Oxygen-Solid Fuel Combustion in Glass Melting Furnaces

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Abstract

With prices of conventional fossil fuels such as natural gas and fuel oil projected to remain relatively high in several regions of the world while the global demand for glass production is comparatively low, many glass manufacturers, particularly in Asia and Latin America, are viewing petroleum coke (petcoke) and, secondarily, coal as potentially viable, low-cost, alternative fuels. There are, however, certain challenges and risks associated with solid fuel utilization for glass melting that need to be understood prior to commercial adaptation. And while petcoke / coal combustion may not be an acceptable choice in every case, Air Products' experience and know-how suggest that enhancement of solid fuel combustion with oxygen will broaden its successful adaptation in glass melting applications relative to the use of air-fuel combustion. This paper explains the challenges and risks of petcoke and coal combustion for glass melting, and via laboratory and field data, highlights the benefit that oxygen enrichment can bring.

Properties of Petcoke and Coal

Petcoke is a solid, essentially carbonaceous, by-product of crude oil refining. As such, it is not surprising that petcoke chemical properties are quite similar to heavy fuel oil (HFO). This is illustrated in Tables I and II, where relevant property ranges are shown for the two types of fuel. Although properties vary substantially with the crude oil source and refinement method, it is evident that, apart from marginally higher sulfur and ash content, (fuel grade) petcoke and heavy fuel oil are, chemically, very similar. Moreover, comparison of petcoke with bituminous coal (Table II) reveals that petcoke generally has much lower volatile matter content and ash content. The low ash content makes petcoke more attractive for glass melting than coal, since it reduces the risk of ash mineral-related glass contamination and defects, and also lowers particulate emissions. However, as subsequently explained, the low volatile matter represents a principal challenge in the effective utilization of petcoke for glass melting.

Table I
Major Constituents of Typical Fuel Grade Petcoke and Heavy Fuel Oil
(wt%, dry basis)

Constituent	Fuel Grade Petcoke	Heavy Fuel Oil
Carbon	85 - 90	83 - 88
Hydrogen	3 - 6	10.5 – 11.0
Nitrogen	0.1 – 2.0	0.15 – 0.40
Oxygen	0 – 1	0.35 – 0.40
Sulfur	4 – 7	2 – 4
Ash	0.1 – 0.5	0.04 – 0.20
Moisture	0.5 – 10	0.3

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Table II
Trace Metals of Typical Fuel Grade Petcoke and Heavy Fuel Oil
(ppmw of ash)

Fly Ash Metal	Fuel Grade Petcoke	Heavy Fuel Oil
Aluminum, as Al_2O_3	40,000 – 70,000	3500 – 123,000
Calcium, as CaO	10,000 – 155,000	5300 – 25,700
Chromium	10 – 100	48 - 4390
Iron, as Fe_2O_3	10,000 – 70,000	9500 – 488,000
Manganese	70 – 300	64 - 1170
Magnesium	15,000 – 24,000	2300 – 211,000
Molybdenum	10 - 20	22 – 2860
Nickel	1200 – 7500	820 – 41,600
Potassium, as K_2O	1000 – 12,000	400 – 80,600
Silicon, as SiO_2	12,000 – 350,000	6000 – 216,000
Sodium, as Na_2O	1800 – 14,000	1632 - 2480
Vanadium, as V_2O_5	500 – 400,000	2200 – 112,000

Combustion Challenges of Petcoke

Of all the properties highlighted in Table III, volatile matter, which comprises several light and heavy hydrocarbons, is the one with the most significant effect on practical petcoke combustion. In particular, the lower the volatile matter, the more difficult the solid fuel is to ignite. Data obtained by Air Products and presented in Figure 1 indicate, for example, that when ignited in room temperature air, petcoke having 10 wt% volatile matter has an ignition energy that is several orders of magnitude higher than a common bituminous coal having 35 wt% volatiles. This more-difficult-to-achieve ignition of petcoke relative to bituminous coal renders its efficient combustion with air difficult to achieve in many applications such as glass melting furnaces, where relatively short residence times are available for the solid fuel to heat up, ignite and burn.

Table III
Trace Metals of Typical Fuel Grade Petcoke and Heavy Fuel Oil
(ppmw of ash)

	Fuel Grade Petcoke	Heavy Fuel Oil
Sulfur	4 – 7	2 – 4
Ash	0.1 – 0.5	6 – 12
Volatiles	8 – 12	30 - 40

The most commonly applied remedial measure for addressing combustion residence time limitations is fine pulverization of the fuel. In coal combustion, for example, it is generally accepted that grind sizes of the order of 70 wt% or greater of the solid fuel passing through a 200 mesh screen (aperture size of approximately 75 microns) are required for efficient combustion with entrained-flow burners. Fine pulverization is indeed essential in applications having limited residence time, of which glass melting is one, yet industry experience suggests that fine pulverization alone is generally not sufficient, particularly in the case of petcoke. This is because while combustion rates are increased for finer particles (due to more abundant surface area), the added surface area has little effect on ignition energy[1].

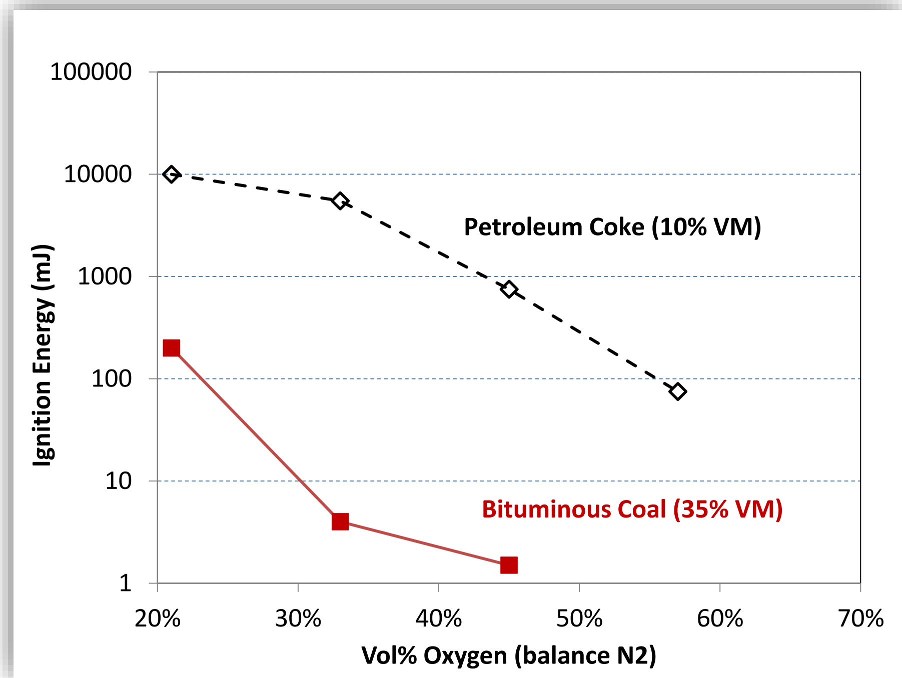

Figure 1.
Ignition energy vs oxygen concentration for typical petcoke and bituminous coal.

However, as seen in Figure 1, when the aforementioned petcoke and bituminous coal ignition energy data are extended to include the effect of oxygen enrichment on the ignition atmosphere, a dramatic reduction in ignition energy is thereby obtained. And although an oxygen atmosphere of 50 mol% (balance N2) is needed to lower the petcoke ignition energy to that of the air-bituminous coal mixture, much lower levels of oxygen enrichment, properly applied, can have a substantial beneficial effect on combustion kinetics.

To illustrate this point for an application with commercial relevance to glass melting, several industrial-scale solid fuel injection nozzles were tested in Air Products Clean Energy Laboratory (CEL), a pilot-scale, multi-fuel facility capable of firing rates up to 20 MMBtu/hr. Key results obtained during the development are highlighted in Figures 2 and 3. The photos in Figure 2, were taken in the CEL for two different simulations of oxygen enhanced combustion of an air-petcoke stream. Both scenarios represent identical conditions in firing rate, transportation air flow rate and overall flame stoichiometry, but differ as to the manner in which oxygen is introduced into the flame. In photo A, transportation air alone, amounting to approximately 10% of the total stoichiometric requirement, conveys the petcoke into a furnace, while the balance of oxygen required for complete combustion is lanced in a parallel stream immediately beneath the injector. By contrast, photo B shows

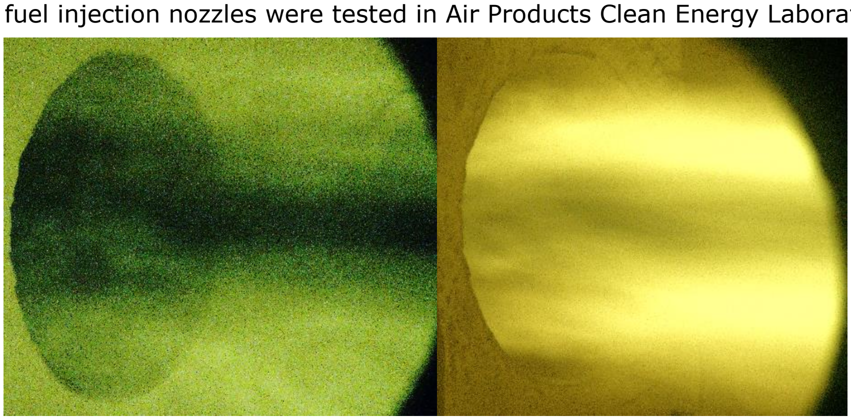

Figure 2. Photos of petcoke flame.
A (left): Air-petcoke flame with oxygen staging.
B (right): Oxygen-enriched air-petcoke flame using SF Port Injector.

the flame produced by Air Products' CLEANFIRE® SF Port Injector (SF for solid fuel), wherein a small fraction of the combustion oxygen is mixed with petcoke within the injector in a proprietary manner, while the balance of oxygen for complete combustion is lanced within the same parallel stream beneath the flame. The early ignition of petcoke with the SF Injector, leading to an "attached" flame, is clearly evident. We have repeatedly observed how, relative to a "lifted" or "detached" flame (as in photo A), the attached flame stabilizes combustion and substantially reduces flame pulsations and furnace pressure fluctuations, while increasing carbon burnout and heat transfer from the flame to its surroundings. Regarding heat transfer to the surroundings, the crown temperature along the furnace axis was recorded during operation with both the air-fuel and SF injectors. Results are plotted in Figure 3 as a function of distance from the hot face of the injector wall. Note how the furnace crown temperatures for the SF injector are systematically higher across the furnace length by between 50 and 150 degrees F, simply due to the early ignition achieved through optimized mixing of a small fraction of the combustion oxygen within the SF injector. We reiterate that the same total flow rate of oxygen was employed for both cases; only the method of introduction was different. The conclusions to be derived from this illustrated are that a) there is a tremendous potential for enhanced solid fuel energy utilization with oxygen, and that b) the oxygen-solid fuel mixing processes must be well controlled to realize the maximum beneficial effect.

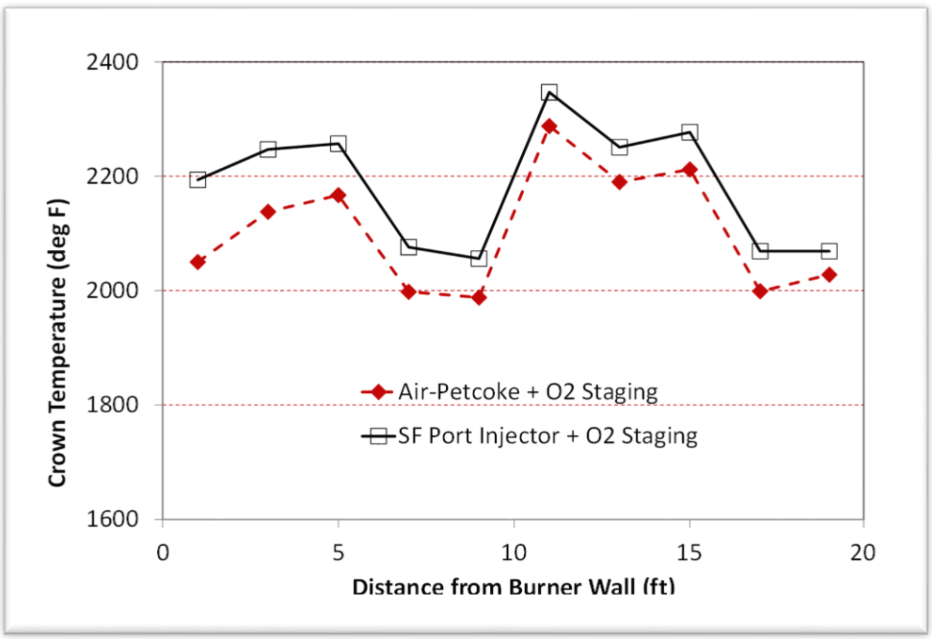

Figure 3.

Lab data showing crown temperature vs distance from burner wall for air-petcoke and SF Port Injector tests.

The lab results for the SF injector vs straight oxygen lancing holds further implication to the effectiveness of port firing of petcoke in a regenerative glass melting furnace. Preliminary results for such an application are provided in a later section of this paper within one of our case studies.

Importance of Solid Fuel Chemistry

Ash from both petcoke and coal contain numerous metals and minerals that have the potential to influence glass quality, color and refractory life. Among these are refractory oxides such as alumina, calcium oxide (lime) and magnesia; metals including sulfur, vanadium and nickel, and naturally carbon, which in and of itself is a strong reducing agent. Non silica-based refractory elements, for example, is known to lead to stones and knots in glass, while inclusions of nickel sulfide, NiS, have been implicated in relation to spontaneous breakage in flat, tempered glass [2]. As such, it is obviously a concern with petcoke firing in float furnaces in particular. Nickel can also impart a color to the glass that varies with the composition of the glass matrix.

Vanadium is a trace metal that is known to react with other commonly occurring ash metals such as nickel, iron and sodium to form high melting point compounds. Silica, alumina and calcium have also been found to adhere to these compounds (once deposited) as separate species[3]. The deposited vanadium compounds, particularly vanadium pentoxide, V_2O_5, and salts such as the various sodium – vanadium compounds, have substantial potential to attack refractory and foul regenerator flow passages. V_2O_5 is a known catalyst with peak activity in the range of 950 – 1300 degrees F [4] and a melting point of approximately 1150 degrees F. Accordingly, in regenerative glass furnaces, deposition and corrosive attack induced by vanadium is particularly prone to occur in regenerators. Finally, vanadium ions in a highly oxidized state are known to affect glass color, typically by imparting either a greenish or brownish tint [5].

A key concern of sulfur in solid fuel is that, via reaction with alkali metals it forms alkali sulfates which can attack and weaken refractory structures [6]. For example, sodium sulfate, Na_2SO_4, which melts at 1623 degrees F is can penetrate and lead to progressive deterioration of alumina-silicate refractories. Of further concern are emissions of sulfur dioxide (SO_2), which is a principle contributor to acid rain, and sulfur trioxide (SO_3) which combines with water vapor to form sulfuric acid, H_2SO_4. The acid then condenses from flue gas in the cold end of the flue gas ductwork, while also forming a condensate mist that can add a visible bluish tint to the furnace exhaust plume. Flue gas scrubbers may be required depending upon regional emissions regulations.

For petcoke in particular, carbon can be the most abundant element in fly ash, and its strongly reducing nature can effect glass redox state [7]. Our experience is that poor petcoke combustion can in practice lead to ash that contains over 90% carbon by weight. Apart from reducing fuel efficiency, which is naturally undesirable, high unburned carbon-in-ash levels produce larger, heavier fly ash particles which are more prone to find their way into both the glass melt and regenerator checker packs. Since, the above mentioned minerals and metals are also constituents of the fly ash, poor combustion will dramatically increase the any deleterious effect of these aforementioned species.

Based on these perspectives, it is clear that the benefits of oxygen enrichment in solid fuel combustion extend beyond fuel efficiency and into the realm of capital and maintenance costs and glass quality.

Material Handling

Combustion systems firing solid fuels can be categorized as directly or indirectly fired. Directly fired systems are those in which coarse fuel is metered and introduced into a grinding mill which, after completion of the grinding process, delivers the pulverized fuel with conveying air into one or more transport lines that carry fuel into the burners. The indirect firing system differs from this in that the pulverization step is decoupled from the transport of the fuel to the burner. The decoupling occurs by short or long term storage of the pulverized fuel in a bin, hopper or other storage container. The indirect firing system is generally preferred for glass melting for at least the following two reasons:

1. For an indirectly fired system, interruptions in the grinding process, which are not uncommon, will not cause an interruption in the fuel being delivered to the furnace.

2. Pulverizers generally require more cool air than is strictly required for lean phase particle transport. Hence, burners in indirectly fired systems are generally smaller, and combustion is less diluted with cool transport air than for directly fired systems.

It is further important to mention that due to its low volatility, long-term storage of pulverized petcoke is generally not plagued by self-heating and spontaneous combustion. Thus, whether or not the pulverization process is carried out onsite or at remote location, storage of the pulverized petcoke onsite is a safe and viable option.

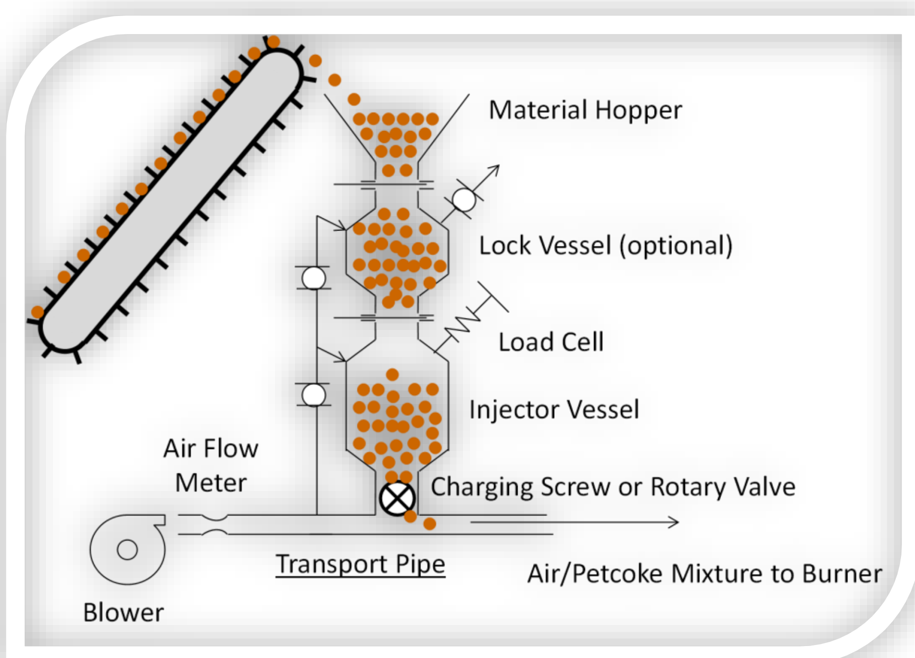

Figure 4.
Typical material handling and transportation system for indirect firing.

Assuming the indirectly fired system is used, the basic material handling equipment package consists of a storage hopper, dust collection system, injector vessel, metering device and transport air blower. One common configuration illustrating the packaging of this equipment, along with auxiliary piping hardware is presented in Figure 4. (Note that while dust collection in the vicinity of the material handling system is strongly recommended, it is omitted from Figure 4 for the sake of brevity.) Many specific design variations are possible within the basic framework of this system. Perhaps the most critical of these relates to the maximum transportation air pressure required at the point of injection of solid fuel into the transportation air line. This is due to the cascading effect that pressure at this initial injection point has upon critical design and operating factors such as air blower / compressor cost and power requirement, material flow stability, dust control, injector vessel design and the need for a pressure isolation vessel. Concerning this latter point, Figure 4 depicts a so-called lock vessel, labeled as optional, which is frequently used for systems where a large pressure increase across the charging screw would otherwise be required. This arrangement provides a buffer between the atmospheric pressure hopper and higher pressure injector vessel, facilitating smooth and continuous material feeding across the charging screw.

In so far as it is highly desirable to maintain the lowest pressure possible at the point of discharge from the charging screw to the transportation line, selection of the transportation air flow rate and transport line size are of considerable importance. Transportation line velocities of between 15 and 30 m/sec are typically acceptable; depending upon particle size, shape and density. Velocity below 15 m/sec can lead to particle drop out and line plugging, while velocity above 30 m/sec will substantially increase both pressure drop and line erosion phenomena. Simultaneously, fuel to transportation air mass flow rate ratios between nominally 1 and 10 are generally preferred for glass melting. A ratio lower than 1 can be too lean for combustion applications, and may promote combustion instabilities, while also diluting the balance of oxidizer mixed at the burner, which will generally be either be hot air or oxygen. Conversely, fuel to transportation air ratios significantly above 10 can bring the onset of unsteady, chugging flow and higher pressure drop associated with dense phase transport. It is emphasized that the stated design ranges for the transportation line are intended for estimation only, and a more precise assessment should include the flow characteristics of the solid fuel particulate as well as details of the transportation line layout.

Concerning integration of the solid fuel handling system with the furnace, the most significant factor is whether or not the glass furnace is of the regenerative type. The regenerative furnace requires periodic side-to-side switching of the fuel delivery. This can generally be accomplished with either a) side-to-side redundancy in the delivery system where only one side delivers petcoke at a given time while the other introduces purge air flow; or b) a single feed system with a switching mechanism coupled to recirculation lines that enable fuel and purge air to be diverted as needed for left or right side firing. While the redundant system (a) requires a higher initial capital cost, it is likely to afford smoother operation during transients, plus less piping complexity and simpler balancing of petcoke flow to each burner. The merits and drawbacks of both systems should be assessed for the particular glass melting application. In this regard, it should be mentioned that non-regenerative furnaces, such as occurs with oxy-fuel, offer the advantage of continuous petcoke delivery to the burners, which will lead to more stable combustion and process conditions than can be achieved in regenerator-based systems.

An additional key factor in material handling system design is whether or not dedicated feeders are used for each burner versus a single feeder with one or more discharge splitters for solid fuel delivery to two or more burners. This, however, requires that burners have been identified by furnace zone that can operate at nominally the same firing rate. Whether or not this level of precision and constraint are acceptable for glass furnace process control needs to be evaluated on a case-by-case basis. A practical example is in regenerative furnaces where fuel delivery to a given port is likely to come from a single feeder and is subsequently split to two or three fuel injectors, depending upon the port firing configuration. It is our experience that evenly splitting a solid fuel delivery header into 3 outlet streams is much more challenging than when only a two-way split is required. Either way, it is crucial to include flow balancing devices such as adjustable/removable orifices or riffles that can be "tuned" during operation to achieve a desired uniformity in flame appearance. We have also found oxygen enrichment at the injector level to be an effective tool in assisting to mitigate the effects of solid fuel flow imbalance on flame appearance and heat release. An example of this is provided in the Case Studies.

Case Studies of Glass Melting with Oxygen-Enriched Solid Fuel Combustion

The following several case studies are intended to briefly highlight a cross-section of key results of our recent experience in oxy-solid fuel combustion for glass melting.

Case 1: Dark Specialty Glass Production using Combination of Oxy-Petcoke and Oxy-Natural Gas Firing
This application utilizes two SF oxy-petcoke burners at the batch end of the nominal 42 tpd cross-fired melter, while the remainder of the furnace comprises 8 Mini HRi™ oxy-gas flat flame burners. Individual feed systems driven by relatively low pressure transportation air blowers deliver the petcoke independently to the two solid fuel burners. The SF burners produce a stable, highly luminous and adjustable-length round solid fuel flame, with back-up gas or oil lances available for rapid fuel-switching between petcoke and other fossil fuels, as dictated for

example by fuel price volatility and/or temporary interruption to the fuel supply. A photo of one of the SF oxy-petcoke flames in this furnace is presented in Figure 5. Note: The SF burners differ from the previously mentioned SF injectors in that the burners are designed for stoichiometric oxy-fuel combustion, while the injectors utilize only a small fraction of the oxygen required for combustion.

Figure 5. Photo of SF Oxy-Petcoke flame in glass melting furnace (Case 1).

Initial results of the switch from full oxy-gas to oxy-gas/petcoke have been favorable. Specifically, bottom temperature beneath the oxy/petcoke burners increased by 10 deg C, and glass quality improved. The fuel-switching experience was not, however, without its challenges, as there were several interruptions in the petcoke pneumatic delivery system early in the project caused by stray material in the fuel supply that required rapid and immediate removal of the SF burner's solid fuel nozzles and immediate replacement with backup oxy-natural gas lances. Overall, the customer is very satisfied with the operation, which has been ongoing for nearly two years, and plans to convert several additional burners to oxy-petcoke in the near future.

Case 2: Dark Specialty Glass Production using Combination of Oxy-Petcoke and Oxy-Fuel Oil Firing
Similar to Case 1, Case 2 is a dark specialty glass produced in a cross-fired oxy-fuel tank with 8 SF burners. Pull rate is nominally 50 tpd. Half of the burners are currently firing petcoke in the melting end of the tank, while the other half are firing heavy fuel oil in the fining end using s Gen1-SF backup oil nozzles. The customer reports that glass quality is as good now as with 100% oxy-oil operation, and plans to eventually convert to 100% oxy-petcoke.

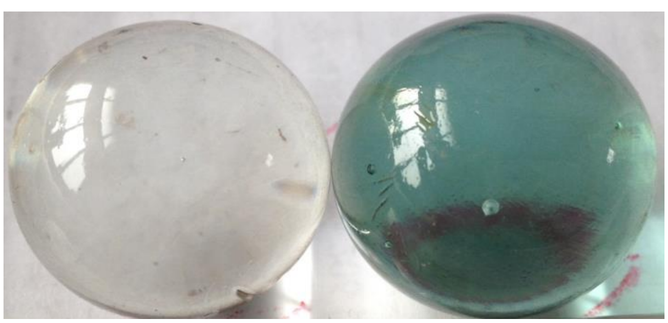

Figure 6. Photo of glass product produced with syngas firing (left) and petcoke firing having high vanadium content and poor combustion (right).

Case 3: Clear Specialty Glass Production using Oxy-Petcoke/Coal Firing
This case involves a small, single-burner 15 tpd melting furnace previously fired with synthetic fuel gas. Notably, the furnace provides very little residence time to achieve complete combustion in comparison to a typical glass melting furnace. Conversion was initially to a single Cleanfire SF burner firing petcoke, but the customer was not satisfied with the color of the product (see Figure 6). Subsequently the customer switched from petcoke to coal and the color problem was resolved. Two factors were identified as being linked to the color problem; high vanadium content and poor combustion. Regarding vanadium content, Table IV summarizes key constituents found in the petcoke from Cases 1 and 3, as well as the coal from Case 3. Note that the magnitude of vanadium, a known coloring agent, in the petcoke from Case 3 was over 10 times higher than either the petcoke from Case 1 or the coal from Case 3.

Table IV
Values represent % of parent fuel

Element	Case 1: Petcoke	Case 3: Petcoke	Case 3: Coal
Vanadium	.018%	.190%	.012%
Iron	Not Sampled	.110%	.096%
Nickel	.0055%	.090%	.035%
Ash	.45%	1.19%	13.1%
Volatiles	10.7%	15%	29%

Combustion problems reported with the petcoke in Case 3 were traced back to a transportation air flow rate that was 2-3 times higher than recommended by Air Products. As such, ignition delay of the petcoke was unavoidable, resulting in significant unburned carbon. Hence, as previously suggested, it is clear that much of the ash-bound vanadium and carbon migrated to the glass melt where it led to redox changes and color contamination of the glass product. It is interesting that, despite the much higher ash content of the coal, the higher coal volatility nevertheless resulted in minimal ignition delay, good combustion and, hence, acceptable glass quality. While it was not possible to differentiate the relative effects on product color of vanadium content versus combustion quality, results from this case affirms the need for attention to be given to ash composition, and further underscores the importance of achieving good combustion.

Case 4: Clear Container Glass Production in a Regenerative Air-Fuel Furnace using Oxygen-Enriched Air Firing of Petcoke

This final case is a 200 tpd regenerative end port furnace producing clear container glass. The customer desired to replace heavy fuel oil with petcoke as the principal fuel, while oxy-natural gas boost was also supplied with Cleanfire Advanced Boost burners. We proposed using oxygen-enriched SF Port Injector technology instead of the combination of air-petcoke injectors plus oxygen lancing, as originally planned by the customer. The first step of this project was thus to compare the two approaches to petcoke combustion. Results are summarized in the photographs of Figure 7.

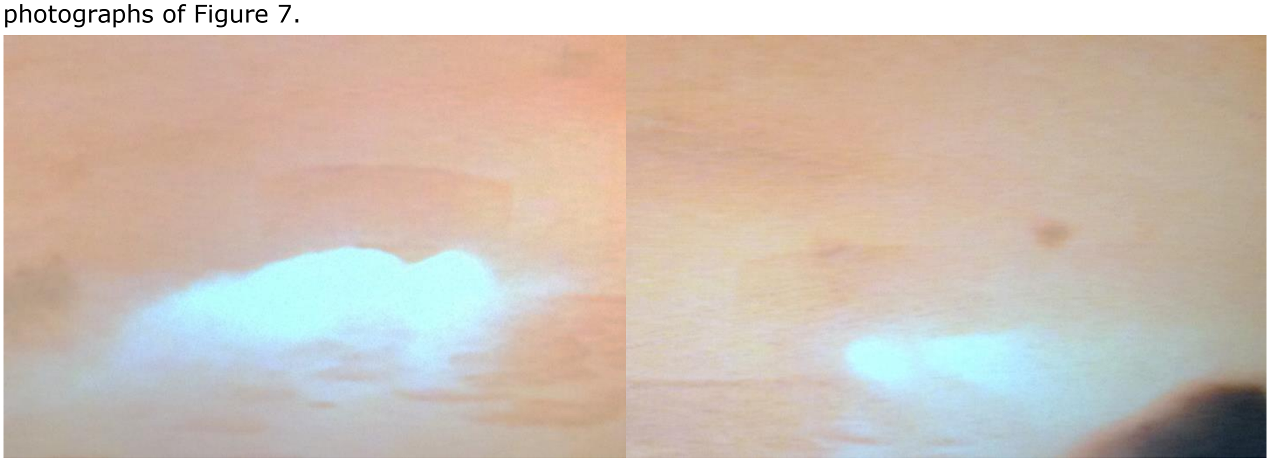

Figure 7. Photos of SF Port Injectors with integral oxygen mixing (left) and air-petcoke injector plus oxygen staging (right) in an end-port regenerative container glass furnace

The photo on the left features three SF injectors, while that on the right shows three air-petcoke lances plus adjacent oxygen lancing. Firing rate and total oxygen enrichment is nominally the same for the two cases. The photos, taken with the same furnace camera, clearly demonstrate that the flames produced by the SF injectors were longer, broader and more luminous than those produced with air-fuel injectors plus O2 lancing. Moreover, close examination of these photos show that while three distinct flames are apparent for the SF injectors, only two can be discerned for the air-fuel lances. The issue here is that a single feeding system with splitting devices was used to supply all three under-port lances on each side of the furnace. However, the fuel split was plagued with imbalances which manifested itself principally in fuel deficiency to the outermost injectors. The fact that the outermost flame is visible, albeit relatively small, for the oxygen-enriched Port injectors, but not readily visible for the air-fuel injectors is, we believe, the result of the oxygen-fuel mixing facilitated by the Port injectors that helped to for the detrimental effects caused by the fuel imbalance. Based on these results the customer chose to move forward using the Port injectors. Note that no negative effects on glass quality have occurred, and while furnace generated NOx has increased somewhat, NOx emissions exiting the SCR system remained the same as they were with air-heavy oil firing. Two key takeaways from this case are that the controlled oxy-fuel mixing occurring within the Port injectors produces a superior flame to the combination of air-fuel injection plus oxygen lancing, and that even splitting of solid fuel streams in pneumatic conveying is inherently challenging and would certainly benefit from strategic placement of balancing devices, as previously suggested.

Economic Considerations

The economic viability of converting of a glass melting furnace from oil or gas to petcoke, as well as that of its ongoing operation, depends upon factors such as the cost of fuel, combustion system efficiency, glass quality and cost/frequency of a furnace rebuild. While not enough data exist to carry out a comprehensive cost study, we propose to compare differential operating costs from a base-case of air-natural gas firing in a regenerative furnace to petcoke firing in either another regenerative air-fuel system (Option A), or employing 100% oxy-petcoke operation (Option B). Key assumptions for the analysis are that:

1. Natural gas price is $18/MMBtu
2. Petcoke price is $9/MMBtu (pulverized and delivered)
3. Oxygen price is $60/MT
4. Pull rate of glass is 300 MTPD
5. Switching from natural gas to petcoke involves no change in fuel efficiency
6. Switching from air/fuel to oxy/fuel increases fuel efficiency by 20%

Results of the analysis, which reduce to a comparison of annualized fuel and oxygen costs, are summarized in Figure 8 (next page), adapted from Goruney et al [8]. Note that both petcoke Options A (air-fuel) and B (oxy-fuel) lead to a substantial reduction in fuel cost from the base air-natural gas firing case; from an air-natural gas baseline of $13MM/yr to $6.4MM/yr for Option A and $5MM/yr for Option B. However, the addition of oxygen in Option B adds $2.8MM/yr of oxygen cost, resulting in an apparent net operating cost increase relative to Option A of approximately $1.4MM/yr, or approximately $12.80/MT of pulled glass. The question then becomes whether or not the higher operating cost with oxygen is offset by benefits related to lower capital cost, longer furnace campaigns and superior glass quality control due improved combustion efficiency and stability. Regarding capital costs, a recent study suggests that, relative to a regenerative air-fuel furnace, oxy-fuel capital costs are lower by 30-40% [9]. Moreover, our discussions with glass manufacturers having experience with air-fuel petcoke combustion confirms combustion quality problems and suggests that furnace rebuilds as frequently as every 2 to 3 years is not uncommon. When we contrast this with the nearly two year successful run as documented herein in Case 1, we believe there is a very persuasive case to be made that oxygen is a vital ingredient in the mix of factors needed for cost-effective glass melting with petcoke.

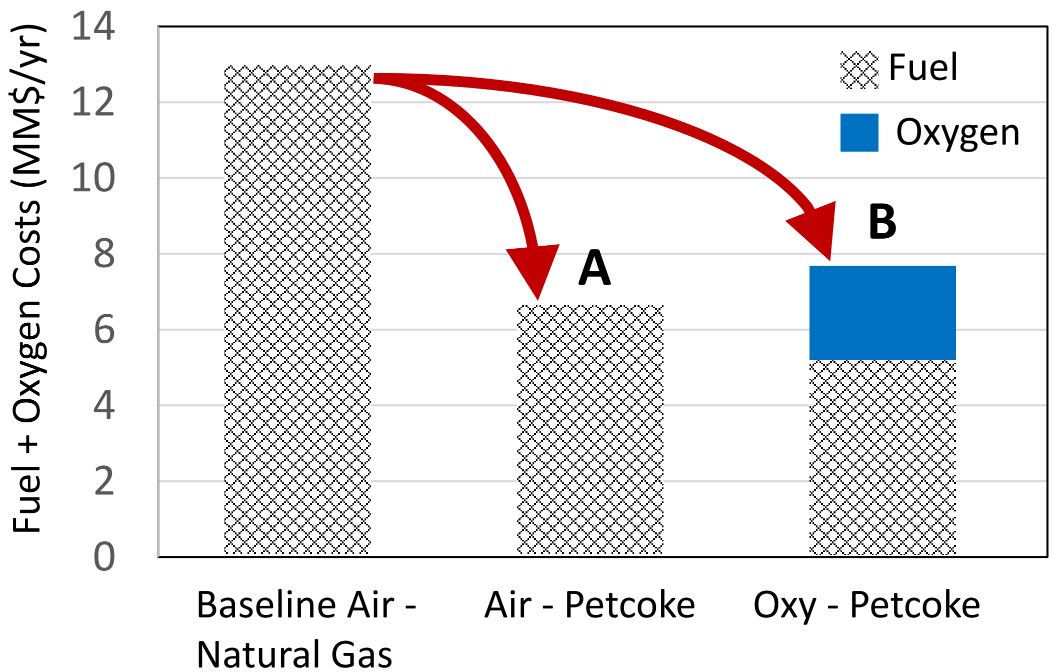

Figure 8.
Graph of fuel plus oxygen cost for 300 MTPD glass melting operation associated with different firing scenarios.

Conclusion

Glass manufacturers have turned to petcoke and other relatively low-cost solid fuels in order to maintain acceptable financial performance during this period of regional fuel price volatility and reductions in production demand. Through experience gained in this area as both an oxygen and combustion technology supplier, we have summarized herein several key findings that are essential to a successful adaptation of solid fuel firing for glass melting. Prior to making the fuel switch, attention must be given to compositional impurities in the fuel, and how they could potentially effect both glass product quality and furnace life. The most important factor during operation is the attainment of complete combustion, which has implications extending beyond melting efficiency, and into the realm of glass redox, color, defects and furnace life. Two essential elements needed to achieve a consistently high-performance solid fuel combustion system are a robust, well-designed material handling system, and oxygen enrichment for combustion. To these points, we have illustrated how the material handling system must be well-matched with the combustion enabling equipment, and that optimization of the oxygen-fuel mixing processes is needed to ensure that the full benefit of oxygen can be realized. Because, even in the best case, solid fuel material handling systems are less reliable than those for oil and gas, on-the-fly back-up fuel firing capability is needed. Finally, serious consideration should be given to full oxy-solid fuel firing, not only for combustion and glass quality reasons, but also to eliminate the need for regenerators which have the potential to be a focal point for fouling and corrosion during solid fuel operation, and are likely to be the largest single factor leading to reduced furnace performance and shortened furnace life.

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