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Project Summary

Feasibility Study of Enhanced Combustion Via Improved Wood Stove Firebox Design

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Emissions from incomplete combustion in wood burning stoves are becoming an increasing environmental problem. In this study, materials were examined which might be used to line the firebox of a wood burning stove to produce more uniform and complete combustion. Although many materials were initially considered, refractory materials appear to possess the qualities desired relative to heat transfer, resistance to the firebox environment, availability, and cost. Specific refractory materials have been further investigated, resulting in a list of material properties of potentially useful refractories and a determination of relative installed costs. The approach used in this study was to establish the conditions for a "basic" wood stove, then to apply various candidate lining materials to the basic stove and analytically estimate the effect of the lining addition. Basic heat transfer calculations were used. The use of refractory materials permitted an increase in stove inner wall temperatures and an increased cooldown time for a stove. The study showed that refractory materials could aid in maintaining internal firebox temperatures above the ignition temperatures of common emissions. This would not be a practical operational mode for an uninsulated stove.

The study concludes that there is a need for actual tests to confirm the results cited in the study.

This Project Summary was developed by EPA's Air and Energy Engineering Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The use of residential wood burning stoves has grown considerably in recent years. As the use of these stoves has increased, so has the amount of polluting emissions. Since these stoves come in a very wide range of designs, combustion and resulting emissions can vary widely. Additionally, operational parameters can result in significantly different emission levels from the same stove design. One design approach for reducing emissions is to place material inside the firebox that can lead to more complete combustion of the wood charge and any emission constituents present. Ideally any design modification should be essentially passive; i.e., requiring little or no attention by the user. Also, due to the large numbers of existing wood burning stoves, it is desirable that any modification lend itself to the retrofit of existing stoves.

Existing Stove Designs

From a review of the design and operational characteristics of existing residential wood stoves, it was determined that various design factors could have a significant effect on wood stove emissions. These design factors include combustion chamber usage, combustion controls and drafting design, and certain operational factors, particularly draft and flue adjustments.

Resistance to the Combustion Process and Increasing Combustion Efficiency

Any material placed in the firebox (for emission reduction purposes) must be resistant to the combustion process, including: firebox temperature extremes and heating and cooling rates, the fuels utilized, and the products evolved during combustion. Additionally, the material should enhance the combustion process while not appreciably degrading stove operation or requiring significant user attention. If a material in the firebox can be maintained above the ignition temperature of emission constituents (see Table 1), combustion can take place which can lead to emissions reduction in the firebox.

Calculation Method: Basic Stove

The initial approach used in this study was to employ standard heat transfer calculation techniques to determine a temperature profile for a generic or basic stove. The basic stove was defined as a cast iron firebox with 1/4-in. (0.64 cm) wall thickness and no lining. The steady state temperature of the firebox gases was assumed to be 1500°F (816°C). A room temperature of 60°F (16°C) was assumed. When these temperatures plus appropriate heat transfer coefficients were inserted into the standard heat transfer equations (considering radiation, convective conductance, and conservation of energy), the basic stove wall temperature was found to be 720°F (382°C) and the heat transferred (per square foot of stove wall) was about 4000 Btu/hrft^2 (12.6 kW/m^2). These values define the steady state condition of the basic stove.

Calculation Method: Lined Stove

Several assumptions were required to determine the steady state temperature profile for a lined stove. The heat transfer rate and the outer wall temperature of the lined stove were assumed to be the same as for the basic stove. (Thus the heat output of the stove will not be affected by the installation of a lining.) Additionally, an inner (liner) wall temperature of 1200°F (649°C) was chosen. This temperature was selected as a conservative adjustment to the carbon monoxide ignition temperature of 1128°F (609°C) (see Table 1). That is, the purpose of the liner is to raise the temperature of the inner stove wall such that the combustion of emission constituents can take place. The use of these temperatures, appropriate heat transfer coefficients, and certain physical properties of a lining material permit the calculation of the required lining thickness and a firebox gas temperature. The required lining thickness will vary for different materials in direct proportion to the conductivity of the material.

Table 1. *Some Combustion Products Resulting from Burning of Wood*

Carbon monoxide[a]	
Naphthalene[b]	*Example of POMs (polycyclic organic matter)*
Biphenyl[c]	*Example of POMs (polycyclic organic matter)*
Benzene[d]	

[a]Ignition temperature 1128°F (609°C)
[b]Ignition temperature 898-1017°F (481-547°C)
[c]Ignition temperature 1071°F (577°C)
[d]Ignition temperature 1097°F (592°C)

Calculation Method: Cooldown

After the steady state temperature profiles of the basic and various lined stoves were determined, the temperature loss or cooldown of the stoves was calculated. The cooldown rate of the stoves was assumed to be governed by an exponential time function. The ability of a lining material to store heat increased the cooldown period of lined stoves compared to the basic stove. (See Figure 1.)

Candidate Materials for Inclusion in the Firebox

A wide range of materials were considered as candidate materials for inclusion in a wood stove firebox. Factors such as resistance to the process environment, cost, and ease of fabrication were considered during the initial evaluation of candidate materials. Additionally, a material must enhance the combustion process by the heat transfer methodology previously described. Based on these considerations and calculations, refractory type materials were determined to be the most potentially viable firebox lining materials.

The effect of various thicknesses of typical refractory materials on inside wall (liner) temperatures is shown in Figure 2. An inside wall temperature of 1200°F (649°C) was used as an effective temperature relative to the ignition of emissions. An outside wall temperature of 720°F (382°C) was used to maintain an equivalent heating rate compared to the basic stove. The required wall thicknesses for various refractory materials were calculated based on the indicated temperatures. Some of these wall thicknesses are shown in Table 2.

Ranking of Candidate Materials

There are various ways of rating or ranking the numerous candidate materials that exhibit acceptable process resistance and potential enhancement of combustion efficiency. A rating criteria of Total Installed Cost (TIC) per unit of surface area would be of interest to both wood stove manufacturers and owners. The ratios of TICs for various refractory materials were calculated based on the previously described assumed temperature profile, with medium duty fire brick assigned a ratio of 1.0 for new fabrication. Table 3 gives examples of the TICs for various refractory materials.

Conclusions

Various types of refractory materials can be installed in a wood stove firebox. These materials can lead to temperatures (occurring at and near the refractory surface) that are above the ignition temperatures of many wood stove emission constituents.

A refractory lined stove has a longer cooldown period than a metal stove.

A quantification of the effectiveness of emission reductions attributable to the types of firebox designs considered here should be determined by various tests.

The refractory materials that are recommended for testing include medium duty fire brick, HW Super Castable, and silica brick. These materials were selected because their relative total installed cost ratios (TICs) are less than 1.5. The calculated wall thickness requirements for each of these materials are similar, which would allow for a more consistent comparison during testing. They also represent typical examples of the broad spectrum of potential materials that could be used.

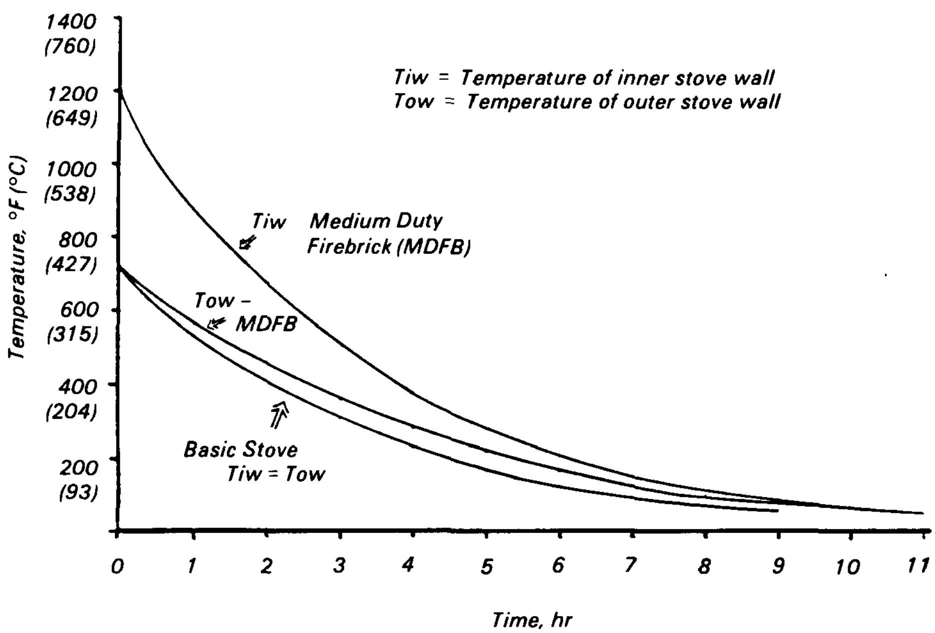

Figure 1. Cooldown of a basic stove and a lined stove (1 in.—2.54 cm—of medium duty fire brick.

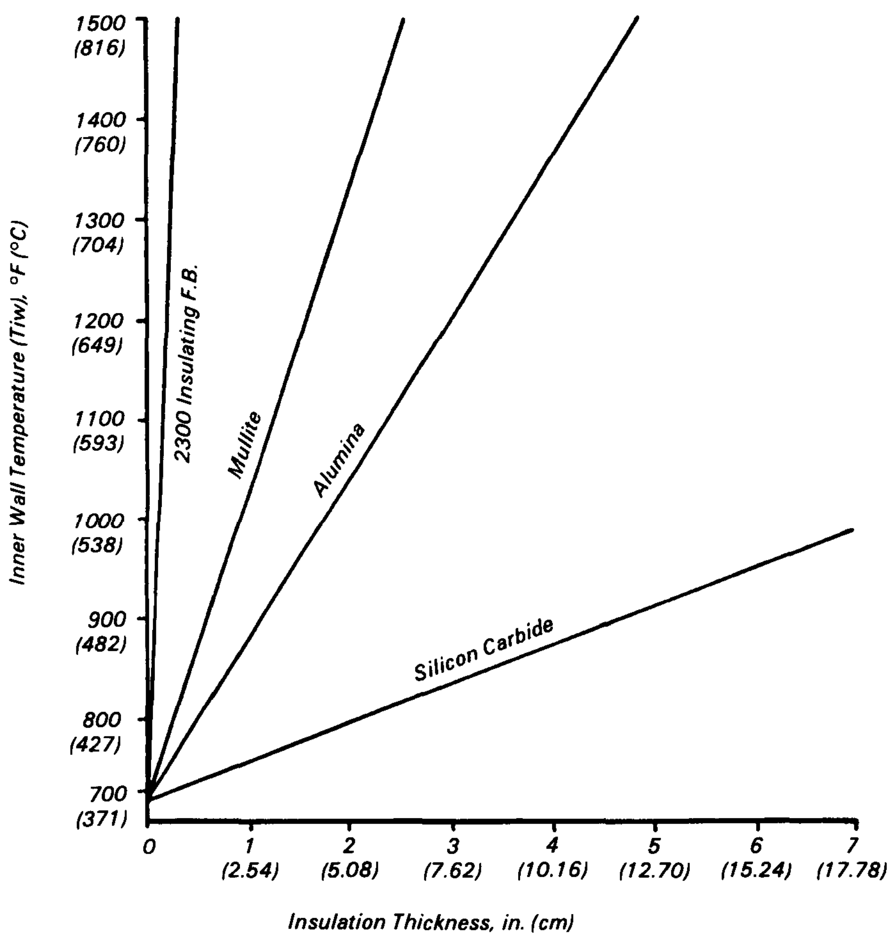

Figure 2. Inner wall temperature versus insulation thickness.

Table 2. Calculated Wall Thickness for Assumed Design Conditions of 1200°F (649°C) Inside Wall Temperature, and 720°F (382°C) Outside Wall Temperature for Various Refractory Materials

Material	Wall Thickness in. (cm)
Bricks	
MDFB	1.0 (2.54)
K23 IFB	0.2 (0.51)
Silica	1.3 (3.30)
Mullite	1.6 (4.06)
Alumina (99/-)	3.2 (8.13)
Silicon Carbide	12.5 (31.75)
Castables	
Kast-set[a]	0.5 (1.27)
HW Super Castable[b]	0.8 (2.03)

[a]A.P. Green Company
[b]Harbison Walker Company

Table 3. Total Installed Cost (TIC) Ratios Per Unit of Surface Area for Various Refractory Materials

Material	TIC Ratio
Bricks	
MDFB	1.0
K23 IFB	0.5
Silica	1.4
Mullite	8.8
Alumina (99/-)	69.8
Silicon Carbide	438.5
Castables	
Kast-set[a]	0.6
HW Super Castable[b]	1.0

[a]A.P. Green Company
[b]Harbison Walker Company

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The complete report, entitled "Feasibility Study of Enhanced Combustion Via Improved Wood Stove Firebox Design," (Order No. PB 86-121 373/AS; Cost: $11.95, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
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