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

Quarterly Technical Progress Report for the Period
August 1, 1996 - October 31, 1996

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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 the full furnace testing with reduced electric boost, installation and testing of the PLC control system for OEAS, finalization of the business plan for commercialization, and preparation of the final report. This report focuses on full furnace parametric and long-term testing. Details of the modeling calculation methodology and results, baseline furnace testing, single port pair implementation, and single port pair results have been presented in earlier quarterly and annual reports.

Full furnace parametric testing with OEAS and long-term OEAS testing were conducted this quarter. In this quarter, two test campaigns were conducted. In one test series, parameters including the primary stoichiometric ratio (PSR), overall stoichiometric ratio (OSR), staging oxidant oxygen concentration, staging balance between the ports, and different OEAS operation on the two sides of the furnace were evaluated. All secondary oxidant was introduced by two hole underport injection, the location determined from single port pair testing to provide the greatest OEAS benefits. The second test series was long-term testing at constant operating conditions to verify smooth long-term operation and repeatable results.

Full furnace OEAS parametric testing was conducted during the period Sept. 23 - 28. During this test period, the furnace was operated with high electric boost and a very low NO_x emission level below 3 lb/ton. Baseline data was taken during which the combustion stoichiometric ratio was found to be 1.12. Tests were then conducted in which the stoichiometric ratio was decreased to 1.01 and no staging was employed. The NO_x emission levels dropped approximately 35% to 1.7 lb/ton while CO emissions rose almost exponentially.

A low combustion stoichiometric ratio (primary stoichiometric ratio or PSR) of 1.02 was selected as a base condition for conducting OEAS tests. a secondary oxidant oxygen concentration of 35% was selected, and tests were conducted to determine the needed overall stoichiometric ratio (OSR). An OSR of 1.08 to 1.10 was sufficient to burn out the CO produced in the primary flame. The NO_x emissions were decreased more than 30% to an average furnace value of 1.8 lb/ton. The low initial value for NO_x kept the decrease low, but even so, the NO_x level with OEAS operating is extremely low. Testing showed the two sides of the furnace were not identical.

Long-term, full furnace OEAS testing was conducted during the period Oct. 22 - 27. During this test period, the furnace was operated with high electric boost and a very low NO_x emission level of approximately 3 lb/ton. Tests were conducted in which the primary stoichiometric ratio was decreased to 1.02 and staging was employed at an OSR (overall stoichiometric ratio) of 1.10. The OEAS was operated continuously and monitored for 48 hours. OEAS was left operating after this test period. The NO_x emission levels dropped approximately 35% to 2.3 lb/ton while CO emissions remained low.

The OEAS system operating manual was completed this month, and Owens Brockway staff were trained in system operation. 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 project team has completed all modeling work, OEAS system design and installation, single port pair testing, and full furnace testing under parametric and long-term conditions. Work next quarter will include full furnace testing with reduced electric boost. A PLC control system for permanent OEAS operation has been called for by the project team, and this system will be specified, purchased, and programmed next quarter. The project team will install the PLC control system and determine preferred furnace primary fining conditions and OEAS system operating conditions. Other work will include preparing the business plan for OEAS on sideport furnaces, update of the OEAS operating manual, and preparation of the project final report.

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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.

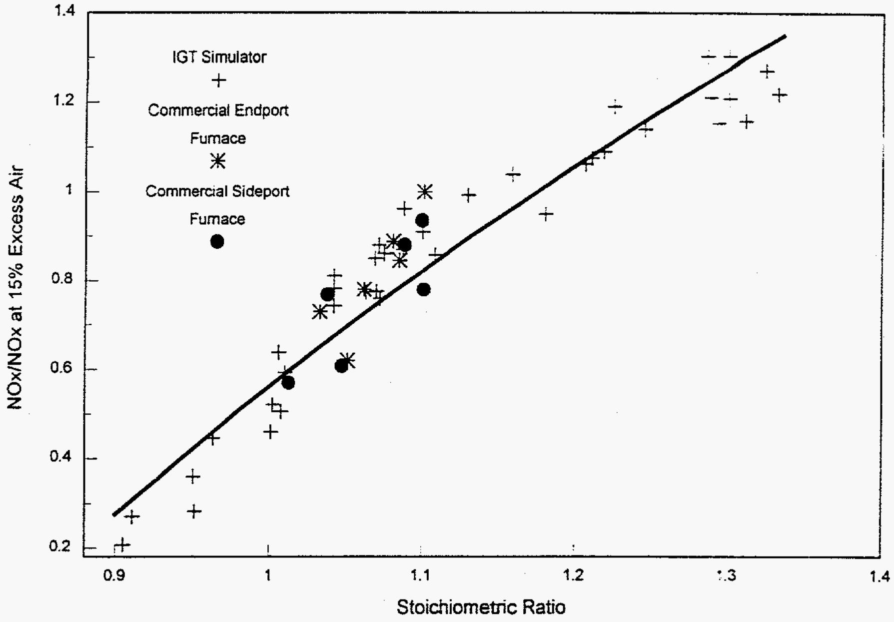

Figure 1. Effect of First-Stage Stoichiometric Ratio on NO_x Production

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.

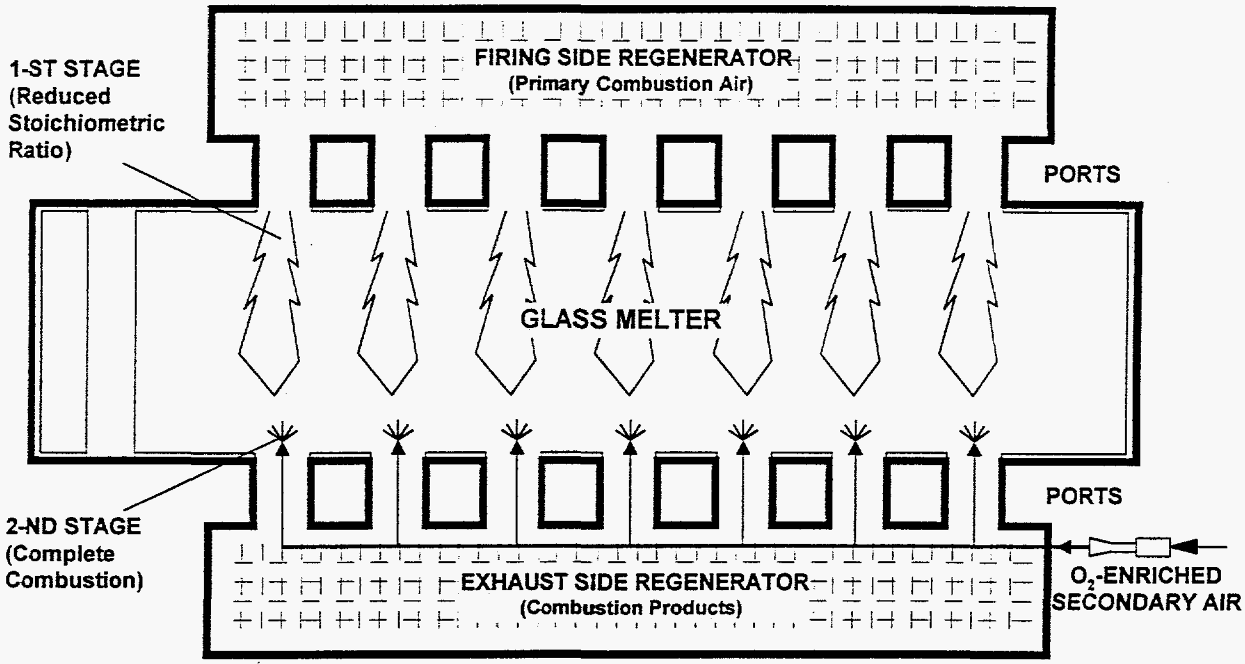

Figure 2. Oxygen-Enriched Air Staging Concept For A Sideport Furnace

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, and part of the OEAS system fabrication have been presented in earlier annual and quarterly reports.[4,5] Full furnace parametric testing and full furnace long-term testing are described in this report along with a preliminary discussion of the testing results. Final OEAS system testing and the business plan will be described in the next quarterly report and the project Final Technical Report.

Two technical papers were written this quarter describing OEAS development for sideport regenerative furnaces. The first paper[6] was prepared for the 57th Conference on Glass Problems, and a formal presentation was made at the conference in October. The second paper contained much of the same material and also included a review of OEAS development and application to endport regenerative furnaces.[7] This second paper was prepared for the 20th World Gas Conference to be held in Copenhagen, Denmark in June, 1997.

Preparations For Full Furnace Testing

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.

Fabrication of injectors and other equipment was completed by CTI in August. Equipment was sent to the test site the same month. Holes for underport injection and complete OEAS set-up were completed during the first two weeks of September. The oxygen and blower air skids installed earlier in the project were sized for full furnace OEAS operation so no hardware modifications were required on them. Set-up in September did include piping and metering to the injectors on each of the twelve furnace ports. Full furnace parametric OEAS testing was conducted during the second half of September. OEAS long-term testing was conducted in October.

Full Furnace Parametric Testing

During the first two weeks of September, the full furnace OEAS installation was completed. This work consisted of drilling two holes under each port, installation of injectors in each hole, running piping to all the ports, connecting the piping and injectors with downcomers, and attached flow adjustment valves to each port. The holes were drilled by Ed Blin and the retrofit work was conducted by Combustion Tec, Inc. with assistance from Lilja personnel.

IGT personnel set up measurement instrumentation on Sept. 18 - 20, and full furnace OEAS parametric testing was conducted during the period Sept. 23 - 28. During this test period, the furnace was operated with high electric boost and a very low NO_x emission level below 3 lb/ton. Baseline data was taken during which the combustion stoichiometric ratio was found to be 1.12. Tests were then conducted in which the stoichiometric ratio was decreased to 1.01 and no staging was employed. The NO_x emission levels dropped approximately 35% to 1.7 lb/ton while CO emissions rose almost exponentially.

Figure 3 illustrates the effects of lowering the combustion air to fuel ratio (the overall stoichiometric ratio) on emissions. This baseline data with no oxygen-enriched air staging operating on the furnace clearly shows that NO_x decreases essentially linearly with decreasing combustion air to fuel ratio while CO levels rise exponentially at overall stoichiometric ratios below 1.12.

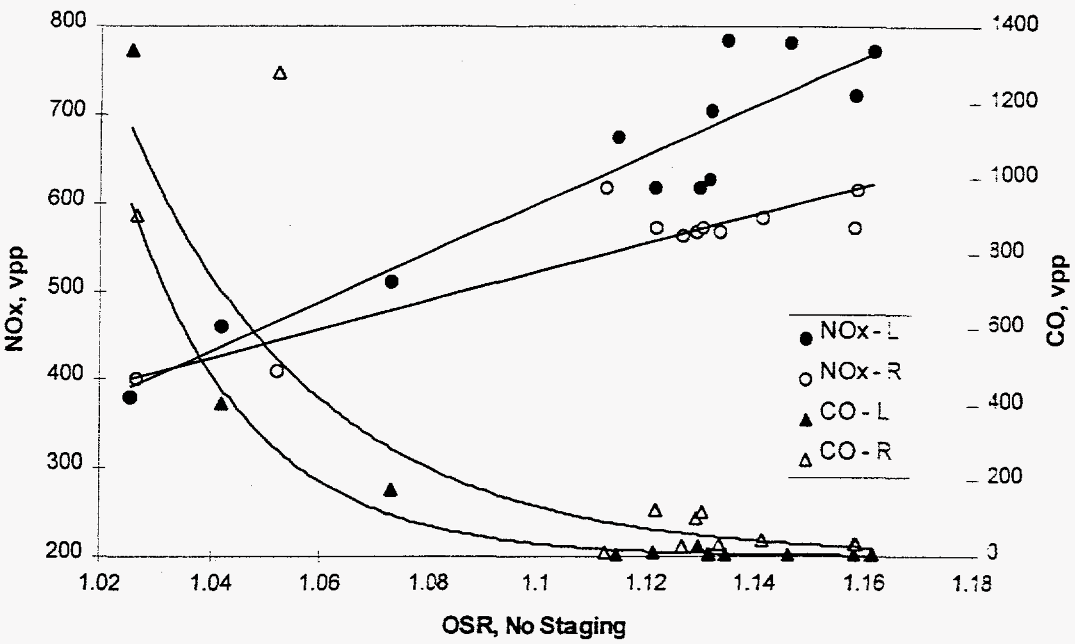

Figure 3. THE EFFECT OF OVERALL STOICHIOMETRIC RATIO (OSR) ON NO_x AND CO EMISSIONS WITH NO STAGING

Data on NO_x emissions collected from the stack during parametric testing is shown for left and right side firing in Figures 4 and 5. The behavior of the furnace is similar from the two firing sides, but not identical. The left side of the furnace tended to have somewhat higher NO_x and lower CO at baseline conditions and when OEAS was operating. The furnace air to fuel ratio was set to be the same when firing from both sides, but a number of factors could influence the air to fuel ratio on the overall furnace and at individual ports. Therefore, the project team was not surprised to find differences in emissions between the two sides of the furnace. Placing an automatic controller on the combustion system so the air to fuel ratio could be set differently for left and right side firing would allow the average NO_x emissions from the furnace to be lowered.

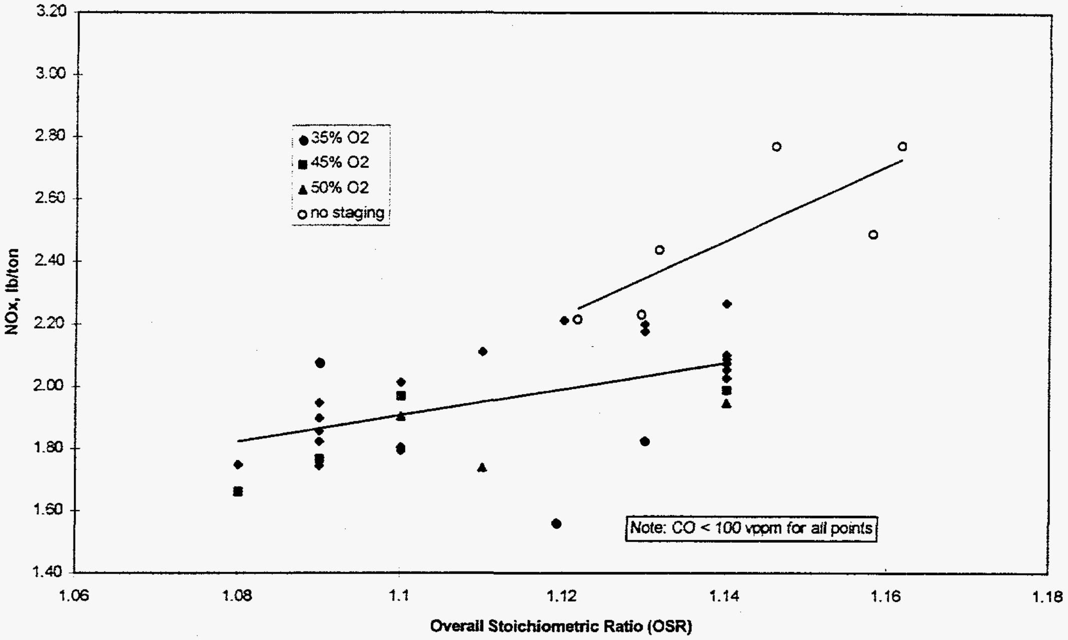

Figure 4. NO_X EMISSIONS AT HIGH BOOST DURING PARAMETRIC TESTING - LEFT SIDE FIRING

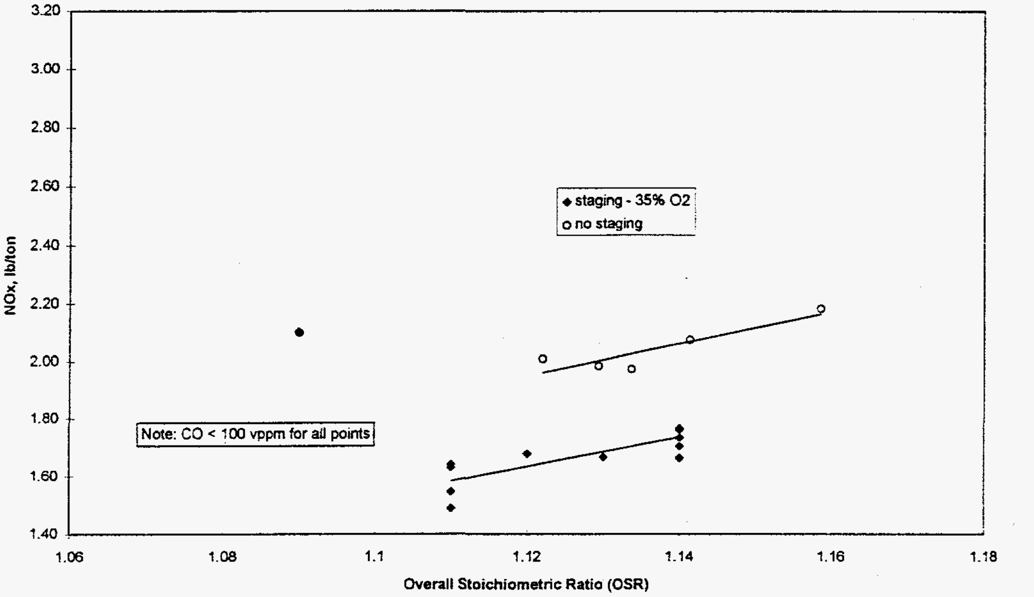

Figure 5. NO_X EMISSIONS AT HIGH BOOST DURING PARAMETRIC TESTING - RIGHT SIDE FIRING

Analysis of the data in Figure 3 in conjunction with a desire to keep an overall oxidizing primary flame Stoichiometry led to the selection of a PSR value of 1.02 for OEAS demonstration. Staging was then applied to all ports using enriched air containing 35% O_2 to raise the overall stoichiometric ratio to various levels. The results of this testing are presented in Figure 6. Firing the furnace from the left and right side produces different NO_x values at the same stoichiometric ratio, but the trend is the same for both. With the PSR kept at 1.02, OEAS effectively reduced the NO_x emissions at the stack by more than 30% to an average value of 450 to 500 vppm. This corresponds to a NO_x production level of 1.8 lb/ton of glass. OSR values of 1.08 to 1.10 were effective at burning out CO produced in the primary flames. Stack CO values were similar to the baseline case with high PSR and no staging.

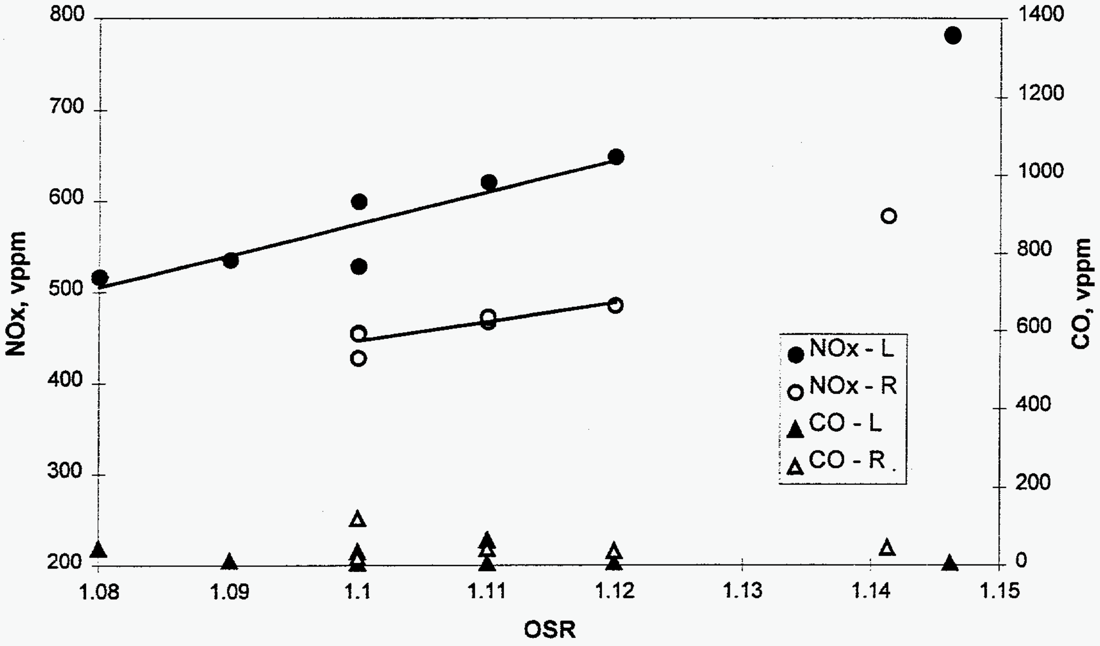

Figure 6. THE EFFECT OF ENRICHED AIR STAGING ON NO_X AND CO EMISSIONS

Testing was also conducted to determine the effect of increasing the concentration of oxygen in the staging oxidant. At a PSR of 1.02 and an OSR of 1.10, the oxygen concentration was varied between 35 and 50%. Results are shown in Figure 7. A small decrease in NO_x of approximately 6% was realized by increasing the oxygen concentration from 35 to 50%. While the result is desirable, there are concerns about possible temperature increases using more highly enriched oxidant and about the higher cost of more enriched oxidant.

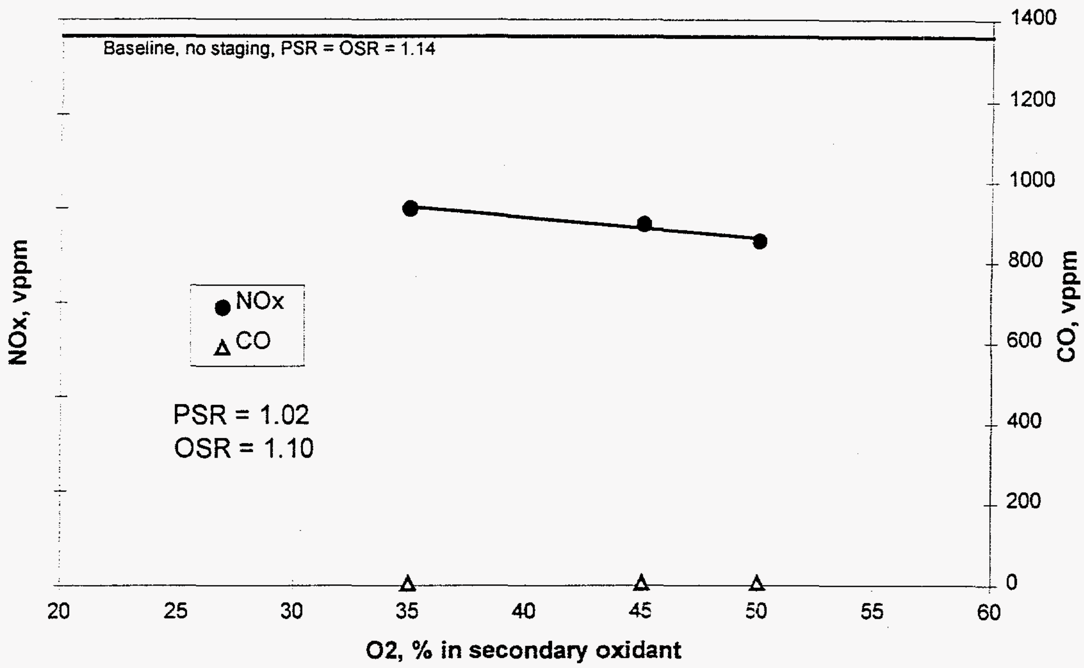

Figure 7. THE EFFECT OF OEAS OXYGEN CONCENTRATION ON NO_X AND CO EMISSIONS

A long series of tests was conducted to balance the staging oxidant to the various ports. Proper balancing allows use of the lowest possible amount of staging oxidant because the OSR is the lowest possible value. Also, NO_x emissions decrease with secondary oxidant levels because a small amount of NO_x is generated by the secondary oxidant. The port balancing indicated the OEAS system is robust and not sensitive to small changes in the amount of secondary oxidant sent to each port. This suggests that long term furnace operation will not require frequent adjustment of the OEAS system.

Full Furnace Long-Term Testing

The project team and Owens Brockway personnel were pleased with the full furnace parametric testing results. Before leaving OEAS operating unattended for extended periods of time, the project team conducted a long-term, monitored test. Primary combustion characteristics and OEAS parameters were set and then not changed for a six day period.

IGT personnel set up measurement instrumentation on Oct. 21, CTI checked the OEAS system at the same time, and long-term, full furnace OEAS testing was conducted during the period Oct. 22 - 27. During this test period, the furnace was operated with high electric boost and a very low NO_x emission level of approximately 3 lb/ton. Tests were conducted in which the stoichiometric ratio was decreased to 1.02 and staging was employed at an OSR of 1.10. The OEAS was operated continuously and monitored for 48 hours. OEAS was left operating after this test period. The NO_x emission levels dropped approximately 35% to 2.3 lb/ton while CO emissions remained low.

A low combustion stoichiometric ratio (primary stoichiometric ratio or PSR) of 1.02 was selected as the base, long-term primary flame stoichiometric condition with OEAS operating. A secondary oxidant oxygen concentration of 30% was selected, and furnace stack emissions were monitored. Furnace natural gas and primary combustion air are set manually on this furnace. For that reason, the combustion air flow and the PSR vary over a daily cycle, with the lowest PSR and lowest NO_x are found during the warmest part of the day. The selected flame and OEAS conditions selected provided the lowest possible average NO_x while maintaining low CO emissions.

Long-term test data from left side firing and right side firing is presented in Figures 8 and 9. As observed during the parametric testing in September, the two firing sides produce different levels of emissions with the left side firing generating higher NO_x and lower CO in the stack at the same primary and overall stoichiometric ratios.

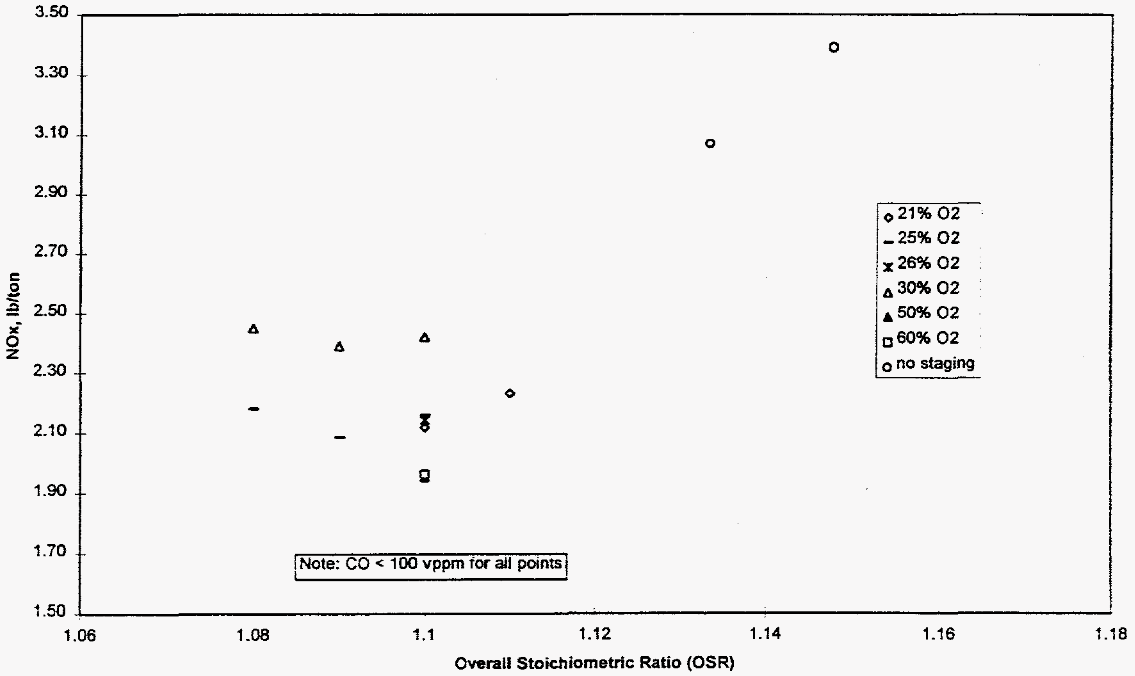

Figure 8. NO_X EMISSIONS AT HIGH BOOST DURING LONG-TERM TESTING - LEFT SIDE FIRING

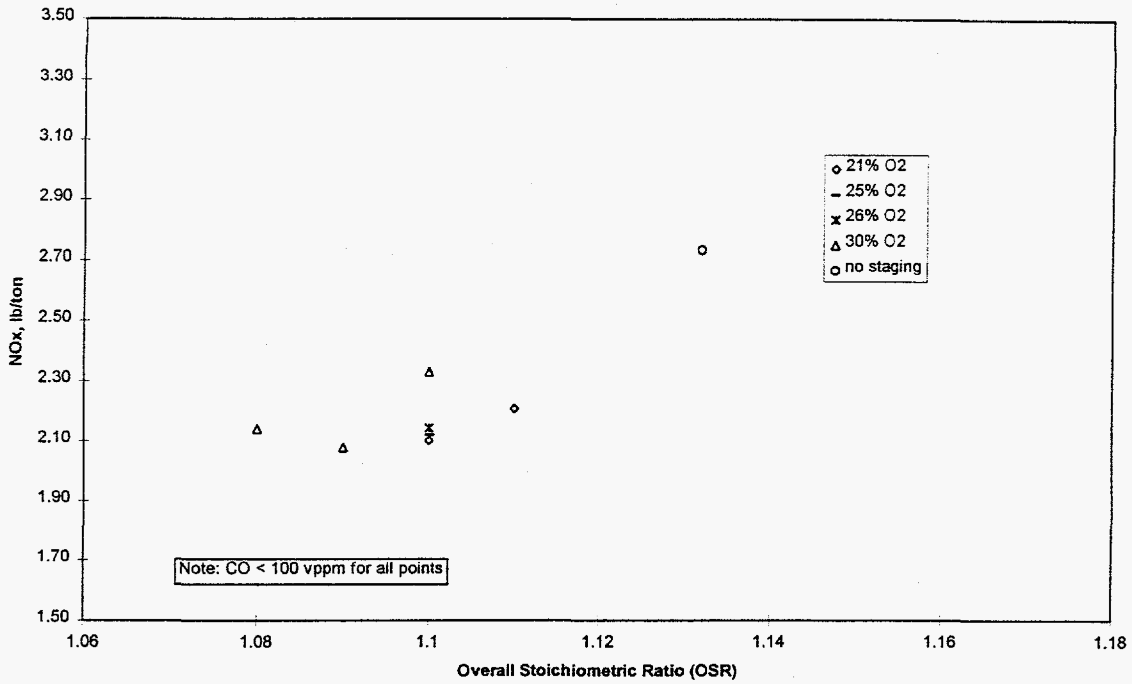

Figure 9. NO_X EMISSIONS AT HIGH BOOST DURING LONG-TERM TESTING - RIGHT SIDE FIRING

The oxygen concentration in the staging oxidant was varied between 21 percent (air) and 60 percent during long-term testing. Data from these tests is also shown in Figures 8 and 9. Parametric testing indicated a slight decrease in NO_x emissions with increasing oxygen concentration. Changing oxygen concentration during long-term testing had no clear effect on NO_x emissions. Oxygen concentrations between 21 and 60 percent were concluded to have only a small effect on NO_x emissions from this furnace.

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 project team has now completed modeling of the OEAS process, installation of OEAS on the full furnace, single port pair testing at different staging locations, full furnace parametric testing, and full furnace long-term testing. The OEAS technology has proven successful at reducing NO_x emissions from this regenerative sideport furnace. A number of tasks remain to be completed before the end of this demonstration program. These remaining tasks consist of additional full furnace testing under low electric boost conditions, updating the furnace control system, developing the OEAS business plan for sideport furnaces, and preparing the final reports.

The specific work to be completed includes:

- Integrate the OEAS system with plant alarms and safety controls
- Specify, order, program, and install the OEAS control system
- Update the OEAS manual to include safety controls and control system
- Measure stack emissions during long-term testing and compared with third-party stack emissions measurements
- Test OEAS system adaptability by removing electric boost and maintaining low NO_x emissions
- Reduce OEAS field test data
- Test the OEAS system with the selected control system operating and all alarms and safety systems properly interfaced
- Extend OEAS endport furnace commercialization plan to include sideport regenerative furnaces for container glass
- Prepare project Final Technical Report

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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