Maintaining Full Production in Furnaces with Failing Regenerators Using Oxy-fuel Combustion

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Abstract

It is well known that the progressive failure of regenerator checker packs that frequently occurs in aging glass furnaces causes a gradual restriction of combustion air and flue gas flow passages. This fouling process, if left unabated, can ultimately lead to a significant reduction in pull rate while also lowering energy efficiency during glass melting. Moreover, even when compartmentalized checkers are employed and hot repairs can be carried out, these are very time consuming and labor intensive processes that may require extended furnace downtime or, at best, extended periods of reduced pull, sometimes up to several weeks or more. Recognizing the need that thereby emerges for a substantial amount of high-temperature and on-the-fly fire-power, often on an emergency basis, Air Products has developed the Cleanfire® ThruPort™ oxy-fuel burner to debottleneck production for furnaces that are constrained by crippled regenerators. To illustrate their use and effectiveness, this paper presents and describes two recently-executed projects using the ThruPort burner on regenerative air-fired float glass furnaces. One furnace, equipped with compartmentalized checkers, used three ThruPort burners during a one-month period over which checker repairs were made. The second furnace, which did not employ compartmentalized checkers, used two ThruPort burners to maintain full production for the final seven months of the furnace campaign. Details presented herein include burner design, installation and operation, oxygen supply and melter performance.

Introduction

As improvements are made regarding refractory, maintenance and operation of glass furnaces, the expected campaign length has increased and in some cases nearly doubled in the last 20 to 25 years. As the life of the melter has improved, the regenerators and checker packs that used to operate for as many as two campaigns now struggle to last one. This is especially true in the float glass industry, where campaigns are approaching 18 to 20 years. This paper describes the experience of two float glass furnaces at different points in their furnace campaigns, both having similar issues with premature failure of the checker packs inside the regenerators.

One solution is to use oxy-fuel combustion to supplement air-fuel combustion over all or part of the furnace. This paper summarizes the field installation, start-up and operation of an oxygen supplemented combustion system. Safety considerations were carried out through training of plant personnel on oxygen safety.

Potential solutions involve combinations of several air-fuel and oxy-fuel options:

- Oxygen enrichment of the combustion air
  - Usually not more than 26%
- Oxy-boost burners
  - Limited by their location in the furnace
- Oxygen lancing
  - Limited by the amount of air available and the achievable mixing rate in the port and furnace
- Cleanfire ThruPort oxy-fuel burners
  - Considered the best solution short of a full conversion to oxy-fuel
  - No combustion air required

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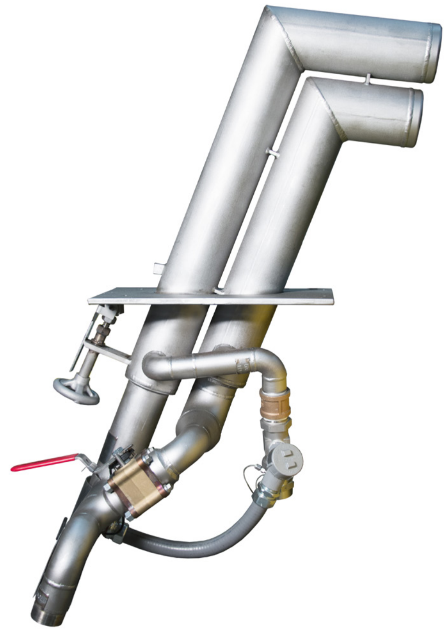
The features of the ThruPort burner (Figure 1) include:

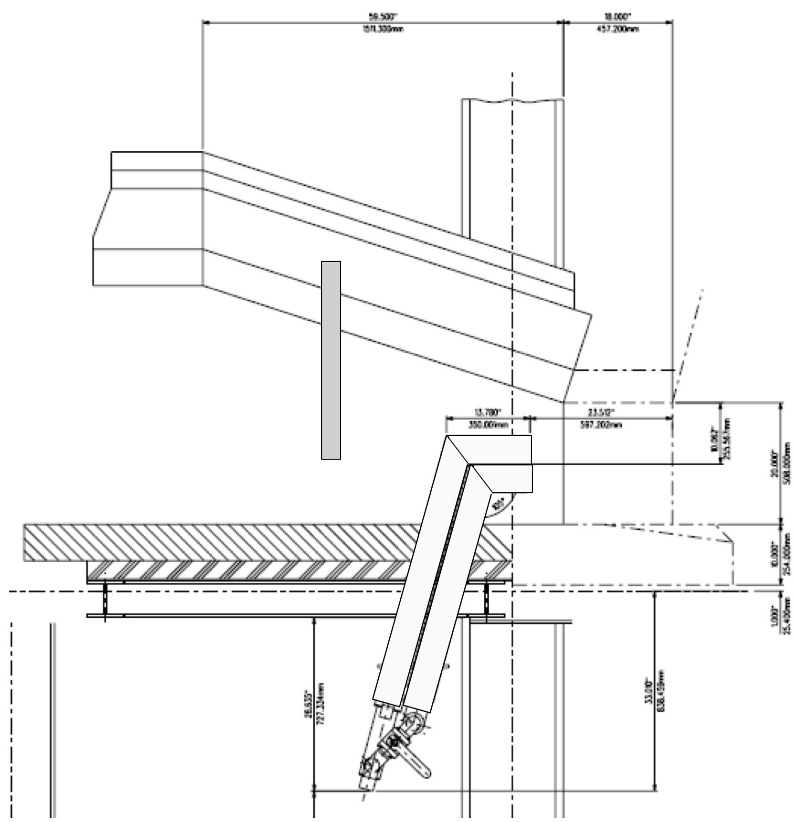
- Firing rate: 4 to 20 MMBTU/hr
- Fuel: natural gas or oil
- Water-cooled jacket
- Oxygen staging
- Bright and luminous flame
- Adjustable flame length and trajectory
- Optional on-line sensors
- Rapid deployment

Figure 1: ThruPort Burner



The ThruPort burner allows for on-the-fly installation through the bottom of the port. This burner allows production to continue without interruption during the installation and is ideal for use during hot checker repairs or to extend the life of the furnace when combustion air is severely restricted. Figure 2 shows a side view of a typical installation of the burner in a port.

Figure 2: ThruPort Burner in Port



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This burner has oxygen staging, which diverts oxygen from the main burner through a second port directly below the flame. The staging of oxygen creates a soot-rich reducing flame, which increases luminosity, lowers the peak flame temperature, and directs the heat flux into the glass. By adjusting the amount of staging, you can tailor the flame shape and length. The reduced maximum flame temperature decreases the production of NOx, while the top soot layer of the flame reflects heat away from the crown and into the glass. The burner can be adjusted up or down in proximity to the glass surface. Figures 3 and 4 highlight the use of staging and the effect of the tilt adjustment.

Figure 3: Oxygen Staging

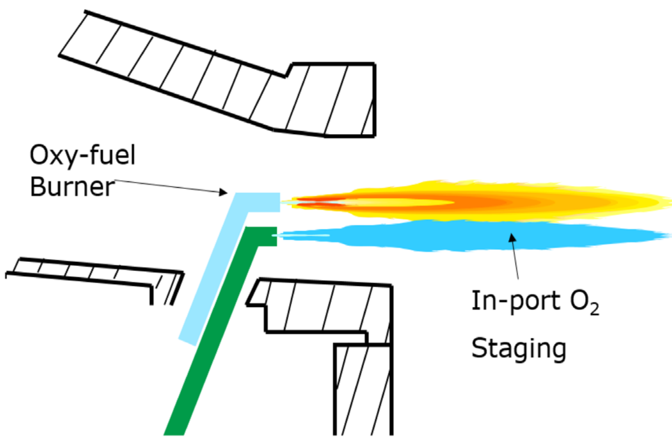
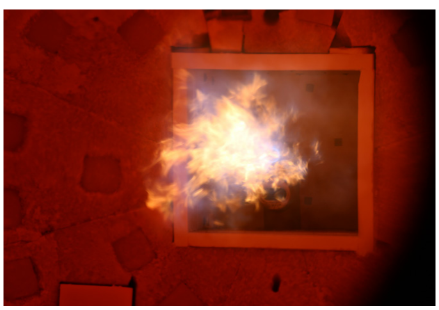


Figure 4: Effect of Staging and Tilt Angle



0 degree tilt, 0 staging

0 degree tilt, full staging

5 degree tilt, full staging

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Field Installations
Two Plants with Similar Challenges

Plant #1

Background

The first float glass plant was aware of the deterioration of the checker pack for about a year. The furnace is a six-port gas-fired regenerative melter with one common regenerator chamber on each side of the furnace. This furnace was near the end of its campaign and had less than one year left until its scheduled rebuild date. The initial conditions reported by the plant indicated that the checker pack on the right side of the furnace had collapsed and the lancing system installed on the first four ports was no longer capable of supplementing the combustion air adequately to allow sufficient combustion to support the desired pull on the furnace. The furnace pull rate had been reduced by 50 t/d in order to produce glass of acceptable quality. In addition, three by-pass flues were installed on the right regenerator to allow combustion air to reach the top of the regenerator. The checker pack on the left side of the furnace had not deteriorated to the point where it had impacted combustion. The furnace had been using four oxy-fuel boost burners for several years, one pair between the charge end wall and the #1 port and a second pair located at what would be considered the #7 port. The lancing system had been installed and operating for two months on the first four ports. With lancing, the furnace pull rate, temperatures and emissions were maintained until further deterioration of the checkers made it impossible to keep temperatures and production at desired levels. At this point the decision was made to install ThruPort burners to keep the furnace running and extend its life until the planned rebuild.

Discussion

The two ThruPort burners would be installed, one on each side of the furnace at the #4 port. The objective was to install these burners and determine if furnace conditions could be stabilized and then see if additional pull could be added.

The following were identified as key resources that would be utilized to support this project.

- Sources of Oxygen
  - On-site VSA oxygen generator
  - On-site liquid oxygen (LOX) storage tank
  - Truck delivery of LOX from local merchant gas production plant

- Vaporizer capacity
  - Existing vaporizers (four) would not be sufficient

- Control Distribution Skids
  - Two oxy-fuel skids
  - One oxygen skid

- Three ThruPort oxy-fuel burners with lift mechanism

- Cooling water supply and return lines

- Oxy-fuel boost burners between the charge end wall (CEW) and #1 port, and in the #7 port position
  - Maximize the heat input from these burners

- Safety training on oxygen for plant personnel and operational training on the ThruPort burner for furnace personnel

- Computational fluid dynamics (CFD) modeling

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It was determined that due to the volume of oxygen required, APEX Express Service units would be used to provide additional on-site oxygen storage and vaporizing capacity. These units consisted of four portable trailers, two for LOX storage and two with dual vaporizer banks. Figure 5 below is a picture of the APEX units.

Figure 5: Typical APEX Units

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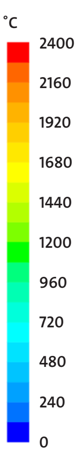
CFD Modeling

To verify the fuel and energy savings seen at Plant #1, a CFD modeling study was conducted. The results of that model are summarized in Table 1. The baseline case was conducted at full pull rate prior to oxygen lancing, with regenerators operating as expected and two of the four boost burners. The fouled regenerator case was at a reduced pull rate, no lancing and four boost burners. The last case is the furnace operating at full pull rate, two ThruPort burners, lancing on three ports and two boost burners. The energy savings produced with the installation of two ThruPort burners and three ports of oxygen lancing show a 9.8% reduction, similar to what was seen in the field and similar to the fuel savings observed at other installations. Figure 6 shows the combustion space temperature profile predicted by the CFD model, with zero port boost burners and normal air fuel firing on all six ports on the left. On the right is the temperature profile predicted with ThruPort burners in the #4 port and zero port boost burners.

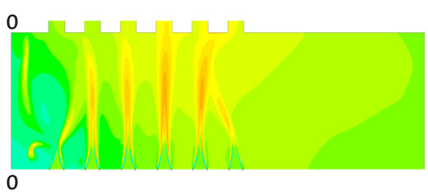
Table 1: Modeling Results

	Units	Baseline	Fouled Regenerators	ThruPort
Pull Rate	TPD	650	600	650
Fuel Firing Rate	mmBTU/hr	163.0	149.9	147.1
Air Flow Rate	scfh	1,681,100	1,512,990	985,000
Air Preheat	Deg C	1250	1000	1000
Glass Temp	Deg C	1296	1270	1286
Flue Gas Temp	Deg C	1501	1476	1321
Energy Consumption	mmBTU/ton	6.02	6.48	5.43

Figure 6: CFD Combustion Space Temperature Profiles

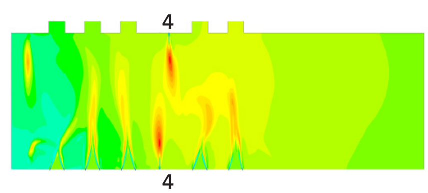


Baseline Case



CFD-predicted combustion space temperature profile for baseline air-fuel operation with zero-port boost burners

ThruPort Case



CFD-predicted combustion space temperature profile with ThruPort$_{e}$ burners in ports 4

Computational Fluid Dynamics (CFD) Modeling demonstrates that adding the two burners generates high temperature flames directly above the hot spot of the glass melting tank, which is ideal for reinforcing critical glass recirculation flow patterns and increasing glass residence time in the melter.

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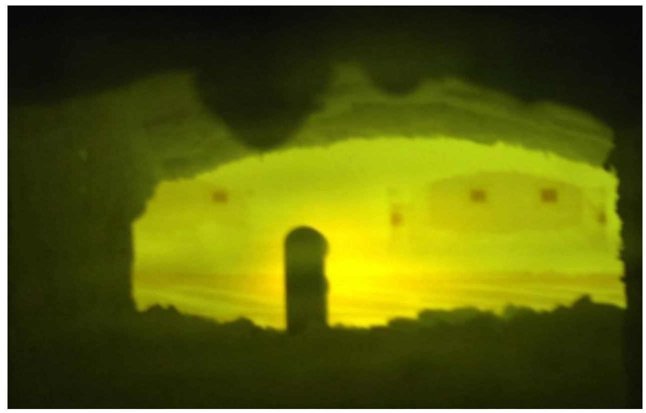
Preparations prior to the installation of the ThruPort burners included port modifications, such as cutting a hole in the port bottom grating and saw cutting a similar hole in the port bottom refractory. The cooling water supply and return lines, and the oxygen and natural gas tie-in points were identified, and appropriate flex hoses and fittings obtained. The logistics of the lift mechanism and how it would be positioned between and under the port was determined. Finally, training was conducted with regard to oxygen safety, as well as installation and operation of the ThruPort burner. Figure 7 is a picture of a mock installation conducted in one of Air Products' combustion laboratory furnaces. Figure 8 is a picture showing the burner installed in the #4 port prior to the back of the port being blocked off.

Figure 7: ThruPort Mock Installation

Figure 8: ThruPort Burner Installed



Once all three combustion systems were operating, adjustments were made to the fuel, oxygen and air flows to optimize furnace operation. The first adjustments increased firing on the air fuel ports and supplemental oxygen lancing as needed. The boost burners and oxy-fuel ThruPort burners were then adjusted. Each adjustment would be made after reviewing excess oxygen levels, temperatures, glass quality and emission levels on the furnace. Since the energy input into the furnace was being supplied by three distinct and different combustion systems, it was understood that it would take some time to optimize the firing rates of each system.

Results

- Two ThruPort burners installed in the #4 port left and right
- Temperature profile on the furnace was re-established
- Pull increased to target level of 650 t/d
- NOx emissions below permit operating limits
- Glass quality back to normal levels
- Furnace life extended seven months to match planned rebuild date
- Close agreement between CFD modeling and results achieved—9.8% vs 9.7%

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Plant #2

Background

Similar to Plant #1, this float glass plant also had failing checkers. The plant had been aware of the deterioration of the checker pack in both regenerators for about a year. The furnace is a six-port gas- fired regenerative melter. The furnace has compartmentalized checkers and was in the eighth year of an expected 16-year campaign. The checkers in the fifth port had collapsed and were plugged to the point where it became necessary to partially remove the division wall between the fifth and sixth ports to allow combustion air and exhaust gases to enter and exit this area of the furnace through multiple paths. At one point, the checker pack in the fourth port right side had started to collapse and was now an added concern. The furnace was pulling ~650 t/d and had acceptable glass quality and melting conditions. The combustion air blower was at or near maximum output, and air flow had been reduced to the first three ports and was being redistributed down tank. CO levels were elevated across all ports, and excess oxygen in the exhaust was at a minimum. NOx levels were near maximum, but below permit limits. Between the charge end of the melter and the first port, a set of Cleanfire® HRi™ advanced boost burners had previously been installed and had been operating successfully for the last several years. Up to this point, the plant was able to counteract the decrease in combustion air by changing the firing profile of the melter and increasing fuel and air to adjacent ports.

Phase I: Oxygen Lancing

Discussion

As conditions deteriorated, it was decided to investigate options for improving the furnace combustion and thereby delay the decision to idle the furnace and perform a hot checker repair. It was at this point the plant contacted Air Products, their gas supplier, to discuss potential solutions. Multiple options were identified, including oxygen enrichment, oxygen lancing and ThruPort burners. Based upon conditions of the furnace at the time, it was decided to eliminate oxygen enrichment as an option due to the extent of enrichment that would be required. Based on the current condition of the furnace and regenerators, it was decided to use oxygen lancing to supplement the lack of combustion air.

Initially one oxygen lance was installed in each side of the #4 and #5 ports under the main natural gas burner. The goal was to increase the excess oxygen as measured in the exhaust port, reduce the CO levels, and hold or reduce current NOx levels while maintaining temperature and pull. The first step in the process was to identify all available resources and define the scope of work required.

The key resources utilized:

- Sources of oxygen
  - On-site VSA oxygen generator
  - On-site LOX storage tank
  - Determine logistics for delivery of 25 t/d of additional LOX

- Oxy-fuel boost burners between the CEW and #1 port
  - Maximize the heat input from these burners

- Distribution and control skid
  - Fabricate new vs. used

- Turn-key project requested by the customer
  - Supply engineering and design
  - Prepare bid package and select mechanical contractor with customer approval
  - Confirm vaporizer capacity was adequate

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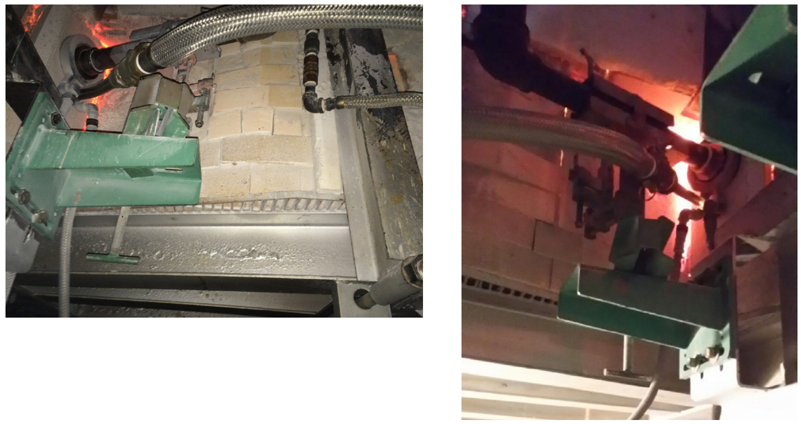
Oxygen lancing was first installed on the #4 and #5 ports on both sides of the furnace. Eventually, lancing was extended to the #3 port left and right as well. Exhaust gas reading were analyzed for excess O2, CO, and NOx before and after the lancing system was installed on each port. Eventually, combustion air was reduced to bring NOx levels back to original levels. The results of Phase I are listed below along with Figure 9, which shows the side of port lancing system in place.

- Successfully provided oxygen lancing to ports 3, 4 and 5 for approximately one year
- Maintained melter temperatures and profile
- Maintained furnace pull
- Emissions kept below permit limits
- Due to limitations on control of O_2/fuel mixing, the point of diminishing returns on O_2 lancing effectiveness was eventually reached

Figure 9: Side of Port Lancing Installation



Phase II: ThruPort Oxy-fuel Burners

Discussion

After one year of increased checker deterioration and collapse, it became clear that the lancing option would not be sustainable for the balance of the furnace campaign. The decision was made to replace the checker packs behind the worst four ports of the melter. To perform this hot checker repair and maintain full production, it was necessary to install ThruPort burners in the affected ports. The most air-starved ports were #3 and #5 right and #4 and #5 left.

It was decided that one regenerator compartment on each side of the furnace would be replaced simultaneously with an expected duration of two weeks for complete demolition and replacement of the checkers. Once completed, the burners would be removed from the repaired ports and moved to the next set of ports to be repaired. The total planned repair would therefore take approximately one month to complete. Given this time line, it was necessary to provide an uninterrupted supply of oxygen.

The first two checker packs to be replaced were #3 right and #4 left. Table 2 shows the furnace fuel distribution prior to and after the installation of the ThruPort burners. The total fuel reduction was approximately 10%, due primarily to the efficiency of the oxy-fuel burners. Figures 10 and 11 show the before and after temperatures of the crown and bottom thermocouples. As indicated, the furnace temperatures remained basically unchanged during the repair period, as did the furnace pull rate, glass quality and emissions. Throughout the repair, the vaporizers were continuously monitored and de-iced as needed to ensure a constant flow of oxygen was delivered to the furnace. As each checker pack was replaced, the port was opened and gradually converted back to air-fuel firing.

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Table 2: Initial and Final Fuel Distribution

Port #	Initial Fuel Flow (scfh)	Final Fuel Flow (scfh)
1	29,615	28,570
2	29,750	29,700
3	27,425	21,190
4	28,395	21,720
5	26,055	26,010
6	9,015	9,000
Total	150,010	136,190

Figure 10: Before and After Crown Temperatures

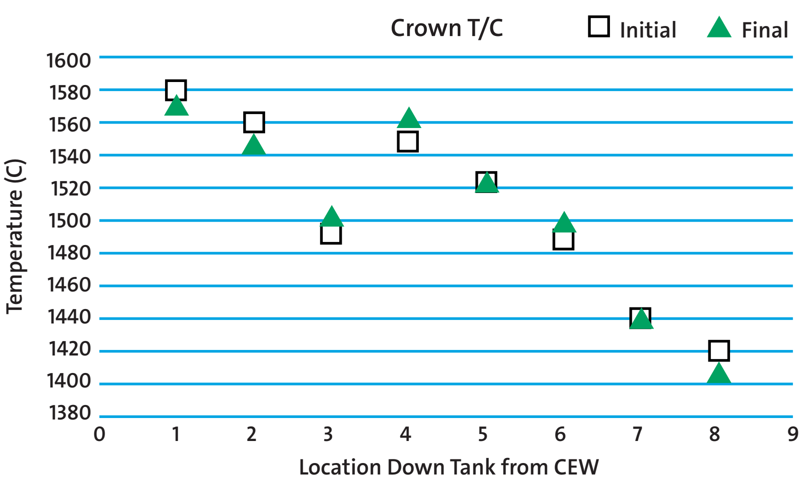
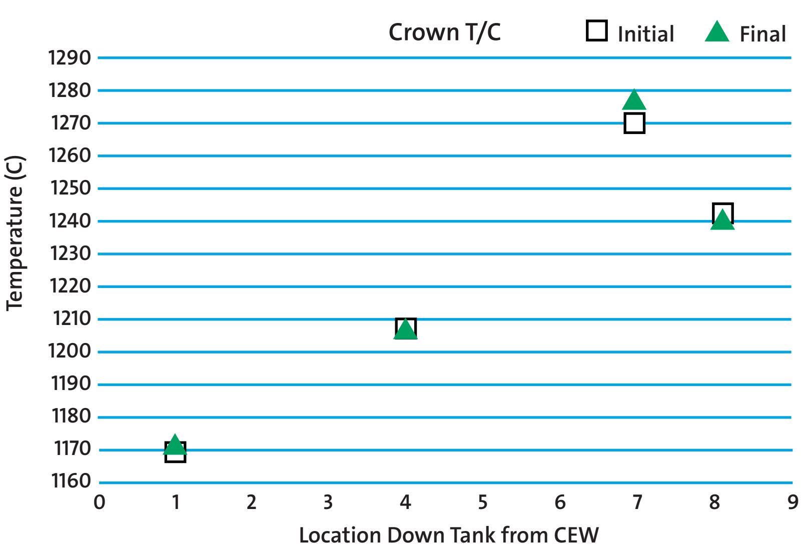


Figure 11: Before and After Bottom Temperatures



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A variety of challenges associated with the layout and operation of the furnace were encountered and addressed. First, the burner could not be centered in the bottom of the port due to the layout of the port support steel. This issue was overcome by the ability of the burner to be adjusted upstream or downstream in the port. Another challenge was the fact that the burners were operated directly across from an air-fired port, and the back of the port could not be blocked off for several days. These conditions were overcome by the flexibility of the burner's oxygen staging feature.

Phase II resulted in:

- Successful installation of one set of ThruPort oxy-fuel burners in two sets of ports for a one-month period while checker packs were replaced
- Maintaining melter temperatures and temperature profile
- Maintaining furnace pull
- NOx emissions kept below permit limits

Summary

The problems associated with failing regenerators, whether it be the need for a hot checker repair or to maintain furnace production and extend the life of the furnace, can be solved by supplementing or replacing the ailing combustion system with oxygen lancing and/or ThruPort burners. The infrastructure to support these systems is available and can be rapidly deployed. Once installed, these solutions can offer the ability to maintain production and glass quality, reduce fuel consumption, and extend the life of the furnace.

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