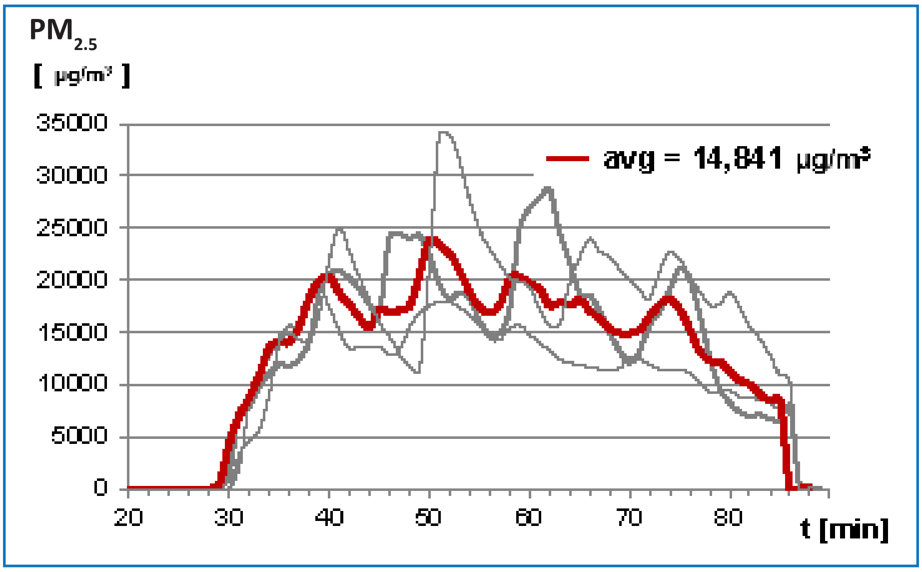
Exposure levels of $PM_{2.5}$ for D1-D3 for DFWL A



This concentration of $PM_{2.5}$ particles reaches approximately 60% of the emission levels of a traditional cookstove as the only pollution source, which showed average levels of 14,841 µg/m³ and peaks near 35,000 µg/m³ in this research. The levels of $PM_{2.5}$ for a traditional cookstove as the only pollutant on D7-D9 and its average can be seen in figure 3.

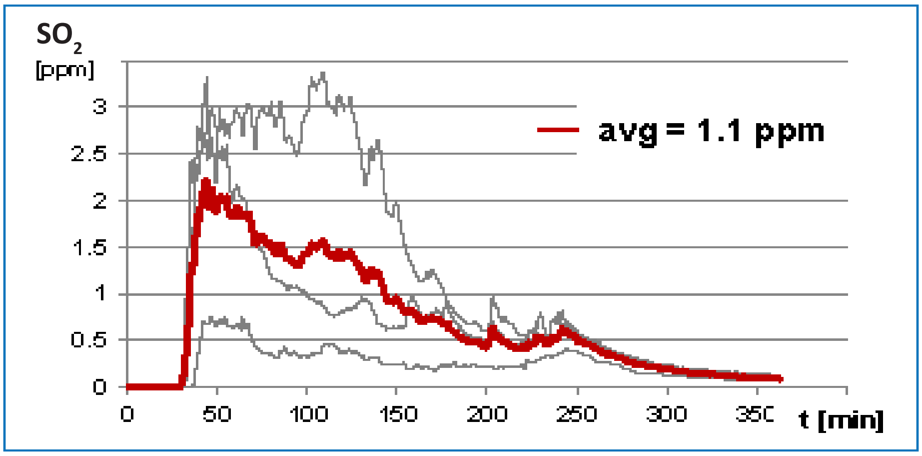
Figure 3

Exposure levels of $PM_{2.5}$ for traditional stove for D7-D9 for DFWL A



The tests with the same DFWL showed that the average concentration of SO_2 emitted after the first 10 minutes of burning was 1.1 ppm, exceeding almost up to seven times the limit allowed by the WHO for 10 minutes exposure of 0.17 ppm. There were peaks over 3 ppm. Figure 4 shows the exposures levels for SO_2 taken on D1-D3 and its average.

Figure 4
Exposure levels of SO_2 for DFWL A on D1-D3



The concentrations of CO and CO_2 from both DFWL didn't show risky levels with 4.8 ppm and 136.4 ppm in average for the worse results with DFWL A respectively. This can be seen on the curves for both gases with DFWL A for D1-D3 in figure 5 and figure 6.

Figure 5
Exposure levels of CO for DFWL A on D1-D3

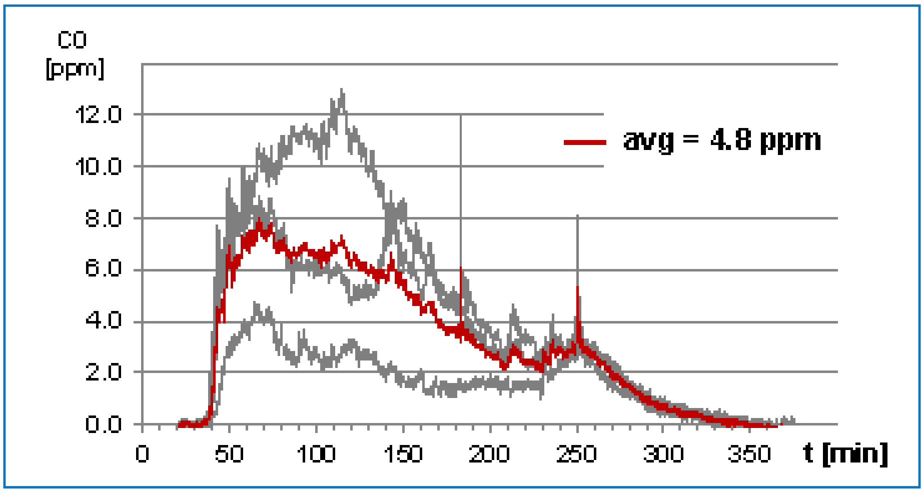
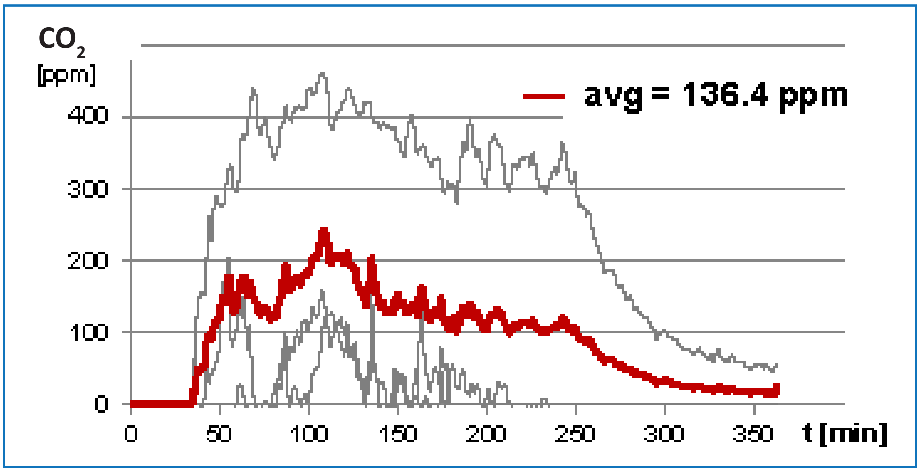


Figure 6

Exposure levels of CO_2 for DFWL A on D1-D3

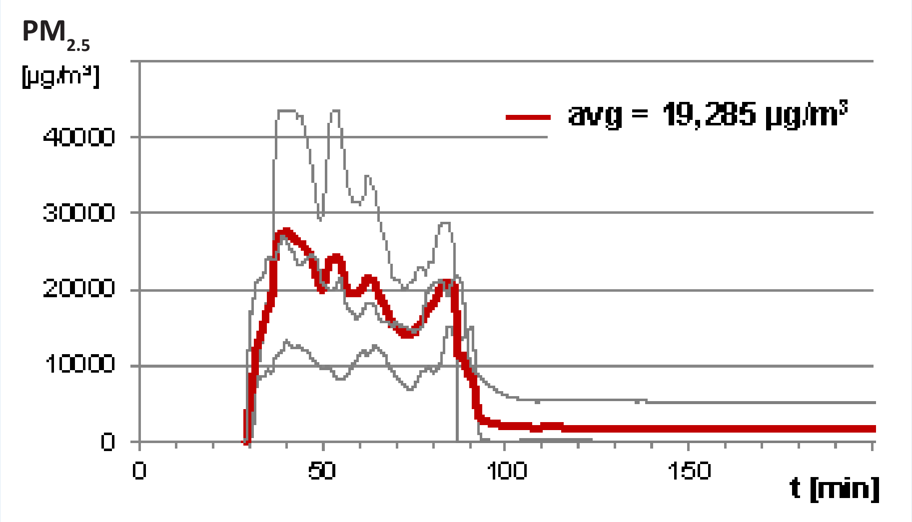


Levels for CO and CO_2 only with the traditional stove as a pollution source show higher levels than recommended for CO (379 ppm in average) and lower levels for CO_2 (1,464 ppm in average). The higher levels for CO are already known from the cookstoves research and those for CO_2 are lower as recommended even with the DFWL A as a second pollution source (664.8 ppm in average).

However the use of the DFWL A simultaneously with a traditional stove regarding $PM_{2.5}$ showed an average level of 19,285 µg/m³ (with peaks over 43,000 µg/m³) having an average increase of nearly 30% from the values with a traditional cookstove as the only pollutant. The evolution of the exposure levels of PM2.5 on D7-D9 with both burning sources can be seen in figure 7.

Figure 7

Exposure levels of PM2.5 for DFWL A on D7-D9 with a traditional cookstove

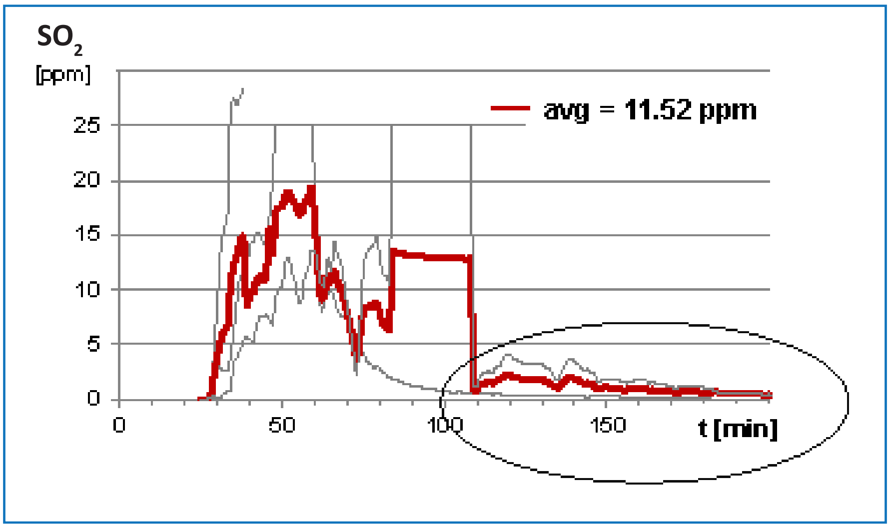


An unexpected result was observed in that a traditional cookstove, as the only source of pollution, reaches levels of sulfur dioxide SO_2 far exceeding the permissible exposure values from various organizations, such as the WHO. SO_2 is not a typical gas taken into account in typical cookstove emission tests.

The intensity of this emissions were so high that they even exceed the maximum possible measurement levels of the instruments (> 15 ppm), hence the concentration levels during the full test couldn´t be monitored properly for both cases (DFWL alone 14 ppm and in addition with a traditional cookstove 11.52 ppm in average respectively). The disrupted evolution of SO_2 on D7-D9 for the case of simultaneous pollution can be seen in figure 8.

Figure 8

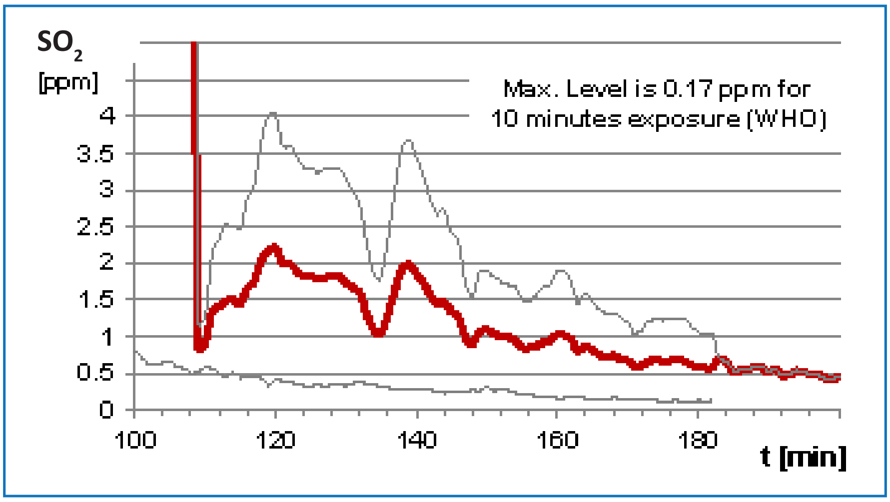
Exposure levels of SO_2 for DFWL A on D7-D9 with a traditional cookstove



SO_2 emission speeds of 0.5 ppm/min and 1.5 ppm/min with DFWL A alone and with both polluting sources respectively could be observed. In addition one hour after having turned off both polluting sources, still remain in the room higher levels of SO_2 as recommended by the WHO. This can be seen in a zoomed picture of previous figure, that is shown on Figure 9.

Figure 9

Remaining exposure levels of SO_2 after turning off both pollution sources on D7-D9



IV. Conclusions

The evaluated DFWL are less pollutant than traditional cookstoves taking into account the exposure levels measured for the pollution from the traditional stove alone in this study for $PM_{2.5}$ and CO. Carbon monoxide emissions do not exceed the recommended exposure levels. However these values for particulate matter represent around 60% of the measure taken for the traditional cookstove.

This could be a serious problem, since both traditional devices exceed by far the exposure limits recommended by WHO and are commonly used simultaneously in rural households. This finding could set an additional challenge to improved cooking stove (ICS) programs, since the usage of ICS alone wouldn´t be enough for those households using in addition DFWL.

In addition both tested DFWLs seem to exceed during the whole burning process the recommended exposure levels of SO_2 by the WHO for 10 minutes. There isn't a value for one hour exposure time, but it would be much lower than the 10 minutes one, making clearer the scope of health impacts by the normal usage of DFWL.

Unexpected results were SO_2 emissions from the traditional cookstove above the recommended exposure levels (when burning alone and simultaneous with a DFWL). These values were higher than the equipment measure capacity and representing at least ten times the values from the DFWL alone. Traditional ICS tests could open the research for SO_2, since it could be an invisible pollutant in the actual efforts for reducing IAP.

The CO_2 emission levels remained by far under the exposure limits recommended by OSHA.

V. Discussion

This study invites further research on indoor air pollution, taking into consideration sulfur dioxide SO_2 and its health implications, either through DFWL or traditional cooking stoves. It is recommended to test other typical diesel burning gases like nitrogen dioxide and evaluate its implications on health comparing results with WHO air quality guidelines.

Furthermore it is suggested that more traditional DFWL are collected from the field and tested with the same methodology so there can be enough evidenced data that serves as consistent basis for a baseline of the pollution from these devices, since they are all different among each other. When this is reached, it is suggested to carry out evaluations with one representative type of DFWL and play with other variables like different types of carburant agents (wicks) since it has been observed that different varieties of wicks emit larger or smaller amounts of fine particles.

The tests performed have also shown the existence of high levels of SO_2, emitted only by wood burning stoves. For this reason, it is suggested to consider the levels of SO_2 emitted during combustion when validating improved stoves.

In the absence of complete simultaneous measurement of pollutants during the tests on DFWL and traditional stoves, it is suggested to perform this test with equipment that allows for a wider range of measurement and records other pollutants, such as nitrogen oxides and sulfur . It is also advisable to measure on different days, following similar time schedules, in order to control environmental variables.

The testing in laboratory may be helpful to have first impressions of the potential inherent risk these devices have However the real risks for the people under real exposure levels can only be measured on the field under real weather and ventilation conditions in real houses and furthermore under manipulation from real users. Only then the potential and the real exposure levels can be linked and concrete consequences to health be inferred.

It is understood that the high pollutant exposure levels recorded (especially $PM_{2.5}$ and SO_2) imply a risk to people who use these traditional devices for lighting and cooking in their homes. So, being the most risky average exposure levels from SO_2 and $PM_{2.5}$ by breathing contaminated air from the DFWL or traditional stoves, people should be warned about the risk of carrying out activities within a closed environment due to the presence of these polluting sources.

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