Oxy-Fuel Firing for the Glass Industry: An Update on the Impact of This Successful Government-Industry Cooperative Effort

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ABSTRACT

The U.S. Department of Energy (DOE) works in close cooperation with industry through its Office of Industrial Technologies (OIT) to achieve improved energy efficiency in energy-intensive industries. In 1990, the DOE contributed about $1 million to demonstrate the practical application of an oxygen-fueled melting process (also known as oxy-fuel firing) for large glass melting furnaces -- as a replacement to traditional furnaces using natural gas or oil with preheated air. The oxy-fuel fired furnace substitutes oxygen for air in the combustion process.

The first successful demonstration of oxy-fuel firing occurred in 1990 at a 80 ton per day (TPD) furnace at Carr-Lowrey Company in Maryland. Soon afterwards, a successful permanent conversion was made to a 350 TPD furnace at Gallo Glass Company in California.

The success of the demonstrations confirmed the commercial viability of oxy-fuel firing for large glass furnaces. The glass industry embraced the technology and penetration accelerated in the mid and late 1990s. The DOE has continued to assist the industry in the adoption of the technology by hosting two workshops on issues relating to oxy-fuel firing. As of September 2000, of the 406 large glass melting furnaces operating in the United States, 114 had been converted to oxy-fuel firing. As other air-gas furnaces are rebuilt at the end of their current campaigns, more conversions to oxy-fuel firing are likely.

The oxy-fuel firing technology has numerous benefits for glass manufacturers. The substitution of oxygen for air in the process significantly reduces nitrogen oxide (NO_x) emissions, reduces the amount of energy required per ton of glass produced, reduces levels of other gases, and reduces the capital costs for furnace regenerators and emissions control equipment. In addition, furnace throughput usually increases.

To make the conversion to oxy-fuel economic for mid-sized furnaces, a vacuum-pressure swing adsorption (VPSA) system was developed to produce oxygen at reduced costs through DOE-funded efforts. The VPSA process was introduced in 1991, and is a point-of-use oxygen supply process that makes the use of 90-95% purity oxygen more economical and convenient. A VPSA plant was installed at the Gallo Glass facility to supply the oxygen onsite to replace delivery of liquid oxygen used in the initial furnace startup and operation.

The objective of this paper is to describe the technology and its impact on the glass industry. The paper will describe the commercial benefits that have been achieved to date including energy savings and productivity improvements, a detailed assessment on the penetration of the technology, the DOE role in the development, demonstration, and adoption of the technology, and potential applications of oxy-fuel firing in other industries.

Background

The U.S. glass industry is a large user of energy in the production of glass containers, float glass for windows in construction and automobiles, fiber glass insulation and other specialty products, such as TV tubes, fiber optic cables and light bulbs. The financial well-being of the glass industry has historically followed the fluctuations of the U.S. economy. Commercial and residential construction as well as automotive purchases and container preferences dominate changes in product shipments.

The glass industry is highly capital-intensive, with total capital requirements for a large facility often in excess of $100 million. The capital costs for a glass furnace are normally $20 million or more per unit, with the majority running continuously for anywhere between 5 and 12 years.

Past energy policies, environmental issues, and fuel pricing and availability have forced the glass industry to switch between using fuel oils, natural gas, and electricity in the melting process. The energy crisis of the 1970s profoundly influenced the glass industry. Restrictions for nitrogen oxide (NO_x) and particulate emissions also significantly affected the industry.

Furnaces for glass production have traditionally burned natural gas or oil with preheated air to produce about 30 to 1000 tons of glass per day (TPD). The high temperatures (greater than 2800° F) required for glass manufacture and the raw materials used in glass result in significant emissions of NO_x and particulates. The oxy-fuel furnace substitutes oxygen for air in the combustion process. This process change significantly reduces NO_x emissions and fuel consumption required per ton of glass produced, and also reduces levels of other exhaust gases.

Technology Development

The U.S. Department of Energy (DOE) began examining enriched combustion methods in the late 1970s – first with air, and later with oxygen. The DOE recognized that lower cost oxygen production technologies would be needed to enhance the commercial viability of oxygen-enriched combustion for industrial applications.

The DOE began R&D on oxygen-enriched combustion in 1985 when the DOE Office of Industrial Technologies (OIT) awarded Praxair, Inc. (then part of the Union Carbide Corporation) support to carry out a three-phase project to evaluate the technical and economic feasibility of using oxygen-enriched combustion for industrial furnace applications. As part of the program, burner tests and combustion modeling were conducted for promising applications, which included glass furnaces using natural gas.

Commercial Demonstration

In addition to the early DOE efforts, Corning, Incorporated was also experimenting with oxy-fuel firing in the late 1980s, and had proven the viability of the technology for very small, specialized furnaces. However, both technical challenges in the furnace combustion space and melt environment and economic challenges in scale-up and reducing oxygen costs remained to adapt it for larger glass furnaces.

Significant progress occurred by 1990, when oxy-fuel firing was successfully demonstrated in Maryland at a 80 TPD furnace owned by a specialty container glass maker, the

Carr-Lowrey Company. That same year, the Gallo Glass Company began a demonstration of the technology by permanently converting a 350 TPD furnace to oxy-fuel firing technology. This demonstration occurred at the Gallo facility in California, which is also the largest container glass facility in the United States. Even though the fuel system, burners, and related equipment represented only a fraction of the total capital requirements for a furnace, there remained substantial risk in testing the viability of the technology with regard to the length of the furnace campaign while employing oxy-fuel firing. However, the reduction of NO_x emissions in oxy-fuel firing was one of the main drivers that convinced Gallo to test the technology.

DOE Involvement

The DOE provided about $1 million for the Gallo demonstration with substantial direct co-funding from Praxair, and also provided the initiative for technical cooperation between glass producers and material suppliers. As part of the demonstration efforts and to make the substitution of oxygen for air more economic for mid-sized furnaces, Praxair developed a vacuum pressure swing adsorption (VPSA) system to produce oxygen at reduced costs, and the first commercial VPSA plant was installed to supply the oxygen onsite to replace delivery of liquid oxygen used in the initial Gallo furnace startup and operation. The VPSA process was introduced in 1991, and is a point-of-use oxygen supply process that makes the use of 90-95% purity oxygen more economical and convenient (Reed 1997).

The VPSA air separation system is based upon a highly selective molecular sieve material that allows oxygen to pass through, while adsorbing nitrogen from ambient air. As the air passes through one of two adsorbent beds, nitrogen is adsorbed by the synthetic zeolite sieve and the enriched oxygen passes through for use. While one bed is adsorbing the nitrogen, the other is purging it; periodically the pressure swings and the beds reverse functions. Between 1990 and 1995, production costs using VPSA were reduced in excess of 30%, making oxy-fuel firing a more attractive option for many glass operations (Hintz 1997). Praxair is still a leader in VPSA technology, with significant competition from other major oxygen suppliers such as Air Products, BOC Gases and American Air Liquide.

By providing funding for demonstration of the new technology, as well as earlier work on combustion modeling and other technical challenges, the DOE opened the door for expansion of oxy-fuel firing technology to larger glass furnaces.

Oxygen Generation

Adsorption systems are only one of three primary methods used to supply oxygen to glass facilities. The other methods are merchant liquid oxygen delivery and cryogenic production systems. The type of method used depends on the specific capital and operating costs of competing technologies that are unique to each installation, and include consumption volume, electricity costs, and proximity to existing oxygen production plants. Production costs increase as purity levels are increased.

While cryogenic production systems allow higher purity, they are also equipment-intensive and generally require too much capital to be cost-effective unless the glass furnace is producing in excess of 200 TPD, putting it beyond the reach of many mid-sized glass facilities. In addition, merchant liquid gas supplies are not economic for furnaces producing at least 10 TPD, which constitutes the vast majority of glass plants.

For glass industry oxygen purity requirements, VPSA is generally the low-cost choice up to the 120 TPD range. Beyond this, the most cost-effective option is decided on a case-by-case basis; beyond 200 TPD, recently commercialized small cryogenic plants are often the best option (Reed 1997). A representative depiction of the most economical option for oxygen supply by furnace size and purity desired is shown in Figure 1 (Grosman 1999).

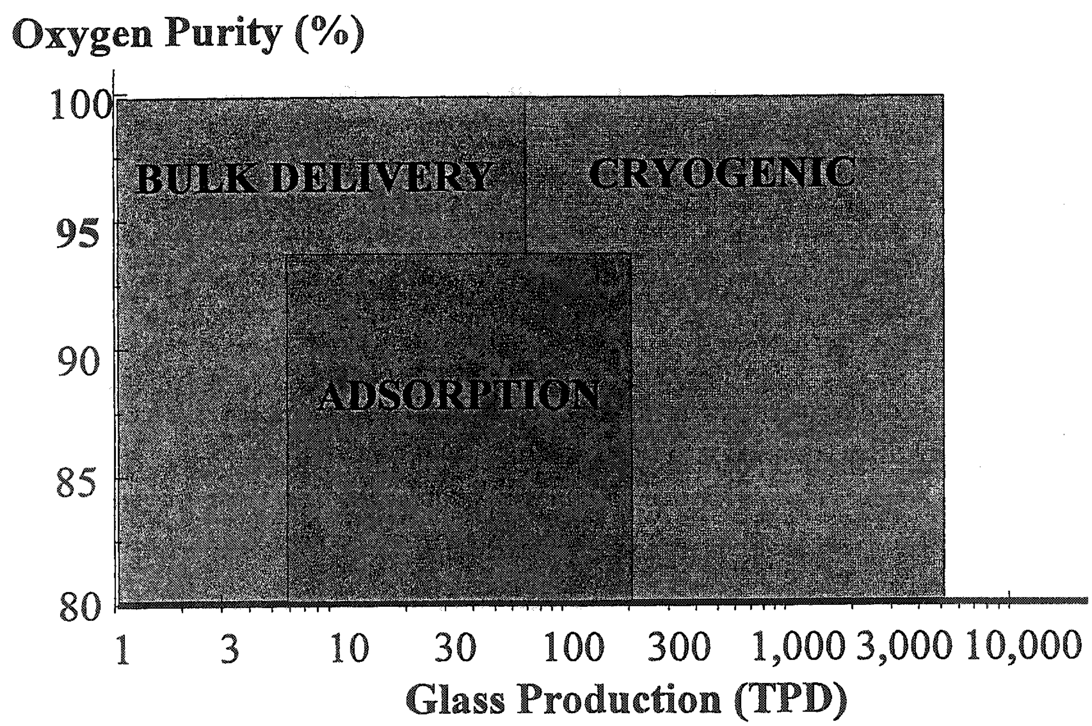

Figure 1. Breakdown of Most Economical Oxygen Supply

Today, the VPSA system is only one of three adsorption systems available, but it continues to be the most energy-efficient and cost-effective when compared to the similar vacuum swing adsorption or pressure swing adsorption systems. Oxygen suppliers have continued to pursue improvements to these technologies to further reduce oxygen production costs.

Related Technology Development

Since commercial introduction, the DOE has continued to fund efforts for improving oxy-fuel firing technology to further reduce energy use, reduce environmental loadings from glassmaking, improve industrial productivity, and broaden applicability to other industrial sectors.

Through the OIT Glass Industry of the Future program, the DOE funded several research projects in the 1990s focused on the application of oxy-fuel firing in glass furnaces including: burners used in oxy-fuel furnaces, refractories that are exposed to the oxy-fuel combustion environment, a better understanding of the heat flux fundamentals and the characterization and modeling of the process, sensing and control instrumentation to better monitor and optimize the melting process, and batch and cullet preheating to utilize exhaust heat.

Market Development and Penetration

As is often the case with mature manufacturing industries, employing new technology presents operational challenges, and market penetration initially was fairly limited. However, the technology continued to gain momentum, and by 1995 about 11% of U.S. glass production had been converted to oxy-fuel firing. Many glass companies were making additional commitments to the technology, which by the end of 1997 had resulted in the conversion of about 25% of glass furnaces to oxy-fuel firing. With the critical mass of operating experience and many new conversions coming on-line, it was an opportune time to transfer knowledge on how to overcome operational difficulties and issues to a broad glass industry audience, and the DOE planned and conducted a workshop in early 1997 on issues regarding oxy-fuel firing for glassmaking. Topics addressed at the workshop included: oxygen generation technologies, burner attributes and needs, furnace design, furnace operation and control, and superstructure refractory needs.

The DOE hosted a similar workshop in 1999 to continue information sharing efforts, which addressed some of the same topics as the earlier workshop as well as some new topics. The topics addressed at the 1999 workshop included: combustion and emissions, oxygen generation technologies, refractories, process optimization (sensors and modeling), and waste heat recovery. Over 100 representatives from glass manufacturers, suppliers, academia, national laboratories, and government attended each workshop.

Recent Market Penetration

As of September 2000, 114 glass furnaces have been converted to oxy-fuel firing in the United States (Ross 2000). This represents about 28% of U.S. commercial scale glass furnaces, and a significant increase from the 1995 level. As other air-gas furnaces are rebuilt at the end of their current campaigns, more conversions to oxy-fuel firing are likely both in the United States and abroad.

The decision by a glass company whether to convert to oxy-fuel firing was dependent on its individual situation. Initially, the primary reason for employing oxy-fuel firing was either for NO_x reduction or for energy savings. Additional reductions in the cost of oxygen during the 1990s also increased the likelihood of utilizing oxy-fuel firing. More recently, the increase in production rate that accompanies oxy-fuel firing has been a deciding factor for several manufacturers.

Market penetration of oxy-fuel firing varies by glass industry sector. Table 1 depicts the penetration of oxy-fuel firing by glass sector within the United States (Ross 2000). Of particular note are the two sectors where penetration is the lowest. The flat glass industry has the lowest penetration, with only two conversions in the United States and no known conversions abroad. This sector has concerns about the potential for bubbles forming in the melting process, and many flat glass facilities are located in rural areas that have less stringent environmental regulations. However, PPG Industries dedicated the second flat glass oxy-fuel conversion last summer and recently announced another planned conversion (PPG 2001). In its announcement, PPG indicated that operational performance at its earlier conversion is exceeding expectations.

Table 1. Oxy-Fuel Penetration and Characteristics by U.S. Glass Industry Sector

Industry Sector	# of Oxy-Fuel Fired Furnaces	Total # of Furnaces	Percent Oxy-Fuel	Typical Furnace Size
TV Glass	9	12	75%	100-300 TPD
Textile Fiber	31	68	46%	75-100 TPD
Lighting	8	21	38%	75-150 TPD
Pressed and Blown	27	79	34%	75 TPD
Wool Fiber	12	43	28%	100-150 TPD
Container	24	126	19%	250 TPD
Flat	2	40	5%	500+ TPD
Total	114	406	28%	

Penetration in the container sector is also relatively low. Severe competition from other materials, environmental compliance, and labor costs caused the closure of 33 plants from 1983 to 1992 and plants closings continue in this sector today (Ross 2000). Given the weak profitability in this sector, there has been less emphasis on oxy-fuel conversion except in environmentally sensitive areas such as California. Another technology, oxygen-enriched air staging, was also developed in the mid 1990s to reduce NO_x emissions. The DOE supported a demonstration of this technology as well. Oxygen-enriched air staging employs a two-stage combustion process where oxygen is injected into the furnace near the exhaust port to complete combustion. This relatively low-cost method to reduce NO_x emissions is now being used in about 10 container glass furnaces.

Technology Benefits

Oxy-fuel firing technology has significant energy, environmental, and productivity benefits. Energy accounts for 13-15% of direct production costs in the manufacture of glass, with over half of total energy consumed in the melting furnace. Generally, smaller air-gas glass furnaces have been less efficient, and the conversion to oxy-fuel has resulted in fuel consumption reductions of up to 45%. Savings in larger furnaces are generally in the order of 15% based on measurements at individual facilities (Reed 1997). However, the energy required to produce the oxygen utilized in the process does offset the energy savings seen by glass manufacturers. On a net basis, energy requirements are still reduced.

Environmental compliance costs at glass facilities are considerable for emissions control equipment and operation. Environmental benefits of oxy-fuel firing include reduction in NO_x emissions by up to 90%, reduction in carbon monoxide emissions by up to 96%, and reduction of particulate emissions by up to 30% (Reed 1997). These reductions help satisfy permitting requirements for continuing production of glass products. Oxy-fuel firing also eliminates the need for regenerators, thereby reducing spent regenerator refractories from hazardous landfills.

Productivity at glass facilities is also improved. Furnace production rates can be increased by up to 25% compared to conventional furnaces, although 10-15% improvements are more common (Reed 1997). This also makes the industry more cost competitive by improving capital effectiveness and lowering labor costs per ton of glass produced.

Other direct economic benefits which manufacturers have experienced include improved product quality, reduced capital expenditures for glass melting furnaces that had previously used regenerators, and reduced capital expenditures for emissions control equipment. Oxy-fuel firing has also contributed improved technical understanding of high-temperature processing, along with information on emissions and opportunities to reduce emissions. Oxy-fuel firing benefits the Nation through improved air quality.

Documented Industry Savings

For more than 15 years, the DOE has tracked the progress of commercial technologies supported by OIT research programs. In 1999, tabulated net energy savings of 4.14 trillion Btu were reported for oxy-fuel firing in glass furnaces, as were NO_x emissions reductions of 290 tons. Cumulative energy savings and emissions reductions since the technology was commercialized are depicted in Table 2 (DOE 2001).

Table 2. Tabulated Net Benefits for Oxy-Fuel Firing in the Glass Industry

	1999	Cumulative through 1999
Energy Savings	4.14 trillion Btu	21.1 trillion Btu
Carbon Dioxide Emissions Reductions	242 thousand tons	1,230 thousand tons
NO_x Emissions Reductions	290 tons	1,470 tons
Particulate Emissions Reductions	6 tons	32 tons

Applications in Other Industries

Oxygen is widely used in a variety of industries, such as the primary and fabricated metals industries, the health services industry, and the chemical industry. However, the primary focus of the DOE is to apply this technology in high temperature processes to reduce energy use.

While technical challenges are different for each application, the knowledge acquired through the glass industry experience with oxy-fuel firing will be valuable in developing the technology for use in other industries.

Other Successful Applications

In the steel industry, oxygen has been used for some time in the basic oxygen furnace to refine iron into steel. More recently, oxy-fuel firing has being tested in a batch steel reheat furnace at an integrated Bethlehem Steel plant through a DOE co-funded project, with Praxair providing technical expertise. Similar benefits to those found in the glass industry have been measured: reduced fuel consumption, reduced NO_x emissions, and increased production rates (DOE 2001). Early indications are that if fully adopted by the steel industry, energy savings will exceed those that are available in the glass industry. The DOE continues to fund oxygen combustion efforts through the OIT Steel Industry of the Future program.

In the aluminum industry, the DOE supported a demonstration project to test an oxy-fuel combustion system at a secondary aluminum melting facility in New York. With technical expertise provided by Air Products and Chemicals and participation by Argonne National Laboratory and Brigham Young University, Wabash Alloys has been utilizing this system since 1999. Like the steel industry, measured benefits include reduced fuel consumption, reduced NO_x emissions, and increased production rates (DOE 2001). The DOE funded this effort through the OIT Aluminum Industry of the Future program.

Other Potential Applications

There are numerous high temperature processes where the use of oxy-fuel firing could potentially save energy. A list of other potential applications is depicted in Table 3 (Mathur, Tomellini, and Tsao 1997).

Table 3. Other Potential Applications for Oxy-Fuel Firing by Industry

Aluminum	Brick	Cement	Chemical
- Calcining - Heat treatment	- Periodic kiln - Tunnel kiln	- Calcining	- Incinerator
Copper	**Lime**	**Petroleum**	**Steel**
- Smelting - Anode furnaces	- Calcining	- Fired heater	- Ladle heat - Soaking pit - Annealing - Forging

Moving Forward

In addition to expanding the technology to other industries and applications, opportunities remain to improve and expand oxy-fuel firing in glass operations. Primary opportunities for improving the energy efficiency of oxy-fuel firing for the glass industry include further improving oxygen generation technology, increasing waste heat recovery, and optimizing the purity of oxygen required for individual furnaces. There is ample opportunity for additional glass industry conversions that would reduce energy use, as penetration is currently less than 50% in almost every sector, and significantly lower in the flat and container sectors.

The combustion community also continues to focus on the potential of oxy-fuel firing. This coming September, the 2001 Joint International Combustion Symposium, sponsored by the American Flame Research Committee, the Japanese Flame Research Committee, and the International Energy Agency, will primarily focus on recent advanced and future trends in oxy-fuel technology (AFRC, JFRC, and IEA 2001).

In summary, the DOE looks forward to continuing the advancement of oxy-fuel technology, and will work with its industrial constituents to reduce energy use and emissions through the application of this technology, both in the glass industry and in other industries.

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