Recent Trends in Oxy-Fuel, Air-Fuel and Hybrid Combustion Technologies

D. Paul Mehta and Amol Nayak, Bradley University

ABSTRACT

The need for energy efficiency captured the attention of all sectors of our society in 1973 when an Oil Embargo was imposed by the oil producing and exporting countries. Interest in energy efficiency continued during the 1980s primarily due to environmental concerns and secondarily because of economic and industrial competitiveness issues. Recent energy supply disruptions caused by hurricanes Katrina and Rita have generated a renewed interest in energy efficiency.

Oil Embargo of 1973 was termed as "energy crisis" and "energy problem" in the industrialized countries. However, the engineers and scientists took it as a challenge and as an opportunity. As a result of their work, today our refrigerators are twice as efficient, heating furnaces are one-third more efficient, cars are one-half more efficient, and light bulbs are four times as efficient.

Interest in energy efficiency during the 1980s by the U. S. Government and its outcome became very handy when Katrina and Rita hit last year. The Industrial Technologies Program (ITP) of the U. S. Department of Energy (DOE) had developed several energy efficient programs such as Best Practices Tools and Energy Efficient Technologies.

One of the energy efficient Technologies is Oxy-Fuel Firing. Oxy-Fuel is a technology for stable energy supply without CO_2 and NOx emissions. Higher thermal efficiency, lower exhaust gas flows, and lower superstructure temperature resulting from Oxy-Fuel Technology have contributed to more widespread cost-effective use of oxygen based firing.

In this paper, an application of the Oxy-Fuel technology to a natural gas fired Floating Glass (FG) manufacturing furnace is discussed. An Energy Saving Assessment was carried out at this plant under the Save Energy Now Program. The details of the application of Oxy-Fuel technology, its impact on energy cost savings, productivity enhancement, and product quality are discussed. Potential for applying additional energy efficient technologies to manufacture glass is reviewed. Commercial availability of these technologies for glass manufacturing industry is discussed in this paper.

Introduction

Furnace is an enclosure in which fossil fuel is converted to thermal energy. Modern furnaces typically use natural gas or electricity. The natural gas furnace is one of the most efficient industrial furnaces. Various applications of multi-burner natural gas-fired furnaces are generally found in the following industries:

- Glass manufacturing
- Aluminum scrap melting
- Steel re-heat furnace
- Forging furnace
- Reheat furnace

- Metal Parts Fabrication
- Metal Casting
- Automobiles
- Aerospace
- Chemical
- Earth Moving Equipment
- Mining
- Electronics
- Paper

Glass manufacturing is a very energy intensive industrial process. Glass is produced by heating the raw materials like silica (Silicon dioxide), sand (Quartz), iron oxide, and other materials to about 1500 to 2000C.

Glass manufacturers who need to increase pull rate (pull rate is the velocity of the glass sheet) and improve quality, consistency, and thermal efficiency while decreasing NOx emissions can use Oxy-Fuel technology. Oxy-Fuel technology has proved to be one of the most energy efficient combustion processes for glass melting furnaces. Ideal burners for any furnace would have the following characteristics: [1]

- Flexibility with respect to flame length and heat transfer.
- Continuity of operations, which can be adjusted during use.
- Multiple fuel usage.
- Robust and compact design.

The Oxy-Fuel burners have most of the above characteristics. It has been observed by a major company in combustion technology that in Oxy-Fuel combustion the volume of the flue gases is approximately 20% of that in the Air-Fuel combustion resulting in a reduction of the amount of heat lost through flue gases. They have developed their own-patented burners and found it to be one of the most efficient ways of reducing NOxs, achieve maximum efficiency, and reduce particulate emissions from glass furnaces. Additional advantages of Oxy-Fuel Combustion in the glass industry are: [1]

- Better glass quality.
- Very low NOx and particulate emissions.
- No air preheating necessary.
- Suitability at higher pull rate.
- Better sequencing of the furnace.
- Smaller filter unit.

Thus with oxygen enrichment, more heat is transferred to the product, less heat is lost in the exiting combustion gases, and the combustion process becomes more efficient. With proper furnace design and burner selection, reduction of NOx by 50-70%, as compared to regenerator furnace is achievable. In addition, reduction of batch carry over is possible. The objective of the work reported in this paper was to study the applications of Oxy-Fuel technology to a conventional natural gas fired glass-melting furnace.

Background

Oxy-Fuel is a technology for stable energy supply with reduced CO2 and NOx emissions. The NOx produced in industry is mostly a bi-product of high temperature process, such as glass melting. Rebirth of this technology can lead to a sustainable energy supply [2]. Higher thermal efficiency, lower exhaust gas flows, and lower superstructure temperatures have contributed to more widespread cost-effective use of oxygen-based firing.

Oxy-Fuel technology has already emerged in recent years as a well-accepted glass melting technology [3]. It has been a boon for melters who have been mandated by the Environmental Protection Agency to reduce particulates. However, many of the recent conversions have been made to achieve other goals. These include lower gas usage, increased melting capacity, fewer man hours per ton, reduced repair costs, and better quality of glass [4].

Methodology of Research

Industrial Visit

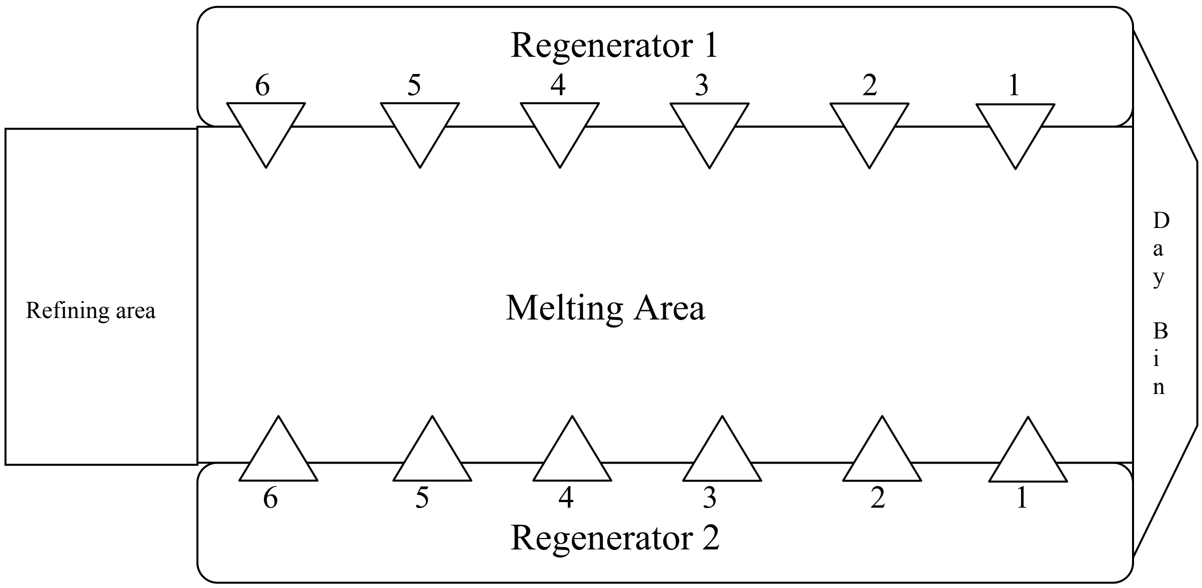
The research work was done by doing a case study at a major Float Glass Manufacturing plant. The plant is about 350,000 square feet in area. The facility produces float glass, which is used in glass windows. The plant runs 24 hours a day, 365 days a year. The facility produces 590 tons of glass a day. The glass sheets are produced in different sizes, the biggest glass size 144" x 96". The heart of the facility is an Air-Fuel Technology furnace.

Furnace Arrangement

The melting furnace schematic is shown above in Figure 1. The furnace has 6 ports and the first 5 ports have two burners on each side and the sixth port has one burner on each side. The raw material is mixed in appropriate proportions and fed to the Day Bin. Then the raw material enters the furnace at a predetermined rate.

The regenerators arrangement is also as shown in Figure 1. In the present arrangement the combustion air is pumped from below to the melter. The air pre-heater works on a 15-minute cycle. The air from the melting region is re-circulated to the combustion chamber through regenerators 1 and 2. For the first 15 minutes regenerator 1 is used for the waste heat recovery, during the next 15 minutes regenerator 2 is used for waste heat recovery. The pre-heated air was measured to be at 220 F. The inlet velocity of air at ports 1 to 5 is 44-53 ft/sec and at port 6 is 53 feet/sec.

Figure 1. Furnace Details



Observations for Oxy-Fuel Technology

- Fuel demand for Oxy-Fuel is less than Air-Fuel even with air pre-heater operating at 220^0F.
- Radiative Heat Transfer losses are reduced by 80-85% compared to the Air-Fuel system.
- The crown temperature for Oxy-Fuel system is lowered thus reducing the wall losses as compared to Air-Fuel system.
- An added advantage of the lower crown temperature is long refractory life.
- The reduction of over all mass flow rate of flue gas results in lower NOxs and reduce flue gas losses.

Recommendations

A detailed study of combustion, heat transfer, and their interactions with glass bath and refractories is required for optimum design of the Oxy-Fuel combustion technology. Following are the recommendations for the implementation of Oxy-Fuel technology:

Burner Alignment

The alignment can be of two types:

a) In line
b) Staggered

The furnace at the assessed plant had all the burners aligned in in-line configuration. The alignment is important for the uniform distribution of the temperature throughout the combustion chamber. The aim of the optimum alignment is that the flame length must cover as much of the tank width as possible. But the power distribution limits the length of the flame. The second consideration in the Burner Alignment is *Momentum Penetration*, which is a function of the gas velocity, jet diameter, and gas temperature. Overall evaluation of flame length and *Momentum Penetration* leads to the conclusion that for narrow furnaces select staggered alignment to avoid collision of the exhaust jets and further deflection which might result in jet impingement on the crown. But in case of wide furnaces in-line burner arrangement should be preferred to avoid cold spots near the opposite wall from the burner position. As a rule of thumb, a furnace width less than 24 feet accommodates a staggered alignment while a width greater than 24 feet will incorporate an in-line approach. [5] In our case the furnace width was about 41 feet wall to wall of the combustion chamber. So it is recommended to retain the in-line burner arrangement. It will avoid collision of the exhaust jets, which will prevent its impingement on the refractory surface and will improve the heat transfer rate.

Pollutant Emissions

The conventional furnaces emit 0.8 to 1.8lb of NOx per ton of class produced. Our plant had the following emission inventory:

Year	$1b_m$ of Sox per ton of glass produced	$1b_m$ of NOx per ton of glass produced
2005	0.546	13.291
2006	0.483	11.460

Use of Oxy-Fuel burner in glass tank has demonstrated that when optimization of the process parameters in the combustion and glass melting operations are implemented NOx emissions in the range of 0.17 -0.64lb/ton are possible. [5]

Burner Height

The burner height is affected by two main factors:

a) Furnace geometry
b) Heat transfer process

To prevent the hot spots on the glass surface and crown, a study of the heat transfer process is important. Furnace height of 18 inches or more above the glass line is recommended to minimize the potential for hot spots on the glass surface. Tuckstone, the furnace structure, and the crown height must be considered to ensure they do not interfere with the desired burner position.

Combustion Control

The three ways for combustion control are:

a) Automatic control for each burner.
b) Automatic control for each zone.
c) Automatic control for the main supply line with manual control of each burner or zone.

For the case in hand the combustion control was of type c. It is recommended to continue with the same arrangement with some modifications to accommodate the flow of oxygen in addition to natural gas. To further reduce the NOx emissions, pulsation of Oxygen and natural gas at the burner will be needed.

Crown Height

Factors affecting crown height are:

a) Thermal efficiency.
b) Temperature stability.
c) Heat flux profile.
d) Gas velocity near refractory surface.
e) Gas flow pattern.

Analysis of ATHENA (a computational fluid dynamic model of furnace) led to the conclusion that low crown configuration should provide a better thermal efficiency. [5] But the refractory wear from high surface velocities and hot spots formations can limit the height of crown. Thus due to higher temperature and velocity configuration of Oxy-Fuel technology, high crown configuration gets an upper hand. In the case in hand the crown height was about 8.5 feet above the glass line which is considered to be a high crown configuration. It is recommended to keep the current high crown configuration of 8.5 feet. This will ensure minimum wear of the refractory material due to hot spots and high surface velocities.

Oxygen Supply

Air separation unit is the best option for oxygen supply. [7] In float glass-meting process the Tin Bath (the process where glass is cooled over tin bed) used for forming glass ribbon uses nitrogen in large quantity to avoid oxidation of tin at glass surface. In order to implement oxy-fuel furnace technology, an air separation plant can be installed to produce oxygen and nitrogen more efficiently than supplying each gas individually. Thus by taking advantage of equipment and process synergies in plant design an added advantage is achieved. A commercially available oxygen generator can be used to supply needed oxygen and nitrogen.

Burner Selection

Commercially available Oxy-Fuel burners come in sizes of 1MMBtu/hr to 20MMBtu/hr. The proprietary staging technique allows exact flame shaping to minimize emissions. These burners are capable of maximizing the radiation and spread it over a large flame area with ability to direct it down to the melt. Thus these burners melt the batch faster with less fuel.

Thermal & Financial Calculations

Anticipated Savings

Anticipated saving of 20% (N_r) fuel usage can be achieved for the furnace under consideration. [6] The assumption is based on the present furnace design, which has a regenerator arrangement.

$$GU_R = (N_r) \times GU \times 8.514$$
$$GU_R = (0.20) \times 1{,}146{,}765.6 \times 8.514$$
$$GU_R = \$1{,}952{,}712.46/yr$$

The above figure of $\$1.952 \times 10^6$ per year will be the annual saving of the fuel usage. The additional costs savings include productivity enhancement of about 5% and NOx credits are worth $1,500/ton.

Cost of Implementation

Installation of 300 tons per day oxygen plant is required for manufacturing 550 tons of glass per day. The implementation cost for this oxygen plant is estimated to be 1.598×10^6 dollars. The initial installation cost should include about 2×10^6 dollars for crown refractory upgrade package. Total additional expenses of $\$3.598 \times 10^6$ are for manufacturing glass at the rate of 550 tons per day.

Conclusions

It is estimated that the pay back period of about 1.84 years can be achieved without considering the savings generated by additional sales due to productivity enhancements and emission savings. Note that due to the difference in on-site operating efficiencies between Oxy-Fuel burners and the original air fuel burners, there might be a slight increase in energy usage due to the replacement suggested above. Due to size and rating limitations, it is suggested that the proposed replacement kit for the burners be a commonly commercially available size.

Nomenclature

GU_R	=	the energy saved due to Oxy-Fuel technology implementation.
N_r	=	the saving of the energy achieved by Oxy-Fuel technology implementation
GU	=	the original energy consumption at the plant.

References

1. www.linde-gas.com

2. Dipl.-Ing. Sonja Gonschorek, Technische Universität Dresden, Institute for Energy Technology et al; "Oxy-fuel Technology – an option for the reduction of CO2- emissions from coal-power plants in Germany".

3. Shamp, D. et al "Oxy-fuel furnace design optimization using coupled combustion/glass bath numerical simulation"; Proceedings of the 1998 59th Conference on Glass Problems.1z

4. Anon et al "Switch to oxy-fuel gives GE more glass capacity"; Anon, Glass Industry, v 76.

5. Roberto Ruiz, Steve Wayman, Benjamin Jurcik, Louis Philippe and Jean-Yves Iatrides, Air Liquide et al; Ceramic Engineering and science proceedings; "Oxy-fuel Furnace Design Consideration"; volume 16, Applied Technology Centre, Countryside, IL 1995, page number 179-189.

6. Kevin A. Lievre and Russell J. Hewertson; "Environmental Benefits and Lower Cost Too!" Air Products and Chemicals, Inc; 62nd Glass Problems Conference, October 16-17, 2001, Urbana-Champaign, Illinois.

7. http://www.airproducts.com/Markets/Glass/burner_types.htm

8. http://www.airproducts.com/Markets/Glass/oxy-fuel-techniques.htm