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Engineering GmbH

COMSOL Conference Rotterdam 2013

Simulation of the molten glass sheets flow

David Wenger, Eva Pelster, Paul Baias, Lilla Puskas

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Key Facts

- Engineering company with 20 employees
- Location: Ulm, Germany
- CEO: Dr.-Ing. David Wenger
- Services:
  - Thermodynamics
  - CFD Simulation
  - Refueling Simulation (H_2 and CNG)
  - COMSOL Multiphysics Consulting
  - MATLAB Programming
  - Simulation Software Development
- Software: MATLAB, Simulink, COMSOL Multiphysics

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Milestones

- 2007:
  - Establishment of the Company
- 2009:
  - First certified COMSOL Multiphysics Consultant in Germany
- 2011:
  - First Apprentice joins the Wenger Engineering Team
- 2012:
  - Certified MathWorks Partner
  - ISO 9001 Certification

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Content

(1) Introduction

- The problem considered in this study involves the manufacturing process for the production of thin glass sheets with a lot of commercial applications, i. e. large screen video displays, mobile phones
- The optimization of the production process is of extreme importance to ensure high quality of the glass sheets, which involves extraordinarily smoothness and purity
- The surface homogeneity and thickness are linked to the uniform distribution of the molten glass flow, which depends on the geometry of the production device
- To gain further knowledge on the production process of thin glass sheets a simulation model with Comsol Multiphysics of the molten glass flow is presented in this study.

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(2) Simulation model with COMSOL Mutliphysics

- The modeled part of the process simulates the end phase of the production, where the molten glass forms thin sheets (see Fig 1.).
- The molten glass arrives in the trough with a predefined mass flow rate, fills the reservoir, then overflows it at both sides of the apparatus.
- The cascading sheets meet at the underside of the trough forming a single sheet

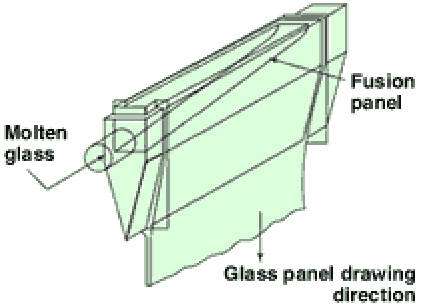

Fig. 1. Fusion process developed by Cornig Inc.

- For a smooth glass sheet we expect a specific uniform mass flux over the whole length of the output surface
- The whole production process relies on the system design generating the correct flow profile of the molten glass.
- The goal is to build a model that provides us the best control of the production process
- With Comsol Multiphysics one has the possibility to optimize the system design easily, reducing thereby the cost of testing

(2) Simulation model with COMSOL Mutliphysics

1. The modelled Geometry

- Simplified geometry, consisting only of the fluid domains: molten glass and surrounding air
- Expanded air region in order to ensure free flow of the glass
- Initial assumptions: Reservoir overfilled with glass (reducing the computation time)

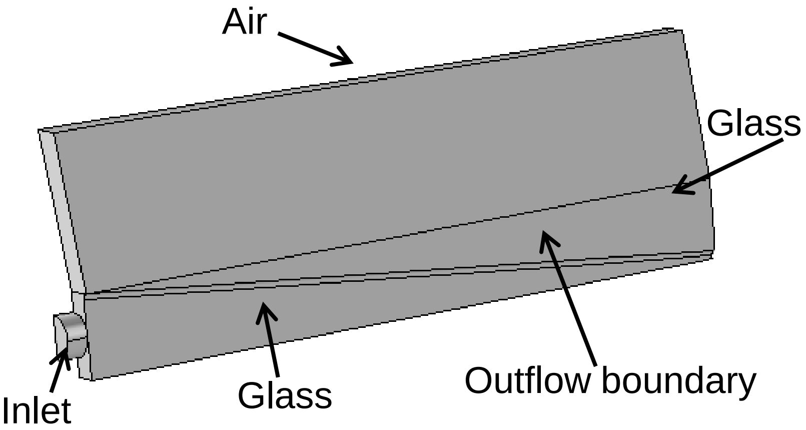

Fig. 2. Simplified Geometry

- The entire setup is parametrized in order to be able to change the geometry quickly when trying to find an optimal shape for desired output behavior

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(2) Simulation model with COMSOL Mutliphysics

2. Physics Model

- For the simulation of the fluid dynamics the **Laminar Two Phase Flow-Level Set** mode was chosen, which is defined to track the fluid-fluid interface
- The Level set interface uses the incompressible formulation of the Navier-Stokes equations:

$$\rho\frac{\partial u}{\partial t} + \rho(u \cdot \nabla)u = \nabla \cdot [-p\mathbf{I} + \mu(\nabla u + \nabla u^T)] + \boldsymbol{F}_g + \boldsymbol{F}_{st} + \boldsymbol{F}_{ext} + \boldsymbol{F}$$

$$\nabla \cdot u = 0$$

- For tracking the moving interface, the following equation is added:

$$\frac{\partial \varphi}{\partial t} + u \cdot \nabla\varphi = \gamma\nabla \cdot \left(\varepsilon\nabla\varphi - \varphi(1-\varphi)\frac{\nabla\varphi}{|\nabla\varphi|}\right)$$

- The density and the dynamic viscosity are functions of the level set function φ: $\rho = \rho_1 + (\rho_2 - \rho_1)\varphi$ and $\mu = \mu_1 + (\mu_2 - \mu_1)\varphi$,
  where ρ_1, ρ_2 and μ_1, μ_2 are the densities and the dynamic viscosities of the two fluids respectively

(2) Simulation model with COMSOL Mutliphysics

3. Material properties and boundary conditions

- The dynamic viscosity and the density for air and glass were defined at T=1273.15K
- **Wetted wall** condition: enable to move the fluid-fluid interfaces along the wall
- To incorporate the effects of gravity, a volume force was used: gravitational force defined in the y-direction

(2) Simulation model with COMSOL Mutliphysics

4. Meshing and Solver Settings

- Mesh: free tetrahedral, extra finer size defined for the wall boundaries and outflow boundary
- Transient solver with initialization phase was used
  - Step Phase Initialization: solves for the distance to the initial interface
  - Step Time Dependent: uses the initial condition for the level set function
- This ensures the advantage to follow the flow behavior step by step

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(2) Simulation model with COMSOL Mutliphysics

4. Results of the simulation

- On Fig. 5. the results for a 0° inclination are presented as 3D plots of the mass flow rate over the outflow boundary at different time steps.
- The flow profile remains relatively constant after 600 s.
- A non-uniform distribution of the glass flow is to experience resulting from the positioning of the inlet
- In order to find an optimal shape of the glass flow the influence of an inclination angle was studied

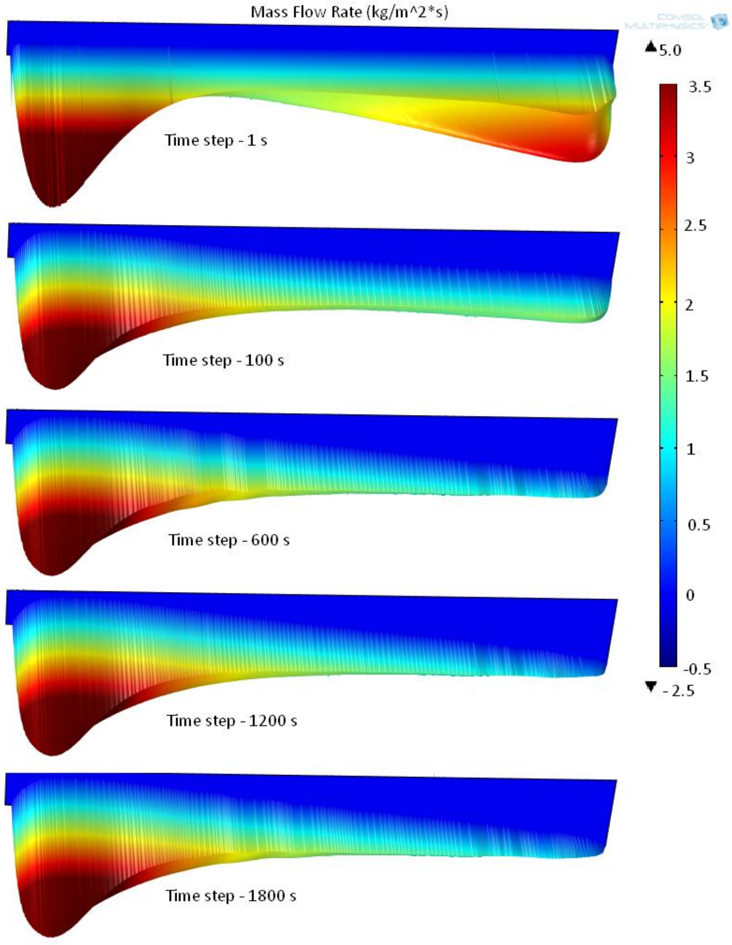

Fig. 5. Flow Profile at the outflow boundary

(2) Simulation model with COMSOL Mutliphysics

4. Results of the simulation

- In optimizing the output flow rate, the trough reservoir with an inclination angle was considered in order to use the effects of the gravity (see Fig. 6.)
- Fig. 7. shows a comparison of the resulting contours with 0° and 7° inclination angle of the flow at t=1800 s.
- The influence of the 7° inclination is clearly visible, the contour of the glass flow changes towards a more homogenous shape which is commonly better for the production process

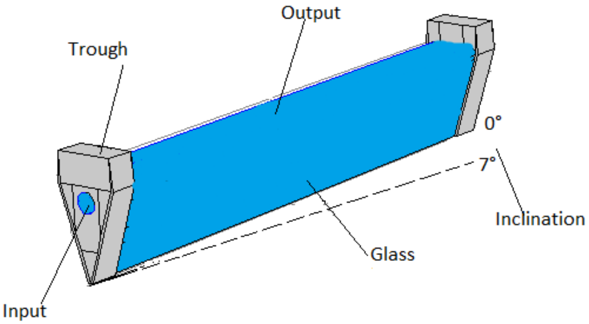

Fig. 6. Reservoir with inclination

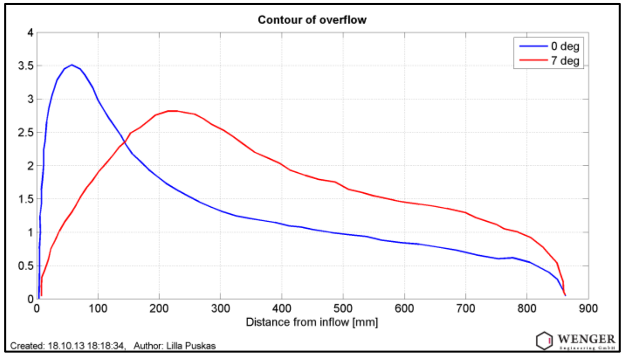

Fig. 7. Contour of outflow at outlet for 1800 s with inclination angle 0° and 7°

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- In this study a method for calculating the flow of molten glass with Comsol Multiphysics was presented
- A parametrized geometry was built in order to model a part of a glass sheet forming process
- It was shown that the model is able to simulate the overflow of the molten glass
- Comsol Multiphysics enables to vary the parameters of the geometry very easily, facilitating the optimization of the apparatus design and therefore the production
- Simulations results with inclined reservoir show a more homogenous flow profile
- Additional tests should be carried out with the model to gather more knowledge of the influence of different parameters

Kontakt:

Dr.-Ing. David Wenger
Wenger Engineering GmbH
Einsteinstr. 55
89077 Ulm
0731-159 37 500
mail@wenger-engineering.de