DOE/ID/13378--T10

Demonstration of Oxygen-Enriched Air Staging at Owens-Brockway Glass Containers

Quarterly Technical Progress Report for the Period November 1, 1996 - January 31, 1997

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March 1997

Work Performed Under Contract No.: DE-FC07-95ID13378

for
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DISCLAIMER

EXECUTIVE SUMMARY

This report presents the work performed by the Institute of Gas Technology, and subcontractors Combustion Tec, Inc. and Air Products and Chemicals, Inc., during the period from November 1, 1996 through January 31, 1997 under a contract (No.: DE-FC07-95ID13378) with the U.S. Department of Energy, Idaho Operations Office.

IGT, and its commercial partners, have developed a technology, oxygen-enriched air staging (OEAS), which has been shown in tests at three commercial endport furnaces to reduce NO_x levels by 50 to 70%. In this program, the OEAS technology is being extended to the other main type of glass furnace, sideport furnaces.

The OEAS technology utilizes a unique method of combustion air staging to control NO_x formation by reducing the oxygen available in the flame's high temperature zone and improving flame temperature uniformity. The amount of primary combustion air entering through the port(s) is reduced to decrease NO_x formation in the flame, and oxygen-enriched air is injected into the furnace near the exhaust port(s) to complete the combustion in a second stage within the furnace. The OEAS technology has been successfully retrofitted to five endport container glass furnaces, including two commercial sales.

Owens-Brockway, the largest container glass producer in the United States, has joined the team to test the potential of the OEAS technology and has chosen to demonstrate it on its 325-ton/day, Furnace C, in Vernon, California. The field evaluation is the subject of this project.

The OEAS technology addresses glass industry research priority 2.d. in DOE RFP. No. DE-PS07-95ID13346, *Develop improved, cost-effective air emissions systems or optimized furnace designs to meet the more stringent regulations of the future (i.e. removal of NO_X, SO_X, and particulates emission). Integrated process improvements are preferred over add-on devices.*

For the successful application of the OEAS technology to sideport furnaces, the key development areas are, 1) to provide good mixing of the secondary oxidant with the primary zone combustion products, and 2) to provide the proper secondary oxidant distribution strategy (equally split between the ports or optimized for each port) to minimize overall NO_x emissions and maximize combustible burnout in the second stage within the furnace, while minimizing oxygen (used to enrich the secondary oxidant) consumption. These key areas can only be addressed through development testing on a representative sideport glass furnace.

The development approach is to 1) acquire baseline operating data on the host sideport furnace in Vernon, California; 2) evaluate secondary oxidant injection strategies based on earlier endport results and through modeling of a single port pair; 3) retrofit and test one port pair (the test furnace contains six port pairs) with a flexible OEAS system; 4) based on the results from testing the one port pair (item 3), design, retrofit, and test OEAS on the entire furnace (six port pairs); and 5) analyze test results, prepare report, and finalize the business plan to commercialize OEAS for sideport furnaces.

During this reporting period, all project work described above was completed up to installation and testing of the PLC control system for OEAS, finalization of the business plan for commercialization, and preparation of the final report. Details of the modeling calculation methodology and results, baseline furnace testing, single port pair implementation, and single port pair results are presented in this report.

Full furnace parametric testing with OEAS and long-term OEAS testing were completed last quarter. In this quarter, two test campaigns were conducted. In one test series, the OEAS system was monitored while a third party contractor measured stack emissions. A comparison of results showed agreement in stack CO, O_2, and NO_x values measured by IGT and the contractor to within 1 percent. The second test series was conducted with electric boost reduced and natural gas firing increased on the furnace. Pull rate was held constant while electric boost was reduced by one third and natural gas consumption was increased by 10 percent. Exhaust gas temperature, crown temperature, and NO_x level all increased. The same level of NO_x reduction (30 to 35%) was achieved at low boost as was achieved at high boost. Since initial NO_x levels were higher with low boost, the final NO_x level with OEAS was approximately 2.5 lb/ton at low boost compared with less than 2 lb/ton at high boost.

The OEAS system operating manual was completed this month, and Owens Brockway staff were trained in system operation. A new alarm light for OEAS was installed in the control room, and a faulty controller on the blower air skid was replaced. The project team agreed that the use of a PLC control system with a touch screen monitor in the control room was economical and would provide the furnace operators a simple and flexible means of OEAS control. The touch screen displays were agreed upon, and the PLC control system was ordered. The system was received by CTI and programmed. The PLC controller will be installed next quarter.

The project team has completed all modeling work, OEAS system design and installation, single port pair testing, and full furnace testing under parametric conditions, long term testing, and reduced boost conditions. The PLC control system for permanent OEAS operation has been specified, purchased, and programmed. The project team is ready to install the PLC control system and determine preferred furnace primary fining conditions and OEAS system operating conditions.

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Introduction

The objective of the program is to demonstrate the use of a previously developed combustion modification technology to reduce NO_x emissions from sideport regenerative container glass melters. This technology, known as oxygen-enriched air staging (OEAS), has been demonstrated, and is now being commercialized, for endport container glass furnaces. A 17-month development program has been established with specific objectives to: 1)acquire baseline operating data on the host sideport furnace in Vernon, California, 2) evaluate secondary oxidant injection strategies based on earlier endport furnace results and through modeling of a single port pair, 3) retrofit and test one port pair (the test furnace has six port pairs) with a flexible OEAS system. and select the optimal system configuration, 4) use the results from tests with one port pair to design, retrofit, and test OEAS on the entire furnace (six port pairs), and 5) analyze test results, prepare report, and finalize the business plan to commercialize OEAS for sideport furnaces. The host furnace for testing in this program is an Owens-Brockway 6-port pair sideport furnace in Vernon, California producing 325-ton/d of amber container glass. The baseline NO_x level of this optimized furnace is about 4.0 lb/ton of glass. An anticipated NO_x reduction of 50% will lower the NO_x production level to below 2 lb/ton. Secondary oxidant staging techniques being considered include oxygen-enriched ambient air staging (OEAS) and oxygen staging (OS)

The OEAS technology utilizes a unique method of combustion air staging to control NO_x formation by reducing the oxygen available in the flame's high temperature zone and improving flame temperature uniformity and combustion efficiency. The amount of primary combustion air entering through the ports is reduced to decrease NO_x formation in the flame, and oxygen-enriched air is injected into the furnace near the exit port to complete combustion in a second stage within the furnace. The OEAS technology has been successfully retrofitted to three endport container glass melting furnaces; a 150 ton/d endport glass tank producing flint glass in Huntington Park, California, a 200 ton/d endport glass tank producing amber glass in Houston, Texas, and a 320 ton/day endport glass tank producing flint glass in Huntington Park, California. With endport furnace NO_x reduction levels of 50-70%, the OEAS technology shows an excellent potential for similar performance on sideport furnaces. Sideport furnaces are used for nearly 65% of U.S. glass production. Although the potential successful application of OEAS to sideport furnaces is high, considerable design effort and development testing are required. Endport and sideport furnaces are similar in concept, but these furnaces are significantly different in physical design and flame characteristics.

The project team consists of IGT, which originated the concept and is the prime contractor, and the following subcontractors: Combustion Tec, Inc. (CTI), combustion equipment manufacturer and commercialization partner; Air Products and Chemicals, Inc. (APCI), O_2 supplier and commercialization partner; and Owens-Brockway Glass Containers, glass producer, and owner of the host site.

Background

Regenerative glass furnaces use high combustion air temperatures (2200° - 2400°F) to improve productivity, product quality, and furnace thermal efficiency. Flame temperatures are thus quite high as is NO_x production. NO_x emissions over 10 lb/ton glass are common.[1] NO_x emission regulations are in force in Southern California and Europe and mandated or planned for other regions. Current limits in Southern California are 4 lb/ton for container glass furnaces. There are no current national U.S. NO_x emission regulations, but this could change in response to the 1990 Clean Air Act Amendments.

To address existing and anticipated regulations, the project team has developed a cost-effective, retrofit NO_x control technology for regenerative, natural gas-fired glass melters. This technology, which involves a unique method of air staging, is already commercial for endport glass furnaces, is being demonstrated on a sideport container glass furnace in the present program, and is applicable to many other types of high-temperature material processing furnaces.

Regenerative glass melters generally produce NO_x by thermal processes. Thermal NO_x depends on the time-temperature history of the flame and increases with both increasing flame temperature and oxygen availability in the high-temperature region. NO_x formation can be reduced by either lowering the peak flame temperature or reducing oxygen availability.

Reducing excess air level is the easiest way to reduce oxygen availability. At excess air levels below 25%, NO_x production declines with decreasing excess air even as flame temperature rises. Since glass melters commonly operate with 5 to 15% excess air, lowering excess air will reduce NO_x formation, but, a secondary result is the formation of carbon monoxide. The unique air staging method known as oxygen-enriched air staging (OEAS) allows an endport furnace or many (to all) of the ports of a sideport furnace to operate at a minimum excess air level or even fuel rich.. NO_x formation is kept to a minimum and the combustion process is completed within the furnace using various staging options. Other benefits of reduced air firing include improved heat transfer to the melt resulting from higher flame temperature, greater luminosity, and higher system efficiency resulting from lower excess air discharge.

In the early 1980s, IGT and Combustion Tec developed and tested several NO_x control techniques, including air staging, on an IGT glass tank simulator. Low excess air firing tests were conducted on the glass tank simulator and two commercial glass furnaces. Also, glass tank simulator tests were conducted in which ambient air, as the secondary oxidant, was injected near the exhaust port to maintain an overall stoichiometric ratio of 1.15. A general correlation, shown in Figure 1, was found between the primary stoichiometric ratio and NO_x production. Reducing the PSR from 1.15 to 1.05 reduced NO_x by 35%, and the secondary oxidant effectively burned out CO generated in the primary flame. Additional testing found an added benefit of reducing the PSR is an increase in heat transfer. A significant increase in heat transfer was realized in the IGT glass simulator tests at the reduced PSR.

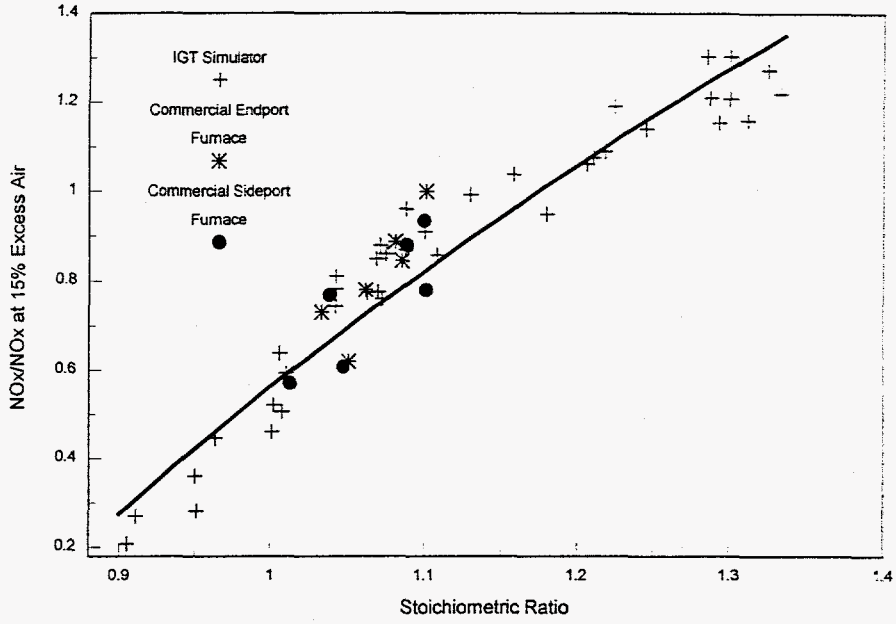

Figure 1. Effect of First-Stage Stoichiometric Ratio on NO_x Production

OEAS has been installed on five endport container glass furnaces producing amber and flint container glass.[2] NO_x emissions were decreased from 50 to 73% using several means and types of oxidants including hot air and compressed ambient air for air staging.[3] Air staging on these furnaces increased CO at the top of the regenerator, but stack CO levels were unchanged.

For the current sideport installation, the enriched air is supplied to injectors at the ports by air and oxygen skids. This approach was selected as a consequence of the distance between the inlet and the exhaust ports which precludes the use of hot inlet air from the firing side as part of the secondary oxidant. Figure 2 illustrates the sideport furnace air staging configuration. The use of two skids allows any desired level of oxygen enrichment to be used for air staging.

Sideport furnace testing provides the opportunity to examine several secondary oxidant injection locations. Successful secondary oxidant injection must meet the following criteria: complete coverage of the exhaust gas stream, sufficient furnace penetration without impinging on the main (primary) flame and forming additional NO_x, and complete burnout of CO and THC (total hydrocarbons) within the furnace.

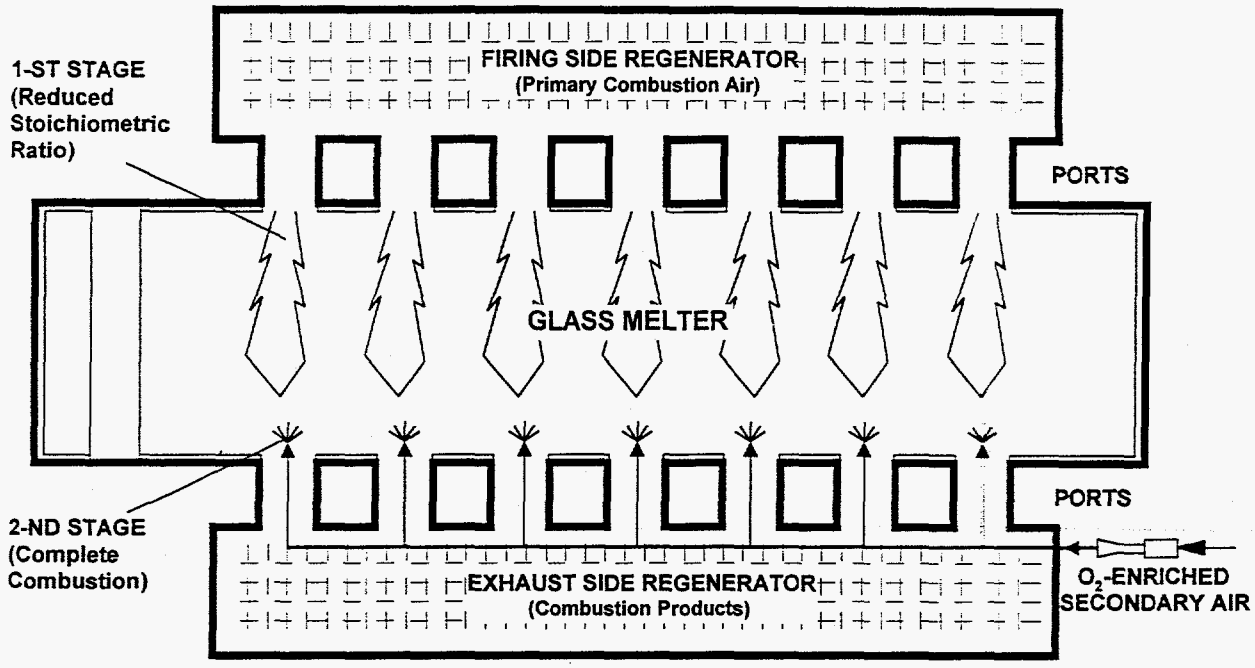

Figure 2. Oxygen-Enriched Air Staging Concept For A Sideport Furnace

Discussion

The work in this project can be divided into modeling of a single port pair, baseline testing, single port pair testing, full furnace parametric testing, full furnace long-term testing, full furnace testing with reduced electric boost, the fabrication and installation of the OEAS system, and business plan preparation. The results of the modeling, baseline testing, single port pair testing, full furnace parametric testing, full furnace long-term testing, and OEAS system fabrication have been presented in earlier annual and quarterly reports.[4,5] The full furnace testing with reduced boost and plans to install a PLC control system are presented in this report. Testing with the PLC controller operating the OEAS system and the business plan will be described in the project Final Technical Report.

Full Furnace Testing at High Boost

Analysis of the single port pair testing showed that two OEAS staging positions: side-of-port and two holes underport, effectively burn out CO while not increasing the overall NO_x level. Staging with enriched air containing 35% O_2 did not increase exhaust port temperatures at either of these positions. Higher oxygen enrichment did result in temperature increases. Evaluation of these two positions revealed significant advantages to the two hole underport position. Therefore, the two hole underport OEAS staging strategy was recommended for the full furnace.

A decision was made to proceed with the full furnace retrofit using the two hole underport injection location. This decision was reached after review of the single port pair testing and examination of the injector locations. Immediately after this decision was agreed to by Owens-Brockway, CTI, and IGT, fabrication of injectors and other equipment was begun at CTI. Efforts were focused on conducting the full furnace parametric testing during September. The results of full furnace parametric testing were presented in the last Quarterly Technical Progress Report[5] and in two conference papers written last quarter.[6,7]

Data for left side firing and right side firing collected during parametric testing in September is presented in Figures 3 and 4. Very low levels of NO_x emissions were observed during both operation without staging and during furnace with OEAS in operation. The average furnace NO_x level was decreased approximately 30% using OEAS from an average value of 2.5 lb/ton to 1.8 lb/ton. The effect of changing oxygen concentration in the staging oxidant is illustrated in Figure 3. Increasing the oxygen concentration from 35 to 50 percent decreased the NO_x emission level by 5 to 10 percent on average. This improvement in emissions level is small and comes at the expense of higher oxygen flows. After testing was complete, a decision was reached with the plant personnel to operate OEAS with 30 to 35 percent oxygen. OEAS is effective at this oxygen concentration and the plant personnel felt comfortable with the OEAS oxygen requirements while also feeling assured that OEAS was not causing any overheating of the refractory.

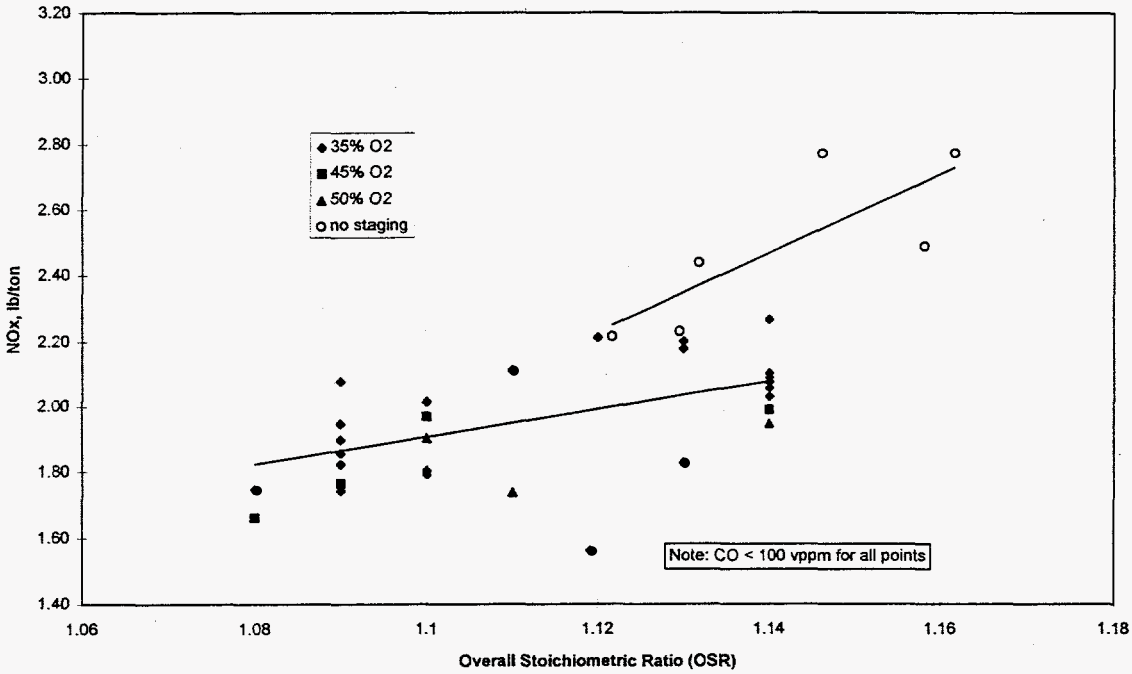

Figure 3. NO_X EMISSIONS AT HIGH BOOST DURING PARAMETRIC TESTING - LEFT SIDE FIRING

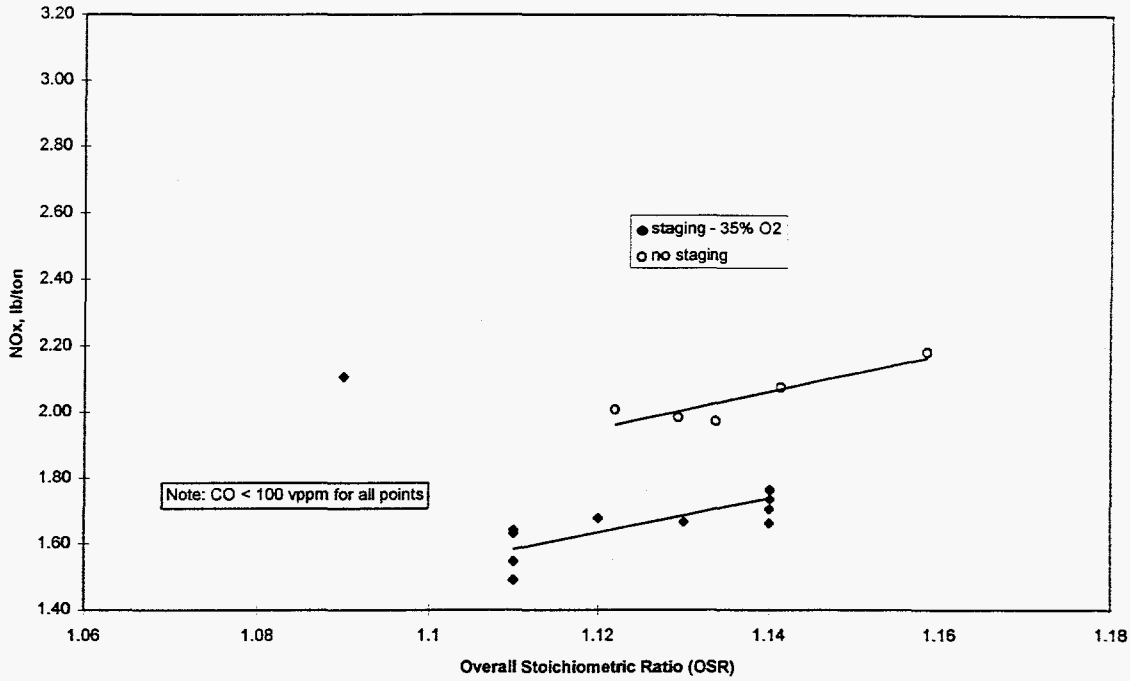

Figure 4. NO_X EMISSIONS AT HIGH BOOST DURING PARAMETRIC TESTING - RIGHT SIDE FIRING

Long-term testing of OEAS on the full furnace was conducted in October. Results are presented in the last quarterly report.[5] During November, the project team returned to the host site to conduct additional long-term testing measurements. The second set of measurements were made to confirm reliable OEAS operation and NO_x reduction. Owens-Brockway hired a third-party contractor to measure stack emissions during the November testing period. Stack measurements of O2, CO, and NO_x were essentially identical between the contractor and the project team. Discrepancies were less than one percent in values. The outside contractor followed EPA protocols in making measurements. The IGT measurement protocol varies somewhat from the EPA procedure, but regular calibrations are similar in both protocols, and similar instrumentation is used.

Only minor changes in furnace firing conditions and OEAS operating parameters were made during the testing in November. The measured NO_x levels for left and right side firing are presented in Figures 5 and 6. The furnace NO_x levels were higher both with, and without, OEAS operating than was observed during the parametric testing in September. The average NO_x emission level was still decreased by better than 25 percent, from 3.1 lb/ton to 2.3 lb/ton. The actual level of NO_x reduction was difficult to determine because baseline values measured in November all had CO emissions with more than 100 vppm. The baseline CO level can be reduced by increasing the primary

stoichiometric ratio which will also increase the level of NO_x in the stack, but this was not done during the long-term testing in November. The baseline values cited are from the September parametric testing, and these values are likely low based on the furnace operating conditions in November.

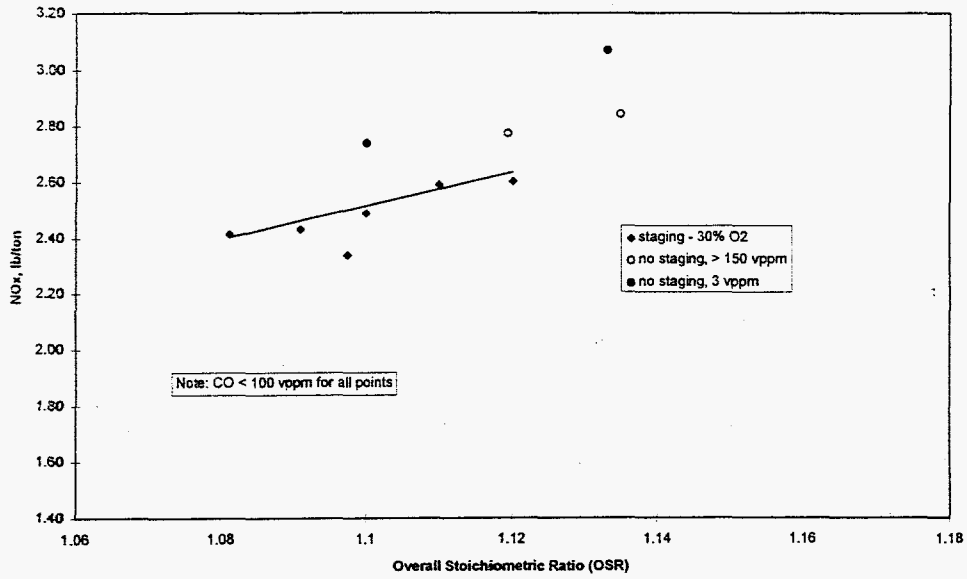

Figure 5. NO_X EMISSIONS AT HIGH BOOST DURING LONG-TERM TESTING - LEFT SIDE FIRING

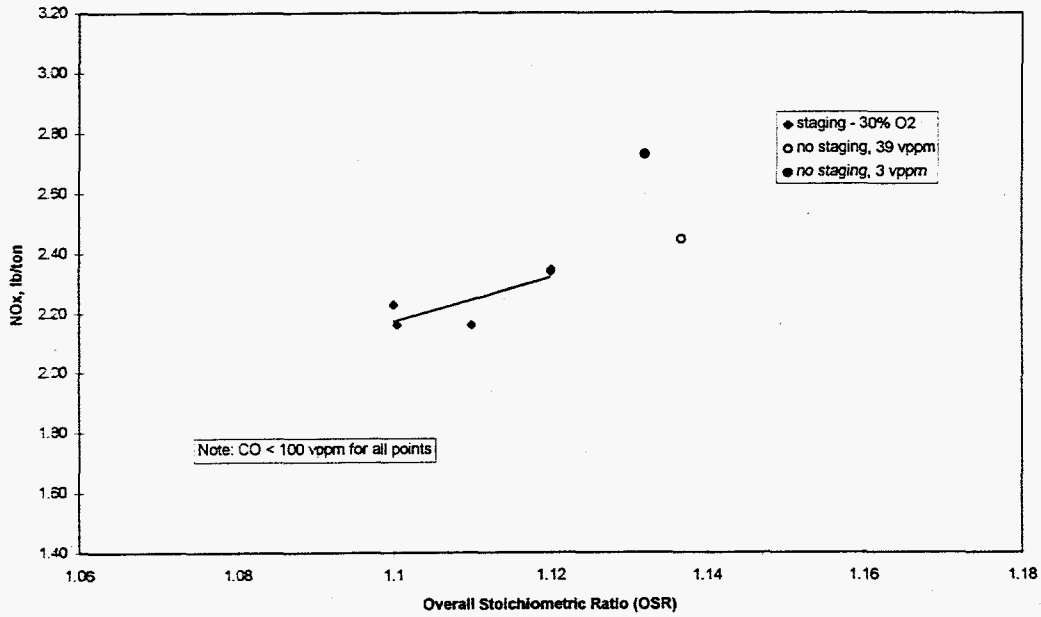

Figure 6. NO_X EMISSIONS AT HIGH BOOST DURING LONG-TERM TESTING - RIGHT SIDE FIRING

Full Furnace Testing at Low Boost

The project team was interested in determining the capability of the OEAS system for reducing NO_x at different levels of electric boost on a furnace. Electric boost is important to the glass making process as a means of supplying heat below the melt line, maintaining glass flow patterns, and controlling the glass quality. Electric boost can also be used to reduce NO_x emissions. Electricity typically costs $12 to $20/MM Btu compared with less than $3/MM Btu. For economical reasons, a furnace operator would like to operate with the lowest acceptable level of electric boost where the exhaust is in compliance with environmental regulations. The reduction in NO_x emissions provided by operating OEAS on a furnace provides the operator this opportunity to reduce the level of electric boost.

The savings from lowering the electric boost depend strongly on the costs of natural gas, oxygen, and electricity to the plant. Generally, electricity is much more expensive on a unit of energy basis than natural gas. Typically, the cost of oxygen and increased natural gas incurred when OEAS is employed and boost is reduced are more than offset by the savings in electricity cost. Table 1 shows the cost advantage for a representative 300 ton/day glass melter using typical 1996 costs for fuel, oxygen, and electricity.

Table 1. ECONOMICS OF LOWERING ELECTRIC BOOST WITH OEAS OPERATION ON A TYPICAL REGENERATIVE SIDEPORT GLASS FURNACE

Glass Pull Rate, ton/day	300
Gas Cost, $/MM Btu	2.50
Oxygen Cost, $/MM Btu	2.00
Electricity Cost, $/kWh	0.07
Changes With OEAS Operating	
Natural Gas, $/ton	1.00
Oxygen, $/ton	0.80
Electricity, $/ton	- 2.80
Savings With OEAS Operating, $/ton	1.00

The calculation in Table 1 estimates OEAS will not only reduce furnace NO_x but will reduce the operating cost of production by $1/ton. The savings would vary widely depending on the cost of fuel, oxygen, and electricity and on the amount of boost that could be reduced while still being in compliance with NO_x regulations.

Owens Brockway performed forehearth work on the C furnace in late November and early December. During this time, the pull rate was cut in half (to 150 ton/day) and

the natural gas rate and electric boost were reduced. A test campaign was conducted in December in which the furnace was brought back to full pull rate with reduced electric boost reduced by approximately one third. Under these conditions, the gas firing rate was increased by approximately ten percent to provide the necessary heat for the furnace. Variables evaluated at low boost included primary stoichiometric ratio (PSR), overall stoichiometric ratio (OSR), natural gas level, and staging oxygen concentration (21 to 50%).

Preliminary results are presented in Figures 7 and 8 for left side firing and right side firing. An average NO_x reduction of 30 percent was achieved. With no staging, the average level of NO_x was 3.4 lb/ton, and this emission level decreased to 2.4 lb/ton when OEAS was employed. The level of NO_x reduction was essentially the same for low boost operation as was achieved with high boost operation. The level of NO_x production was higher with low because more fuel was burned and the temperature above the glass was higher.

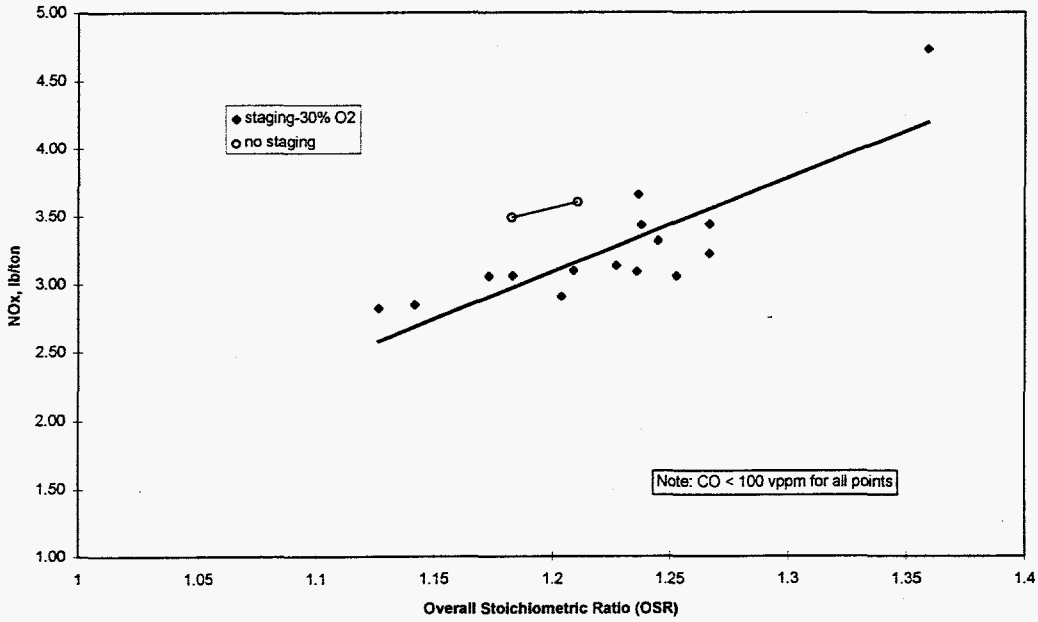

Figure 7. NO_X EMISSIONS AT LOW BOOST - LEFT SIDE FIRING

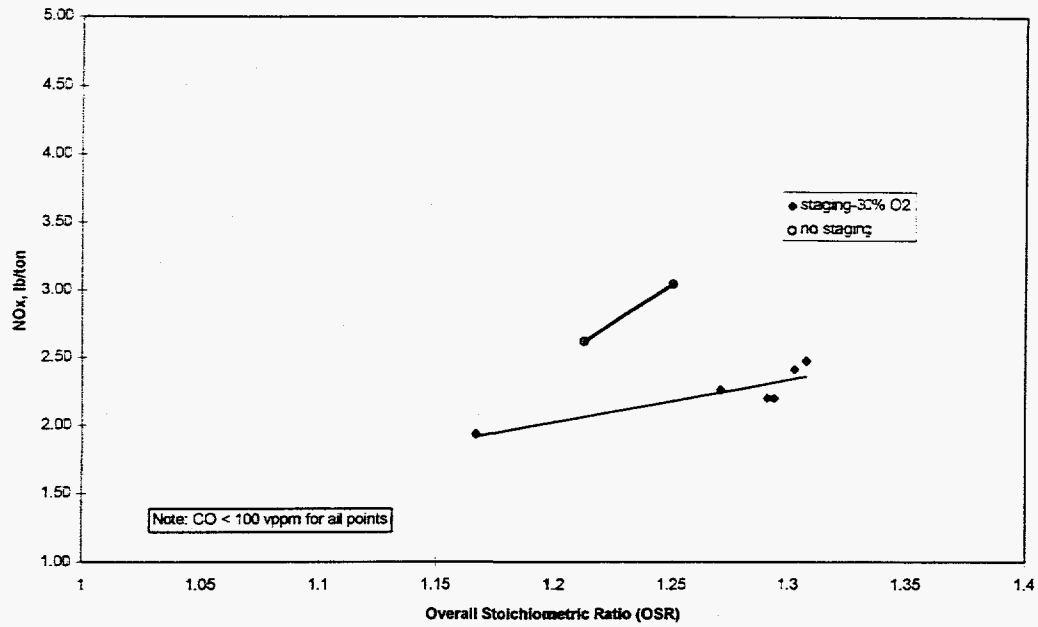

Figure 8. NO_X EMISSIONS AT LOW BOOST - RIGHT SIDE FIRING

Installation of PLC Control System For OEAS

During this quarter, the project team purchased an Allen Bradley Programmable Logic Controller (PLC) control system to facilitate routine operation of the OEAS system on the host sideport furnace. The PLC system is equipped with a touch screen monitor to allow process control. CTI engineers redesigned the OEAS control and alarm circuits and laid out the screen delays for the PLC. Information on the OEAS system and the furnace combustion system is sent to the PLC system and used to determine OEAS control parameters. The PLC alarm system is designed to be interfaced directly with the furnace alarm system.

The PLC system is economical. The decision to add this type of controller to the OEAS system was reached because it will provide furnace operators with a simple and flexible means of OEAS control. CTI intends to include PLC control in all commercial sales of OEAS technology for sideport furnaces.

PLC system programming was completed this quarter, and the system was prepared for shipment to Vernon, California. Work began on updating the OEAS system operation manual to include the PLC system. Plans were made to provide furnace operators with instruction on the PLC system. CTI believes the PLC will allow assembly of a more commercially attractive OEAS package for sideport furnaces while providing a more robust OEAS control method that is more transparent to the operators.

Problems Encountered

There have been no changes in the scope of work or implementation of this project. Several delays at the host site have slowed the project, but these delays have not been a significant problem. The project team expects to complete all contracted work in a timely manner. The objectives of this project remain to demonstrate the OEAS on a commercial sideport container glass furnace and to leave a working OEAS system in place on the furnace to provide reduced NO_x emissions.

Future Work

The next quarter is the final quarter of this project. Work to be completed before the end of next quarter is described below.

The PLC control system will be shipped to the Vernon site and then installed by CTI personnel. All electrical and instrumentation interfaces including alarms will be connected and calibrated. OEAS operation will then be initiated, and IGT personnel will join CTI in operation and final adjustment of the OEAS system with the PLC control system.

The OEAS system operation manual will be modified to include the PLC control system. This operation manual will be used to conduct plant training on OEAS system operation and maintenance. The PLC system will be installed and tested with OEAS operating. This OEAS system testing will be conducted at furnace operating conditions determined to provide low NO_x and good CO burnout. Software in the PLC was written to allow operation of the left and right side firing of the furnace with different overall stoichiometric ratios. This will allow the project team to achieve lower NO_x levels from the furnace. The OEAS system will be left operating at conditions within the operating range of the OEAS skids and injectors while using an acceptable level of plant-supplied oxygen

At the end of the project, a business plan will be developed for moving the OEAS sideport furnace technology to commercial sales. This plan will be modeled after a plan devised, and now being implemented, for OEAS application to endport furnaces. A Final Technical Report will be prepared describing all aspects of this demonstration project, discussing all testing results, including the modeling results, describing the OEAS and PLC systems, and presenting the business plan for sideport container glass furnaces.

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