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D'INGÉNIERIE ET DE GESTION
DU CANTON DE VAUD
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Green Fire emissions characterization

Project report - AGP # 93525

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1 Introduction

The Hydrantman Swiss Association has mandated the HEIG-VD to characterize the emissions of its "Green Fire" wood pellet stove. The measurements made were inspired by the method defined in ISO 19867-1. Only one measure was conducted.

This measure was completed by an analysis of the burner, during the different combustion phases.

2 Tests

2.1 Installation

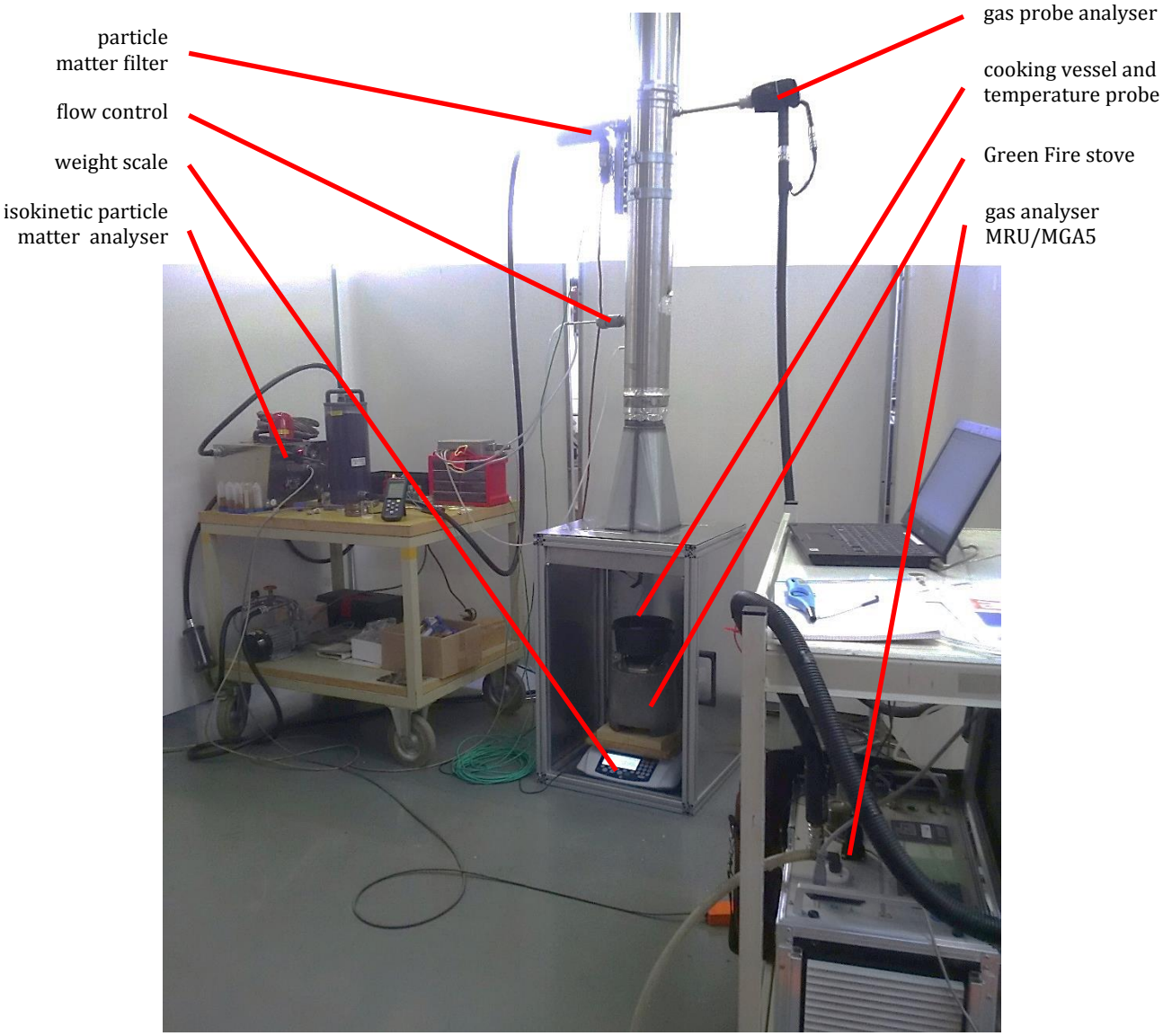


Figure 1: measurement installation inspired by ISO 19867-1

Material used for the measurements:

- gas analyser: MRU/MGA5 calibrated with a calibration gas presented in annexe 4.2;
- wood pellet, analysed in annexe 4.1;
- ITES: automatic isokinetic sampling system from Paul Gothe;
- glass filter for analysis Ahlstrom/Munktell MG 160 (annexe 4.3).

2.2 Green Fire power

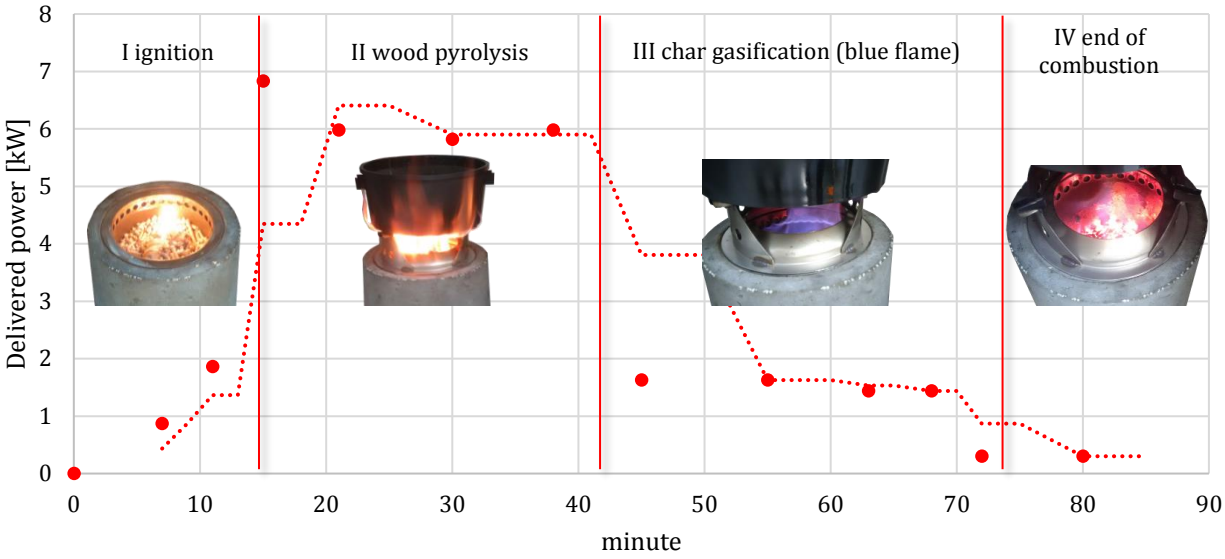


Figure 2: combustion phases and power evolution

Four phases (Figure 2) can be noticed:

- first: ignition of 770 g of wood pellets, lighted on the top of the load;
- second: wood pyrolysis;
- third: no wood left, only char; the flam is blue, the power decreases;
- fourth: burnt out, only ashes left.

During the test, a vessel filled with water (2 litters) was set on the stove. Figure 3 shows water temperature evolution which allows to determine: start (0 min), boiling (15 min) and end time of heating (65 min, defined as 5°C less than the temp. max.).

This graph also shows the water weight loss due to evaporation.

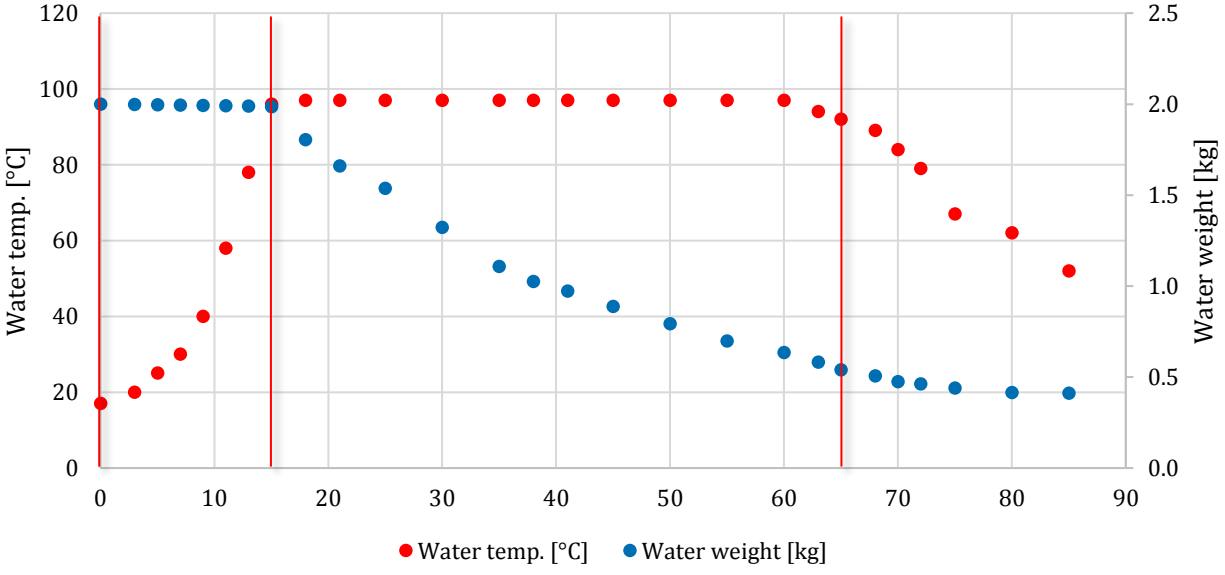


Figure 3: water temperature and weight evolution

According to ISO 19867-1, the following values are determined:

Useful energy delivered (Q_1)	3856	kJ
Cooking power calculation Pc	1.0	kW
Total power delivered by pellet	3.4	kW
Cooking thermal efficiency	30%	

The size of the vessel is not normalized and could have an influence on the efficiency calculated. A larger vessel could increase the amount of heat transferred to the water, and therefore the overall efficiency.

2.3 Green Fire emissions

The aim of the dilution tunnel defined in ISO 19867-1, fig. B1, p68 (annexe 4.4) is to determine the total emissions of a stove. Figure 4 shows that the maximum pollutants (CO and hydrocarbons) are emitted during the second phase and at the end of the combustion for the CO. Converted in weight, the corresponding emissions are:

	total	phase I	phase II	phase III
PM [mg]	813	258	468	87
CO [g]	33	6	20	7
CO_2 [g]	1391	265	737	389

According to the standard, particle mater filter of 2.5 µm should be used. For this test, the filter used collected particles with diameter down to 0.3 µm (see annexe 4.3). This means that the values measured are higher that would be expected with the normalized test.

High CO_2 emission and low CO emission are a sign of a good combustion (Figure 4). In our case, the global ratio between CO and CO_2 is 2.4%

It is very important to avoid: - to put the fire out during the third phase;
- to wait for the combustion to end, and the burner to cool before reloading it.

In both case, if not doing so, the CO and hydrocarbons emissions can dramatically raise to levels dangerous for the users.

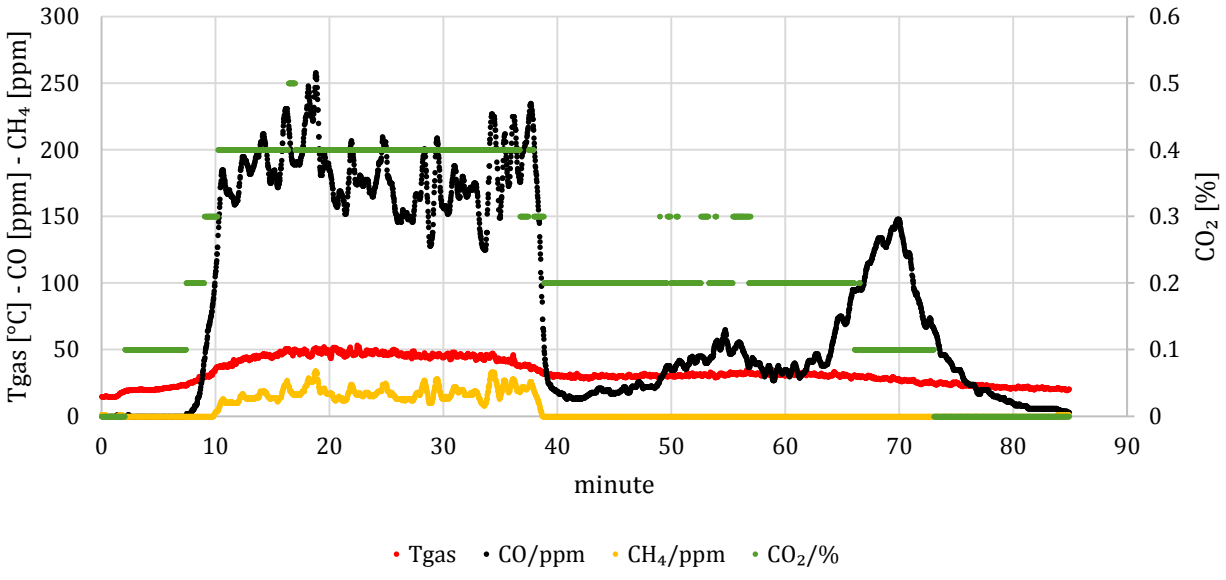
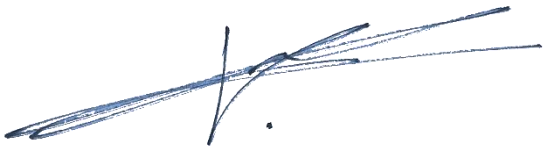


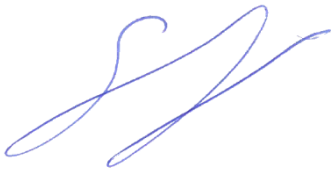
Figure 4: gas emission during combustion test in a diluted tunnel of Ø150 mm at average velocity of 3.5 m·s^{-1}

3 Conclusion

The Green Fire is a top-lit updraft gasifier (TLUD) with a complete combustion (no production of char). There are only ashes left at the end and it doesn't need any control adjustment during the combustion. The total power of this stove is 3.4 kW and the cooking efficiency is 30% with two litres of water.

Yverdon-les-Bains, the 13th October 2019





Julien Ropp

Scientific assistant

Thierry Stäger

Project Engineer

4 Annexe

4.1 Wood pellet characterization

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ANALYSES

Customer	Hydrantman
Wood pellets provider	Tschopp
Realised	IMY
# samples	1

measured value
calculated value

W_R relative moisture [% as received] ISO 18134-3

Test number	1	2	3	μ	*s*	CI *
1/	6.4	6.4	6.4	6.4	*0.0*	**6.4 ± 0 %**

Ash [% on dry] ISO 18122

Test number	1	2	3	μ	*s*	CI *
1/	0.34	0.34	0.35	0.34	*0.01*	**0.3 ± 0 %**

C-H-N-S [% on dry, without ash] ISO 16948

Test number	1	2	3	moyenne	*écart type*	CI *
C	49.84	49.98	49.48	49.77	*0.26*	**49.8 ± 0.3 %**
H	6.16	6.13	6.06	6.12	*0.05*	**6.1 ± 0.1 %**
N	0.00	0.00	0.00	0.00	*0.00*	**0 ± 0 %**
S	0.00	0.00	0.00	0.00	*0.00*	**0 ± 0 %**
O	44.00	43.89	44.46	44.12	*0.31*	**44.1 ± 0.4 %**

Gross calorific value on dry [kJ·kg^{-1}] ISO 18125

Test number	1	2	3	μ	*s*	CI *
1/	19858	19332	19687	19626	*268*	**19630 ± 330**

Gross calorific value as received [kJ·kg^{-1}] ISO 18125

Test number	1	2	3	μ	*s*	CI *
	18583	18091	18423	18365	*251*	**18370 ± 310**

Net calorific value on dry [kJ·kg^{-1}] ISO 18125

Test number	1	2	3	μ	*s*	CI *
	18598	18072	18426	18365	*268*	**18370 ± 330**

Net calorific value as received [kJ·kg^{-1}] ISO 18125

Test number	1	2	3	μ	*s*	CI *
	17256	16763	17095	17038	*251*	**17040 ± 310**

* *confidence interval with α = 5%*

4.2 Calibration gas certification for MRU/MGA5 gas analyser

Carbagas
gaz sur mesure

Air Liquide
creative oxygen

Certificat d'analyse
N° 1996020

N° de commande client : 70321 ROJ

Stabilité garantie jusqu'au : 01.05.2021

N° de mélange :	26697
Classe de réalisation :	Saphir
N° de commande interne :	1293075698
N° client :	10628919
Nom du client :	HEIG-VD-Sport 20
Adresse du client :	Av. des Sports 20, 1400 Yverdon
Code Produit :	G000003014A001

Composant	Qualité	Concentration Demandée (mol.)	Concentration Réalisée	Incertitude (±)
NO	30	400.0 ppm	394.0	2.00%
CH4	45	400.0 ppm	398.1	2.00%
CO	47	0.10 %	0.100	2.00%
CO2	50	12.00 %	11.97	2.00%
N2	57	Reste		

Type d'emballage :	10.0 l. Aluminium
N° de bouteille :	A1EN2LM
Pression finale :	150 Bar
Raccord vanne :	DIN 1 W21.8x1.14" gauche inox
Pression min. d'utilisation :	2 Bar
Temp. Minimum :	-10 °C

Date et lieu de l'analyse : Domdidier, 07.05.2019

Il s'agit d'un certificat réalisé par ordinateur, qui est valable sans signature.
CARBAGAS AG
route d'Avenches 89 1569 Domdidier
Visa : S. Guerra

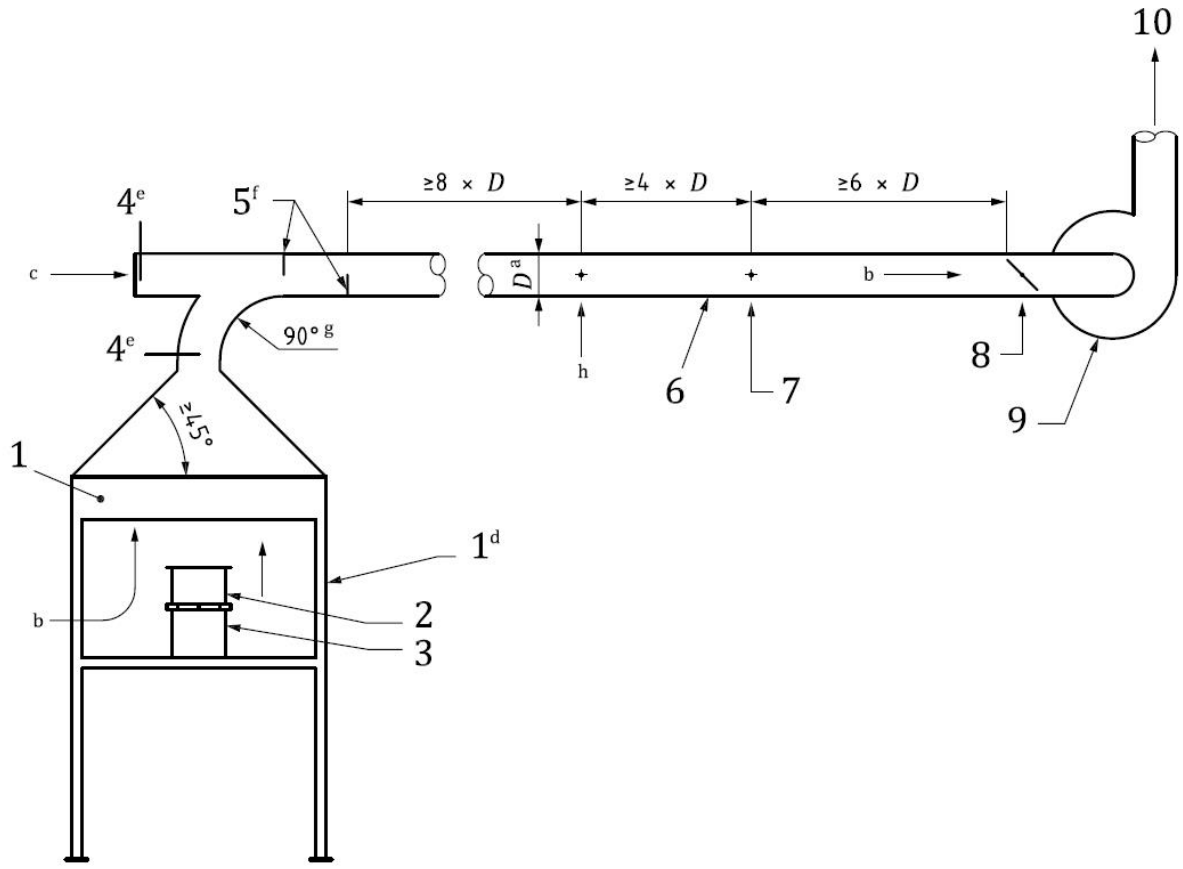


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4.3 Filter for particulate matter analysis

Surface mass [g·m⁻²]	75
Thickness [mm]	0,40
Filtration capacity at 0,3 µm [%]	> 99,998
Temperature max. [°C]	500

4.4 Extract of total-capture dilution tunnel gravimetric method for measurement of PM – ISO 19867-1



Key

1	hood	a	D = 15 cm recommended or 10 cm to 30 cm acceptable.
2	cooking vessel	b	Air flow.
3	cookstove	c	Additional dilution air (optional).
4	gate valve	d	Hood enclosed on three sides.
5	baffles	e	Optional.
6	dilution tunnel	f	See Note.
7	sample ports	g	Elbow.
8	damper or other flow control	h	Velocity measurement location.
9	blower		
10	exhaust		

NOTE Baffles not required if adequate mixing is demonstrated (see text).

Figure B.1 — Hood and dilution tunnel apparatus for collecting emissions from cookstoves without tall chimneys