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COMPARATIVE STUDY OF COMBUSTION PRODUCT EMISSIONS OF PAKISTANI COAL BRIQUETTES AND TRADITIONAL PAKISTANI DOMESTIC FUELS[†]

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MARTIN MARIETTA ENERGY SYSTEMS, INC.
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ABSTRACT

A comparative emissions study was conducted on combustion products of various solid domestic cooking fuels; the objective was to compare relative levels of organic and inorganic toxic emissions from traditional Pakistani fuels (wood, wood charcoal, and dried animal dung) with manufactured low-rank coal briquettes (Lakhra and Sor-Range coals) under conditions simulating domestic cooking. A small combustion shed (12 m^3 internal volume, air exchange rate 14 h^{-1}) was used to simulate south Asian cooking rooms. 200-g charges of the various fuels were ignited in an Angethi stove located inside the shed, then combusted to completion; effluents from this combustion were monitored as a function of time. Measurements were made of respirable particulates, volatile and semi-volatile organics, CO, SO_2, and NO_x.

Overall it appears that emissions from coal briquettes containing combustion amendments (slaked lime, clay, and potassium nitrate oxidizer) are no greater than emissions from traditional fuels, and in some cases are significantly lower; generally, emissions are highest for all fuels in the early stages of combustion. Coal amendment proved effective in reducing respirable particulate emissions by a factor of about 4-fold compared to unamended coal; relative to traditional fuels, emission levels for the amended coals were comparable or lower. No significant emissions of toxic metals were detected. Of all the fuels investigated, the amended Lakhra coal produced the lowest volatile and semi-volatile organics emissions, while unamended Lakhra coal produced the highest organics emissions; organics emissions from amended coals were comparable with those from traditional fuels. Peak concentrations of CO in the range of 100-300 ppm were measured for all fuels; amended coals produced somewhat lower integrated emissions of CO than unamended coal, but all were comparable to traditional fuels. Coal additives significantly reduced total production of SO_2 (about 3- to 4-fold relative to unamended coal), but were ineffective in reducing peak emission of SO_2, which occurred during the ignition phase. Total SO_2 emissions from amended coals were comparable to those of traditional fuels. NO_x emissions were comparable for all fuels for both peak and integrated emission.

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1. INTRODUCTION

The Fuel Research Centre of the Pakistan Council of Scientific and Industrial Research (FRC-PCSIR) has developed several low-smoking coal briquette products using an inexpensive, dry briquetting process. If means can be found for using Pakistan's high-sulfur, lignitic coal economically and safely, it can be substituted for the traditional cooking fuels: wood, charcoal, animal dung, and kerosene. Deforestation could thus be slowed and kerosene imports reduced. Market evaluations of coal-based briquettes have indicated their attractiveness for use in domestic cooking, firing brick kilns, heating chicken brooders at poultry farms, and for cooking at road-side restaurants. The economics of the briquette products are favorable, with the relative ratio of BTU per Pakistani Rupee being [briquettes] > [wood] > [charcoal] > [kerosene].

The United States Agency for International Development (USAID) has provided machinery and equipment to carry out development of coal briquetting. Composition of the coal briquette products developed are summarized in Table 1. No evaluation had previously been conducted of combustion product emissions from these coal briquettes, or their potential impacts on indoor air quality and human health.

Briquette	Component	Composition
Coal A	Lakhra Coal	64.5%
	Slaked Lime	24.5%
	Clay	10.0%
	Potassium Nitrate	1.0%
Coal B	Lakhra Coal	54.8%
	Slaked Lime	20.8%
	Clay	8.5%
	Potassium Nitrate	0.8%
	Coke Dust	15.0%
Coal C	Sor-Range Coal	83.3%
	Slaked Lime	5.7%
	Clay	10.0%
	Potassium Nitrate	1.0%
Coal D	Lakhra Coal	100%

Table 1. Composition of coal briquettes. Specific surface of slaked lime, 7.67 m^2/g, measured by nitrogen sorption, courtesy E.L. Fuller, ORNL.

2. EXPERIMENTAL

2.1 COMBUSTION FACILITIES

A small outdoor combustion facility was constructed on the Oak Ridge Reservation; this building consisted of a commercial aluminum storage shed (4-m wide x 3-m deep x 2-m high, internal volume 12 m^3), with a non-combustible aluminum floor; a tarpaulin was affixed 0.5 m above the roof of the shed to minimize heat gain from sunshine. A schematic of the test facility is shown in Figure 1. A variable-speed fan connected to an external air intake allowed fresh air to be admitted into the building at a continuous rate; for all tests reported here, the fan was set to provide an air exchange rate of 14 h^{-1}. Air samples were collected during combustion using one of two approaches: particulates, volatile organics (VOCs) and semi-volatile organics (SVOCs) were collected on integrative filters situated inside the shed, approximately 0.3 m above and to the side of the burning sample; VOCs and inorganic oxides were sampled and analyzed continuously via ports on a wide-bore recirculating sample manifold, which had a fan directed into the mouth of the manifold. Two additional fans were located at opposite corners of the shed to facilitate homogenization of the interior air volume.

2.2 COMBUSTION PROTOCOL

Fuels were combusted on the grill of an Angethi stove, which is the traditional domestic cooking stove in Pakistan. The Angethi stove consists of a cylindrical metal barrel placed on end, with a metal grill situated radially at the mid-point. The upper portion includes a baked mud liner, which reduces the internal diameter from approximately 30 cm to 25 cm; the combustion chamber is approximately 12-cm deep. Fuel was placed in the upper chamber on top of the grill, and in our experiments was burned uncovered. The stove utilized in this study was designed to accept approximately 1- to 1.5-kg charcoal. Because of the copious emissions from this amount of fuel, the amount of fuel used was reduced to 200 g for these studies in order to maintain gas concentrations within the span of our monitoring instruments.

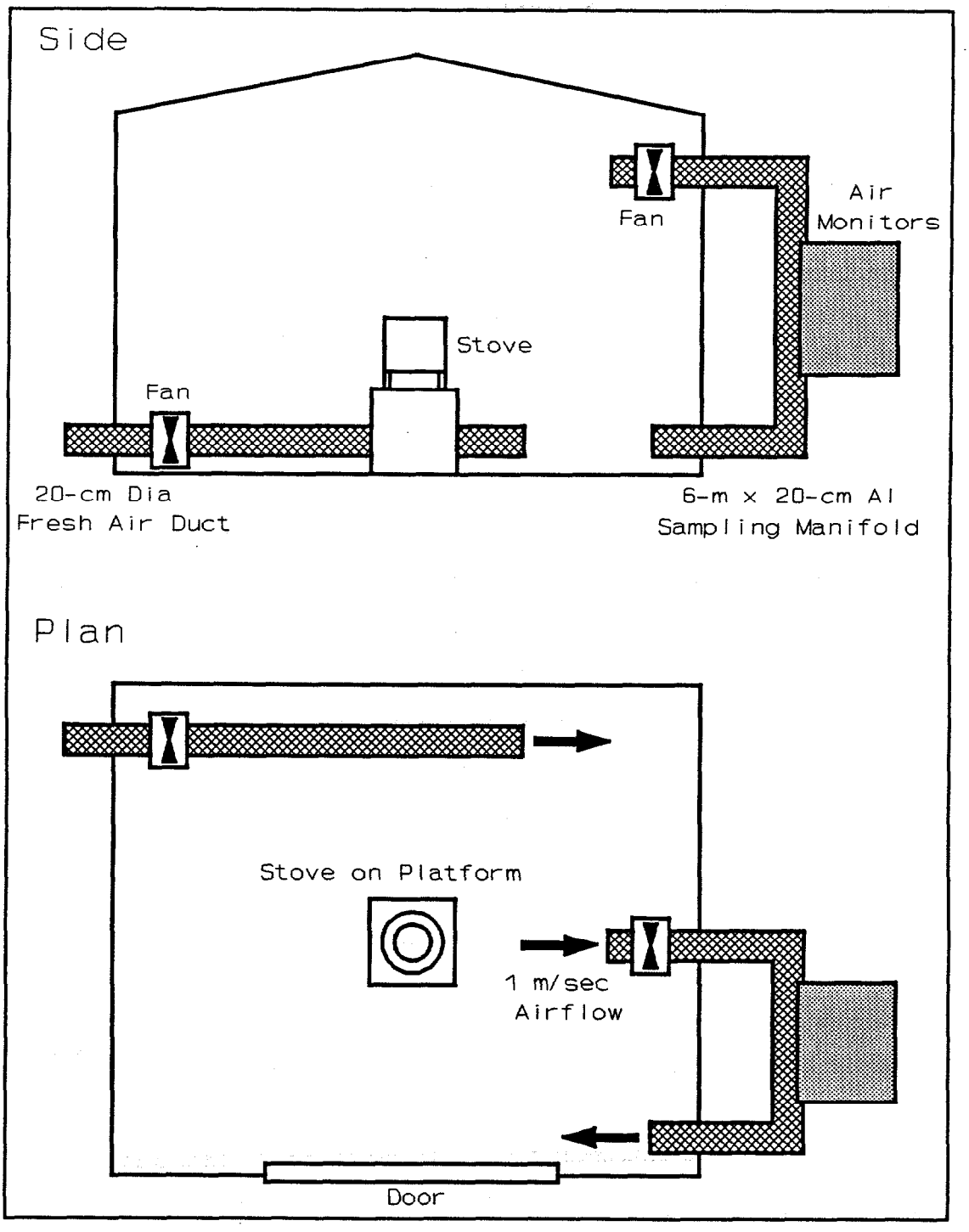

Figure 1. Briquette combustion shed at ORNL.

The 2.5 cm x 7.5 cm briquettes were broken into smaller pieces (ca. 1- to 2-cm on edge) to facilitate combustion of the smaller than normal charge. The fuel was arranged in a pyramidal pile in the center of the grill, and the loaded stove was placed at the center of the floor of the shed. Fuel was ignited using a propane torch, held below the grate for approximately 5 minutes; emission monitoring commenced upon contact of the flame with the fuel. After this ignition step, the door to the shed was kept closed throughout the remainder of emission testing to maintain the standard air exchange rate. In blank tests using only the propane torch and no solid fuel, no significant emissions of the target pollutants were detected. An oxygen monitor was used inside the shed to verify that oxygen depletion did not occur during combustion.

2.3 INSTRUMENTATION

A battery of instruments was required to conduct the full set of emissions measurements. These are classified below by analyte:

Inorganic particulates:	Harvard particulate sampler, 0.0035 m^3 min^{-1} flow rate, 2-μm pore, 41-mm diameter PTFE membrane filter, 200-min sampling interval. Samples analyzed gravimetrically and by ICP/MS, EPA Method 200.8.
Organic particulates:	Pallflex particulate sampler, 0.010 m^3 min^{-1} flow rate, Putnam Type T60A20 glass fiber membrane filter, 200-min sampling interval. Samples analyzed gravimetrically and for polynuclear aromatic content by ORNL method ACD-8270, based on EPA Method 625.
VOCs/SVOCs:	Triple sorbent trap, composed of 14-mm long x 4-mm diameter beds of Supelco Carbotrap C, Carbotrap, and Carbosieve S-III, in series; 0.170 m^3 min^{-1} flow rate, 15-min sampling interval. Collected samples analyzed by 250°C thermally-aided purge and cryogenic trap GC/MS, 70 eV electron-impact ionization.

VOCs:	Photovac 10S50 photoionization gas chromatograph (GC/PID), ambient temperature operation; Photovac SA1020 column, 530-μm diameter wide-bore fused silica, Chrompack CPSil 5 CB coating. Grab sampling analyzed by immediate on-column injection.
Carbon Monoxide:	GasTech GX-4000 electrochemical monitor, 0-250 ppm range.
Sulfur Dioxide:	GasTech GX-4000 electrochemical monitor, 0-50 ppm range.
Nitrogen Oxides:	Columbia Scientific CSI-1600 NO_x Analyzer, 0-5.0 ppm range.
Oxygen Monitor:	GasTech GX-4000 electrochemical monitor, 0-25% range.

2.4 MONITORING PERIOD

Complete combustion was generally achieved within about one hour; however, to provide accurate emission factors, monitoring was continued until the gas analyzers returned to baseline; this generally required monitoring for a period of 3-4 hours following ignition.

2.5 SAMPLES TESTED

All samples studied were provided by the FRC, and represented either traditional Pakistani domestic fuels or potential fuel replacements. Along with the four coal briquette types shown in Table 1, samples of wood, wood charcoal, and animal dung were tested. Order of burning of the various samples was randomized. A minimum of three combustion runs were conducted for each fuel.

2.6 CALCULATIONS

Combustion data reported are averaged for replicate analyses. Since combustion conditions (such as air exchange rate and sample size) were maintained within a carefully

regulated range, this approach minimizes the effects of differences between individual burns; such differences might arise due to minor variations in initiation and rate of combustion, incomplete combustion in briquette cores, loss of material through the grate of the Angethi stove, and sample inhomogeneities. Based on the approach used by Wilson and Hawthorne in earlier briquette combustion tests, the following calculations were made [1]:

Combustion Efficiency: $[1-A/W]\bullet 100\%$

Respirable Particulates: $[\delta W_f \bullet V]/[W \bullet F \bullet T]$

Relative Emission Factor: $\int C/W$

where A is the ash weight (kg), W is the weight of fuel (kg), δW_f is the weight of particulates on a filter (mg), V is the chamber volume (m^3), F is the sampling rate of sampler (m^3/min), T is the sampling interval (min), and $\int C$ is the integrated concentration of a pollutant (g/m^3).

2.7 QUALITY ASSURANCE

Gas monitors were calibrated throughout the study utilizing commercially available standards, as shown in Table 2. The GC/PID system was calibrated prior to each combustion run using toluene and benzene vapor standards. Integrating samplers (particulates and VOC/SVOC traps) were calibrated according to the appropriate EPA protocol (identified in Section 2.3).

Calibrant	Concentration	Source
Air	Ultra Zero Grade	Alphagaz
CO	47 ppm	Alphagaz
SO_2	1.3 ppm	Alphagaz
NO_2	5 ppm	Alphagaz
Benzene	9.7 ppm	Scott Specialty Gases
Toluene	9.9 ppm	Scott Specialty Gases

Table 2. Gas standards for instrument calibration.

3. RESULTS

3.1 COMBUSTION EFFICIENCY

Combustion efficiency is the percent weight loss of combusted fuel, primarily via combustion of carbonaceous components, and is based on gravimetric analysis of ash. Combustion efficiencies for the fuel samples varied substantially, with traditional fuels providing the most complete combustion. Average values and sample ranges are shown in Table 3. Traditional fuels burned readily, leaving little residue; because of the very fine, flocculent nature of the ash from animal dung, complete collection of ash was impossible, requiring estimation of combustion efficiency. Among the briquettes, Coal D, which is composed of pure, unamended Lakhra coal, furnished the most complete combustion. Because of its non-combustible amendments, Coal C burned less completely than Coal D, and produced a somewhat coarser ash. Coals A and B burned significantly less efficiently, and produced hard cinder-like ash. Furthermore, these very hard briquettes frequently left an unburned core, which complicates calculation of combustion efficiencies.

Sample	Combustion Efficiency (CE)			Ash Description
	Average	Range	N	
Coal A	54.4 ± 5.1	61.3-49.0	3	Cinders
Coal B	40.8 ± 8.5	52.2-32.0	3	Cinders
Coal C	77.0 ± 3.9	81.6-71.1	4	Grainy
Coal D	80.5 ± 3.2	83.7-77.3	3	Grainy
Wood	92.6	-	1	Fine-Grainy
Charcoal	96.1 ± 0.4	95.7-96.5	2	Grainy
Dung	> 95	-	3	Fine

Table 3. Combustion data for samples tested.

3.2 RESPIRABLE PARTICULATES

Respirable inorganic and organic particulate emissions from each fuel type are summarized in Table 4. Inorganic particulates were collected using Harvard samplers at three locations: *Proximal*, at a lateral distance of 25 cm from the Angethi stove; *Medial*, at a distance of 50 cm; and *Distal*, 100 cm; sampler inlets were at an elevation 25 cm above the top of the stove, approximating the face location of a cook at the stove. As expected, despite thorough mixing of the air in the shed, particulate levels were found to fall rapidly with distance from the source. Amended coal briquettes (Coals A, B, and C) produced inorganic particulates at levels comparable to wood; animal dung and charcoal emissions were approximately 3-fold greater; and Coal D produced the highest emissions, with levels roughly 4-fold greater than the amended coals. Organic particulates, collected on a single Pallflex sampler located 25 cm lateral and vertical distance from the stove, showed the same trend in total emissions. The gravimetric data is compared graphically in Figure 2. These emission profiles support the conclusion that particulate emissions fall into two categories: a low emission category, consisting of Coals A, B, and C, along with wood; and a high emission category, Coal D, dung, and charcoal. In comparison with Canadian domestic indoor air quality standards as provided in Table 5 [2], the relative levels are not exceptionally high: for example, a 200-g sample of Coal D produces a maximum estimated 1-h particulate exposure of 1-2 $\mu g/m^3$ under the combustion conditions utilized in this study; this is considerably lower than the 1-hr standard of 100 $\mu g/m^3$.

Sample	Inorganic			Organic
	Proximal	*Medial*	*Distal*	
Coal A	0.292 ± 0.120	0.172 ± 0.120	0.095 ± 0.120	0.186
Coal B	0.249 ± 0.034	0.198 ± 0.069	0.138 ± 0.034	-
Coal C	0.232 ± 0.138	0.120 ± 0.103	0.095 ± 0.112	0.345
Coal D	0.955 ± 0.421	0.731 ± 0.353	0.731 ± 0.327	0.720
Wood	0.258	0.215	0.198	0.147
Charcoal	0.783 ± 0.447	0.585 ± 0.387	0.559 ± 0.387	-
Dung	0.774 ± 0.413	0.344 ± 0.069	0.430 ± 0.146	0.564

Table 4. Total respirable particulate emissions, mg/kg fuel combusted.

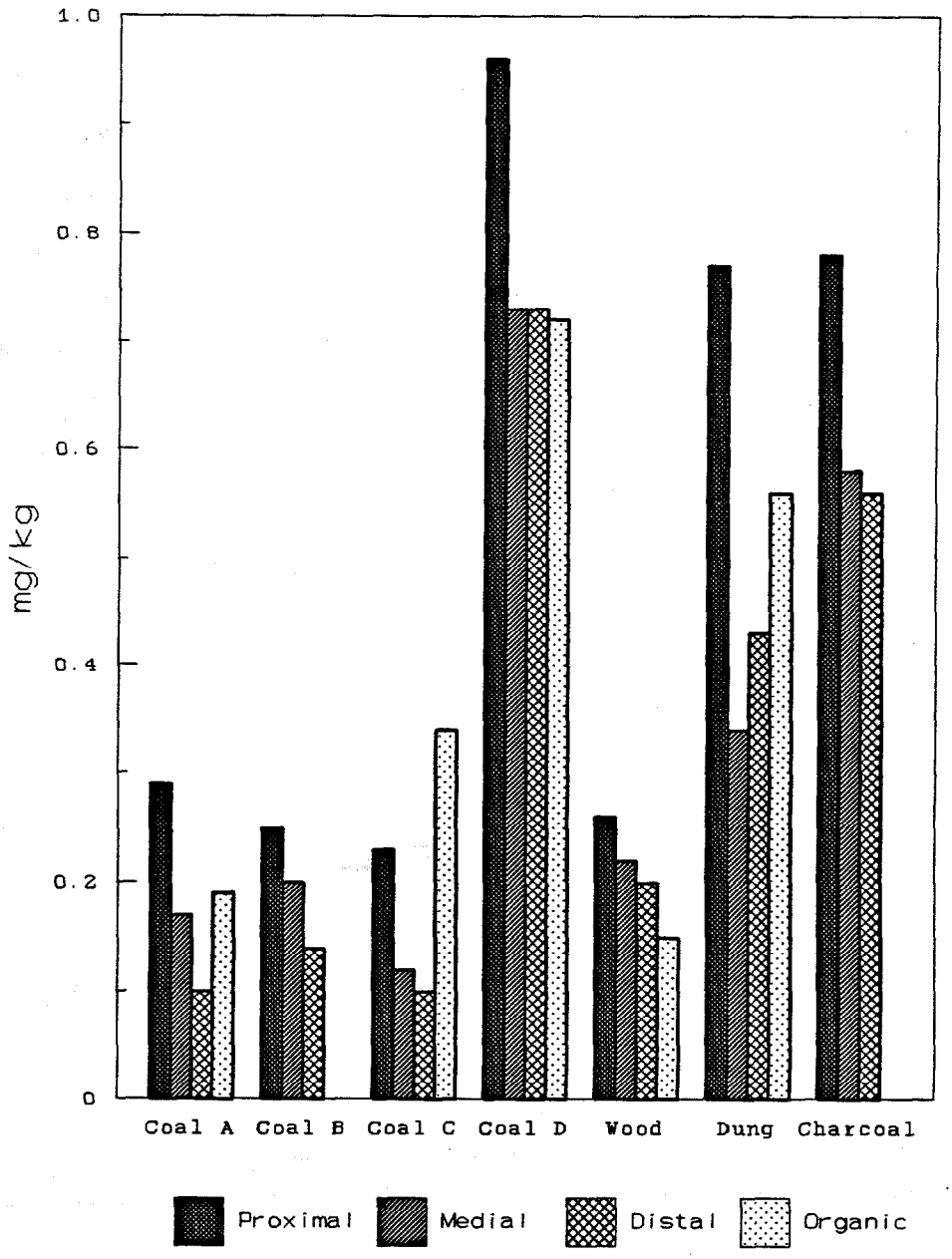

Figure 2. Analysis of inorganic and organic respirable particulates.

	Exposure	Duration	$\mu g/m^3$
Respirable Particulates	ALTER	8 h	≤ 40
	ASTER	1 h	≤ 100
Total Organics	ALTER	8 h	≤ 5,000
CO	ALTER	8 h	≤ 11,000
	ASTER	1 h	≤ 2,500
SO_2	ALTER	8 h	≤ 50
	ASTER	5 min	≤ 1,000
NO_x	ALTER	8 h	≤ 100
	ASTER	5 min	≤ 480

Table 5. Canadian domestic indoor air quality guidelines [2]. ALTER, acceptable long-term exposure range; ASTER, acceptable short-term exposure range.

	Std. Coal	Dung	Wood	Coal A	Coal B	Coal C	Coal D
Weight Collected, μg		7.0, 13.4	3.0	10.1, 10.4	2.9, 3.0	3.4	11.3, 11.0
No. Trials	101	2	1	2	2	1	2
As	14.0	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Be	1.6	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cd	2.5	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Cr	13.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Pb	34.8	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Sb	13	n.d.	n.d.	n.d.	n.d.	n.d.	2.2 ± 2.9
Se	2.1	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Zn	272.3	n.d.	1.2	3.0 ± 0.28	n.d.	1.2	1.8 ± 0.5

Table 6. Analyses of inorganic particulates, by ICP/MS, reporting total μg detected. Std. Coal represents the mean concentration (ppm) in 101 coals [3]. n.d., not detected.

Analyses of the inorganic and organic composition of the collected particulates indicated that no elevated levels of toxic substances were detectable; these data are summarized in Tables 6 and 7. Very low levels of zinc are found in particulates from Coals A and D, as well as wood; similarly low levels of antimony are found for Coal D. Fluoranthene is found at levels barely above the detection limit of 100 mg/Kg of particulates from Coal C. Overall, these levels are quite low, and there is no clear basis for distinction between the briquettes and traditional fuels. Because numerous studies have demonstrated significant levels of polycyclic aromatic hydrocarbons (PAHs) in coal smokes, the organic particulate results are suspicious, and are being repeated.

Sample	Target Compounds	Other Compounds
Coal A	n.d.	10 Hydrocarbons
Coal C	110 mg/Kg fluoranthene	12 Hydrocarbons
Coal D	n.d.	12 Hydrocarbons
Dung	n.d.	n.d.
Wood	n.d.	n.d.

Table 7. Analyses of organic particulates, by GC/MS. Target compounds, per EPA Method 625. n.d., not detected.

3.3 ORGANIC VOLATILES

Organic volatile analyses were conducted during combustion of the fuels; grab samples were collected 15, 30, and 45 minutes into a trial, to estimate flux in emissions from ignition through char-burning phases. Samples were immediately analyzed by photoionization gas chromatography for content of benzene, toluene, and total photoionizable compounds (PIC). Results of these analyses are provided in Table 8, and are shown graphically in Figure 3.

Comparison of GC/PID results shows that, in terms of relative aromatic emissions, combustion of Coal D generated approximately 4-fold greater concentrations of benzene and toluene than all other fuels. The amended coals and traditional fuels are clustered in a range below about 20 ppm. Combustion of the unamended Coal D briquettes also generated significantly higher levels of total PIC emissions than all other fuels.

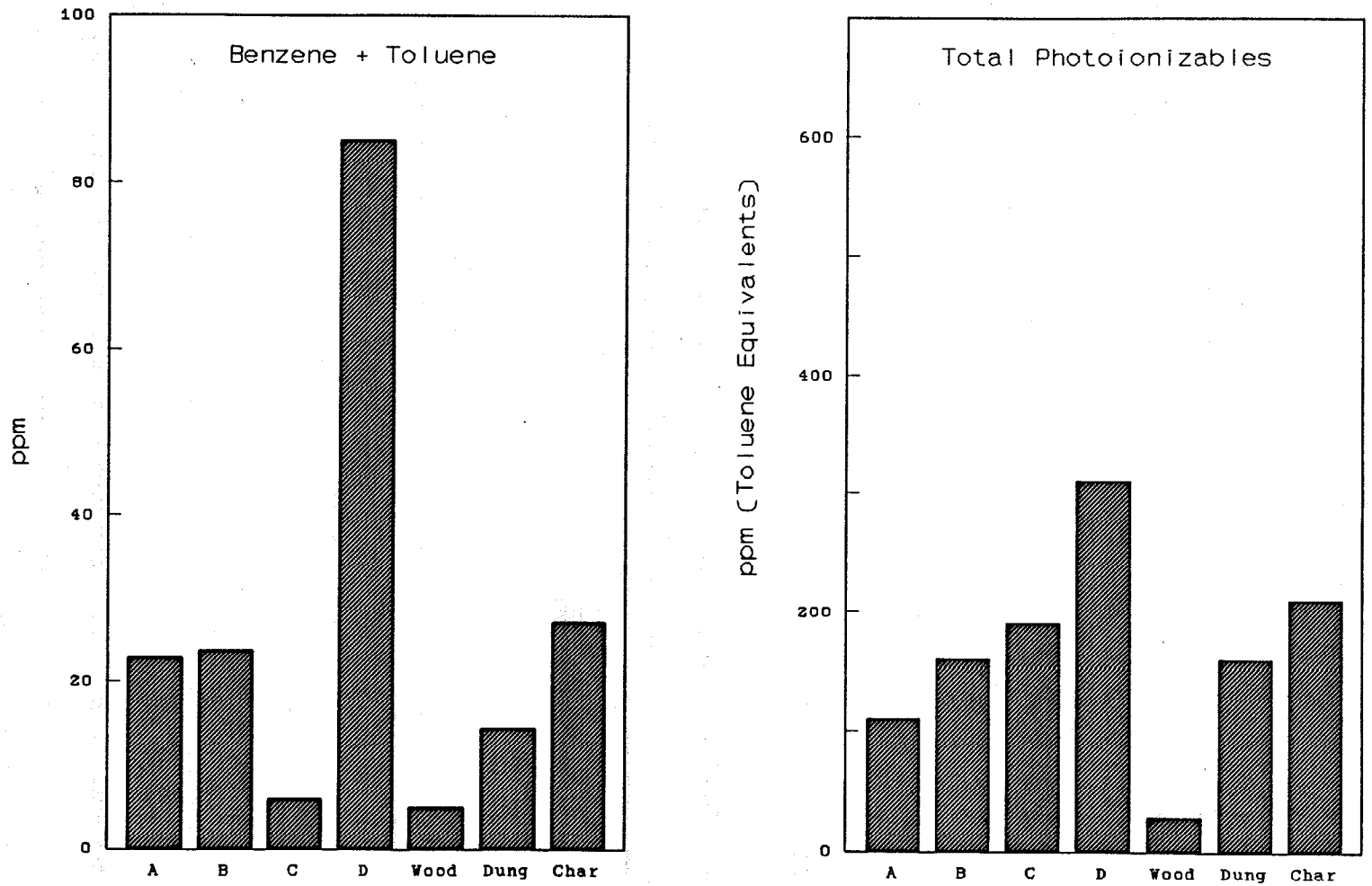

Figure 3. GC/PID analysis of VOC combustion products.

Sample	Benzene			Toluene			Total PIC		
	15 min	30 min	45 min	15 min	30 min	45 min	15 min	30 min	45 min
Dung	5.8±1.8	-	0.6	8.5±0.7	-	0.8	160	-	13
Wood	3.7	0.5	n.d.	1.1	n.d.	n.d.	28	4	4
Charcoal	11	2.0	n.d.	16	1.1	n.d.	210	16	2
Coal A	12.8±6.2	10.4±1.6	n.d.	9.9±7.1	6.0±4.0	n.d.	110	68	3
Coal B	8.6	12	4.3	15	16	2.0	160	220	34
Coal C	2.8	4.9	1.6	3.0	3.5	0.3	190	180	110
Coal D	52	34	1.5	33	15	0.4	310	120	4

Table 8. Effluent analysis by photoionization GC. Benzene and toluene in ppm, total PIC in toluene equivalents.

3.4 ORGANIC VOLATILES AND SEMIVOLATILES

Integrated VOC and SVOC analyses were conducted on materials entrained on triple sorbent traps during fuel combustion; these samples allow estimatation of total effluent from ignition through char-burning phases. Samples were analyzed by EI-GC/MS, and the resulting fragmentation patterns and relative retention times were used for tentative compound identification. Results are tabulated in Table 9, and shown graphically in Figure 4.

Mirroring the GC/PID results, Coal D produced the highest emissions in nearly all categories, except phenols and furans; no phenols were observed for any of the coals, while these emissions were fairly substantial for the traditional fuels. Emissions of combined benzene, toluene and xylenes (BTX) were considerably greater for Coal D than for any other fuel. In contrast, emissions for the amended coal briquettes were comparable to or lower than those of the traditional fuels for all compound classes. Of interest, emissions of light polycyclic aromatic hydrocarbons (PAHs), having 2- to 3-ring structures, were observed for all fuels; this is contradictory to the organic particulate data, which showed no significant PAH content for any of the fuels. Again, Coal D produced significantly higher levels of this potentially important pollutant category.

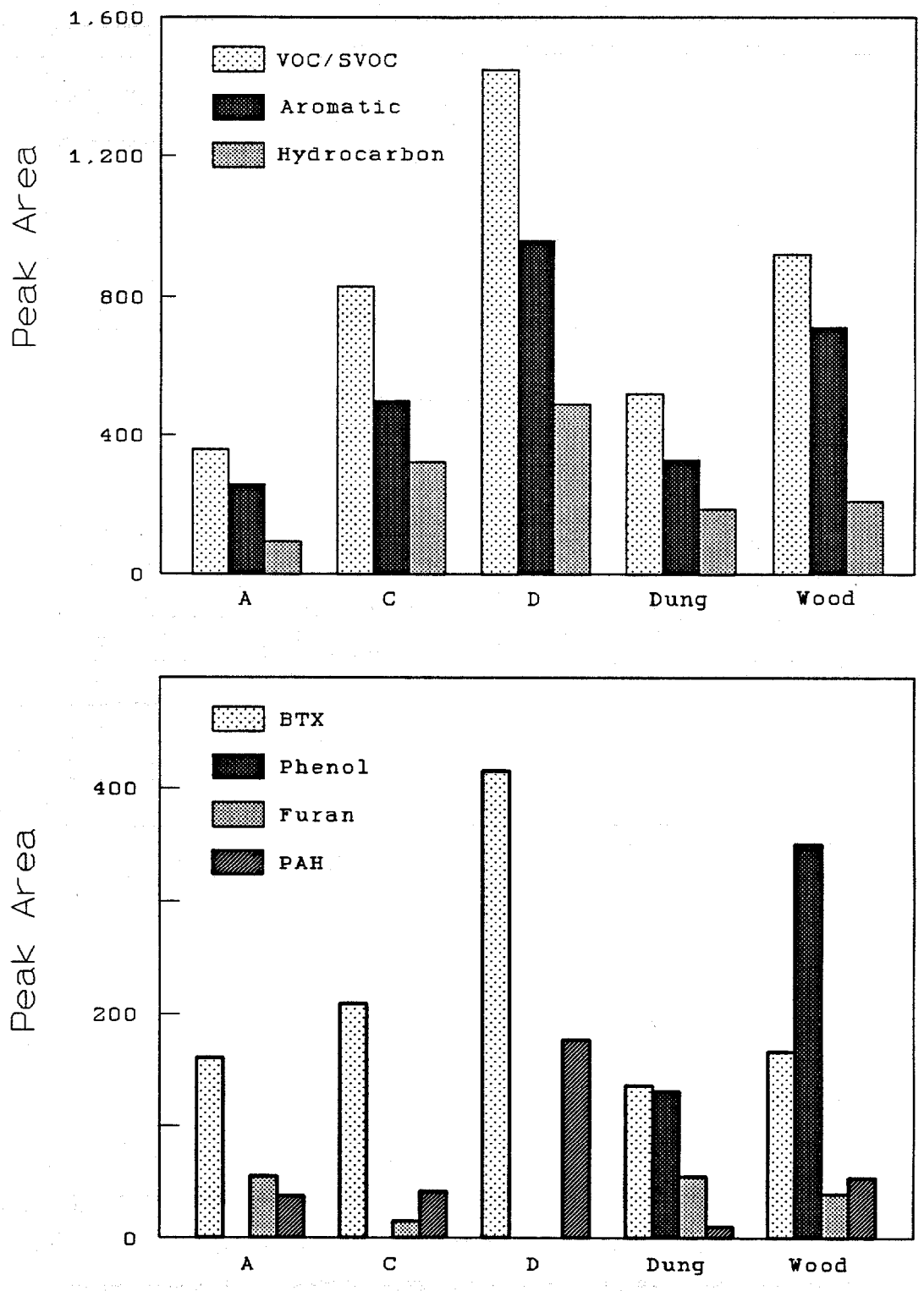

Figure 4. GC/MS analysis of VOC and SVOC combustion products.

Analyte	Coal A	Coal C	Coal D	Dung	Wood
Total Organics	0.248	0.572	1.000	0.359	0.634
Aromatic	0.179	0.345	0.662	0.228	0.490
BTX	0.110	0.143	0.286	0.094	0.114
Phenols	0.000	0.000	0.000	0.090	0.241
Furans	0.038	0.010	0.000	0.038	0.028
PAHs	0.026	0.029	0.121	0.007	0.037
Hydrocarbon	0.066	0.224	0.338	0.131	0.145

Table 9. Relative GC-MS response, by tentative chemical class.

	CO			NO_x			SO_2		
	[Pk]	t	EF	[Pk]	t	EF	[Pk]	t	EF
Coal A	92	0.30	26	2.2	0.18	0.32	14.6	0.32	2.2
Coal B	277	0.22	42	6.2	0.17	0.58	15.1	0.20	1.7
Coal C	138	1.18	50	0.7	0.28	0.19	13.8	0.25	3.5
Coal D	179	0.33	54	1.8	0.27	0.34	18.2	1.18	7.2
Wood	239	0.20	34	1.9	0.22	0.31	11.2	0.33	2.0
Dung	203	0.53	41	8.4	0.15	0.57	15.4	0.32	2.5
Char	313	0.57	66	2.5	0.60	0.63	6.8	0.57	1.4

Table 10. Peak concentrations ([Pk] in mg/m^3), peak times (t in hours), and relative emission factors (EF in g/kg) for inorganic oxides.

3.5 CARBON MONOXIDE

Results from continuous monitoring of carbon monoxide levels throughout combustion are provided in Table 10, and are shown graphically in Figure 5. While no major differences are noted between fuels, several general observations are possible. Obviously the briquettes are comparable or lower than the traditional fuels in peak and total CO emissions; however,

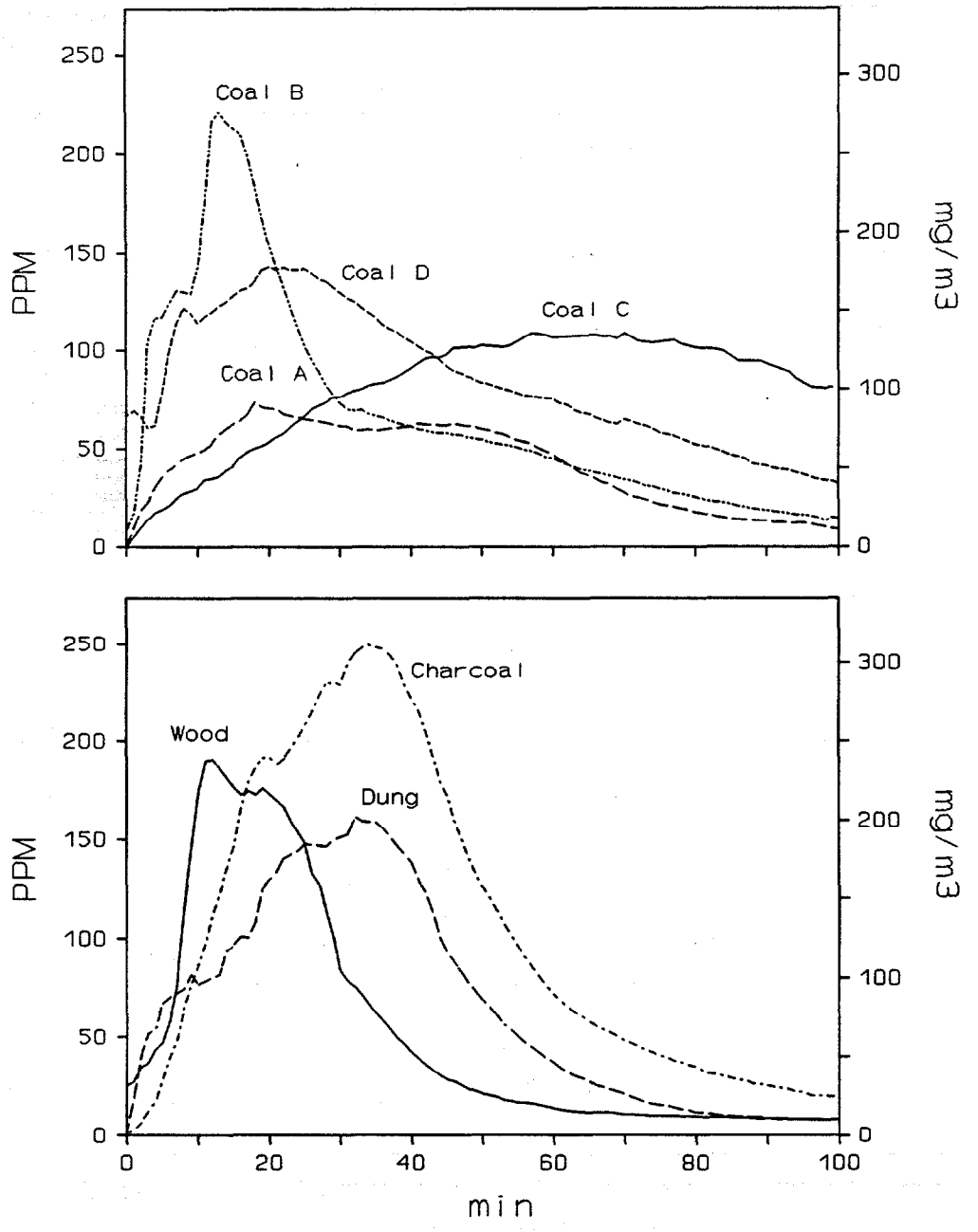

Figure 5. Carbon monoxide emissions.

since peak concentrations significantly exceed the 25 mg/m^3 ASTER level [2] and may produce transient or long-term toxic effects, the CO emissions of all fuels tested are significant. Emissions are generally greatest immediately following ignition, and tend to decrease rapidly upon transition to the char-phase of burning. CO emissions for the briquettes are proportional to the fraction of combustible fuel present (inversely proportional to weight percentage of additives), suggesting that the fuel additives have no significant effect on CO emission per unit of matter burned.

3.6 NITROGEN OXIDES

Results from continuous monitoring of nitrogen oxide levels are provided in Table 10, and shown in Figure 6. No clear trends are obvious from this data; note however, that NO_x levels are relatively high for all fuels (ASTER NO_x, 480 $\mu g/m^3$). No significant background was detected for the propane torch used as an ignition source. Hence, differences in measured NO_x levels seem to be primarily related to characteristics of the fuels.

3.7 SULFUR DIOXIDE

Results from continuous monitoring of sulfur dioxide levels are provided in Table 10, and shown in Figure 7. Charcoal is significant for its low peak and total SO_2 emissions, while Coal D is equally significant for its elevated total emissions; the amended coals and the other traditional fuels are comparable in terms of peak and total emissions. Amendment has the benefit of reducing total SO_2 emissions from the low-range coals, but peak emissions for all fuels are still significant (ASTER SO_2, 1 mg/m^3).

3.8 COMPARISON OF OXIDE RESULTS

Oxide emission profiles are compared in Figure 8; this figure allows relative comparison of peak and integrated emission factors for all fuels. It is clear from this representation that emissions from the coal briquettes are comparable to or lower than those from the traditional fuels, with the significant exception of SO_2 emissions from the unamended Lakhra coal briquettes (Coal D).

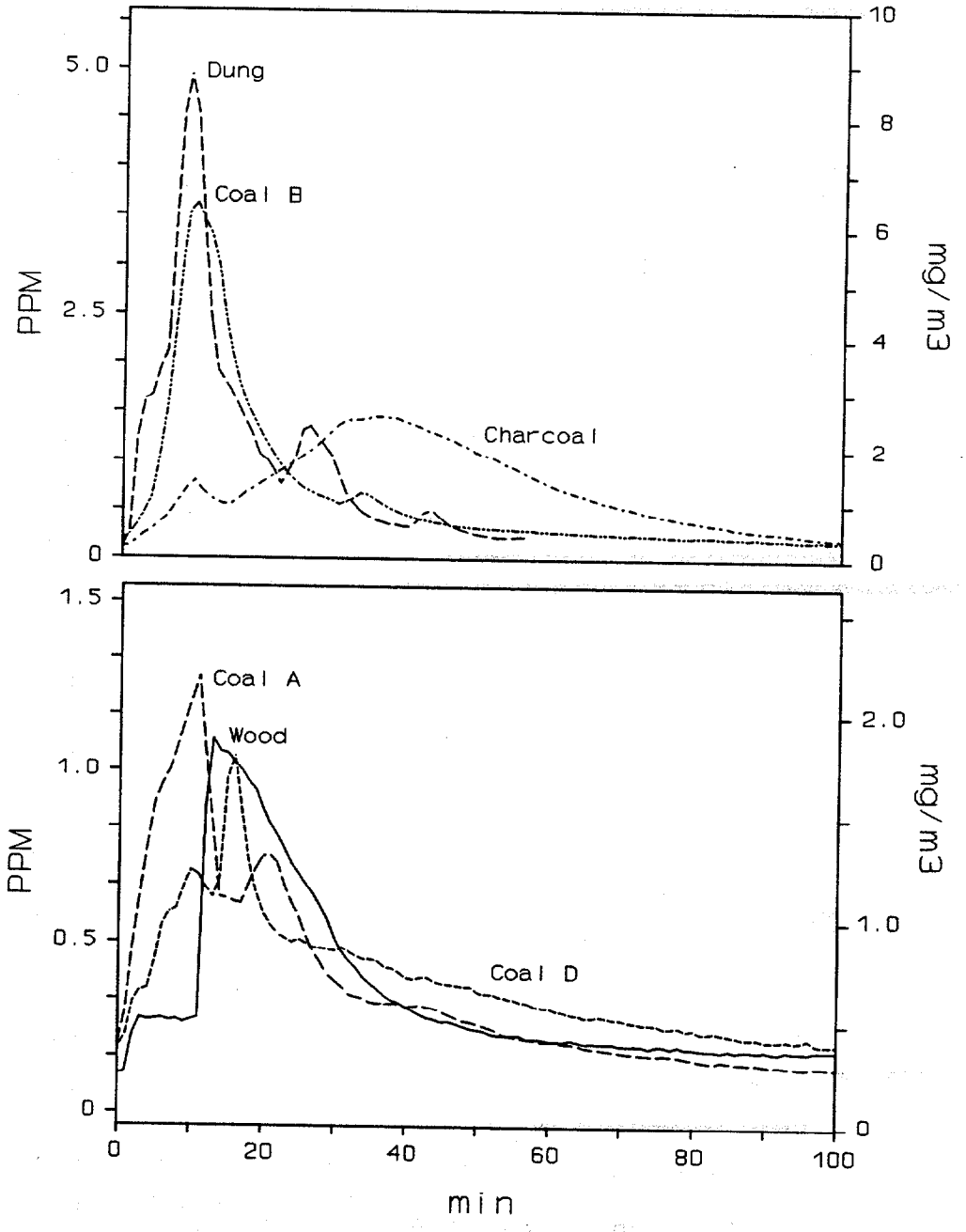

Figure 6. Nitrogen oxides emissions.

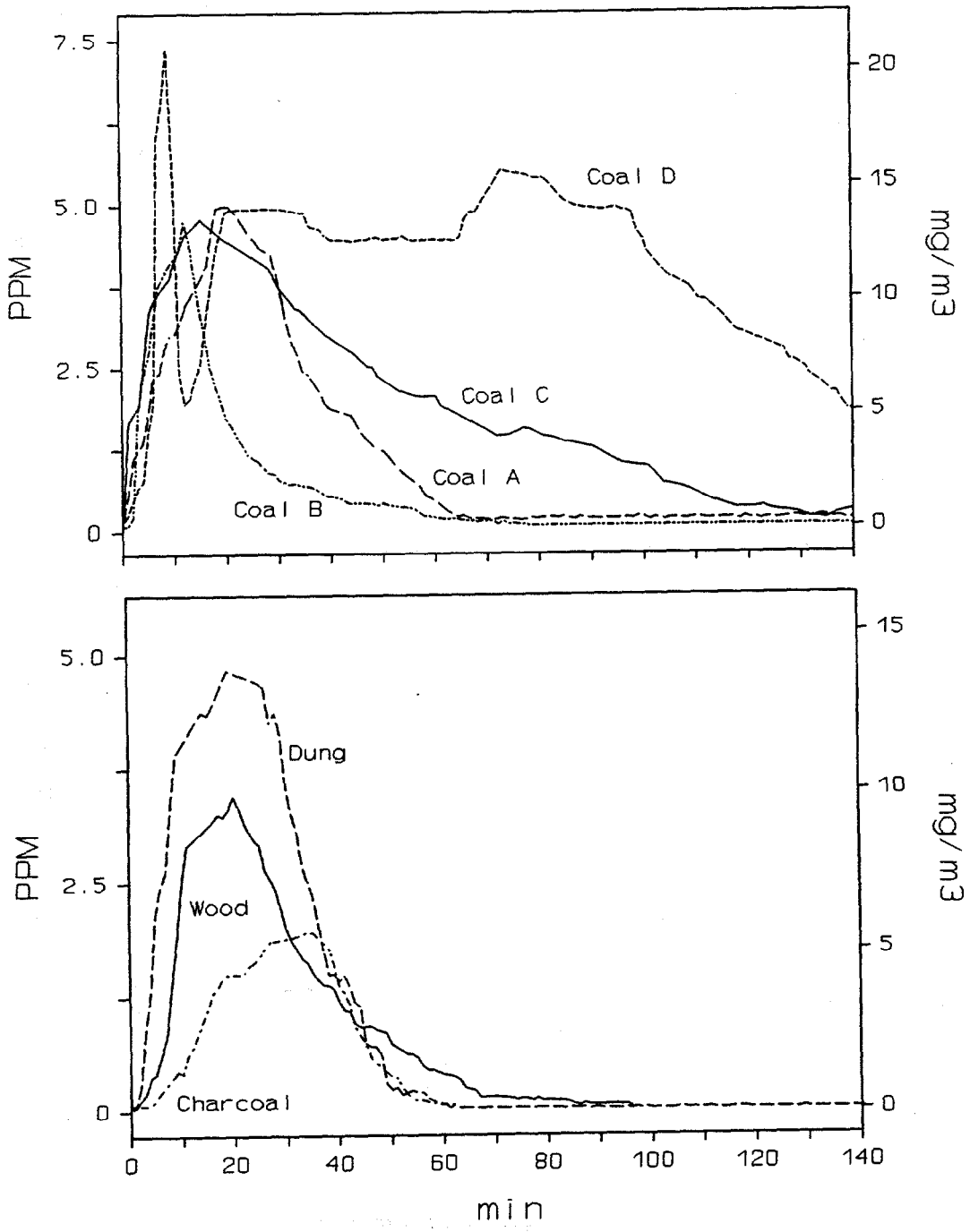

Figure 7. Sulfur dioxide emissions.

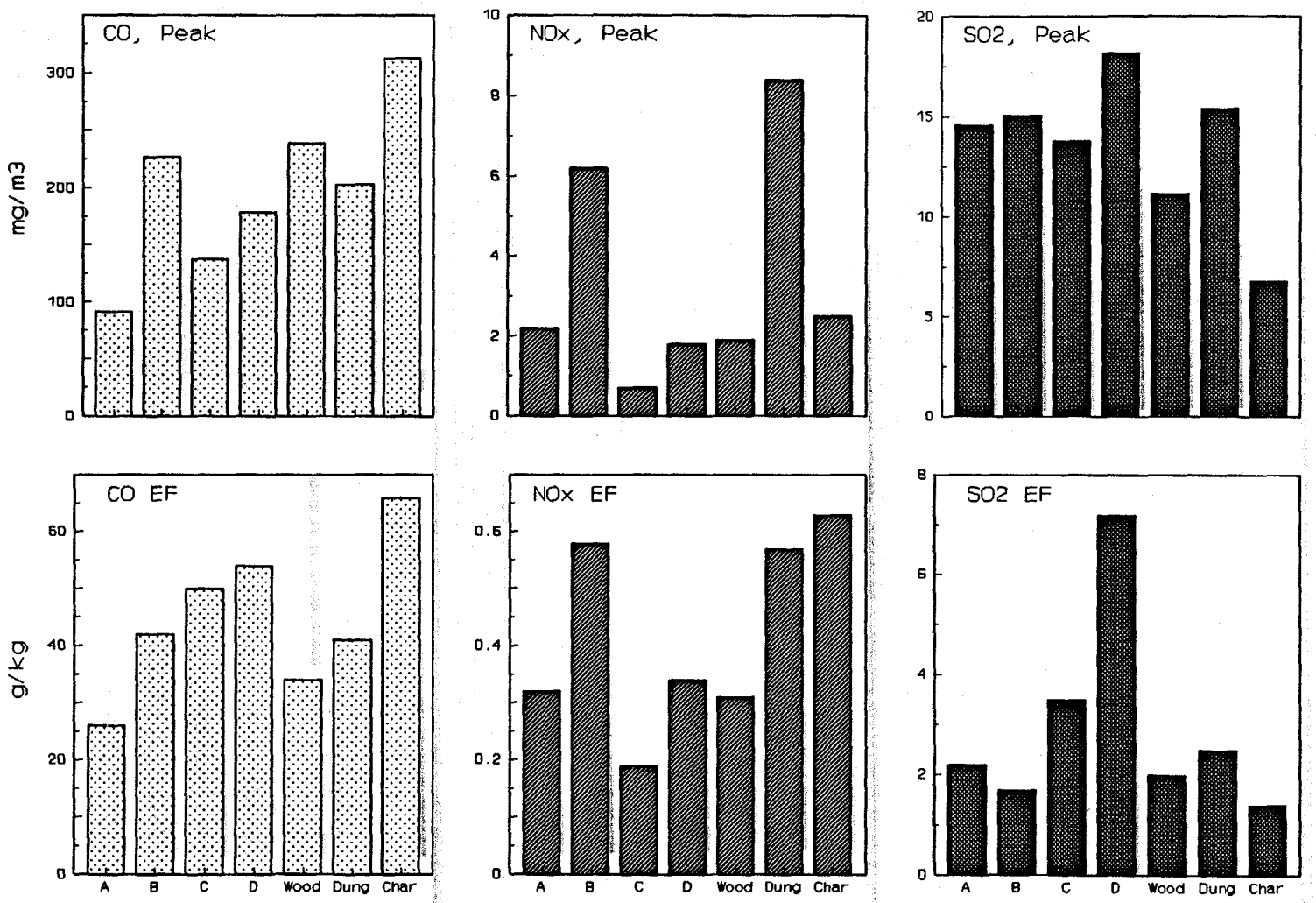

Figure 8. Comparision of oxide emissions.

4. SUMMARY

The purpose of the coal briquette study was to measure and evaluate combustion emissions from Pakistani domestic fuels. Under normal fuel usage conditions, where fuels are burned indoors in unvented, open stoves, pollutant emissions may be at levels sufficient to pose both acute and chronic health threats. The results permit comparison on a relative scale between emissions from amended coal briquettes, unamended coal briquettes, and traditional fuels such as wood, wood charcoal, and animal dung. Overall, it appears that emissions from the amended coal briquette products are comparable to or lower than those from traditional fuels for all pollutant categories investigated (organic and inorganic respirable particulates, VOC and SVOC emissions, and CO, NO_x, and SO_2 emissions). Emissions of particulates, VOCs and SVOCs, and of total sulfur dioxide appear to be significantly reduced for low-range coal briquettes *via* the introduction of the amendments shown in Table 1.

These generally favorable pronouncements need further qualification. The peak emissions and relative emission factors are valid only for the standard conditions used in our tests (*i.e.*, 200 g charge of fuel burned in a medium-sized Angethi stove inside a 12 m^3 shed at an air exchange rate of 14 h^{-1}). This relatively small charge of fuel was needed to accommodate the high sensitivities of our monitoring devices. Such a small charge of fuel resulted in rather uneven and sometimes incomplete burning. Coal briquettes were frequently left with an unburned core which complicated calculation of emission factors. Further tests should be conducted under more representative conditions of fuel loading (ca. 1-1.5 kg) of the Angethi stoves; provision for dilution of the sampled air will probably be necessary to protect monitoring equipment.

Potential heath affects resulting from high peak exposures soon after initial firing can be avoided by lighting the stove in the open and later moving the burning stove inside. If combustion is conducted in this manner, the coal briquettes with additives become even more attractive as an alternative for traditional domestic fuels from a human health perspective.

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