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A Test Facility for Physical Modelling of A Steel Reheating Furnace

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Introduction

Industrial flames are commonly used in applications where the process objectives may be of two kinds, power generation and provision of energy for product processing. Examples in the first category include most types of combustion engines where the process output is directly measured by energy conversion through shaft work. Product processing operations include kilns, boilers and steel processing operations such as reheat furnaces. In such operations we are interested in energy transfer to the product where factors such as product quality and yield are also important considerations.

Regardless of the process objective, fuel costs, quality and availability; the need to meet environmental regulations and improve product quality are issues forcing industry to make significant changes and implement more sophisticated technology.

The steel reheat furnace serves as a good example where constant improvements are sought. The nature of hot rolling makes it one of the most energy consuming operations in the steel processing sequence. For example, in the area of slab reheating alone, a 7°C reduction of the reheat furnace discharge temperature yields approximately a 1% savings in the annual fuel cost [1]. However, other factors such as product quality, must also be considered in designing the thermal profile for slab reheat systems. Of great importance for the rolled product quality is uniformity of temperature across the slab. The steel slab rides within the furnace on parallel cooled rails which locally block radiation; the resulting "skid marks" pose problems for subsequent rolling operations. Intermittent and/or mixed charge may also require special modulation of the heat flux from the burners.

With a broad goal of gaining a better understanding of the reheat furnace processes and providing solutions for existing problems, Queen's University at Kingston has launched a research programme in advanced reheat furnace technology. This programme, funded by FERA, NSERC, the Ontario Ministry of Energy and three Natural Gas Companies; Consumers Gas, Union Gas, ICG Utilities (Ontario), is the first of a series of combustion projects which researchers at Queen's intend to pursue. A specially equipped building has been constructed to house a pilot plant furnace capable of modelling steel reheat furnace conditions. This furnace will provide experimental data for a complementary numerical modelling study. The work is also supplemented with experimental cold modelling studies of flows similar to those encountered in steel reheat furnaces.

The general objectives of this research programme are:

1. Develop a combustion test facility for relevant laboratory and pilot plant combustion experiments.
2. Carry out well designed experiments to provide data describing normal operation and special conditions of interest as input to the modelling investigations.
3. Develop state-of-the art laser based and conventional instrumentation capable of simultaneous, time and space resolved measurements of velocity, temperature, species concentration and heat fluxes in nonreactive and combusting flows.

The overall programme involves the design and construction of the pilot plant test facility and an experimental testing programme in conjunction with a computer code development phase. Some of these activities are carried out in parallel, e.g. cold modelling and computer code developments have been in progress during the pilot plant construction phase. Some of these activities are presented elsewhere in papers presented at this conference [4], [5], [6].

Experimental work

Steel reheat furnaces typically utilize many burners in complex arrays to provide the desired heat transfer characteristics, Fig. 1. Hence in order to provide a realistic representation of these complexities within the limitations of a pilot scale test facility, the furnace can be regarded as being made up of cells or modules, one to each burner as shown in Fig. 2. Essential features of the furnace might be reasonably investigated with scaled-down cold and hot models incorporating up to three one-burner cells.

Cold Modelling

A three-burner, 1/6 scale cold model of a reheat furnace has been designed and constructed. Geometric and dynamic similarity is maintained with the real furnace. The model permits measurements of fluid velocities using a two component, three beam Laser Doppler Anemometry (LDA) system operating in a back-scatter mode.

A schematic of the cold model is shown in Fig.3. Details of the experimental set-up and the data acquisition and processing can be found in [3].

Fig.4 shows examples of the mean velocity vector field for the channel flow with three burner jets entering a transverse cross flow. These measurements provide quantitative and qualitative information on the flow structure within the model. The flow issuing from each burner appears to turn rapidly without impinging the far wall of the model and the upstream jets shield the downstream jet(s) from the impact of the cross flow. Additional work in our laboratories will include tests with three pairs of opposing jets and the flow issuing from nine roof burners.

Hot Modelling

A new laboratory building has been designed and constructed to provide a base for the planned experimental activities. An elevation and two plan views of the laboratory with the experimental furnace are shown in Fig. 5. The design of the furnace is 1/2 scale with provision for three long flame side wall burners or nine roof, short flame burners. The major structural components of the furnace were manufactured in-house while burners, control system and refractory were purchased from commercial suppliers.

A decision to build a half-scale model was based on a constant magnitude of the buoyancy parameter $Ri = gV(p - \rho_0)/\bar{\rho}u^2A$ to correctly model the furnace aerodynamics, while maintaining the dominant role of radiative heat transfer. Trends of relevant parameters can be seen in Table 1 and Table 2. Table 1 summarizes a typical real reheat furnace conditions for a one burner cell and Table 2 shows the model operating conditions for the constant buoyancy parameter.

Table 1

Typical Real Furnace Conditions For a One Burner Module

- Module Dimensions:

Length	L	m	6.0
Heigth	H	m	2.2
Width	W	m	2.2
Volume	V	m^3	29.0
Plane Area	S	m^2	13.2
V/S		m	2.2

- Firing Rate:

Combustion Heat Release	MW	2.9
	MMBtu/h	10.0
Natural Gas Flow	kg/h	210.0
	m^3	290.0
Gas Cost \$ $0.19/m^3$	\$/h	55.0

- Stoichiometric Air Flow, m^3/h=2760 or 1630 SCFM.
- Firing Density:

$\dot{Q}_c/V$	MW/m^3	0.10
$\dot{Q}_c/S$	MW/m^2	0.22

- Gas Temperature,1200^0C.

Table 2
Simulation at Constant Buoyancy Parameter

Length Scale		1/4	1/2	1
Buoyancy Parameter	$\frac{V^{5/3}}{\dot{Q}_c^2}$	33	33	33
Firing Density:				
$\dot{Q}_c/V$	MW/m^3	0.2	0.14	0.1
$\dot{Q}_c/S$	MW/m^2	0.11	0.16	0.1
Firing Density:				
$\dot{Q}c$	MW	0.09	0.51	2.9
Natural Gas	$/h	1.7	10	55
Stoichiometric Air	m^3/h	86	490	2760

The furnace was designed to burn methane with preheated air. As mentioned above, the burner configuraton involves three side wall, long flame burners and nine roof, short flame burners. They can be fired in a number of arrangements: (i) a single side wall burner for near field studies, (ii) three side wall burners, (iii) three roof burners or (iv) nine roof burners. Total firing rate of the side wall burners is 1206 kW and 567 kW for the roof burners.

The walls and roof of the furnace are lined with Fibreframe insulation panels. The density of the panel material is much less than castable refractory commonly used in industrial furnaces. This lower thermal mass means that steady state can be reached far more quickly under pilot plant test conditions.

The floor of the furnace incorporates a base of water-cooled, instrumented panels which will permit measurements of heat fluxes to the floor. One, two or three levels of steel radiative baffle plates may be placed above the water-cooled base. These baffles will attain a temperature intermediate between the "zone" temperature and the cooled base temperature.

Provision was also made for the insertion of instrumented steel specimens through the roof ports to simulate heating of the slabs for studies of scale growth and heat transfer.

Burner design

The burners and control system for the experimental furnace were designed by Bloom Engineering Company, Inc. A schematic diagram of the side wall burner is shown in Fig. 6. This burner was designed to ensure low level of NO_x emissions.

Factors effecting NO_x generation relate both to the combustion process and to the furnace variables. The primary condition for increased NO_x levels are high local values of both temperature and oxygen concentration. Such conditions can be avoided by staging the combustion air, staging the fuel and by recirculation of the combustion gases and flue gas into the primary combustion zone.

The evolution of the low NO_x burner design is shown in Fig. 7 [2]. The low NO_x burners consist of four air holes spaced circumferentially to allow for recirculaton between the air jets; there is an additional recircuiation chamber at the point of gas injection. The advantage of this design is that the flame momentum of the conventional burner has been retained and, within this restriction, the low NO_x capability provided. A schematic diagram of the roof burner is shown in Fig. 8. This is a short flame burner, which allows for upstream furnace flue gas recirculation to help reduce NO_x emissions.

Diagnostic Instrumentation

The data package to be produced in our experiments is intended to provide modellers with the necessary information to validate the results of computer simulation codes; this includes the required input information for the computational routines and a complete set of reference data for comparison with the program output. The diagnostic instrumentation to be used in our experimental work is listed in Table 3. Additional data will also be provided by thermocouples and pressure transducers placed at the furnace walls and roof. This instrumentation will provide mean and fluctuating temperature and velocity data, composition, total and radiative heat fluxes at various locations within the furnace. The furnace also features a large number of spot ports for traversing and three Pyrex glass windows for visual observation.

Table 3
Diagnostic Instrumentation:

Heat Transfer to Load: instrumented water-cooled panels comprise furnace floor.

Irradiance: ellipsoidal radiometer.

Gas Temperature: suction pyrometer and Pt/Pt-10%Rh bare microthermocouples.

Gas Velocity: 5-hole probe .

Gas Velocity and Velocity Fluctuations: two-component, three-beam Laser Doppler Anemometry system.

Gas Composition: gas chromatograph, oxygen sensor, NO_x analyzer.

Summary

A versatile and sophisticated combustion laboratory for advanced combustion technology is being developed at **Queen's** University at Kingston. This test facility comprises;

- An experimental furnace capable of producing a variety of burner and flame configurations.
- Two component, three beam LDA system capable of measuring velocities within a real, large scale combustion device.
- Temperature, total and radiative heat fluxes, gas composition data acquisition systems.
- Auxiliary systems, such as preheated combustion air and fuel supply networks, LDA seeders, LDA data acquisition and processing schemes and optical flow visualization.

Acknowledgments

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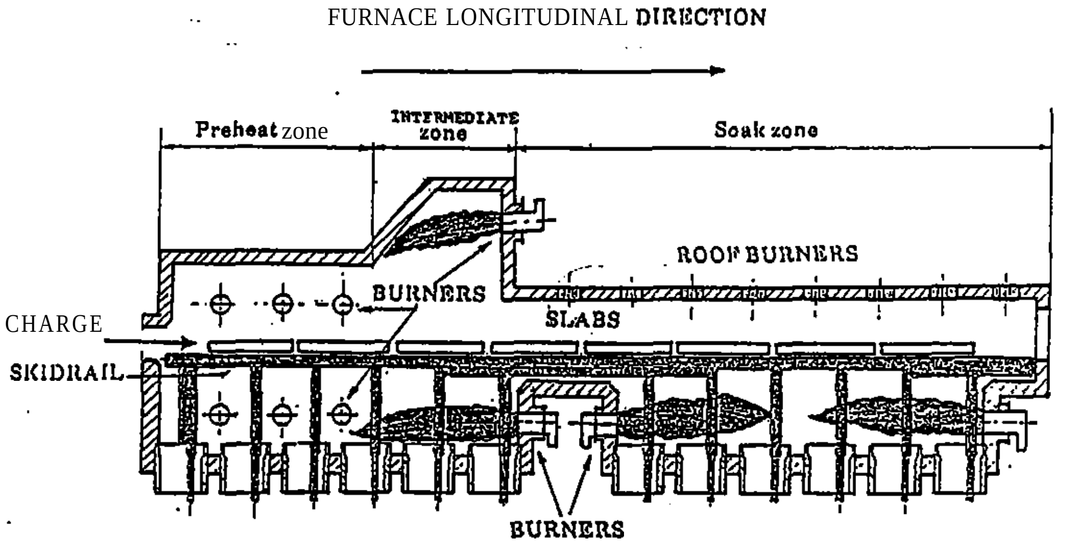


Figure 1: Profile of walking beam reheating furnace.

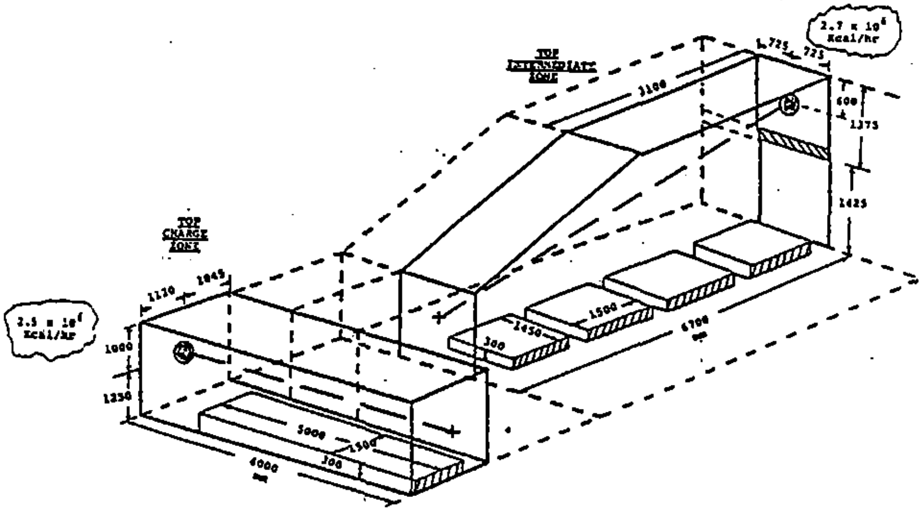


Figure 2: Firing geometry of two typical burner "cells".

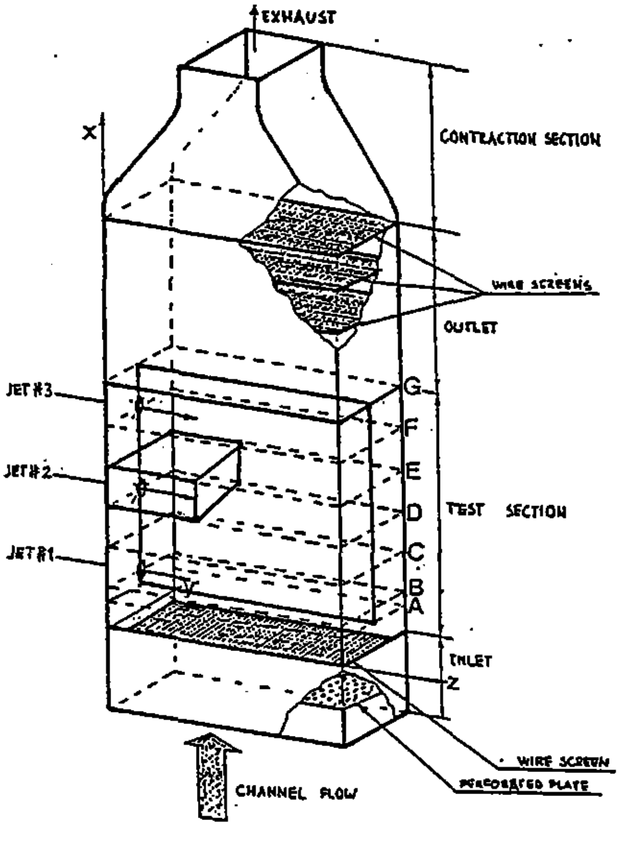


Figure 3: Schematic of cold-air flow model.

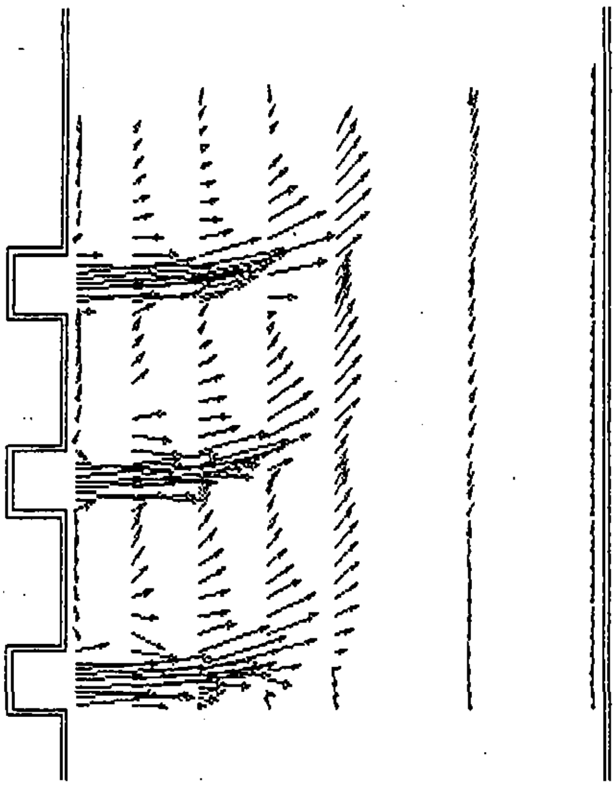


Figure 4: LDA measured mean velocity vectors on a plane through the axis of the burners .

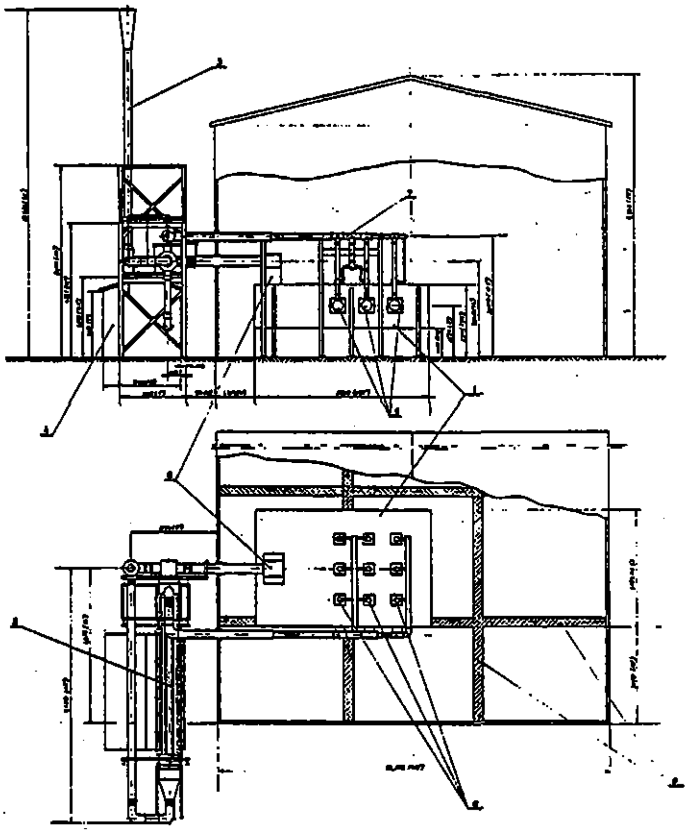


Figure 5: Laboratory building and experimental furnace.

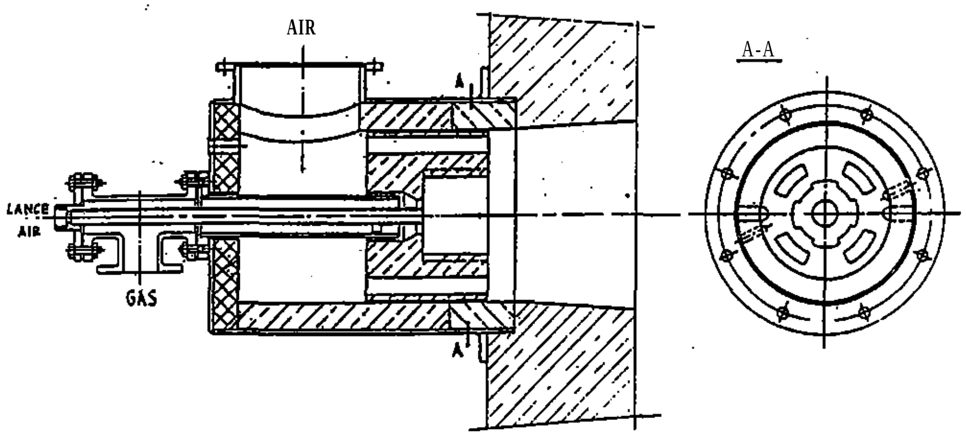
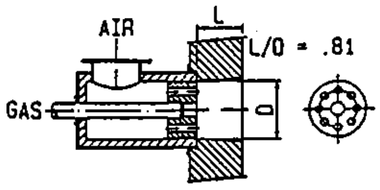
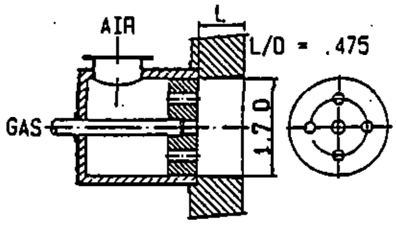


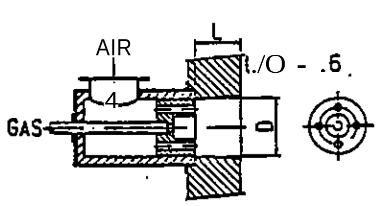
Figure 6: Schematic of side wall, long flame burner.



CONVENTIONAL BURNER



LOW NOX BURNER



COMPACT LOW NOX BURNER

Figure 7: Evolution of design of the low NO_x burner.

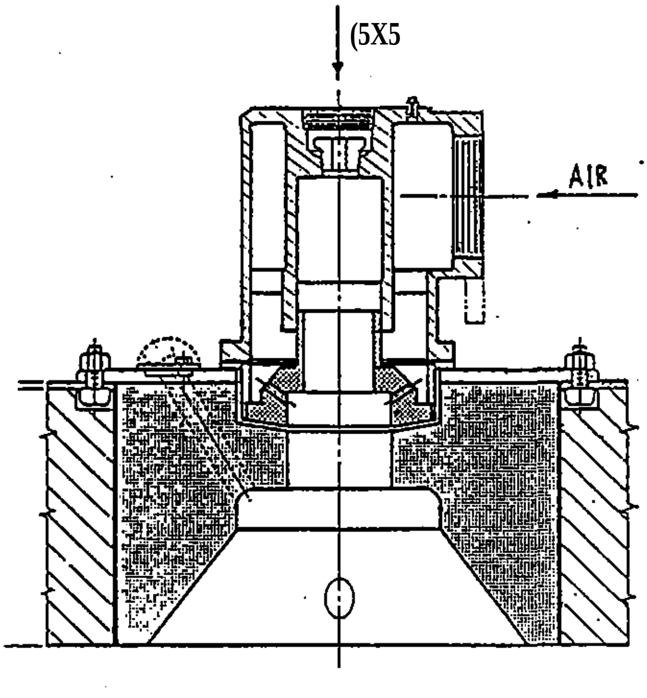


Figure 8: Schematic of roof, flat flame burner.