Chemical Dissection of $PM_{2.5}$ in Cigarette Smoke: Main and Sidestream Emission Factors and Compositions

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Table S1 Parameters of cigarettes selected for experiment

Serial number	Cigarette brand and model	Prices ¥/pc	Weight g/pc	Weight of Filter Tip g/pc	Weight of burnable part g/pc	Length /mm	Circumference /mm	Tar mg/pc	Nicotine mg/pc	CO mg/pc
1	JS1	2.5	0.86	0.17	0.69	84	24.5	10	1	10
2	JS2	3.5	0.90	0.32	0.58	84	24.5	10	1	10
3	JS3	10	0.81	0.25	0.57	74	24.5	10	1	10
4	JS4	6	0.67	0.25	0.42	88	24.5	10	1	9
5	JS5	5	0.55	0.13	0.42	97	16	8	0.7	7
6	JS6	9.9	0.93	0.25	0.68	84	24.51	10	1	10
7	FR	2.7	0.80	0.28	0.51	75	24.5	9	0.9	9
8	LQ	1.6	0.85	0.20	0.65	84	24.5	11	1	11
9	YX	2.3	0.91	0.17	0.74	84	24.5	11	1	11
10	HHL	3	0.85	0.29	0.57	88	20	10	1	11
11	ZH	4.5	0.90	0.18	0.72	84	24.5	11	1	11

[1] with flavor pods in the filter tip

Table S2 Emission factors of $PM_{2.5}$ from main and sidestream smoke of cigarettes in this study and EFs of particles in other researches

Classification of combustibles	**Combustible**	**Combustion state**	**PM emissions from combustion**	**EF** (μg/g)	**Source of the data**
Cigarette	Inner layer of tobacco leaves is being smothered by the burning tip	Alternating between Smoldering and bright combustion within the cigarette's tail end burns the inner layer of tobacco leaves	$PM_{2.5}$ from mainstream smoke	422.1	This study
	Outer layer of tobacco leaves near the cigarette's lit end	free combustion	$PM_{2.5}$ from sidestream smoke	193.8	This study
Fuel in residential areas	Refuse incineration	Mixed smoldering and flaming	$PM_{2.5}$	7810	(U.S. Environmental Protection Agency 2024)
	Anthracite	Mixed smoldering and	$PM_{2.5}$	1054	(Zhang et al.,2008)

		flaming			
	Bituminous coal	Mixed smoldering and flaming	$PM_{2.5}$	7373	
	Briquettes	Mixed smoldering and flaming	$PM_{2.5}$	5242	
	Peat	Mixed smoldering and flaming	$PM_{2.5}$	7020	(Christian et al.,2003)
	Liquefied petroleum gas	Mixed smoldering and flaming	TSP	520	
	Dry natural gas	Mixed smoldering and flaming	TSP	150	(Zhang et al.,2000)
	Landfill gas	Mixed smoldering and flaming	TSP	150	
	Liquefied natural gas	Mixed smoldering and flaming	$PM_{2.5}$	200	
	Gasoline	Mixed smoldering and flaming	$PM_{2.5}$	700	(Habib et al.,2008)
	Manure cake	Mixed smoldering and flaming	$PM_{2.5}$	5400	
	Straw	Mixed smoldering and flaming	$PM_{2.5}$	11400	
Crop residue	Rice straw	Mixed smoldering and flaming	$PM_{2.5}$	8500	(Ni et al.,2017)
	Cornstalk	Mixed smoldering and flaming	$PM_{2.5}$	12000	
Branches of tree		Flaming	$PM_{2.5}$	17400	(Reisen et al.,2018)
		Smoldering	$PM_{2.5}$	49800	

Table S3 Emission factors of water-soluble ions in $PM_{2.5}$ from mainstream cigarette smoke(μg/g)

Ions / Cigarettes	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}	NO_2^-	NO_3^-	SO_4^{2-}
JS1	19.24	12.30	0.41	1.89	27.06	18.95	50.68	22.80
JS2	19.79	8.97	5.84	1.85	18.51	11.45	31.19	16.91
JS3	17.49	9.55	7.82	1.86	16.22	15.83	19.64	22.76
JS4	24.18	5.96	0.58	2.88	22.04	29.89	50.93	18.99
JS5	24.21	17.24	11.18	7.74	20.02	17.62	32.99	17.98
JS6	14.00	12.22	0.49	2.51	9.86	15.29	26.04	20.20
FR	17.10	11.95	0.19	1.39	10.81	27.72	33.32	17.09
LQ	58.21	17.97	10.29	5.22	11.07	14.64	17.57	7.74
YX	49.53	15.25	3.76	3.97	9.09	39.43	12.77	11.13
HHL	62.44	18.47	12.26	4.51	10.11	22.06	16.18	10.42
ZH	52.28	15.62	6.79	3.27	31.24	18.98	60.84	12.86

Table S4 Emission factors of water-soluble ions in $PM_{2.5}$ from sidestream cigarette smoke(μg/g)

Ions / Cigarettes	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}	NO_2^-	NO_3^-	SO_4^{2-}
JS1	16.41	22.59	5.94	0.59	17.24	13.97	21.01	34.44
JS2	25.28	20.03	12.35	0.54	29.05	18.22	28.79	47.39
JS3	18.01	27.33	3.35	0.62	17.99	28.31	17.48	31.74
JS4	25.37	15.24	0.35	0.31	23.82	17.13	26.89	35.08
JS5	23.41	30.77	2.36	1.48	21.39	26.71	20.79	39.37

JS6	15.36	30.13	4.74	0.47	10.94	13.68	15.77	31.04
FR	14.85	18.19	1.18	0.55	12.42	13.53	24.88	27.95
LQ	60.57	18.05	8.20	0.70	8.60	23.71	15.81	17.67
YX	47.45	23.03	5.73	0.38	8.35	16.27	13.43	16.51
HHL	61.85	27.32	7.32	0.24	8.85	15.49	15.30	31.89
ZH	53.14	16.57	7.74	0.22	19.30	57.41	21.70	64.79

Table S5 Emission factors of Heavy metals in $PM_{2.5}$ from mainstream cigarette smoke(μg/g)

Ions / Cigarettes	V	Cr	Mn	Co	Ni	Cu	Zn	As	Cd	Sb	Ba	Pb
JS1	12.17	6.36	3.25	2.26	0.00	11.08	6.94	14.09	0.52	2.37	0.02	0.50
JS2	11.46	5.61	2.11	3.41	0.00	14.79	9.15	10.03	10.07	4.54	0.08	1.32
JS3	18.75	5.90	11.47	0.69	0.00	4.32	14.61	12.91	0.27	2.72	0.01	0.00
JS4	14.20	4.75	3.36	1.75	3.96	9.11	4.86	10.01	4.84	3.22	0.02	0.79
JS5	105.99	9.48	11.22	4.14	4.98	11.52	10.21	15.06	1.63	3.42	0.05	0.97
JS6	75.68	6.49	2.11	5.49	4.01	9.21	6.99	10.95	3.15	1.75	0.01	0.39
FR	17.14	1.63	4.68	1.80	2.93	5.43	4.02	7.91	3.48	1.79	0.01	4.87
LQ	5.69	6.40	5.60	0.91	5.01	3.97	5.53	8.32	5.65	2.35	0.01	0.55
YX	43.67	10.31	5.14	1.19	0.00	1.49	4.60	21.04	1.23	2.59	0.01	0.44
HHL	11.75	5.41	1.66	4.16	0.00	5.27	6.46	30.86	5.65	2.79	0.01	1.79
ZH	4.60	1.57	5.10	0.87	0.00	6.14	2.42	11.59	3.02	2.83	0.01	0.57

Table S6 Emission factors of Heavy metals in $PM_{2.5}$ from sidestream cigarette smoke(μg/g)

Ions / Cigarettes	V	Cr	Mn	Co	Ni	Cu	Zn	As	Cd	Sb	Ba	Pb
JS1	24.67	12.10	16.79	2.18	0.00	11.97	46.89	28.02	29.37	2.19	0.02	1.03
JS2	22.55	13.40	23.15	2.31	0.00	3.33	117.12	19.13	7.04	8.56	0.04	1.73
JS3	25.03	14.09	15.92	1.28	0.00	9.79	30.33	33.76	20.30	3.69	0.02	0.45
JS4	21.62	17.26	23.87	1.69	10.92	9.77	16.22	27.89	6.36	3.44	0.01	0.10
JS5	22.71	22.88	20.84	3.65	0.00	40.59	23.46	21.68	18.54	3.03	0.03	1.45
JS6	14.49	35.39	11.16	3.44	43.92	24.37	79.07	12.18	15.89	2.24	0.00	9.89
FR	13.76	8.76	14.82	1.61	0.00	19.99	11.84	13.21	9.69	1.84	0.01	0.46
LQ	15.59	5.21	7.57	1.44	0.00	3.23	10.43	29.84	18.50	2.22	0.05	0.73
YX	13.82	23.57	4.46	2.43	0.00	1.41	34.04	44.97	9.12	4.41	0.02	1.01
HHL	47.99	47.75	8.69	1.70	0.00	11.03	29.18	27.82	7.22	3.16	0.01	0.55
ZH	14.17	12.90	8.99	3.19	0.00	4.29	13.31	53.15	12.71	3.65	0.11	2.29

1. Christian, T.J., Kleiss, B., &Yokelson, R.J. (2003). Comprehensive laboratory measurements of biomass-burning emissions: Emissions from Indonesian, African, and other fuels. J. Geophys. Res. 108:(D23). https://doi.org/10.1029/2003JD003704
2. Habib, G., Venkataraman, C., Bond, T.C., &Schauer, J.J. (2008). Microphysical and Optical

Properties of Primary Particles from the Combustion of Biomass Fuels. Environ. Sci. Technol. 42(23):8829-8834. https://doi.org/10.1021/es800943f

3. Ni, H., Tian, J., &Wang, X. (2017). $PM_{2.5}$ Emissions and Source Profiles from Open Burning of Crop Residues. China, Atmos. Environ.169:229-237. https://doi.org/10.1016/j.atmosenv.2017.08.063
4. Reisen, F., Meyer, C.P., Weston, C.J., &Volkova, L. (2018). Ground-Based Field Measurements of $PM_{2.5}$ Emission Factors From bright combustion and smoldering combustion in Eucalypt Forests. J. Geophys. Res. 123:8301-8314. https://doi.org/10.1029/2018JD028488
5. U.S. Environmental Protection Agency. Clearinghouse for Inventories & Emissions factors, http://www.epa.gov/ttn/chief/index.html.
6. Xu, H., Li, Y., &Guinot, B. (2018). Household Heating and Cooking in Rural Guanzhong Plain, Northwestern China, Atmos. Environ. 185:196-206.
7. Zhang, Y., Schauer, J., &Zhang, Y. (2008). Characteristics of particulate carbon emissions from real-world Chinese coal combustion. China, Environ. Sci. Technol. 42(14):5068-5073. https://doi.org/10.1021/acs.est.7b01543
8. Zhang, J., Smith, K.R., &Ma, Y. (2000). Greenhouse gases and other airborne pollutants from household stoves in China: a database for emission factors. China, Atmos. Environ. 34(26):4537-4549. https://doi.org/10.1016/S1352-2310(99)00450-1