ABSENCE OF COMBUSTION IN AN ELECTRICALLY HEATED TOBACCO SYSTEM - AN EXPERIMENTAL INVESTIGATION

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Introduction and Objectives

Combustion occurs when biomass such as tobacco is ignited by a heat source in the presence of an oxidant (oxygen in air). Biomass combustion involves, simultaneously or sequentially, the gas-phase combustion of volatiles produced by the thermal decomposition and degasification of the heated biomass and by the gas-solid reaction occurring at the interface or in the bulk of the residual solid. The tobacco in a lit cigarette undergoes smoldering combustion and burns at temperatures in excess of 600 °C [1]. A self-sustaining combustion process is established that consumes the tobacco forming ash and smoke. The latter containing more than 8,000 chemicals [2], a number of which have been classified by Regulatory bodies as harmful and potential harmful constituents (HPHCs) [3].

One approach to reduce the levels of HPHCs associated with cigarette smoke has been to generate an aerosol by heating, rather than burning, tobacco. Some of the earlier tobacco products developed using this approach have been briefly reviewed by Baker [1] and Schorp et al. [4].

A series of experiments were performed to investigate if combustion of a specifically designed tobacco substrate, referred to here as the Electrically Heated Tobacco Product (EHTP), occurs when used in a newly developed and patented electrically heated tobacco system[‡].

[1] R.R. Baker, Progress in Energy and Combustion Science 32, pp.373–385, 2006
[2] A. Rodgman, T.A. Perfetti, The chemical components of tobacco and tobacco smoke. CRC Press, Boca Raton. 2013.
[3] Federal Register Food and Drug Administration, 77, pp. 20034, 2012
[4] M. Schorp, A. Tricker, and R. Dempsey. Regul. Toxicol and Pharmacol. 64, pp. S1-S10, 2012.

Methods

- Temperature data for the tobacco in the EHTP at different distances from the heating blade was measured using a Class 2 K type thermocouple (diameter 0.25 mm). The position of the thermocouple was controlled using a micrometer and the thermocouples were inserted into the EHTP holder through a small drilled hole.
- Aerosol chemistry data for the operation of the EHTP under nitrogen and air in comparison to smoke from a 3R4F cigarette was generated by Labstat® International ULC, Canada. CO_2 and CO analysis was also performed by PMI R&D using a linear smoking machine type Borgwaldt LM20X. Puffs were drawn using the Health Canada Intense (HCI) puffing protocol [puff volume of 55 mL, puff duration of 2 s, puff frequency 30 s]. The laboratory conditions used were 22°C ± 2°C and 60% ± 5% relative humidity. The 3R4F cigarette is a standard reference cigarette used for research.
- Weight loss data for the tobacco material in the EHTP after use were compared to the 3R4F reference cigarette.
- Water and ultimate analysis (C, H, N, O) of the tobacco substrate in the EHTP and in the 3R4F reference cigarette before and after use was performed by Solvais AG, Switzerland.

Results

Temperature Measurements in Tobacco

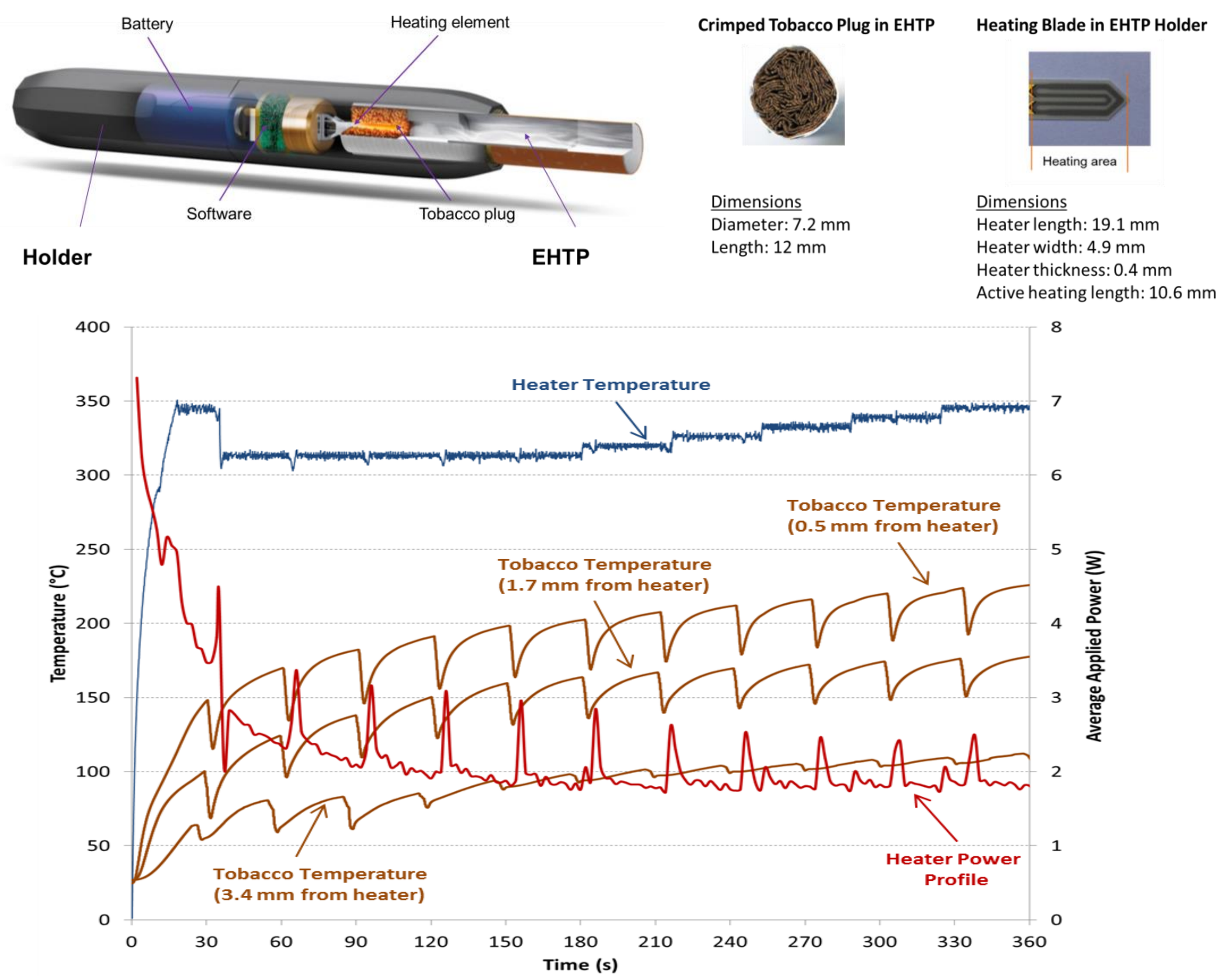

Figure 1. Average temperature and power profile of heating element in EHTP Holder, and average tobacco temperature (measured at three different positions from the heating element) during use. Average of 5 replicates.

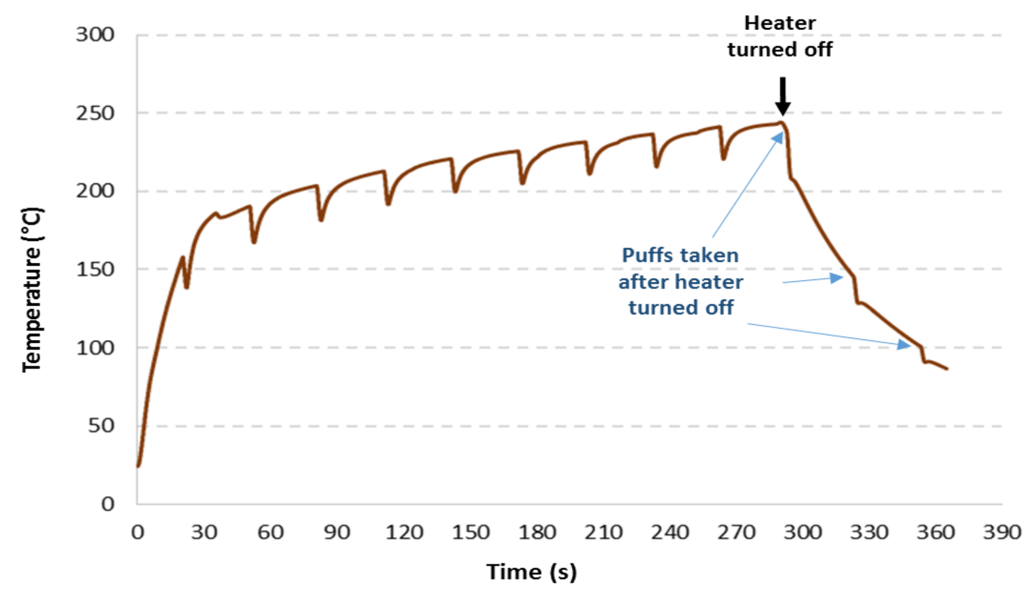

Figure 2. Average tobacco temperature (measured 0.5 mm from the heater) when the heater is turned off after the 10th puff during product use. Average of 3 replicates.

Aerosol Chemistry

Table 1. Levels of aerosol constituents obtained when operating the EHTP under atmospheres of air and nitrogen and compared to smoke from a reference cigarette

		EHTP in Nitrogen		EHTP in Synthetic Air		3R4F Cigarette		Blank	
Constituents	unit	Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.	Average	Std. Dev.
TPM*	mg/unit	54.0	1.5	55.2	1.6	45.8	1.38	0.006	0.015
Water	mg/unit	34.7	4.3	37.3	3.8	16.3	0.94	BDL	BDL
NFDPM†	mg/unit	17.9	3.1	16.5	3.4	27.6	----	BDL	BDL
Glycerin	mg/unit	4.38	0.24	4.39	0.40	2.3	0.09	BDL	BDL
Nicotine	mg/unit	1.38	0.10	1.37	0.09	2.0	0.01	BDL	BDL
CO	mg/unit	<0.53 but ≥0.16	----	0.54	0.16	33.4	0.54	BDL	BDL
NO	µg/unit	18.8	0.9	19.9	1.3	529	54	BDL	BDL
NOx (NO + NO_2)	µg/unit	19.5	1.0	20.8	1.4	581	54	BDL	BDL
Benzo[a]pyrene	ng/unit	0.60	0.09	0.61	0.11	17.3	0.9	BDL	BDL
1_3_butadiene	µg/unit	0.3	0.03	0.3	0.02	98.2	8.4	BDL	BDL
isoprene	µg/unit	2.6	0.4	2.3	0.1	913	79	BDL	BDL
acrylonitrile	µg/unit	0.2	0.02	0.2	0.02	26.1	4.3	BDL	BDL
benzene	µg/unit	0.5	0.07	0.6	0.06	90.7	12.5	BDL	BDL
toluene	µg/unit	1.9	0.3	2.0	0.2	158	24	NQ	NQ
pyridine	µg/unit	7.4	0.6	7.8	1.4	35.1	2.4	0.2	0.1
quinoline	µg/unit	<0.011 but ≥0.003	----	<0.011 but ≥0.003	----	0.49	0.05	BDL	BDL
styrene	µg/unit	0.8	0.3	0.7	0.2	18.2	1	0.1	0.01
Hydroquinone	µg/unit	7.4	0.7	7.0	0.2	92.5	0.6	BDL	BDL
Resorcinol	µg/unit	<0.055 but ≥0.016	----	<0.055 but ≥0.016	----	2.0	0.0	BDL	BDL
Catechol	µg/unit	14.7	1.1	14.3	0.5	84.2	1.2	BDL	BDL
Phenol	µg/unit	1.3	0.1	1.4	0.1	12.8	0.8	NQ	NQ
p-cresol	µg/unit	0.07	0.01	0.07	0.01	8.14	0.3	BDL	BDL
m-cresol	µg/unit	0.03	0.01	0.03	0.01	3.2	0.2	BDL	BDL
o-cresol	µg/unit	0.07	0.01	0.06	0.01	3.9	0.2	BDL	BDL
Formaldehyde	µg/unit	6.1	1.2	9.1	1.4	87	3	1.7	0.2
Acetaldehyde	µg/unit	211	16	230	21	1656	26	NQ	NQ
Acetone	µg/unit	31.0	2.3	35.9	4.3	708	18	NQ	NQ
Acrolein	µg/unit	8.4	1.3	10.7	1.7	162	3	BDL	BDL
Propionaldehyde	µg/unit	13.7	1.1	14.9	1.9	125	4	BDL	BDL
Crotonaldehyde	µg/unit	<3.29 but ≥0.988	----	<3.29 but ≥0.988	----	54	1	BDL	BDL
Methyl Ethyl Ketone	µg/unit	7.0	0.6	7.6	0.8	197	6	BDL	BDL
Butyraldehyde	µg/unit	22.5	1.9	23.1	1.9	91	3	NQ	NQ
1_aminonaphthalene	ng/unit	0.07	0.01	0.07	0.01	22.4	0.42	NQ	NQ
2_aminonaphthalene	ng/unit	0.04	0.01	0.04	0.01	14.1	1.99	0.02	0.00
3_aminobiphenyl	ng/unit	0.01	0.00	0.01	0.00	4.5	0.16	NQ	NQ
4_aminobiphenyl	ng/unit	0.02	0.00	0.02	0.00	3.1	0.03	0.01	0.01

Labstat report numbers NS201 for EHTP and NS190 and NS179 for 3R4F Cigarette. Mainstream aerosol and smoke levels. *Total Particulate Matter. Health Canada Intense regime. ISO 4387 method "Determination of total and †nicotine-free dry particulate matter using a routine analytical smoking machine" was used to determine TPM, nicotine, water and NFDPM values. BDL: Below the Limit of Detection, NQ: Below the Limit of Quantification- above LOD but below LOQ. LOQ for quinoline, resorcinol, and crotonaldehyde = 0.011, 0.055 and 3.29 µg/unit, respectively. Unit = EHTP or 3R4F, respectively.

Table 2. CO and CO_2 Aerosol Levels

		EHTP		3R4F cigarette	
Constituents	unit	Average	Std. Dev	Average	Std. Dev
CO	mg/unit	0.54	1.5	31.4	1.5
CO_2	mg/unit	6.1	0.6	86.2	2.9

Yields are based on 12 puffs drawn using the Health Canada Intense (HCI) protocol. The number of replicates performed were 19 and 8, respectively, for the EHTP and 3R4F reference cigarette. Unit = EHTP or 3R4F, respectively.

Figure 3. Photograph of a EHTP and *3R4F reference cigarette

Table 3. Weight Loss and Ultimate Analysis Data

	EHTP - Tobacco Substrate					Cigarette - Tobacco Cut Filler				
	C	H	N	Water	Weight	C	H	N	Water	Weight
	[%w/w]	[%w/w]	[%w/w]	[%w/w]	[mg]	[%w/w]	[%w/w]	[%w/w]	[%w/w]	[mg]
Before	38.4 ± 0.3	6.1 ± 0.2	2.0	14.3 ± 0.5	324 ± 15	38.2 ± 0.8	5.9 ± 0.2	1.8 ± 0.3	13.2 ± 0.4	817 ± 20
After	46.6 ± 1.2	5.4 ± 0.3	2.6 ± 0.2	2.8 ± 0.4	212 ± 12	7.6 ± 0.9	0.8 ± 0.1	1.0 ± 0.2	1.9 ± 0.2	381 ± 14

Weight data: average and standard deviation values shown the number of replicates performed were 20 and 8, respectively, for the EHTP tobacco substrate and 3R4F reference cigarette tobacco filter.
Ultimate analysis: average and standard deviation values shown. 3 replicates were performed.

Discussion

Two indicators may be used to unambiguously detect biomass or tobacco combustion: (i) the presence of relevant quantities of nitrogen oxides in the gaseous products, not formed from the decomposition of nitrates present in the original biomass/tobacco; (ii) clear evidence of a self-sustaining exothermic process. The two conditions should be simultaneously verified.

Contrary to the increase in the temperature of tobacco that occurs when air is drawn through a lit cigarette [1], there is a significant drop in the temperature of the tobacco substrate in the EHTP when a puff is taken (Figure 1). The highest average temperature of the tobacco in the EHTS measured in close proximity to the heating blade is well below the temperature required for combustion of the tobacco substrate to occur[5]. Torrefaction and a darkening of the tobacco substrate occurs close to the heating element. Operation of the EHTP in an atmosphere of nitrogen (where combustion cannot occur) yields an aerosol that is substantially equivalent to that produced in air. Evidence for the absence of a self-sustaining exothermic reaction is also provided by the drop in temperature of the tobacco material when the heater is turned off (Figure 2).

While CO, CO_2, and H_2O are products of biomass combustion processes their presence in an aerosol are not unambiguous chemical markers that a combustion process has occurred. These chemical species can be generated from non-combustion, lower temperature thermal processes such as drying and torrefaction of biomass [6-8].

Further confirmation of the absence of combustion phenomena in the EHTP comes from the low level of NO_x in the aerosol, that is unaffected by the presence or absence of air. The presence of NO_x can be attributed to the decomposition of nitrates in the tobacco substrate [9].

The low levels of volatile organic compounds in the EHTP aerosol, the presence of unconverted fixed carbon in the EHTP after heating, and the absence of ash formation provide additional evidence of the lower temperature processes occurring in the EHTP compared to tobacco burning in a lit cigarette.

[5] Barontini, F., Tugnoli, A., Cozzani, V., Tetteh, J., Jarriault, M. Zinovik, I. Ind. Eng. Chem. Res. 52 (42),14984-14997, 2013
[6] Basu P., Biomass Gasification and Pyrolysis - Practical Design and Theory, Academic Press, 2010
[7] Baker, R. The formation of the oxides of carbon by the pyrolysis of tobacco, Beit. zur Tabak., 8, 1, 1976
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[9] Im H., Rasouli F., Hajaligol M., Formation of Nitric Oxide during Tobacco Oxidation, Journal of Agricultural and Food Chemistry, 51, 7366-7372, 2003

Conclusions

The results of the experiments conducted confirm the absence of combustion occurring in the EHTP when used as intended. Due to the controlled operating temperature of the heater, the aerosol generated is formed principally by the evaporation of water, nicotine and glycerin from the tobacco substrate. The EHTP aerosol also contains substantially lower levels of harmful and potentially harmful compounds compared to smoke generated from a lit cigarette.

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ABBREVIATIONS: ‡ The Electrically Heated Tobacco System (EHTS) was developed by Philip Morris International. It is also referred to as the Tobacco Heating System 2.2 (THS 2.2).

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