DESIGN OF ADVANCED COMBUSTION SYSTEMS FOR COFIRING OF NATURAL GAS WITH REFUSE DERIVED FUELS AND LANDFILL GAS

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ABSTRACT

The Gas Research Institute is developing an advanced combustion system for MSW furnaces which can be used to control emissions of polychlorinated dibenzo(p) dioxins and furans while simultaneously improving system performance on issues such as start up and load following. This advanced combustion system involves the cofiring of a small amount of natural gas in a strategic and controlled manner and was developed after extensive pilot scale development and full-scale characterization studies. The system will be demonstrated on a full-scale RDF plant during 1990. During the field evaluation, the cofiring system will also be utilized to provide for the co-incineration of landfill gas. In this paper, the advanced gas cofiring technique and the preliminary system design for the field evaluation site will be discussed.

INTRODUCTION

The Gas Research Institute (GRI) is developing advanced gas firing strategies for use with municipal solid waste combustion systems. These firing strategies are designed to improve the overall performance of municipal waste combustors as well as to control pollutant emissions. The programs initiated to date are addressing the control of NO_x and polychlorinated dibenzo(p) dioxin and furans (PCDD/PCDF). The GRI program is multifaceted addressing the area of municipal solid waste combustion from a number of different perspectives such as market studies, bench and pilot scale tests of advanced concepts, characterization of existing units, and full-scale evaluations of advanced firing schemes.

In the portion of the program described in this paper, the initial focus has been on controlling PCDD/PCDF from Refuse Derived Fuel (RDF) fired systems. New federal regulations are currently being developed which will likely require stricter emissions controls to be placed on both new and existing municipal waste combustors [1]. Tests conducted on these systems to date have indicated that RDF fired systems can have higher levels of PCDD/PCDF emissions than modern mass burn facilities; however, control schemes that are suitable for RDF fired systems have not been established. For this reason, the initial focus of this program has been on the development of natural gas based systems that can be retrofitted to existing facilities to provide control in a cost effective manner.

There is evidence that spray dryer/baghouse combinations can control PCDD/PCDF air emissions [2]. However, this approach may not be acceptable since it will only remove the pollutants from the gas stream and transfer them to the fly ash. In addition, these technologies are expected to be expensive or impossible

TABLE 1 GOALS OF RDF PLANT GAS COFIRING SYSTEM

ISSUE	GOAL
Dioxin Emissions	Less than 125 ng/Nm^3
Carbon Monoxide	Less than 150 ppm (7% O_2, 4 hour rolling average)
Load Fluctuations	Less than 10 percent variation in steam flow
Landfill Gas	To supply 10 percent of heat input
Start Up	Achieve controllable, smokeless start-up
Coal Cofiring	Eliminate ash problems

to retrofit to existing systems. The advanced firing concept developed under the GRI program is designed to destroy the PCDD/PCDF and the precursors species in the furnace, not just transfer the material to another form. In addition, the system may have a number of added benefits that allows the combustion system to perform in a better manner. The overall goals of the gas cofiring scheme are summarized in Table 1.

Finally, there is more interest in the disposal of gas generated from the natural decomposition of garbage in landfills. This landfill gas should be collected and destroyed or used in an environmentally acceptable manner. If local facilities are available, one possibility is to cofire the landfill gas in the same furnace as municipal solid waste in order to take advantage of the fuel value of the gas as well as to destroy the hazardous constituents in the gas. This application has some appeal, but can be detrimental to the performance of the facility if not carried out correctly. In this program, the use of natural gas to aid in the incineration or combustion of the landfill gas is being explored.

DEVELOPMENT PROGRAM

In the study discussed in this paper, the design of an advanced firing system was developed for an existing RDF fired facility. The system includes natural gas firing schemes for: PCDD/PCDF control, unit start-up, landfill gas incineration, and system load following. The program involved in the development of this design included a number of activities:

(a) market studies and user surveys
(b) pilot scale tests for process development
(c) field characterization of two RDF fired units
(d) conceptual design

In the near future, the system will be installed on an RDF fired utility boiler and its performance will be evaluated.

The pilot scale studies conducted under this program have lead to new insights into the formation and control of PCDD/PCDF. These studies were conducted in a specially designed facility that simulates the important features of RDF fired furnaces. In the pilot scale tests, process studies were conducted in which the impacts of different firing schemes were evaluated with respect to the emission of PCDD/PCDF. The experimental procedure and the results of these studies are presented elsewhere [3]. To date, these studies have shown that gas cofiring can be used to control pollutant emissions from RDF combustion systems.

In the following sections, the results of the field characterization studies and the resulting design of the gas cofiring scheme which is based upon both the field and pilot scale studies will be described.

FIELD CHARACTERIZATION STUDIES

Two separate field characterization studies have been conducted including tests on PCDD/PCDF formation and in-furnace profiles at a 360 ton/day (13,600 kg/h) RDF fired facility [4] and furnace performance tests on the 2400 ton/day (90,700 kg/h) RDF fired facility in Columbus, Ohio. The objective of these tests has been to determine the germane features of RDF fired spreader stokers that dictate the design criteria of a gas cofiring system. These studies have included characterization of the plant and boiler operation and performance, obtaining data on nominal furnace operation, identifying temporal and spatial variations in conditions within the furnace, and gathering preliminary furnace and boiler operating and performance data to supply key inputs to engineering design models.

The City of Columbus Municipal Electric Plant is described in detail elsewhere [5]. The plant began operation in 1983 and consists of six RDF-fired boilers that supply superheated steam to three 30 MW turbines. The furnaces consist of Detroit Stoker travelling grate spreader stokers and Babcock and Wilcox Stirling-type watertube boilers. The boilers were originally designed to fire a blend of stoker coal and RDF at a maximum continuous rating (MCR) of 165,000 lb/hr (74,800 kg/h) steam at 700°F (644 K) and 700 psig (4826 kPa). Each boiler at Columbus is equipped with a mechanical collector, hot-side electrostatic precipitator and regenerative air preheater.

Since the initial commercial operation of the Municipal Electric Plant, the City of Columbus has been working to optimize the operation of each boiler. Early problems associated with the design of the RDF feed system and the bottom ash handling system have been solved [5]. W hile great progress has been made, some operational problems that are characteristic of RDF-fired systems still exist. These operating problems include the following:

(a) load fluctuations
(b) coal cofiring
(c) start up
(d) emissions

The field characterization tests at Columbus were designed to evaluate the sources of these problems and to define the requirements for a gas cofiring system that would alleviate them. These tests consisted of in-furnace traverses for temperature, velocity, and gas species in conjunction with periodic visual observations of the furnace operation and combustion characteristics. In addition, measurements were conducted at the boiler economizer outlet in order to establish the degree of gas stratification and the normal boiler operating stoichiometry. Tests were conducted on boilers operating on RDF and on coal for comparison. The following sections describe the observed behavior.

Load Fluctuations

The fluctuations observed for coal and RDF fired boilers are illustrated by the steam flow production charts shown in Fig. 1. During the one week test,the nominal variation in steam flow typical of RDF firing was approximately 20–25% as compared to 10% when coal was fired. These variations are primarily caused by fluctuations in the RDF composition or flow rate leading to changes in the boiler heat release. In addition, while firing RDF, some occasional, extreme fluctuations were encountered in steam flow ranging from very little steam flow to steam flows greater than those measurable with the plant equipment. Visual observations of the combustion zone indicated that major changes in RDF feed flow and/or quality were responsible for these fluctuations. Low steam flows were typically produced by large, wet clumps of RDF falling to the grate and quenching the bed or by pieces of RDF plugging the feed chutes and interrupting the RDF flow to the boiler. On the other extreme, large quantities of unburned material could sometimes accumulate on the grate and suddenly ignite. This phenomenon was also observed when coal was added onto a bed of unburned RDF in an attempt to maintain steam flow and proved to be difficult to control. The nominal load fluctuations observed during the characterization tests at Columbus are consistent with data from other RDF fired boilers, but may be higher than typically experienced by the plant due to the large fraction of high moisture materials, such as wet grass, that were present in the RDF during the test period.

Coal Cofiring

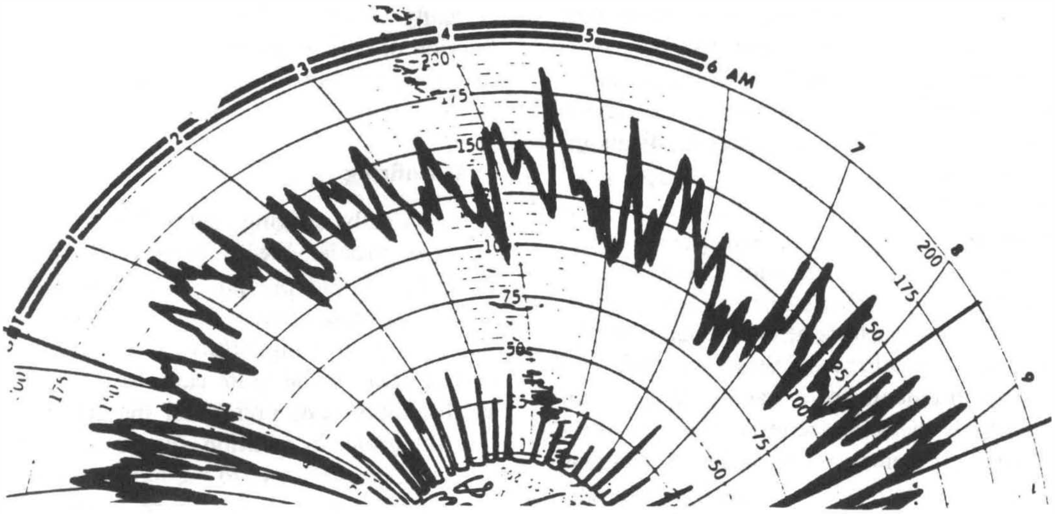
Historically, cofiring coal with RDF has been found to cause problems with grate operation due to ash sintering on and plugging the grate and to the formation of large clinkers that are difficult for removal. The high grate temperatures associated with combustion of coal on the grate can also cause metals, such as aluminum cans present in the RDF, to melt and clog the grate. In addition, due to the high density of the coal pieces relative to the lighter more fluffy RDF, the grate speed for proper burnout of the coal pieces is much slower than that for RDF. Therefore, when cofired with the RDF, a large fraction of the coal leaves the grate unburned resulting in poor combustion efficiency. As discussed above, the use of coal to follow load when the RDF combustion is insufficient can cause fluctuations in the load that are difficult to control. For these reasons, coal cofiring with RDF has been found to be unacceptable for normal operation at Columbus.

Furnace Start-up

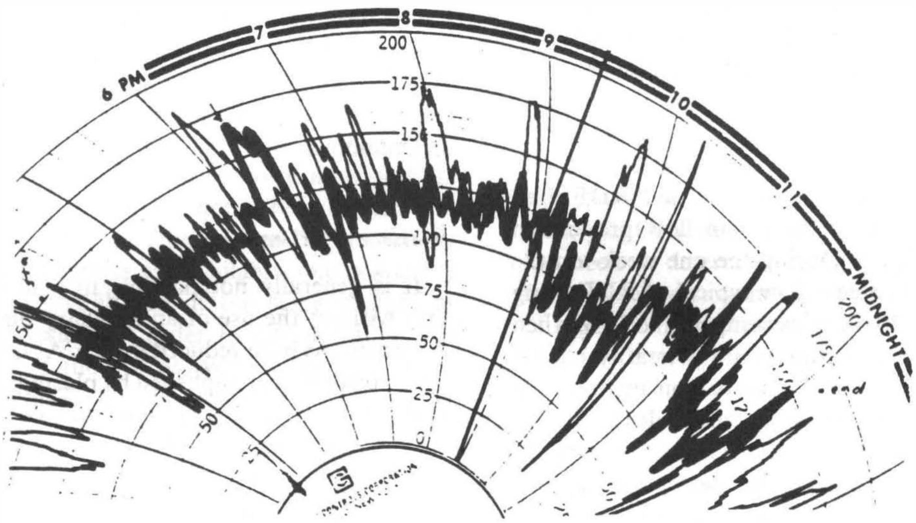
It is generally not possible to cold start an RDF unit without the use of an auxiliary fuel even though the waste has been reduced in size. At Columbus, start-up is normally accomplished by placing oil soaked rags, wooden pallets, and other combustible material on the grate while injecting coal. This technique produces a lot of smoke due to incomplete combustion and results in high opacity until gas temperatures are raised high enough to allow the electrostatic precipitator to be turned on. In addition, the current start-up approach can be difficult to control.

Emissions

Since the emissions of trace organics have not been quantified from the unit to date, only indirect indications of the emission levels can be suggested. Reported PCDD/PCDF emissions from other RDF fired units vary between 120–13600 ng/Nm^3 [6]. Therefore, it is expected that the levels of trace organics from this unit are likely to be higher than the federal standards which will soon be proposed. The emissions of trace organics from RDF fired systems have been attributed to the spatial and temporal variations in



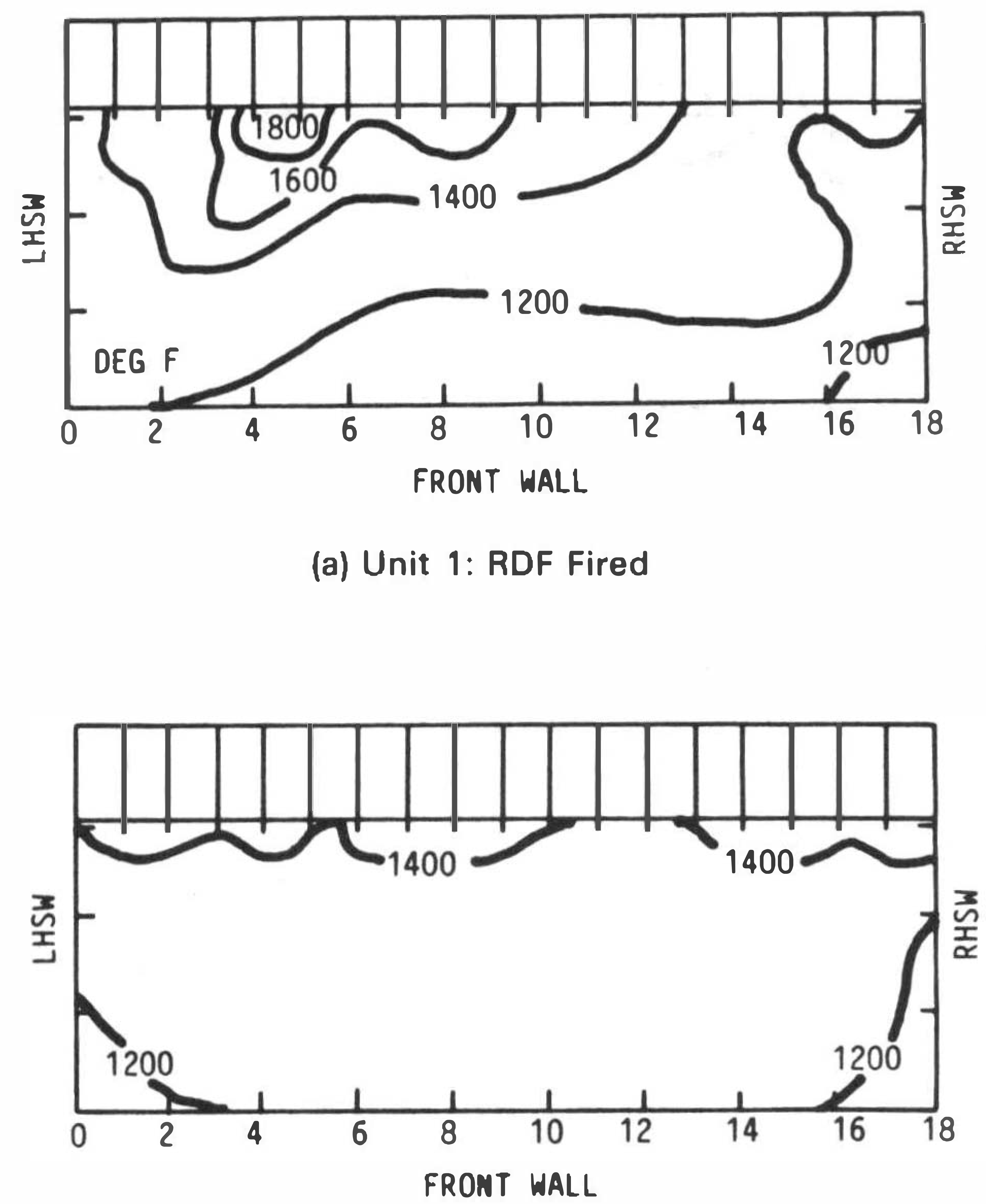
(A) RDF Fired Boiler



(B) Coal Fired Boiler

FIG. 1 LOAD FLUCTUATIONS FOR RDF AND COAL FIRED BOILERS

stoichiometry and temperature that exists within the furnace which provide pathways for organics to escape. In order to quantify these variations, in-furnace measurements were made of gas temperature, carbon monoxide, and oxygen along with visual observations of the grate burning process on the Columbus unit. Visual observations indicated nonuniform distribution of the RDF onto the grate with the RDF typically forming burning of piles of waste. Under normal conditions, the larger light density materials burn until they enter the convective section and, at times, flames were observed in the upper furnace. These observations indicate that some quantity of unburned material was escaping the furnace. In Figs. 2 and 3, upper furnace profiles of temperature, CO and O_2 for boilers operated on coal and RDF are shown. These measurements were



(a) Unit 1: RDF Fired

(b) Unit 5: Coal Fired

FIG. 2 UPPER FURNACE TRAVERSE OF GAS TEMPERATURES

conducted through ports in the upper furnace which were approximately 56 ft (17 m) above the grate. Measured gas temperatures for the RDF fired unit ranged from 1200°F to 1800°F (920–1260 K) while those of the coal fired unit ranged from 1200°F to 1400°F (920–1030 K). As indicated by a comparison of these two figures, the hot gas temperatures generally correspond to locations where the excess air is low and the cooler temperatures correspond to locations where the excess air is high. In addition, the high temperature/low excess air zones correspond to locations where flames were observed in the upper furnace.

Characteristics of Landfill Gas

One of the goals of this program is to utilize the landfill gas from the nearby Franklin County Landfill. The municipal landfill gas is collected by a total of 47 wells that are interconnected to a blower which provides vacuum on the wells allowing extraction of the gas from the landfill. The properties of the landfill gas

TABLE 2 LANDFILL GAS PROPERTIES

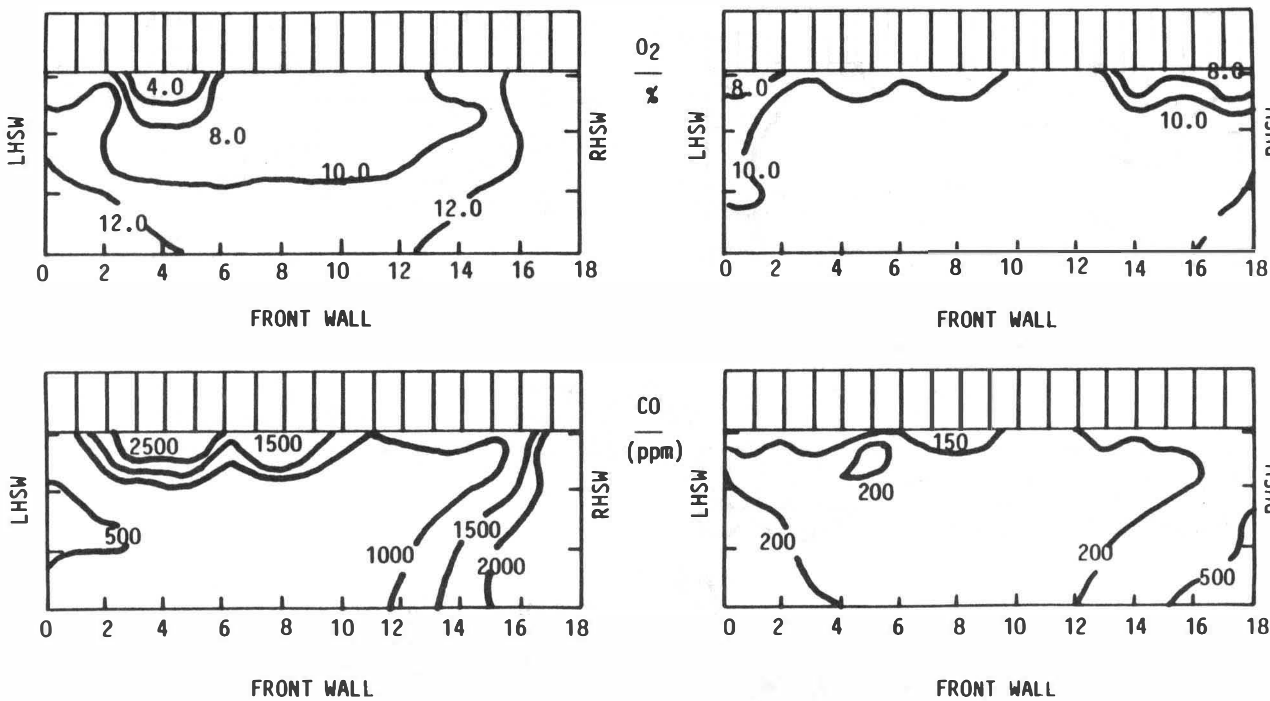
ITEM	NOMINAL VALUE	MAXIMUM VALUE	MINIMUM VALUE
CH_4 (VOL %)	57.2	58.7	52.6
CO_2 (VOL %)	41.0	42.5	39.5
N_2/O_2 (VOL %)	1.8	0.15	9.04
HHV (Btu/lb)	575	600	530
TRACE SPECIES	PPMV		
Hydrocarbons	1184.83		
Aromatics	97.2		
Cl, Fl Hydrocarbons	50.3		
Hydrogen Sulfide	6.0		
Mercaptans	22.0		

are summarized in Table 2. The gas has a medium Btu fuel value which is expected to remain consistent if pumped at a steady rate.

GOALS OF THE COFIRING SYSTEM

The characterization tests have revealed several operating limitations of the current facility that could be addressed with the natural gas cofiring system. The natural gas cofiring system should alleviate many of these problems by providing a controllable fuel that can be introduced in a uniform and on demand manner. The initial goal of the system is to provide load following and system stabilization. The program goal is to improve the load following ability while firing RDF from the current level of greater than ±20% to a level more like the levels achievable by coal combustion, i.e., ±10%. At the same time, the system must be designed to reduce the large load fluctuations that are possible when firing RDF. The boiler start-up will also be improved using natural gas firing. The goal is to use gas firing to bring the unit up to hot conditions such that the ESP can be brought on line before the RDF is fed to the furnace. In this manner, the start-up can be accomplished without smoke emissions. In addition, many of the problems associated with cofiring of coal and RDF can be avoided by load following with natural gas rather than coal.

The key advantage of gas cofiring is expected to be the ability to control trace organic emissions by destroying them in the furnace. Pilot scale tests have revealed that the emissions of PCDD/PCDF can be lowered by over 90% by the proper use of only 15% natural gas on a thermal basis [7]. These tests have



(a) Unit 1: RDF Fired

(b) Unit 5: Coal Fired

FIG. 3 UPPER FURNACE TRAVERSES OF O_2 AND CO

shown that the control of dioxin requires the control of precursors, including unburned particulate matter and gaseous organic matter, in the furnace. The goal of this program is to reduce the precursors to the level such that the total PCDD/PCDF (tetra through octa) emissions will be less than 125 ng/dscm. In addition the emissions of carbon monoxide, which is commonly used as the indirect measure of trace organics emissions, will be held to less than 150 ppm (1 hr average corrected to 6% O_2). These levels can only be accomplished by compensating for the natural temporal and spatial variations in the furnace through the use of upper furnace injection of natural gas. Also some redistribution of the combustion air will prevent the entrainment of the particulate matter that act as the precursors for dioxins. Because of the relative cost of natural gas, the goal is to use as little gas as possible. In this program, the goal is to use only 20% natural gas (on a thermal input basis) to control both PCDD/PCDF emissions and load fluctuations. For other applications where the only goal is to control PCDD/PCDF, the use of natural gas could be restricted to 10–15% of the total load of the furnace.

DESIGN OF THE COFIRING SYSTEM

The site characterization studies have been used to design a natural gas cofiring system for the boilers at Columbus that is suitable to achieve the program goals described above. The most stringent goal is the control of trace organics and hence the major focus has been placed on this design issue. At the same time, the goal is to improve the load following of the boiler by cofiring natural gas according to steam demand.

The preliminary design for the gas cofiring system is shown in Fig. 4. In this scheme, the upper burners are designed to cofire natural gas and landfill gas, while the lower burners are designed to fire natural gas only. The rationale for the design of the gas cofiring system will be described in the following.

For combustion control of trace organics, the amount of all unburned material escaping the furnace must be reduced. This is especially true for particulate matter and unburned hydrocarbons which can act as precursors for PCDD/PCDF. The approach followed in this program is to fire gas through a set of burners at an elevation above the RDF distributor creating an

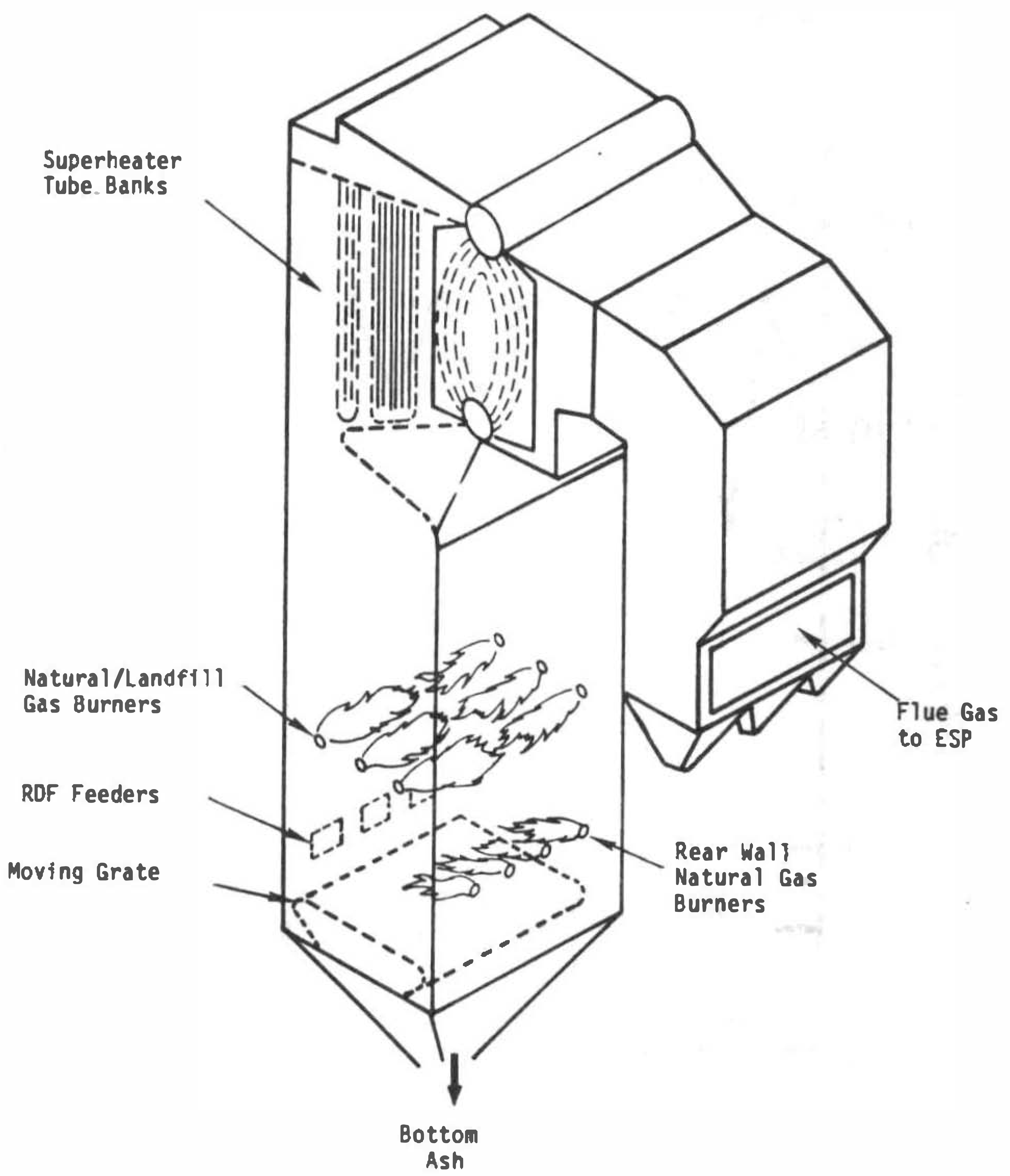


FIG. 4 GAS COFIRING SYSTEM DESIGN

in situ "afterburner" zone through which all of the combustion gases and unburned material must pass. This zone will increase combustion of the suspended RDF and improve the overall distribution of temperature and stoichiometry. The upper burners are designed to fire approximately 10% of the heat input to the furnace at full load. Multiple burners arranged on the sidewalls of the furnace will be used to completely cover the furnace flow. Burner velocities have been designed to allow the flames to penetrate into the furnace flow field. These burners will be operated at relatively constant flows for a given steam demand to maintain the integrity of the afterburner zone. Therefore, they will be used to fire the landfill gas in addition to natural gas. However, provisions are included to allow variation of burner flows in response to thermal profile changes. The final feature of the trace organic control system is the redistribution of the combustion air to minimize the carryover of particulate matter. This has been shown to be directly related to the emissions of PCDD [8] and can be minimized by changing the relative amount of underfire air. This air redistribution will not require any system modifications. However, optimization of the air flows without detrimentally impacting the grate burning behavior or grate temperature must be determined in actual operation and will be performed during the system shakedown tests.

The load following and start-up system will be separate from the trace organic control burners. These burners will be positioned closer to the grate region in order to provide heat input to the grate for start-up and to sustain the bed combustion. In order to control load fluctuations to 20%, these burners are designed to provide 10% of the total thermal input to the grate at nominal conditions. The burners used for load control will have high turndown capacity since they would be expected to vary from 0 to 20% of the heat input of the grate. Based upon the design of the Columbus boilers an ideal location, in terms of ease of retrofit, for these burners would be on the rear wall at the elevation of the existing intermediate overfire air ports. These burners are designed to minimize the impact of gas firing on the normal combustion of the RDF.

The natural gas and landfill gas cofiring strategy is illustrated in Fig. 5. The goal of the program is to maintain the current RDF utilization at the plant at the current level. The gas cofiring is thus expected to result in an increase in the boiler generating capacity. Figure 5 shows the nominal fluctuations in the RDF thermal input of 20%. The gas used for load following will be varied in response to changes in the thermal input of the RDF via a modified control system that is tied to the natural gas flow. To provide for control of the gas cofiring system, control hardware will be installed to link the gas cofiring system components to the existing boiler master and controls system. The addition of gas for control of the boiler load is expected to reduce the overall fluctuations in the steam flow to at least 10% and result in an overall increase in the boiler load. The addition of more gas to create an in situ afterburner will result in another increase in average steam flow. In order to maintain furnace exit temperatures below those that can cause increased superheater corrosion, the overall increase in load must be such that the boiler steam flow is below the maximum continuous rating of the boiler at the peaks in steam flow production. As shown on the heat input chart in Fig. 5, the gas used to create the afterburner will typically be supplied at a constant total thermal input. The control of the upper burners will be on a separate control circuitry which is tied to temperature monitors located in the upper furnace region which will indicate if low temperature regions are developing in the furnace.

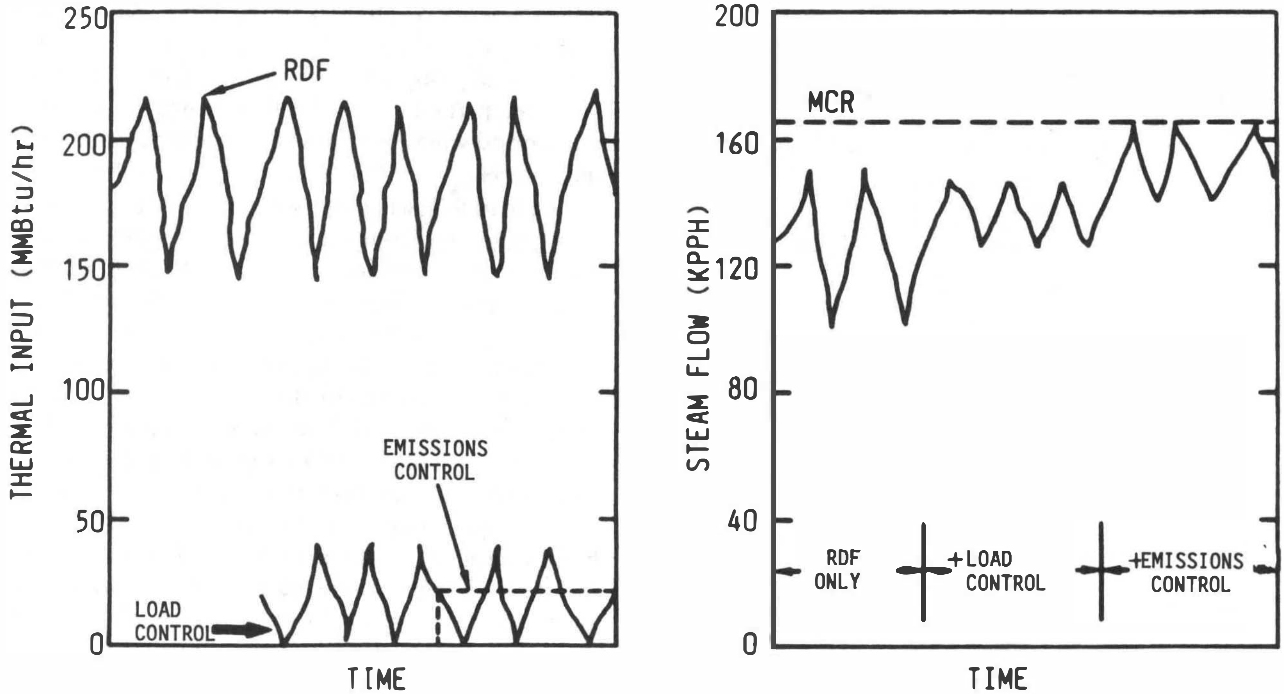


FIG. 5 GAS COFIRING STRATEGY

SUMMARY

An advanced combustion system has been developed for a RDF fired boiler that is expected to alleviate many of the currently encountered problems characteristic of such systems. The design will be evaluated at full scale with respect to its ability to meet the design goals established in Table 1 as well as any impacts on upper furnace gas temperatures. The system uses the strategic cofiring of natural gas to provide uniform combustion conditions which are difficult to achieve in any other manner. A bi-level burner arrangement was developed for the Columbus facility which provides load following as well as improvements in emissions control and start-up. The system also allows the firing of landfill gas in an environmentally acceptable manner without detrimental impacts on the boiler operation.

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Keywords: Combustion; Dioxins; Emissions; Landfill Gas; Refuse-Derived Fuel