Technologies to decarbonise the glass industry

Ranajit Ghosh* and Michael J. Gallagher** discuss technologies which provide glass manufacturers in the early stages of their decarbonisation journey with a viable pathway to achieve their goals.

As global glass manufacturers work towards fulfilling their decarbonisation goals, there is still uncertainty to which technological path will be the most practical and economical in terms of the source of carbon-free energy for glass melting.

Renewable electricity used for direct melting of glass via joule heating consumes the least amount of power compared to paying the energy penalty of producing green hydrogen via electrolysis followed by combustion.

Nevertheless, there are still challenges in the widespread and continuous availability of green electricity and to scaling up electric furnaces beyond 400 tons per day.

There are other issues including the shorter lifetime of electric furnaces from accelerated wear of refractories. Also, as glass is only electrically conductive in the molten state, the melting cycle must be initiated using chemical energy from combustion processes. Finally, melting energy from combustion will also be needed to supplement renewable power from wind and solar during intermittency events or power outages.

Therefore, practically speaking, an electric-combustion hybrid furnace seems to be the most logical choice for supplying energy for the continuous, uninterrupted production schedule that most furnaces operate with.

To minimise the carbon footprint in combustion, blue or green hydrogen will be needed and industrial gas suppliers, including Air Products, are working on several such projects to build the supply and distribution infrastructure.

Technical complexities related to the integration of chemical and electrical melting and the commercial viability at scale, for reduced-carbon or carbon-free processes, make large-scale adoption of such technologies challenging. There are technologies available today though that glass manufacturers can implement to start their decarbonisation journey and make an immediate impact on carbon emissions. Combining an oxy-fuel combustion system with energy recovery technology is one example of a well-established process that can reduce carbon dioxide (CO_2) emissions by as much as 30% compared to an air-fired regenerative glass furnace.

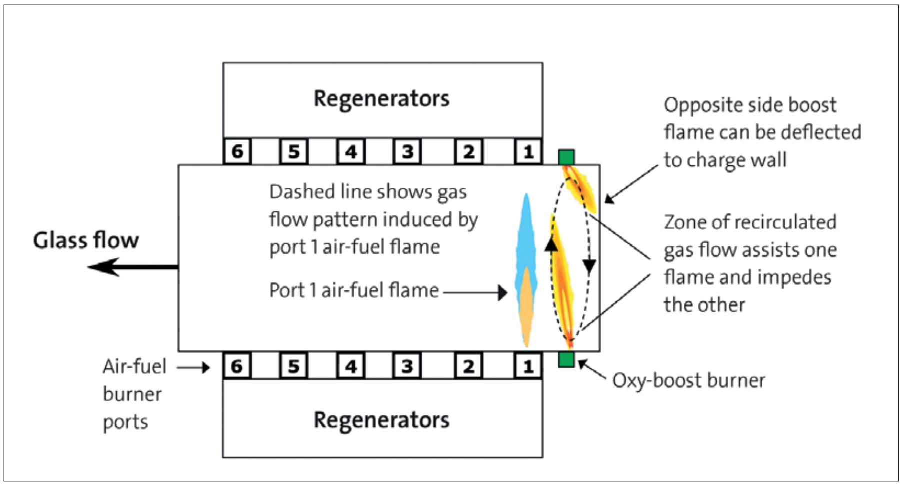

Fig 1. Deflection of the oxy-fuel boost burner flames due to recirculated gas flow.

The conversion to oxy-fuel systems has the added advantage of requiring minimal changes to current production methods and furnace designs, while reducing furnace footprint.

CO_2 emissions can be further reduced with natural gas and hydrogen (NG/H_2) fuel blends by combining oxy-fuel combustion with energy recovery.

For example, assuming a blended NG/H_2 fuel comprised of 30% energy content from H_2 and the balance from natural gas, up to 50% CO_2 emissions savings can be achieved as compared to traditional air-fired glass melting furnaces.

In addition, as smart technologies, including artificial intelligence and machine learning, continue to grow, their adoption into glass manufacturing will lead to further innovations that increase efficiency and/or prevent additional CO_2 emissions.

Adopting industrially-proven decarbonisation technologies using a phased approach can substantially reduce the risk of upsetting production and provide glass manufacturers a commercially viable pathway towards their decarbonisation goals.

Air Products has been working with manufacturers to develop technologies to reach their decarbonisation goals.

The stepwise approach from air-fuel to oxy-fuel with energy recovery and integration of smart technology for improving efficiency, as outlined in the next sections, would provide manufacturers in the early stages of their journey with a viable pathway to achieve their complete goal.

Synchronised oxy-fuel boost

Zero-port oxy-fuel boost burners have

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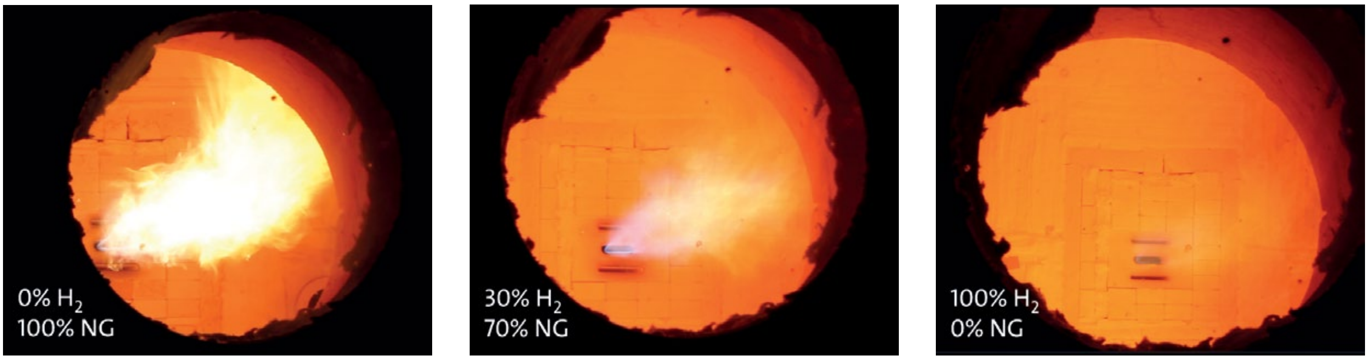

Fig 2. The HRx burner firing various blends of hydrogen + natural gas (by volume). The flame luminosity decreases dramatically as the content of hydrogen increases.

become widely accepted in float glass melting furnaces as a valuable means for increasing glass production and/or improving efficiency.

However, boost burner effectiveness is limited by flame interaction with the highly turbulent air-fuel flames.

Both the strength and direction of these oxy-fuel flames versus air-fuel flame interactions are shifted following each regenerator reversal cycle.

The result of these effects can include overheating of the charge wall and 'snubbing' of the flame, causing concentrated heat release close to the breast wall and/or flame lofting toward the crown (***Fig 1***).

By understanding the nature of these interactions, Air Products' researchers have developed a smart burner technology capable of automatically adjusting flame properties (particularly length, luminosity and momentum) with each regenerator reversal to avoid negative effects, while maximising oxy-fuel performance benefits.

Results show a 2-3% reduction in energy consumption, a 12° Fahrenheit reduction in crown temperature and a simultaneous reduction of 8% and 21% in bubbles and stones, respectively, over a non-synchronised oxy-boost burner.[1]

Combustion system

Air Products has focused on developing an integrated oxy-fuel combustion system for the glass industry that combines oxy-fuel burner technology, a low-pressure Vacuum Swing Adsorption (VSA) oxygen delivery system, and an energy recovery technology that utilises flue gas waste energy to preheat oxygen and natural gas.

The centrepiece technology is the Cleanfire HR_x burner, which is a flat-flame, low-nitrogen oxide (NOx) oxy-fuel burner with oxygen staging capability.

The HR_x burner, with its secondary foam control capability and efficient directional heating, has been proven to increase oxy-fuel melting efficiency compared to other burner technology.

The technology was further enhanced to operate at low oxygen supply pressures and with high temperature oxygen and natural gas.

The low-pressure VSA offers the benefits of lower power consumption, higher reliability and lower CO_2 footprint due to the removal of the oxygen compressor.

Oxygen is delivered with pressure of approximately five pounds per square inch-gauge (psig) (345 millibar-gauge) with no loss in combustion performance.

The newest addition to the Integrated System is our Energy Recovery system offering using series-connected heat exchangers for preheating of oxygen to 550° Celsius and natural gas to 450° Celsius.

The Energy Recovery system alone has the capability of reducing fuel consumption and carbon emissions by as much as 10-12%. For glass manufacturers which convert from air-fired regenerative furnaces, a fuel savings and carbon emissions reduction of up to 30% could be achieved.

HR_x burner with H_2 blending

According to the International Energy Agency (IEA), the annual production of low-emission hydrogen could reach 38 megatons in 2030, if all announced projects are realised.[2]

Air Products has made investments in blue and green hydrogen and ammonia production. An example is the NEOM Green Hydrogen project[3] located in Saudi Arabia, where abundant wind and solar power will generate green hydrogen.

The hydrogen will be converted to ammonia to be shipped to other regions of the world where it will be converted back into hydrogen for decarbonising the transportation sector and other industries.

Replacing natural gas with hydrogen for combustion comes with its own challenges and there are unknowns that can impact glass production. These unknowns include the effect on combustion performance (NOx and heat transfer), the concern over potential increases in melting defects, and premature degradation of furnace refractory leading to reduced furnace lifetime.

Over the past few years, research has been conducted to study hydrogen combustion in glass furnaces and several short-term demonstrations have shown positive results with few negative consequences.[4]

The HR_x burner was also used in similar hydrogen trials and the results show that the burner can fire up to 50% hydrogen/50% natural gas blends (by volume) without needing any modifications to the burner design or refractory block.

Higher hydrogen blends will require minor changes to the burner nozzle, without requiring any alterations to the refractory block.

Figure 2 is an example of the HR_x burner flames with 0%, 30%, and 100% H_2 + natural gas blends (by volume).

The flame's luminosity diminishes as the hydrogen concentration increases and the flame length tends to shorten due to the rapid reaction kinetics of hydrogen-oxygen combustion.

To counteract unwanted shortening of the flame, the HR_x burner's oxygen staging feature delays mixing of fuel and oxidizer, which allows for precise control of flame length and heat release.

Additionally, the core flame temperature is reduced with higher levels of oxygen staging and this is known to prevent NOx formation.

Gallagher, et. al demonstrated the reduction of NOx as well as control of

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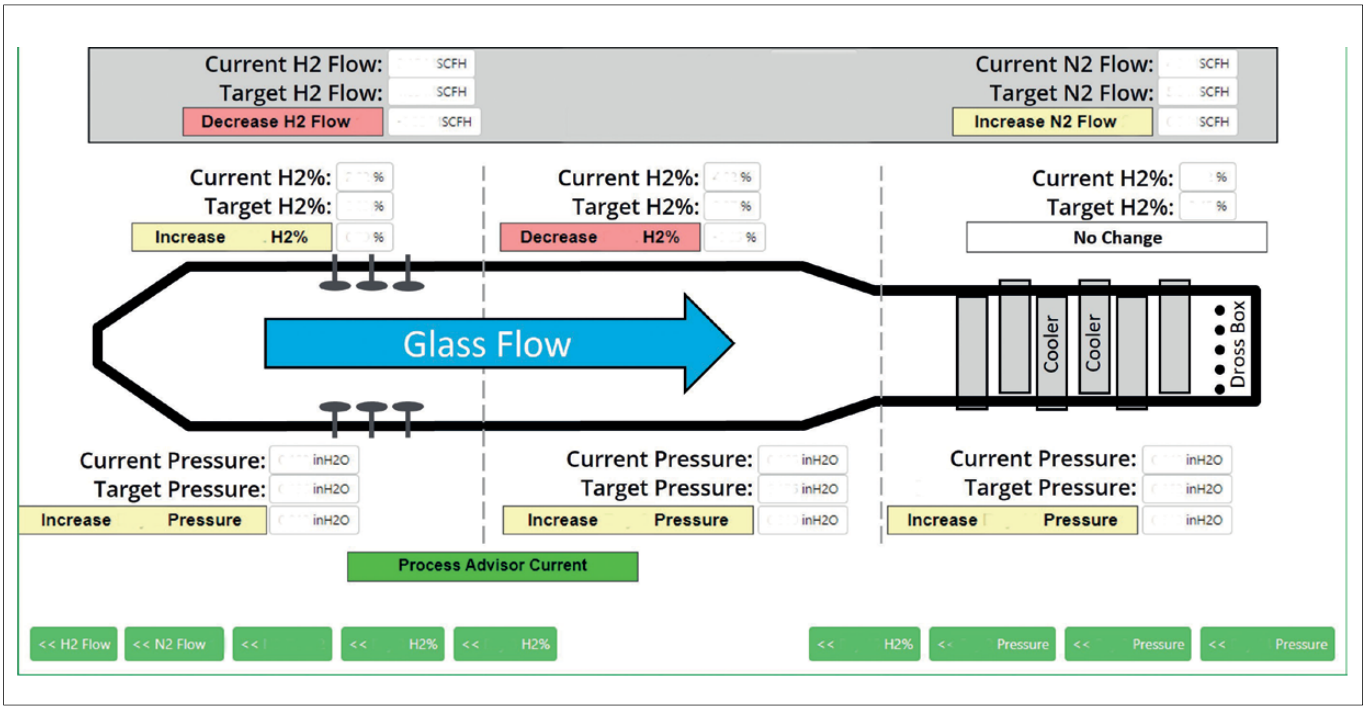

▲ Fig 3. Tin Bath Process Advisor

flame length for hydrogen blends up to 30% (by volume) using oxygen staging feature of the HR_x burner.[5]

Smart technologies

Smart technologies using Artificial Intelligence (AI) with machine learning are being developed across many industries with the goal of improving production speed and/or product quality.

Air Products has developed a novel, smart system to reduce tin-based defects in float glass.

Its Tin Bath Monitoring and Optimisation system uses AI algorithms to analyse hundreds of process variables, including defect data, in real-time to drive down tin-based defects and/or to optimise hydrogen and nitrogen consumption within the tin bath.

A digital twin of the tin bath runs alongside the actual process and provides operators with the information they need for optimum real-time control (***Fig 3***).

Furthermore, as the condition of the furnace changes over time, machine learning allows the programme to self-update without human intervention.

The system was developed and successfully tested with a float glass manufacturer and has been in continuous operation for more than two years.

This solution is an example of how AI can be used within the glass industry to increase efficiency and reduce excess consumption of gases.

Such optimisation will save energy and reduce defects, which in turn reduces the plant's overall carbon footprint.

Conclusion

Air Products is committed to developing technologies that help customers use industrial gases more efficiently in their processes.

We believe the glass industry can start to decarbonise now by adopting commercial-ready technologies that provide an immediate reduction in CO_2 emissions without upsetting production or affecting profitability.

Our research and development laboratories and our diverse team of engineers are focused on developing technical solutions for the glass industry and we look forward to helping the industry make these changes as the future of decarbonisation unfolds. ■

*PhD, Director, Applications R&D,
**PhD, Technology Lead, Combustion Glass,
Air Products and Chemicals, Allentown, PA, USA,
www.airproducts.com/melting-glass

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