How the Industrial Revolution 4.0 will impact the Glass Industry

Furnace Image analysis part of ES 4.0 a key component towards Industry 4.0
• Introduction GS
• What it means to be Industry 4.0
• Present Automation of Glass Production
• Furnace melting automated by Expert System III and 4.0
• GS Furnace Camera Identification Techniques
• Outlook
Glass Service Inc. (headquarter)
Czech Republic (total approx. 100 people)

- Furnace modeling
  - Model studies (Regen. & FH)
  - GFM SW License
- Furnace Control
  - ESIII MPC
  - Batch Monitoring Industry 4.0 control by ES 4.0
- Lab. Services
  - Glass Defects
  - R&D Projects
  - Lab Equipment Rapidox HTO
- Applied Modeling
  - Physical Modeling
  - Forming Modeling
  - Other Forms specialized Simulations Eg. Tin Bath
- Engineering Services
  - Pot Furnaces
  - Specialized Glass Tanks
  - Equipment for Hand Production
  - Electric Boosting Electric Furnaces FIC

Other Divisions of Glass Service Inc.:
- Furnace data analysis & Inspections
- Raw Materials Deliveries
- Offices in USA, UK, NL, FR, D, SK, Rus, China, Japan
- 790 Customers Worldwide
1. Industrial revolution
Introducing mechanical production machines powered by water and steam

Industry 1.0

End of the 18th century.

2. Industrial revolution
Introducing mass production lines powered by electric energy

Industry 2.0

Beginning of the 20th century

3. Industrial revolution
Through the use of electronics and IT further progression in autonomous production

Industry 3.0

Beginning of the 1970s

4. Industrial revolution
Based on cyber-physical systems

Industry 4.0

Today

Steam

Electricity

Computers

Cyber-Physical

Source: DFKI/Bauer IAO
Industry 4.0 is a name for the current trend of automation and data exchange in manufacturing technologies. It includes cyber-physical systems, the Internet of things, cloud computing. Industry 4.0 is commonly referred to as the fourth industrial revolution. Industry 4.0 creates what has been called a "smart factory".

- Builds on the Digital revolution
- The Internet of things
- Smaller & powerful sensors
- Artificial Intelligence (AI)
- Machine Learning
- Labor & Energy Cost

A cyber-physical system (CPS) is a mechanism that is controlled or monitored by computer-based algorithms, tightly integrated with the Internet and its users.
New trends in data processing (Xpar)

Examples industria 4.0

- Inspection machines design to be intelligent and learn from Production conditions & adjust settings
- Hot End IR-D Inspection and data analysis
- Automatic Swabbing Robots with safety sensors
- GS ESIII using Furnace Camera to process data and control.
Container Glass production

Raw Material delivery
Mixing raw Material
Melting
Forming
Cooling
Quality Inspection
Packing

Level of automation
70% 90% 40% 60% 70% 95% 90%

Missing is automatic interpretation & interconnection of info exchange & feedback
Additional PC computer with OPC/DDE communication is only necessary HW addition to run ESIII. Original control equipment is used:
• Standard PID control loops are used for fast processes with single input/output variables (almost entire glass production line).

• Strong correlations between multiple input and output variables, incl. disturbance variables.

• GS ESIII state of the Art with about 5% of glass furnaces worldwide installed
MPC PROCESS MODELS EXAMPLES

<table>
<thead>
<tr>
<th>Gas</th>
<th>Boosting</th>
<th>Cullet Ratio</th>
<th>Pull</th>
<th>Bubbling</th>
</tr>
</thead>
</table>

![Graphs showing process models for different parameters including Gas, Boosting, Cullet Ratio, Pull, and Bubbling.](image)

**PID**  
**MPC**
Temperature stability Improvement, with energy savings 3%

ESIII™ setpoint zone ± 1°C for TB control

Data sample 2 months

ESIII™ was in control for 96% of the time

Data sampling 5 minutes

<table>
<thead>
<tr>
<th>TB tolerance</th>
<th>Operator</th>
<th>ESIII™ (old furnace)</th>
<th>ESIII™ (new furnace)</th>
</tr>
</thead>
<tbody>
<tr>
<td>± 2 °C</td>
<td>19.6%</td>
<td>64.8%</td>
<td>74.4%</td>
</tr>
<tr>
<td>± 4 °C</td>
<td>44.5%</td>
<td>91.6%</td>
<td>97.4%</td>
</tr>
</tbody>
</table>

Percentage of time TB is within tolerances ± 2 °C and ± 4 °C during entire process control, including pull changes
**ESIII™ Advanced Process Control for Glass Production**

1. is a comprehensive supervisory advanced control tool – keeps existing PID loops
2. Models are made in most cases from historical database or step testing
3. is designed for glass melting and conditioning processes
4. stabilizes long and short term processes
5. provides full automatic control of glass production temperatures
6. brings consistent furnace operation to furnace – 24/7 independent on operator
7. uses energy sources efficient – saving energy and costs
8. stabilizes glass forming conditions – increase yield
9. optimizes combustion – emission control
10. stable furnace operation – impact on furnace lifetime
Present Trend of Industry 4.0 is motivating glass production for further automation of the glass melting process with less need of operators.

Part of the glass melting process such as the batch blanket spread in most furnaces and Glass Ribbon in Tin Float baths relies on operator visual regular inspection and his personal interpretation, followed by some decision making.

Management understands that there are alternatives to current conditions and changes can be done in the near future.
• GS IP HD Visual & Infrared cam with electronic retraction system
- Monitoring
- Input to the ES 4.0
Measured data, statistics, analysis

Projection

Correspondence between the real world and the images

Image processing
Analyzing via picture archive easy long term video
- Bubblers position and size detection
- Batch flow direction and velocity
- Batch coverage / Batch periphery = Batch fragmentation

Picture 7: Container furnace measurement
• TCP/IP client integrated in ES IV
• Might be used separately also
• Viewing and history browsing pictures and videos
• Fast playing forward and backward possibility
• Multiple monitors and screens can be defined
New Camera provides 2 video streams: regular vision information plus calibrated temperatures using Infrared parallel.
• Operator can review temperature history
• Operator can use “virtual thermocouples”
• Using IR camera for spread detection, improved detection

Picture 12: Ribbon Spread detection IR camera
Adding Intelligent “Vision” to the process

Newer (available) sensors

- Batch/Cullet Humidity
- LIBS (Laser Induced Breakdown Spectroscopy)
- Batch Line
- BTU
- Oxygen sensor
- Mass Spec Fuel & Flue gas
- Corrosion
- ESIII Feedback

Existing standard sensors

- Disturbances
- Operators
- Temperature sensor
- Glass level sensor
- Neural Network Defect recognition
- ESIII Feedback

Batch preparation

Melter

Working end

- Forming
- Annealing
- Inspection
- Forehearth
- Forehearth
- Defects imaging

Defects Mass Spec

Oxygen sensor

Viscosity sensor

Gob Image

Mold temp Thermo vision

Online stress
Final HMI process overview for advanced control, 2 melters and 6 forehearths example
ES/// References till mid 2017

GS EXPERT SYSTEM INSTALLATIONS WORLDWIDE: 1996 – 2017

Total number of GS ADVANCED CONTROL SYSTEMS: 185
Top 10 Skills to be relevant in Industry 4.0

<table>
<thead>
<tr>
<th>in 2020</th>
<th>in 2015</th>
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</thead>
<tbody>
<tr>
<td>1. Complex Problem Solving</td>
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</tr>
<tr>
<td>2. Critical Thinking</td>
<td>2. Coordinating with Others</td>
</tr>
<tr>
<td>3. Creativity</td>
<td>3. People Management</td>
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<td>5. Coordinating with Others</td>
<td>5. Negotiation</td>
</tr>
<tr>
<td>6. Emotional Intelligence</td>
<td>6. Quality Control</td>
</tr>
<tr>
<td>7. Judgment and Decision Making</td>
<td>7. Service Orientation</td>
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Source: Future of Jobs Report, World Economic Forum