THE GTI HIGH PERFORMANCE RADIANT TUBE SYSTEM: LOW-EMISSION NATURAL GAS BURNERS FOR ALLOY RADIANT U-TUBES IN METALS INDUSTRY APPLICATIONS

FINAL REPORT

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DISCLAIMER

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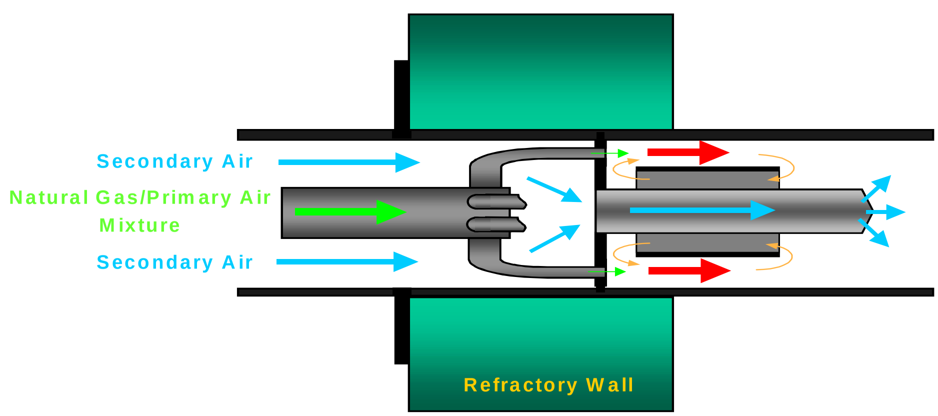
EXECUTIVE SUMMARY

This project was intended to successfully demonstrate that GTI's Forced Internal Recirculation Burner (FIRB) can be applied to high temperature alloy radiant U-tubes for metals heat treating applications and reduce NO_x emissions by up to 60% from typical levels of approximately 200 ppmv.

The FIRB operates by utilizing three innovative techniques:

1. Combustion air/natural gas premixing
2. Combustion air staging
3. Forced internal recirculation of partial products of combustion from the primary zone in order to reduce peak flame temperatures



Forced Internal Recirculation Burner Concept for Radiant Tubes

GTI's FIRB technology has been commercially applied to industrial water tube boilers with success, but has yet to be applied to metal heat treating furnaces. These types of furnaces emit an estimated .003 - .004 tons of NO_x per day in California.

This demonstration project was conducted at ITW CIP Stampings located in Santa Fe Springs, California. Their #15 Heat Treat furnace was be utilized throughout this project. This is a three-zone austempering, mesh-belt furnace with a total of thirteen radiant U-tube burners.

Original Performance Goals:

- 60 % reduction in NO_x emissions
- 3 % reduction in CO emissions
- 3 % increase in energy efficiency
- 25% increase in radiant tube longevity as a result of the improved temperature uniformity
- Improved product quality because of the improved temperature uniformity thereby requiring less product rework and/or generating less waste

Original Project Goals:

- Develop and demonstrate a scaled-up FIR burner that can be applied to continuous metal processing furnaces that use radiant tubes (Task 1)
- Confirm the environmental, productivity, and energy savings, and determine the economics of this application by demonstrating the technology in a mesh belt furnace (Task 2)

Task 1 of the original ICAT grant:

1.1 Development of FIRB for 6" radiant U-tube

1.2 Fabrication of FIRB's for field Demonstration

Task 2 of the original ICAT grant:

2.1 Conduct baseline testing at ITW CIP Stampings

2.2 Install FIRB system & conduct field testing at ITW CIP Stampings

2.3 Evaluate & prepare technical report

Early in the conduct of Task 2.2, a design deficiency became apparent. Resources beyond those that the ICAT grant approved to expend were determined to be needed to continue a modified project to completion. Therefore, the work supported by the ICAT grant was concluded and the project is ongoing with other sources of support. Nevertheless, the limited data taken before the conclusion of the grant indicates a high potential for realization of the original goals once the design problem has been surmounted.

Results with Respect to Original Goals Prior to Burner Failure:

- > 68% reduction in NO_X emissions
  - Baseline: 199 ppmv Spot Checks: ~ 62 ppmv
- > 72% reduction in CO emissions
  - Baseline: 22 ppmv Spot Checks: ~ 6 ppmv
- > 5% fuel savings by increased preheat air temperature
  - Baseline: 550°F Spot Checks: ~ 800°F

The preliminary emissions and fuel savings analysis above compares collected baseline data of previous conventional burners in averaged "as-is" condition (11/13/02 – 11/15/02) to an average of spot checks of burner emissions and waste gas/preheated air temperatures during furnace operation with FIR burners (6/30/03 – 7/3/03).

This report summarizes the results of Task 1 and Task 2 work which was to verify that GTI's Forced Internal Recirculation Burner (FIRB), previously developed for 4" diameter radiant U-tubes and whose concept was successfully demonstrated under other applications, performs equally as well in a 6" diameter radiant U-tube, which was the size of the tube used at the field demonstration site.

Testing at GTI's Energy Utilization Center Combustion Laboratory established that one relatively minor addition to the FIRB for 4" diameter radiant U-tubes was necessary to produce equivalent performance values when fired in a 6” diameter radiant U-tube. The addition consisted of an insulation-wrap around the internal mixing chamber of the FIRB. By using the FIRB in a 6” diameter tube, as opposed to a 4” diameter tube, an annulus exists between the outer surface of the mixing chamber and the inner surface of the radiant U-tube. Gasses were found to be circulating back into this annulus volume creating a high temperature environment thereby heating the natural gas primary mixture to the extent that flashback was occurring. Not to include this insulation-wrap required that the burner be fired with excess air greater than necessary which reduced burner efficiency.

In a follow up meeting with the burner manufacturer, Eclipse Combustion, it was concluded that insulating the exterior of the mixing chamber was an acceptable addition to this burner from the standpoints of ensuring performance and the ultimate burner manufacturing cost.

Baseline testing was conducted during the week of November 11, 2002. GTI analysis equipment was installed and three consecutive days of data collection followed to establish ITW’s then-current operating conditions and furnace performance.

Installation of the original-design FIRB’s took place during ITW’s regularly scheduled furnace outage beginning June 25, 2003. The previous combustion system (all thirteen burners, recuperators and radiant tubes) was removed from Heat Treat Furnace #15 and was replaced with the GTI FIRB’s, standard Eclipse bayonet recuperators, and new radiant U-tubes identical to those previously used. Miscellaneous control equipment (individual burner shut-off valves, adjustable gas orifices, and air butterfly valves) were also installed at this time.

After approximately 650 hours of operation from initial light-up of the new FIRB equipment, catastrophic burner failures began to occur. Investigation into this phenomenon concluded that flame flashback occurred within the burner’s internal mixing chamber due to heat radiating back to this component while the burner was in the “off” (non-firing) cycle. The combination of the

FIRB's premix design and ITW's on-off burner operation led to this flashback condition and eventually structural failure within the FIRB internals.

Due to the flashback occurrences, it was decided to replace Heat Treat Furnace #15's original burners temporarily while the FIRB design would undergo internal modifications to better suit the application.

The results-comparison of FIR type burners to conventional style burners shows that this technology reduces emissions and reduces fuel usage within radiant tube applications exceptionally well. The performance goal or metric of increased radiant tube longevity was not able to be established or imputed as failures of certain internal burner elements were noted at 140-160 hours of furnace (burner) operation after start up. The site has removed all thirteen FIR burners and reinstalled their conventional burners to maintain continuity of operation.

Notwithstanding the shortened field trial, ITW CIP Stampings was impressed with the substantial reduction in emissions and additionally, advised GTI that there was a significant reduction in furnace heat up time (from 180 minutes to 45 minutes) with the FIR burners installed. ITW CIP is eager to have GTI resolve the durability issues and proceed with the continued demonstration of this technology on their heat treat furnace. GTI has discussed a modified heat trial with Norbert Markl of ITW CIP Stampings and he is amenable to retrofitting a single zone of the furnace or individual burners in each zone.

GTI is currently working with the burner manufacturer, Eclipse Inc., to make the appropriate modifications to the FIRB design in efforts to successfully demonstrate the FIRB concept on this metals heat treating application. A lab-test prototype is scheduled to be performance tested during the fourth-quarter 2004 and a finalized FIRB will be demonstrated on ITW CIP Stampings' #15 Heat Treat Furnace in first-quarter 2005.

INTRODUCTION

Description of Technology

This project demonstrates the low emissions, high energy efficiency operation of GTI's patented, innovative FIR burner for operation in high-temperature alloy radiant U-tubes for metals heat treating applications (Fig.1). This burner uses the same technology as does GTI's FIR burners developed for use in water tube boilers. The FIR burner for use in water tube boilers has been demonstrated at 2.5 to 200 million Btu/hr operation (including two demonstrations in California[1]) and has achieved greater than 70% reduction in NO_x emissions.

The FIR burner uses several innovative techniques to dramatically reduce NO_x and CO emissions from natural gas combustion while retaining high-energy efficiency (Fig.2):

- Combustion air/natural gas premixing
- Combustion air staging
- Forced internal recirculation of partial products of combustion from the primary zone in order to reduce peak flame temperatures.

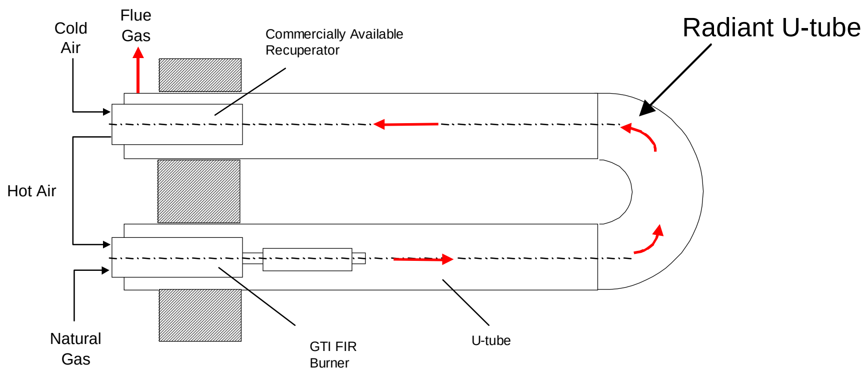


Figure 1. GTI FIR Burner Installed in Radiant U-Tube

[1] Vandenberg Air Force Base and a confidential industrial client

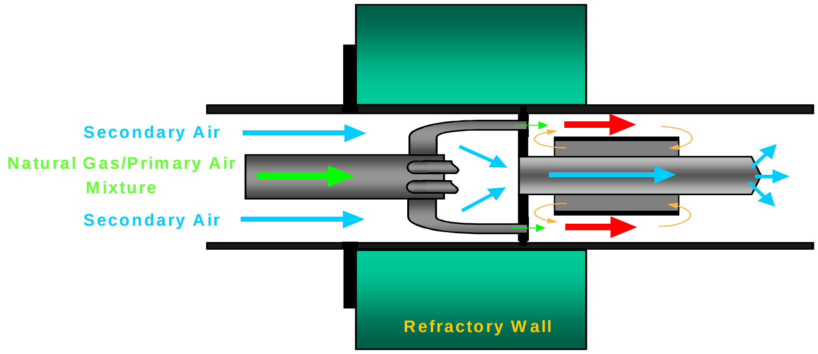


Figure 2. Forced Internal Recirculation Burner for Radiant Tubes

GTI's patented FIR burner technology has been developed and demonstrated with the assistance of the US Department of Energy, the natural gas industry, Southern California Gas Company, Eclipse Combustion, U.S. Steel Corporation, the US Air Force – Vandenberg Air Force Base, and other industrial companies. The FIR burner is easily retrofittable into existing radiant U-tubes to allow maximum market penetration.

The FIR burner has been successfully demonstrated on boilers from 2.5 – 200 million Btu/hr (including a 2.5 million Btu/hr boiler at the Vandenberg AFB under the ENVEST program and a 60 million Btu/hr boiler in a major California brewery[2].

The burner has long flame lengths to provide uniform temperatures (±25ºF) along the length of the tube. This improves the temperature uniformity in the furnace and will improve the quality of the products being processed in the furnace.

Use of the FIRB for radiant tubes was developed to produce:

- 60 % reduction in NO_x emissions

[2] Confidential client

- 3 % reduction in CO emissions
- 3 % increase in energy efficiency
- 25% increase in radiant tube longevity as a result of the improved temperature uniformity

In this patented (U.S. Patent No. 5,350,293) concept, the above listed NO_x reduction techniques are integrated into a burner design that achieves low-emissions without sacrificing efficiency. Other burner manufacturers utilize conventional techniques, such as forced or induced external flue gas recirculation, water or steam injection, or post-combustion treatment to achieve NO_x reduction, which all result in parasitic efficiency losses and increased capital, maintenance, and operating costs. This is in contrast with the FIR burner, which will increase energy efficiency.

Description of Project

The goals of this project were:

- Develop and demonstrate that FIR burners can be applied to continuous metal processing furnaces that use radiant tubes;
- Confirm the environmental, productivity, and energy savings that determine the economics of this application by demonstrating the technology in a mesh belt furnace.
- Verify that the FIR burner will reduce NO_x emissions 60% lower and CO, 3% lower than are currently achievable with typical high air preheat (850ºF and greater) radiant tube burners. (<80 ppm NO_x achievable with FIR vs. 200 – 250 ppm with alternative burners).

The FIRB was to be demonstrated in a mesh belt austempering furnace at ITW CIP Stamping's Santa Fe Springs, California facility. This furnace (Heat Treat Furnace #15) contains three indirect heated zones containing a total of thirteen radiant U-tubes. Thirteen U-tube units (including burners and recuperators) were to be removed and replaced with new U-tubes each fitted with GTI's FIRB and a standard commercially available recuperator.

The tubes were to be instrumented to determine the NO_x and CO emissions and energy efficiency and the uniformity of the tube temperature. This data was to have been compared with baseline test data to determine the efficiency and economics of using the FIR burners as compared to alternative methods of reducing NO_x emissions.

BURNER DEVELOPMENT (TASK 1)

Test Facility Description

During this phase of the project, two adjustments to the FIR Burner were devised, and evaluated at GTI's Combustion Lab to determine whether design changes would be required to the FIRB firing in the 6" radiant U-tube.

The laboratory testing of U-tube System was conducted using the Heat Treating Test Facility at GTI's Energy Utilization Center Combustion Laboratory. The photograph below shows the GTI heat treat furnace (Fig.3).

Figure 3. GTI Heat Treating Test Furnace

The laboratory furnace is equipped with a water-cooled atmosphere circulation fan and is modified to accept up to four radiant U-tubes in a number of different mounting orientations. Honeywell temperature controllers control the combustion system.

The fuel flow and combustion air to the FIRB test burner were controlled by adjustable limiting orifices and butterfly valves, respectively. To measure air and fuel flow, standard orifice assemblies were utilized. Furnace temperature was controlled via two thermocouples set in the furnace roof. A thermocouple was inserted in the exhaust pipe to measure the flue gas temperature. To accommodate the existing FIR burner design and 6" U-tube, installation of a special adapter flange was designed and fabricated (Fig. 4).

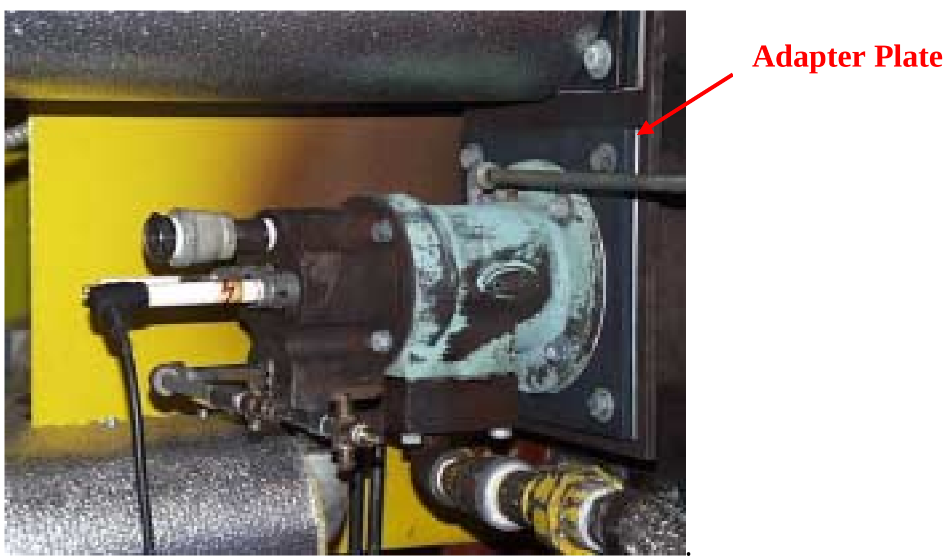


Figure 4. FIRB External View with Adapter Plate

Performance testing of the FIR Burner was conducted in GTI's laboratory heat treating furnace using one conventional radiant 4"tube burner as an auxiliary support to expedite furnace preheat to set point temperature conditions. The test 6" radiant U-tube was fitted with thirteen thermocouples to measure temperature uniformity along the length of the tube (Fig.5).

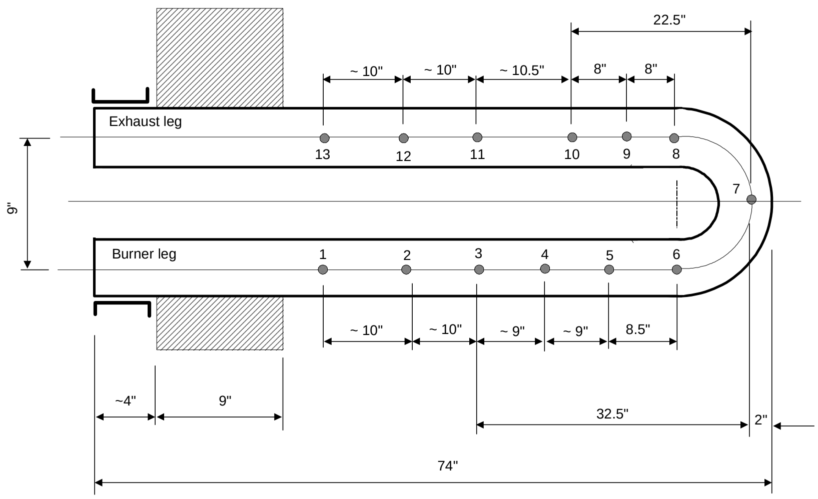


Figure. 5 Thermocouple Locations along the Length of the 6" Alloy U-tube

During the laboratory evaluation, the following parameters were measured and recorded:

- Natural gas input, SCFH
- Total air flow, SCFH
- U-tube surface temperature, ºF
- Temperature of recirculation sleeve, ºF
- Exhaust gas temperature, ºF
- Combustion Air preheat temperature, ºF
- Exhaust gas emissions (O_2, CO, CO_2, NO_x THC)
- Furnace temperature, ºF

An OPTO22 Data Acquisition System was used for collecting and electronically recording all real-time data during the entire analysis.

To establish temperature uniformity, the HSOA (hot spot over average) temperature was calculated using the following equation:

$$\mathbf{HSOA = T_{max} - T_{avg}}$$

where T_{max} and T_{avg} are maximum and average temperatures, respectively.

Performance Testing of the FIRB

Test #1: Firing the FIR burner with no modification (Fig. 6).

Figure 6. FIRB with No Modifications

As the furnace temperature increased, it was observed that the flame front moved back through the burner nozzle into the mixing tube (flashback). This condition, verified both visually and by thermocouples located within the burner's internals, was the result of direct radiation from the outer tube (U-tube), which raised the temperature of the mixing tube (and air/gas mix)high enough to produce a flashback, i.e., the flame velocity exceeds the fuel/air mixture velocity through the burner nozzle.

Test #2: Firing the FIRB with an insulated mixing tube.

The FIR burner was tested with an insulated mixing tube to reduce the temperature of the mixing tube surface and the temperature of the air/gas mixture (Fig.7).

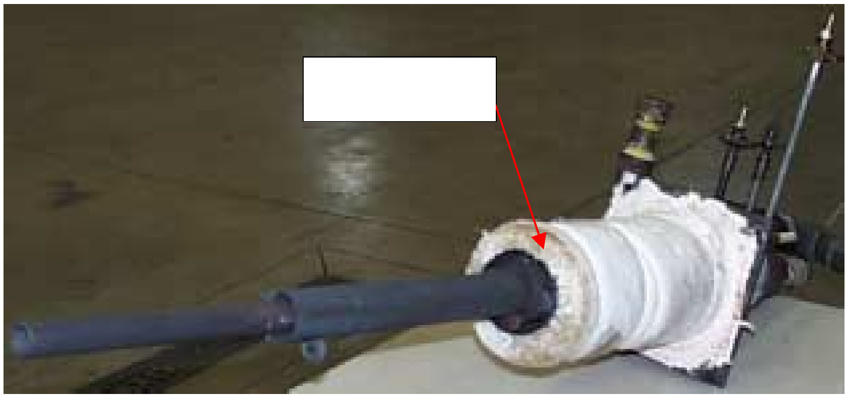


Figure 7. FIRB with Insulated Mixing Tube

With this modification, the temperature of the air/gas mixture was sufficiently low enough to eliminate any auto-ignition inside the mixing tube or flame movement back to the mixing tube. The flame stabilized itself on the nozzle surface as designed.

With 30% excess air at a cold start (cold furnace) satisfactory results were attained, i.e., stable (without flashback) combustion.

Test #3: Firing the FIR burner with the addition of a short metallic shroud.

The FIRB was modified with a shroud, or sleeve, to ensure the same velocity at the re-circulation section in the 6” U-tube as experienced in the 4” U-tube and insulated mixing tube (Fig.8).

Figure 8. FIRB with a Short Shroud and Insulated Mixing Tube

Performance analysis of the FIRB with the shroud showed no benefit to the burner's operation. It was decided not to utilize this modification into the FIRB's design for 6" radiant U-tubes.

The results of the FIRB laboratory evaluation, with Eclipse's Bayonet Ultra Air recuperator and 6" diameter alloy radiant U-tube in the GTI's heat treating furnace are presented in Appendix A.

Maximum NO_x emission levels are different with each burner modification and excess air. For example, an FIRB forms maximum NO_x emissions at approx 20% excess air. Any decreases or increases in excess air from that point will lead to NO_x reduction. Lower excess air results in lower temperature conditions due to incomplete mixing. Higher excess air results in lower temperature levels due to the increased air flow at a relatively cooler temperature. Both conditions have the capability of lowering NOx levels, .but at the cost of reduced efficiency.

The highest NO_x level during lab testing (110 ppmv @ 3% O_2) was obtained in test #1 (no modifications to the FIRB). This is due to a higher level of radiant heat flux, which is the result of the larger radiant tube surface. At the same heat flux, FIRB tests #2 (insulation around mixing chamber) and #3 (insulation around mixing chamber and shroud around recirculation sleeve) resulted in less than 100ppm @ 3% O_2.

Figures 13, 14, 15 and 16 (see Appendix A) show the temperature distribution along the tube. As shown, the modification in test # 3 (FIRB with shroud) provided a smoother tube temperature distribution than in tests #1 and #2. The temperature uniformity while firing the FIRB without the shroud, as compared to the temperature uniformity while utilizing the shroud, is slightly reduced due to a longer flame length (diffused flame). The slower velocity resulting from the larger inner diameter of the 6" radiant tube produced slower air-gas mixing and thus, the extended flame length. This condition is further proven by comparing the 6" radiant tube results (HSOA: 73-101 ºF) to the 4" radiant tube results (HSOA: 35 ºF), as indicated in Table 2 below.

The NO_x formation at 3.5% O_2 at a furnace temperature of 1650ºF with a 200,000 Btu/hr input was only 67 ppmv corrected to 3% O_2 (see Fig. 14 in Appendix A). Since the mesh belt furnace at the test site operates at similar temperatures, it is expected that these low NO_x results will be replicated.

Summary and Recommendations

Three tests were undertaken in this phase of the project and are summarized in Table 1 below:

1) The FIRB was fired into a 6" diameter tube without any adjustments to the design.

2) The FIRB was fired with insulation wrapped around the air-gas mixing chamber.

3) The FIRB was fired with the insulation used in test No. 2 and a metallic shroud surrounding the recirculation sleeve.

Comparative Testing of FIRB-6				
	PREVIOUS WORK	**TEST 1**	**TEST 2**	**TEST 3**
	4” U-tube System FIRB-6	6”U-tube System FIRB-6 w/o Modification (See Fig.6)	6”U-tube System FIRB-6 w/ Insulated Mix Tube (See Fig.7)	6”U-tube System FIRB-6 w/ Shroud and Insulated Mix Tube) (See Fig. 8)
Natural Gas Flow Rate (scfh)	180	200	200	200
Total Air Flow Rate (scfh)	2300	2640	2665	2690
Air Inlet Pressure, Before the Recuperator (in. w.c.)	25	25	26	27
Gas inlet pressure (in. w.c.)	2	1.3	1.3	1.2
Primary/Secondary Air Ratio	60/40	60/40	60/40	60/40
O2 in POC (%)	3.1-2.2	4.1	3.9	3.3
Air Preheat Temp (ºF	850-900	902	927	911
Furnace Temp. (ºF)	1850	1850	1850	1850
HSOA (ºF)	35	90	101	73
Recirculation Sleeve Temp. (ºF)	2200	1920	2172	2100
Thermal Efficiency. (%)	70	78	79	78.5
Emissions @1850 ºF (3%O2)				
NO_x (ppmv)	80-85	110	94	95
CO (ppm)	9-11	15	6	11
CO2 (%)	10.3-10.5	9.8	9.7	9.5
THC (ppm)	0	0	0	0

Table 1. FIRB Lab Testing Data Comparison

For each FIR burner modification, the design was developed to burn natural gas with acceptable emissions and performance characteristics. The following results were obtained:

- The FIRB performance is acceptable at firing rates up to 200,000 Btu/hr. At 60 Btu/in^2-hr heat flux, which is the optimum working regime for this furnace, the burner can operate with excess air at 15-20%. Although increasing the excess air further can result in a slight NO_x reduction, a sharp efficiency decrease will result. Having the highest efficiency burner operated at 15-20% excess air creates NO_x at approximately 67ppm @ 3% O_2 and 1650 °F furnace temperature (similar to field demonstration conditions).. In comparison, existing radiant tube burners emit approximately 200+ ppm (@ 3% O_2).
- The FIRB firing in the 6" U-tube burns natural gas efficiently (>70% at 1650º-1850ºF furnace temperature).
- The FIRB firing in the 6" U-tube reveals a reasonable level of temperature uniformity. The maximum temperature difference of 128°F and HSOA of 125 °F occurs at a furnace temperature of 1650 °F. An approximate HSOA of 100 °F occurs at a furnace temperature of 1850 °F. (Fig.15 in the Appendix).

As can be seen, the results in test No. 3, when compared to results in test No. 2, do not lead to the conclusion that the metallic shroud significantly improves performance. In a follow up meeting with the burner manufacturer, Eclipse Combustion, it was concluded that since the shroud did not materially effect the operation of the burner, the use of a shroud would not be included. It was however, concluded that insulating of the mixing chamber minimized flashback. As a result, the wrapped-insulation feature was adopted as the only major change or addition to the FIR burner for this field experiment.

Three minor changes were adopted for the finalized FIRB design for 6" radiant U-tubes.

- Two supplemental alignment ears were fabricated into the primary nozzle to better align the burner's components centrally within the radiant tube (Fig. 9).

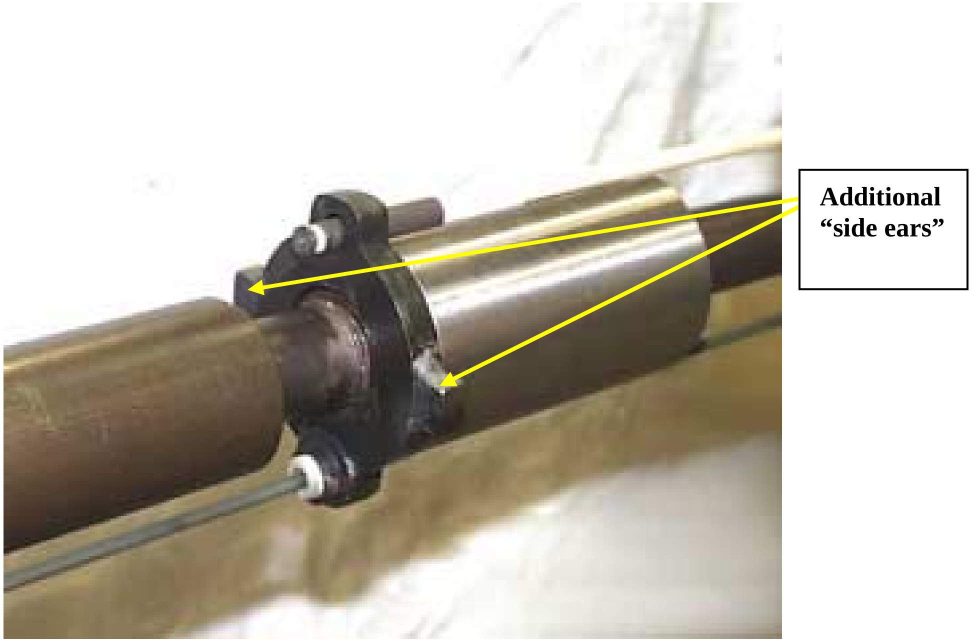


Figure 9. Primary Nozzle Alignment Ears

- The internal secondary air adjustment is to be eliminated as testing showed that its use did not significantly benefit the burner’s performance in any way.
- A ceramic-insulated spark rod is to be utilized for burner ignition.

FIELD DEMONSTRATION (TASK 2)

Test Site Description

The field test demonstration site is ITW CIP Stampings, located in Santa Fe Springs, CA. The test furnace is ITW's Heat Treat Furnace #15. This furnace is a continuous, mesh belt, austempering heat treat furnace with three indirect fired, non-isolated zones with a total of thirteen radiant U-tubes as follows (Fig. 10):

- Zone 1 6 radiant U-Tubes
- Zone 2 4 Radiant U-Tubes
- Zone 3 3 Radiant U-Tubes

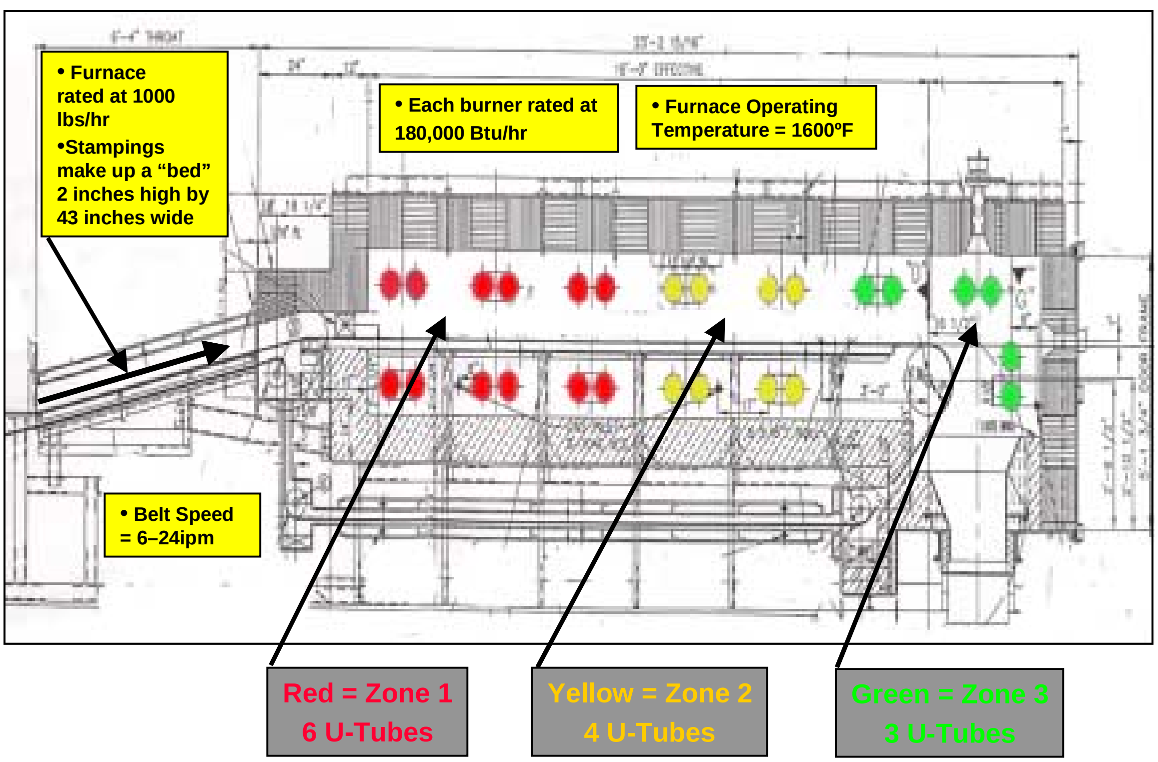


Figure 10. ITW CIP Stamping Heat Treat Furnace #15

The combustion system operates with "on-off" cycling. When any zone reaches temperature setpoint, the burners in that zone shut off completely (i.e., both air and gas valves to the zone close). Upon the call for heat, the burner is reignited via spark ignition.

The furnace is used to heat treat small metal parts for the automobile industry (i.e., springs, clips, etc.). Typical furnace temperature is 1540 – 1570 ºF, following very strict temperature recipes for individual parts. The product is carried through the furnace along a continuous mesh belt (Fig. 11) before dropping into a salt bath.

Figure 11. Heat Treat Furnace #15 Product Feed

Baseline Testing

Baseline testing was conducted during the week of November 11, 2002. GTI analysis equipment was installed on-site and three consecutive days of data collection followed. The furnace was tested under normal operating conditions using ITW's then-current system. All data was recorded and is located in Appendix B.

Averaged performance results for Heat Treat Furnace #15 are shown below in Table 2. These figures will be used as a reference for comparison to the post-FIRB retrofit.

Average Fuel Consumption (SCFH Natural Gas per Pound of Product)	Average Throughput (Pounds of Product per Hour)	Average NOx (at 3% O2) Emissions (ppmv)	Average CO (at 3% O2) Emissions (ppmv)	Average CO_2 Emissions (%)
2.46	558	199	22	7.95

Table 2. Averaged Baseline Results

FIRB Installation

ITW's next scheduled furnace outage began on June 25, 2003. Installation of the GTI FIRB equipment took place at this time. The previous combustion system, including burners, recuperators and 6" radiant U-tubes, was removed from Heat Treat Furnace #15 and was replaced with the FIRB's, standard Eclipse bayonet recuperators and new radiant U-tubes identical to those previously used. Individual burner control equipment (burner shut-off valves, adjustable gas orifices, and air butterfly valves) was also installed at this time. The necessary plumbing of combustion air and natural gas lines to each burner was also a substantial part of the retrofit process (Fig 12).

Figure 12. Installed FIRB's on ITW's Heat Treat Furnace #15

Initial light-up of the FIRB's occurred on June 30, 2003. Balancing and set-up of the new combustion system followed. The burners in Zones 2 and 3 of the test furnace were set-up and operated as expected. The burners in Zone 1 (the largest zone), however, did not operate as stable as was expected.

Issues seen in Zone 1's operation included flashback (natural gas igniting prematurely within the burner's internal structure) and "tube pops" (failure of initial ignition resulting in a minor explosion within the radiant tube due to a flammable mixture). Both of these issues appeared to be occurring because of insufficient air flow to the burners along Zone 1's common header. The burners farthest away from the air supply seemed to be most affected, indicating that with the furnace's present controls and plumbing, the gas flow to the these burners reacts much quicker than the air flow upon the call for heat in this zone. Because of this issue, the first two burners in Zone 1 (Burner #1 and Burner #8) were left temporarily valved off, while the remaining burners were set up to operate correctly and the furnace was then left with this status over the holiday weekend. The furnace would continue to cycle at setpoint in preparation for production start at 11:00 PM on July 6, 2003.

GTI returned to the test site on July 7, 2003 to continue setup, to resolve the issues stated above and to conduct field testing of the FIRB equipment. Further inspection revealed that several FIRB's has structurally failed due to recurring flashback conditions produced within the FIRB's internal mixing chamber. It was decided to immediately remove the FIRB's and replace them with the original conventional burners in order to continue production for fear of further complications.

GTI's Brian Masterson, Janus Technology Group's Richard Bennett (private consultant) and Wirth Gas' Alan Roughton (Eclipse representative) visited the test site on August 4, 2003 to inspect the removed FIRB's and analyze the situation.

From the investigative analysis, it appears that flashback was indeed the primary cause for the burner failures. It is theorized that under production conditions, the internals of the FIRB's reached temperatures sufficient to ignite the fuel-air mixture within the premix tube. This resulted in flame upstream of the burner's nozzle, producing an intense heat source within the burner's internal structure. This caused greater than normal permanent growth of the secondary air tube. This growth pushed the nozzle out of its desired position thereby reducing the mixture velocity and further aggravating the flashback issue. Flashback also caused unwanted stress on the upstream joint connecting the air tube to the nozzle leading to failure (fracture) at this location.

FIRB Design Modification

Due to the flashback conditions present in the initial field testing, GTI and Eclipse agreed to cooperate to make the necessary modifications to the FIRB internal design to eliminate any reoccurrence of flashback.

GTI developed two modified design-concepts for consideration by the project partners. The objectives of this redesign are to improve the FIRB performance by: adjusting the nozzle design such that no flashback can occur (velocity, flame shape, etc.) with the premixing of primary air and natural gas; and optimization of the insert and secondary air tube diameters. Drawings will be prepared and Eclipse will fabricate at least one test burner. The modified FIRB will be tested in the heat treat test furnace at GTI's combustion laboratory to determine temperature levels within the burner internals and other metrics. Once a comprehensive set of data are obtained, iterations in design modifications will be made with testing in the GTI heat treat furnace for each modification. The objective will be to alter the present design sufficiently enough so that a partial retrofit at the host site will be accomplished at a later date. The approved funding for this work will be other-funded.

A follow up meeting between GTI and Eclipse personnel was held on February 6, 2004 to further discuss the modified designs. It was decided that a partial-premix concept would best suit the application as well as prevent any occurrence of flashback or pre-ignition.

GTI has completed initial computer modeling of the accepted redesigned FIRB and reviewed the results. This modeling optimized internal component dimensions for improved burner performance. Recommendations to the redesign concept are currently being prepared and will have been discussed with Eclipse.

RESULTS

Results with Respect to Original Goals Prior to Burner Failure:

- > 68% reduction in NO_X emissions
  - Baseline: 199 ppmv Spot Checks: ~ 62 ppmv
- > 72% reduction in CO emissions
  - Baseline: 22 ppmv Spot Checks: ~ 6 ppmv
- > 5% fuel savings by increased preheat air temperature
  - Baseline: 550°F Spot Checks: ~ 800°F

    (14.5% fuel savings) (~ 20% fuel savings)

The preliminary emissions and fuel savings analysis above compares collected baseline data of previous conventional burners in averaged “as-is” condition (11/13/02 – 11/15/02) to an average of spot checks of burner emissions and waste gas/preheated air temperatures during furnace operation with FIR burners (6/30/03 – 7/3/03).

The results-comparison of FIR type burners to conventional style burners shows that this technology reduces emissions and reduces fuel usage within radiant tube applications exceptionally well. The performance goal or metric of increased radiant tube longevity was not able to be established or imputed as failures of certain internal burner elements were noted at 140-160 hours of furnace (burner) operation after start up. The site has removed all thirteen FIR burners and reinstalled their conventional burners to maintain continuity of operation.

Notwithstanding the incomplete field trial, ITW CIP Stampings was impressed with the substantial reduction in emissions and additionally, advised GTI that there was a significant reduction in furnace heat up time (from 180 minutes to 45 minutes) with the FIR burners installed. ITW CIP is eager to have GTI resolve the durability issues and proceed with the continued demonstration of this technology on their heat treat furnace. We have discussed a modified heat trial with Norbert Markl of ITW CIP Stampings and he is amenable to retrofitting a single zone of the furnace or individual burners in each zone.

CONCLUSIONS

The original design FIRB showed very promising results when tested in the GTI combustion laboratory. However, when combined with the on/off operation at the field demonstration site, the FIRB's failed to withstand the stresses resulting from radiative heat while in the "off" cycle. With no air flow to carry away the heat within the internal components when the burner was not firing, the internal mixing chamber of the FIRB reached sufficient temperature to ignite the air/gas mixture in the incorrect location (upstream of the primary nozzle) upon the call for heat. This caused a flashback condition inside the FIRB mixing chamber. By generating flame within the mixing chamber, an excessive amount of heat caused significant growth of the secondary air tube. This growth dislocated the primary air nozzle, resulting in decreased mixture velocity and further aggravated the flashback condition.

GTI and Eclipse have agreed to modify the internal components of the FIRB sufficiently enough so that this flashback condition will not occur. Altering the design to optimize air and fuel velocities specifically for the 6" diameter radiant U-tube and utilize a partial premix design concept will eliminate the issues faced with the original FIRB design in this and future applications.

GTI and Eclipse have agreed on the modified design concept and computer numerical simulation evaluation has been carried out to optimize all dimensional parameters. Assembly drawings are currently underway. Fabrication and lab testing of the modified FIRB will follow immediately upon the approval of these drawings.

ITW CIP Stampings has cooperated fully throughout this entire project and eagerly awaits the installation of the modified FIRB's on the test furnace. Their support is greatly appreciated and is integral to the ultimate success of this technology.

Although this project is continuing under other funding, CARB has optioned to be issued their Final Report at this time and receive a courtesy copy of the report at the ultimate conclusion of the project.

REFERENCES

1. Fayerman, Matthew and Masterson, Brian, The GTI High Performance Radiant Tube System, Progress Report Task 1 (Draft), Gas Technology Institute, June 2002.
2. Bennett, Richard L., Investigation into Failure if FIR Burners at ITW CIP Products, Santa Fe Springs, CA, Janus Technology Group, Inc., August 19, 2003.

APPENDIX A

FIRB Development Data Sheets

Burnertype	FIRB
Max. input	200,000Btu/hr
Fuel	
Gross heating value	
F.R. / UV scanner	
Type of relais	
Customer	GTI
Project no.	40496
Date	May 24, 2002
By:	Matthew Fayerman
Page	

Analyzers

O_2

CO_2

NO_x

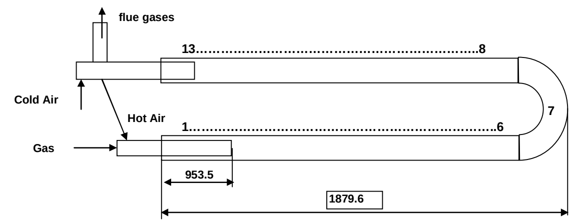
CO

Other

Orifices

Air	#		/
	#		/
	#		/
Fuel	#		/
	#		/
	#		/

Test description



T burner body = 217F

T recup body =155F

Time	Test	Input Kbtu/h	Gas Flow scfh	Gas DP "wc	Gas Inlet P "wc	Air Flow scfh	Air DP "wc	Air Inlet P "wc	Temp Preh F	Total XSA %	T mix chamb. F	P body "wc	Rec sleeve F	Flue gas F	Eff %	Flue Gas meas. O2 %	Flue Gas meas. CO2 %	Flue Gas meas. CO ppm	Flue Gas meas. TCH ppm	Flue Gas meas. NOx ppm	3%O2 CO ppm	3%O2 TCH ppm	3%O2 NOx ppm
8:40	**1**	200	200	1.8		2950																	
8:55	**2**	200	200	1.8	1	2850		7.7		36.364		1				5.6	8.8	8	0	34	8.831	0	37.53
9:55	**3**	200	200	1.8	1	2750		8.3	708	29.63	783	1.3	1882	1070	78.2	4.8	9.2	8	0	56	8.395	0	58.77
10:20	**4**	200	200	1.8	1.1	2710		9.4	746	28.834	859	1.4	1898	1101	78.2	4.7	9.2	8	0	62	8.344	0	64.66
10:45	**5**	200	200	1.8	1.1	2700		9.5	776	28.049	894	1.4		1125	78.3	4.6	9.3	9	0	68	9.329	0	70.49
11:15	**6**	200	200	1.8	1.1	2675		9.6	811	27.273	1034	1.4	2037	1155	78.3	4.5	9.4	9	0	76	9.273	0	78.3
11:55	**7**	200	200	1.8	1.1	2670		9.8	852	27.273	1106	1.4	1848	1207	77.8	4.5	9.4	10	0	87	10.3	0	89.64
12:45	**8**	200	200	1.8	1.2	2650		10	896	25.749	1182	1.5	1700	1235	78.2	4.3	9.5	10	0	105	10.18	0	106.9
1:15	**9**	200	200	1.8	1.2	2630		10	912	24.26	1209	1.5	1659	1247	78.3	4.1	9.6	12	0	110	12.07	0	110.7
3:30	**10**	200	200	1.8	1.3	2640		10.1	902	24.26	1217	1.6	1927	1235	78.4	4.1	9.8	15	0	110	15.09	0	110.7

Time	Test	Tube temp.F 1 F	2 F	3 F	4 F	5 F	6 F	7 F	8 F	9 F	10 F	11 F	12 F	13 F	HSOA F	max-min F	Furnace 14 F	Furnace 15 F
8:40	**1**							cold start										
8:55	**2**	1	2	3	4	5	6	7	8	9	10	11	12	13				
9:55	**3**	1581	1516	1474	1411	1409	1392	1375	1378	1376	1340	1400	1382	1370	165.3	211	1305	1307
10:20	**4**	1669	1694	1546	1571	1516	1500	1486	1488	1489	1448	1506	1500	1478	138.9	191	1415	1416
10:45	**5**	1759	1700	1635	1611	1610	1596	1583	1584	1585	1547	1600	1594	1574	145.3	185	1513	1516
11:15	**6**	1826	1770	1707	1687	1687	1674	1661	1662	1663	1626	1675	1672	1653	136.5	173	1597	1601
11:55	**7**	1906	1862	1803	1787	1787	1776	1764	1764	1764	1731	1775	1773	1752	118	154	1697	1700
12:45	**8**	1989	1962	1901	1890	1892	1882	1871	1869	1870	1842	1876	1876	1853	98.77	136	1805	1805
1:15	**9**	2022	1999	1941	1932	1936	1926	1915	1913	1913	1889	1921	1917	1894	89.85	128	1848	1851
3:30	**10**	2007	1975	1922	1909	1912	1904	1891	1887	1887	1874	1896	1894	1871	97.08	136	1820	1821

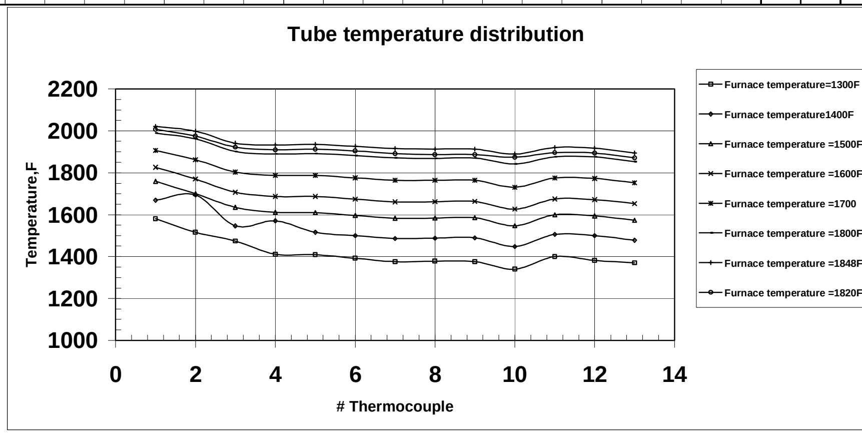


Figure 13. FIRB Development Test #1 – No Modifications

Burnertype	**FIRB(with insul.mix tube)**
Max. input	200,000Btu/hr
Fuel	
Gross heating value	
F.R. / UV scanner	
Type of relais	
Customer	GTI
Project no.	40496
Date	May 30, 2002
By:	Matthew Fayerman
Page	

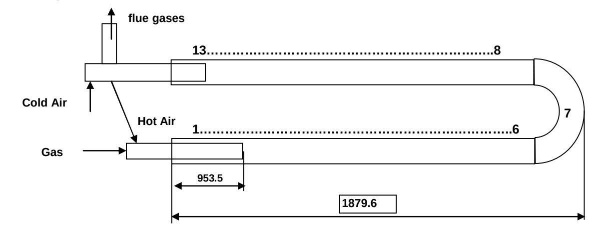
Analyzers

O_2	
CO_2	
NO_x	
CO	
Other	

Orifices

Air	#	/	
	#	/	
	#	/	
Fuel	#	/	
	#	/	
	#	/	

Test description



T burner body = 198F

T recup body =155F

Time	Test	Input	Gas			Air										Flue Gas meas.				
		Kbtu/h	Flow	DP	Inlet P	Flow	Pbefore recup	Inlet P	Temp Preh	Total XSA	T mix chamb.	P body	Rec sleeve	Flue gas	Eff	O2	CO2	CO	TCH	NOx
			scfh	"wc	"wc	scfh	"wc	"wc	F	%	F	"wc	F	F	%	%	%	ppm	ppm	ppm
8:30	**1**																			
9:50	**2**	200	200	1.8	1.2	2740	24	9	721	24.555	619	1.4	1926	1040	78.7	4.14	9.5	8	0	56
10:11	**3**	200	200	1.8	1.2	2720	24	9.1	752	22.807	651	1.4	1958	1095	79	3.9	9.5	7	0	56
10:45	**4**	200	200	1.8	1.3	2700	24.5	9.3	788	22.093	686	1.4	1999	1125	79	3.8	9.5	6	0	62
11:20	**5**	200	200	1.8	1.3	2685	25	9.3	825	21.387	725	1.4	2014	1158	79	3.7	9.6	6	0	66
11:45	**6**	200	200	1.8	1.3	2700	25.2	9.3	848	20	747	1.4	2064	1174	79.2	3.5	9.6	7	0	69

Time	Test	3%O2			Tube temp.F														max-	Furnace	
		CO	TCH	NOx	1	2	3	4	5	6	7	8	9	10	11	12	13	**HSOA**	**min**	14	15
		ppm	ppm	ppm	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F
8:30	**1**	cold start			1	2	3	4	5	6	7	8	9	10	11	12	13				
9:50	**2**	8.066	0	**56.47**	1623	1568	1463	1428	1424	1410	1392	1391	1396	1363	1443	1506	1466	171.2	157	1319	1320
10:11	**3**	6.959	0	**55.67**	1688	1637	1539	1508	1506	1492	1475	1474	1478	1445	1521	1577	1538	158.9	150	1405	1409
10:45	**4**	5.93	0	**61.28**	1760	1718	1627	1600	1599	1587	1571	1568	1573	1537	1610	1658	1621	142.4	139	1501	1506
11:20	**5**	5.896	0	**64.86**	1841	1798	1713	1692	1692	1682	1668	1664	1669	1632	1701	1744	1709	132.9	132	1597	1602
11:45	**6**	6.8	0	**67.03**	1885	1843	1767	1744	1745	1736	1722	1717	1722	1687	1752	1793	1757	125.8	128	1650	1654

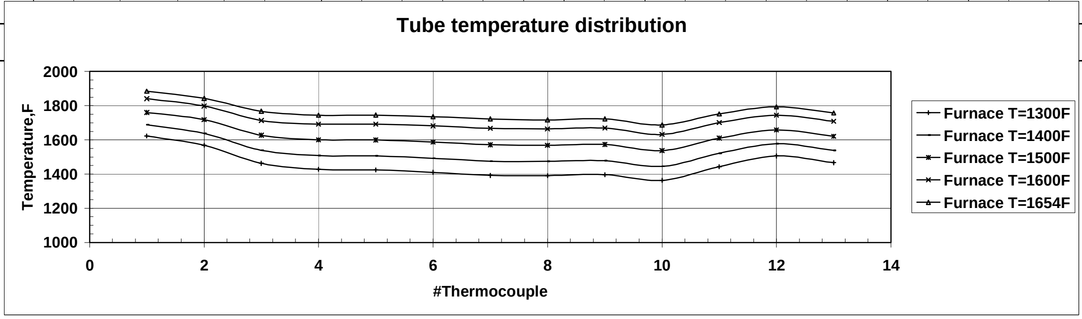
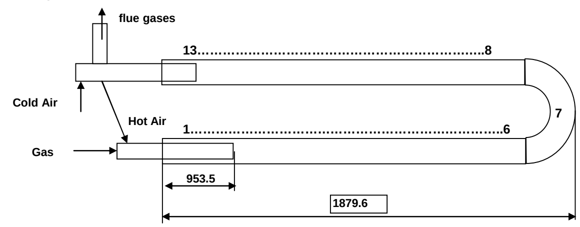


Figure 14. FIRB Development Test #2 – Insulation around Mixing Chamber (1 of 2)

Burnertype	**FIRB(with insul.mix tube)**	***Analyzers***	
Max. input	200,000Btu/hr	O_2	
Fuel		CO_2	
Gross heating value		NO_x	
		CO	
F.R. / UV scanner		Other	
Type of relais			
		Orifices	
Customer	GTI	Air	# /
Project no.	40496		# /
			# /
Date	May 29, 2002	Fuel	# /
By:	Matthew Fayerman		# /
Page			# /

Test description



T burner body = 198F

T recup body =155F

Time	Test	Input Kbtu/h	Gas Flow scfh	Gas DP "wc	Gas Inlet P "wc	Air Flow scfh	Air Pbefore recup "wc	Air Inlet P "wc	Air Temp Preh F	Total XSA %	T mix chamb. F	P body "wc	Rec sleeve F	Flue gas F	Eff %
8:30	**1**	200	200	1.8	0.9	3000	19.7	7.3				1.1			
10:25	**2**	200	200	1.8	1.2	2775	24.4	9.1	716	25.749	623	1.4	1943	1074	78.5
10:50	**3**	200	200	1.8	1.2	2750	24.6	9.2	748	24.26	649	1.4	1968	1094	78.8
11:25	**4**	200	200	1.8	1.3	2730	25.1	9.3	787	25	689	1.4	2009	1127	78.7
12:00	**5**	200	200	1.8	1.3	2720	25.4	9.4	821	23.529	722	1.4	2055	1158	78.7
12:55	**6**	200	200	1.8	1.3	2700	25.5	9.5	861	22.807	762	1.4	2105	1190	78.8
1:55	**7**	200	200	1.8	1.3	2675	26	9.6	95	22.807	808	1.4	2159	1224	79.4
2:30	**8**	200	200	1.8	1.3	2665	26.2	9.7	927	22.807	832	1.5	2172	1240	79
	9														
	10														

Time	Test	Flue Gas meas. O2 %	CO2 %	CO ppm	TCH ppm	NOx ppm	3%O2 CO ppm	3%O2 TCH ppm	3%O2 NOx ppm	Tube temp. 1 F	2 F	3 F	4 F	5 F	6 F	7 F	8 F	9 F	10 F	11 F	12 F	13 F	HSOA F	max-min F	Furnace 14 F	Furnace 15 F
8:30	**1**	5.3	9	9	0	31	cold start			1	2	3	4	5	6	7	8	9	10	11	12	13				
10:25	**2**	4.3	9.5	7	0	55	7.126	0	59.55	1583	1513	1440	1406	1403	1390	1372	1372	1378	1337	1394	1392	1368	171.6	215	1300	
10:50	**3**	4.1	9.5	7	0	58	7.041	0	59.04	1661	1596	1524	1496	1496	1483	1467	1465	1471	1424	1483	1484	1462	160.1	199	1398	
11:25	**4**	4.2	9.5	6	0	64	6.071	0	64.38	1746	1690	1622	1598	1599	1587	1573	1570	1575	1529	1584	1586	1567	144	179	1502	
12:00	**5**	4	9.5	6	0	69	6	0	69.82	1819	1769	1706	1686	1688	1678	1665	1662	1666	1623	1672	1674	1655	129.5	164	1598	
12:55	**6**	3.9	9.6	5	0	75	4.971	0	75	1901	1858	1799	1783	1786	1778	1765	1761	1765	1725	1768	1770	1751	115.6	150	1699	
1:55	**7**	3.9	9.7	6	0	87	5.965	0	86.49	1986	1948	1893	1881	1885	1878	1866	1861	1864	1826	1866	1868	1849	103.6	137	1800	
2:30	**8**	3.9	9.7	6	0	95	5.965	0	94.44	2031	1991	1939	1929	1932	1926	1915	1909	1912	1874	1913	1914	1894	101.8	137	1850	
	9																									
	10																									

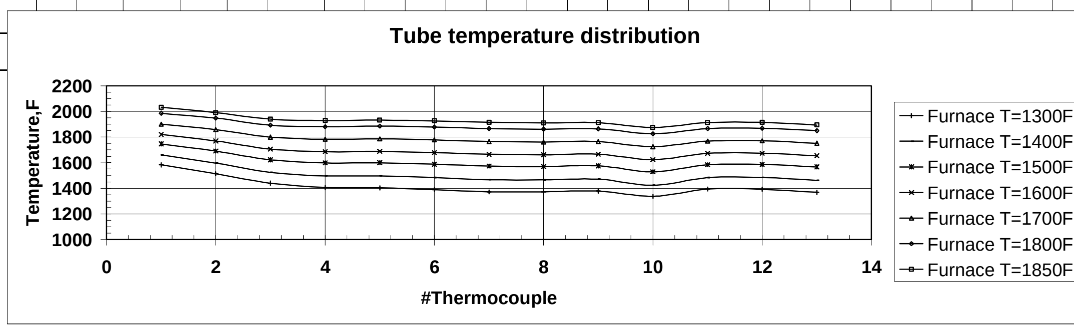


Figure 15. FIRB Development Test #3 – Insulation around Mixing Chamber (2 of 2)

Burnertype FIRB(with ins.mix tube+sleeve)
Max. input 200,000Btu/hr
Fuel Natural Gas
Gross heating value

F.R. / UV scanner
Type of relais

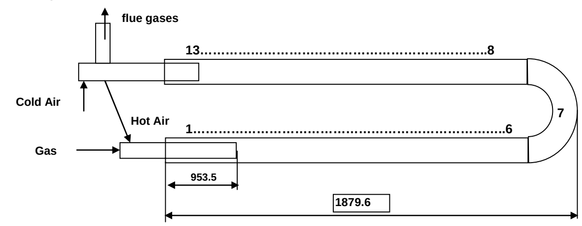
Customer GTI
Project no. 40496

Date June 3, 2002
By: Matthew Fayerman/Brian Mastersor
Page

Analyzers
O_2
CO_2
NO_x
CO
Other

Orifices
Air # /
/
/
Fuel # /
/
/

Test description



T burner body = 198F
T recup body =155F

Time	Test	Input Kbtu/h	Gas Flow scfh	Gas DP "wc	Gas Inlet P "wc	Air Flow scfh	Air Pbefore recup "wc	Air Inlet P "wc	Air Temp Preh F	Total XSA %	T mix chamb. F	P body "wc	Rec sleeve F	Flue gas F	Eff %
	1														
10:05	2	200	200	1.8	1.1	2830	25.8	9.6	671	22.093	773	1.4		1049	78.5
10:25	3	200	200	1.8	1.1	2810	25.8	9.6	701	18.644	809	1.4		1076	78.7
10:55	4	200	200	1.8	1.1	2775	25.8	9.7	735	17.978	853	1.4		1109	78.6
11:30	5	200	200	1.8	1.1	2750	26	9.7	774	16.022	900	1.4		1141	78.7
12:10	6	200	200	1.8	1.2	2740	26	9.8	815	15.385	952	1.4		1174	78.8
1:00		200	200	1.8	1.2	2720	26.5	9.8	857	18.644	1004	1.4		1203	78.7
2:05		200	200	1.8	1.2	2700	27.2	9.9	890	20	1060	1.4		1236	78.4
2:45		200	200	1.8	1.2	2690	27.3	10.3	911	18.644	1092	1.5		1253	78.5

Time	Flue Gas meas. O2 %	CO2 %	CO ppm	TCH ppm	NOx ppm	3%O2 CO ppm	TCH ppm	NOx ppm	Tube temp. 1 F	2 F	3 F	4 F	5 F	6 F	7 F	8 F	9 F	10 F	11 F	12 F	13 F	HSOA F	max-min F	Furnace 14 F	Furnace 15 F
							cold start		1	2	3	4	5	6	7	8	9	10	11	12	13				
10:05	3.8	9.3	16	0	54	16.74	0	**56.51**	1497	1464	1352	1321	1316	1294	1278	1275	1283	1244	1350	1410	1372	**154.2**	**125**	1201	1203
10:25	3.3	9.4	14	0	56	14.24	0	**56.95**	1570	1543	1440	1412	1409	1388	1373	1369	1378	1339	1437	1490	1453	**139.2**	**117**	1299	1301
10:55	3.2	9.4	13	0	59	13.15	0	**59.66**	1648	1625	1530	1507	1507	1488	1474	1470	1477	1437	1527	1573	1537	**124.9**	**111**	1399	1401
11:30	2.9	9.5	12	0	62	11.93	0	**61.66**	1725	1709	1621	1603	1604	1588	1575	1570	1576	1535	1619	1658	1620	**109.4**	**105**	1498	1501
12:10	2.8	9.6	10	0	66	9.89	0	**65.27**	1805	1793	1715	1700	1703	1689	1676	1672	1676	1634	1711	1744	1706	**95.46**	**99**	1600	1602
1:00	3.3	9.6	10	0	73	10.17	0	**74.24**	1882	1875	1802	1792	1797	1785	1773	1768	1771	1729	1801	1829	1790	**82.46**	**92**	1698	1702
2:05	3.5	9.5	9	0	86	9.257	0	**88.46**	1965	1960	1894	1885	1888	1877	1865	1861	1864	1823	1890	1914	1872	**75.92**	**93**	1796	1801
2:45	3.3	9.5	11	0	94	11.19	0	**95.59**	2011	2005	1943	1935	1938	1929	1918	1912	1915	1877	1938	1960	1917	**72.69**	**94**	1846	1850

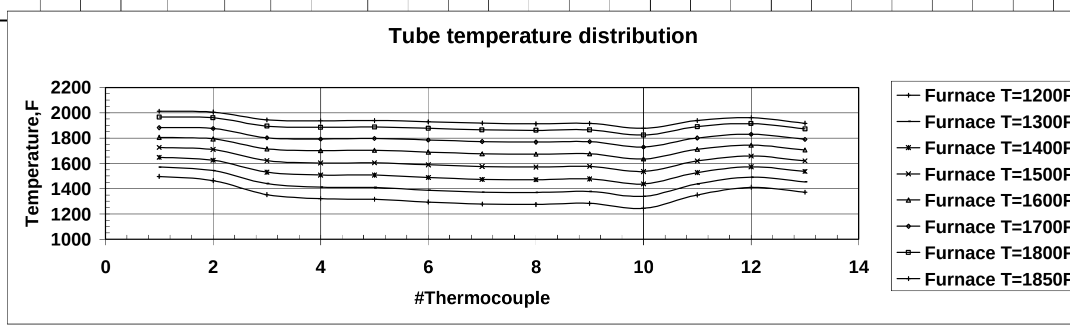


Figure 16. FIRB Development Test #3 – Insulation and Recirculation Shroud

APPENDIX B

Baseline Testing Data Sheets

BASELINE TESTING DATA

ITW CIP Stampings - Santa Fe Springs, CA

GTI Projects: 40496-02, 30797-06, 85010-02, 40510-01

DATE:________11/13/02____________

		Burner												
		1N	**2N**	**3N**	**4N**	**5N**	**6N**	**7N**	**8S**	**9S**	**10S**	**11S**	**12S**	**13S**
Burner														
Input (1)	KBTU/Hr	145	146	155	120	99	106	96	133	120	143	91	121	154
Gas Flow (2)	SCFH	144.8	145.8	154.8	120.2	99.2	105.9	96.1	132.9	120.0	142.7	91.0	121.0	154.2
Gas Inlet Pressure	" WC	0.90	0.59	1.00	0.45	0.50	0.65	N/A	0.61	0.45	N/A	0.61	N/A	N/A
Air Flow "ON" (3)	SCFH	1866.1	1861.1	1964.0*	1656.8	1562.0	1964.0*	1645.3	1767.6	1718.7	1920.7	1524.8	1639.5	1778.2
Air Differential Pressure	" WC	18.0	17.9	20.0*	14.1	12.5	20.0*	13.9	16.1	15.2	19.1	11.9	13.8	16.3
Cold Air Temperature	F	127	127	127	127	127	127	127	127	127	127	127	127	127
Preheat Temperature	F	586	589	635	493	520	553	569	610	602	546	528	551	560
Flue Gas Temperature Before Recuperator	F	1384	1432	1477	1337	1351	1386	1355	1417	1408	1428	1346	1398	1446
XS Air (4)	%	33.23	32.03	31.23	42.56	62.86	91.86	77.05	37.51	48.12	39.18	73.29	40.17	20.03
Burner Efficiency (5)	%	65.4	64.2	64.1	63.1	60.0	55.0	59.2	64.3	62.7	62.1	58.8	63.0	65.2
Flue Gas Measurement														
O2	%	5.58	5.43	5.33	6.65	8.53	10.50	9.58	6.09	7.22	6.28	9.32	6.39	3.76
CO2	%	8.67	8.78	8.81	8.10	7.00	6.00	6.41	8.47	7.84	8.34	6.64	8.23	9.67
CO	ppm	17	17	17	16	19	13	38	17	16	16	14	16	20
NOx	ppm	175	137	274	165	223	137	151	91	103	179	129	146	222
Corrected to 3% O2														
CO	ppm	19.8	19.7	19.5	20.1	27.4	22.3	59.9	20.5	20.9	19.6	21.6	19.7	20.9
NOx	ppm	204.3	158.4	314.7	207.0	321.9	234.9	238.0	109.9	134.5	218.9	198.8	179.9	231.8
Furnace														
Zone 1 Temperature (S.P. 1580 F)	F	1549	1553	1562	1560	1535	1560	1545	1574	1564	1615	1660	1536	1600
Zone 2 Temperature (S.P. 1570 F)	F	1600	1573	1560	1575	1556	1618	1565	1582	1588	1593	1596	1592	1615
Zone 3 Temperature (S.P. 1570 F)	F	1566	1562	1560	1554	1553	1566	1568	1576	1563	1564	1560	1555	1581
Product Description		Part #04855 and #04488, Small Metal Parts for Auto Manufacturers												
Belt Speed	"/min	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3	13.3
Total NG Usage (Meter Reading)	SCFx100	65412	65414	65416	65419	65431	65424	65427	65389	65395	65398	65401	65409	65404
Order of Testing		7	8	9	10	13	11	12	1	2	3	4	6	5
Test Start Time		11:55	12:02	12:12	12:24	1:10	12:39	12:53	10:07	10:36	10:49	11:02	11:43	11:19
Test End Time		12:00	12:08	12:20	12:32	1:14	12:45	12:57	10:16	10:42	10:56	11:09	11:46	11:24
Test Duration	Hr	0.083	0.100	1.333	1.333	0.067	0.100	0.067	0.150	0.100	0.117	0.117	0.050	0.083

NOTES:

1. Input to be determined after gas flow is established
2. Gas flow to be back calculated after air flow and %O2 are determined
3. Air flow to be determined according to Hauck spec sheet for OMG115-00 orifice with 0.75" bore
4. Excess air determined by O2 content in flue gas analysis
5. Individual burner efficiency determined with Hauck e-Solution software after excess air, combustion air temp. and flue gas temp are established

Figure 17. ITW Baseline Test Data – 11/13/2002

BASELINE TESTING DATA

ITW CIP Stampings - Santa Fe Springs, CA

GTI Projects: 40496-02, 30797-06, 85010-02, 40510-01

DATE:________11/14/02____________

		Burner												
		1N	**2N**	**3N**	**4N**	**5N**	**6N**	**7N**	**8S**	**9S**	**10S**	**11S**	**12S**	**13S**
Burner														
Input (1)	KBTU/Hr	147	151	154	122	101	110	98	139	121	146	92	120	155
Gas Flow (2)	SCFH	147.2	150.9	153.7	121.9	100.8	109.9	97.9	138.9	121.2	145.7	92.2	120.3	154.7
Gas Inlet Pressure	" WC	0.95	0.60	1.00	0.40	0.45	0.63	N/A	0.61	0.45	N/A	0.55	N/A	N/A
Air Flow "ON" (3)	SCFH	1877.6	1922.3	1964.0*	1622.5	1573.5	1964.0*	1668.2	1794.9	1719.0	1964.0*	1542.6	1609.7	1841.9
Air Differential Pressure	" WC	18.1	19.1	20.0*	14.1	12.6	20.0*	14.2	16.5	15.1	20.0*	12.1	13.2	17.4
Cold Air Temperature	F	123	123	123	123	123	123	123	123	123	123	123	123	123
Preheat Temperature	F	581	582	629	504	516	562	564	614	615	533	525	570	545
Flue Gas Temperature Before Recuperator	F	1382	1439	1478	1348	1344	1377	1360	1426	1411	1389	1332	1407	1443
Flue Gas Temperature After Recuperator	F													
XS Air (4)	%	31.87	31.71	32.10	41.07	61.35	84.79	76.17	33.64	46.71	39.36	73.01	38.38	23.09
Burner Efficiency (5)	%	65.6	63.9	63.8	63.2	60.4	56.9	58.9	64.8	63.2	63.0	59.3	63.5	64.4
Flue Gas Measurement														
O2	%	5.41	5.39	5.44	6.49	8.41	10.08	9.52	5.63	7.08	6.30	9.30	6.19	4.22
CO2	%	8.96	8.95	8.94	8.25	7.20	6.26	6.70	8.80	8.00	8.40	6.75	8.45	9.49
CO	ppm	18	18	18	18	19	26	14	19	17	17	14	17	21
NOx	ppm	165	131	241	154	203	124	135	89	94	158	117	140	188
Corrected to 3% O2														
CO	ppm	20.8	20.8	20.8	22.3	27.2	42.9	22.0	22.3	22.0	20.8	21.5	20.7	22.5
NOx	ppm	190.5	151.1	278.8	191.0	290.2	204.4	211.7	104.2	121.6	193.5	180.0	170.2	201.7
Furnace														
Zone 1 Temperature (S.P. 1570 F)	F	1532	1548	1536	1552	1540	1536	1547	1540	1536	1518	1600	1566	1586
Zone 2 Temperature (S.P. 1560 F)	F	1567	1559	1561	1611	1570	1557	1577	1568	1571	1562	1575	1629	1638
Zone 3 Temperature (S.P. 1560 F)	F	1566	1563	1565	1559	1581	1577	1560	1566	1558	1553	1562	1566	1567
Product Description		Part #04478, Small Metal Parts for Auto Manufacturers												
Belt Speed	"/min	13.3	13.2	13.3	13.3	13.3	13.3	13.3	13.5	13.5	13.6	13.6	13.2	13.2
Total NG Usage (Meter Reading)	SCFx100	65717	65719	65722	65748	65746	65744	65708	65724	65722	65733	65737	65738	65740
Order of Testing		2	3	4	13	12	11	1	5	6	7	8	9	10
Test Start Time		9:58	10:08	10:17	12:05	11:58	11:47	9:20	10:30	10:37	11:00	11:15	11:22	11:30
Test End Time		10:04	10:14	10:21	12:10	12:02	11:54	9:25	10:35	10:41	11:04	11:19	11:25	11:34
Test Duration	Hr	0.100	0.100	0.067	0.083	0.067	0.117	0.083	0.083	0.067	0.067	0.067	0.005	0.067

NOTES:

1. Input to be determined after gas flow is established
2. Gas flow to be back calculated after air flow and %O2 are determined
3. Air flow to be determined according to Hauck spec sheet for OMG115-00 orifice with 0.75" bore
4. Excess air determined by O2 content in flue gas analysis
5. Individual burner efficiency determined with Hauck e-Solution software after excess air, combustion air temp. and flue gas temp are established

Figure 18. ITW Baseline Test Data – 11/14/2002

BASELINE TESTING DATA

ITW CIP Stampings - Santa Fe Springs, CA

GTI Projects: 40496-02, 30797-06, 85010-02, 40510-01

DATE:________11/15/02____________

		Burner												
		1N	**2N**	**3N**	**4N**	**5N**	**6N**	**7N**	**8S**	**9S**	**10S**	**11S**	**12S**	**13S**
Burner														
Input (1)	KBTU/Hr	144	146	151	120	100	109	99	133	118	143	92	120	153
Gas Flow (2)	SCFH	143.5	146.3	150.9	120.3	100.2	109.1	99.2	133.1	117.8	143.2	92.2	120.2	153.0
Gas Inlet Pressure	" WC	0.90	0.55	1.00	0.45	0.50	0.63	N/A	0.60	0.42	N/A	0.60	N/A	N/A
Air Flow "ON" (3)	SCFH	1868.0	1878.0	1964.0*	1665.4	1583.6	1927.1	1682.4	1780.5	1693.6	1941.6	1571.5	1642.5	1791.0
Air Differential Pressure	" WC	18.1	18.3	20.0*	14.3	12.9	19.3	14.6	16.4	14.8	19.6	12.7	13.9	16.6
Cold Air Temperature	F	129	129	129	129	129	129	129	129	129	129	129	129	129
Preheat Temperature	F	546	569	599	488	489	550	561	583	606	539	511	472	560
Flue Gas Temperature Before Recuperator	F	1342	1419	1451	1335	1334	1357	1330	1388	1412	1407	1331	1333	1434
Flue Gas Temperature After Recuperator	F													
XS Air (4)	%	34.62	32.75	34.62	43.12	63.45	82.71	75.44	38.29	48.63	40.17	76.17	41.26	21.07
Burner Efficiency (5)	%	65.5	64.0	63.5	62.9	59.6	57.6	60.1	64.4	62.6	62.4	58.4	62.9	65.3
Flue Gas Measurement														
O2	%	5.75	5.52	5.75	6.71	8.58	9.95	9.47	6.18	7.27	6.39	9.52	6.51	3.92
CO2	%	8.73	8.87	8.79	8.14	7.11	6.35	6.66	8.42	7.82	8.29	6.53	8.08	9.61
CO	ppm	18	18	18	17	16	15	15	19	17	17	21	42	19
NOx	ppm	157	130	234	154	197	128	136	83	97	176	117	126	215
Corrected to 3% O2														
CO	ppm	21.2	20.9	21.2	21.4	23.2	24.4	23.4	23.1	22.3	20.9	32.9	52.2	20.0
NOx	ppm	185.3	151.2	276.2	194.0	285.5	208.5	212.3	100.8	127.2	216.8	183.4	156.5	226.6
Furnace														
Zone 1 Temperature (S.P. 1540 F)	F	1525	1544	1522	1521	1564	1573	1530	1547	1563	1595	1515	1537	1610
Zone 2 Temperature (S.P. 1540 F)	F	1553	1540	1543	1600	1560	1556	1539	1560	1552	1553	1583	1554	1558
Zone 3 Temperature (S.P. 1540 F)	F	1533	1543	1556	1550	1538	1548	1539	1539	1541	1538	1542	1538	1549
Product Description		Part # 30710, Small Metal Parts for Auto Manufacturers												
Belt Speed	"/min	15.0	15.0	15.0	15.0	15.1	15.0	15.0	15.1	15.1	15.1	15.1	15.1	15.1
Total NG Usage (Meter Reading)	SCFx100	66001	66003	66005	66009	66007	66004	65999	66013	66015	66017	66020	66019	66018
Order of Testing		2	3	5	7	6	4	1	8	9	10	13	12	11
Test Start Time		9:06	9:14	9:30	9:44	9:38	9:22	8:58	10:07	10:15	10:21	10:40	10:36	9:28
Test End Time		9:10	9:18	9:35	9:47	9:41	9:26	9:03	10:12	10:19	10:24	10:44	10:38	9:31
Test Duration	Hr	0.067	0.067	0.083	0.050	0.050	0.067	0.093	0.083	0.067	0.050	0.067	0.033	0.050

NOTES:

1. Input to be determined after gas flow is established
2. Gas flow to be back calculated after air flow and %O2 are determined
3. Air flow to be determined according to Hauck spec sheet for OMG115-00 orifice with 0.75" bore
4. Excess air determined by O2 content in flue gas analysis
5. Individual burner efficiency determined with Hauck e-Solution software after excess air, combustion air temp. and flue gas temp are established

Figure 19. ITW Baseline Test Data – 11/15/2002