DEMONSTRATION OF OSCILLATING COMBUSTION ON A HIGH TEMPERATURE FORGING FURNACE

by

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PRESENTATION OUTLINE

- GTI & Combustion Group Background Info
- Principle of Oscillating Combustion
- Project Goals
- Furnace Description
- Work Scope
- Prior Relevant Burner Testing
- Test Results
- Recommendations
- Current Status

GAS TECHNOLOGY INSTITUTE (GTI)

- An independent, not-for-profit energy and environmental research and technology development center
- Created in April 2000 from the combination of the Institute of Gas Technology (IGT) (established in 1941) and Gas Research Institute (GRI) (founded in 1976)
- Performs conceptual, bench-scale, pilot-scale, and full-scale technology evaluation, demonstration, and commercialization
- Provides educational, information, and technology transfer programs and services

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GTI RESEARCH GROUPS

- **Combustion Technology**
- **Biotechnology**
- **Electrochemical Technology**
- **Energy Systems and Business Analysis**
- **Gas Operations Technology**
- **Gas Processing Technology**
- **Process Development and Engineering**

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GTI COMBUSTION TECHNOLOGY GROUP

- Industrial Process Heat
- Steam and Power Generation
- Residential / Commercial
- Waste Processing

COMBUSTION TECHNOLOGIES DEVELOPED

- **Oscillating Combustion**
- **Ceramic Radiant Tubes**
- **Low Inertia Furnace**
- **Oxygen-Enriched Air Staging**
- **High Luminosity Burner**
- **Submerged Combustion Melter**
- **Cyclonic Waste Melter**
- **Methane de-NOX**
- **Force Internal Recirculation Burner**
- **Surface Combustor**
- **Cyclonic Boiler Burner**
- **Partial Oxidation**

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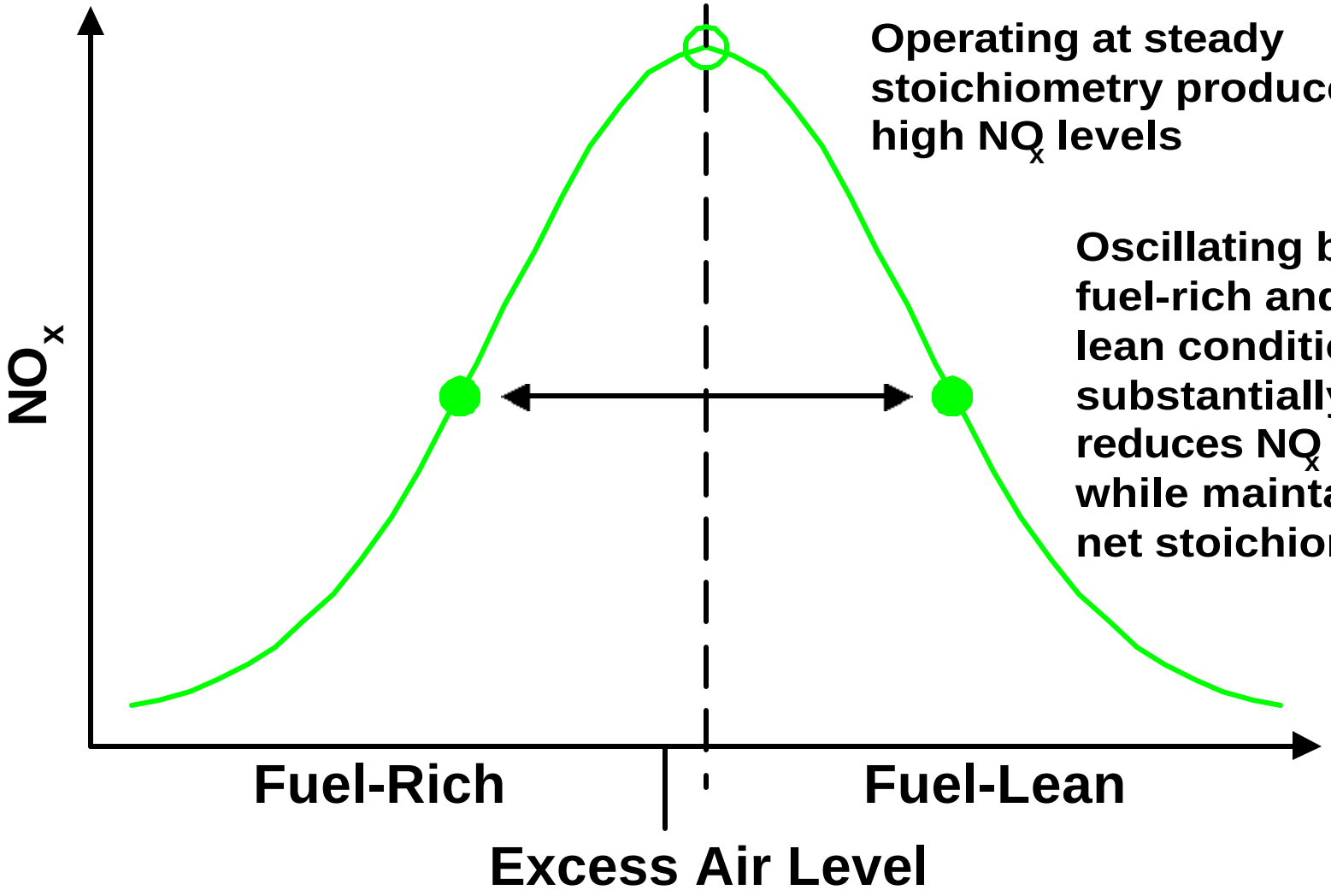
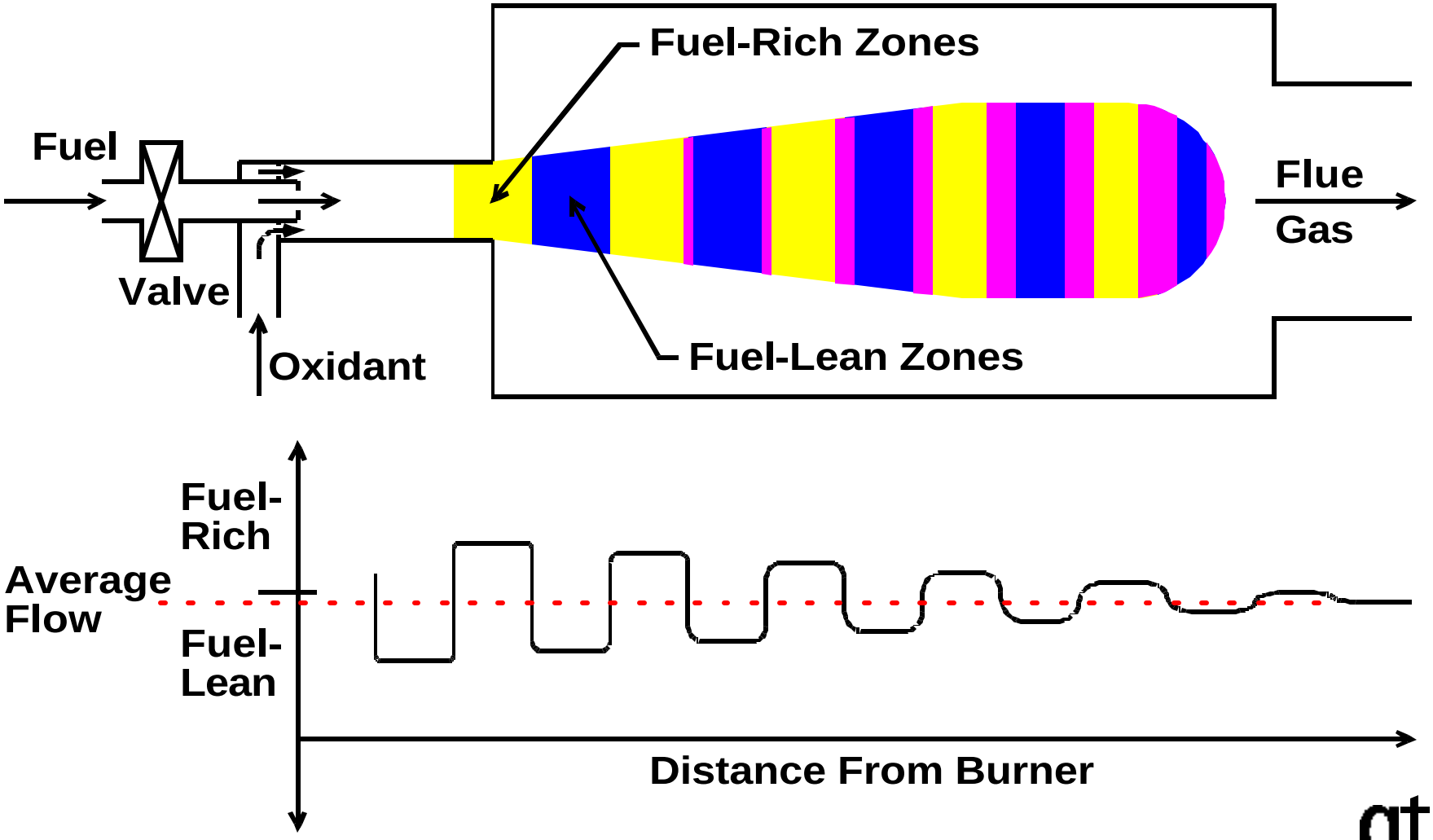
OSCILLATING COMBUSTION CONCEPT



OSCILLATING COMBUSTION PROCESS



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TECHNICAL DESCRIPTION

- Fuel flow oscillates between a high rate and a low rate several times a second
- Oxidant flow rate remains steady or oscillates out-of-phase with the fuel flow rate
- Oscillating stoichiometry creates successive, NO_x-formation-retarding, fuel-rich and fuel-lean zones within the flame
- Heat transfer is enhanced by the increased luminosity and the breakup of the thermal boundary layer
- Heat is transferred from the fuel-rich and fuel-lean zones to the load before the zones mix
- Final mixing and burnout occurs within the furnace at reduced temperature which minimizes additional NO_x formation

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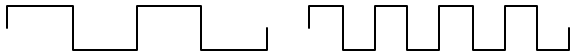
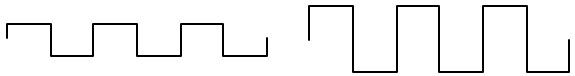
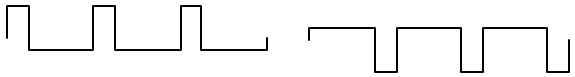
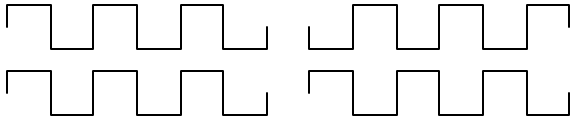
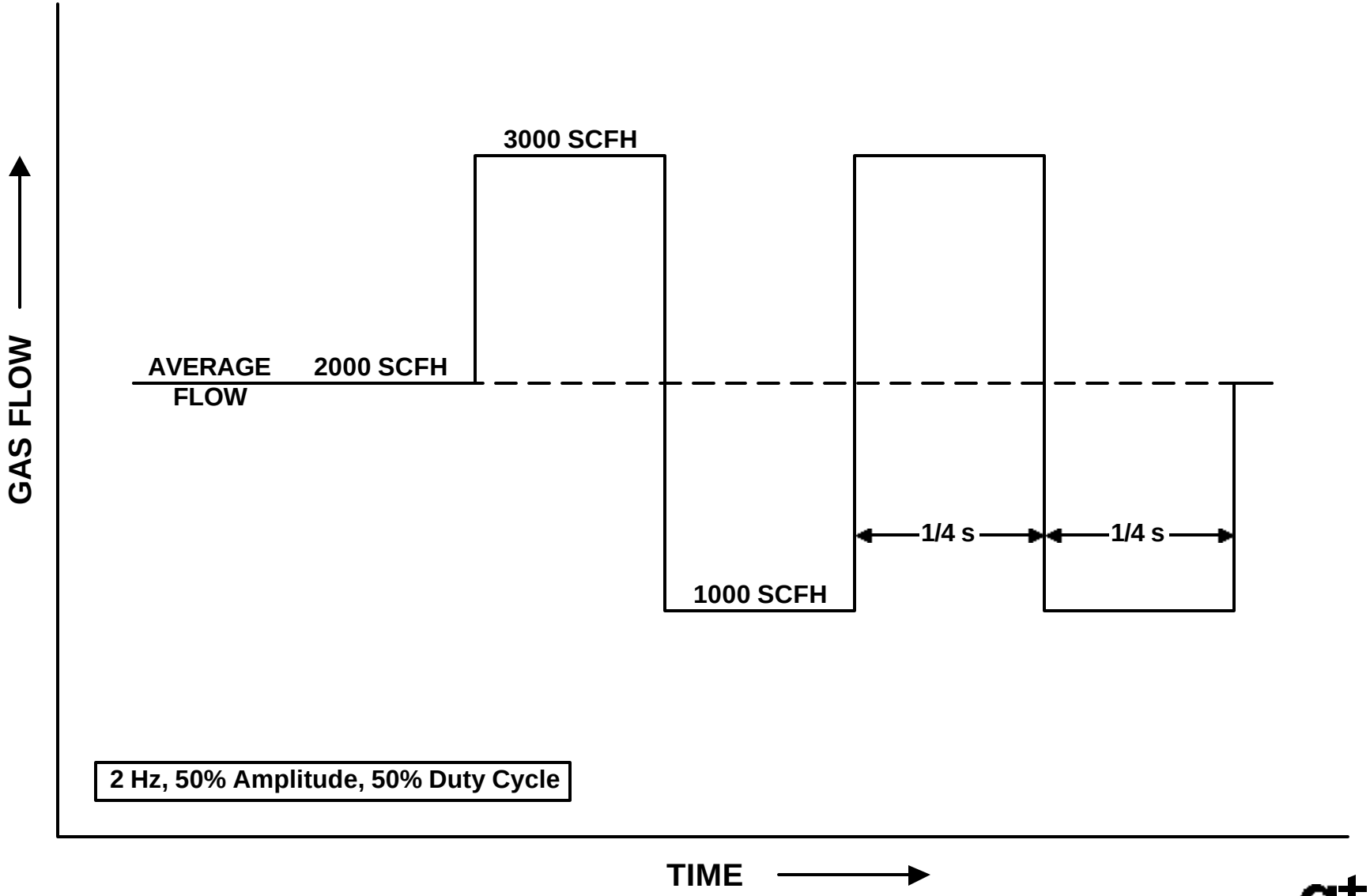
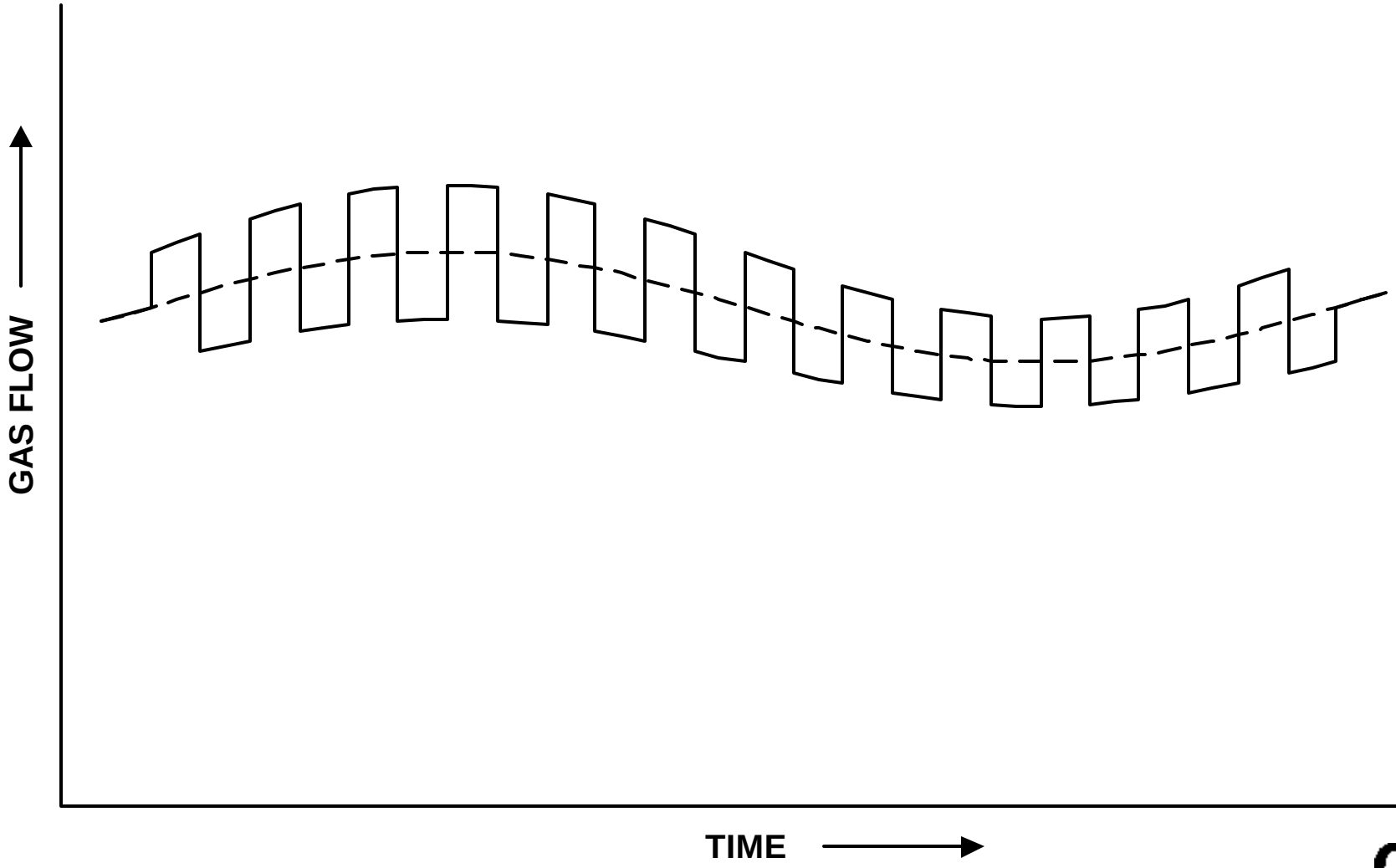
OSCILLATING PARAMETERS

Parameter	Definition	Unit	Comments
Frequency	Number of oscillation cycles per unit time 	Hz	¥ Hz (not 0 Hz) is used to denote steady (non-oscillating) operation.
Amplitude	Relative change in gas flow rate during the oscillation cycle above or below the average flow rate 	%	0% is for no oscillations. 100% is for oscillating between zero flow and double the average flow.
Duty Cycle	Fraction of time the gas flow rate is above the average flow rate during each oscillating cycle 	%	50% is for equal time above and below the average flow.
Phasing Between Burners	Relative offset in time between the start of oscillating cycles for different burners 	° (deg.)	0° is for in-phase oscillations. 180° is for completely out-of-phase oscillations.

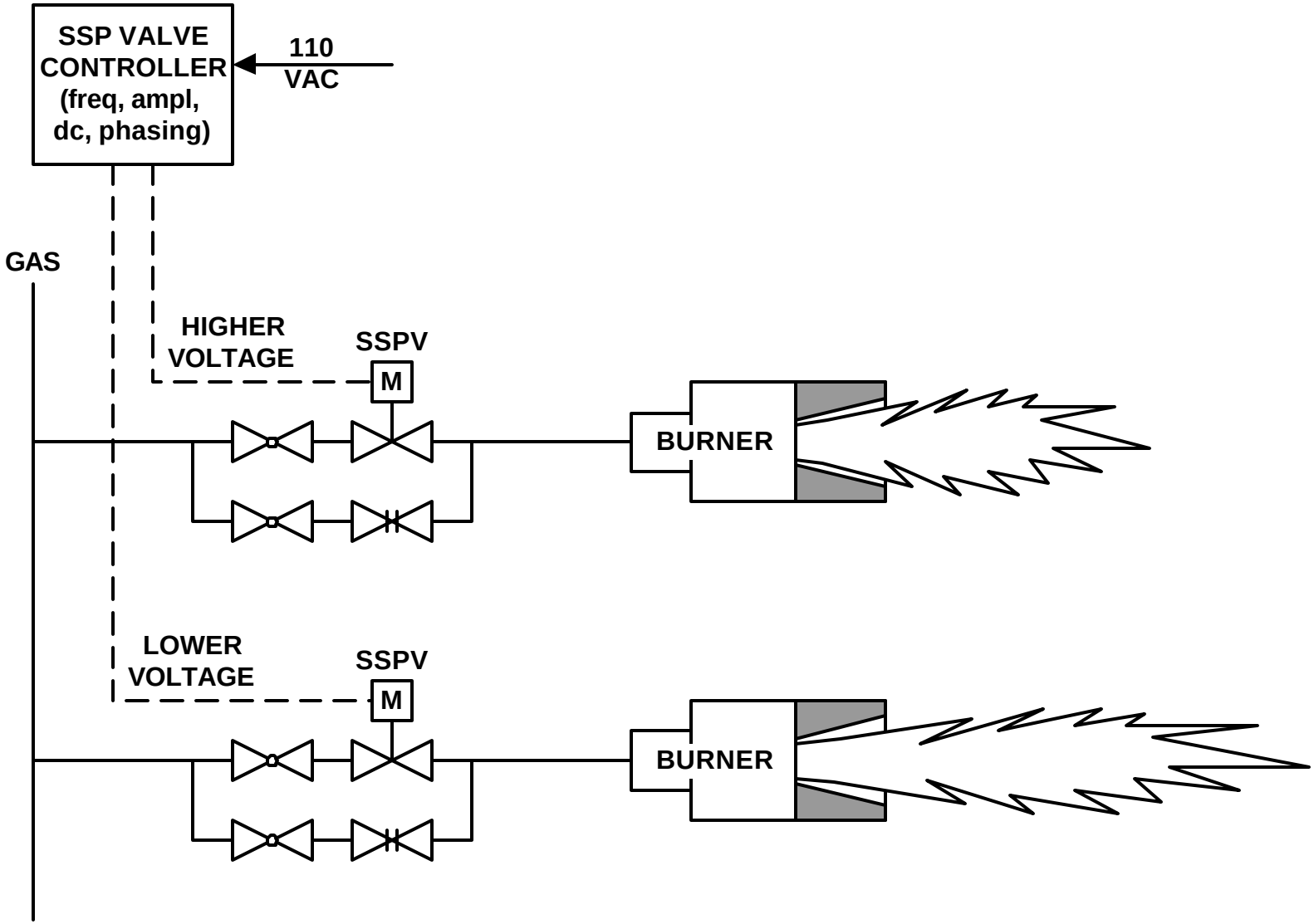
GAS FLOW PATTERN



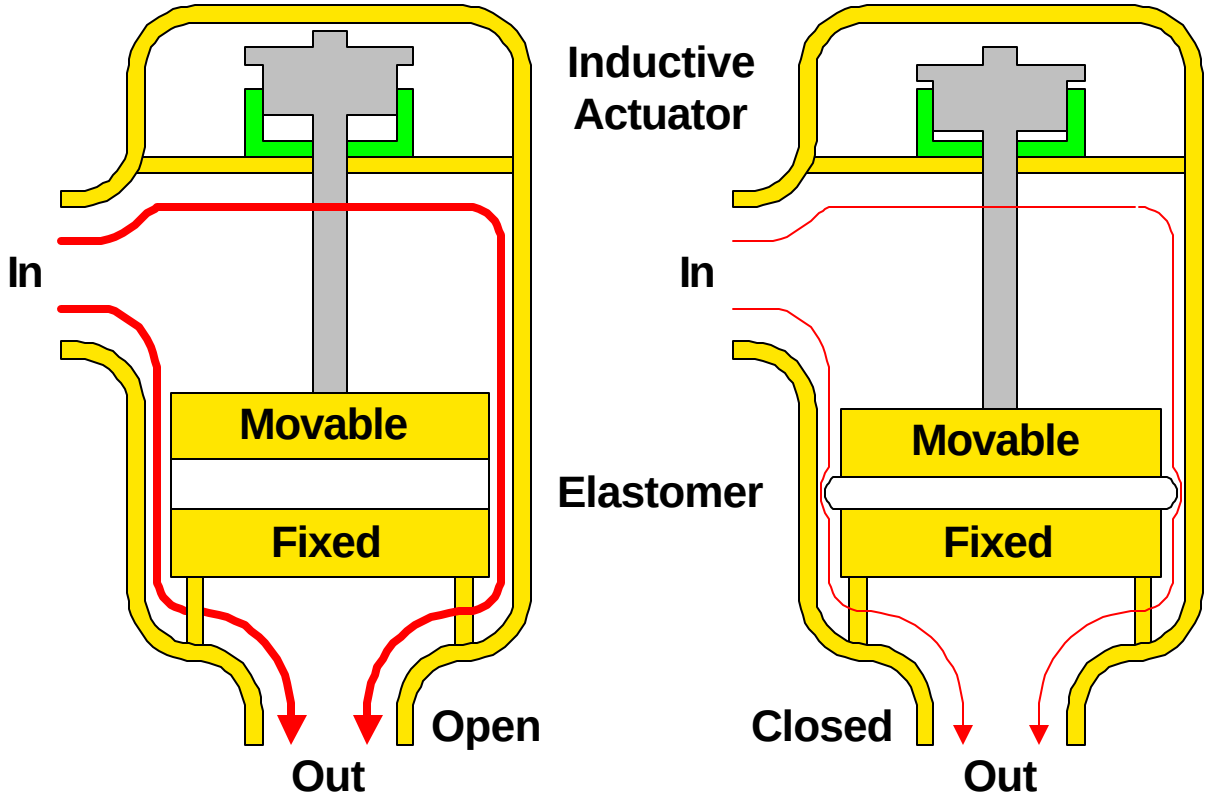
SUPERIMPOSED PULSES ON MODULATING GAS FLOW



ONE-PAIR OPERATION



SOLID-STATE PROPORTIONING (SSP) VALVE



DEVELOPMENT TEAM

- CeramPhysics, Inc. -- development of solid state proportioning (SSP) valve
- GTI -- development and demonstration of oscillating combustion, overall project management
- Shultz Steel Co. -- host site; provided forging furnace for field demonstration
- California Air Resources Board, Southern California Gas Company, GTI's Sustaining Membership Program -- sponsors

WHY DEVELOP OSCILLATING COMBUSTION?

- Offers lower cost retrofittable solution than post-combustion techniques and low-NO_x burners
- Reduces NO_x generated from nitrogen in combustion air, industrial oxygen, natural gas, and air infiltrated into furnace
- Increases heat transfer
- Allows industry to retain natural gas as the preferred fuel and gain competitive advantages through increased furnace productivity and sale of NO_x emissions credits.

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COST COMPARISON

Technology	Applicability	Advantages & (Disadvantages)	NO_x Reduction, $/ton
Flue Gas Recirculation	Limited	(High retrofit downtime); (Increased CO emissions); (Decreased energy efficiency and production rate)	>$2000
Air Staging	Moderate	(High retrofit downtime)	$500-1000
Low NO_x burner	Limited	(Major investment)	>$2000
Pulsed Combustion	Limited to small sizes	Increased energy efficiency; Higher productivity; (Usually not retrofittable); (Very high noise)	Very high
Gas Reburn	Limited	(High retrofit downtime); (Combustion in flue); (Decreased efficiency)	$500-1000
Oscillating Combustion	Very wide	Increased energy efficiency; Higher productivity; Rapid retrofit	<$250 (excluding efficiency/ productivity benefits)

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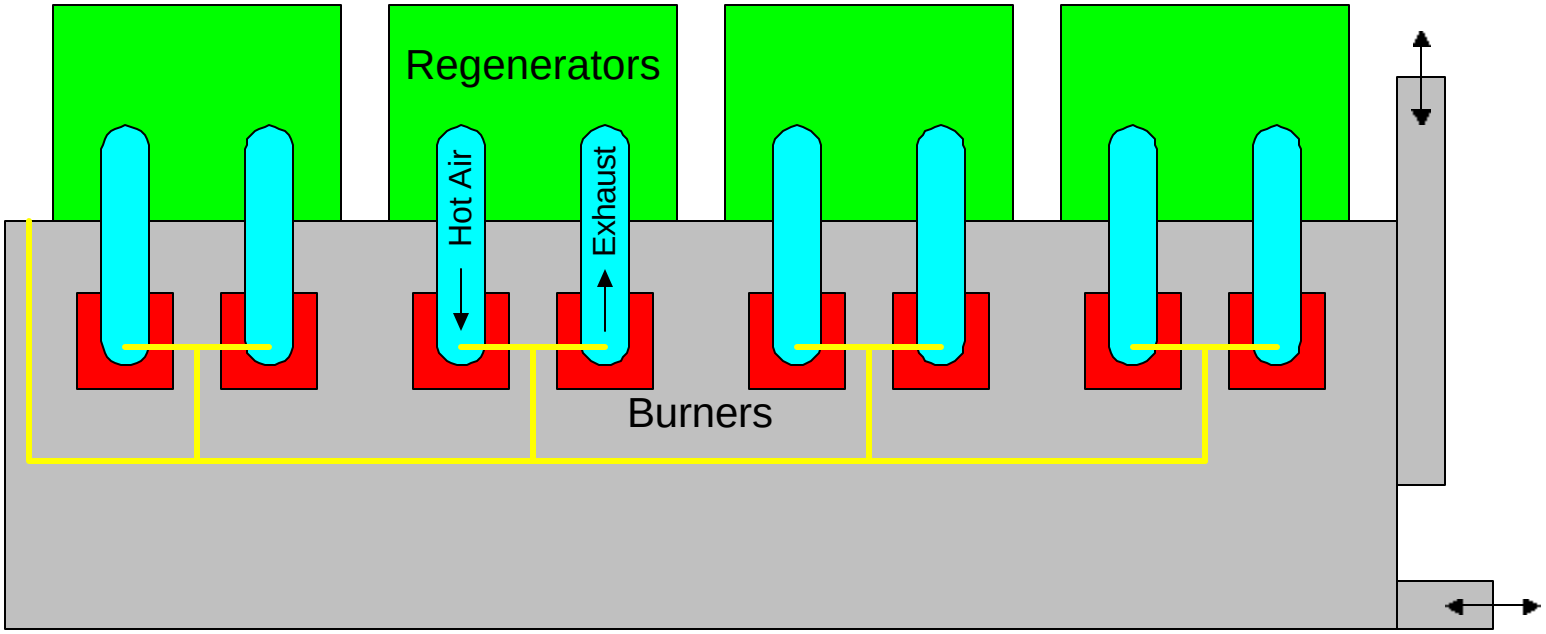
PROJECT GOALS

- 50% NO_x reduction
- 5% fuel savings
- No adverse affect on product quality (H_2 impregnation level of certain metals)
- Maintain product temperature uniformity
- Acceptable CO level in exhaust (< 100 vppm)

SHULTZ STEEL COMPANY
CAR-BOTTOM FORGE FURNACE

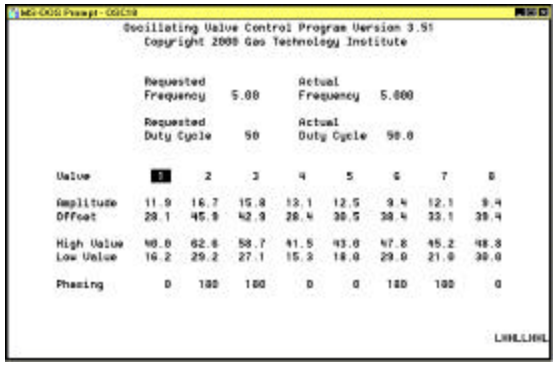


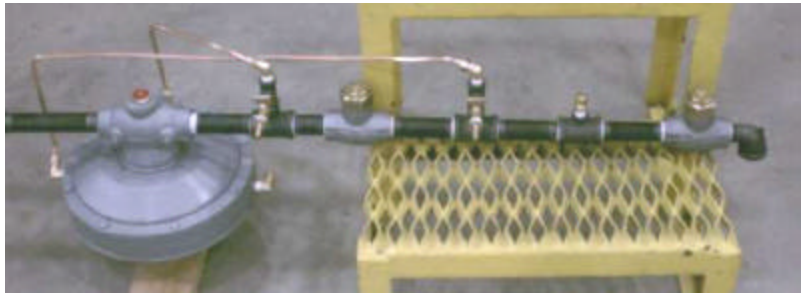
- 4 burner pairs (each pair controlled independently by zone temperature)
- Burners rated at 2.6 MMBtu/h each

WORK SCOPE

- Task 1. Retrofit Design
  - Survey site
  - Test titanium samples
  - Design retrofit installation
- Task 2. Setup
  - Set up GTI instrumentation
  - Install oscillating combustion hardware
  - Tune system
- Task 3. Testing
  - Baseline testing
  - Oscillating combustion testing
- Task 4. Analysis & Reporting
  - Execute field test agreement
  - Analyze data
  - Report results

DESIGN AND SETUP





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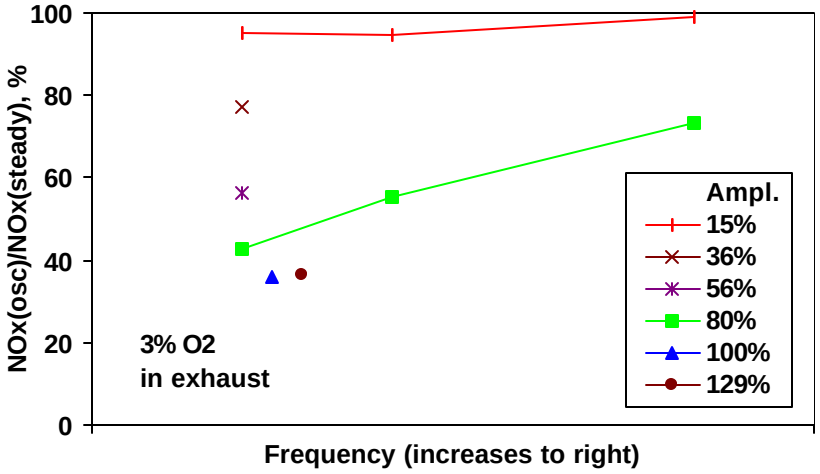
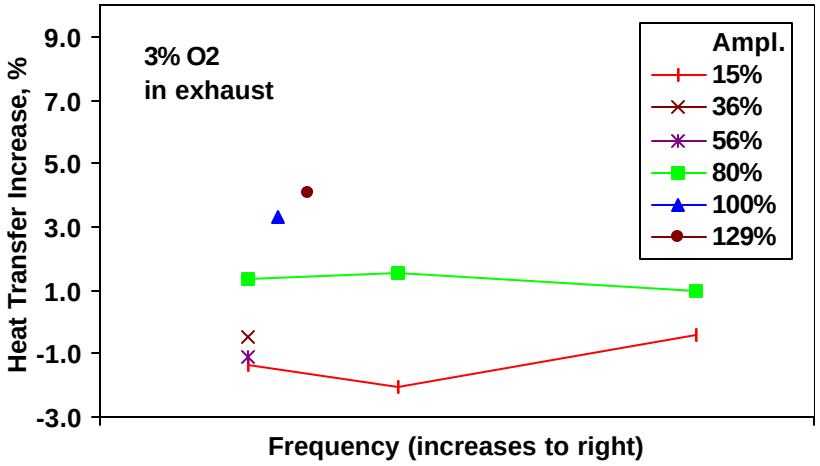
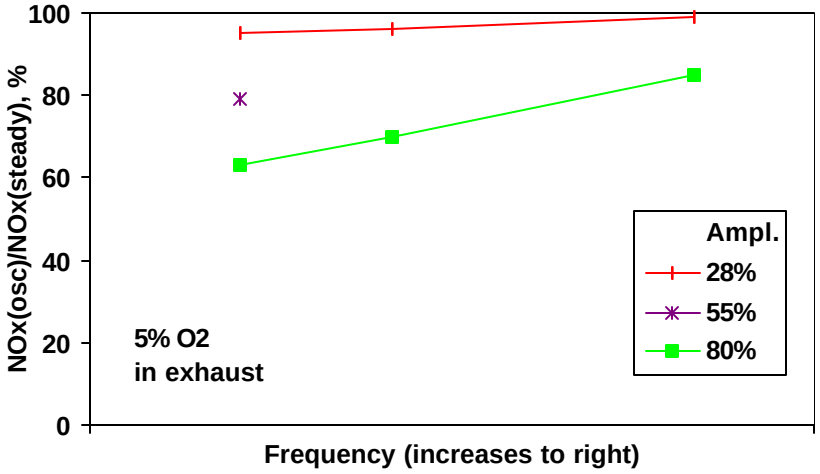
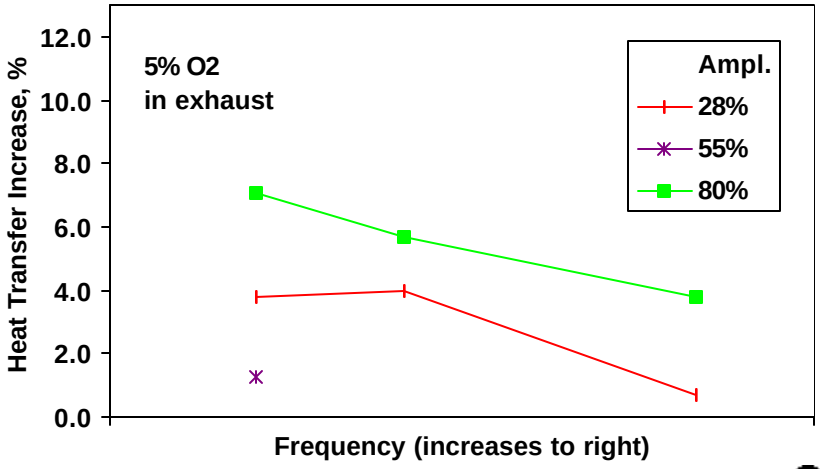
PRIOR ZEDTEC BURNER LABORATORY TEST RESULTS









TITANIUM SAMPLE LAB TEST RESULTS

Piece No.	Location	Excess Air Level	Oscillation Amplitude	Percent of Max Allowed H2 Concentration
1	Control Sample	-	-	5%
9	Control Sample	-	-	10%
5	Under Flame	15%	None	34%
4	Downstream	15%	None	11%
2	Under Flame	15%	Low	36%
14	Downstream	15%	Low	14%
13	Under Flame	15%	High	51%
3	Downstream	15%	High	12%
11	Under Flame	28%	None	24%
12	Downstream	28%	None	14%
7	Under Flame	28%	Low	25%
6	Downstream	28%	Low	14%
8	Under Flame	28%	High	32%
10	Downstream	28%	High	18%

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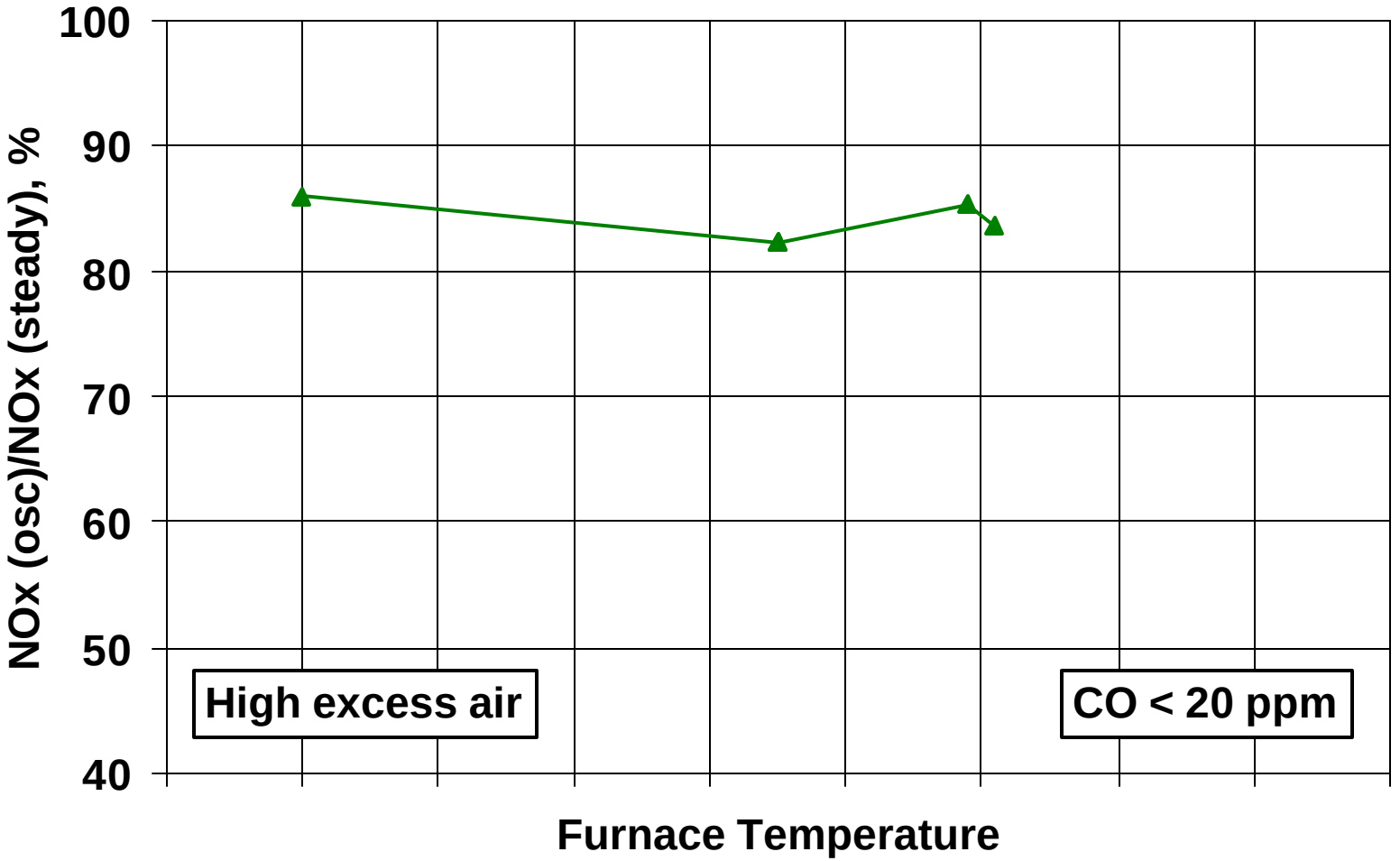
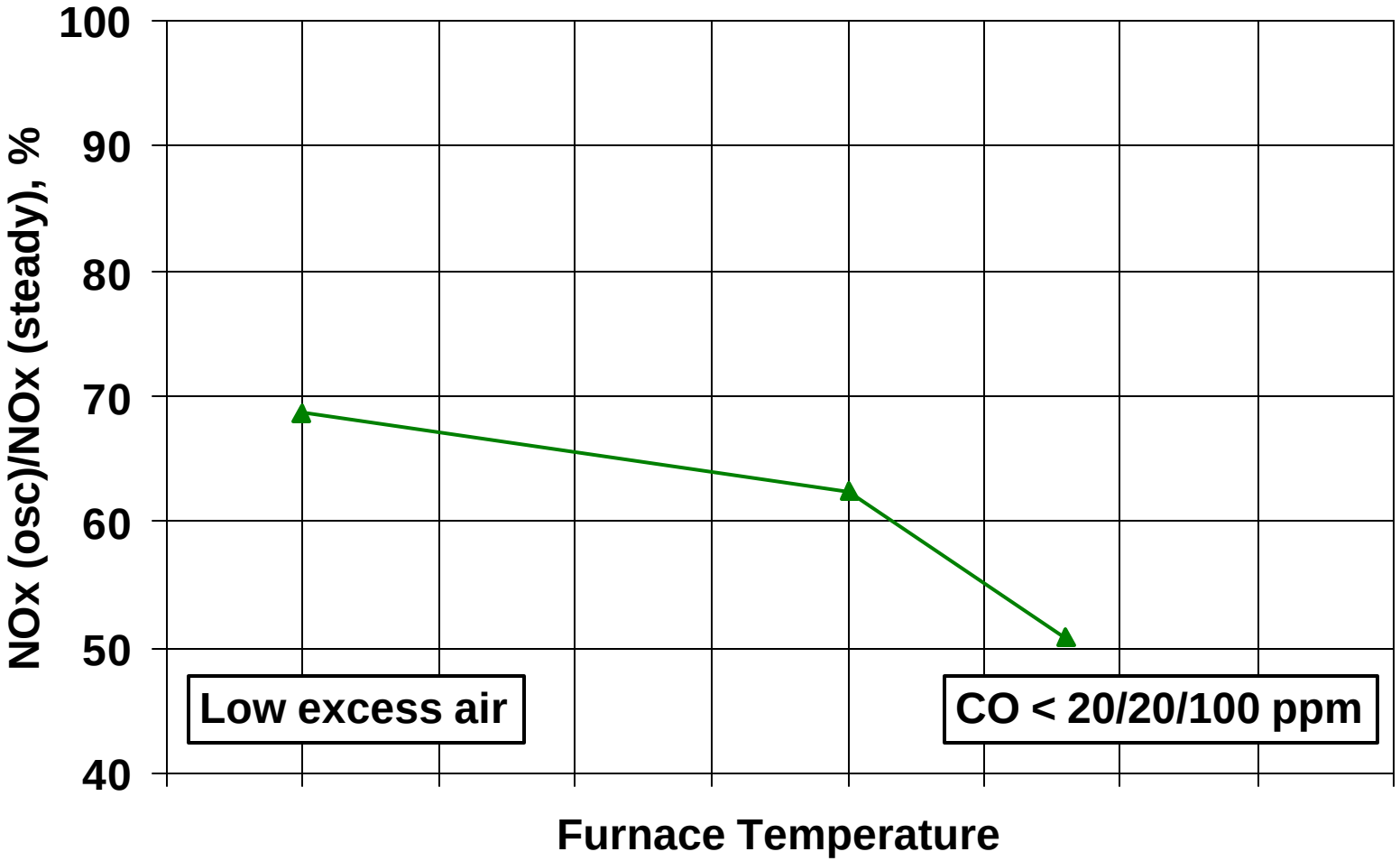
FIELD TEST RESULTS
(High Excess Air)



FIELD TEST RESULTS
(Low Excess Air)



TEST RESULTS SUMMARY

- Lab testing (Oct. 2000)
  - Titanium samples do not adsorb excessive amount hydrogen
- Field testing (Apr.-Jun. 2001)
  - NO_x reduction of up to 49% with low excess air
  - NO_x reduction of up to 18% with high excess air
  - Fuel savings of up to 3%
  - Oscillating combustion hardware performed well with the valves logging one million aggregate oscillation cycles

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RECOMMENDATIONS

- **Operate with a constant, low excess air level**
  - **Oscillating combustion produces high NO_x reduction percentages when the furnace is operated at a constant, low excess air level. Good control of the air-fuel ratio is necessary for the successful implementation of oscillating combustion.**
- **Control strategy of cycling burners on and off**
  - **To achieve a large turndown and/or convective current, but still maintain a constant excess air level, the simplest strategies would be to have**
    - **on-off (or pulse) firing**
    - **modulating firing down to the turndown limit, and on-off firing below that**
- **Coping strategies for transient over-temperature swings**
  - **It may be necessary to adjust over-temperature limits, or move their thermocouples, to avoid tripping the limits due to the altered flame shape and larger temperature swings after disturbances possible with oscillating combustion.**

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CURRENT STATUS

- **Shultz Steel is evaluating the potential savings on NOx credits if oscillating combustion is applied to this and other furnaces, some of which are also candidates for retrofit with low-NOx burners.**

COMMERCIALIZATION PLAN

- **Air Liquide has a world-wide, exclusive license for oxy-gas oscillating combustion and a nonexclusive right for air-gas oscillating combustion.**
  - **Air Liquide will market oscillating combustion to its industrial gas customers through its existing sales, engineering, and support channels**
- **GTI has retained a nonexclusive license for air-gas oscillating combustion.**
  - **GTI is planning to license Synergistic Partners, Inc. of Pittsburgh, PA to offer air-gas oscillating combustion commercially in the U.S.**
  - **Synergistic Partners, Inc. would also support marketing of oxy-gas oscillating combustion through Air Liquide.**

COMMERCIALIZATION PLAN (cont.)

- Steps are being taken to ensure that oscillating combustion packages (valves and controller) are available for select applications by Summer 2002.
- The forging plant markets that are subject to lower NO_x emissions will be targeted initially.
- Commercial prototypes of oscillating valves are currently being developed by Safmatic (based on the SSP design), and Outsource Tech, Inc. (based on a rotary design).
- GTI has developed a comprehensive database of lab and field results. GTI plans to transfer this experience and technology know-how to its commercialization partners, Air Liquide and Synergistic Partners, Inc.

APPENDIX

SSP VALVE STATUS

- Developed by CeramPhysics under support from SoCalGas and Columbia Gas
- Licensed to Safmatic, an Air Liquide affiliate
- Scaled up by Safmatic to 6.8 MMBtu/h (average flow rate on an oscillating basis)
- Manufacturing prototypes have been tested by Air Liquide

GLOSSARY

AL	Air Liquide
CARB	California Air Resources Board
CO	Carbon monoxide
CPI	CeramPhysics, Inc.
GTI	Gas Technology Institute
H_2	Hydrogen
lb	Pound (mass)
MMBtu	1,000,000 Btu
NG	Natural gas
NO_x	Nitric oxide and nitrogen dioxide

GLOSSARY
(Continued)

OSC	**Oscillating Combustion**
PC	**Personal computer**
ppm	**Parts per million by volume**
SCFH	**Standard cubic foot per hour**
SMP	**GTI Sustaining Membership Program**
SoCalGas	**Southern California Gas Company**
SSC	**Shultz Sheet Company**
SSP	**Solid-state proportioning**