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Supplement of

Speciated online PM_1 from South Asian combustion sources – Part 1: Fuel-based emission factors and size distributions

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1. Experimental Setup

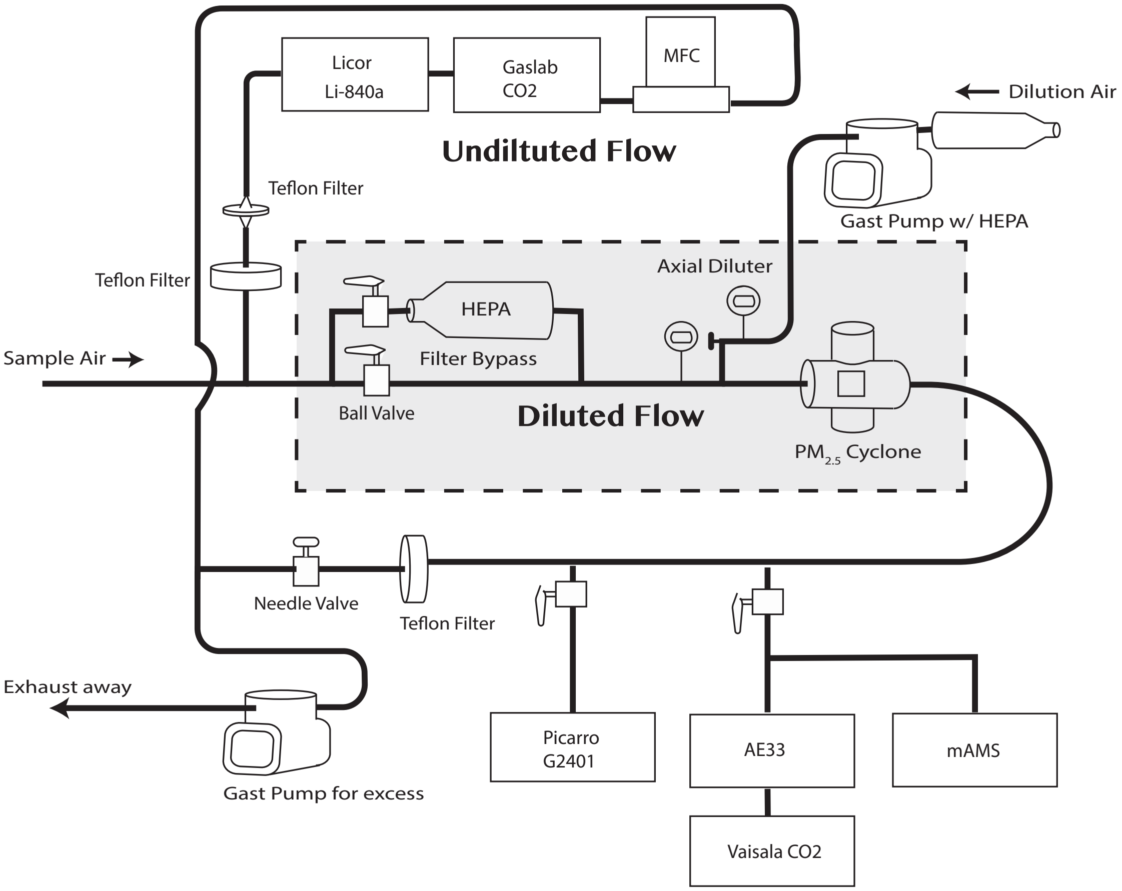

Figure S1. Diagram of the NAMaSTE on-line aerosol sampling system. The MFC is a mass flow controller fixed at ~ 1 slpm and HEPA is defined as a high efficiency particulate air filter.

2. Intercomparison of undiluted CO_2 measurements by the Picarro CRDS and Li-Corr Li840A

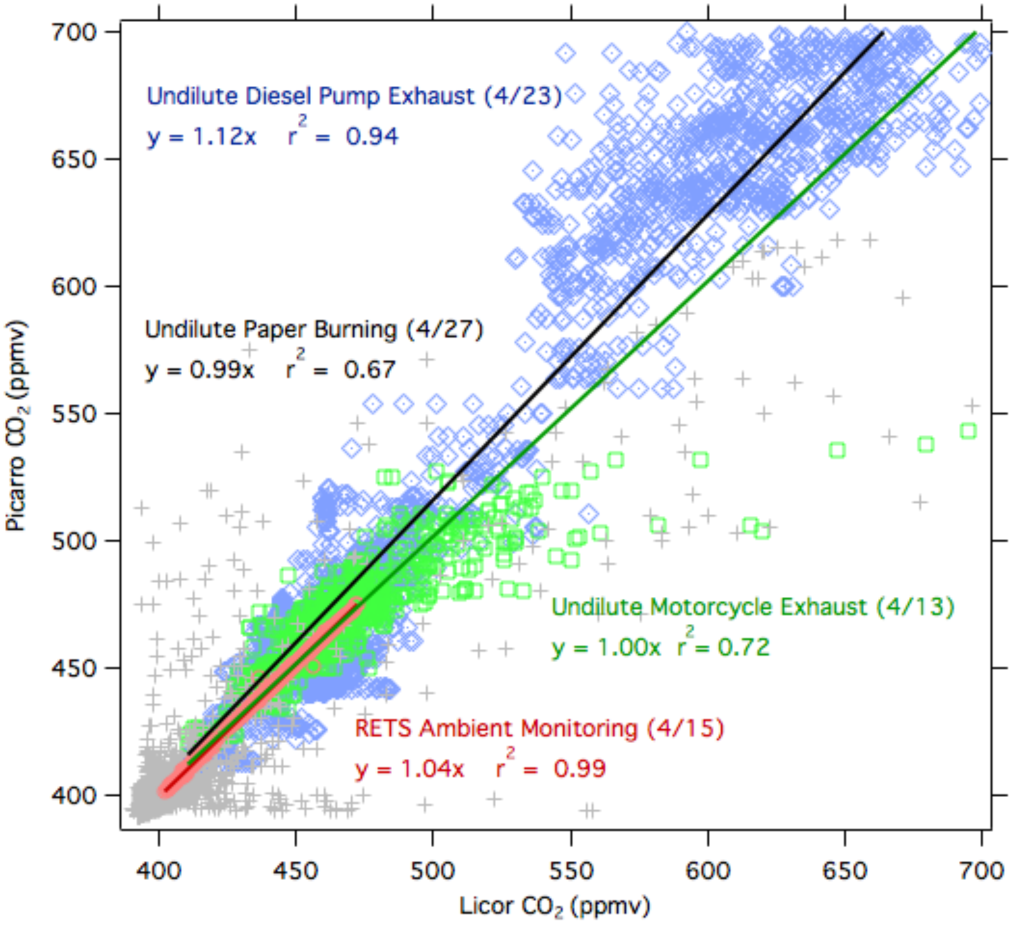

Figure S2. Scatter plot of undiluted Picarro CRDS CO_2 and Li840A measurements throughout the NAMaSTE campaign. Markers represent 1-second measurements and lines represent the linear fit for each sampling event.

3. Size Distribution Conversions from Vacuum Aerodynamic Diameter

Continuum regime vacuum aerodynamic diameter bins measured by the mAMS were converted to volume equivalent diameter and transition regime aerodynamic diameter based on estimates of density (or literature values) for each aerosol component and with the assumption a sphericity using methods described in DeCarlo et al. (2004). Volume equivalent diameter (D_{ve}) was calculated using eq. S1 (DeCarlo et al., 2004, Eq. 31), where D_{va} is vacuum aerodynamic diameter in nanometers, ρ_p is the particle density in g cm^{-3}, ρ0 is the standard density (1 g cm^{-3}), and χ is the dynamic shape factor.

$$D_{ve} = \frac{D_{va}\,\chi\,\rho_0}{\rho_p} \qquad \text{(SI1)}$$

For χ, all non-refractory aerosol measured by the mAMS was assumed to be spherical and without voids and therefore $\chi = 1$. Organic particle density was estimated using elemental ratios (e.g. H:C, O:C) from the average mass spectral profiles of each emission source type using methods described in Kuwata et al. (2011). The ρ_p, for OA can be found in Table 2 of the main text. For inorganic materials, ρ_p is from literature values for the major inorganic species, including HCl, NH_4Cl, H_2SO_4, NH_4HSO_4, $(NH_4)_2SO_4$ and can be found in Table S1. To simplify the sulfate density the average density of the three major components (1.8 g cm^{-3}) was used for the conversion of the sulfate related size distributions. It should be noted that chloride species, HCl or NH_4Cl, used for the size distribution conversions of chloride aerosol was assumed based on whether ammonium was observed above detection limits in the same emissions and had a similar D_{va} size distribution to chloride. For example, with the Clamp kiln emissions, ammonium was detected and had a similar D_{va} distribution to chloride and therefore NH_4Cl was assumed to be the dominant aerosol species. Alternatively, for garbage burning ammonium was not detected and therefore HCl was assumed to be the dominant chloride species. Assumptions about other chloride species like organic chloride salts or KCl cannot be discussed because we did not have the capability to differentiate these species from HCl or NH_4Cl.

Table S1. Density of aerosol components found in NAMaSTE measured emissions.

Aerosol Component	Material Density **[g/cm^3]**
Refractory Black Carbon	1.80
H_2SO_4	1.84
NH_4HSO_4	1.78
$(NH_4)_2SO_4$	1.77
Sulfate Average	1.80
HCl	1.19
NH_4Cl	1.54

Assuming aerosol mass and volume are proportional, the total density (ρ_{total}) for each emission source was calculated using an additive approach as described in DeCarlo et al. (2004) for material density and found in equation S2:

$$\rho_{total} = \frac{MF_{total}}{\rho_{OA}MF_{OA} + \rho_{BC}MF_{BC} + \rho_{SO4}MF_{SO4} + \rho_{Cl}MF_{Cl} + p_{NH4}MF_{NH4}} \qquad \text{(S2)}$$

Where ρ_x and MF_x are the density and mass fraction for that aerosol component, respectively. Component mass fractions and ρ_{total} can be found in Table S2.

Transition regime aerodynamic diameter (D_a) was estimated using equation S2 (DeCarlo et al., 2004, Eq. 28), where C_c is the Cunningham slip correction factor as a function of D_a and D_{ve}.

$$D_a = D_{ve}\sqrt{\frac{\rho_p C_c(D_{ve})}{\chi\, \rho_0\, C_c\,(D_a\,)}} \qquad \text{(S3)}$$

The shape factor, χ is assumed to be 1 and the C_c as a function of D_{ve} was calculated using equation 9.34, from Seinfeld and Pandis (2016) and assuming standard temperature and pressure. The values of D_a and $Cc(D_a)$ were then solved for simultaneously by constraining D_a to be greater than or equal to D_{ve} and $C_c(D_a)$ to be less than or equal to $C_c(D_{ve})$ as discussed in DeCarlo et al. (2004).

For each emission source, D_{va} was converted to D_{ve} and D_a by assuming $\rho_p = \rho_{total}$. Because the relationship between the different distribution types are linear at the reported bin sizes, the conversions are reported as diameter ratios (e.g. D_{ve}/D_{va}, D_a/D_{va}, D_a/D_{ve}). Full results for the D_{va} to D_{ve} and D_a conversions can be found in Table S2.

Table S2. Aerosol component mass fraction (MF), density (ρ), and diameter conversion factors for NAMaSTE tested emission sources.

Emission Source	ρ_{OA} [g/cm^3]	MF_{OA}	MF_{BC}	MF_{SO4}	MF_{CHL}	MF_{NH4}	ρ_{total} [g/cm^3]	D_{ve}/D_{va}	D_a/D_{va}	D_a/D_{ve}
Clamp Kiln	0.98	0.57	0.01	0.28	0.05	0.10	1.20	0.83	0.91	1.09
Zig Zag Kiln	1.06	0.16	0.26	0.52	0.00	0.06	1.60	0.62	0.79	1.26
Garbage Burning	1.02	0.50	0.48	0.00	0.02	0.00	1.29	0.77	0.88	1.14
Chip Bags	1.03	0.60	0.40	0.00	0.00	0.00	1.25	0.80	0.90	1.12
Mixed Plastic	1.05	0.84	0.14	0.00	0.03	0.00	1.12	0.89	0.95	1.06
Motorcycles	0.98	1.00	0.00	0.00	0.00	0.00	0.98	1.02	1.02	1.00
Irrigation Pump 1	0.99	0.71	0.29	0.00	0.00	0.00	1.13	0.88	0.94	1.06
Irrigation Pump 2	0.99	0.16	0.83	0.00	0.00	0.00	1.59	0.63	0.80	1.26
Hardwood	1.08	0.87	0.08	0.01	0.04	0.00	1.13	0.89	0.94	1.06
Sticks and Twigs	1.06	0.76	0.22	0.00	0.01	0.00	1.17	0.85	0.92	1.09
Dung	1.03	0.76	0.05	0.00	0.15	0.04	1.13	0.89	0.94	1.06
Dung and Hardwood	1.01	0.81	0.04	0.00	0.12	0.03	1.09	0.92	0.96	1.04
Mixed Ag. Residue	1.08	0.77	0.12	0.01	0.10	0.00	1.15	0.87	0.93	1.07
Wheat	1.08	0.73	0.14	0.01	0.10	0.01	1.17	0.86	0.92	1.08
Mustard	1.08	0.77	0.13	0.03	0.06	0.00	1.16	0.86	0.93	1.08
Grass	1.08	0.68	0.11	0.00	0.20	0.02	1.21	0.83	0.91	1.10

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3. Summary Statistics of Speciated Fuel-based Emission Factors

Source Type	Fuel	f [a]	MCE[b]		Fuel-based emission factor (g/kg fuel)							
					PM$_1$ [c]	OA[d]	BC	SO$_4$	NO$_3$	Chloride	NH$_4$	PAH
1-pot traditional mudstove	**dung**	**0.33**	**0.908**	median		1.039	0.064	0.007	0.002	0.250	0.068	0.003
			(0.945)	25th (10th)		0.701(0.365)	0.037(0.022)	0.004(0.003)	0.002(0.001)	0.162(0.099)	0.047(0.027)	0.002(0.001)
				75th (90th)		1.576(2.283)	0.122(0.220)	0.011(0.017)	0.004(0.006)	0.358(0.471)	0.095(0.120)	0.006(0.015)
				μ (σ)		1.367(1.472)	0.092(0.104)	0.009(0.009)	0.003(0.003)	0.268(0.149)	0.072(0.040)	0.005(0.007)
				integrated	**1.787**	**1.351**	**0.086**	**0.008**	**0.003**	**0.270**	**0.069**	**0.005**
	hardwood[e]	**0.5**	**0.914**	median		1.070	0.117	0.011		0.062		0.007
			(0.962)	25th (10th)		0.385(0.174)	0.009(0.00)	0.008(0.005)		0.021(0.009)		0.002(0.001)
				75th (90th)		2.514(4.647)	0.276(0.476)	0.017(0.030)		0.138(0.252)		0.016(0.027)
				μ (σ)		1.916(2.685)	0.184(0.226)	0.017(0.022)		0.096(0.105)		0.011(0.012)
				integrated	**2.715**	**2.370**	**0.208**	**0.016**	**-**	**0.121**	**-**	**0.012**
	sticks and twigs[f]	**0.5**	**0.933**	median		0.777	0.197	0.009	0.003	0.022		0.008
			(0.945)	25th (10th)		0.288(0.092)	0.007(0.00)	0.005(0.002)	0.002(0.001)	0.009(0.004)		0.003(0.001)
				75th (90th)		2.286(7.263)	0.566(1.201)	0.015(0.030)	0.007(0.014)	0.042(0.073)		0.020(0.052)
				μ (σ)		2.444(4.880)	0.385(0.526)	0.014(0.020)	0.006(0.008)	0.030(0.032)		0.019(0.035)
				integrated	**2.363**	**1.794**	**0.521**	**0.009**	**0.004**	**0.035**	**-**	**0.025**
2-pot traditional mudstove	**dung and hardwood**	**0.4**	**0.912**	median		2.417	0.204	0.014	0.005	0.325	0.070	0.019
			(0.965)	25th (10th)		1.430(0.602)	0.092(0.067)	0.008(0.005)	0.002(0.001)	0.246(0.117)	0.051(0.030)	0.010(0.007)
				75th (90th)		5.200(16.779)	0.273(0.488)	0.029(0.087)	0.007(0.017)	0.858(2.222)	0.270(0.533)	0.037(0.069)
				μ (σ)		4.836(5.750)	0.204(0.139)	0.026(0.031)	0.006(0.007)	0.676(0.749)	0.160(0.181)	0.027(0.023)
				integrated	**4.095**	**3.303**	**0.161**	**0.018**	**0.005**	**0.501**	**0.107**	**0.020**

a. Carbon mass fraction of fuel from Stockwell et al. (2016)
b. Average modified combustion efficiency ($\Delta CO2/(\Delta CO+\Delta CO2)$) from Stockwell et al. (2016)
c. Sum of detected species (PAH not included)
d. Primary organic aerosol measured with the mAMS
e. Baikano (*Melia azedarach*)
f. *Shorea robusta* is primary component.

(-) Indicates that the species was not detected above detection limit

Source Type	fuel	f[a]	MCE[b]		Fuel-based emission factor (g/kg fuel)							
					PM_1[c]	OA[d]	BC	SO_4	NO_3	Chl	NH_4	PAH
Crop Residue Burning	**mixed residue**	**0.42**	**0.957**	median		1.244	0.275	0.020	0.008	0.170		0.004
			(0.943)	25th (10th)		0.439(0.153)	0.079(0.002)	0.008(0.004)	0.003(0.001)	0.064(0.030)		0.002(0.001)
				75th (90th)		3.039(7.424)	0.552(0.852)	0.068(0.168)	0.014(0.027)	0.374(0.865)		0.010(0.018)
				μ (σ)		2.754(3.970)	0.371(0.396)	0.056(0.100)	0.011(0.012)	0.341(0.560)		0.007(0.007)
				integrated	**3.436**	**2.641**	**0.410**	**0.019**	**0.008**	**0.358**	**-**	**0.006**
	wheat	**0.42**	**0.949**	median		2.359	0.308	0.104	0.007	0.139	0.034	0.004
			(0.888)	25th (10th)		1.013(0.424)	0.00(0.00)	0.039(0.013)	0.004(0.001)	0.067(0.025)	0.020(0.008)	0.003(0.002)
				75th (90th)		4.485(18.779)	0.555(1.226)	0.289(0.407)	0.030(0.081)	0.477(1.786)	0.107(0.230)	0.013(0.042)
				μ (σ)		2.850(3.849)	0.353(0.389)	0.121(0.120)	0.013(0.018)	0.301(0.463)	0.056(0.059)	0.007(0.009)
				integrated	**4.547**	**3.339**	**0.639**	**0.051**	**0.010**	**0.446**	**0.062**	**0.009**
	mustard	**0.42**	**0.920**	median		1.061	0.433	0.145	0.009	0.060		0.004
			(0.902)	25th (10th)		0.230(0.107)	0.132(0.024)	0.025(0.014)	0.002(0.001)	0.009(0.002)		0.001(0.000)
				75th (90th)		5.599(8.602)	1.083(2.316)	0.326(0.523)	0.041(0.094)	0.262(0.955)		0.011(0.020)
				μ (σ)		3.172(5.429)	0.677(0.761)	0.183(0.202)	0.022(0.028)	0.218(0.385)		0.006(0.007)
				integrated	**4.177**	**3.217**	**0.559**	**0.111**	**0.021**	**0.269**	**-**	**0.004**
	grass	**0.42**	**0.961**	median		1.150	0.213		0.005	0.475	0.080	0.003
			(0.866)	25th (10th)		0.404(0.175)	0.106(0.014)		0.002(0.000)	0.147(0.022)	0.024(0.010)	0.001(0.001)
				75th (90th)		3.147(14.353)	0.443(0.949)		0.009(0.023)	1.290(2.540)	0.222(0.337)	0.008(0.029)
				μ (σ)		2.776(4.929)	0.292(0.286)		0.006(0.007)	0.735(0.906)	0.111(0.149)	0.007(0.011)
				integrated	**2.686**	**1.817**	**0.283**	**-**	**0.003**	**0.528**	**0.055**	**0.005**

a. Carbon mass fraction of fuel from Stockwell et al. (2016)
b. Average modified combustion efficiency ($\Delta CO2/(\Delta CO+\Delta CO2)$) from Stockwell et al. (2016)
c. Sum of detected species (PAH not included)
d. Primary organic aerosol measured with the mAMS

(-) Indicates that the species was not detected above detection limit

Source Type	Fuel	f [a]	MCE[b]	Fuel-based emission factor (g/kg fuel)							
					PM_1[c]	OA[d]	SO_4	NO_3	Chl	NH_4	PAH
Open Garbage Burning	**Mixed Refuse 1**	**0.5**	**0.937**	median		1.574	0.002	0.003	0.047		0.003
			(0.990)	25th (10th)		0.512(0.091)	0.001(0.001)	0.002(0.001)	0.016(0.009)		0.001(0.001)
				75th (90th)		5.225(11.820)	0.004(0.005)	0.005(0.008)	0.124(0.242)		0.007(0.029)
				μ (σ)		3.277(4.513)	0.002(0.002)	0.003(0.002)	0.084(0.102)		0.006(0.010)
				integrated	**3.771**	**3.497**	**0.002**	**0.003**	**0.083**	**-**	**0.004**
	Mixed Refuse 2	**0.5**	**0.980**	median		1.024			0.046		
			(0.957)	25th (10th)		0.321(0.077)			0.011(0.003)		
				75th (90th)		3.076(5.416)			0.111(0.244)		
				μ (σ)		2.032(2.922)			0.076(0.091)		
				integrated	**4.086**	**1.353**	**-**	**-**	**0.059**	**-**	**-**
	Mixed Refuse (1 and 2)	**0.5**	**0.923**	median		1.148	0.003	0.002	0.045		0.002
			(0.976)	25th (10th)		0.448(0.077)	0.001(0.000)	0.001(0.000)	0.013(0.003)		0.001(0.000)
				75th (90th)		3.424(6.499)	0.006(0.010)	0.004(0.007)	0.111(0.242)		0.005(0.010)
				μ (σ)		2.477(3.608)	0.004(0.003)	0.003(0.002)	0.079(0.095)		0.004(0.007)
				integrated	**3.991**	**1.998**	**0.000**	**0.002**	**0.066**	**-**	**0.003**
	Mixed Plastic	**0.74**	**0.962**	median		11.047	0.014		0.331		0.017
			(0.987)	25th (10th)		4.719(2.785)	0.009(0.005)		0.160(0.121)		0.005(0.003)
				75th (90th)		35.474(73.734)	0.025(0.045)		0.782(1.807)		0.030(0.080)
				μ (σ)		23.260(30.191)	0.018(0.015)		0.576(0.631)		0.026(0.040)
				integrated	**19.836**	**16.590**	**0.015**	**-**	**0.502**	**-**	**0.023**
	Chip Bags	**0.63**	**0.989**	median		2.456	0.004		0.012		0.004
			(0.986)	25th (10th)		1.238(0.567)	0.003(0.001)		0.004(0.002)		0.001(0.001)
				75th (90th)		4.965(15.976)	0.007(0.013)		0.033(0.098)		0.006(0.024)
				μ (σ)		4.846(8.504)	0.005(0.004)		0.026(0.040)		0.008(0.018)
				integrated	**5.804**	**3.484**	**0.003**	**-**	**0.021**	**-**	**0.005**

a. Carbon mass fraction of fuel from Stockwell et al. (2016)
b. Average modified combustion efficiency ($\Delta CO2/(\Delta CO+\Delta CO2)$) from Stockwell et al. (2016)
c. Sum of detected species (PAH not included)
d. Primary organic aerosol measured with the mAMS
(-) Indicates that the species was not detected above detection limit

					Fuel-based emission factor (g/kg fuel)							
Source	Type (fuel)	*f*[a]	MCE[b]		PM$_1$[c]	OA[d]	BC	SO$_4$	NO$_3$	Chl	NH$_4$	PAH
Motorcycles	**idling**	**0.85**	**0.6**	median		0.067						
	(gasoline)		(0.678)	25th (10th)		0.024(0.010)						
				75th (90th)		0.218(1.329)						
				μ (σ)		0.408(1.142)						
				integrated	**0.127**	**0.127**	-	-	-	-	-	-
Irrigation pumps	**Pump 1**	**0.87**	**0.987**	median		5.892	2.342					
	(diesel)		(0.978)	25th (10th)		4.654(4.024)	2.038(1.794)					
				75th (90th)		7.304(10.284)	2.698(3.490)					
				μ (σ)		5.983(2.167)	2.366(0.620)					
				integrated	**7.245**	**5.178**	**2.067**	**-**	**-**	**-**	**-**	**-**
	Pump 2	**0.87**	**0.996**	median		0.419	3.402	0.006				0.003
	(diesel)		(0.997)	25th (10th)		0.309(0.203)	2.643(2.329)	0.003(0.002)				0.002(0.001)
				75th (90th)		0.583(0.759)	4.840(5.912)	0.008(0.010)				0.005(0.015)
				μ (σ)		0.452(0.223)	3.685(1.458)	0.005(0.003)				0.009(0.030)
				integrated	**2.713**	**0.445**	**2.264**	**0.004**	**-**	**-**	**-**	**0.006**
Brick Kilns	**Batch Style Clamp Kiln (coal and harwood[e])**	**0.64**	**0.950**	median		0.604	0.011	0.353		0.042	0.126	
			(0.961)	25th (10th)		0.231(0.113)	0.003(0.000)	0.158(0.059)		0.015(0.004)	0.055(0.022)	
				75th (90th)		1.341(2.587)	0.024(0.043)	0.700(1.239)		0.101(0.207)	0.242(0.414)	
				μ (σ)		0.977(1.110)	0.022(0.056)	0.504(0.564)		0.082(0.113)	0.179(0.202)	
				integrated	**1.759**	**0.999**	**0.014**	**0.484**	**-**	**0.094**	**0.168**	**-**
	Forced-draft Zig-zag Kiln (coal and bagasse[f])	**0.72**	**0.994**	median		0.317	0.191	1.009			0.113	
			(0.991)	25th (10th)		0.136(0.077)	0.113(0.033)	0.582(0.229)			0.066(0.055)	
				75th (90th)		0.474(0.561)	0.871(1.111)	1.458(1.628)			0.142(0.179)	
				μ (σ)		0.295(0.183)	0.381(0.386)	0.912(0.528)			0.106(0.045)	
				integrated	**1.823**	**0.294**	**0.466**	**0.955**	**-**	**-**	**0.108**	**-**

a. Carbon mass fraction of fuel from Stockwell et al. (2016)
b. Average modified combustion efficiency (ΔCO2/(ΔCO+ΔCO2)) from Stockwell et al. (2016)
c. Sum of detected species (PAH not included)
d. Primary organic aerosol measured with the mAMS
e. Kiln estimated to be co-fired with 10% hardwood
f. Used as a starter fuel

(-) Indicates that the species was not detected above detection limit

4. AE33 Scattering Corrected Absorption Coefficient Emission Factors of Field Tested Emission Sources

		Absorption Coefficient (m^2/kg)	
Source Type	**Type (Fuel)**	**370 nm**	**880 nm**
1-pot traditional mudstove	dung	16.385	0.659
	hardwood	19.245	1.619
	sticks and twigs	24.652	4.045
2-pot traditional mudstove	dung and hardwood	13.824	1.251
Crop residue burning	mixed residue	21.219	3.189
	wheat	32.140	4.962
	mustard	35.462	4.345
	grass	17.254	2.201
Open garbage burning	mix 1	3.165	1.443
	mix 2	60.865	20.776
	mixed plastic	69.736	21.205
	chip bags	51.469	17.838
Motorcycles		bdl	bdl
Irrigation pumps	pump 1 (diesel)	50.639	16.060
	pump 2 (diesel)	44.093	17.573
Brick kilns	clamp (coal)	3.824	0.112
	zig-zag (coal)	7.149	3.618

Bdl = below detection limits