

**COMPARISON OF NICOTINE EMISSIONS RATE, “NICOTINE FLUX”, FROM HEATED, ELECTRONIC, AND COMBUSTIBLE TOBACCO PRODUCTS: DATA, TRENDS, AND RECOMMENDATIONS FOR REGULATION**

Mario El Hourani<sup>1,3</sup>, ME; Alan Shihadeh<sup>1,3</sup>, ScD\*; Soha Talih<sup>1,3</sup>, PhD; Thomas Eissenberg<sup>2,3</sup>, PhD; and the CSTP Nicotine Flux Work Group

<sup>1</sup>Mechanical Engineering Department, Maroun Semaan Faculty of Engineering and Architecture, American University of Beirut, Bliss Street, PO. Box 11-0236, Beirut, Lebanon

<sup>2</sup>Department of Psychology, Virginia Commonwealth University, 821 West Franklin Street, Richmond, Virginia 23284, United States

<sup>3</sup>Center for the Study of Tobacco Products, Virginia Commonwealth University, 821 West Franklin Street, Richmond, Virginia 23284, United States

\* Corresponding Author: Alan Shihadeh

Tel: + 961 1 344444

Email address: as20@aub.edu.lb

Address: American University of Beirut  
PO Box 11-0236 Beirut, Lebanon

## SUPPLEMENTAL MATERIAL

**Table S1.** Summary of the nicotine yield and flux of various tobacco products and the corresponding puffing topography parameters.

\* Average puff number under ISO smoking regime was used.

Tobacco Product	Brand	Puff Number	Puff duration (s)	Nicotine Yield (mg/unit)	Nicotine Flux ( $\mu\text{g/s}$ )	Reference	Year of Publication
Cigarettes	Maintained nicotine cigarette	15	2	2.7	90.0	[1]	1988
	Middle tar cigarette	15	2	2.9	96.7		
	Low tar cigarette	14	2.5	1.8	51.4		
	Regular-yield brands (9-15 mg ISO tar)	11.5	1.4	2	124.2	[2]	2006
	Matinee extra mild (4 mg ISO tar)	13.4	1.6	1.5	70.0		
	Own brand (female smokers)	13.5	1.33	1.92	106.9	[3]	2007
	Own brand (male smokers)	12	1.48	2.2	123.9		
	Kent (non-menthol cigarette)	14.4	1.17	0.9	53.4	[4]	2017
	Benson & Hedges Light (menthol cigarette)	15.1	1.23	1.05	56.5		
	Marlboro red	12.2	1.68	2.54	123.9	[5]	2020
	Lucky Strike	10.7	1.8	1.3	67.5	[6]	2018
	Lucky Strike Menthol	10	2	1.3	65.0		
	Lucky Strike	16.6	1.6	1.5	56.5	[7]	2020
	Low-yield cigarettes ( $\leq 0.8$ mg of nicotine/cigarette)	12.7	1.5	1.7	89.2	[8]	2000
	Medium-yield cigarettes (0.9–1.2 mg of nicotine/cigarette)	12.1	1.5	2.39	131.7		
	2R4F	9.5	2	0.829	43.6	[9]	2014
	1R6F	8.0	2	0.73	45.6	[10]	2018
	1R6F	8.4	2	2.34	139.3		
	3R4F	9.0	2	0.74	41.1		
	3R4F	10.7	2	2.38	111.2		
	Regular-yield brands (9-15 mg ISO tar)	9	2	1.1	61.1	[2]	2006
		12.1	2	2.4	99.2		
	Low-yield cigarettes ( $\leq 0.8$ mg of nicotine/cigarette)	9	2	0.7	38.9	[8]	2000
Medium-yield cigarettes (0.9–1.2 mg of nicotine/cigarette)	9	2	1.11	61.7			
Marlboro Ultra Smooth	7.2	2	0.42	29.2	[11]	2006	
	6.9	2	1.09	79.0			
Marlboro Regular	12	2	1.99	82.9	[12]	2018	
VLNC	VLN King	9*	2	0.03	1.7	[13]	2019
Roll Your Own Cigarettes	Average of 13 brands	12.4	2	1.3	52.4	[14]	1985
	Average of 11 brands	9.42	2	1.90	100.8	[15]	2014
	Average of 517 cigarettes made by 26 regular users	12.3	2	1.30	52.8	[16]	1998
Tobacco Heating Products	glo with Bright Tobacco Kent Neostiks	11.6	1.8	0.3	14.4	[6]	2018
	glo with mentholated Intensely Fresh Kent Neostiks	10	1.8	0.3	16.7		
	iQOS with Essence tobacco HeatStick	10.55	1.8	0.9	47.4		
	glo with Bright Tobacco Kent Neostiks	15.4	1.6	0.34	13.8	[7]	2020
	iQOS with Essence tobacco HeatStick	15	1.4	0.98	46.7		

	carbon-based Eclipse	25	2	2.36	47.2	[17]	2019
	Glo with Bright Tobacco Kent Neostiks	8	2	0.462	28.9	[18]	2018
	Glo with mentholated Intensely Fresh Kent Neostiks	8	2	0.365	22.8		
	Unspecified Heat not Burn Device	12	2	1.4	58.3	[12]	2018
	Unspecified Heat not Burn Device with Mentholated flavor	12	2	1.38	57.5		
	Unspecified Heat not Burn Device	12	4	1.41	29.4		
	Unspecified Heat not Burn Device with Mentholated flavor	12	4	1.43	29.8		
	Carbon-based Eclipse	12	2	0.14	5.8	[17]	2019
Carbon-based Eclipse	18.3	2	0.56	15.3			
<b>Electronic Nicotine Delivery Systems</b>	<i>Volish, eGo-3 (nicotine concentration 18 mg/ml; liquid composition: Propylene glycol, nicotine, vanillin, linalool, flavorings)</i>	15	2.8	1.06	25.2	[19]	2015
	<i>Volish, eGo-3 (nicotine concentration 18 mg/ml; liquid composition: Propylene glycol, glycerin, nicotine, ethanol, flavorings)</i>	15	2.8	1.15	27.4		
	<i>Volish, eGo-3 (nicotine concentration 24 mg/ml; liquid composition: Glycerin, nicotine, propylene glycol, linalool, vanillin, flavorings)</i>	15	2.8	1.05	25.0		
	<i>Volish, eGo-3 (nicotine concentration 22 mg/ml; liquid composition: Glycerin, propylene glycol, nicotine, flavorings)</i>	15	2.8	1.43	34.0		
	<i>Volish, eGo-3 (nicotine concentration 12 mg/ml; liquid composition: Glycerin, propylene glycol, nicotine, flavorings)</i>	15	2.8	0.88	21.0		
	<i>Volish, eGo-3 (nicotine concentration 16 mg/ml; liquid composition: Glycerin, propylene glycol, nicotine, flavorings)</i>	15	2.8	1.02	24.3		
	<i>Volish, eGo-3 (nicotine concentration 25 mg/ml; liquid composition: Glycerin, propylene glycol, nicotine, ethanol, flavorings)</i>	15	2.8	1.36	32.4		
	<i>Volish, eGo-3 (nicotine concentration 28 mg/ml; liquid composition: Glycerin, propylene glycol, nicotine, ethanol, malic acid, flavorings)</i>	15	2.8	1.49	35.5		
	<i>Volish, eGo-3 (nicotine concentration 11 mg/ml; liquid composition: Glycerin, nicotine, menthol, vanillin, aromatic oils, vanilla)</i>	15	2.8	0.77	18.3		
	<i>Blu Cigs (Tobacco-flavored cartomizers with nicotine concentration of 16 mg/ml)</i>	33	2.75	1.2	13.2	[20]	2015
	<i>V2 Cigs (Tobacco-flavored cartomizers with nicotine concentration of 18 mg/ml)</i>	31	2.54	1.4	17.8		
	<i>Lab Assembled ECIG 6 W (E-liquid concentration range 6-18 mg/ml)</i>	57	4.6	3.5	13.3	[21]	2018
	<i>Lab Assembled ECIG 10 W (E-liquid concentration range 6-18 mg/ml)</i>	46	3.8	4.2	24.0		
	<i>KangerTech Mini ProTank with own flavor (E-liquid nicotine concentration range 1.6-16.7 mg/ml and PG/VG ratio range of 69/31-5/95)</i>	106	4.3	3.4	7.5	[22]	2018
	<i>KangerTech Mini ProTank with strawberry flavored e-liquid (E-liquid nicotine concentration 19.9 mg/ml and PG/VG ratio of 40/60)</i>	73	3.2	5.4	23.1		
	<i>KangerTech Mini ProTank with Tobacco flavored e-liquid (E-liquid nicotine concentration 19.3 mg/ml and PG/VG ratio of 44/56)</i>	69	2.8	4.1	21.2		
	<i>Vype with 'Twilight Tobacco' flavored e-liquid (E-liquid nicotine concentration 5 mg/ml and PG/VG ratio of 40/60)</i>	61.1	1.45	0.75	8.5	[7]	2020
	Vapour 2 cigs (E-liquid nicotine concentration 20 mg/ml and PG/VG ratio of 50/50)	12	2	0.46	19.2	[12]	2018
		12	4	0.86	17.9		
	eGo style, Epsilon (E-liquid nicotine concentration 20 mg/ml and PG/VG ratio of 50/50)	12	2	0.51	21.3		
	12	4	1.73	36.0			

	EVIC VTC Mini battery with Nautilus Mini atomizer (E-liquid nicotine concentration 20 mg/ml and PG/VG ratio of 50/50)	12	2	0.82	34.2			
		12	4	1.84	38.3			
<b>Electronic Nicotine Delivery Systems</b>	Vype Disposable Regular	1	3	0.04	13.3	[17]	2019	
		1	5	0.06	12.0			
	Intellicig XL	1	3	0.03	10.0			
		1	5	0.07	14.0			
	V4L CoolCart cartomizers (8.53 mg/ml nicotine concentration)		2	15	0.11	3.7	[23]	2015
			4	15	0.30	5.0		
			4	15	0.29	4.8		
			8	15	0.72	6.0		
			8	15	0.68	5.7		
			2	15	0.64	21.3		
			4	15	1.18	19.7		
			4	15	1.50	25.0		
			8	15	3.23	26.9		
			8	15	3.09	25.8		
	V4L CoolCart cartomizers (15.73 mg/ml nicotine concentration)		4	15	0.48	8.0	[23]	2015
			8	15	4.7	39.2		
	JUUL US - Tobacco flavor ( 65 mg/ml nicotine concentration)	15	4	1.3	21.7	[24]	2020	
	JUUL UK - Tobacco flavor (19 mg/ml nicotine concentration)	15	4	0.4	6.7			
	JUUL US - Tobacco flavor ( 69 mg/ml nicotine concentration)	15	4	2.07	34.5	[25]	2019	
	JUUL US - Tobacco flavor	1	2.5	0.157	62.8	[26]	2019	
JUUL US – Crème brulee flavor	1	2.5	0.170	68.0				
JUUL US – Fruit punch flavor	1	2.5	0.154	61.6				
JUUL US - Mint flavor	1	2.5	0.188	75.2				
JUUL US – Tobacco flavor ( 69.8 mg/ml nicotine concentration)	15	4	1.67	27.8				
Ezzy Oval – Berry Cool flavor (53.8 mg/m nicotine concentration)	15	4	4.07	67.8	[27]	2021		
Ezzy Oval – Mango Lychee flavor (75.4 mg/m nicotine concentration)	15	4	5.44	90.7				
Hyde – Cherry lemonade flavor (86.9 mg/m nicotine concentration)	15	4	3.15	52.5				
Puff Bar – Banana ice flavor (83.4 mg/m nicotine concentration)	15	4	6.72	112.0				
SEA – Mint flavor (54.3 mg/m nicotine concentration)	15	4	1.67	27.8				
<b>Waterpipes</b>	-	77.7	3.6	1.6	5.8	[28]	2016	
	-	290	2.9	5	5.9	[29]	2018	
	-	220	2.8	4.8	7.8	[30]	2010	
	-	105	2.6	5.4	19.8	[31]	2019	
	-	171	2.6	2.96	6.7	[32]	2005	
	-	100	3.0	2.25	7.5	[33]	2003	
	-	171	2.6	6.06	13.6	[34]	2008	
	-	171	2.6	7.75	17.4	[35]	2011	
<b>Cigarillos</b>	<i>Black &amp; Mild</i>	23.1	2.8	2.3	35.6	[36]	2018	
	<i>Winchester</i>	9.8	2	1.8	91.8	[36]	2018	
<b>Small Cigars</b>	Average values of 8 commercially available small cigars in the US	16.6	2	1.24	37.3	[10]	2018	
		16.5	2	3.49	105.8			

	Little cigars with cigar wrapper (average of 5 brands)	8.5	2	1.60	94.1	[37]	1976
	Little cigars with paper wrapper (average of 5 brands)	9.4	2	1.60	85.1		
	Average of 10 brands	14.4	2	2.1	72.9	[14]	1985
<b>Large Cigars</b>	Average of 5 brands	70.3	1.5	2.4	22.8	[37]	1976
	Average of 6 brands	108	1.5	1.9	11.7	[14]	1985
<b>Kretek</b>	Sampoerna	12.6	2	0.74	29.4	[9]	2014
	Garam	17.3	2	1.78	51.4		
	Kretek-R	14.4	2	1.72	59.7		
<b>Bidi</b>	Average of 21 brands	21	2	2.70	64.3	[38]	2003
	Average of 24 brands	17	2	1.86	54.7	[39]	1998
<b>Nicotine Patch</b>	NiQuitin Clear 7 mg	-	24 hrs	7	0.08	[40]	2019
	NiQuitin Clear 14 mg		24 hrs	14	0.16		
	NiQuitin Clear 21 mg		24 hrs	21	0.24		
<b>Nicotine Gum</b>	Zonnic 2mg	-	30 min	2	1.11	[41, 42]	2018/2020

## REFERENCES

- [1] Armitage AK, Alexander J, Hopkins R, *et al.* Evaluation of a low to middle tar/medium nicotine cigarette designed to maintain nicotine delivery to the smoker. *Psychopharmacology* 1988;96(4):447-453.
- [2] Hammond D, Fong GT, Cummings KM, *et al.* Cigarette yields and human exposure: a comparison of alternative testing regimens. *Cancer epidemiology, biomarkers & prevention : a publication of the American Association for Cancer Research, cosponsored by the American Society of Preventive Oncology* 2006;15(8):1495-1501.
- [3] Melikian A, Djordjevic M, Hosey J, *et al.* Gender Differences Relative to Smoking Behavior and Emissions of Toxins From Mainstream Cigarette Smoke. *Nicotine & tobacco research : official journal of the Society for Research on Nicotine and Tobacco* 2007;9:377-387.
- [4] Watson CV, Richter P, de Castro BR, *et al.* Smoking Behavior and Exposure: Results of a Menthol Cigarette Cross-over Study. *American journal of health behavior* 2017;41(3):309-319.
- [5] Pauwels CGGM, Boots AW, Visser WF, *et al.* Characteristic Human Individual Puffing Profiles Can Generate More TNCO than ISO and Health Canada Regimes on Smoking Machine When the Same Brand Is Smoked. *Int J Environ Res Public Health* 2020;17(9):3225.
- [6] Gee J, Prasad K, Slayford S, *et al.* Assessment of tobacco heating product THP1.0. Part 8: Study to determine puffing topography, mouth level exposure and consumption among Japanese users. *Regulatory Toxicology and Pharmacology* 2018;93:84-91.
- [7] Jones J, Slayford S, Gray A, *et al.* A cross-category puffing topography, mouth level exposure and consumption study among Italian users of tobacco and nicotine products. *Scientific Reports* 2020;10(1):12.
- [8] Djordjevic MV, Stellman SD, Zang E. Doses of Nicotine and Lung Carcinogens Delivered to Cigarette Smokers. *JNCI: Journal of the National Cancer Institute* 2000;92(2):106-111.
- [9] Piadé JJ, Roemer E, Dempsey R, *et al.* Toxicological assessment of kretek cigarettes: Part 2: Kretek and American-blended cigarettes, smoke chemistry and in vitro toxicity. *Regulatory Toxicology and Pharmacology* 2014;70:S15-S25.
- [10] Goel R, Trushin N, Reilly SM, *et al.* A Survey of Nicotine Yields in Small Cigar Smoke: Influence of Cigar Design and Smoking Regimens. *Nicotine & tobacco research : official journal of the Society for Research on Nicotine and Tobacco* 2018;20(10):1250-1257.
- [11] Laugesen M, Fowles J. Marlboro UltraSmooth: a potentially reduced exposure cigarette? *Tobacco control* 2006;15(6):430-435.
- [12] Farsalinos KE, Yannovits N, Sarri T, *et al.* Nicotine Delivery to the Aerosol of a Heat-Not-Burn Tobacco Product: Comparison With a Tobacco Cigarette and E-Cigarettes. *Nicotine & tobacco research : official journal of the Society for Research on Nicotine and Tobacco* 2018;20(8):1004-1009.
- [13] Carmines E, Gillman I. Comparison of the Yield of Very Low Nicotine Content Cigarettes to the Top 100 United States Brand Styles. *Beiträge zur Tabakforschung International/Contributions to Tobacco Research* 2019;28:253-266.
- [14] Rickert WS, Robinson JC, Bray DF, *et al.* Characterization of tobacco products: A comparative study of the tar, nicotine, and carbon monoxide yields of cigars, manufactured cigarettes, and cigarettes made from fine-cut tobacco. *Preventive Medicine* 1985;14(2):226-233.
- [15] Marcilla A, Beltran MI, Gómez-Siurana A, *et al.* Comparison between the mainstream smoke of eleven RYO tobacco brands and the reference tobacco 3R4F. *Toxicol Rep* 2014;1:122-136.
- [16] Darrall KG, Figgins JA. Roll-your-own smoke yields: theoretical and practical aspects. *Tobacco control* 1998;7(2):168-175.

- [17] McAdam K, Davis P, Ashmore L, *et al.* Influence of machine-based puffing parameters on aerosol and smoke emissions from next generation nicotine inhalation products. *Regulatory toxicology and pharmacology : RTP* 2019;101:156-165.
- [18] Forster M, Fiebelkorn S, Yurteri C, *et al.* Assessment of novel tobacco heating product THP1.0. Part 3: Comprehensive chemical characterisation of harmful and potentially harmful aerosol emissions. *Regulatory toxicology and pharmacology : RTP* 2018;93:14-33.
- [19] Kosmider L, Sobczak A, Szołtysek-Bołdys I, *et al.* Assessment of nicotine concentration in electronic nicotine delivery system (ENDS) liquids and precision of dosing to aerosol. *Przegląd lekarski* 2015;72(10):500-504.
- [20] Behar RZ, Hua M, Talbot P. Puffing topography and nicotine intake of electronic cigarette users. *PLoS One* 2015;10(2):e0117222.
- [21] Farsalinos K, Poulas K, Voudris V. Changes in Puffing Topography and Nicotine Consumption Depending on the Power Setting of Electronic Cigarettes. *Nicotine & Tobacco Research* 2018;20(8):993-997.
- [22] St Helen G, Shahid M, Chu S, *et al.* Impact of e-liquid flavors on e-cigarette vaping behavior. *Drug and alcohol dependence* 2018;189:42-48.
- [23] Talih S, Balhas Z, Eissenberg T, *et al.* Effects of user puff topography, device voltage, and liquid nicotine concentration on electronic cigarette nicotine yield: measurements and model predictions. *Nicotine & tobacco research : official journal of the Society for Research on Nicotine and Tobacco* 2015;17(2):150-157.
- [24] Talih S, Salman R, El-Hage R, *et al.* A comparison of the electrical characteristics, liquid composition, and toxicant emissions of JUUL USA and JUUL UK e-cigarettes. *Sci Rep* 2020;10(1):7322.
- [25] Talih S, Salman R, El-Hage R, *et al.* Characteristics and toxicant emissions of JUUL electronic cigarettes. *Tobacco control* 2019;28(6):678.
- [26] Reilly SM, Bitzer ZT, Goel R, *et al.* Free Radical, Carbonyl, and Nicotine Levels Produced by Juul Electronic Cigarettes. *Nicotine & tobacco research : official journal of the Society for Research on Nicotine and Tobacco* 2019;21(9):1274-1278.
- [27] Soha Talih RS, Eric Soule, Racehl El Hage, Ebrahim Karam, Nareg Karaoghlanian, Ahmad El-Hellani, Najat Saliba, Alan Shihadeh. Electrical features, liquid composition and toxicant emissions from 'pod-mod'-like disposable electronic cigarettes (Under Review). 2021.
- [28] Ramôa CP, Shihadeh A, Salman R, *et al.* Group Waterpipe Tobacco Smoking Increases Smoke Toxicant Concentration. *Nicotine & tobacco research : official journal of the Society for Research on Nicotine and Tobacco* 2016;18(5):770-776.
- [29] Jawad M, Eissenberg T, Salman R, *et al.* Toxicant inhalation among singleton waterpipe tobacco users in natural settings. *Tob Control* 2019;28(2):181-188.
- [30] Katurji M, Daher N, Sheheitli H, *et al.* Direct measurement of toxicants inhaled by water pipe users in the natural environment using a real-time in situ sampling technique. *Inhalation toxicology* 2010;22(13):1101-1109.
- [31] El Hourani M, Talih S, Salman R, *et al.* Comparison of CO, PAH, Nicotine, and Aldehyde Emissions in Waterpipe Tobacco Smoke Generated Using Electrical and Charcoal Heating Methods. *Chemical research in toxicology* 2019;32(6):1235-1240.
- [32] Shihadeh A, Saleh R. Polycyclic aromatic hydrocarbons, carbon monoxide, "tar", and nicotine in the mainstream smoke aerosol of the narghile water pipe. *Food and chemical toxicology : an international journal published for the British Industrial Biological Research Association* 2005;43(5):655-661.
- [33] Shihadeh A. Investigation of mainstream smoke aerosol of the argileh water pipe. *Food and chemical toxicology : an international journal published for the British Industrial Biological Research Association* 2003;41(1):143-152.

- [34] Saleh R, Shihadeh A. Elevated toxicant yields with narghile waterpipes smoked using a plastic hose. *Food and chemical toxicology : an international journal published for the British Industrial Biological Research Association* 2008;46(5):1461-1466.
- [35] Schubert J, Hahn J, Dettbarn G, *et al.* Mainstream smoke of the waterpipe: does this environmental matrix reveal as significant source of toxic compounds? *Toxicology letters* 2011;205(3):279-284.
- [36] Pickworth WB, Rosenberry ZR, Yi D, *et al.* Cigarillo and Little Cigar Mainstream Smoke Constituents from Replicated Human Smoking. *Chemical research in toxicology* 2018;31(4):251-258.
- [37] Irwin S, Klaus DB, Dietrich H, *et al.* On the Chemistry of Cigar Smoke: Comparisons between Experimental Little and Large Cigars. *Beiträge zur Tabakforschung International/Contributions to Tobacco Research* 1976;8(6):367-377.
- [38] Watson CH, Polzin GM, Calafat AM, *et al.* Determination of tar, nicotine, and carbon monoxide yields in the smoke of bidi cigarettes. *Nicotine & Tobacco Research* 2003;5(5):747-753.
- [39] Pakhale SS, Maru GB. Distribution of major and minor alkaloids in tobacco, mainstream and sidestream smoke of popular Indian smoking products. *Food and chemical toxicology : an international journal published for the British Industrial Biological Research Association* 1998;36(12):1131-1138.
- [40] Omega Pharma Ltd. NiQuitin Pre-Quit Clear 21mg Patch. *Electronic Medicines Compendium* 2019; <https://www.medicines.org.uk/emc/product/2938/smpc> (accessed 3 December 2021).
- [41] Shiffman S, Scholl SM, Mao J, *et al.* Using Nicotine Gum to Assist Nondaily Smokers in Quitting: A Randomized Clinical Trial. *Nicotine Tob Res* 2020;22(3):390-397.
- [42] Lande RG. What is the role of nicotine gum in the treatment of nicotine addiction? *Medscape* 2018; <https://www.medscape.com/answers/287555-158527/what-is-the-role-of-nicotine-gum-in-the-treatment-of-nicotine-addiction> (accessed 3 December 2021).