

Supplemental Information for Emission of PM_{2.5}-bound Polycyclic Aromatic Hydrocarbons from Biomass and Coal Combustion in China

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Table S1. Description of combustion sources

Source type	Stove/boiler type and specification	Fuel type	APCDs	Test load (%)
Open burning		wheat straw maize stover	None	
Household biofuel burning	improved stove with an enclosed combustion chamber and a chimney, built-in-place brick stove	wheat straw maize stover woody fuel	None	
household coal combustion	built-in-place brick stove with a chimney	bituminous coal	None	
coal-fired boiler for electricity generation	Pulverized coal boiler with a steam flow rate of 670 t/h	bituminous coal	ESP+WFGD	100
coal-fired industrial boilers	chain-grate boiler with nominal capacity of 20 t/h	bituminous coal	spray scrubber	80
	chain-grate boiler with nominal capacity of 4 t/h	bituminous coal	cyclone	80

Table S2. Proximate analysis and ultimate analysis for the tested biomass and fuel

Source type	Fuel type	Proximate analysis (as received, %)				Ultimate analysis (dry basis, %)			
		moisture	volatile matter	fix carbon	ash	C	H	N	S
Open burning	wheat straw	9.59	65.54	18.83	6.04	44.80	7.01	0.56	0.17
	maize stover	8.79	68.93	18.43	3.85	41.09	6.85	1.62	0.20
Household biofuel burning	wheat straw	10.32	69.61	14.74	5.33	44.80	7.01	0.56	0.17
	maize stover	8.90	63.58	17.20	10.32	41.09	6.85	1.62	0.20
	woody fuel	9.49	74.35	15.19	0.97	47.66	7.20	0.15	
household coal combustion	bituminous coal	7.04	33.91	53.71	5.35	70.02	3.87	0.94	0.23
coal-fired boiler for electricity generation	bituminous coal	6.5	25.17		32.65	51.44			1.01
coal-fired industrial boilers	bituminous coal	10.11	29.60	53.69	6.60	71.41	4.50	0.94	0.23
	bituminous coal	16.3	22.56	26.53	34.61	43.87	3.43	0.92	0.96

Table S3. Summary of emission factors of PAHs (mg/kg fuel burned) from various combustion sources in the literatures

Source type	Fuel type	APCDs	Sampling method	Samples	EF	Reference
Household stove						
cookstove(L ^a)	wood	None	hs ^f	p ^c +g ^d	110.2	S1
	coal briquette				101.5	
	charcoal				24.7	
stove (L)	fuelwood	None	dilution sampling	p	2.0-3.2	S2
	dung-cake			p	3.1-5.5	
	biofuel briquette			p	2.8-3.0	
stove (L)	honeycomb coal briquette	None	dilution sampling	p+g	69-160	S3
stove (L)	coal chunk	None	dilution sampling	PM _{2.5}	0.13-5.2	S4
	coal briquette				0.53-23.9	
stove (L)	biofuel biofuel briquette	None	dilution sampling	PM _{2.5}	0.18-18.7	S5
stove (L)	biofuel coal	None	naturally cooled	p+g	5.2-47.3 41-405	S6
improve metal stove(F ^b)	coal briquette	None	naturally diluted	p+g	13-15	S7
brick stove(F)	coal cake				148-210	
metal stove without chimney(F)	wood				141-276	
cookstove (F)	crop straw	None	naturally diluted	p+g	120-550	S8
coal stove (F)	anthracite coal chunk	None	naturally diluted	p+g	26.0±30.4	S9
biofuel gasifier stove(F)	wood				74.2±50.1	
stove (F)	bituminous coal	None	dilution sampling	PM _{2.5}	68.7±21.8	S10
	anthracite coal				1.7±0.9	
	biofuel				29.5-83.3	
heated kang	biofuel	None	dilution sampling	PM _{2.5}	84.5-344	S11
traditional stove semi-gasifier (F)	coal				38-206	
brick stove (F)	biofuel	None	naturally diluted	p	21.7-429	S12
traditional iron stoves(F)	wood				106-254	
	coal chunk				62.2	
	honeycomb				18.3	
gasifier stove(F)	wood				24.6	
Open burning						
wind tunnel simulation	cereals	None	dilution sampling	p+g	7.9-359	S13
	wood				14.2-30.6	
lab simulation	wheat straw	None	dilution	PM _{2.5}	1.8	S14

	rice straw		sampling		15.7	
lab simulation	rice straw maize residue leaf litter	None	dilution sampling	PM ₁₀	0.47-0.91	S15
lab simulation	rice straw	None	dilution	PM	2.2±0.2	S16
field measurement	rice straw		sampling	PM _{2.5}	16.6±1.7	
Coal-fired boiler						
PC boiler	bituminous coal	ESP	hs ^f	p+g	0.003-0.018	S17
PC boiler	Indonesian coal Australian coal	SCR+ESP+WFGD	hs ^f	p+g	0.002	S18
PC boiler	Bituminous coal	ESP	hs ^f	p+g	0.6	S19
PC boiler	Bituminous coal	SCR+BH+SWFGD	hs ^f	p+g	0.24	S20
PC boiler	Bituminous coal	SCR+ESP+WFGD	hs ^f	p+g	0.44	
CFB boiler	bituminous coal	fabric filter	hs ^f	p+g	3.53	S21

^aL: lab simulation. ^bF: field measurement. ^cp: particulate phase. ^dg: gas phase. ^fhs: hot temperature sampling

References

- S1. Kim Oanh, N.T.; Bætz Reutergårdh, L.; Dung, N.T. Emission of Polycyclic Aromatic Hydrocarbons and Particulate Matter from Domestic Combustion of Selected Fuels. *Environ. Sci. Technol.* **1999**, *33*, 2703–2709.
- S2. Venkataraman, C.; Negi, G.; Sardar, S.B.; Rastogi, R. Size distributions of polycyclic aromatic hydrocarbons in aerosol emissions from biofuel combustion. *J. Aerosol Sci.* **2002**, *33*, 503–518.
- S3. Chen, Y. J.; Sheng, G. Y.; Bi, X. H.; Feng, Y. L.; Mai, B. X.; Fu, J. M. Emission factors for carbonaceous particles and polycyclic aromatic hydrocarbons from residential coal combustion in China. *Environ. Sci. Technol.* **2005**, *39*, 1861-1867.
- S4. Chen, Y. J.; Zhi, G. R.; Feng, Y. L.; Tian, C. G.; Bi, X. H.; Li, J.; Zhang, G. Increase in polycyclic aromatic hydrocarbon (PAH) emissions due to briquetting: A challenge to the coal briquetting policy. *Environ. Pollut.* **2015**, *204*, 58-63.
- S5. Sun, J.; Shen, Z. X.; Zeng, Y. L.; Niu, X. Y.; Wang, J. H.; Cao, J. J.; Gong, X. S.; Xu, H. M.; Wang, T. B.; Liu, H. X.; Yang, L. Characterization and cytotoxicity of PAHs in PM_{2.5} emitted from residential solid fuel burning in the Guanzhong Plain, China. *Environ. Pollut.* **2018**, *241*, 359-368.
- S6. Shen, G. F.; Tao, S.; Wei, S. Y.; Chen, Y. C.; Zhang, Y. Y.; Shen, H. Z.; Huang, Y.; Zhu, D.; Yuan, C. Y.; Wang, H. C.; Wang, Y. F.; Pei, L. J.; Liao, Y. L.; Duan, Y. H.; Wang, B.; Wang, R.; Lv, Y.; Li, W.; Wang, X. L.; Zheng, X. Y. Field Measurement of Emission Factors of PM, EC, OC, Parent, Nitro-, and Oxy-Polycyclic Aromatic Hydrocarbons for Residential Briquette, Coal Cake, and Wood in Rural Shanxi, China. *Environ. Sci. Technol.* **2013**, *47*, 2998-3005.
- S7. Shen, G.F.; Tao, S.; Wei, S.Y.; Chen, Y.C.; Zhang, Y.Y.; Shen, H.Z.; Huang, Y.; Zhu, D.; Yuan, C.Y.; Wang, H.C.; et al. Field Measurement of Emission Factors of PM, EC, OC, Parent, Nitro-, and Oxy-Polycyclic Aromatic Hydrocarbons for Residential Briquette, Coal Cake, and Wood in Rural Shanxi, China. *Environ. Sci. Technol.* **2013**, *47*, 2998–3005.
- S8. Wei, S. Y.; Shen, G. F.; Zhang, Y. Y.; Xue, M.; Xie, H.; Lin, P. C.; Chen, Y. C.; Wang, X. L.; Tao, S. Field measurement on the emissions of PM, OC, EC and PAHs from indoor crop straw burning in rural China. *Environ. Pollut.* **2014**, *184*, 18-24.
- S9. Shen, G. F.; Chen, Y. C.; Xue, C. Y.; Lin, N.; Huang, Y.; Shen, H. Z.; Wang, Y. L.; Li, T. C.; Zhang, Y. Y.; Su, S.; Huangfu, Y. B.; Zhang, W. H.; Chen, X. F.; Liu, G. Q.; Liu, W. X.; Wang, X. L.; Wong, M. H.; Tao, S. Pollutant Emissions from Improved Coal- and Wood-Fuelled Cookstoves in Rural Households. *Environ. Sci. Technol.* **2015**, *49*, 6590-6598.
- S10. Sun, J.; Shen, Z.X.; Zeng, Y.L.; Niu, X.Y.; Wang, J.H.; Cao, J.J.; Gong, X.S.; Xu, H.M.; Wang, T.B.; Liu, H.X.; et al. Characterization and cytotoxicity of PAHs in PM_{2.5} emitted from residential solid fuel burning in the Guanzhong Plain, China. *Environ. Pollut.* **2018**, *241*, 359–368.

- S11. Zhang, Y.; Shen, Z. X.; Sun, J.; Zhang, L. M.; Zhang, B.; Zou, H. J.; Zhang, T.; Ho, S. S. H.; Chang, X. J.; Xu, H. M.; Wang, T.; Cao, J. J. Parent, alkylated, oxygenated and nitrated polycyclic aromatic hydrocarbons in PM_{2.5} emitted from residential biomass burning and coal combustion: A novel database of 14 heating scenarios. *Environ. Pollut.* **2021**, *268*, 115881.
- S12. Du, W.; Wang, J. Z.; Zhuo, S. J.; Zhong, Q. R.; Wang, W.; Chen, Y. C.; Wang, Z. L.; Mao, K.; Huang, Y.; Shen, G. F.; Tao, S. Emissions of particulate PAHs from solid fuel combustion in indoor cookstoves. *Sci. Total Environ.* **2021**, *771*, 145411.
- S13. Jenkins, B.M.; Jones, A.D.; Turn, S.Q.; Williams, R.B. Emission Factors for Polycyclic Aromatic Hydrocarbons from Biomass Burning. *Environ. Sci. Technol.* **1996**, *30*, 2462–2469.
- S14. Hays, M. D.; Fine, P. M.; Geron, C. D.; Kleeman, M. J.; Gullett, B. K., Open burning of agricultural biomass: Physical and chemical properties of particle-phase emissions. *Atmos. Environ.* **2005**, *39*, 6747–6764.
- S15. Wiriya, W.; Chantara, S.; Sillapapiromsuk, S.; Lin, N. H. Emission Profiles of PM₁₀-Bound Polycyclic Aromatic Hydrocarbons from Biomass Burning Determined in Chamber for Assessment of Air Pollutants from Open Burning. *Aerosol Air Qual. Res.* **2016**, *16*, 2716–2727.
- S16. Oanh, N. T. K.; Ly, B. T.; Tipayarom, D.; Manandhar, B. R.; Prapat, P.; Simpson, C. D.; Liu, L. J. S. Characterization of particulate matter emission from open burning of rice straw. *Atmos. Environ.* **2011**, *45*, 493–502.
- S17. Yin, X.F.; Yang, W.T.; Xue, H.M. PAHs Emission Characteristics and Assessment from the Coal Combustion Process in the Large Capacity Power Plant Boilers. In *Advanced Materials Research*; Trans Tech Publications Ltd.: Bäch SZ, Switzerland, **2013**; Volume 726–731, pp. 1908–1916.
- S18. Hsu, W. T.; Liu, M. C.; Hung, P. C.; Chang, S. H.; Chang, M. B. PAH emissions from coal combustion and waste incineration. *J. Hazard. Mater.* **2016**, *318*, 32–40.
- S19. Yang, H.H.; Lee, W.J.; Chen, S.J.; Lai, S.O. PAH emission from various industrial stacks. *J. Hazard. Mater.* **1998**, *60*, 159–174.
- S20. Lu, C. M.; Dat, N. D.; Lien, C. K.; Chi, K. H.; Chang, M. B. Characteristics of Fine Particulate Matter and Polycyclic Aromatic Hydrocarbons Emitted from Coal Combustion Processes. *Energy Fuels* **2019**, *33*, 10247–10254.
- S21. Wang, R. W.; Liu, G. J.; Sun, R. Y.; Yousaf, B.; Wang, J. Z.; Liu, R. Q.; Zhang, H. Emission characteristics for gaseous- and size-segregated particulate PAHs in coal combustion flue gas from circulating fluidized bed (CFB) boiler. *Environ. Pollut.* **2018**, *238*, 581–589.