EFFICIENCY OF RECIRCULATION HOODS

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ABSTRACT

Recirculation hoods equipped with carbon and plasma filters are becoming more and more popular. The aim of this study is to determine the effectiveness of recirculation hoods with regard to $PM_{2.5}$ and NOx removal in a 26 m^3 lab kitchen with a gas furnace. With the carbon filter $PM_{2.5}$ is reduced for about 30%. A fresh carbon filter removed about 60% of the NO_2, dropping within a few weeks of cooking to 20%. With the plasma hood NO_2 concentrations were above the WHO 1-hour limit and the Dutch health council 15 minutes limit. For plasma hoods it is recommended to optimize odor and particulate matter reduction while minimizing the ozone production. As recirculation hoods have favorable properties in terms of applicability and energy conservation it is recommended to add a particulate filter to recirculation hoods and to apply them preferably in combination with electrical cooking.

KEYWORDS

Cooking emissions, Particulate Matter, activated carbon, plasma filters

1 INTRODUCTION

Cooking emissions have long been seen as an odour problem. However recent field studies showed that Particulate Matter (PM) is the main health risk of indoor air (Logue, 2013) and cooking can be a major source of $PM_{2.5}$. In case of cooking on gas aside PM also nitrogen dioxide (NO_2) is being generated. Dennekamp (Dennekamp, et al., 2001) reported substantial concentrations of NOx due to cooking on gas with no extraction and poor ventilation. Using four rings for 15 minutes produced peak concentrations of 1000 ppb NO_2 and 2000 ppb nitric oxide (NO). Expressed in mass this amounts to 2000 µg/m^3 NO_2. Logue (Logue, 2014) simulated assuming no use of hoods, that in 55 – 70% of the Californian dwellings the NAAQS 1-hour acute standard is exceeded during a typical week in winter. By assuming hoods with an effectiveness of capturing 55% of the emissions, the exceedance percentage is reduced to 18 – 30% of the dwellings. The lower percentage correspond to a deposition rate of 0.5 h^{-1} and the higher to a deposition rate of 1,05 h^{-1}.

Recirculation hoods equipped with activated carbon and plasma filters are becoming more and more popular. The aim of this study is to study the effectiveness of recirculation hoods with regard to $PM_{2.5}$ and NO_2 and to compare the resulting concentrations with existing legal limits and occupational guidelines.

1.1 Legal limits and occupational guidelines for $PM_{2.5}$

At the moment there are only guidelines for $PM_{2.5}$ outdoor. However, the steering group assisting WHO in designing the indoor air quality guidelines concluded (WHO, WHO guidelines for indoor air quality - selected pollutants, 2010) that there is no convincing evidence of a difference in the hazardous nature of particulate matter from indoor sources as compared with those from outdoors and that the indoor levels of PM_{10} and $PM_{2.5}$, in the presence of indoor sources of PM, are usually higher than the outdoor PM levels. Therefore, the air quality guidelines for particulate matter recommended by the 2005 global update are also applicable to indoor spaces. Other legal limits are listed in Table 1.

Table 1: overview of legal limits and guidelines for Particulate Matter (PM).

	period	**PM_{10} [µg/m^3]**	**$PM_{2.5}$ [µg/m^3]**
WHO	yearly	20	10
EU	yearly daily	40 50*	25 -
US	yearly daily	50 150	15** 35

**Max 35 days higher than 50 µg/m^3* ***3 years average*

1.2 Legal limits and occupational guidelines NO_2

WHO (WHO, WHO guidelines for indoor air quality - selected pollutants, 2010) recommends an 1-hour indoor nitrogen dioxide guideline of 200 µg/m^3, see Table 2. At about twice this level, asthmatics exhibit small pulmonary function decrements. Those who are sensitized may have small changes in airway responsiveness to a variety of stimuli already at this level. An annual average indoor nitrogen dioxide guideline of 40 µg/m^3 is recommended by WHO. WHO states that having a gas stove is equivalent to an increased average indoor level of 28 µg/m^3 compared to homes with electric stoves, and meta-analysis showed that an increase in indoor nitrogen dioxide of 28 µg/m^3 is associated with a 20% increased risk of lower respiratory illness in children. Homes with no indoor sources were estimated to have an average level of 15 µg/m^3. WHO (WHO, Air Quality Guidelines - Global update 2005, 2005) states that these results support a lowering of the annual nitrogen dioxide guideline value. However, since nitrogen dioxide is an important constituent of combustion-generated air pollution and is highly correlated with other primary and secondary combustion products, it is unclear to what extent the health effects observed in epidemiological studies are attributable to nitrogen dioxide itself or to other correlated pollutants. The current scientific literature, therefore, has not accumulated sufficient evidence to change WHO's 2000 guideline value of 40 µg/m^3 for annual nitrogen dioxide concentration. The Dutch Social and Economic Council (SER, 2007) advises a 15 minutes maximum value of 1000 µg/m^3.

Table 2: overview of legal limits and occupational guidelines for nitrogen dioxide (NO_2)

	NO_2 [µg/m^3], exposure period			
	Yearly	**8 hourly**	**hourly**	**Standard (reference)**
WHO indoor	40	-	200	WHO (WHO, 2010)
Dutch health council	-	400	1000 (15 min)	SER (2007)
EU ambient	40	200*	-	2008/50/EG (EU, 2008)
US ambient	57 100	- -	339 188	CAAQS (CAAQS, 2010) NAAQS (EPA, 2012)

**Max 18 hours per year exceedance.*

2 MATERIALS/METHODS

In the TNO lab a kitchen has been set up with dimensions of 3.65 x 2.66 x 2.68 m. The kitchen setup is according to NEN-EN-IEC 61591 In all experiments room ventilation has been kept constant at 21 dm^3/s. The air in the room is mixed up with a mixing fan. Frying three hamburgers on a gas furnace for 10 minutes in extra virgin olive (OK, Plus) oil at 220 ^{0}C has been used as model dish. This combination of frying of hamburgers olive oil has also been used in a previous research (Jacobs, 2016). A stainless steel 24 cm diameter pan with a soldered temperature sensor has been used. The pan temperature has been kept constant by regulating the gas flow to the furnace. After the frying the hamburgers have been removed from the room.

Figure 1: frying hamburgers in stainless steel pan with temperature sensor.

During the 10 minutes frying and consequently 50 minutes ventilating the room the following components have been measured: $PM_{2.5}$, Elemental Carbon (EC, soot), Polycyclic aromatic hydrocarbon (PAH), ozone, NO and NO_2. The details of the measuring equipment are mentioned in Table 3.

Table 3: specifications of measurement equipment

$PM_{2.5}$	Grimm 11R
Elemental Carbon (EC)	Multi Angle Absorption Photometer (MAAP) 5012, Thermo Environmental
16 EPA PAHs	Measuring head with particle filter and XAD-2 absorption grains, analysis on the 16 EPA PAHs
NOx	Thermo Environmental (model 42i) NOx monitor
Ozon	Photometric O_3 Analyzer model 400, API Inc.

Three different situations have been assessed:

1. No exhaust hood;
2. Recirculation hood (ATAG, WS9011QAM) equipped with an fresh carbon filter (ACC928UU) dimensions 28 x 18 x 2 cm, recirculation flow 430 m^3/hour;
3. An commercial plasma hood (see Figure 2, right).

Figure 2: left positioning of recirculation hood and measurement equipment, right plasma hood.

3 RESULTS

Table 4 gives an overview of the experimental results. The $PM_{2.5}$ emission is strongly dependent on the temperature, increasing the baking temperature from 180 to 220 ºC resulted in a four-fold higher peak concentration. Particulate matter is also formed if only oil is used. Soot makes 0.1 - 1.1% share of the $PM_{2.5}$ emission. The measured maximum soot concentrations are in the order of magnitude from 0.8 to 3.0 µg/m^3. There is no set clear relationship with the temperature. The PAH concentrations are not listed as there were no significant increased concentrations found. The concentration of Benzo(a)pyrene (BaP), a PAH, was in all experiments, below 1 ng/m^3, the annual averaged EU air standard. Application of the recirculation and plasma hood, respectively, resulted in a reduction of 28% and 31% of the peak $PM_{2.5}$ concentration. The peak concentration of NO_2 was by application of the recirculation hood by 67% lower. When using the plasma hood the NO_2 peak concentration was greatly increased to 667 and 1155 ug/m^3 (duplicate measurements). This can be explained by the fact the plasma hood also generates ozone thereby NO is converted to NO_2 and possibly also nitrogen from the air turnover to NO_2. This is supported by the variation in time of the gaseous compounds as shown in Figure 3.

Table 4: cooking emissions per experiment expressed as peak concentrations.

T_{pan} [ºC]	Number of hamburgers	Wasemkap	Ventilation [dm^3/s]	Max. $PM_{2,5}$ [µg/m^3]	Max. EC (soot) [µg/m^3]	Max. NO_2 [µg/m^3]	Max. O_3 [ppb]
180	3	-	21	194	1.47	-	-
180	3	-	21	195	1.38	274	-
220	3	-	21	894	3.04	-	-
220	3	-	21	615	1.41	350	-
220	3	-	21	808	0.82	358	-
220	Only oil	-	21	751	2.88	222	-
220	3	Recirculation	21	569	2.81	126	-
220	3	Recirculation	21	512	0.64	138	-
220	3	Recirculation*	21	595	0.42	91	-
220	3	Plasma	21	561	6.34	667	69 – 194
220	3	Plasma	21	507	0.76	1155	166 - 441

** free flow towards ceiling to prevent disturbance of the air flow pattern under the hood.*

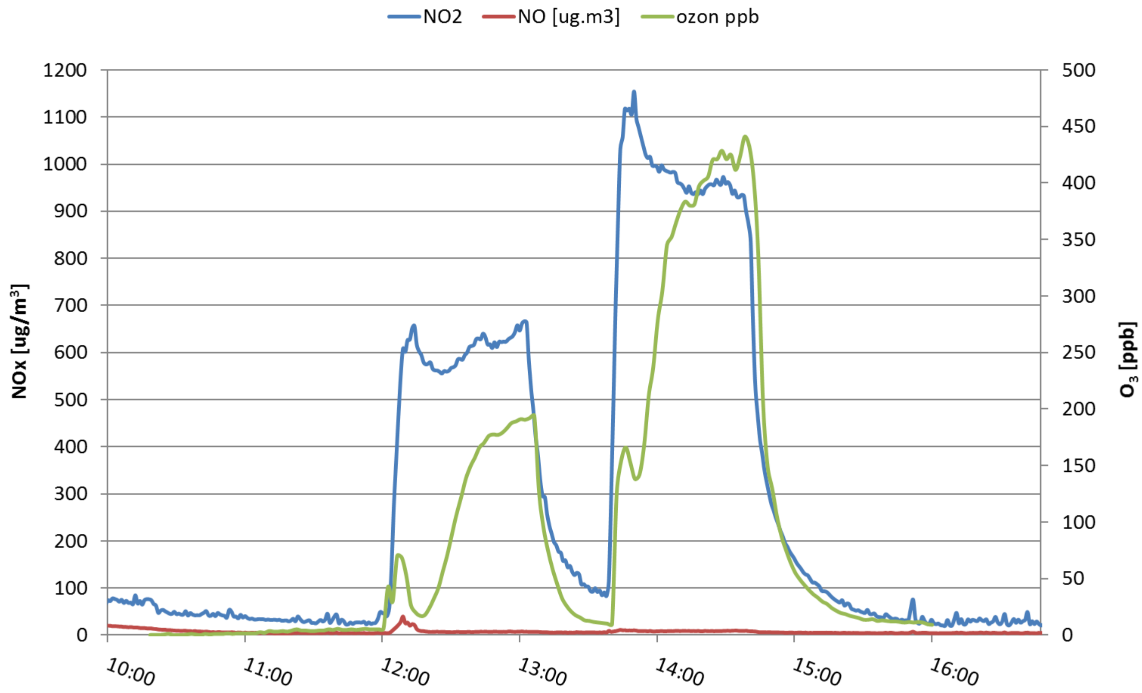

Figure 3: NOx and ozone concentration with plasma hood duplo experiment.

The higher NO_2 and ozone concentration in the second experiment is probably due to the fact that the carbon filter has not been refreshed. An aging test performed on the carbon filter of the recirculation hood simulating 19 days of cooking (20 minutes/day 5 kW) showed an initial NO_2 reduction of 56% and after 19 days only 19%.

4 DISCUSSION

4.1 PM2,5

The measured concentrations are in line with earlier research of Schiavon (Schiavon, 2015) in a 20 m^3 room and Jacobs (Jacobs, 2016). The relatively small $PM_{2.5}$ reduction of about 30% by the recirculation hood and the plasma hood can be explained by the fact that carbon filters are very open filters that are designed to absorb gaseous odorants but leave particulate matter almost unobstructed. In air tight dwellings with low ventilation flows this can lead to exposure to relative high $PM_{2.5}$ levels. This is supported by the findings in a field study (Jacobs et al., 2016) that a recirculation hood in contrast otits relative high exhaust capacitie not that effective towards $PM_{2.5}$ mitigation. As recirculation hoods have favorable properties in terms of applicability and energy conservation it is recommended to add a particulate filter to recirculation hoods.

4.2 NO_2

The peak concentration of NO_2 was by application of the recirculation hood 67% lower. This is higher as measured by Paulin (Paulin, 2014) in an intervention study in homes with unvented gas stoves in Baltimore City. Air purifier placement in that study resulted in an immediate decrease of 27% in the kitchen and 22% in the bedroom, but at 3 months a significant reduction was seen only in the kitchen (20 %). This may be caused by the fact that loading the filter reduces the absorption potential as demonstrated by the 19 days aging test. Applying the plasma hood did not decrease but increase the NO_2 concentration towards concentrations which are above the WHO 1-hour limit and the Dutch health council 15 minutes averaged concentration limit. This can be explained by the ozone that almost instantaneously converts the NO towards NO_2: $3NO + O_3 \rightarrow 3\ NO_2$

In figure 3 after stopping the baking the concentration NO_2 remains constant. One would expect a dilution by the ventilation. This can be explained the fact that ozone is still being generated as the hood is still on. Probably NO_2 is generated from N_2 available in the room air. Note that in this study only one burner of the gas furnace has been used. Based on the limited data gained in this study the combination of a gas furnace and a plasma hood seems unfavorable with regard to NO_2 formation. In general ozone production should be avoided. It is recommended to do more research towards optimizing odor and particulate matter reduction while minimizing the ozone production.

4.3 Elemental Carbon (EC) and PAH's

There is no set clear relationship between the concentrations of Elemental Carbon and PAH's with the temperature and the effect of a recirculation or plasma hood. In the last experiment with the recirculation hood the capture efficiency may be improved due to less disturbance of the air flow pattern under the hood. It may be possible that the carbon filter reduces the concentration Elemental Carbon. In this research no significant increased PAH concentrations were found. A literature review (Abdullahi, 2013) has shown that the cooking method has a large influence on PAHs. Chinese cooking, characterized by frying at high temperatures, can lead to much more PAH's compared to western-style fast food cooking.

5 CONCLUSIONS

This study indicates that recirculation hoods based on carbon and plasma filters remove $PM_{2.5}$ for about 30%. A fresh carbon filter removed about 60% of the NO_2, dropping within a few weeks of cooking to 20%. In case of a recirculation hood based on plasma technology additional NO_2 can be formed leading to concentration which are above the WHO 1-hour limit and the Dutch health council 15 minutes limit. For plasma hoods it is recommended to optimize odor and particulate matter reduction while minimizing the ozone production. As recirculation hoods have favorable properties in terms of applicability and energy conservation it is recommended to add a particulate filter to recirculation hoods and to apply them preferably in combination with electrical cooking.

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7 REFERENCES

Abdullahi, K., Delgado-Saborit, J., & Harrison, R. (2013). Emissions and indoor concentrations of particulate matter and its specific chemical components from cooking: a review. *Atmospheric Environment*, 260-294.

CAAQS. (2010). *California Ambient Air Quality Standards*. Retrieved December 2016, from https://www.arb.ca.gov/research/aaqs/caaqs/no2-1/no2-1.htm

Dennekamp, M., Howarth, S., Dick, C., Cherrie, J., Donaldson, K., & Seaton, A. (2001). Ultrafine particles and nitrogen oxides generated by gas and electric cooking. *Occup. Environ. Med.*, 511-516.

EPA. (2012). Retrieved from https://www3.epa.gov/ttn/naaqs/standards/nox/s_nox_history.html

EU. (2008). *2008/50/EG.* Retrieved from http://eur-lex.europa.eu/legal-content/NL/ALL/?uri=CELEX:32008L0050

Jacobs, P., Borsboom, W., & Kemp, R. (2016). PM2.5 in Dutch dwellings due to cooking. *AIVC conference Alexandria*.

Jacobs, P., Cornelissen, H.J.M. ., & Borsboom, W. (2016). Energy efficient measure to reduces PM2.5 emissions due to cooking. *Indoor Air conference.* Gent.

Logue, J., Klepeis, N., Lobscheid, A., & Singer, B. (2014). Pollutant exposures from natural gas cooking burners; a simulation-based assessment for southern California. *Environment Health Perspectives*, 43-50.

Paulin, L. (2014). Home interventions are effective at decreasing indoor nitrogen dioxide concentrations. *Indoor Air*, 416 - 424.

Schiavon, M., Rada, E., Ragazzi, M., Antognoni, S., & Zanoni, S. (2015). Domestic activities and PM generation: a contribution to the understanding of indoor sources of air pollution. *Int. J. Sus. Dev. Plann.*, 347 - 360.

SER. (2007). *Occupational health values*. Retrieved from SER.nl: https://www.ser.nl/nl/themas/arbeidsomstandigheden/grenswaarden.aspx

WHO. (2005). *Air Quality Guidelines - Global update 2005.* WHO.

WHO. (2010). *WHO guidelines for indoor air quality - selected pollutants.* WHO.