Numerical Simulation of Glass Fiber Manufacturing Processes: Overview and Challenges

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Owens Corning at a Glance

- Founded in 1938, an industry leader in glass fiber insulation, roofing and glass fiber reinforcements
- 2016 sales: $5.7 billion
- 15,000 employees in 26 countries
- Fortune® 500 company for 63 consecutive years
- Component of Dow Jones Sustainability World Index
- Three powerful businesses
  - Insulation
  - Roofing
  - Composites
Presentation Outline

• Technologies:
  • Insulation Glass Fiber
  • Reinforcement Glass Fibers

• Different steps:
  – Glass Melting & Conditioning
  – Glass Forming
  – Downstream processes

• Simulation Results Management

• Concluding Remarks
Fiberglass Insulation Process Overview

Batch Storage and Mixing

Channel

Forehearth

Binder Application

Furnace

Fiberizing

Forming

Curing

Fabrication

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Reinforcement Glass Fiber Manufacturing Process

Batch

Furnace

Forehearth

Sizing

Winder

Front-end

Delivers molten glass

To Packaging

Melts raw materials

Fiber glass forming

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Forming & Size Application

Fiber forming

Sizing Application

=> Glass quality is key

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Fiberglass Reinforcement Products

Fiberglass filament → Roving → Fabric → Final Applications

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- Raw materials react/melt to make glass
- Complex physics & chemistry
Glass Melting Furnace and Front End

- High-cost process
  - Capital investment
  - Operating expenses
- Important to operate carefully and efficiently
  - Avoid damage and extend life
  - Assure complete melting, fining, and conditioning
- Numerical simulations assist design and operation
Modeling Capabilities

- Temperature contours & local values
- Electric Joule Heating – distribution, voltage potential, current
- Flow velocities and shear rates
- Batch position
- Particle residence times and other KPIs
- Sand dissolution rates
- Bubble paths

- Heat fluxes – conduction, convection, radiation
- Contours of unburned fuel
- Turbulence
- Energy input – fuel & electric
- Superstructure heat losses

RESIDENCE TIME DISTRIBUTION

“SHORT CIRCUIT” PATHS

AVERAGE PATHS
Verification & Validation efforts

- Temperature values
  - Combustion space
  - Glass

- Tracer Tests

Cumulative Residence Times distribution

Predicted times are in good agreement with tracer trial measurements.

\[ R^2 = 92.3\% \]
Example: Electric Boost and Glass Recirculations

**PAST SITUATION:**

Imbalance caused by electrode failures

*Calculated Mixing index <1*

Clearly more glass recirculation on the right

=> Performance issues

**NEW SITUATION:**

Perfect Balance after recabling

*Calculated Mixing index >2*

Glass flow recirculation more balanced Left/Right !!!

=> Better glass mixing improves furnace performance
Valuable Insights from Furnace & Front-end Simulations

- Melting Furnace
  - Profiling burners, E-boost, bubblers, etc.
  - Calculating & comparing residence times and other performance indices

- Front-end
  - Identifying cold, stagnant zones (risk of devit growth)
  - Assessing the effects of pull rate changes
  - Thermal disturbances and transient effects
Challenges of Furnace Numerical Modeling

- Validation data & accuracy
- Material properties & aging
- Process Changing Physical Properties
  - Batch materials to glass
- Improved constitutive models
  - Foam, refractory erosion

Balance details with computation time

Still need a high level of expertise to use such tools...
Fiber Forming

Glass from Forehearth

Refractories

Bushing

Tip plate

Fibers

Bushing:
- Made of precious alloy
- electrically energized to control temperature

Fiber break @ forming leads to process interruption

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Fiber Forming physics

- Combination of fluid dynamics and heat transfer
  - Surface tension and viscosity = f(T)
  - Radiation and convection heat transfer

![Diagram of fiber forming process]
Balancing Accuracy and Cost

Cost = human hours & computational time
Accuracy = geometrical details, physics & chemistry

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Forming Position Simulations

- Rich in Physics
  - Complicated flow patterns
  - Multi-phase
    - Water sprays
    - Coupled & interacting
  - Complex heat transfer

- Different length scales
  - Forming Tunnel, Forehearth, Positions
  - Bushing, tip plate, fins, & tips
  - Fibers

POST-PROCESSING

- Air entrainment into fiber fan
- Temperature at applicator
- Moisture concentration (vapor and liquid)
Temperatures at the Applicator

Validation Metric
Forming Position - Challenges

- Validation
  - Limited quantitative data
  - Qualitative – flow pattern descriptions

- Uncertain performance indices
  - How air flow relates to fiber breaks?
  - How to assess and compare configurations?

- Full forming tunnel simulations require very large computational resources
Drying Oven Simulations

- Drying time
- Uniformity
  - Over-dried packages
  - Under-dried packages
- Product Quality
- Energy Efficiency

Wound fiberglass packages on carriers ready to enter drying oven

Configurations can vary
- Alternative 2 has lower average but *higher minimum*
- Also, *less pkg-to-pkg variation*

**CHALLENGES**

- Validation – mainly qualitative
  - Full oven
  - Complete drying cycle

  *Limited by opportunities*

  *Limited by computational resources*
Summarizing CFD Simulations in Glass Fiber Manufacturing

- Several process applications
- Complex systems with coupled transport phenomena and interacting materials/zones/domains

Challenges

- Characterizing materials and interactions
- Balancing geometrical fidelity with computational efficiency
- Post-processing to make sound operational and/or business decisions
- Obtaining sufficient and/or accurate validation data
Failure during early stage of furnace campaign
- Large crack → 2 pieces

Transient thermal conditions
- Stress build-up during heat up
- Introduction of cold batch causing radiative heat loss
- Burner air (without fuel) leading to sudden cooling

Complex shape imposing stress concentration
Need to Manage Modeling & Simulation Activity and Data

- Ever larger & complex simulations
- More participants in simulations & Multi-disciplinary Engineering Roles
  - Modelers & Analysts
  - Designers & Plant Support Engineers
  - R&D Engineers
- Need for organizing, scheduling, and prioritizing simulations
- Sharing simulation results across the globe
Numerous Advantages identified

- Facilitates collaboration
  - Eliminates extra copies of modeling files
  - Keeps various data files “in sync”
    - Geometry
    - Mesh
    - Model data (i.e. properties, bc’s, etc)
    - Post-processing reports

- Searching
  - Common repository

- Recycling/Resurrecting Data
  - Model data
    - Quickly launch a comparative study to help decision-making

- Data Security
Conclusions

- Modeling is a critical tool in design & operations
  - Furnace
  - Frontend
  - Fiber forming & downstream processes

- Challenges of Numerical Modeling
  - Validation
  - Physical Properties
    - e.g. Batch materials
  - Need Improved models
    - Foam, refractory erosion

- Simulation Data Management a must have
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