glass WORLDWIDE

Achieving optimum heat efficiency in large-scale furnaces

David Dai, Rock Ren, Xike Ruan, Steven Sun and Andrew Wang from Anderson Thermal Solutions discuss results from a low NOx burner velocity study using two gas streams with different gas velocities.

There is an art to adjusting the burner flame in a glass-melting furnace. Combustion handbooks indicate that the flame will be shorter with a high momentum of fuel particles, which, with certain fuel, is related to fuel velocity at the burner nozzle.

In order to achieve the lowest energy consumption in float glass production, increasingly large-scale designs are being adopted, which is posing a challenge for the design of burners, mainly in flame length, heat transfer rate and NOx emissions.

Using two gas streams with different gas velocities can produce a burner performance suitable for modern glass industry requirements. There are several companies currently on the market that can deliver this type of burner; what we lack is the know-how behind the two gas streams. This paper aims to identify and define the best performance settings by using CFD analysis and actual furnace data.

Burner set-up

Burner set-ups (see Figure 1) can include:

1. Inner gas 50%; 100% open.
2. Outer gas 50%; 75%, 100% open.
3. Inner gas tube aligned with outer gas tube same face.
4. Inner gas tube pulled 4cm back from outer gas tube.

Flame length

Flame shape and size determine many combustion characteristics, such as temperature field, pollutant emissions, combustion efficiency, and material safety. The geometric properties of a turbulent non-premixed flame include flame shape, flame length L_f, flame width w, flame centre, and flame centre length L_c.

The flame Froude number Fr_f is used to characterise the relative importance of the initial jet flux and buoyancy acting on the flame.

The flame Froude number can be expressed as:

$$Fr_f = \frac{v_e f_s^{3/2}}{(\frac{\rho e}{\rho\infty})^{1/4}\left[\frac{T_f - T\infty}{T\infty} g d_j\right]^{1/2}}$$

Where ρ_e is the density of the nozzle fluid and ρ_∞ is the ambient fluid density. T_f represents the flame temperature, approximately equal to the adiabatic flame temperature T_{ad}, while $T\infty$ is the ambient fluid temperature. In addition, g is the acceleration of gravity, d_j is the diameter of the nozzle outlet, and ve is the nozzle outlet velocity, which is calculated by:

$$v_e = \frac{\dot{m}_e}{\rho_e \pi {d_j}^2/4}$$

Where $\dot{m}_e$ represents the mass flow rate of the nozzle fluid. The stoichiometric mixture fraction fs is calculated from:

$$f_s = \frac{1}{(\dot{m}_{air}/\dot{m}_{fuel})_{stoic}+1}$$

Where $\dot{m}_{air}\dot{m}_{air}$ represents air mass flow, $\dot{m}_{fuel}$ represents fuel mass flow, and the subscript stoic represents stoichiometry. ▸

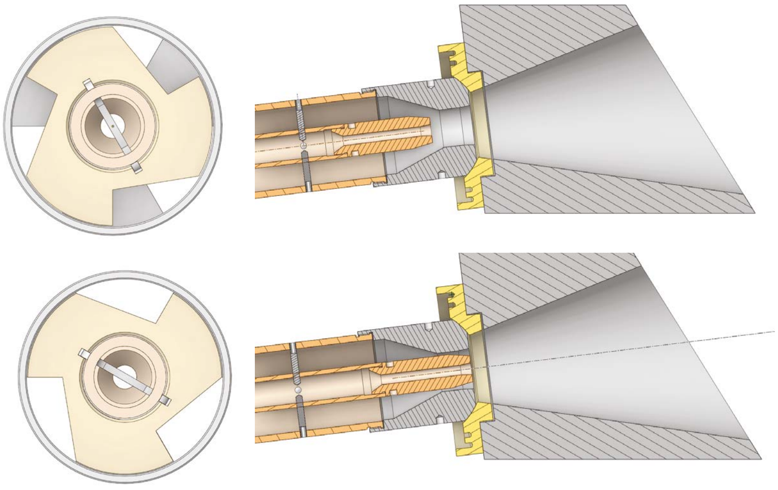

Figure 1: Burner set-ups. Top: Inner tube pulled back 4cm; inner gas 100% open and outer gas 50% open
Below: Inner tube and outer tube aligned on same face; inner gas 75% open and outer gas 100% open.

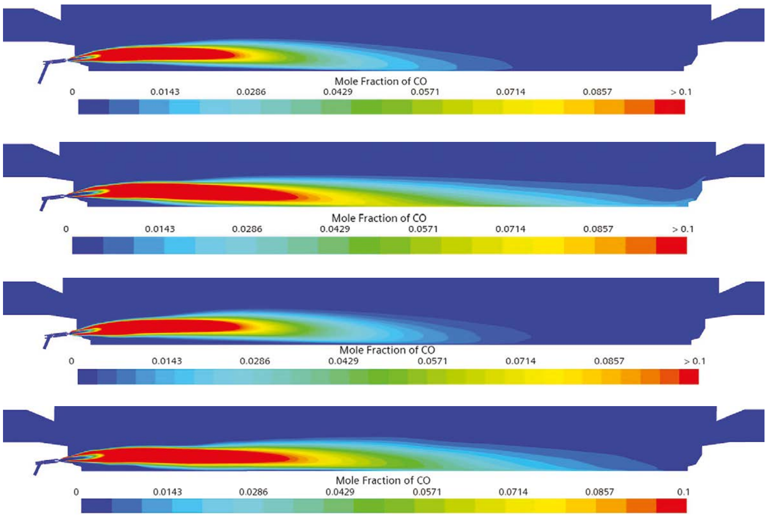

Table 1: Flame length simulation result.
From top: Flame length 8.9m. Inner tube and outer tube aligned on same face; inner and outer gas 100% open.
Flame length 100%+ of furnace width. Inner tube pulled back 4cm, inner and outer gas 100% open.
Flame length 9.15m. Inner tube and outer tube aligned on same face; inner gas 50% open and outer gas 100% open.
Flame length 10.8m, about 80% of furnace width. Inner tube pulled back 4cm; inner gas 50% open and outer gas 100% open.

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This article is based on a paper presented at the 44th ASEAN Glass Conference in Pattaya, Thailand, in November 2022 **www.aseanglass.org**

Glass Worldwide is the official journal of AFGM

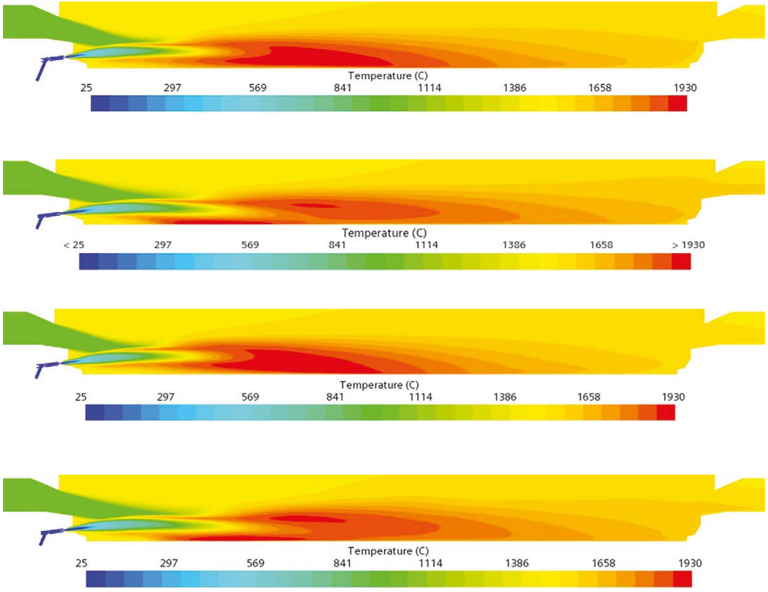

Table 2: Flame temperature simulation result

From top: Flame temperature over 1,800°C, reaching 79% of furnace width. Inner tube and outer tube aligned on same face; inner and outer gas 100% open.

Flame temperature over 1,800°C, reaching 73% of furnace width. Inner tube pulled back 4cm; inner and outer gas 100% open.

Flame temperature over 1,800°C, reaching 65% of furnace width. Inner tube and outer tube aligned on same face; inner gas 50% open and outer gas 100% open.

Flame temperature over 1,800°C, reaching 71% of furnace width. Inner tube pulled back 4cm; inner gas 50% open and outer gas 100% open.

For momentum control state, $Fr_f \geq 5$, for a momentum-dominated flame, L_f no longer changes with Fr_f, so this is not included in this equation:

$$L_f = 23\frac{(\rho_e/\rho_\infty)^{1/2} d_j}{f_s}$$

Using this theory to simulate flame length, some scenarios were produced for the study (see Table 1).

Heat transfer rate

The heat transferred from the flame of the glass furnace to the melt glass surface is mainly reflected in the thermal radiation energy, according to Boltzmann's law:

$$Q_S = C_s A\left(\frac{T}{100}\right)^4$$

C_s: Heat value transferred by flame radiation.

A: Flame coverage area.

T: Absolute flame temperature.

Increasing the flame temperature and the coverage area of the flame can obtain a larger radiation effect. However, the higher the temperature, the higher the NOx formation.

The temperature simulations are shown in Table 2.

Steven Sun presenting at the 44th ASEAN Glass Conference in Pattaya, Thailand in November 2022.

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	序号	点名	点描述	选择值	当前值	显示...	显示...	单位
√	1	JKSO2_ZS.AV_0#	进口二氧化硫折算值	106.55	83.63	1500...	0.00	mg/m3
√	2	JKO2.AV_0#	进口氧气	5.42	5.66	25.00	0.00	%
√	3	JKNOX_ZS.AV_0#	进口氮氧化物折算值	1868.65	1998.98	3500...	0.00	mg/m3

Figure 2: NOx emission real time monitor data

Figure 3: Left side firing.

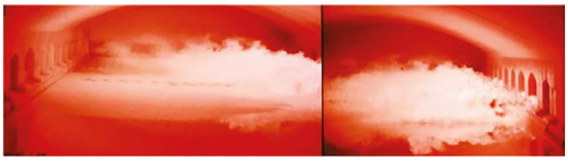

Figure 4: Right side firing.

Emissions control

Due to the direct relationship between combustion emissions and air quality, controlling combustion emissions has become the focus of environmental protection work. Here is a brief list of existing NOx reduction technologies:

- Lower flame temperature (by recirculation, staging gas or air supply)
- Oxygen reduction (through flue gas recirculation and staged air)
- Premixed with excess air
- Shorten residence time
- Nitrogen removal

Two gas streams act as staged combustion; with higher outside velocity, the internal FGR (flue gas recirculation) effect is greater.

Combining temperature data and NOx emission study together, the best burner settings should follow these requirements:

With slower gas velocity, inner and outer gas, NOx will be even lower when two gas streams have different velocities; the best ratio will be 1:2~1:6

Reducing gas into the inner tube will produce lowest NOx, up to half of the maximum capacity of the inner tube design.

Actual furnace operation data

Anderson Thermal Solutions has supplied burners for a designed pull rate 1,200tpd furnace. After two years in operation, data averages were as follows:

a) Energy consumption: 1,344–1,392kcal/kg
b) Production data: good rate over 96%
c) Emissions: NOx <2,000mg/m^3 (see Figure 2)
d) Flame appearance from camera (see Figures 3 and 4) ●

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