High Momentum Flame Technology for Low NO_X Formation in SER Radiant Tube Burners.

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High momentum jet flames are widely used in different industrial applications to develop intensive flue gas recirculation for better forced convection heat transfer and temperature uniformity in the working chamber. The working chambers of radiant tube burners are confined within four major types of geometry: coaxial tubes (SER design), U, W and P shapes. This article discusses the main design advantages and performance of the Auto-Recupe burner mounted inside of a single-ended radiant tube (SER), developed by Eclipse Combustion, Inc., that employs this high momentum flame technology to satisfy industry requirements and environmental regulations.

Emissions output is an important aspect of contemporary thermal process technology especially in view of today's environmental regulations. New burner technology has been developed to increase thermal efficiency, raise flux rates and improve temperature uniformity. In addition, generation of nitrogen oxides (NOx) can be significantly reduced using staged air/gas mixing or staged combustion. Staged combustion is a combination of two technologies: rich combustion (under-stoichiometric condition) and lean combustion (over- stoichiometric condition).

Under a rich mixing condition, the combustion air provided to the mixing zone creates oxygen-starved zones, which lead to incomplete fuel oxidation and, as a result, less peak flame temperature. Both a flame temperature reduction and a lack of oxygen in the mixing/rich combustion zone lead to NOx reduction. Under lean mixing conditions, the combustion air provided to the mixing zone creates a flame with excess air above the stoichiometric level. The higher the excess air, the more heat is wasted in preheating that excess air, hence a lower flame temperature and reduced NOx emissions.

Staging of air causes a gradual air premix to the flue gas stream. Staging of gas causes a gradual gas premix to the full combustion air stream. This is usually accomplished with a special nozzle/mixer design. Staging leads to the formation of rich or lean combustion zones. The first stage produces the richest or leanest mixture, the next one – less rich or lean and so on. The last stage in a staging process produces the formation of a stoichiometric mixture (or whatever percentage of excess air is required).

Initial momentum of the flame jet determines the intensity of flue gas recirculation in the working chamber. The higher the momentum, the higher the flue gas recirculation inside the chamber. This results in a larger amount of flue gases being returned into the flame envelope. Recirculating flue gases contain less oxygen than combustion air and these flue gases also have a lower temperature than a flame envelope, therefore the total flame jet temperature is lowered, thus reducing emissions.

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Burner Design and Principles of Operation

A single-ended radiant tube burner, known as the Auto-Recupe Ultra (AR-Ultra), has been developed employing Eclipse high velocity burner technology. A nozzle supplies air jets to the gas flow in a progressive manner creating a staged air mixing along the gas flow path.

The burner consists of a housing with exhaust outlet and air and gas inlet blocks each equipped with a flow metering orifice plate. The rear cover provides openings for a flame rod or UV scanner, spark rod and a peepsight. Other components include a recuperator and a gas supply tube to connect the gas inlet block to a nozzle located inside the combustor. The burner is mounted to the furnace wall with an adapting flange. The radiant tube is located inside the furnace chamber and connected to the burner through the same adapting flange. The inner tube is assembled from ceramic elements and mounted inside the radiant tube. From the burner side, there is a mounting gap between the combustor outlet and the inner tube inlet. At the end of the radiant tube, a specially shaped ceramic element is installed to reverse the direction of the combustion products from inside the inner tube to the annulus gap formed between the inner tube and the radiant tube (see Figure 1).

A high momentum flame jet creates intensive recirculation of the combustion products inside the radiant tube. Due to the Venturi effect, part of the stream is entrained back into the flame envelope through the gap between combustor outlet and the inner tube inlet, diluting the flame with cooler combustion products. Moving through the recuperator to the exhaust, combustion products preheat combustion air coming to the nozzle for gradual mixing with the gas flow. Getting heat from the flame and the recirculating combustion products, radiant tubes re-radiate the heat to the furnace chamber including load, refractory walls and accessories. Using ceramic elements (instead of alloy) to assemble the inner tube allows the AR-Ultra burner to operate at a higher heat flux - as high as 40.9 kW/m^2 (90 Btu/hr in^2). This higher heat flux results in fewer burners being required on the furnace to achieve the same capacity. If there is a need for increased furnace capacity, AR-Ultra burners are able to intensify heat transfer, and hence, deliver more heat per second to the surface of the load. The flexible ceramic inner tube is able to withstand higher temperature levels and fluctuations, be more responsive to the radiant tube deviation and temperature expansion, and hence, prolong the total service time of the burner.

Temperature Uniformity in AR-Ultra Radiant Tube Burners

Temperature uniformity of the radiant tube is an important criterion in estimating burner performance. The higher the temperature uniformity, the more even the heat distribution in the furnace chamber resulting in improved quality of the final product. Temperature uniformity (ΔT) is an expression of the difference between the hottest (T max) and the coolest (T min) spots on the radiant tube surface ($\Delta T = T_{max} – T_{min}$). The data, illustrated in Figures 2 and 3, reflects a tendency of the tube temperature to improve with higher furnace temperatures.

This tendency occurs for all three fuels tested: natural gas, propane, and butane. Tests were performed on radiant tubes of ∅150 mm (6”) outer diameter and 1400 mm (55”) effective length (figure 2), and ∅200 mm (7.5”)/2030 mm (80”) (figure 3). Input was constant through the furnace temperature cycle and the average heat flux was about 34 kW/m^2 (75 Btu/hr in^2). The burner was operating at 15% excess air from cold start up to the final furnace temperature. The temperature was measured by thermocouples placed evenly along the tube surface.

The testing of a single radiant tube was accomplished in the batch type furnace with partial ‘load’ simulation. In continuous heat treating furnaces the influence of a load on tube ΔT

is different from one furnace type to another, therefore the data shown in Figures 2 and 3 may be slightly different from one application to another.

Furnace Temperature and NO_X Emission

Usually the furnace thermocouple reads the temperature of the furnace atmosphere influenced by radiation from the radiant tube and re-radiation from load, wall and accessories. The radiant tube is an energy source for the load heating. The temperature difference between the radiant tube and the load is the largest difference in the system. The wall and atmosphere temperatures are in between these two. The higher the furnace and radiant tube temperatures, the higher the NO_X emissions in the exhaust (see Figures 4 and 5). Because of their higher flame temperatures, propane and butane combustion produces NO_X levels approximately 30% higher than natural gas.

Radiant Heat Flux, Combustor Outlet Velocity and NO_X Emission

Figures 6 and 7 show the NO_X emission data versus radiant heat flux, measured at 950°C (1750F°) furnace temperature. The heat flux was calculated based on fuel input, burner thermal efficiency, and effective tube surface area. The higher the heat flux dissipated from the tube to the furnace chamber, the lower the NO_X emissions in the burner's exhaust. This is due to flame quenching inside the inner tube causing the release of more radiant energy from the burner.

Flame jet outlet velocity from the combustor is an important factor in creating an optimum recirculation within a radiant tube. Optimizing the tube temperature uniformity helps to lower NO_X emissions, and increase burner efficiency. As shown in Figure 8, increased velocity promotes NO_X reduction by approximately 8% for natural gas, and 4% for propane. This higher velocity also increases the rate of recirculation resulting in even lower NO_X emissions. This is due to the increased dilution of the fresh and hot flame jet with the cooler returning combustion products.

Flue Gas Recirculation and NOx Emissions

Three factors determine the amount of flue gas recirculation possible in radiant tube burners: combustion outlet velocity; flow rate (input); and the size of the gap between the combustor outlet and the inlet to the inner tube. Tests conducted reveal than when this gap is optimized in relation to the other two factors, NOx emissions can be reduced 10% and ΔT lowered by 30% over the results achieved using a burner with no gap (and therefore, no recirculation). See Figure 9.

Conclusions

The newly developed Eclipse AR-Ultra single ended recuperative radiant tube burner operates at a heat flux higher than conventional burners with high tube temperature uniformity and low NO_X emissions. This results in increased fuel efficiency, better heat flux uniformity and improved heat penetration into the load.

References

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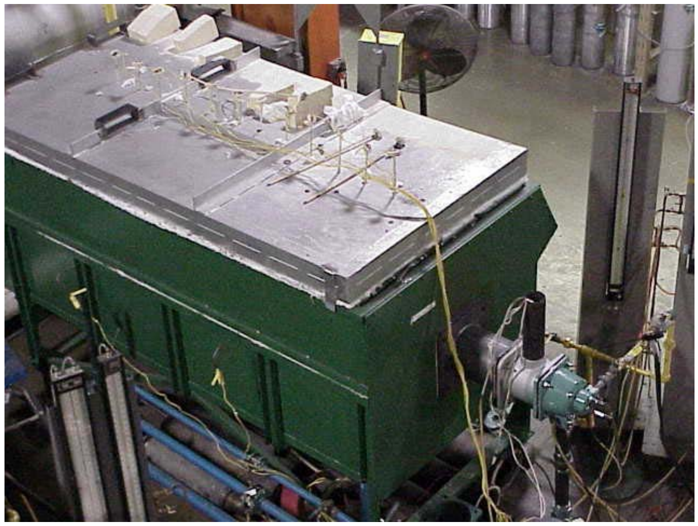

Development lab testing of the AutoRecupe Ultra

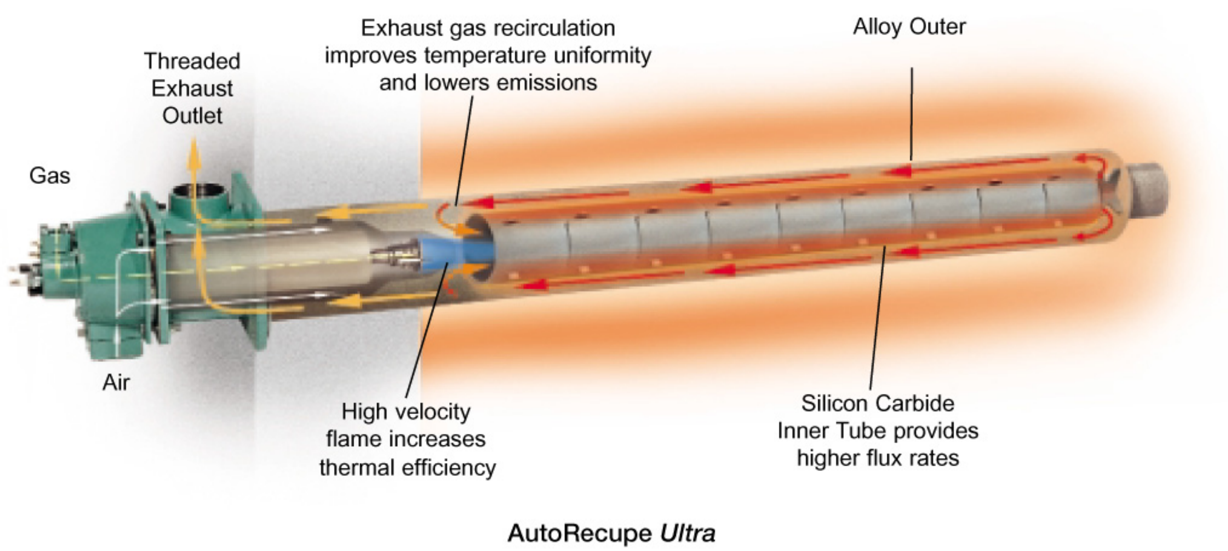

Figure 1. Burner design and flame/combustion products recirculating pattern.

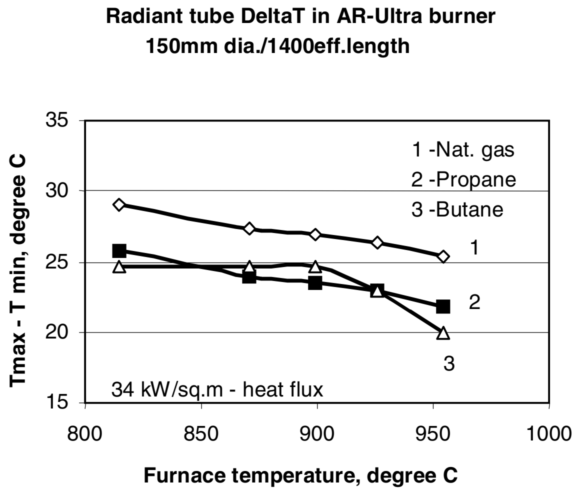

Figure 2 Radiant tube temperature uniformity in AR-Ultra burner of 150 mm dia. vs furnace temperature

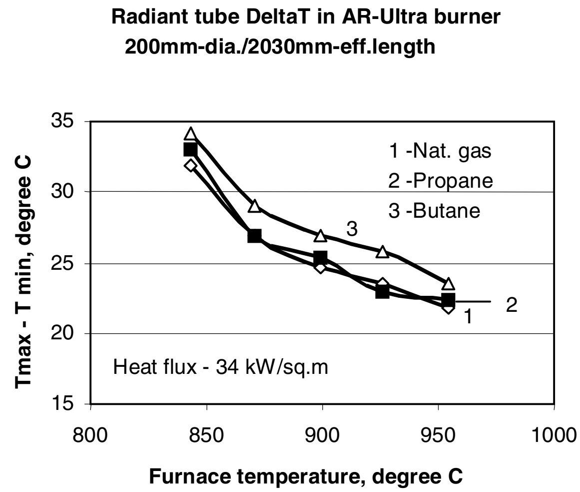

Figure 3 Radiant tube temperature uniformity in AR-Ultra burner of 200 mm dia. vs furnace temperature

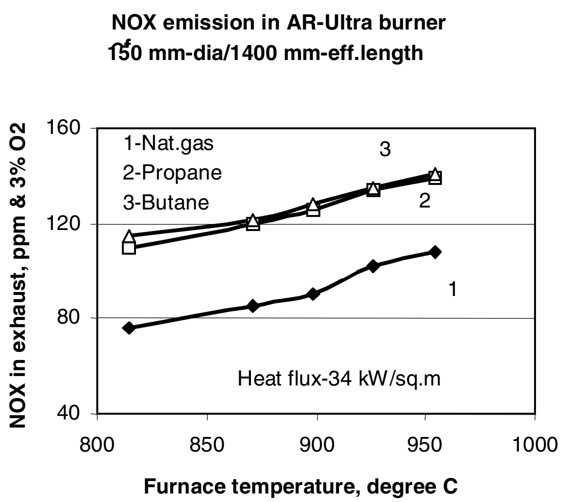

Figure 4 NO_X emission in AR-Ultra burner of 150 mm dia. vs furnace temperature

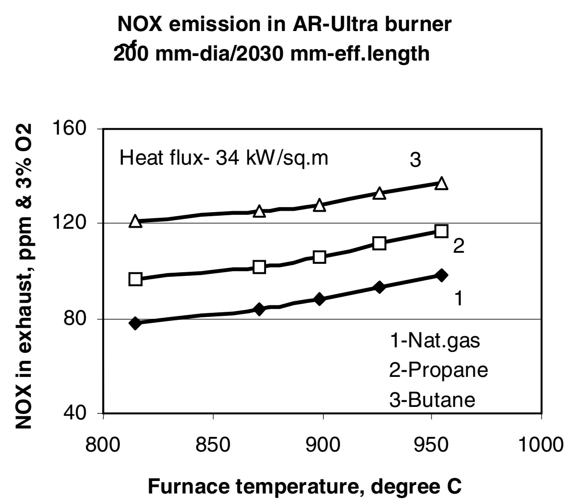

Figure 5 NO_X emission in AR-Ultra burner of 200 mm dia. vs furnace temperature

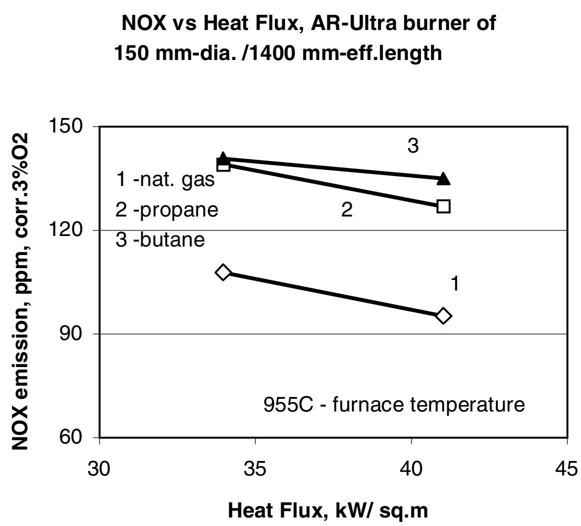

Figure 6 NO_X emission in AR-Ultra burner of 150 mm dia. as a function of heat flux

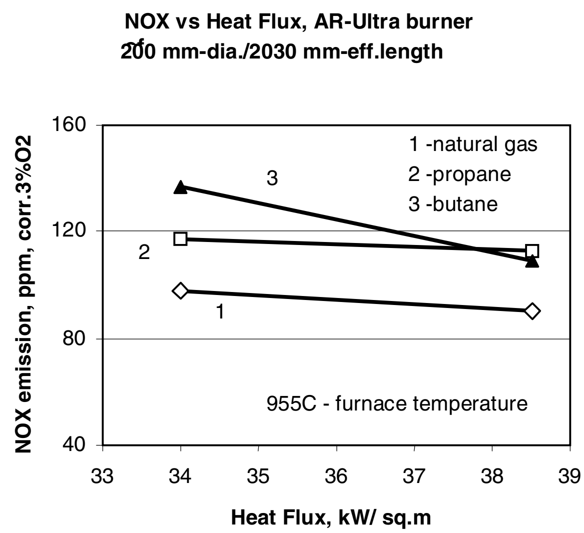

Figure 7 NO_X emission in AR-Ultra burner of 200 mm dia. as a function of heat flux

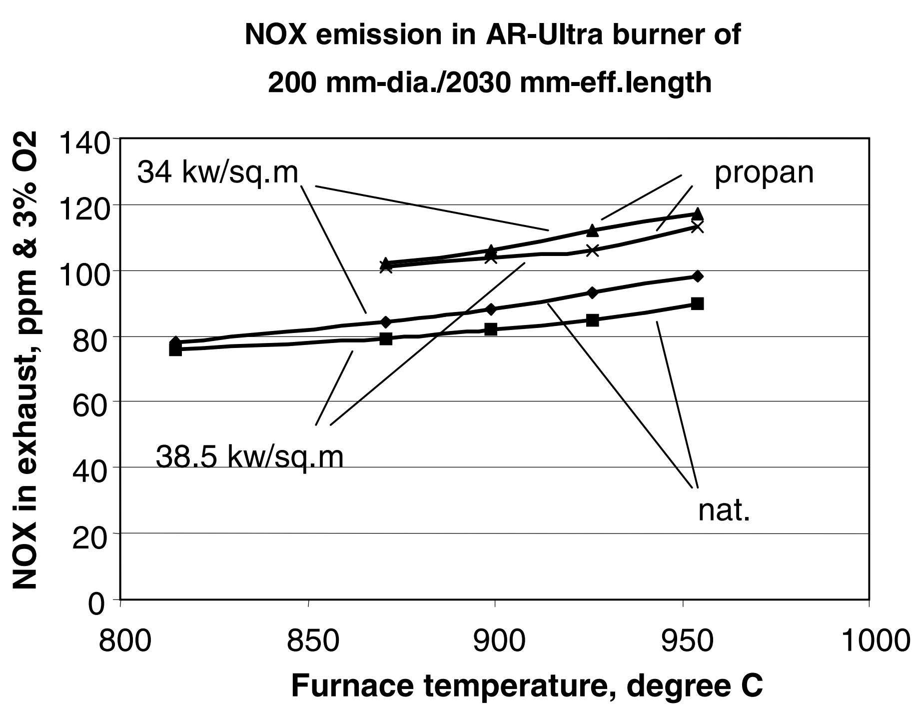

Figure 8 Flame outlet velocity influence on NO_X emission

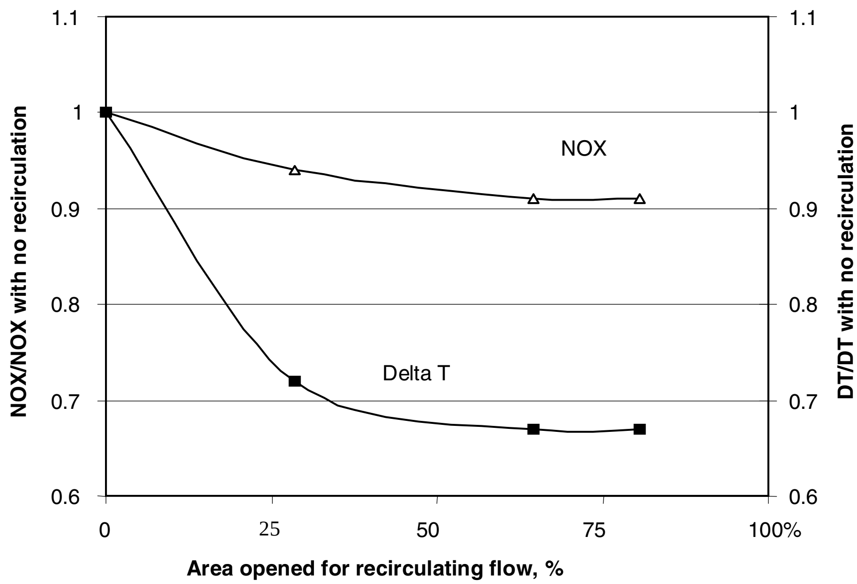

Figure 9 Influence of the flue gas recirculation on relative NOX emission and relative tube temperature difference ΔT.