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### EMISSIONS FROM INDUSTRIAL WOOD COMBUSTION WHAT AND HOW MUCH

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April 1982

Prepared for: Industrial Wood-Fired Boiler Workshop  
Combustion and Emissions Control  
U.S. Environmental Protection Agency and  
North Carolina State University, with APCA and ASME  
Raleigh, North Carolina, April 1982

ENERGY RESEARCH PROGRAM  
ENERGY RESEARCH LABORATORIES  
REPORT ERP/ERL 82-26(OP)



# EMISSIONS FROM INDUSTRIAL WOOD COMBUSTION: WHAT AND HOW MUCH

by

A.C.S. Hayden\*

## ABSTRACT

The combustion of wood in industrial boilers offer major potential to displace non-renewable premium fuels. This paper discusses the compounds formed during industrial wood burning and quantifies their relative levels with regard to other potential energy sources.

Particulate emissions are generally quite high unless good after-the-fact control technology such as electrostatic precipitators are used as downstream collection devices. Carbon monoxide and hydrocarbon levels can be high if good combustion techniques are not followed. Nitrogen oxides are on the same range as from other sources, depending on the nitrogen content of the wood waste, while sulphur dioxide emissions are negligible.

The Canadian program to examine boiler performance in the pulp and paper industry will be important for filling certain knowledge gaps and to define design and operational guidelines to improve performance.

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## INTRODUCTION

Until recently, the major thrust in North American energy usage was to eliminate the use of solid fuels in all but some of the largest installations, where coal was retained for the generation of electricity, with attendant high pollution potential. The premium, less polluting fuels, oil and gas, became predominant.

With the rapid increase in energy prices, as well as some supply shortfalls which have occurred since 1973, along with the realization that fossil fuels are a finite resource, have caused many to look to energy conservation and to forms of renewable energy to reduce demand.

In Canada, the National Energy Program, as announced in the fall of 1980, has set a goal to reduce the use of oil in each of the residential, commercial and industrial sectors to no more than 10% of the total energy used in those sectors by 1990. In order to achieve this, the Program is providing incentives for and promoting research into greater use of renewable energy options. Renewables, and particularly wood, are projected to provide 6% of Canada's total energy budget by the end of this period.

One of the major areas where wood, primarily in the form of wood waste, can contribute significantly is in industrial combustion systems. In order that this new energy use does not seriously impinge on the environment, consideration must be given to the flue gas emissions from industrial wood combustion.

This paper discusses the compounds formed during industrial wood burning and attempts to quantify their relative levels, both to each other and to the emissions which would result from the use of more conventional fossil fuels.

## FUEL ANALYSIS

While coal properties change dramatically from lignite to sub-bituminous to bituminous to anthracite, as well as from area to area, wood properties tend to be much more uniform. Table 1 presents average proximate and ultimate analyses, on a dry basis, for averages of seven wood waste samples and ten woods, as analyzed by the Solid Fuels Analysis Laboratory, CCRL. In general, the volatile matter for wood waste tends to be slightly lower than for the debarked woods, although all tend to be in the range of 76%

to 83%. Ash is greater for wood waste than for debarked wood, but is still much lower than for most coals.

From the ultimate analyses, carbon is about 50%, hydrogen 5-6%. The major difference from other common fuels is the high oxygen content, in the area of 40%.

An average ash analysis from all the above samples is presented in Table 2. The major component is calcium, at 44%, with silica next at 26%.

For residential wood combustion, the fuel is habitually air-dried for one year before use, and usually has a moisture level of 16% to 22%, on a wet basis.

For industrial combustion of wood waste, the moisture level tends to be much higher, usually in the range of 40% to 65%, unless the fuel has been specially prepared. The higher the moisture, the more energy is lost in the form of latent heat. At very high moisture levels, it is often difficult to sustain combustion in most systems.

#### COMBUSTION CURVES

To aid in the determination of the various parameters required for the combustion performance of wood, a set of curves have been developed for wood waste, similar to those presented in Reference 1 for various Canadian and U.S. coals.

These curves show:

- (1) The weight and volume of combustion air required and flue gas produced per unit of wood fired for a range of temperature and excess air conditions.
- (2) The heat losses resulting from the combustion of the fuel for a range of conditions.
- (3) The theoretical concentrations of carbon dioxide and oxygen in the flue gas.

Combustion calculations for wood are complicated by its variable and high moisture content. This procedure bases its calculation on dry wood, with the user making corrections for the actual moisture level. The reader is referred to Reference 1 for details on how these corrections are performed.

Dry flue gas represents the moisture free components of the flue gas. Total flue gas represents the preceding components plus the moisture resulting



from the combustion of hydrogen in the coal. It does not include coal moisture nor moisture in the combustion air.

#### MASS COMBUSTION DATA

Fig. 1 shows the weight of combustion air required, along with the weights of dry and total flue gas produced, for the combustion of one pound of wood versus the per cent of total combustion air. Total combustion air is defined as the per cent of air relative to stoichiometric conditions, or per cent excess air plus 100. Flue gas analysis may be related to total combustion air by either the  $\text{CO}_2$  curve or the  $\text{O}_2$  curve.

#### VOLUMETRIC COMBUSTION DATA

Fig. 2 shows the volumes, at different temperatures, of the dry combustion air required and the total flue gas produced, along with the dry flue gas at  $32^\circ\text{C}$ , produced when one pound of dry wood is burned, plotted against total combustion air. To obtain the wet flue gas volume produced when wet wood is burned, corrections must be made for the moisture in the wood, and in the combustion air.

#### DRY FLUE GAS LOSS

Fig. 3 shows the heat loss, in per cent of fuel input, represented by the sensible heat in the dry flue gas leaving the system. It is dependent on the excess air level and the difference between the flue gas temperature and the combustion air temperature.

#### HEAT LOSS DUE TO WOOD MOISTURE CONTENT

Fig. 4 shows the heat loss, in per cent of fuel input, due to the moisture in the wood. Heat is required to raise the fuel moisture to boiling temperature, evaporate it, and superheat the vapour to the final flue gas temperature. The loss is dependent on wood temperature, moisture content of the wood and flue gas temperature.

#### HYDROGEN LOSS

Fig. 5 shows the heat loss, as a per cent of fuel input, due to moisture in the flue gas formed from the combustion of hydrogen in the wood. It comprises the heat necessary to evaporate this moisture and superheat it to the flue gas temperature. It is dependent on fuel temperature and flue gas

temperature.

#### HEAT LOSS DUE TO UNBURNED COMBUSTIBLE IN REFUSE

Fig. 6 gives the heat loss, in per cent of heat input, versus the per cent combustible in the refuse, assuming the unburned combustible is totally carbon.

#### HEAT LOSS DUE TO CARBON MONOXIDE

Fig. 7 shows the heat loss, in per cent of fuel input, due to carbon monoxide in the flue gas resulting from incomplete combustion.

### EMISSIONS

Emissions from combustion equipment in general and wood-fired equipment in particular have similar emissions, albeit at relatively different levels. For the gaseous emissions, there is carbon monoxide, sulphur dioxide, nitrogen oxides and hydrocarbons. Some of the hydrocarbons are what is known as polycyclic organic matter (or POM's). Solid emissions are also present in the form of particulates. A description of the various emissions and how they compare in relation to other sources follows.

#### CARBON MONOXIDE

This gaseous emission, resulting from incomplete combustion of the fuel, is significant for wood combustion. For residential equipment volumetric flue gas measurements often exceed 0.5% during a burn cycle. At this high level, it can constitute a major hazard to the home occupant in the event of flue reversal, leakage or blockage, as well as a downstream air pollution problem. Improved combustion design, whereby incomplete combustion products are brought back into the flame zone for ignition, can result in lower levels (2).

EPA emission factors (3) for wood and bark combustion in boilers indicate the CO levels for industrial units are very low.

However, the evidence is contradictory. Reference 4 presents CO levels for wood higher than those for other fuels, as shown in Fig. 8.

It is thought that this disparity is due mainly to poor combustion conditions in some of the installations which can, as mentioned for domestic wood-fired appliances, quickly lead to high carbon monoxide emissions.

### HYDROCARBONS

This gaseous emission is also due to incomplete combustion. For residential equipment, its variation over the burning cycle, as measured with a flame ionization detector with heated cell, closely mirrors the levels for carbon monoxide (2).

Fig. 9 shows the hydrocarbon emissions for industrial wood boilers relative to those for other fuels, as expressed in terms of nanograms per Joule (ng/J) (4).

### SULPHUR DIOXIDE

For most fuels,  $\text{SO}_2$  levels are a direct function of the amount of sulphur in the fuel, with about 98% of the sulphur going to sulphur dioxide and the rest to sulphur trioxide. Wood has a very low level of sulphur, usually from 0.02% to 0.08%, as seen from Table 1, about an order of magnitude less than for No.2 oil.

As well, wood ash is strongly alkaline, often with over 50% composed of calcium, potassium and sodium, as shown in Table 2. These compounds react readily with sulphur to neutralize it, so that the actual  $\text{SO}_2$  emission is likely to be much lower than even predicted theoretically.

In fact, this property will be used to advantage in a CCRL-sponsored demonstration-scale fluidized bed boiler designed to burn high sulphur (greater than 5%) coal and wood chips, the latter supplying up to 30% of the design heat input of 22 MJ/h. Two of these boilers, now in the construction phase, are to supply steam for district heating for the Canadian Armed Forces Base at Summerside, Prince Edward Island (5). The alkaline properties of the wood ash will help to neutralize the sulphur in the coal, lowering the overall demand for limestone as a bed material.

Fig. 10 compares the  $\text{SO}_2$  emissions from industrial sources fired with wood to those fired with other fuels.  $\text{SO}_2$  levels from wood are negligible while those for coal and residual oil are high.

### NITROGEN OXIDES

Wood-fired combustion systems emit considerably less nitrogen oxides (NOX) than do fossil fuel-fired units. A recent study conducted by TRW (6), made measurements on fourteen industrial boilers firing wood alone or in combination with a fossil fuel, coal, oil or gas. Results of the study are presented in Table 3.

There was a definite correlation between NOX emissions and boiler size with larger units, above 10 MW, yielding substantially higher levels. For units below 10 MW, operating at very high excess air levels, above 300%, NOX rates were 0.3 g/kg wood fired. For units above 10 MW, excess air levels were less than half those of the smaller units, but NOX emissions were five times greater.

For units primarily fired with fossil fuel, with the wood used only as a supplement, NOX emissions were 2.5 times higher than for the wood-alone units.

With the low nitrogen content of wood, nitrogen oxide formation is due primarily to fixation of atmospheric nitrogen. However, because combustion temperatures in wood-fired equipment is often much lower than in conventional systems, due both to the systems themselves and to the high moisture content of the fuel, this source of NOX is also minimized.

Consequently, NOX emissions from wood-fired equipment tend to be rather low, as shown in Fig. 11.

#### PARTICULATES

Particulate matter is any emission existing in the solid or liquid state under ambient conditions, excluding water. For wood burning, this includes ash from the fuel, inorganic material fed in with the fuel such as dirt, unburned carbon and condensed organic compounds.

EPA's listed emission rate for particulates is 50g/kg fuel (0.5 lb/10<sup>6</sup>Btu).

A series of performance trials carried out on wood-fired boilers were reported in Reference 7. Average particulate loadings from 134 units were found to be 5g/kg or 0.112 gr/Scf at 12% CO<sub>2</sub>. The tests are for a wide variety of boilers firing different wood and bark fuels, with and without particulate controls.

In conjunction with these measurements, effects of varying certain combustion parameters were also examined. In particular, increasing the firing rate generally tended to increase particulate loading by about a factor of two, going from 50% load to full load. Reducing excess air also tended to lower particulates, at least to the point where satisfactory combustion was still achievable.

Particulate levels from wood-fired equipment tend to be quite high, although not so high as for coal. While wood waste generally has ash levels

from 0.3% to 3.0%, levels of ash in coal can range to well over 20%, and can usually be considered to be an order of magnitude higher than for wood. Resistivity of the fly ash from wood combustion is less than  $10 \times 10^{10}$  /cm, the industry criteria for the onset of problems, as cited in Reference 8.

Dust loadings vary between 0.5 to 4 gr/Scf, although somewhat lower levels were measured in the CCRL pilot scale boiler. Fig. 12 (4) compares the particulate emissions from wood boilers with those fired with other fuels. While wood is generally less than half coal, it is substantially above the emissions from liquid and gaseous fuels in terms of particulates.

#### POLYCYCLIC ORGANIC MATTER (POM)

These are multi-ring organic compounds, sometimes referred to as polynuclear aromatic hydrocarbons (PAH), although POM's may be more appropriate to wood combustion, because of the presence of oxygen in many of the compounds. They are of concern because many of the specific molecules have been shown to be carcinogenic, such as benzo(a)pyrene. They usually have high molecular weights and high boiling points.

POM's have been found to some degree in all forms of combustion systems, but seem to be most prominent in those instances where localized pyrolysis occurs, where the burning intensity is low or where the fuel has a significant amount of polycyclic (aromatic) compounds.

Table 4 (9) makes an estimate of the POM emissions from various sources. Open burning, such as wildfires and agricultural burning accounts for the largest amount, followed closely by residential wood combustion, especially from controlled combustion (airtight) space heaters or central furnaces.

Preliminary data from an advanced design residential space heater (10), where the combustion intensity is increased by using forced combustion downdraft into refractory, show much lower POM levels than for state-of-the-art equipment. The greater combustion intensity with industrial wood burners seems to have resulted in much lower levels of POM emissions.

Although Reference 11 indicated that emissions of POM's from wood boilers could be quite high ( $0.8 \text{ mg/m}^3$ ) under some conditions, recently completed work by EPA and the State of North Carolina (12) indicates that POM's from industrial wood combustion are much lower and can likely be considered insignificant.



## CANADIAN COMBUSTION RESEARCH LABORATORY (CCRL) EXPERIMENTS

### PELLETIZED WOOD WASTE

Limited combustion trials have been conducted on pelletized wood waste in the CCRL pilot scale research boiler, as described in Reference 13. The boiler incorporates two opposed in-shot pulverized fuel coal burners tilting downward into a refractory chamber. It has a full load capacity of 2500 MJ/h, generating 730 kg/h of steam at 690 kPa.

For these trials, No.2 oil was used for support firing. Fuel moisture content was low, on the order of 10%. Particulate sampling yielded concentrations of 0.06 to 0.2 grains/Scf, with NOX levels varying from 200 ppm at a firing rate of 25 kg/h up to 270 ppm at a firing rate of 45 kg/h.

### MILLED WOOD WASTE IN LIME KILN

Performance of different sized milled wood waste in the CCRL pilot scale refractory-lined kiln, fired through an IFRF variable swirl burner, has been evaluated and compared to No.2 oil and No.6 oil on a comparable input basis, as described in Reference 14. Performance was comparable to the reference oil fuels, with the fine waste actually transferring about 10% more heat than the oils. Carbon monoxide levels were generally the same for all fuels. NOX levels for the milled waste were similar to those for No.2 oil, but only about 40% that of No.6 oil. Particulate levels decreased with the degree of milling, from coarse to fine, with the medium grain, having a mass mean diameter of 510  $\mu$ m yielding levels of 0.12 gr/Scf.

## CANADIAN TEST PROGRAM ON BOILERS BURNING WOOD REFUSE

Because knowledge gaps exist in the performance of newer large wood refuse-fired boilers, a major field test program (15) has been initiated with the Canadian Boiler Society, as part of the Canadian Government's ENFOR program, established in 1978 to promote substitution of forest biomass for non-renewable fuels.

Detailed experimental programs will be carried out on bark-fired and refuse-fired boilers at five selected Canadian pulp and paper mills. The major objectives will be to effect improvements in design and operations so as to optimize efficiency while minimizing environmental impact. Results will be available to designers and operators of similar units to afford effective

transfer of technology. The program is similar to one recently carried out on coal-fired boilers in the United States for the American Boiler Manufacturers' Association and the EPA.

The first unit selected for evaluation is a chemical recovery boiler recently converted to a bark-fired boiler, equipped with a travelling grate, mechanical stokers, auxiliary tangential oil burners, mechanical dust collectors and electrostatic precipitators.

Measurements will be made of efficiency, operational characteristics and gas composition with a detailed examination of all emissions, including CO, hydrocarbons, NOX, POM and particulates measuring concentrations, sizing and resistivity before and after the electrostatic precipitators.

#### SUMMARY

Particulate emissions from industrial wood burning are seen to be significant. At the same time, there is some indication that levels of POM from some types of industrial wood combustion may be relatively high. Carbon monoxide and hydrocarbon levels are likely to be high only during poor combustion conditions. NOX levels are somewhat higher, but may be controlled by varying combustion parameters while sulphur dioxide levels are insignificant for wood combustion.

The Canadian program to examine in detail the performance of pulp and paper industry boilers burning wood refuse is likely to clarify many of the knowledge gaps now existing with respect to the emission levels from these sources, as well as define important design and operating conditions to improve their efficiency and reduce their emissions.

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Table 1 - Average analyses of wood waste vs wood

Parameter	Wood Waste	Wood
	<u>% by weight</u>	<u>% by weight</u>
Volatile Matter	76.3	82.1
Fixed Carbon	22.0	17.6
Carbon	51.5	49.7
Hydrogen	5.6	5.8
Sulphur	0.05	0.02
Nitrogen	0.35	0.09
Ash	1.7	0.3
Oxygen	40.8	44.1

Table 2 - Average ash analysis from wood waste

<u>Component</u>	<u>% by Weight</u>
SiO <sub>2</sub>	26.2
Al <sub>2</sub> O <sub>3</sub>	5.6
Fe <sub>2</sub> O <sub>3</sub>	3.7
CaO	44.0
MgO	4.5
Na <sub>2</sub> O	1.6
K <sub>2</sub> O	6.8
Other	13.2

Table 3 - NOX emissions from wood-fired boilers

Boiler Size	NOX Emissions	
	<u>g/kg fuel</u>	<u>ng/J</u>
10 MW	0.3	9
10 MW	1.6	70
10 MW *	4.0	170

\* Wood used as supplement to fossil fuel.

Table 4 - Estimate of POM emissions by source type

<u>Source</u>	<u>% total POM emissions</u>
Open Burning	37
Residential Wood Combustion	35
Road Vehicles	10
Coal-Fired Boilers	0.6
Wood-Fired Boilers	0.1

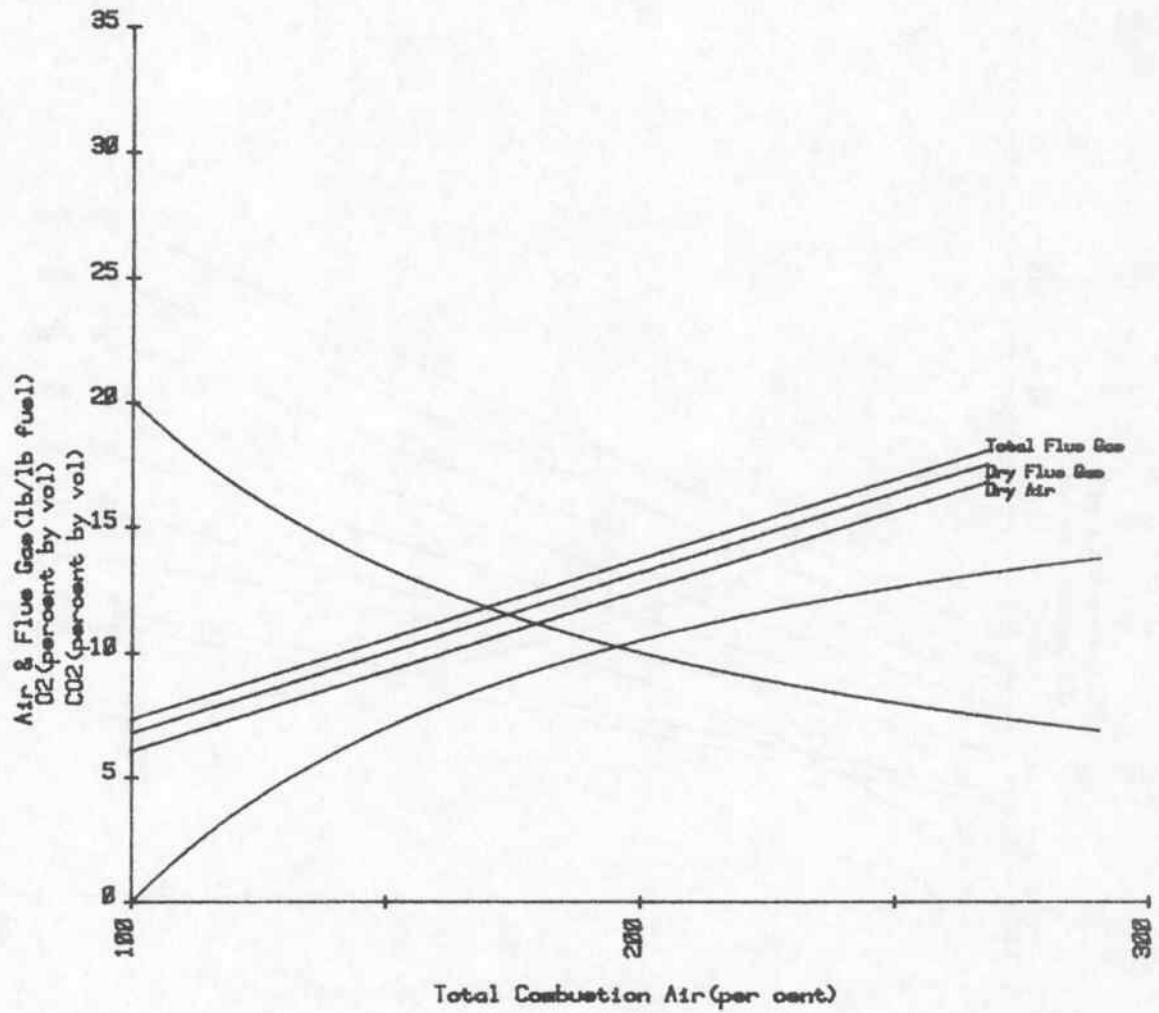


Figure 1. Combustion data for wood waste, mass basis.

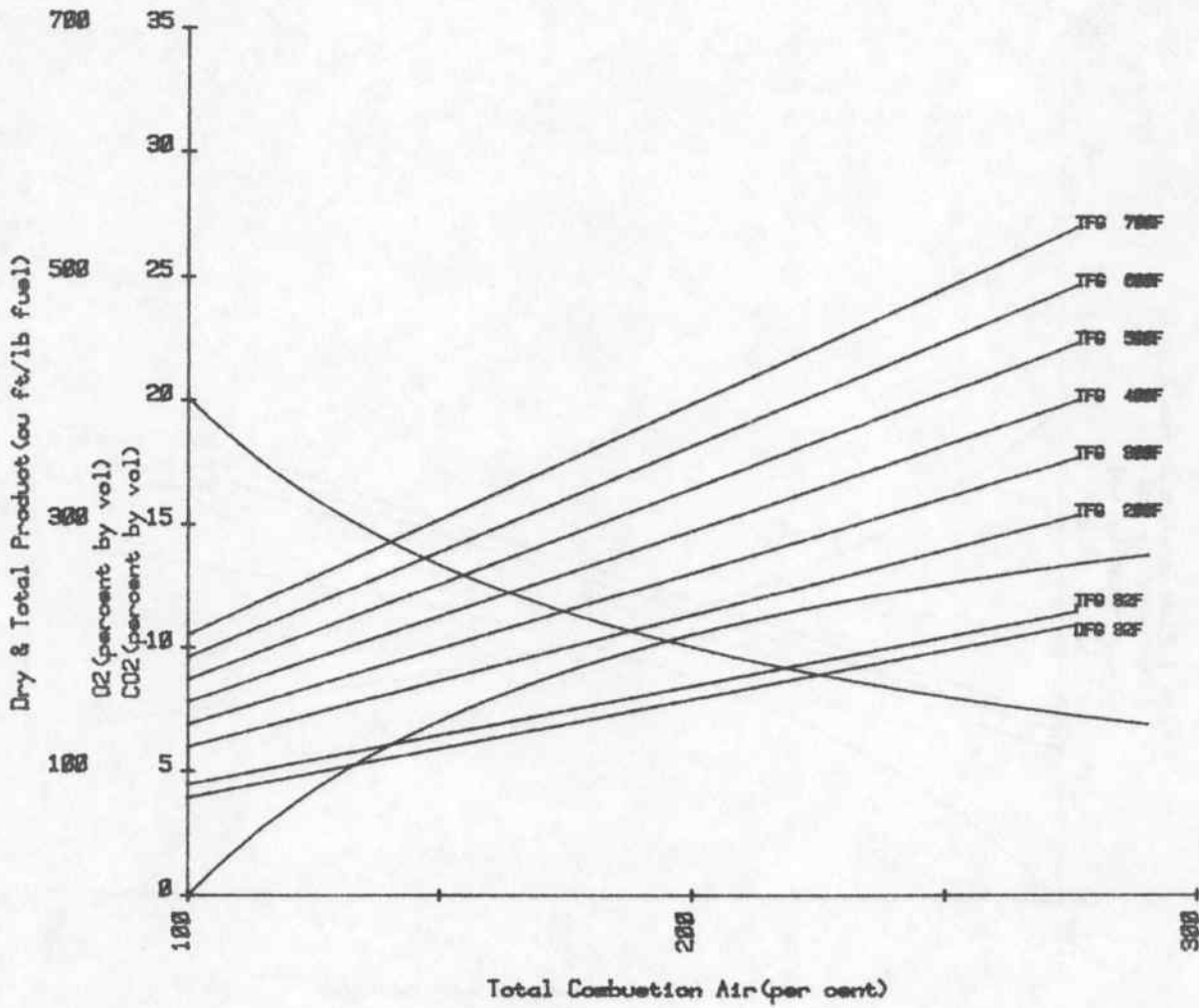


Figure 2. Combustion data for wood waste, volume basis.

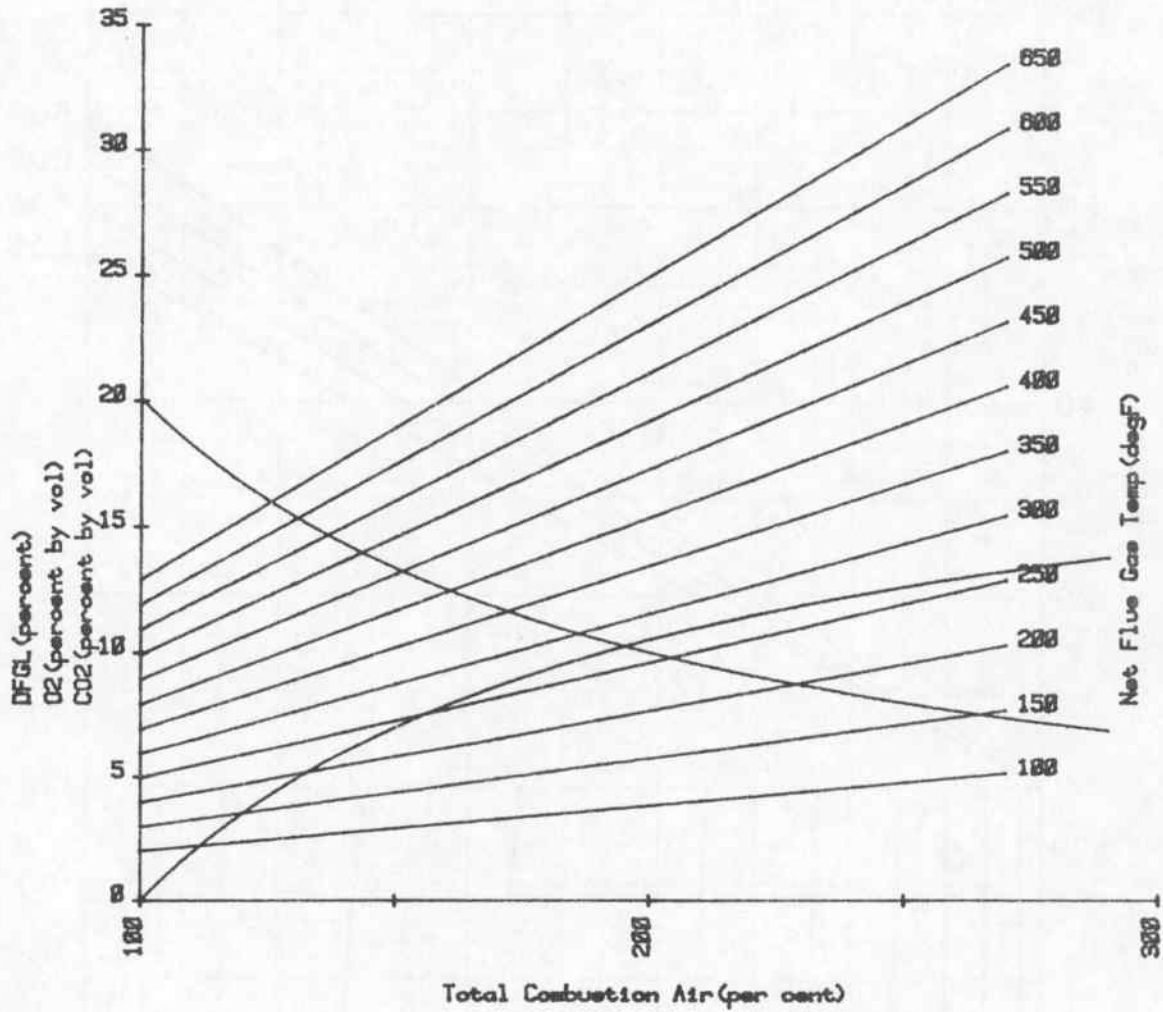


Figure 3. Dry flue gas loss for wood waste,  
for a range of temperature differentials.

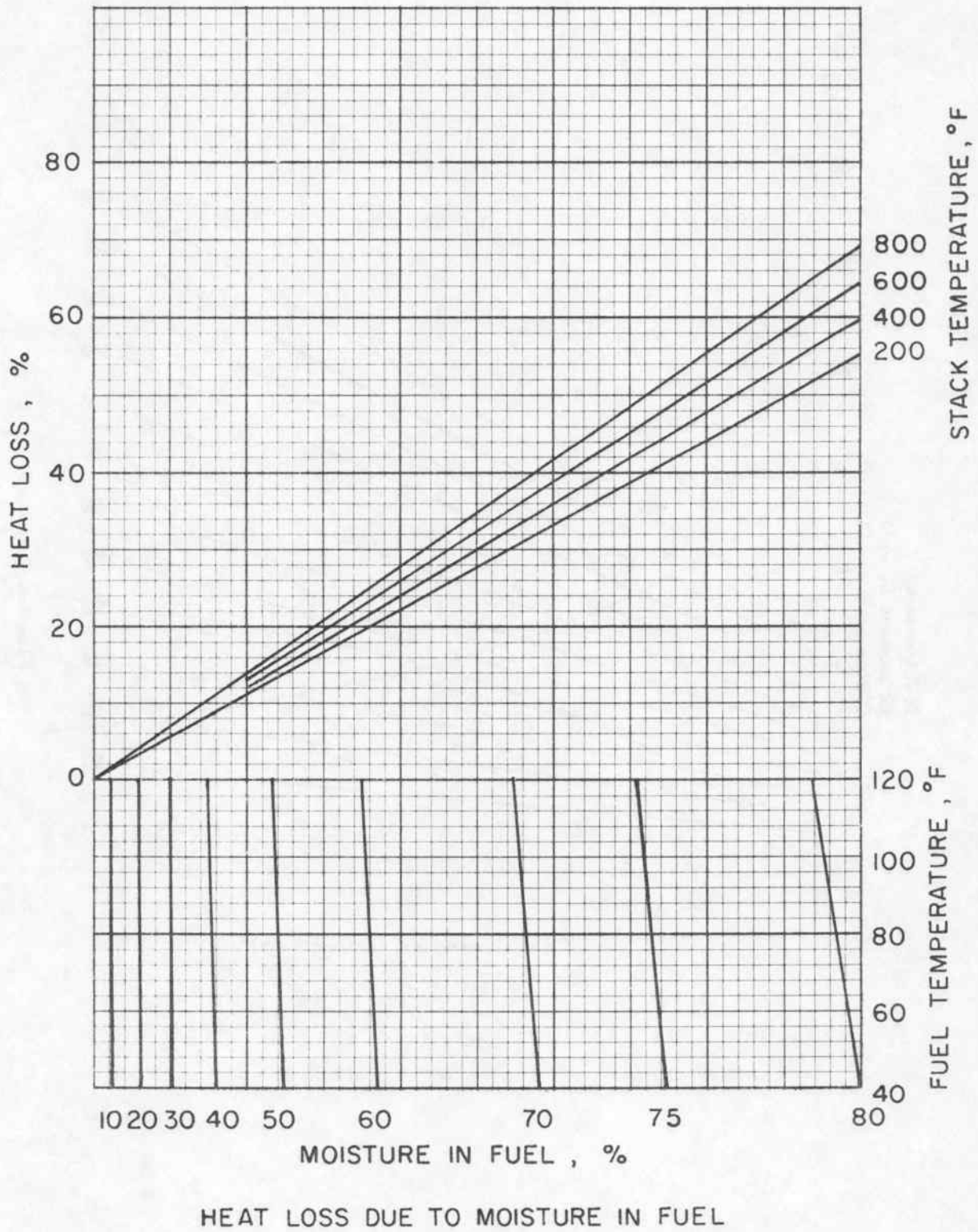


Figure 4. Heat loss due to moisture in wood waste.



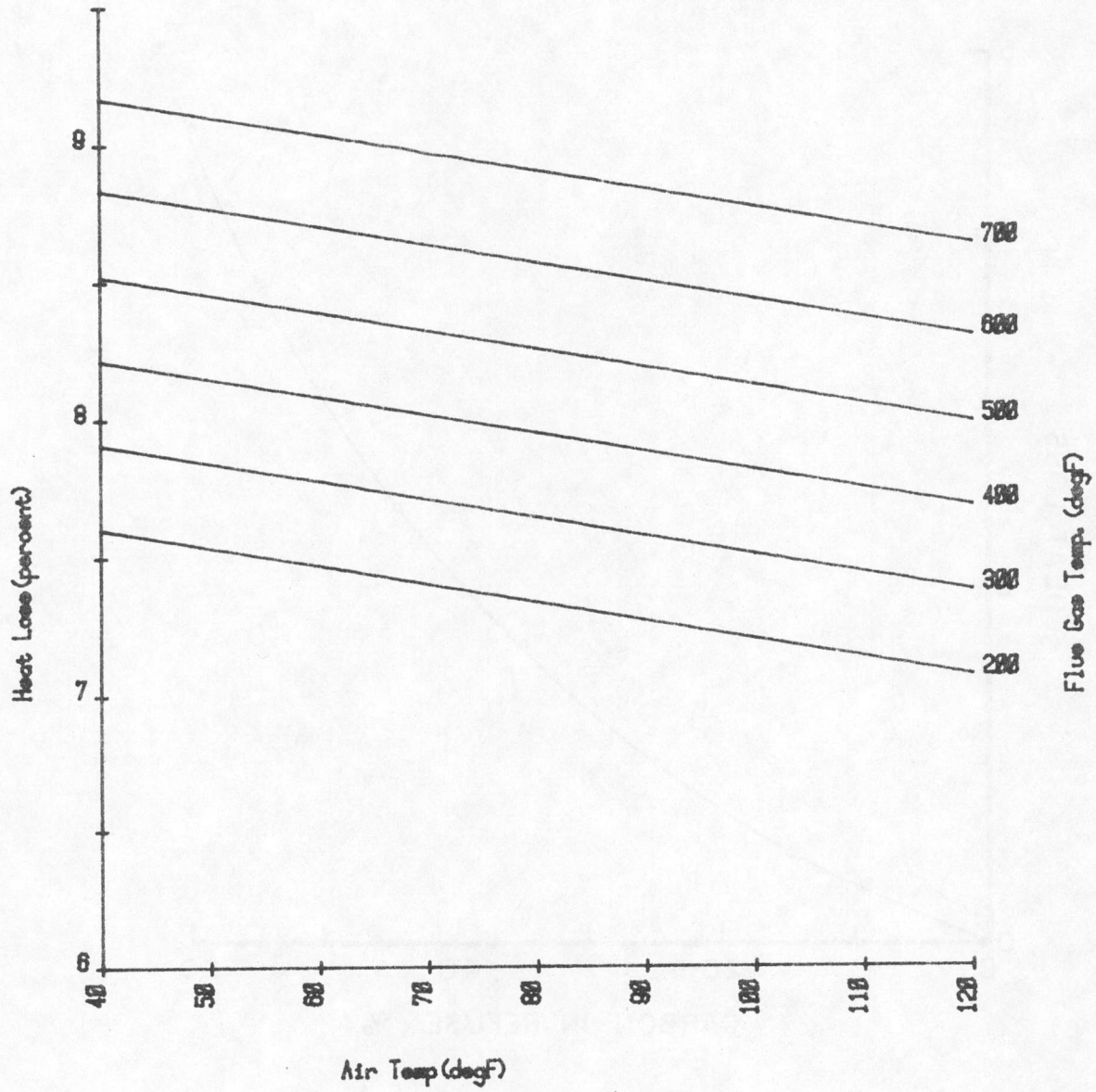


Figure 5. Hydrogen loss for wood waste.

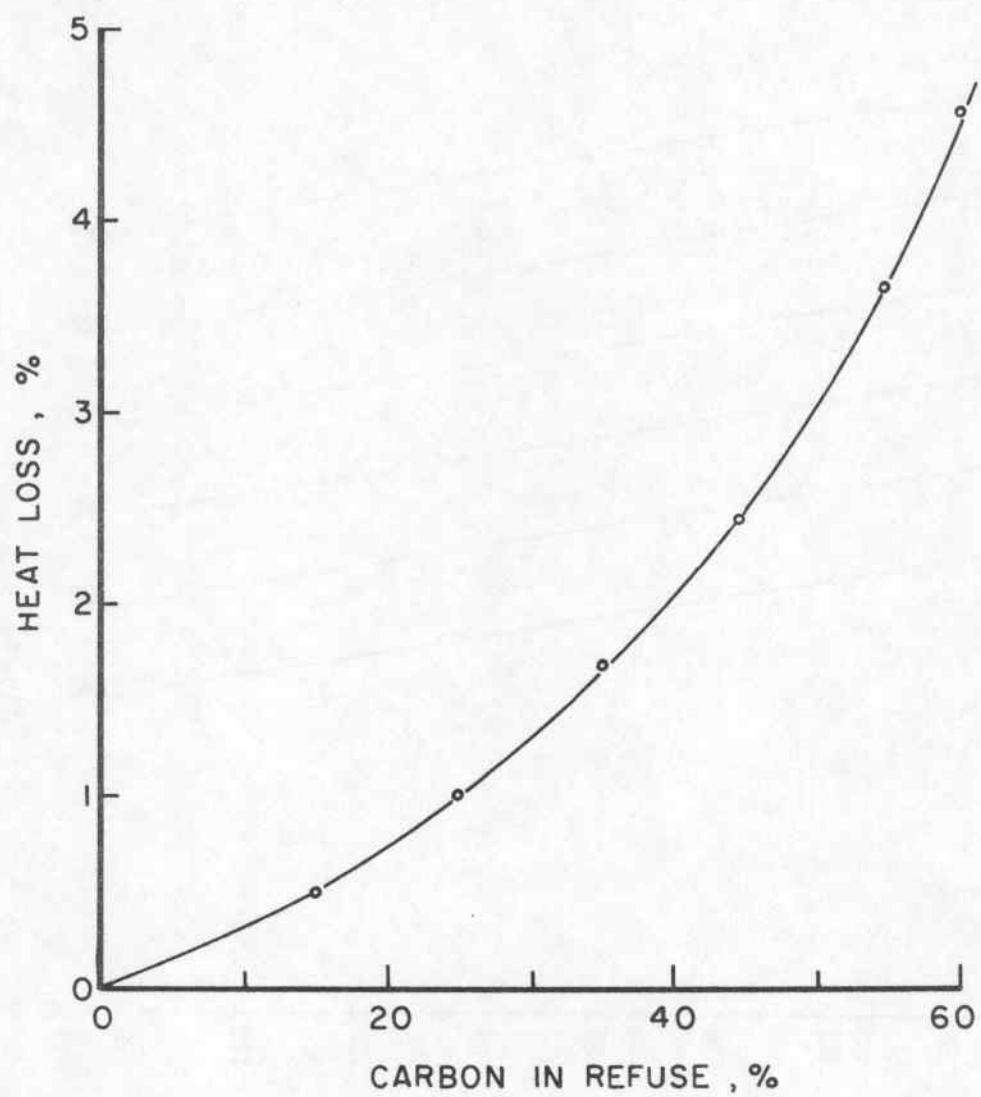


Figure 6. Heat loss due to unburned combustible in refuse.

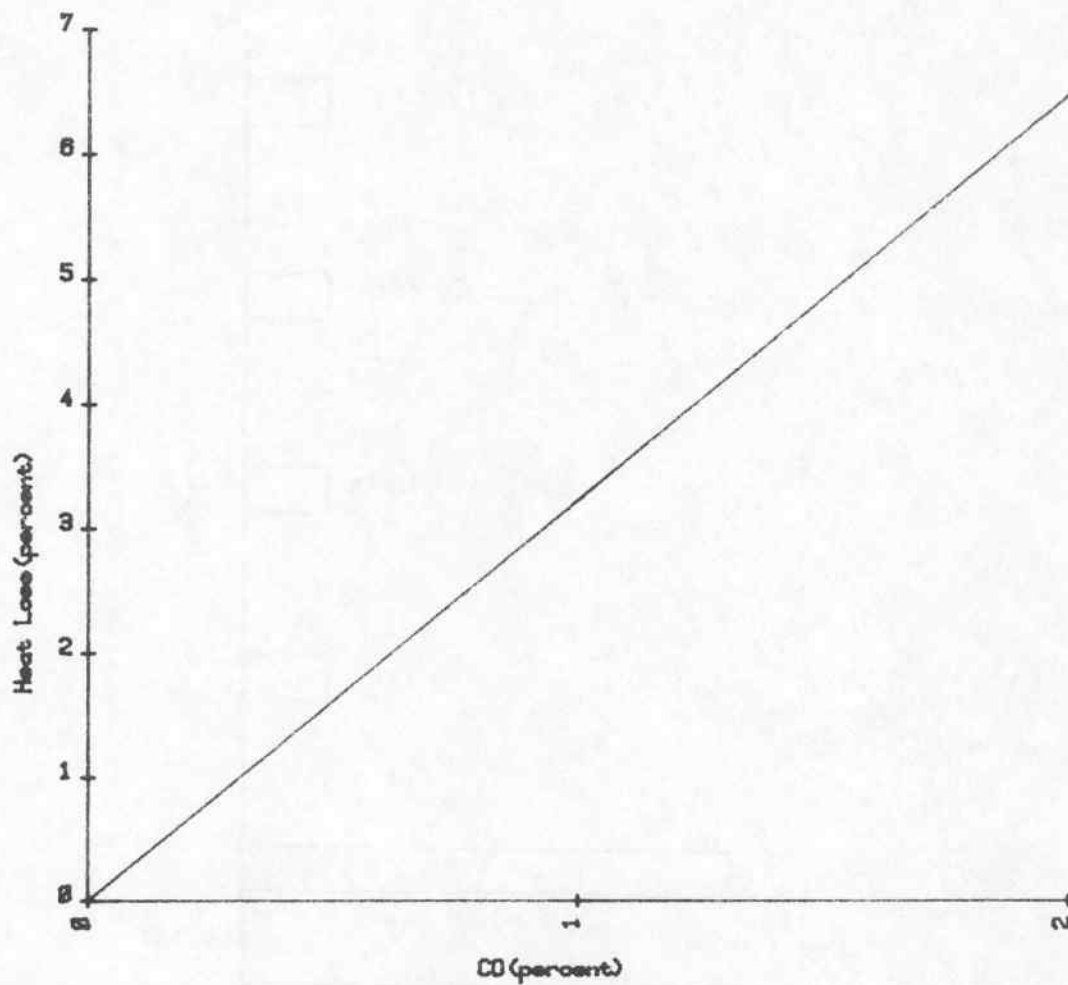


Figure 7. Heat loss for a range of carbon monoxide levels, assuming negligible excess air.

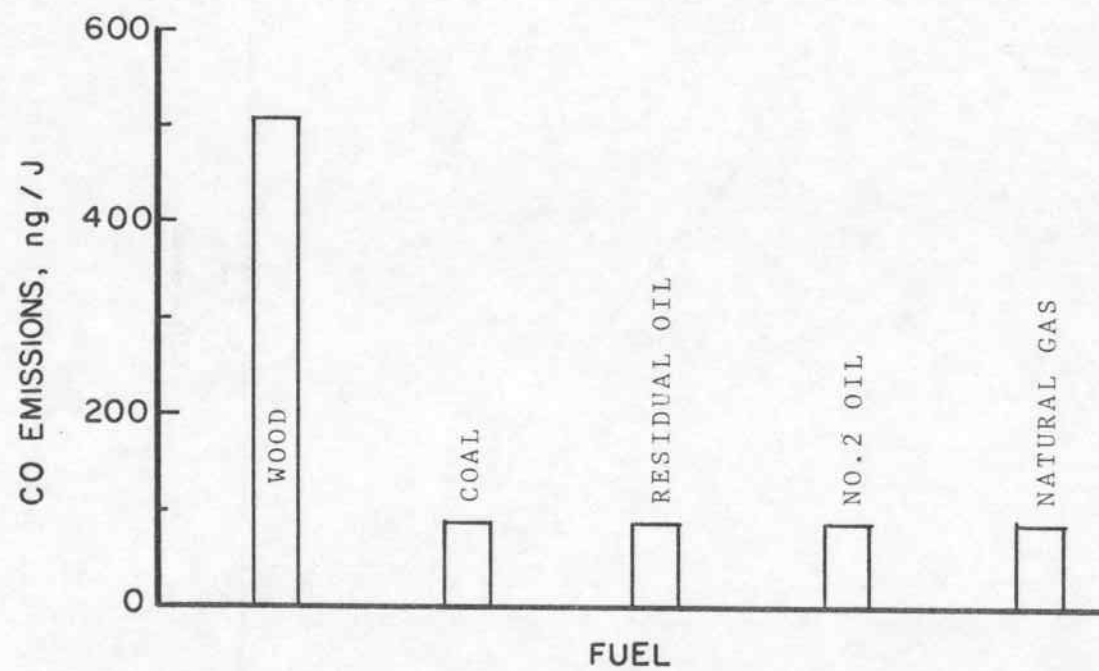


Figure 8. Carbon monoxide emissions from industrial boilers.

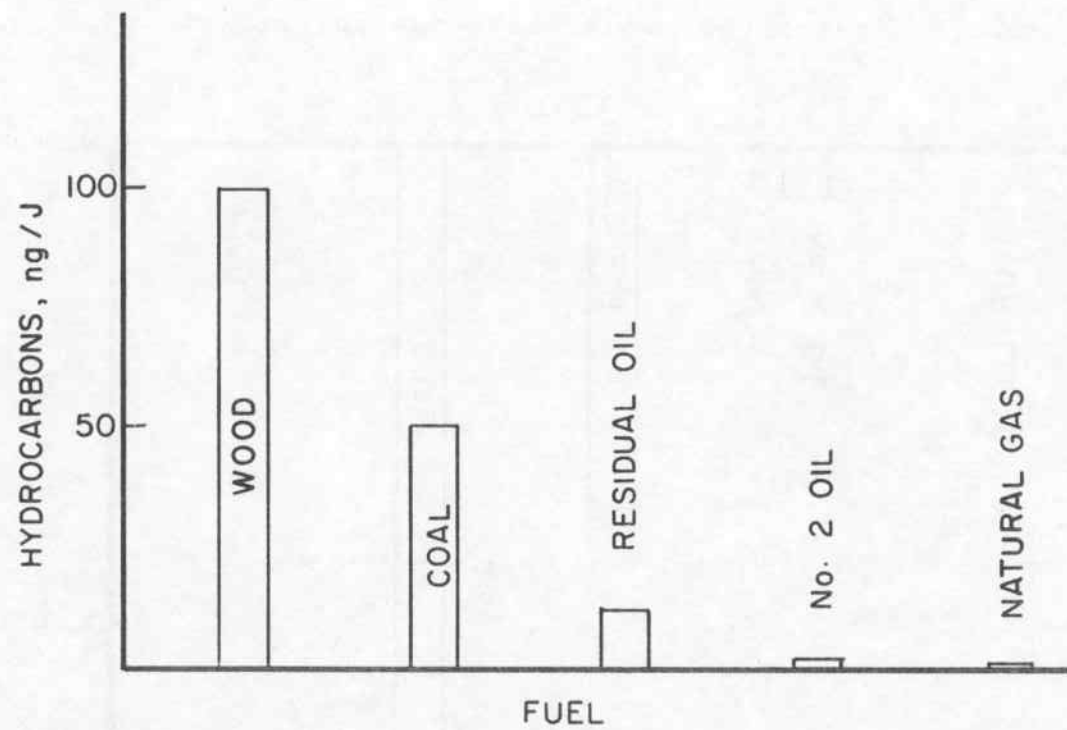


Figure 9. Hydrocarbon emissions from industrial boilers.

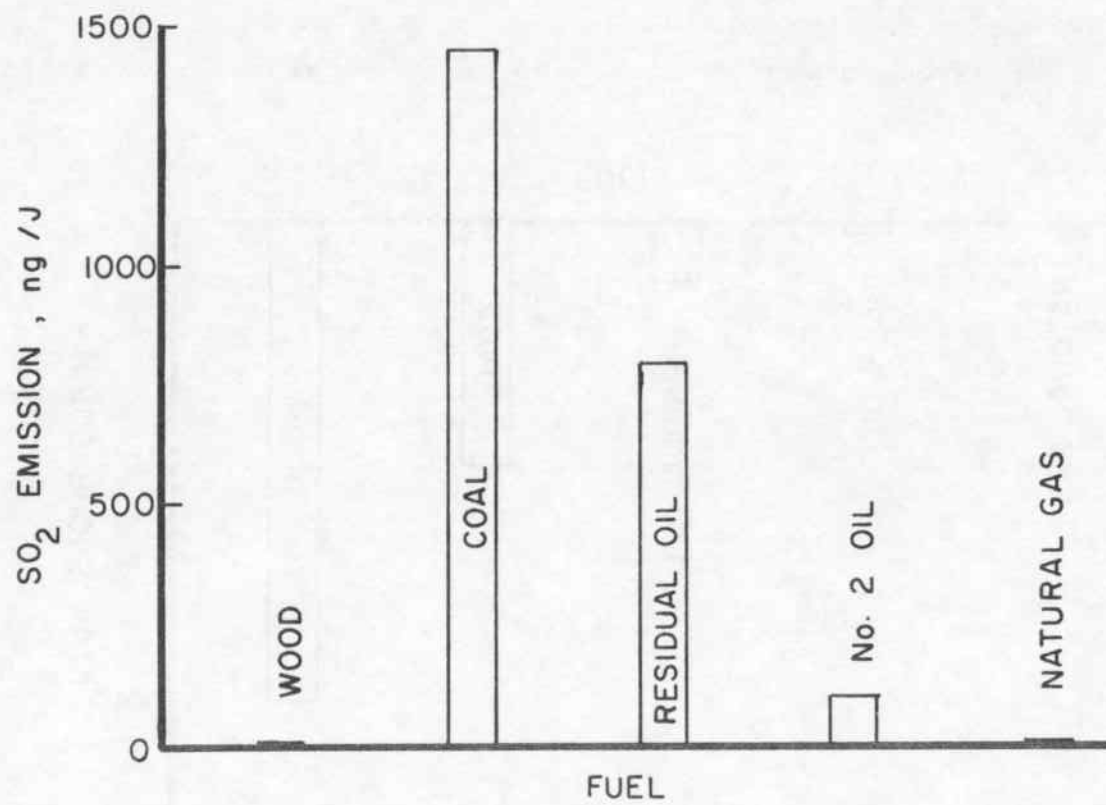


Figure 10. Sulphur dioxide emissions from industrial boilers.

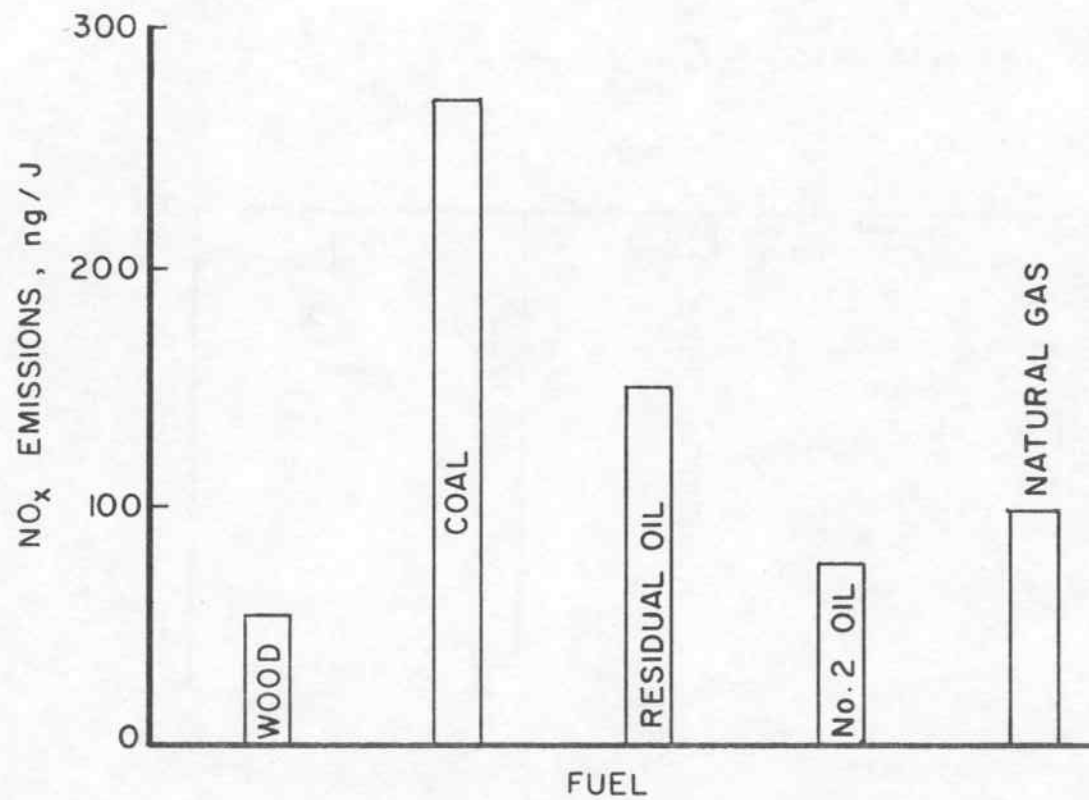


Figure 11. NO<sub>x</sub> emissions from industrial boilers.

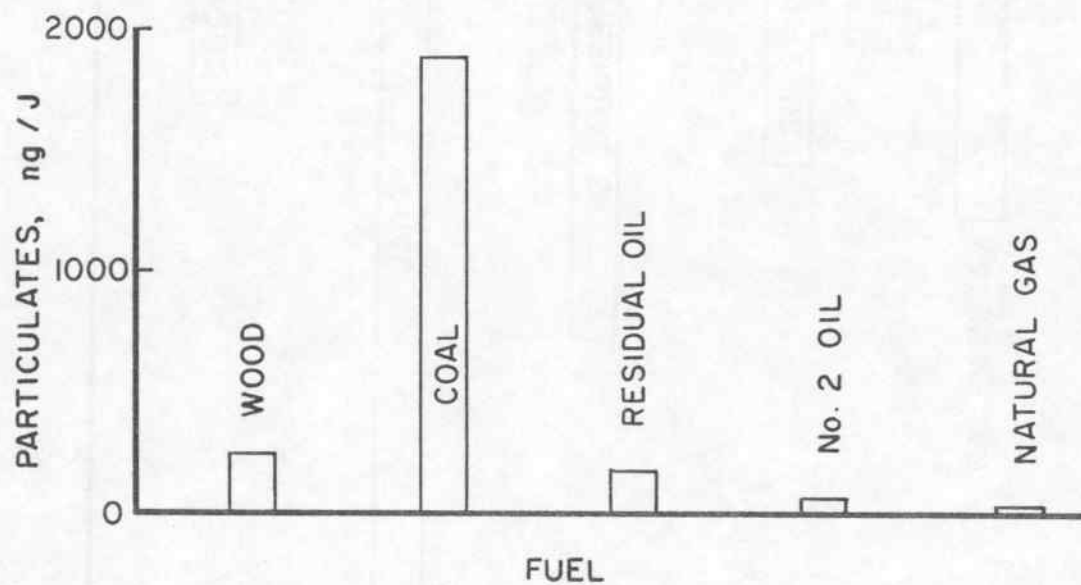


Figure 12. Particulate emissions from industrial boilers.





100

100

100