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Sheraton Mustika Yogyakarta - INDONESIA

AFGM
ASEAN FEDERATION OF GLASS MANUFACTURERS

The **COLORFUL World** of **Glass** : Shaping The **Future** and **Breakthroughs** to **Excellence**

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Digitalisation of Glass Melting Process

—

Possibilites and Limitations

– is the ‘Glass Furnace 4.0‘ possible ? –

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1. Introduction

- Big discussion about 'Industry 4.0'.
  Machines & Software are beeing developped in many areas of the Manufacturing process.

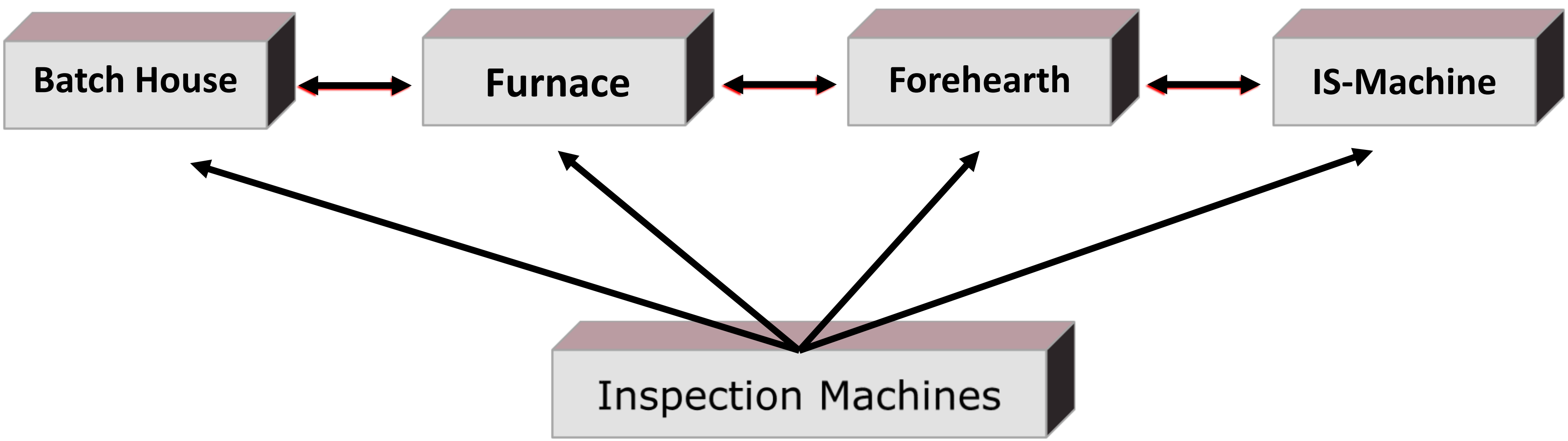
- Basis of digitalisation is sensor-based collection of data

- Problems in Glass making:
  - → Extreme Temperature
  - → "unexplored" chemical melting process
  - → huge number of dependences for any result (e.g. Blister investigation)
  - → long reaction times
  - → collection of data more difficult than in other industries
  - → lack of experienced personnel

1. Introduction

→ Proper sensors necessary

→ Interaction of currently rather distinct production areas



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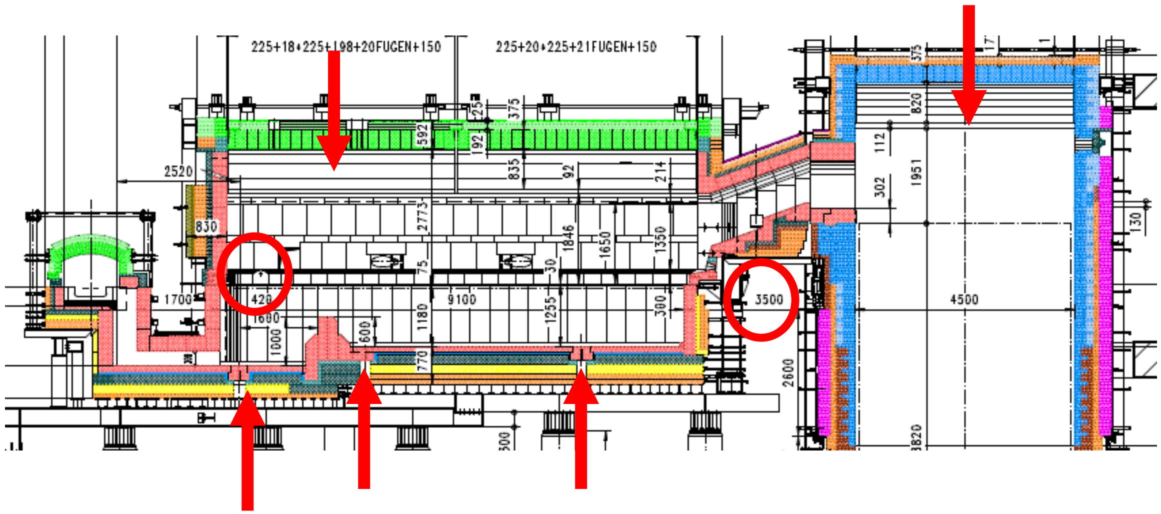
Necessary Sensors for Glass Melting – Bare Minimum



- 1 direct thermocouple in crown
- 1-2 indirect thermocouple in crown
- 2-3 indirect thermocoules in bottom
- 1 furnace pressure probe
- 1 gas amount measurement

No/low limitation of:

- Emissions (NOx, CO, SOx)
- Energy consumption
- Glass quality

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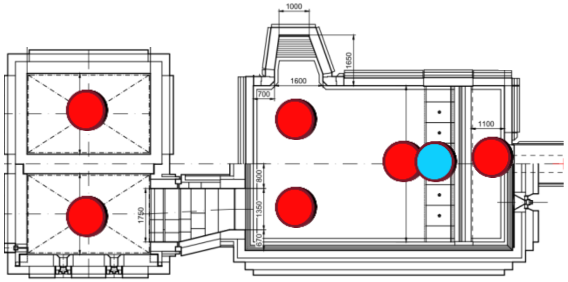
Necessary Sensors for Glass Melting

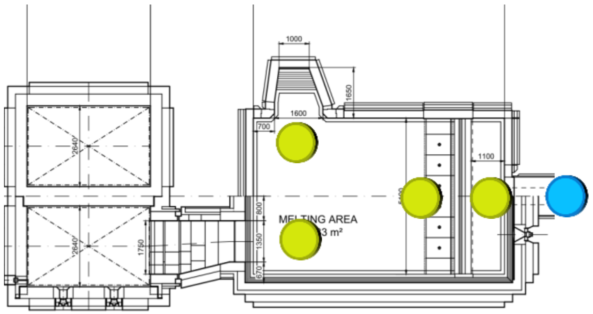
incooperating limitations for Emissions, Energy and Glass Quality

- 1 direct thermocouple in crown
- 4 indirect thermocouples in crown
- 4 indirect thermocouples in bottom
- 1 direct thermocouple in riser
- 2 furnace pressure probes (backup)
- 1 chimney draft measurement
- 1 fuelflow meter (port control)
- (1 fuelflow meter each burner or nozzle)
- 1 airflow meter
- 2 direct thermocouple at top of regenerator
- 2 oxygen probe at top of regenerator
- 1-2 Glass level measurement
- Furnace camera
- Measuring devices for electric boosting
- Process Control System (PCS)

TC Crown



TC Bottom



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Necessary Sensors for Glass Melting

incooperating limitations for Emissions, Energy and Glass Quality

Additional Sensors / Tools for Functional Safety:

- Safety control system CPU
- Redundant airflow measurement device/transmitter
- Redundant furnace pressure transmitter
- Redundant direct crown transmitter

→ Certified sensors are neccesary!

➔ There is a lot of effort necessary to maintain a good, stable and safe process!

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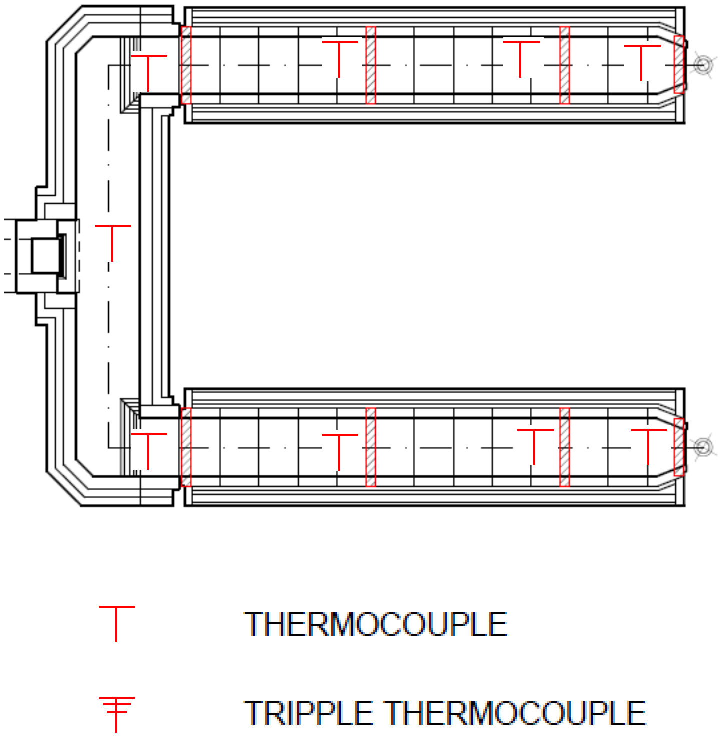
Necessary Sensors for Conditioning – Bare Minimum

- 1 direct thermocouple in glass each zone of distributor and forehearth
- 1 pressure probe fuel each zone

→ Combustion airflow and cooling dampers can be adjusted manually

➔➔➔ Very time consuming
➔➔➔ Very much experience necessary (visual adjustment)
➔➔➔ No measuring of homogeniety



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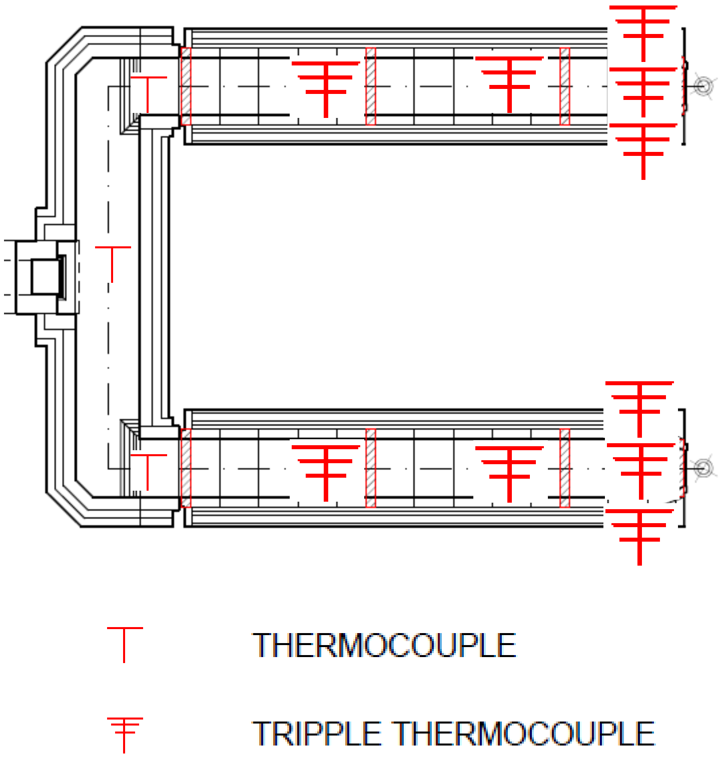
Necessary Sensors for Conditioning

- For many Job Changes, Reproducibility and high homogeniety

- 1 direct thermocouple each zone of distributor
- 1 direct triple thermocouple each zone of forehearth
- 3 direct triple thermocouple each zone of forehearth
- 1 pressure sensor fuel each zone
- Ratio control valve each zone
- Combustionair flow measurement
- Coolingairflow (in-)direct cooling
- *(remote control dampers with positioning sensor)*
- *(Lambda-Control by residual O2 measurement)*



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3. Current Control Loops – Dist. / FH

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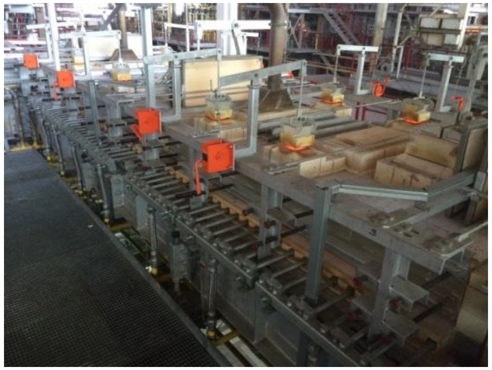

Control Loops Distributor / Forehearth

- Temperature control
- Cooling Air Control

Advanced Control Systems Distributor / Forehearth

- Integrated forehearth control (simultaneous control of combustion and cooling)
- Setpoint Slope
- Lambda Control

Model Predictive Control Systems Distributor / Forehearth

- Self optimizing
- Not very common yet

3. Current Control Loops – Dist. / FH

Standard Control Strategy

Manual setting

- Cooling Fans (regulation flap or frequency converter)
- cooling dampers / chimneys (manually or with actuators)
- Fuel/combustion air ratio

Temperature Control

- Affects combustion only
- Supporting tools like setpoint slope

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Advanced Control Strategy – Integrated Control

Integrated Temperature Control

- Affects combustion, cooling fans and dampers
- Combustion is in a defined range (optimum 15 - 25mbar)
- Cooling is used to cool down and keep combustion in optimum range
- PID – temperature controller sends signal to PCS module. For every actuator exists a predefined control curve

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Advanced Control Strategy – Cascade Control Loops

Manual setting

- Gob weight } pull
- Cut number }
- Gob viscosity for forming process

→ Gob temperature is calculated from batch house data
→ All temperatures before are adjusted with integrated control
→ Possibly even optimum distributor entrance temperature is adjusted in the melting end
→ Feedback from inspection machines for
- IS – Machine settings (shape)
- Batch house (color)
- Melting end (glass quality)

This is kind of a dream?

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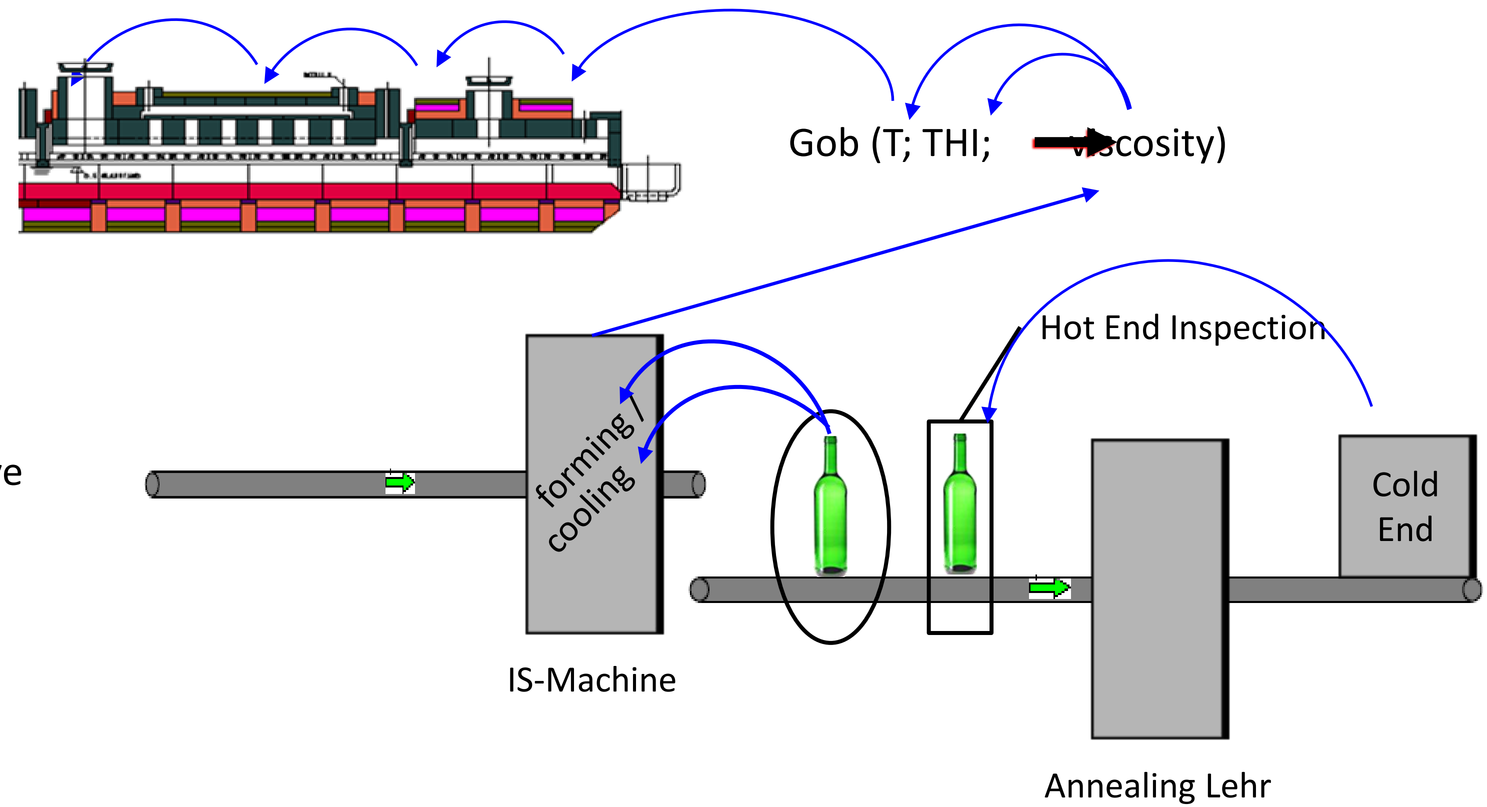
3. control loops / control strategy

Defect sourcing /starting from cold end

Glass T_{entry}



defects mostly have reverse origin

"old saying":

Half of the bottle is produced
In the Forehearth

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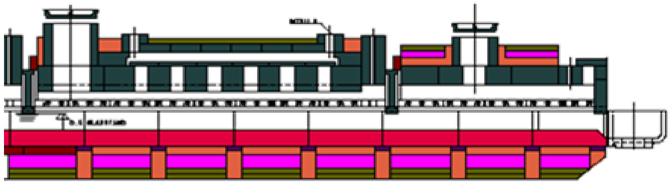
Good Production Time Gain with Cascade Control Loop



Fully controlled FH

Gob inspection machine

Hot inspection machine

-	Reaction time:	- Feeder EQZ Zone	x – (a+b+c+d)
		- Drop from spout	x – (a+b+c)
		- IS - Machine	x – (a+b)
		- cooling lehr	x – a
		- cold end inspection	x (= time when defect is found)

➔ Long time between action and **reaction**. Too long for efficient production!

➔ Hot or gob inspection machines or fully controlled forehearth necessary

(→“detects” defect source in conditioning before it occurs at spout)

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General Aspects of Industry 4.0

Prerequsites:

- **Process description**
- **Interlinkage of data**
- **Data base**

} Invest and Specialists

Automatic Process Control *is not free of maintenance*

- **Self-learning is not automatic** *(has to be adjusted and checked – setpoints, priorities, restrictions)*
- **Model predictive control (MPC)**

Predicative Maintenance *for stable process operation*

- **Checks**
- **Exchange of wear parts**
- **Documetation**

} Structures have to be organized

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Control Aspects to improove

Goals:

- **Faster reaction time** for less production loss
- **More precise regulation** for optimum performance
- **Less manpower** for more time for innovation
- **Same control strategy for the whole day** for stability

Solutions

- **More control loops**
- **Self optimizing systems**
- **Interlinkage between single production units**

Tools

- **More Sensors for better resolution?**
- **Better Sensors for higher accuracy?**
- **Different Sensors for additional information?**
- **More sophisticated control methods / algorithms?**

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Measures to improve Control Aspects

- **More Sensors for better resolution?**
  - *Grid measurement*
- **Better Sensors for higher accuracy?**
  - *lower measuring failure*
  - *lower drift over time, e.g. pyrometer*
- **Different Sensors for additional information?**
  - direct temperature measurement in melting end
  - redox probe in glass
  - faster reaction time due to earlier information
- **More sophisticated control methods**
  - *Energy balance based control*
  - *CFD Model based control*
- **Interlinkage between single production units**

Higher cost (first three items)

Mostly use of available tools (last two items)

4. Future needs

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Possible New/Advanced Sensors for Glass Melting

- REDOX probe in glass
- SOx Sensor in glass

} High cost for short lifetime

- Natural Gas analyser (to be able to react on fuel quality changes) → expensive
- Flue gas analyser (Laser type in port neck or extractive for complete analysis) → expensive and high maintenance
- Thermographic camera → only sensible with combustion optimization
- More direct thermocouples in glass (for faster reaction time) → weak point of furnace structure
- Hot end inspection machine for faster reaction time

➔ Probably information can be gathered elsewhere in process. E.g. from distributor/forehearth (e.g.temperature) or inspection machines (e.g. redox by color analysis or melting temperature by seedcount)

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Possible New/Advanced Actuators for Glass Melting

Melting End

- Automatic burner angle adjustment
- Additional injection lances of air, natural gas or oxygen (ggENOx, COROX, counter air at port neck)
- Automatic insulation removal / mounting (e.g. in refining part)

Distributor Forehearth

- Active cooling elements
- Automatic insulation removal / mounting
- Automatic adjustment of residual O2

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Available or Possible Advanced Control Systems

Melting End

- Model Predictive Control

Distributor Forehearth

- Model Predictive Control
- Integrated temperature control
- Cascade temperature control (setpoint is at the end of production chain, all other zones are subordinated and automatically adjusted)

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Possible Links between distinct Production Steps

Melting End	Batch House
Energy consumption Foam on the furnace	Batch humidity Cullet content Sulphate/Carbon amount

Inspection Machine	Batch House
Color	(de)coloring agent, Redox

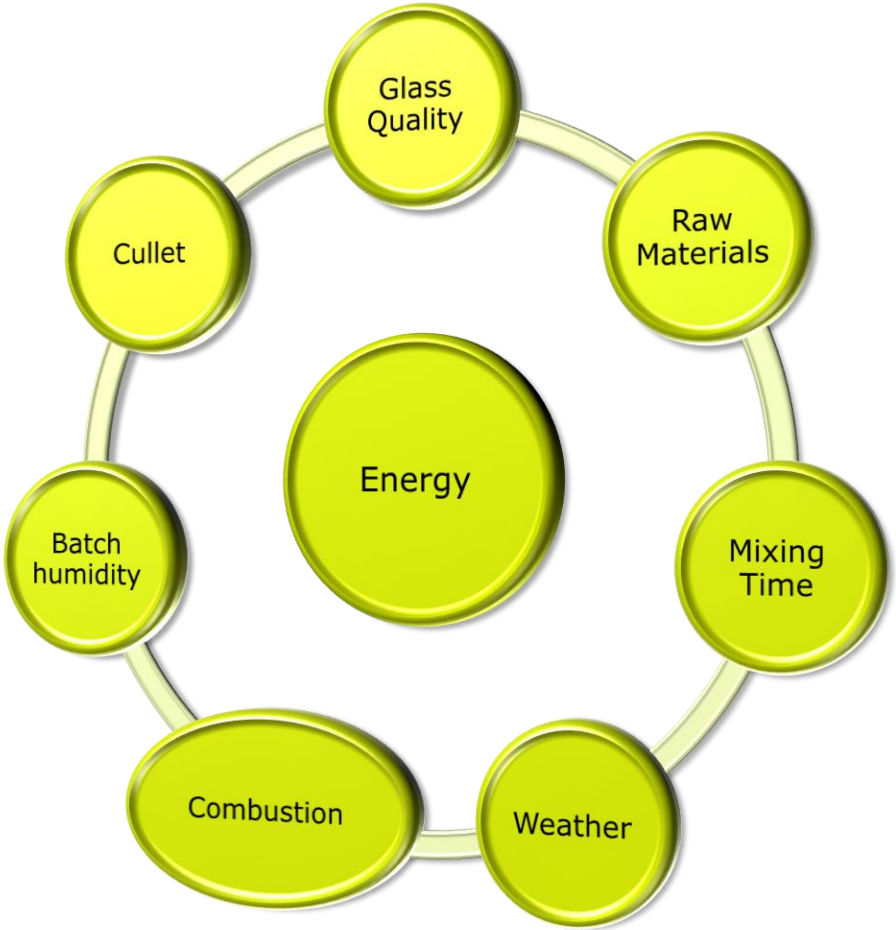
Inspection Machine	Furnace
Glass Quality	Energy consumption

Inspection Machine	Forehearth
Bottle Shape	Setpoint gob temp

5. Predictability of Glass melting / conditioning process

Glass Melting is a complex process and can be predicted by:

- Energy balance models
- Mathematical approximations *(only valid for one furnace at one time)*
- Complete CFD Model
- Experience

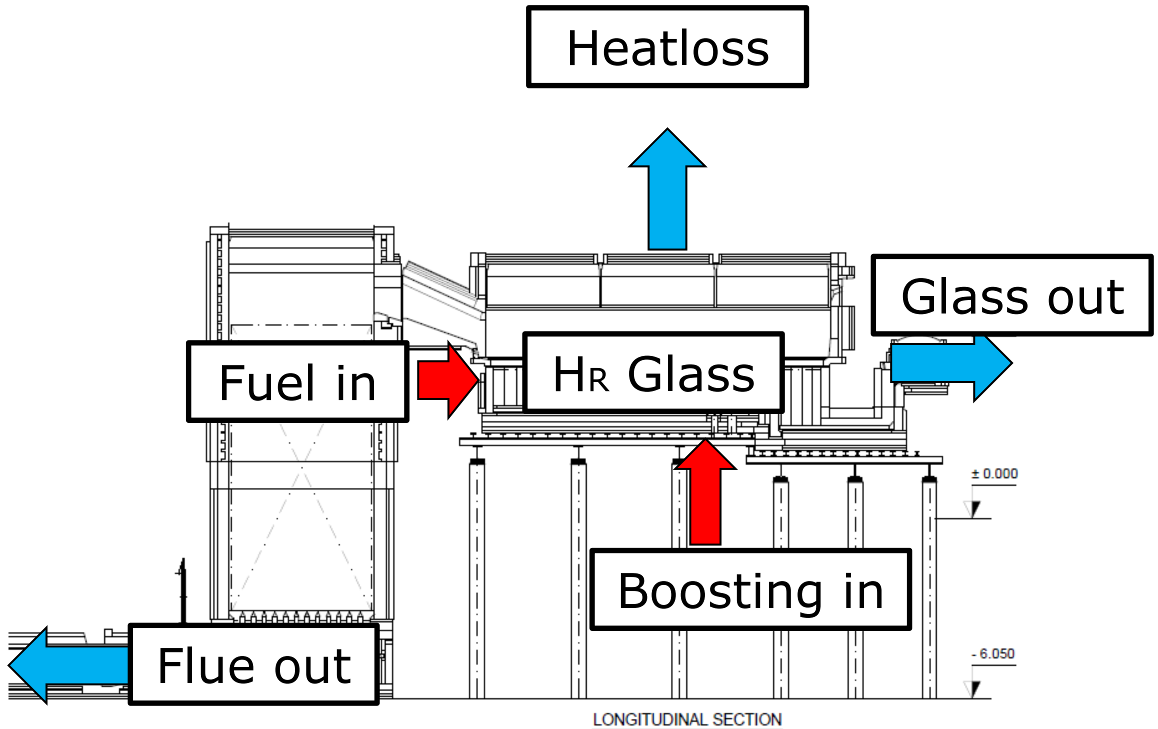


5. Predictability of Glass melting / conditioning process

Energy Balance Model of Melting End

All numbers are known or easy to calculate:

- Fuel in – known
- Boosting in – known
- H_R Glass - calculate
- Flue out – calculate
- Glass out – calculate
- Heatloss – residue
- Batch in - neglible
- Air in - neglible

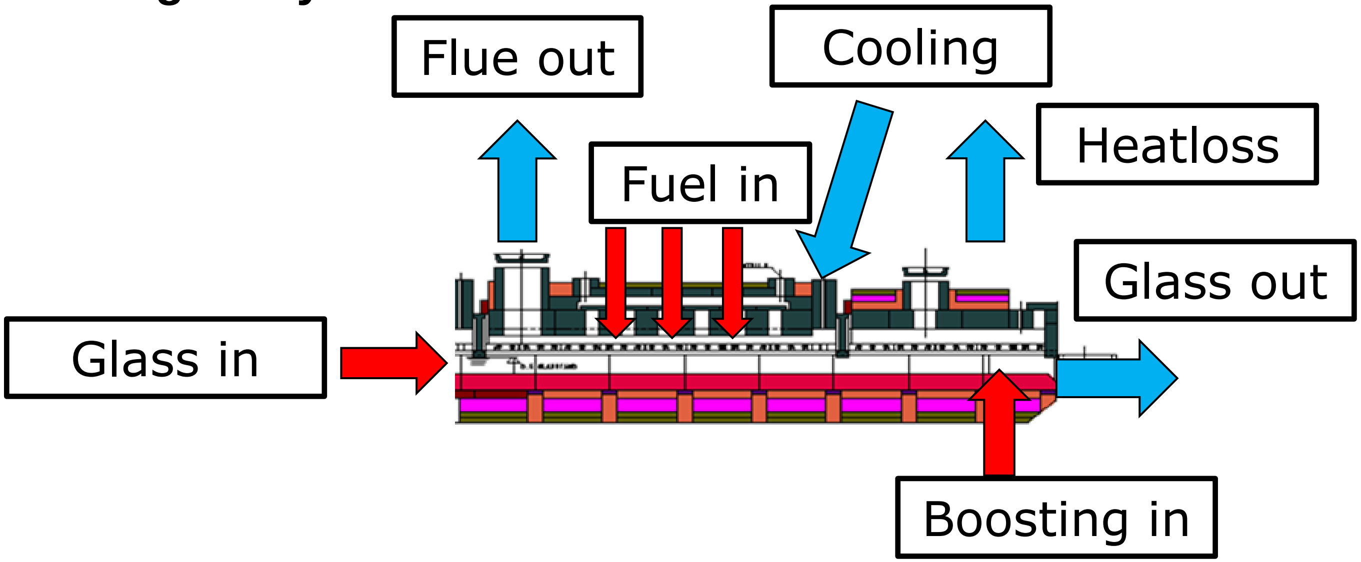


Greatest uncertainities:

- Cp value of glass
- Reaction enthalpy of glass (also batch humidity)

Energy Balance Model of Conditioning Process

Is currently not used for forehearth control, but for forehearth design. Easier than furnace model, but no information about essential output: Homogeniety



➔ Needs to be connected with restrictions and probably self optimizing algorithms, **possibly feasible for energy control, but not for homogenisation**

5. Predictability of Glass melting / conditioning process

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Model Predictive Control

To develop a working totally predictive model is very time consuming and needs a lot of data.
Since every furnace is different, it has to be adjusted to the circumstances.

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Cyber Maintenance

Cyber Maintenance is already reality for
- **Software (PCS)**
- **Failure diagnosis (e.g. pushing of electrodes, or batch charger failure)**

Data is already transfered
- **Via internet and VPN or Team Viewer to another client**
- **Via wireless LAN to cell phones/tablets in plant**

There are little robots for mechanical work, though robot number is increasing rapidly:
- **Swabbing robots**
- **Inspection machines**
- **Packaging machines**

➔ Probably some machines will be equipped self repairing/saving systems, e.g. a batch charger that can pull out itself in case of clogged funnel. Most probably these special activities will be done still by humans

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7. Future outlook / conclusion

Many companies are working on self conducting and optimizing processes. Every stupid and hard work will be done more and more by robots and employees have to cope with totally different problems than today.
The fourth industrial Revolution will lead to

- More sensors
- More actuators (robots)
- Other qualification needs for employees
- Less physical work and more brainwork
- Different company structures

THANK YOU
FOR YOUR ATTENTION!

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