

# 80th Conference on Glass Problems

Edited by  
S.K. Sundaram

*Ceramic*  
**T***ransactions*  
Volume 268



WILEY



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# 80<sup>th</sup> Conference on Glass Problems

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A Collection of Papers Presented at the 80<sup>th</sup> Conference on  
Glass Problems  
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# Foreword

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The 80<sup>th</sup> Glass Problem Conference (GPC) was organized by the Kazuo Inamori School of Engineering, The New York State College of Ceramics, Alfred University, Alfred, NY 14802 and The Glass Manufacturing Industry Council (GMIC), Westerville, OH 43082. The Program Director was S. K. Sundaram, Inamori Professor of Materials Science and Engineering, Kazuo Inamori School of Engineering, The New York State College of Ceramics, Alfred University, Alfred, NY 14802. The Conference Director was Robert Weisenburger Lipetz, Executive Director, Glass Manufacturing Industry Council (GMIC), Westerville, OH 43082. The GPC Advisory Board (AB) included the Program Director, the Conference Director, and several industry representatives. The Board assembled the technical program. Donna Banks of the GMIC coordinated the events and provided support. The Conference started with a half-day plenary session followed by technical sessions. The themes and chairs of four technical sessions were as follows:

## **Melting and Combustion**

Uyi Iyoha, Praxair, Inc., Peachtree City, GA, Jan Schep, Owens-Illinois, Inc., Perrysburg, OH, and Justin Wang, Guardian Industries, Auburn Hills, MI

## **Batch, Environmental, and Modeling**

Phil Tucker, Johns Manville, Littleton, CO and Chris Tournour, Corning Inc., Corning, NY

## **Refractories**

Larry McCloskey, Anchor Acquisition, LLC, Lancaster, OH and Eric Dirlam, Ardagh Group, Muncie, IN

## **Sensors and Control**

Adam Polycn, Vitro Architectural Glass, Cheswick, PA and Glenn Neff, Glass Service USA, Inc., Stuart, FL



# Preface

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This volume is a collection of papers presented at the 80<sup>th</sup> year of the Glass Problems Conference (GPC) in 2019. The GPC continues the tradition of publishing the papers that goes back to 1934. The manuscripts included in this volume are reproduced as furnished by the presenting authors, but were reviewed prior to the presentation and submission by the respective session chairs. These chairs are also the members of the GPC Advisory Board.

As the Program Director of the GPC, I am thankful to all the presenters at the 80<sup>th</sup> GPC. This year's meeting was record breaking in many sense. We had a total of 570 registered attendees including 40 students from across the country. I appreciate all the support from the members of Advisory Board. Their volunteering sprit, generosity, professionalism, and commitment were critical to the high quality technical program at this Conference. I also appreciate continuing support and strong leadership from the Conference Director, Mr. Robert Weisenburger Lipetz, Executive Director of GMIC and excellent support from Ms. Donna Banks of GMIC in organizing the GPC. I look forward to continuing our work with the entire team in the future.

Please note that The American Ceramic Society and myself did minor editing and formatting of these papers. Neither Alfred University nor GMIC is responsible for the statements and opinions expressed in this volume.

S. K. Sundaram  
Alfred, NY  
*March 2020*



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Finally, I am indebted to Donna Banks, GMIC for her patience, support, and attention to detail in making this conference a big success and this Proceedings possible.



# PLENARY SESSION

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# FUTURE OF OXY-FUEL GLASS MELTING: OXYGEN PRODUCTION, ENERGY EFFICIENCY, EMISSIONS AND CO<sub>2</sub> NEUTRAL GLASS MELTING

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## ABSTRACT

Over 300 commercial glass melting furnaces have been successfully converted to oxy-fuel firing worldwide since 1991 when the first full oxy-fuel conversion of a large container glass furnace took place. The main benefits of oxy-fuel conversion are fuel reduction, glass quality improvement, emissions reduction (CO<sub>2</sub>, CO, NO<sub>x</sub>, SO<sub>2</sub>, particulates), and productivity improvements. Significant changes in the melting and fining behaviors were observed under oxy-fuel firing. Most furnaces required some batch modifications to optimize the glass fining chemistry and to control foam. Improved oxy-fuel burner and furnace designs have reduced alkali volatilization and silica crown corrosion. Silica crown is expected to last for a full furnace campaign, especially with new no-lime silica bricks. Today most of high-quality specialty glass products such as LCD display glass and fiber glass are melted in oxy-fuel fired glass furnaces. Oxy-fuel conversion of large soda lime glass furnaces, however, has been limited to about sixty container and ten float/flat glass furnaces due to the additional cost of using oxygen. Key factors to improve the economics of oxy-fuel fired such as efficiency of air separation technology and waste heat recovery are reviewed. The potential of using hydrogen and renewable fuels with oxygen to reduce CO<sub>2</sub> emissions is also discussed.

(key words: oxy-fuel, glass melting, CO<sub>2</sub> reduction, hydrogen combustion)

## INTRODUCTION

In 1988, the U.S. Department of Energy awarded a program to Praxair, Inc. (a member of the Linde group now) to demonstrate the use of oxy-fuel combustion in a large commercial glass furnace using an on-site vacuum-pressure swing adsorption (VPSA) technology. A container glass furnace at Gallo Glass Company was rebuilt in 1991 as the first large scale oxy-fuel fired furnace<sup>1</sup>. The successful conversion of the furnace and the demonstration of significant fuel savings (15%) and emissions reduction (80% reduction in NO<sub>x</sub> and CO, and 30% particulates) stimulated the glass industry to adopt the new technology at a rapid rate. By 1996 about 90 commercial glass furnaces were converted to oxy-fuel firing worldwide<sup>2</sup>. Although the rate of oxy-fuel firing conversions slowed down since then, over 300 commercial glass furnaces are fired with oxygen today. Most of specialty glass furnaces such as LCD glass furnaces are fired with oxygen as high glass melting temperature, relatively small furnace size and the high glass quality requirement made oxy-fuel firing more economic. Over one hundred insulation and reinforcing glass fiber furnaces have been converted to oxygen firing as large fuel savings are achieved when air fired recuperative furnaces are converted to oxy-fuel firing. About fifty container glass furnaces and about ten float/flat glass furnaces have been converted for NO<sub>x</sub> reduction, production rate increase, and capital cost reduction.

Most of fuel efficiency gains of oxy-fuel fired furnaces come from the elimination of nitrogen contained in combustion air (i.e., about 78% N<sub>2</sub> and 1% Ar by volume) and the corresponding reduction in the flue gas sensible heat loss<sup>3</sup>. Fuel savings of 5 to 50% have been achieved without using any flue gas heat recovery systems under oxy-fuel firing as compared with

various air fired furnaces. Fuel savings achievable by oxy-fuel conversion depend on the type of heat recovery systems used in the air fired furnaces and their conditions. About 10 to 15% fuel savings have been achieved on the furnace campaign average for large container and float glass furnaces equipped with efficient regenerators to preheat combustion air to about 1300C. The efficiency of regenerators deteriorates with furnace age due mainly to deposits build up in the regenerator passage and to increase in air infiltration<sup>4</sup>. For example, specific fuel consumption for an air fired regenerative furnace may increase by 16% over 12 years (i.e., 1.35% per year)<sup>5</sup>, while that for oxy-fuel fired furnace without heat recovery may increase only by 6% over 12 years. Thus, fuel savings by oxy-fuel firing is relatively small in early furnace campaign and increases as the furnace ages. For fiber glass furnaces with metallic recuperators fuel savings by oxy-fuel conversion are typically in a range of 30 to 50%. Metallic recuperators can preheat combustion air only up to about 800C and the furnace energy efficiency is significantly lower than the furnaces equipped with regenerators. For small specialty glass furnaces operating at high temperatures, fuel savings over 50% have been achieved in some furnaces since small recuperators and regenerators are not very efficient.

Reduction of NO<sub>x</sub> emissions was an important benefit and an economic driver for oxy-fuel conversion, especially in the U.S.. Due to the high furnace temperature required for glass melting significant “thermal NO<sub>x</sub>” is formed in the flame region. The rate of formation of thermal NO<sub>x</sub> is strongly temperature dependent and approximately proportional to the concentration of nitrogen in the furnace. The conversion of an air fired furnace to oxy-fuel firing typically results in NO<sub>x</sub> reduction by 80 to 90% as the nitrogen concentration in the furnace is reduced from about 70% in the air fired furnace to about 5 to 10% in typical oxy-fuel fired furnaces. Other key factors influencing NO<sub>x</sub> emission are oxy-fuel burner design which influences the peak flame temperature, excess oxygen and batch nitrogen content<sup>6</sup>.

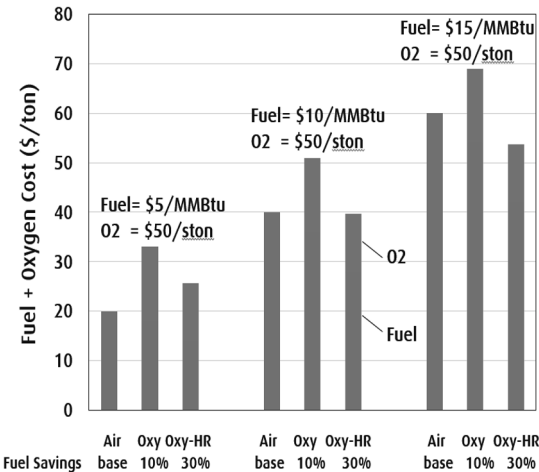
Melting and fining behaviors change significantly under oxy-fuel firing due to the interaction between the furnace atmosphere and glassmelt and changes in the heat transfer characteristics. The concentration of water vapor in the furnace atmosphere is about 16-18% in the air-natural gas fired furnace, which increases to 50-55% in the oxy-fuel fired furnace. Higher water vapor concentration increases water dissolution into glassmelt and enhances fining reactions<sup>7</sup>. Extensive laboratory studies and mathematical modeling have been conducted to investigate heat transfer, glass fining, alkali volatilization and refractory corrosion mechanisms under oxy-fuel firing. Most furnaces required some batch modifications to optimize the glass fining chemistry<sup>8</sup>. Although accelerated silica crown corrosion was experienced in early conversions, improved burner and furnace designs and the development of new silica crown materials with low lime extended the life of the silica crown close to that of a conventional air fired furnace<sup>9-10</sup>. A review paper<sup>11</sup> describes technical differences between oxy-fuel firing and the air-firing in more details.

Recent advances in oxygen production and oxy-fuel technology aim to make oxy-fuel glass melting a more cost-effective solution to meet the sustainability goal of CO<sub>2</sub> reduction. For example, the efficiency of air separation technology has improved and the power consumption to produce oxygen has decreased significantly. Advanced waste heat recovery technologies for oxy-fuel fired furnaces have also been developed to reduce the fuel and oxygen requirement for oxy-fuel furnaces<sup>12-14</sup>. Oxy-hydrogen combustion is considered a leading option for glass melting of future. This paper reviews the key economic factors of oxy-fuel glass melting and discusses the future of oxy-fuel combustion for CO<sub>2</sub> neutral glass melting.

## ECONOMICS OF OXY-FUEL FIRING

The economics of oxy-fuel conversions depends mainly on the fuel savings achievable, fuel cost and oxygen cost for operating cost comparison. The value of fuel savings needs to be greater than the cost of oxygen to achieve a net saving in the operating cost when other oxy-fuel benefits such as NOx reduction and production rate increase are not considered. Many air fired furnaces less than 100 tpd capacity were converted to oxy-fuel firing as the small waste heat recovery systems, especially recuperators, are not very efficient and large fuel savings of 40-50% were achieved. For large container and float glass furnaces with efficient regenerators about 10 to 15% fuel savings have been achieved on the furnace campaign average. The economic drivers for the conversion were capital cost savings of eliminating regenerators, especially for green field projects, furnace capacity increase, and NOx reduction.

Figure 1 compares the fuel and oxygen costs for a generic 300 mtpd (metric ton per day) container glass furnace with 50% cullet and no electric boosting at three different fuel costs of 5, 10 and 15 dollars per MMBtu HHV (million Btu in higher heating value) and at a constant oxygen cost of \$50/ston (short ton). For the typical natural gas composition represented as methane, one short ton of O<sub>2</sub> is required to combust about 12 MMBtu (HHV) of natural gas. The baseline specific fuel consumption for the air fired furnace with regenerators is 4 MMBtu/ston and fuel and oxygen savings of 10% and 30% are assumed for oxy-fuel firing without heat recovery (“Oxy”) and oxy-fuel firing with heat recovery (“Oxy-HR”) respectively. At the low fuel cost of \$5/MMBtu the baseline melting cost is \$20/ston of glass. With 10% fuel savings the specific fuel cost and the oxygen cost are \$18 and \$15 per ston of glass respectively. The combined cost of \$33 per ston is higher than the baseline cost. Even with 30% fuel savings achieved by using a flue gas heat recovery system with oxy-fuel firing the combined cost of melting increases by \$5.7/ston. At \$10/MMBtu the melting cost of Oxy-HR becomes slightly less than the air case and at a high fuel cost of \$15/MMBtu about \$5/ston savings in melting cost is projected with Oxy-HR. This example illustrates that achieving high fuel savings and reducing oxygen cost are key economic factors to make oxy-fuel glass melting as the economic choice in the future.



**Figure 1.** fuel and oxygen costs for a generic 300 mtpd (metric ton per da ) container with 50% cullet and no electric boosting

## OXYGEN GENERATION TECHNOLOGY

Oxygen for glass furnace conversion applications is typically supplied by the on-site oxygen generation system using a vacuum-pressure swing adsorption (VPSA) technology and backed up with delivered liquid (LOX) in a storage tank. Most of oxy-fuel fired flat glass furnaces use cryogenic air separation systems as the nitrogen co-produced from the cryogenic separation system is used for the float tank. Cost of oxygen is highly site specific and involves many factors including the plant size, electric power cost, VPSA equipment, manufacturing, construction, engineering and operation. Electric power cost is typically the most important cost element and constitutes about 1/3 to 2/3 of the overall oxygen cost depending on the power cost and the plant size. Advancements in the air separation technology have reduced the power required to separate air to make oxygen (kwh/ton O<sub>2</sub>) over the years. Figure 2 shows a historical trend and expectation for future in a relative scale by assigning 100% for year 2019. Specific power consumption was about 40% higher in 2000. The trend is likely to continue and further improvements of 20-30% reduction are expected in the next 5 to 10 years.

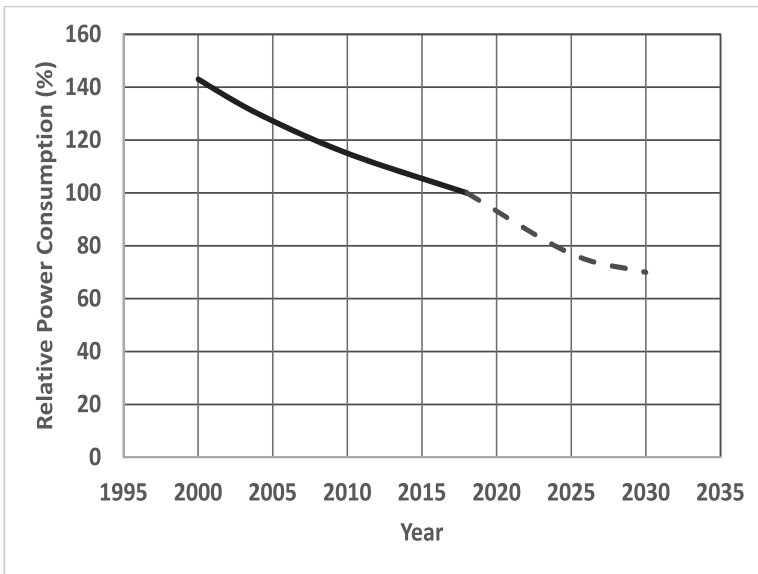


Figure 2. Historical trend of specific electric power consumption to make VPSA oxygen

## ENERGY EFFICIENCY IMPROVEMENTS FOR FUTURE

In a large oxy-fuel fired glass furnace without flue gas heat recovery about 25-30% of the heat generated by combustion is lost in the sensible heat of flue gas and the balance is available in the furnace to melt glass batch/cullet and to compensate for the wall heat losses. Figure 3 shows projected improvements on specific fuel consumption for a 300 tpd oxy-fuel fired container glass furnace with 50% cullet and no electric boost. Without any flue gas heat recovery the baseline fuel consumption is 3.7 GJ LHV/t (lower heating value per metric ton or 3.52 MMBtu HHV/ston) for this state-of-the-art oxy-fuel fired furnace. The electric energy consumption for oxygen production is assumed to be 250 kWh/t O<sub>2</sub> generated and the primary fuel required to produce the electricity was assumed to be 9 MJ/kWh at 40% electric power generation efficiency. With the assumed primary fuel required to make oxygen overall fuel consumption becomes 4.3 GJ/t. With a full flue gas heat recovery system to reduce flue gas temperature to 250°C specific fuel consumption of 2.85 GJ/t is projected and the oxygen requirement is reduced proportionally.