Glass Characterization as a First Simulation Stage

Jornada sobre Simulación en Procesos de Fabricación de Vidrio

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Ramon Clemente Glass

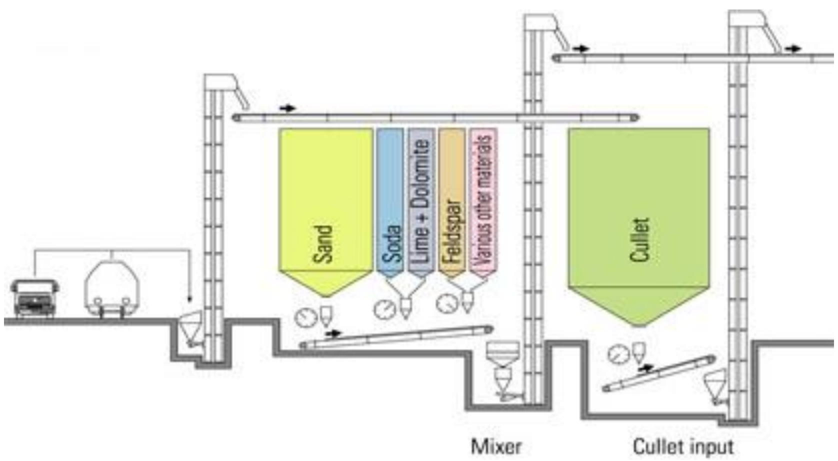
Ramon Clemente Glass is a container glass manufacturing company located in El Masnou, Barcelona:

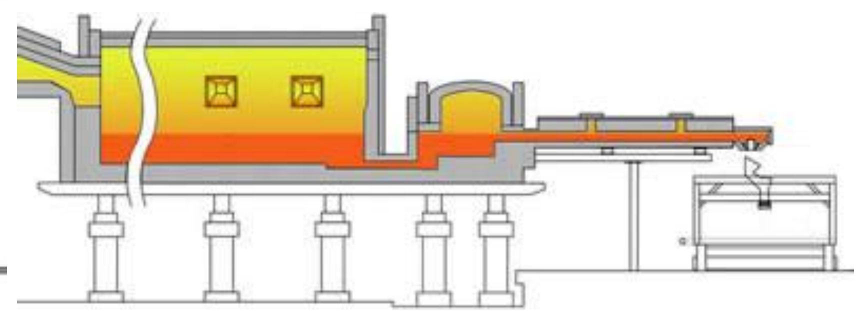
- Works on around **50 new projects every year**.
- Produces more than **60M bottles per year**.
- Is specialized in fast developments, short series, flexibility and tailored productions.
- There are more than **100 job changes every month**.

Ramon Clemente GLASS

Production Process (1)
Glass forming

Initially, raw materials are melted and become glass, spending large amounts of energy in this stage.



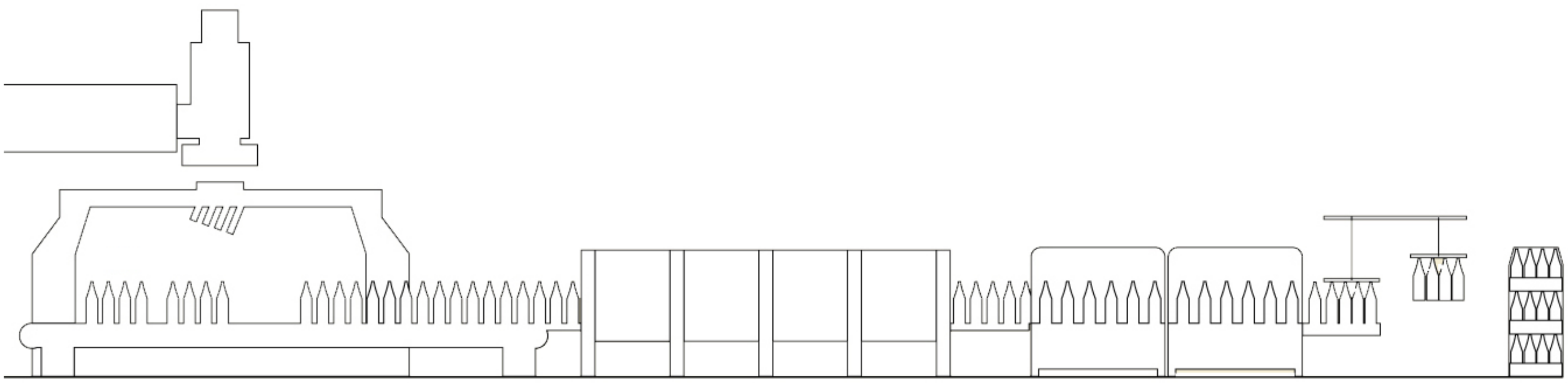


Melting at furnace: 1200 to 1500 ºC
Refining at working end: 1350 ºC
Conditioning at forehearth: 1250 ºC

Production Process (2)

Gob & Container forming

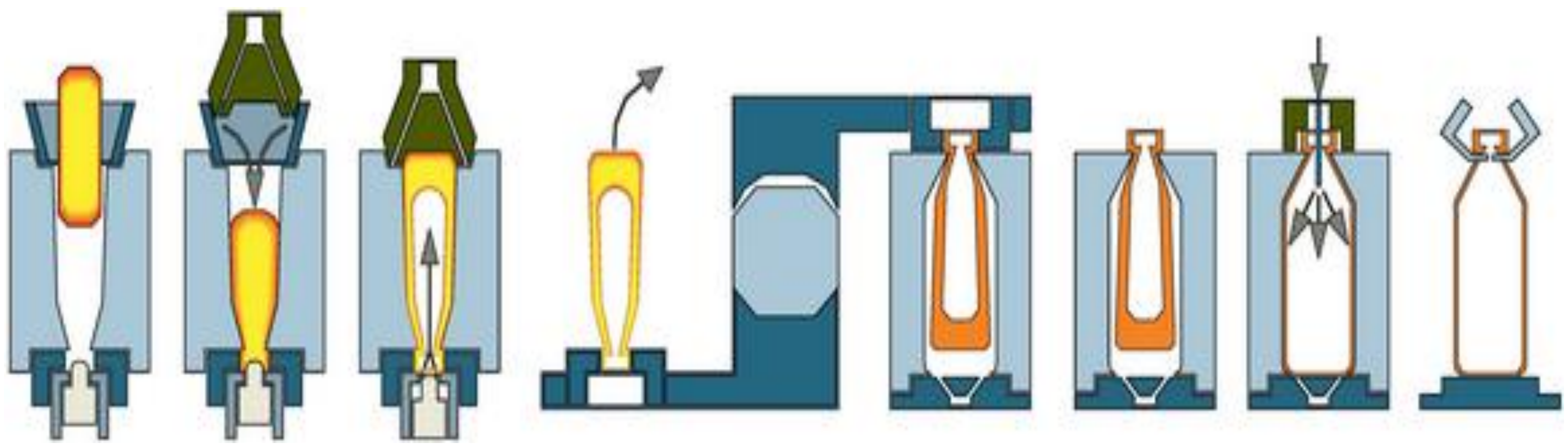
Subsequently, glass is cooled down while containers are being formed within the molds at the IS machines.



Gob forming at feeder: 1200 ºC
IS machine: 1150 to 700 ºC
Annealing: 400 to 550 ºC + room T

Forming Process

Mold equipment remove certain amount of heat from glass during container manufacturing. **Glass viscosity strongly varies** and completely modifies its mechanical behavior.



Blank mold: 1150 to 900 ºC

Blow mold: 900 to 700 ºC

Forming Process Difficulties (1)

During container glass forming process:

- IS machines spend around **8 s to manufacture a single container.**
- In this period of time **glass temperature decreases from** a range of **1200 ºC to 700 ºC.**
- **Glass viscosity increases** from log 3 to log 8 (dPa·s).
- Glass is cooled down mainly due to its contact with mold equipment and pressurized blown air.

Forming Process Difficulties (2)

But also, container forming process **applied to perfume industry** has its own issues:

- Perfume containers are **not** usually **axi-symmetric.**
- Perfume industry demands **high quality requirements** to its containers.
- Mold equipment design is based in **trial and error**.
- The design of the **blank mold is a key issue** to obtain the desired glass distribution and may require several iterations.
- **Each job has its own and unique parameters** according to it's weight, capacity, shape, etc.

Forming Process Difficulties (3)

Ramon Clemente Goals

Our aim is to **simulate the blow forming process**. A model which predicts container glass distribution would help to:

- **Improve** the **quality** of our product.
- **Speed up** the **development** of new containers.
- **Reduce** production line **downtime**.

Ramon Clemente is working in this project along with:

Simulation Goals (1)

Thoughts to be taken into account:

- **Simulations must be fed** with initial values, material data, boundary conditions, etc.
- This values will be obtained from Ramon Clemente production line.
- **The more accurate experimental values** measured, **the more accurate results** will be obtained.
- Results will have to be validated using experimental values.

Simulation Goals (2)

Two main objectives have been defined in order to feed the simulations with the right values:

a) Characterize Ramon Clemente glass in the IS working range.

b) Measure geometry and glass properties in the production line.

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Glass Characterization (1)

Most **relevant glass properties** that will be taken into account for simulations are:

- **Viscosity**
- Density and Thermal expansion coefficient
- **Emissivity**
- **Heat conductivity coefficient**
- Specific heat capacity

Material properties are strongly related to glass composition and glass processing conditions.

Glass Characterization (2)

Cast iron properties will be used for modeling heat transfer phenomena at the glass-mold contact interface.

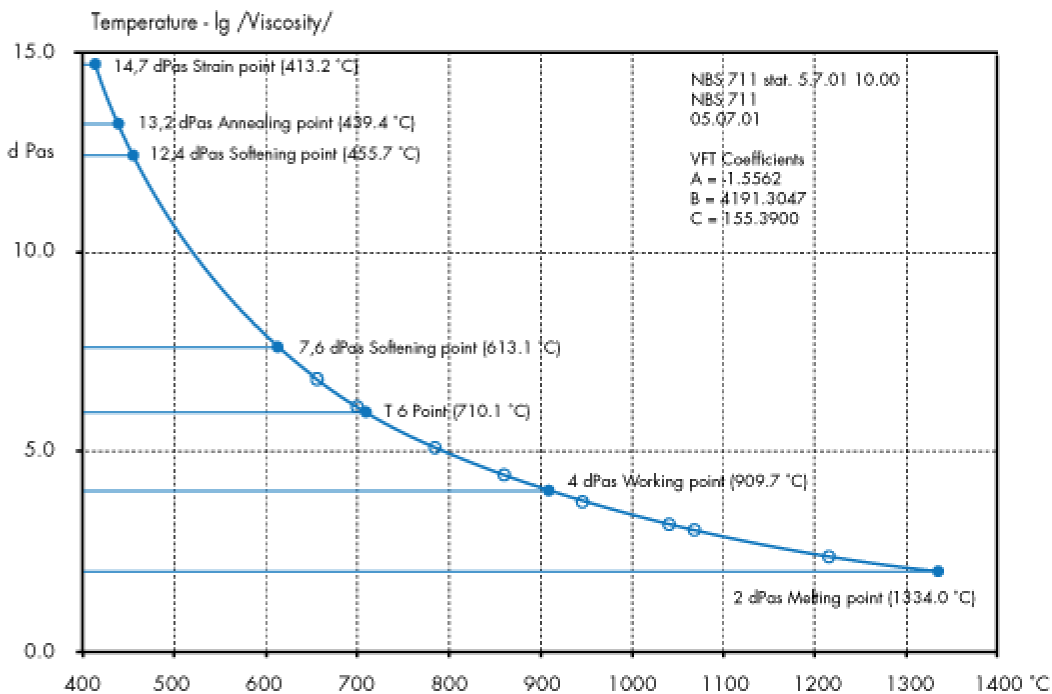
Most **relevant cast iron** mold **properties** that will be taken into account for simulations are:

- **Emissivity**
- **Heat conductivity coefficient**
- Specific heat capacity
- Thermal expansion coefficient
- Cavity geometry

Glass Characterization

Viscosity

Due to its high temperature sensibility, **viscosity** completely **defines mechanical behavior of glass**:

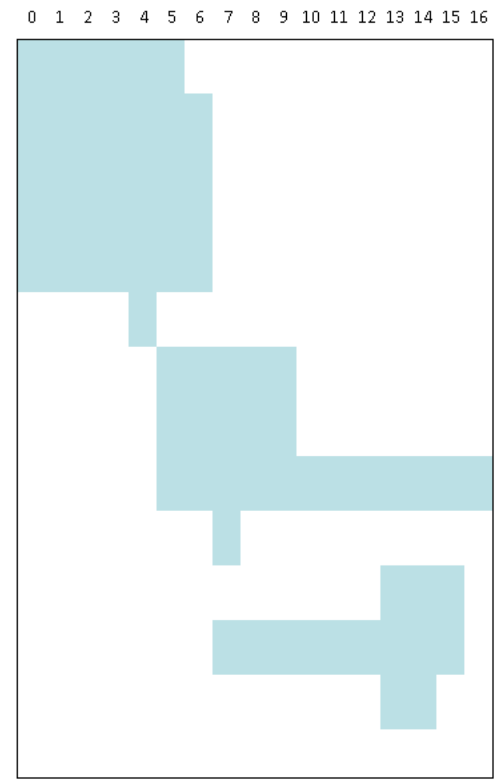


Lead-Silica Glass Viscosity Measurement Over a Wide Temperature Range

Metodologies for Glass
Viscosity Characterization (1)

Procedures for determination of glass viscosity:

Range	Method	Viscosity (dPa·s)
	Falling sphere or drawing-up sphere	$<10^{5}$
Melting	Rotation viscometer (a) Rotating spindle and fixed crucible. (b) Rotating crucible combined with fixed inner cylinder.	$<10^{6}$
	Sinking bar viscometer	$=10^{4}$
	Parallel plate	$10^{5} < \mu < 10^{9}$
	Penetration viscometer	$10^{5} < \mu < 10^{9}$
Softening and annealing	Fiber elongation	$10^{5} < \mu < 10^{16}$
	Softening point	$=10^{7.65}$
	Annealing point and strain point	$=10^{13}$ and $10^{14.5}$
	Beam bending	$10^{7} < \mu < 10^{14.7}$
	Annealing point and strain point	$=10^{13.2}$ and $10^{14.7}$
Glass Tg	Dilatometer: DTA, DSC	



Metodologies for Glass
Viscosity Characterization (2)

Procedures are defined at ISO and ASTM standards:

STANDARDS CATALOGUE - 81.040.01 - GLASS IN GENERAL

ISO 7884-1:1987 to ISO 7884-8:1987 Glass - Viscosity and viscometric fixed points

Part 1: Principles for determining viscosity and viscometric fixed points

Part 2: Determination of viscosity by rotation viscometers

Part 3: Determination of viscosity by fibre elongation viscometer

Part 4: Determination of viscosity by beam bending

Part 5: Determination of working point by sinking bar viscometer

Part 6: Determination of softening point

Part 7: Determination of annealing point and strain point by beam bending

Part 8: Determination of (dilatometric) transformation temperature

ASTM

ASTM C336 Standard Test Method for Annealing Point and Strain Point of Glass by Fiber Elongation

ASTM C338 Standard Test Method for Softening Point of Glass

ASTM C598 Standard Test Method for Annealing Point and Strain Point of Glass by Beam Bending

ASTM C657 Standard Test Method for D-C Volume Resistivity of Glass

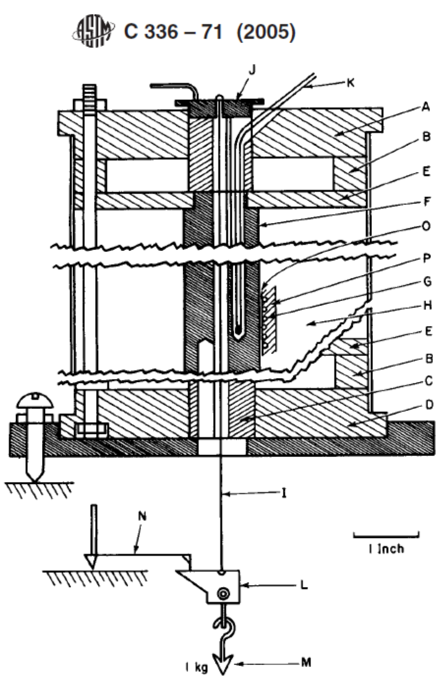
ASTM C965 Standard Practice for Measuring Viscosity of Glass Above the Softening Point

ASTM C1350M Standard Test Method for Measurement of Viscosity of Glass Between Softening Point and Annealing Range by Beam Bending

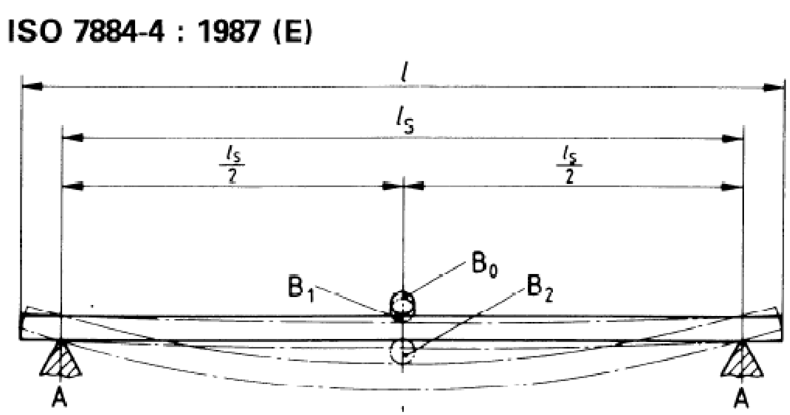
Metodologies for Glass

Viscosity Characterization (3)

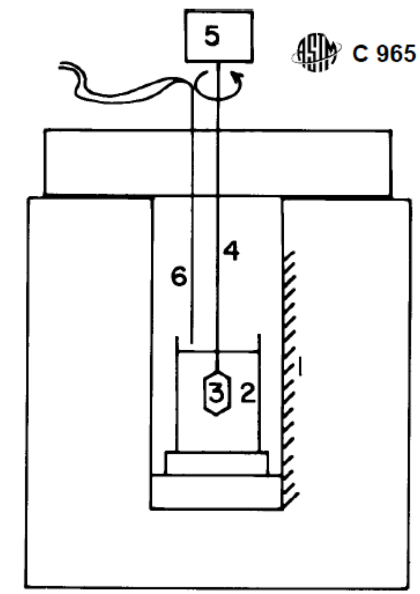
Glass can be subjected to various types of stress during its characterization depending on the followed procedure.



Fiber elongation



Beam bending



Rotation viscometer

Simulation Goals (2)

Two main objectives have been defined in order to feed the simulations with the right values:

a) Characterize Ramon Clemente glass in the IS working range.

b) Measure geometry and glass properties in the production line.

Measurements in Production Line

Glass properties can be measured following standardized procedures **under laboratory conditions**.

There is information that has to be obtained **from the production line**:

- IS machine settings
- Blowing pressure

These values are both defined by us, but there is still more to be measured… **GLASS**!

Measurements in Production Line
Glass

Glass is the core of our activity and production process, so glass will also be the most important parameter of our simulations and measurements.

The most important parameters to be measured are:

a) Glass and mold equipment temperatures.

b) Glass geometries: gob, parison and final container.

Measurements in Production Line
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a) **Glass and mold equipment temperatures.**

b) **Glass geometries: gob, parison and final container.**

Measurements in Production Line

Temperature

Different methodologies and instrumentation may be used to measure temperature.

The most suitable methods to **measure glass at high temperatures** are:

- Thermocouples.
- Pyrometers.
- IR thermal cameras.
- Special applications for glass industry.

Measurements in Production Line

Thermocouples

Thermocouple application for **temperature measurement of mold equipment surface** during an IS cycle (± 8 s). A very high sampling rate is required to obtain these values.

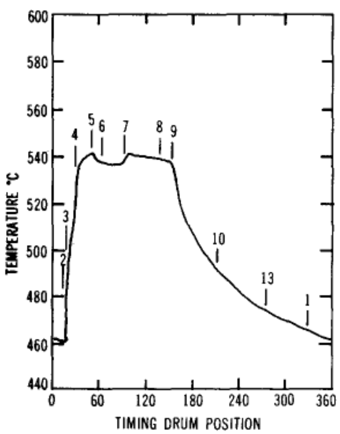


Figure 5: Temperature Below Load Line in Blank.

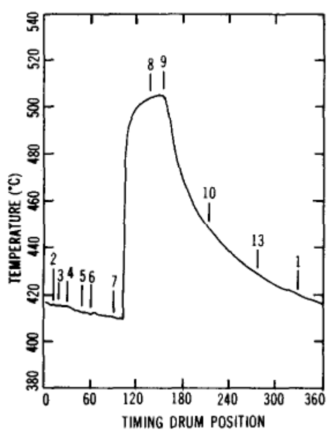


Figure 6: Temperature Above Load Line in Blank.

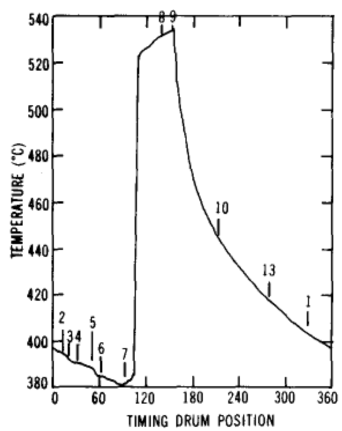


Figure 7: Temperature of Baffle.

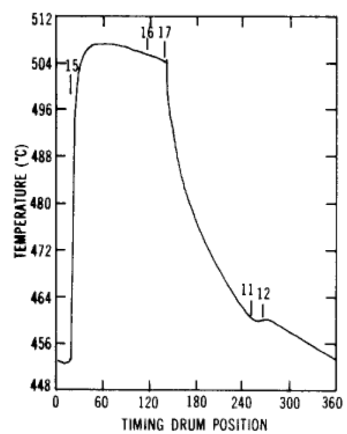


Figure 9: Temperature of Mold Sidewall.

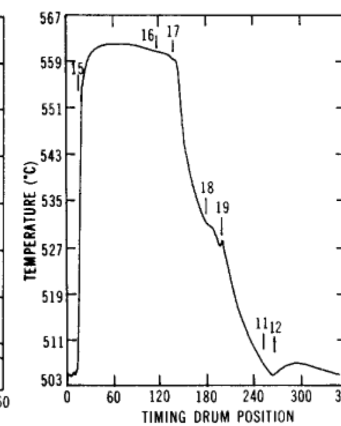


Figure 10: Temperature of Bottom Plate.

Measurements in Production Line

Infrared (IR) Devices

IR devices measure radiation from emitting sources at different wavelengths. Pyrometers measure in only a single point, **thermal cameras have a wider field of view**.

Advantages using IR devices:

- Non-contact measurements.
- High sampling rate, microbolometer vs N_2.
- Can be used as a portable device or installed on a fixed location.

However, **emissivity of the material must be defined.**

Measurements in Production Line

Special applications

Measuring devices have been adapted to glass industry. Some have been tested or studied to see their viability.

Unfortunately, **this devices are more focused on** obtaining information for **process control** rather than measuring “absolute” temperature values.

SpeedGob+

tiama hot mass

Measurements in Production Line

Temperature & geometry

IR thermal cameras are capable of measuring glass temperature and glass geometry.

Both parameters can be measured at the same time!

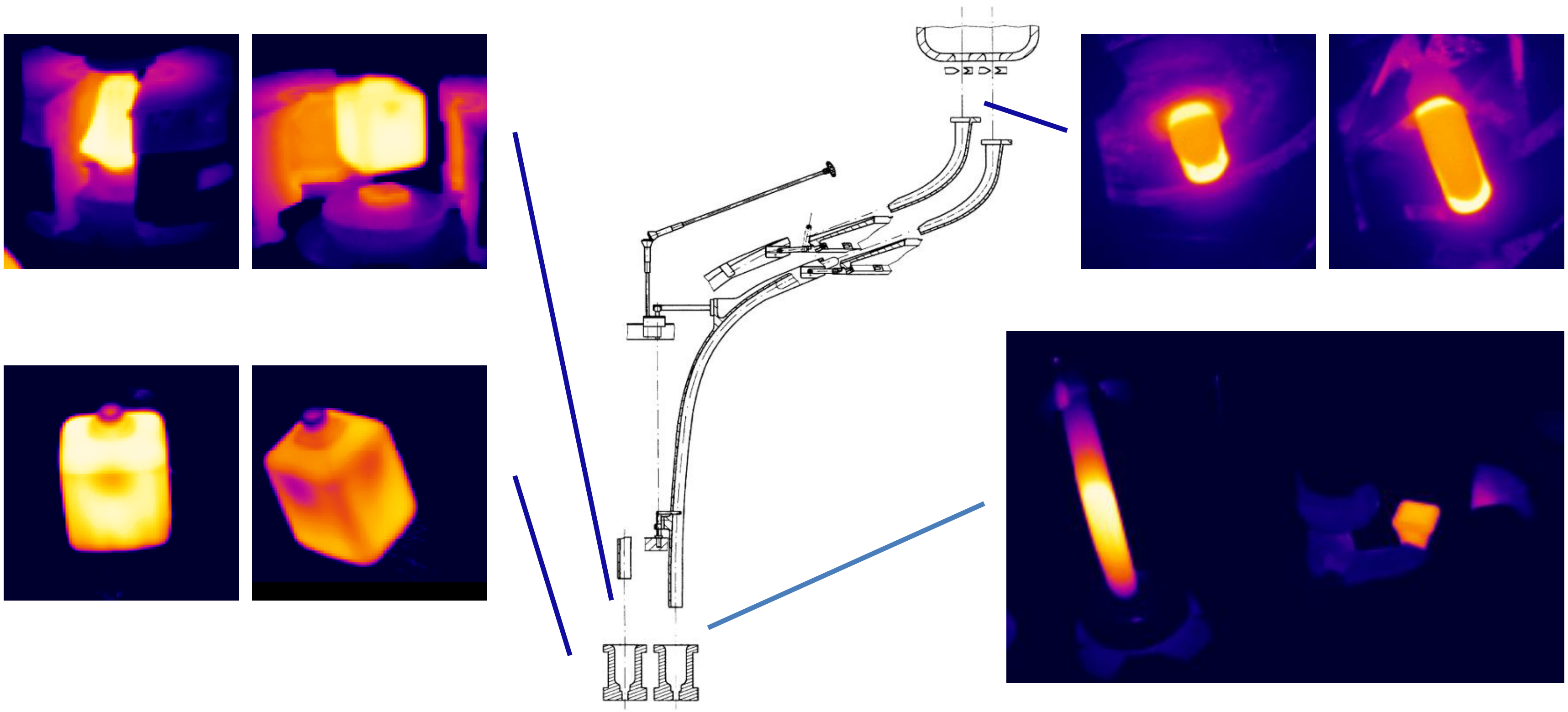
a) Glass and mold equipment temperatures.

b) Glass geometries: gob, parison and final container.

Measurements in Production Line

Temperature & geometry

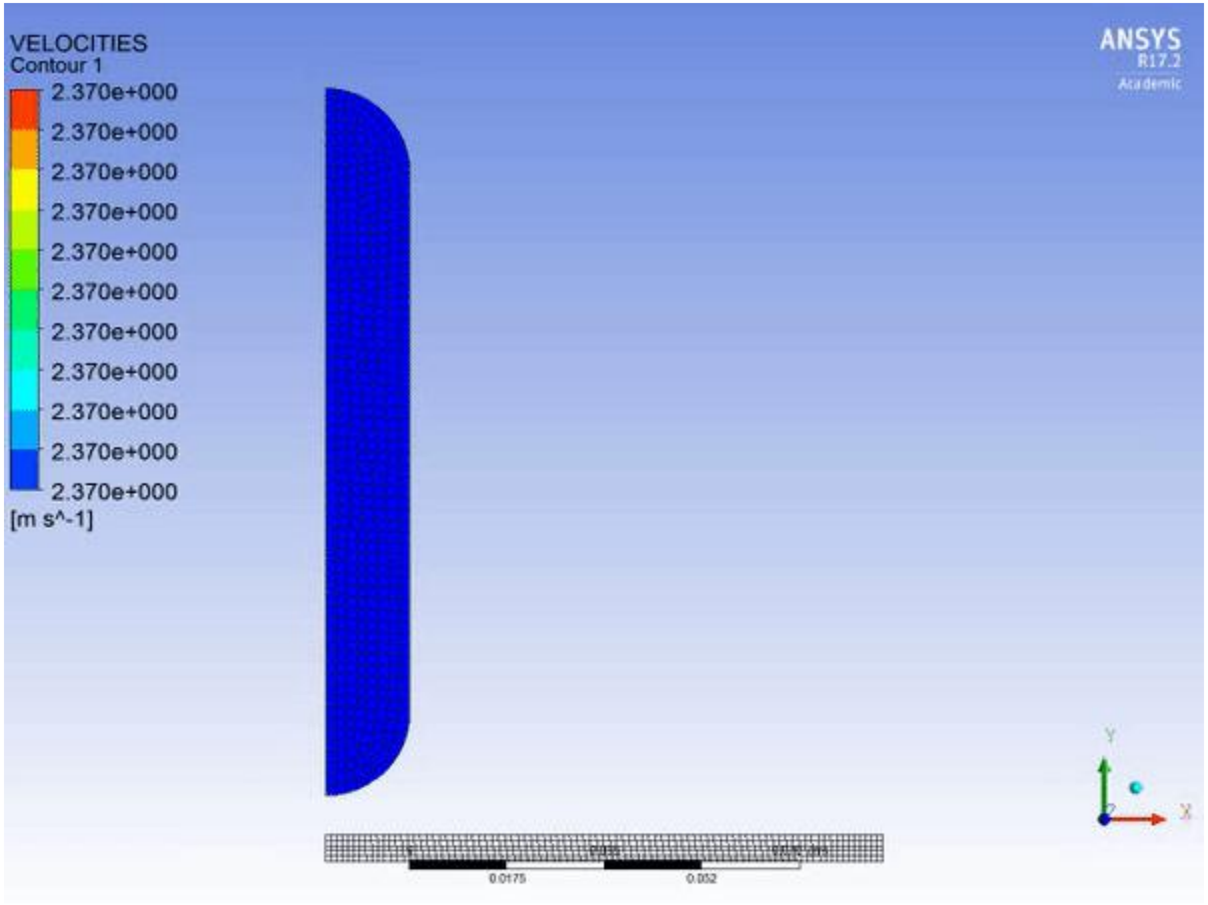
There are different stages of the forming process where glass can be seen, therefore where it can be measured:



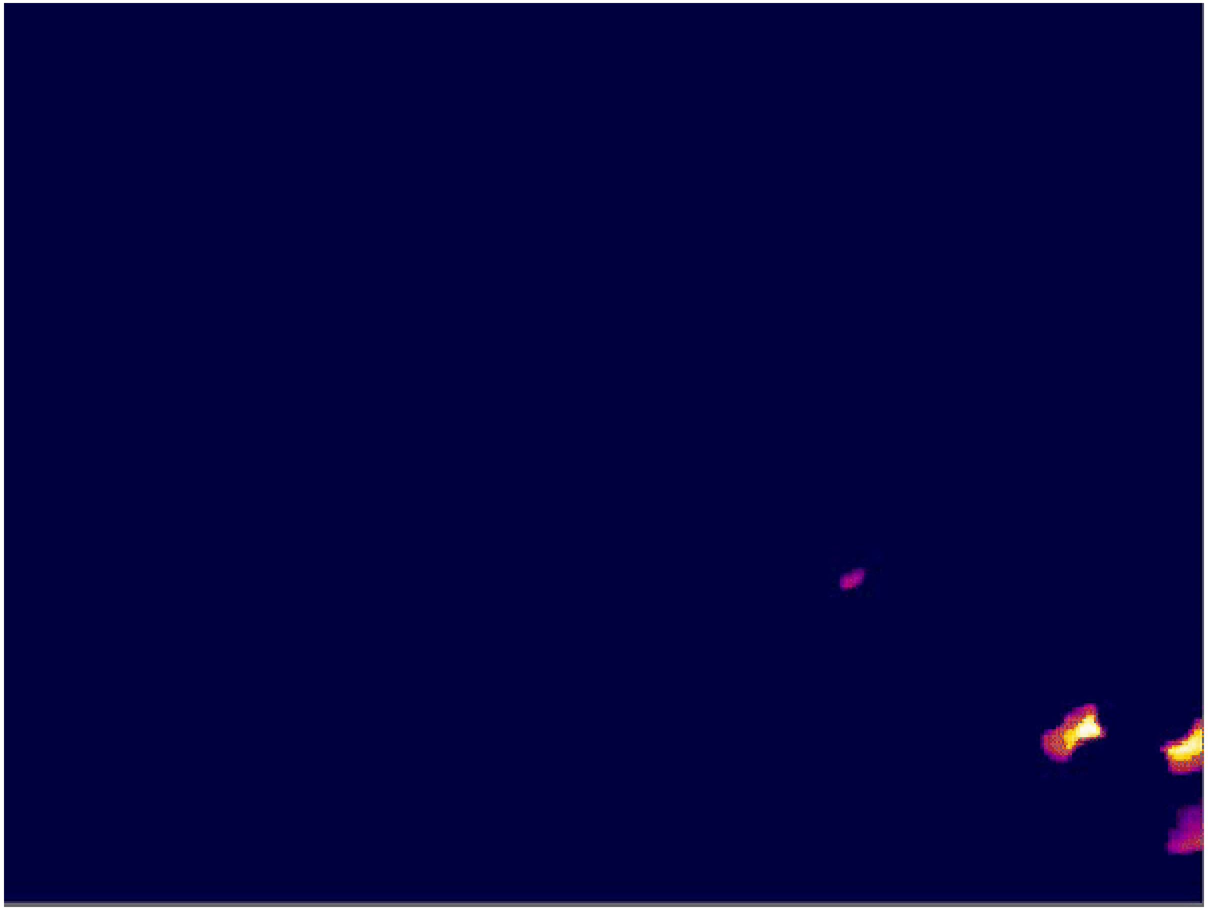
Simulation results (1)

Simulations **always give results but should we always trust them?**

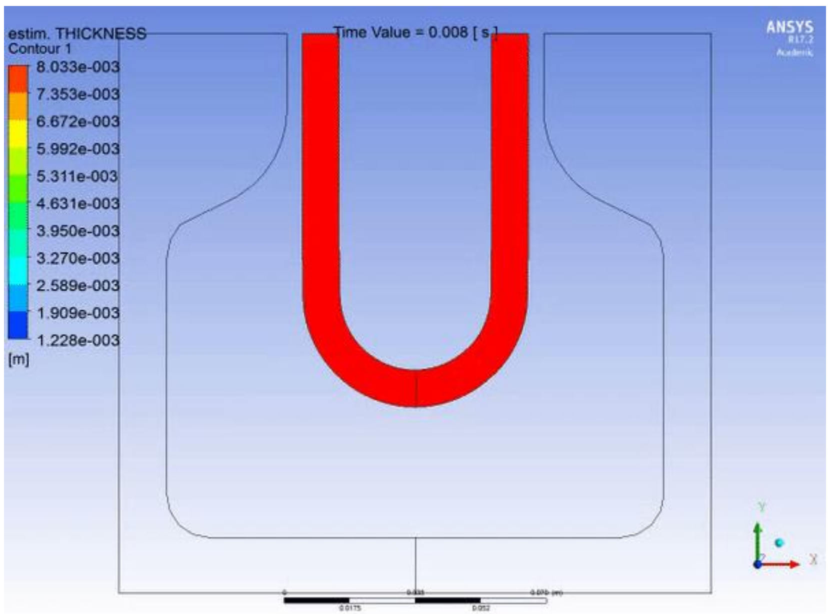
Simulation Results
Gob Droptest (1)



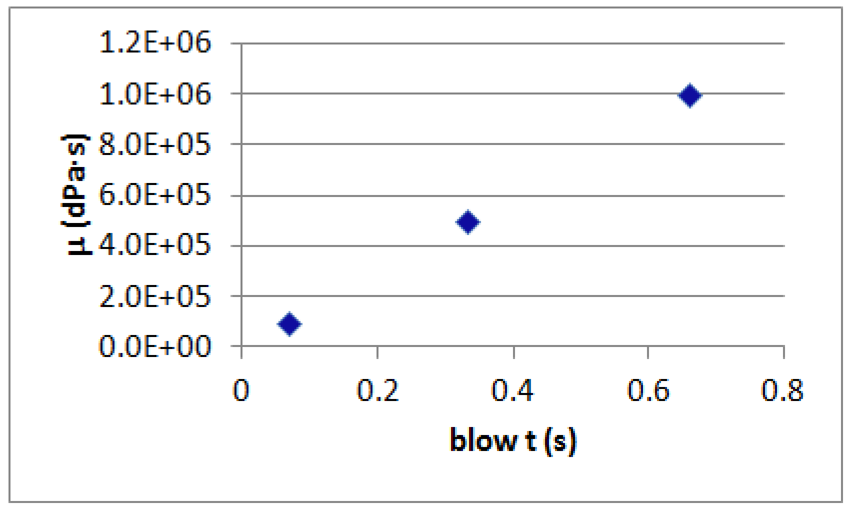
Simulation Results
Gob Droptest (2)



Simulation Results
Blowing Time (1)



μ (dPa·s)	log μ (dPa·s)	T (ºC)	blow t (s)
1.0E+05	5	897.07	0.067
5.0E+05	5.70	838.71	0.332
1.0E+06	6	816.50	0.66



Simulation Results
Blowing Time (2)

Blowing time at the blow mold **was increased from 0 s to its production value.** At least **2.1 s were needed to complete the glass expansion** inside the blowmold.

Half expanded bottle (1 s) Fully expanded bottle (4.1 s)

Simulation results (2)

Simulations **always give results but should we always trust them?**

Expansion of glass in blow molding simulations may make sense. **But have we ever seen how real glass is blown inside the mold?**

Is mandatory **to be critical** with the obtained results. And **do the proper validations to be confident with** the computational model results.

Conclusions

As a summary:

- **Simulations must be fed** with values, **proper glass characterization is a key issue**.
- Many **material properties can be characterized under laboratory conditions.**
- **Production line values** can be obtained **from the IS**.
- **Glass temperature and geometry can be measured using an IR thermal camera.**
- **The more accurate experimental values** measured, **the more accurate results** will be obtained.

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