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REDUCED EMISSIONS FROM INEXPENSIVE HIGH-SULPHUR COAL BRIQUETTES

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Abstract

Airborne emissions were measured during the combustion of Pakistani high-sulphur coal, cold briquetted with lime and clay; comparison was made to emissions from raw coal and traditional fuels burnt in a native, mud-lined Angethi stove. Compared to raw coal, the amended coal gave fourfold reduced emission of respirable-size particles (RSP) and threefold reduced total releases of SO_2. In domestic cooking, substitution of the amended coal briquettes for traditional fuels will not worsen indoor air quality with respect to CO, SO_2, NO_x, and RSP. The high peak amounts of CO (100 - 250 ppm), SO_2 (2-5 ppm), and NO_x (1-5 ppm) were limited to the early phase of burning. The high thermal value of the coal briquettes, together with a simple briquetting technology, make this fuel an attractive energy alternative in countries that are underdeveloped, developing, or experiencing major restructuring.

Introduction

Countries that are underdeveloped, developing, or restructuring often have deposits of high-sulphur coal. This energy source is generally underutilized because of severe pollution problems associated with its combustion or the high costs of technologies to suppress emissions of smoke and SO_2. Pakistan has poor quality coal, lignitic to sub-bituminous in rank and with high mineral and sulphur (3-7%) contents.

Support by the U.S. Agency for International Development was provided to the Fuel Research Center, Karachi, Pakistan, for coal briquetting machinery. Inexpensive, cold-briquetting procedures were developed for producing inexpensive lime- and clay-containing coal briquettes that gave optimally reduced emissions of SO_2 and smoke.[1] Oak Ridge National Laboratory was given the task of evaluating the emissions under conditions simulating domestic cooking in a Pakistani hut. A major objective was to rank the emissions from amended coal briquettes against the emissions produced in burning raw coal and traditional fuels such as wood, charcoal, and dung.

An initial market assessment indicated that a substantial Pakistani market exists for the briquettes, including the poultry industry that uses heating stoves, brick kilns, space heating, and household cooking.[2] The amended briquettes have a thermal value about twice that of wood, charcoal, or kerosene.[3] To cook a typical meal using briquettes costs about six cents U.S.

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Methods

The crushed coal was cold briquetted with slaked lime (6-25%), bentonite clay (10%), and water in amounts depending on the type of coal and its sulphur content. A potassium nitrate oxidant (1%) was added to improve combustability. To simulate the domestic cooking environment, a traditional Angethi stove was operated inside a 12 m^3 metal shed. Forced ventilation produced a constant rate of air exchange of 14 h^{-1}. Particulates were sampled directly inside the shed. Volatile effluents were monitored external to the shed inside a mobile van via a sampling manifold through which shed air was rapidly transported (8 m/sec). A schematic in Fig. 1 shows the arrangement used.

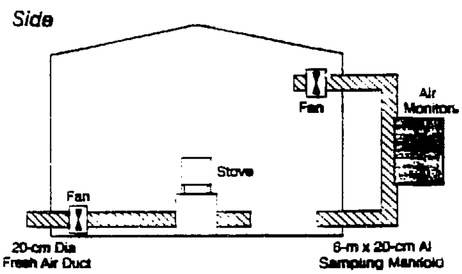


Fig. 1. Shed, air ventilation, and air circulation

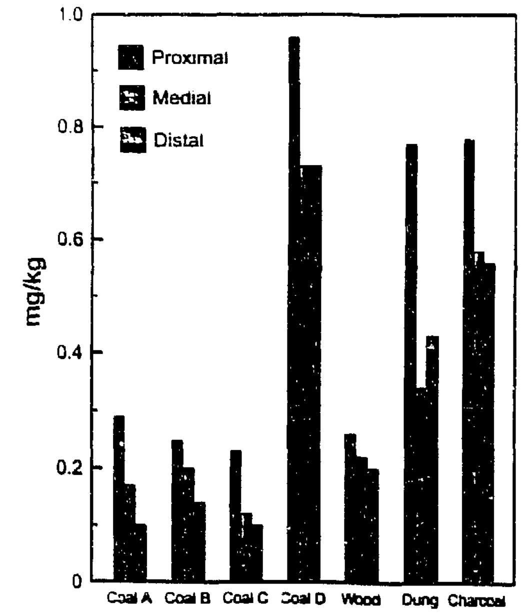
The Angethi stove was partially loaded with a 200 g charge, compared to a full charge of 1 Kg. The smaller than normal charge was necessary to keep the SO_2, CO, and NO_x monitors on scale. The usual type of commercially available instrument was used to measure SO_2, CO and NO_x.

Results

The amended coals (Table 1) are designated A, B, and C. The raw coal analog of A is designated D.

Table 1.
Formulations of coal briquettes

Briquette	Component	Weight 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%



Total RSP collections in µg per Kg of fuel burnt are depicted in Fig. 2 at proximal (25 cm), medial (50 cm), and distal (100 cm) positions, each at a height of 25 cm above the stove top.

Fig. 2. Respirable size particulates emitted during burning of 200 g charges

The collected particulates were analyzed by ICP/MS for eight toxic heavy metals. The particulates were devoid of heavy metals above a 1 µg detection limit except for occasional Zn and Sb in the trace amounts of 1-3 µg.

The patterns of temporal SO_2 and CO emissions are shown in Fig. 3. The interrupted emission structures are caused by uneven burning of the 200 g charges.

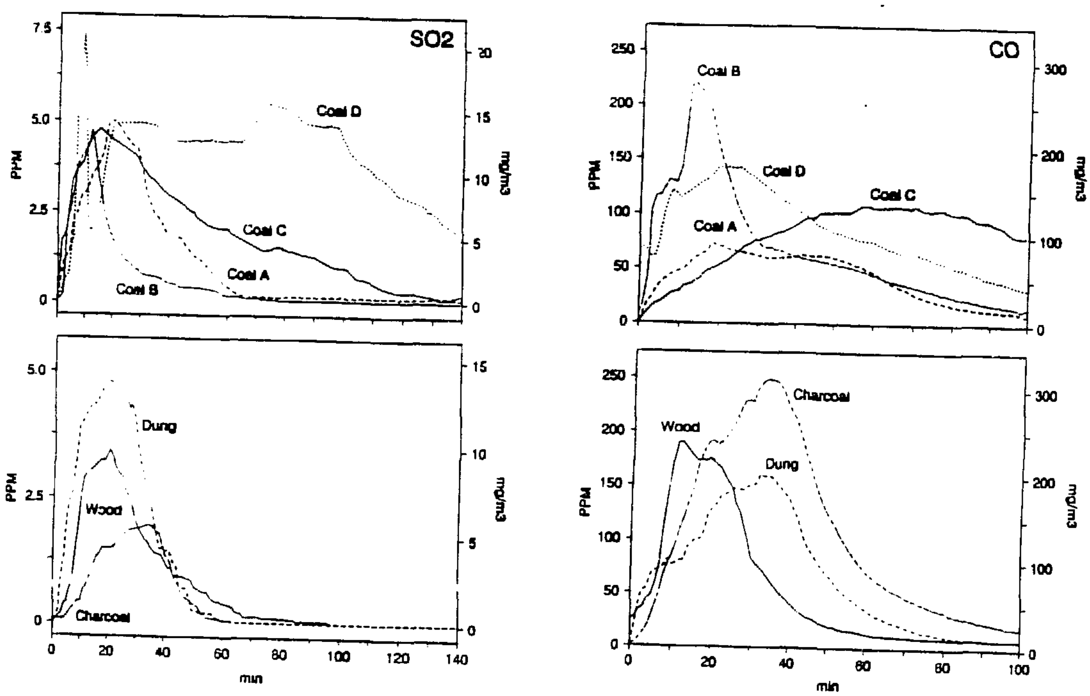


Fig. 3. Emission profiles of SO_2 and CO

Peak and integrated emission factors (EF) are presented in Fig. 4 for CO, NO_x and SO_2.

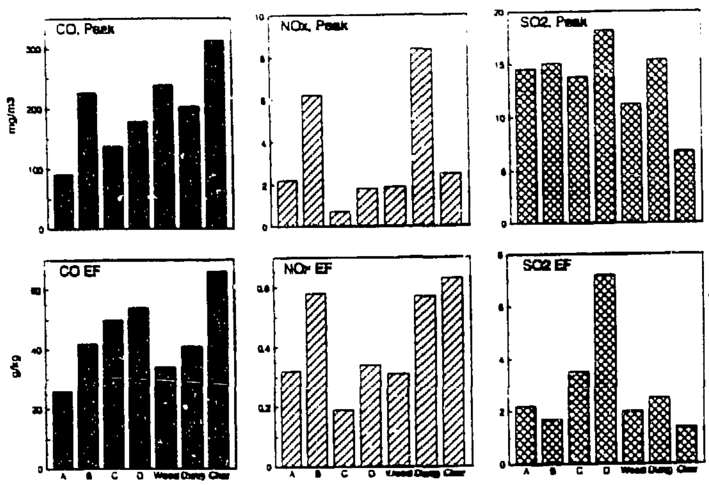


Fig. 4. Peak and total emission factor for coal briquettes and traditional fuels

Discussion

The RSP data show a clear pattern, relatively easy to interpret. The raw Lakhra coal (D) produces a heavy smoke and the highest RSP loadings. The lime- and clay-amended coals (A, B, and C) produce only one fifth to one quarter as much RSP. The slagging and catalytic effects of the lime and clay serve to catalytically crack the heavier organics and bind the non-combustible minerals in the coal. Coals A, B, and C produce amounts of RSP on a par with wood but less than dung and charcoal. Toxic metals in the RSP are present in such low concentrations that they do not constitute a health hazard.

Emissions of SO_2 are of particular concern because of the high sulphur content of low-rank Pakistani coals. The raw coal (D) is clearly the worst offender with high levels of SO_2 emitted at all stages of burning. The amended coals, while giving the same early peak concentrations of SO_2 (5-7 ppm), produce substantially less SO_2 once the briquettes are burning well.

A combined chemical/physical process is visualized to explain the sequence of SO_2 emissions. Early in the burn cycle, burning is restricted to the skin of the individual briquettes. The SO_2 produced at the briquette surface has maximum possibility for escape before reacting with any lime or its more active product of dehydration, quicklime.[4] Once the interior of the briquette is burning, SO_2 has to pass through a thickening layer of quicklime with an increasing likelihood of being fixed rather than escaping.

Peak concentrations of CO range from a minimum of 100 ppm for coal A to a maximum of 300 ppm for charcoal. Integrated emission factors (EF) vary twofold; coal A produces the least amount (26 g/kg) and wood charcoal the greatest amount of CO (66 g/kg). If, however, the EF values are normalized by factoring in noncombustible, non-CO producing material, then the EF for coal A increases to 63 g/kg. Corrected EF values for CO are 63-120 g/kg and 42 g/kg for the different types of coal briquette and dung, respectively. The physical structure of the different fuels and the ability of air to access the burning regions are prime determinants in CO production.

There have been few reported measurements of NO_x from burning domestic fuels in underdeveloped/developing countries. In our study, peak concentrations of 1-5 ppm NO_x were measured. Dung gave the highest peak of 5 ppm.

Conclusions

Substitution of amended coal briquettes for domestic cooking fuels of firewood, charcoal, or dung will not worsen indoor air quality with respect to respirable size particulates, SO_2, CO, and NO_x. Given the favorable economics of coal briquettes and the possibility for a lessened rate of deforestation in Pakistan, their promotion as an alternate fuel source should be encouraged.

Countries in central and eastern Europe with high-sulphur coals should consider adopting coal-briquetting technology for utility boiler fuel and other small-scale applications, at least as a low-cost, stopgap measure for reducing air pollution.

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