Combustion in glass furnaces: recent developments and next challenges

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21st "Journées d'études" (JDE) of the belgian section of the Combustion Institute
Liège, 11th May 2010
AGC – Asahi Flat Glass Company

World’s leading glass manufacturer

North America

AGC
Flat Glass
- 7 floats
- R&D Centre
- 4,500 employees

Automotive Glass

Europe

Flat Glass
- 18 floats
- R&D Centre
- 10,700 employees

Automotive Glass

Asia

Flat Glass
- 15 floats
- R&D Centre
- 11,300 employees

Automotive Glass

Production / transformation / distribution

Note: 2006 figures.
Outlines

- Flat glass production process
- Flat glass furnace: air combustion
- Combustion for glass furnaces
  - Numerical simulation
  - Labscale trials: oil atomization bench
- Oxycombustion
  - Burners development
  - Heat recovery technology
- Conclusions and challenges
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Flat glass production

From....

Sand, limestone, dolomite, soda, sulphate, slag, cullet

To....

Control Cutting
Max size 6 m X 3.2 m

Lehr Cooling
T\text{max} \approx 600\,^\circ\text{C}

Float Tin bath
T\text{max} \approx 1000\,^\circ\text{C}

Furnace +/- 40MW
T\text{max} \approx 1500\,^\circ\text{C}

40 MW \equiv 20,000\ domestic\ boilers

AGC

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Step 1. Glass furnace

- Furnace lifetime = 13-15 years
- From Raw materials to melted glass
- Fining zone to remove bubbles
**Step 2. Float**

- Melting glass floated on liquid tin (+/- 15 cm)
- Temperature input/output: 1100°C / 600°C
- Good thickness given by setting of top rollers
- Atmosphere of H₂ and N₂ to avoid tin oxidation
- CVD coating intra or extra float
**Step 3. Lehr**

- To cool the glass from 600 °C to ambiance temperature
- Air natural cooling and force cooling
- Cooling defines the constraints into the glass
- Laser detection of defaults (stones, bubbles,...)
- Cutting max 6 m X 3.2 m
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Glass furnace – General view

Furnace lifetime = 13-15 years
Aero Combustion Regenerative furnace
Glass furnace – Regenerative furnace

- Regenerators to recover heat from fumes
- Cycle (20 min): Air is heated (~1250 °C) by checkers / Fumes are cooled (~500 °C) because of heat transfer to checkers
- Reversal time < 1 min
Glass furnace – Regenerative furnace

- Regenerators to recover heat from fumes
- Cycle (20 min): Air is heated (~ 1250 °C) by checkers / Fumes are cooled (~ 500 °C) because of heat transfer to checkers
- Reversal time < 1 min
Glass furnace – Combustion

- From 5 to 6 burners of oil or gas
- Classical consumption of oil furnace: 4500-5000 kg/h
- Heat transfer from flame to glass bath by radiation
  - Importance of radiative properties of flame
  - Oil flame more efficient (more soots production) than gas flame
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Combustion in glass furnace

Why to work on combustion:

- To decrease energy consumption
  (Furnace consumption: \(~=5000\) kg heavy oil/hour)
- To optimize heat transfer from combustion space to glass bath

Environmental constraints by decreasing emissions of NOx, CO\(_2\), CO, SOx ....
- To develop Low-Nox combustion
- To increase efficiency of natural gas combustion
  (compared with oil more efficient in glass furnace)
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Numerical simulation of combustion space

CFD modeling (Ansys-Fluent)

- Turbulent : $k-\varepsilon$ standard (non premixed combustion)
- Chemical species : PDF tables (1 oxidizer/ 1 Fuel)
- Radiation : WSGG, Discrete Ordinate Models
- Soot : Generalized 2 steps Models

Kind of models

- Burner ; 1 slice of the furnace ; Complete furnace (more than $10^6$ cells) following accuracy of results needed
Numerical simulation of combustion space: Examples

With Oil/Gas and Air/Oxygen
On burner, 1 slice or complete furnace

Burners design
Nozzle angles
Side-Port vs. Under-Port
Coupling with glass bath
Port neck design

Glass bath simulation with dedicated tools: GTM from TNO, Glass Service
Numerical simulation of combustion space

Challenges

- Accuracy of soot CFD model
- Improvement of gas heat transfer to the glass

Oil flames

Gas flames
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Labscale pilot trial: heavy oil atomization

Objective

- to analyze heavy oil atomization (diameter and velocity of droplets)
- input data’s for numerical simulation (DPM model Fluent)
- to characterize best tip design/setting for combustion

droplets diameter distribution (Malvern) and velocities (LDV)
Labscale pilot trial: heavy oil atomization

droplets diameter distribution (Malvern)
Labscale pilot trial: heavy oil atomization

Droplets velocities distribution (Laser Doppler Velocimetry)
Labscale pilot trial: heavy oil atomization

Numerical simulation (Ansys - Fluent)
Heavy oil atomization: Discrete phase model
Labscale pilot trial: heavy oil atomization

Challenges

- LDV reproducibility measurements
- Use of data’s as input of combustion CFD model
- Results accuracy analyze and industrial validation
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Oxycombustion: burners development

Main idea:

\[ \text{H}^0(T0) = 33860 \text{ MJ/Nm}^3 \]

\[ \text{CH}_4 + 2 \left( \text{O}_2 + 3.76 \text{N}_2 \right) \rightarrow \text{CO}_2 + 2 \text{H}_2\text{O} + 7.52 \text{N}_2 \]

Consequences:

Increases of molar enthalpy of products of reaction

- Reduces fuel consumption at identical products enthalpy vs air (down to 50% as a function of air combustion system and of the process)
  - reduce Carbon usage thus CO2 emission
  - reduce SOx emissions
- Reduces N2 in flame \( \rightarrow \) reduces “mathematically” NOx

Un-direct consequences

- CO2 capture technologies
- Possibility to reduce NOx by controlling NOx production processes
Oxycombustion: radiation of oxyflames

Radiation difference between air and oxy-firing

Spectral radiation intensity for a column (1m) of hot gases mixture at 2100 K at 1 bar absolute for two different representatives to air and oxy-firing conditions

- Air-firing: 18% H2O, 9% CO2, 73% N2
- Oxy-firing: 62% H2O, 31% CO2, 7% N2
Oxycombustion: from theory to industrialization

Oxidant

- Oxygen
- Enriched air
- Air
- H₂

Fuel

- Natural gas
- Fuel oil
- Hydrogen

Type

- Premixed
- Hybrid
- Diffusion

Pressure

- 100 atm
- 10 atm
- 1 atm

Firing rate

- 100 MW
- 1 MW
- 1 kW

Richness

- Rich
- Stoechiometric
- Lean

Staging

- Pipe in pipe
- Separated Jets

Velocities

- 1 m/s
- 10 m/s
- 100 m/s

Oxidant / Fuel ratio

PCI, viscosity, density

Ex: Corrosion of walls, Foam, Fining
Oxycombustion: example of O2 staged burner for glass industry

**Block**
1. Corrosion
2. Hot operation maintenance
3. Moulding

**Metallic part**
1. Maintenance?
2. Mounting metallic part on refractory blocks?

**Safety system**
1. Detection of flame intensity
2. Adequate location

**Ignition system**
1. Function of furnace temperature
2. Managing of transient
Oxycombustion: Oxy-burner in other industries

- **ALGLASS FC in pilot Furnace**
- **ALGLASS FC in industrial furnace**

### Technologies

- **ATR POx Technology**
  - Pressure 60 bars

### Other Industries

- **ALROLL for steel industry**
- **Lacq pilot plant**
  - 3 x 4 MW Pyrejet for EAF’s

### Performance Indicators

- **Temperature of 1200°C**
- **30% of flue gases recirculation**
- **High momentum 100 to 200 m/s**
- **4 x 8 MW demo**

**AIR LIQUIDE**

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Synopsis: Burners development challenges

Technologies
- More efficient and less pollutant burners
- Improve flame control
- Enhance heat recovery systems
- High resistant steels

Environment
- Reduction of pollutants by 90% until 2020
- Reduction of CO2

Fuels
- Multi-fuels burner
- New fuels (Biomass, coal, syngas…)

Cost savings
- Burner manufacture
- Adapt the offer to customer
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Increase plant site efficiency was a challenge some years ago, it is an economic necessity today. In glassmaking industry, solutions are investigated (R&D or Industrial scale). Among them one consists in recovering waste energy from plant site.

Two-steps approach
- Air/fumes recuperator
- Air/Reactants exchangers
  - Oxygen T ~ 550°C
  - Gas T ~ 450°C
Heat Recovery: Develop an oxygen burner adapted to preheated reactants

STEP #1: Choice of the technology

- For security reasons the most adapted technology is the “Higly Separated Jets”
- Description of the burner:
  - Bi-fuel burner
  - Natural Gas or Fuel Oil
  - Covering the range of 0.5 to 7 MW
  - Control of oxygen distribution
- The qualification of the burner design consists in:
  - Checking the temperature of flanges and sensible element
  - Assessing Flame stability with power and reactants temperature
  - Verifying burner maintenance issues due to oxygen and natural gas preheating
  - Measuring noise levels
  - Validating of insulation type and settings (thickness, length, …)
- In respect with International Norms for the pressure equipments, oxygen safety, Combustion process usage
Heat Recovery: First results of prototype furnace

STEP #2: Industrial validation at pilot scale (2005 & 2006)

After R&D labscale tests, industrial pilot trials have been performed in a glass furnace equipped with two ALGLASS SUN 4MW Burners in Port#1 configuration with preheated reactants with an air/O2 exchanger. Natural gas was preheated electrically.


Furnace has been started in 2008.

<table>
<thead>
<tr>
<th></th>
<th>Energy consumption reduction</th>
<th>CO2</th>
<th>NOx</th>
<th>SOx</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold reactant</td>
<td>12%</td>
<td>7.7%</td>
<td>76.7%</td>
<td>16%</td>
</tr>
<tr>
<td>Hot reactant</td>
<td>25%</td>
<td>15%</td>
<td>83.3%</td>
<td>34.7%</td>
</tr>
</tbody>
</table>

Completed

Target

At the same time, other parameters of the process are tracked:

- Flame emissivity,
- Crown temperatures,
- Refractories and furnace proof,
- Flue gases,
- Glass Quality,
- Pull rate flexibility.

STEP #4: Validation of hot oxygen first performances
Heat Recovery: First results of prototype furnace

The equipment has been started some months after the furnace. Thanks to an adapted preparation between AL, AGC and exchanger supplier, the different transient regime and unsteady situations we faced were controlled one after one.

Next challenges
- Work to reduce fuel consumption
- Improving natural gas burner operations
- Deposits on burner face to be controlled
- Long-term follow-up of heat recovery aging
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Conclusions and challenges

- Combustion is a major research topic for flat glass process

- Main objectives are
  - to decrease glass production plants energy consumption
  - to decrease pollutant emission

- Available tools are numerical simulation, labscale industrial pilot or full scale industrial prototype

- AGC and Air Liquide succeed to start the greener flat glass furnace in Europe with oxy combustion and reactant preheating

- Challenges remain to improve further process. Among others
  - better understanding of fuel oil combustion process (atomization)
  - natural gas combustion improvement for glass industry (radiative exchange vs. oil)
  - understanding of long term interaction between preheated reactants flames and glass production process (corrosion, foaming, …)
Thank you very much for your attention

The project is funded by EC Life+ program

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www.oxyfuel-heatrecovery.com