Efficient Mass Production of Fuel Cells

The increasing demand for fuel and electrolysis cells cannot be met with current furnaces. Continuous production furnaces are needed for cost-efficient mass production which deliver high-quality products and excellent process reliability for large quantities.

According to the Hydrogen Council's "Hydrogen Insights 2021" study, companies plan to increase their hydrogen investments six-fold by 2025 and 16-fold by 2030. Larger production capacities in particular will have to be built to meet the growing demand for electrolysis capacities and fuel cells. The mass production of solid oxide ceramic fuel cells (SOFC) and electrolysis cells (SOE) is not feasible with simple chamber furnaces with only a few square meters of useful space. It leads to higher scrap rates, longer processing times and high energy consumption in relation to throughput as production numbers increase. One of the key problems is insufficient temperature uniformity within a chamber or batch furnace, which significantly affects both cell geometry and binder/gas removal, and thus product quality.

Now, Onejoon has a solution for cost-efficient mass production of SOFC cells. The specialist for technologically sophisticated furnace systems, formerly known as Eisenmann Thermal Solutions, began the development of continuous production furnaces for the special requirements of ceramic fuel cells and electrolysis cells in the fall of 2019 and completed it in the first quarter of 2021. In this process, the steps from laboratory to small-series scale and finally to the large-series process were completed successfully (Figure 1).

Continuous production furnaces for oxide ceramic cells

A decisive step in cell production processes is the controlled heating and gas flow of products in the first heating step, debinding. Any binder substances released during this step must be removed entirely in a narrow process window. At the same time, a specified heating rate must not be exceeded locally. In order to be able to estimate the heat transfer coefficients under real process conditions in the design phase, Onejoon has carried out detailed measurements and subsequent simulation studies in its own test center and in real production.

In addition to thermogravimetric analysis, priority was given to temperature measurements at relevant measuring points in the furnace. In this way, the most important set of parameters and tolerances for a uniform, reliable, and reproducible continuous thermal process were determined.

One of the special challenges in the production process is controlled debinding. Since the reactions are usually exothermic, poor process control can result in uncontrolled binder release and a local temperature inhomogeneity inside the product. Possible consequences are cracking and swelling of the cell and, in the worst case, rejection. Furthermore, this can lead to a lack of oxygen in the process and to carbon residues in the microstructure, which causes undesirable pore formation during sintering. During sintering, temperature homogeneity is of primary importance to prevent uneven expansion and shrinkage of the cell. The resulting changes in the microstructure can hinder the subsequent gas exchange of the cell.

To address this issue, the furnace specialist developed an alternative heating concept for heat control in the continuous debinding furnace. The energy exchange takes place through a controlled air flow both by thermal radiation and forced convection. Here, a finely adjustable array of nozzles forms a homogeneous and well controllable air flow that actively removes the binder gas.

In addition, to provide improved temperature homogeneity, the company developed

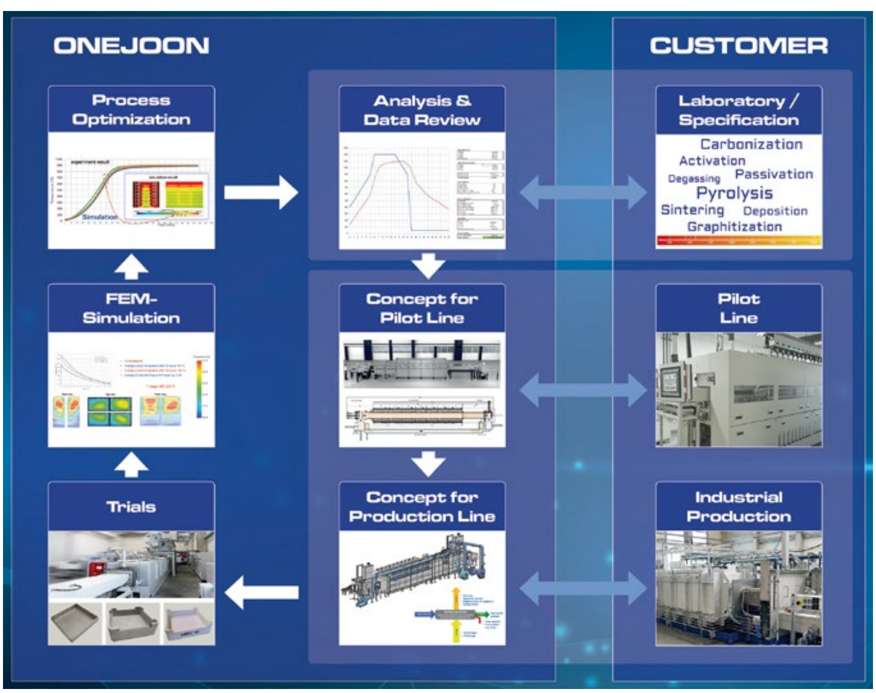

Figure 1 The complete development process from laboratory to production furnace. (© Onejoon)

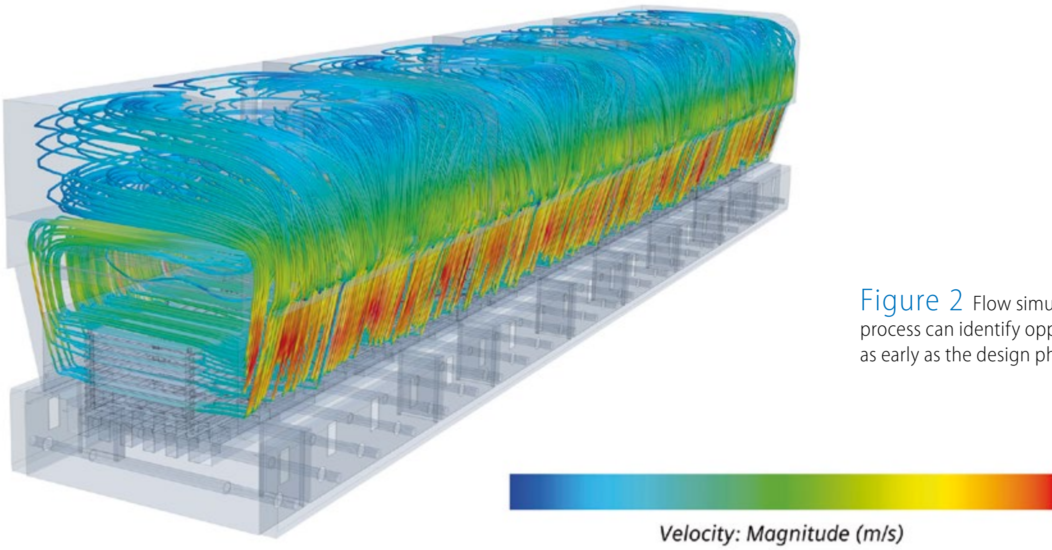

Figure 2 Flow simulation in a SOFC debinding process can identify opportunities for improvement as early as the design phase. (© Onejoon)

an optimized light weight kiln furniture. Due to the high thermal coupling between product and kiln furniture, the product is heated evenly throughout the complete kiln cross-section and a better control of the heating process.

Product-specific simulation and optimization

The path to the optimal furnace for a specific SOFC/SOE product takes place in close cooperation between the plant operator and the design and simulation departments. In this way, validated, physical models can be used to make predictions about the thermal treatment of the cells during the furnace processes at an early stage in the development of an SOFC production process. The simulation used for this purpose is based on a representative model of the subsequent furnace zone or a defined furnace area. The furnace area to be investigated is selected and a discrete computational grid is generated on the basis of a CAD model.

Simulation enables customer specifications and boundary conditions to be checked at an early stage for potential difficulties in production, and design adjustments to be made even before the real application (Figure 2). Problems with existing plants can also be detected and corrected by simulation. This model-based design engineering provides plant operators with technical and economic advantages by visualizing and evaluating the function of the furnace. Depending on the product, optimizations can be made, for example, to the kiln furniture structure, the air injection nozzles, the air flow patterns or the heating power and control.

For the production of SOFC/SOE products, the pusher kiln and the roller hearth kiln are the most suitable continuous production furnaces. The pusher kiln is particularly suitable for mass production at high throughputs with low energy losses (Figure 3). The roller hearth kiln is characterized by a high degree of flexibility with heating curves that can be controlled in detail and is therefore particularly well suited for optimizing processes on a mass production scale.

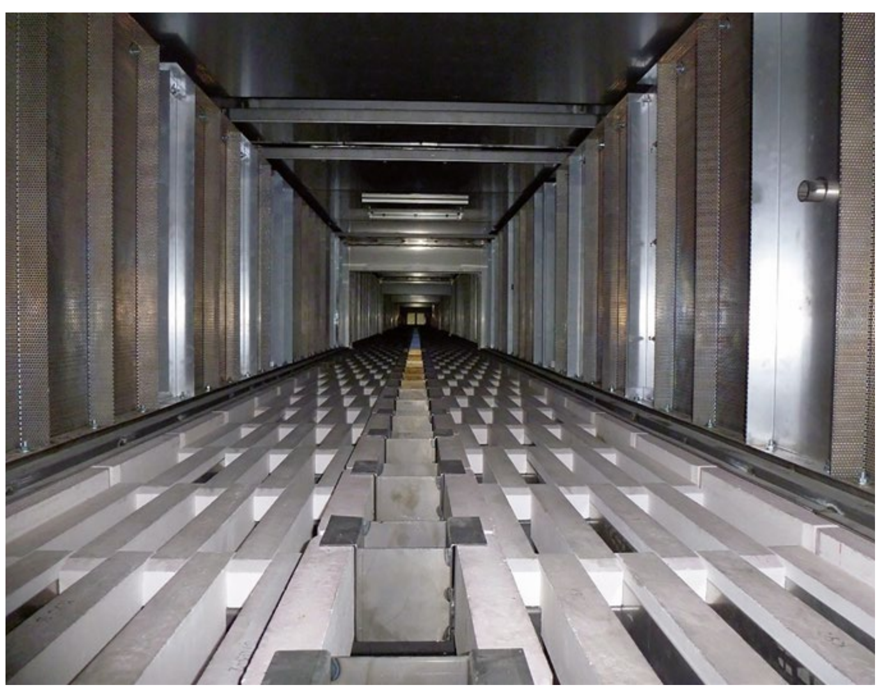

Figure 3 The pusher kiln is particularly suitable for large-scale production of SOFC/SOE products due to its high throughputs with low energy losses. (© Onejoon)

Onejoon uses a standardized engineering process to adapt the furnaces to new SOFC/SOE products. This means that only a few months are required from the initial request to the validated model with this process. In addition, the company also offers a turnkey solution that includes cell handling, kiln furniture design, and exhaust gas aftertreatment as a turnkey system (Figure 4). An outlook: In the 3rd quarter of 2021, Onejoon will put its first-on-the-market continuous SOFC test furnace for the requirements of fuel cells into operation in its in-house test center.

Advantages for mass production

Continuous production furnaces have distinct advantages in the conversion of SOFC/SOE products to mass production:

- Faster, more even heating
- Increased product quality due to better debinding
- Greater flexibility and higher process control
- Safer production
- High energy efficiency
- To production within twelve months

The product is transported through a fully and uniformly heated furnace zone, resulting in better heat transfer and temperature uniformity within the product batch. This allows temperature deviations to be limited to ± 5 K. Forced convection ensures complete binder and gas removal from the cells and prevents carbon deposits. In addition to the alternative heating concept, smaller control zones are realized. They allow better setting and monitoring of the process parameters. This also enables faster adjustments to be made in the event of batch-related material fluctuations or when starting up the process. In addition, different temperature profiles can be used for different products. Adjustable exhaust and supply vents within each zone allow the concentration of flammable gases to be better monitored and controlled. Less energy is required to maintain the desired temperature than with a discontinuous furnace. Wall and heating losses are reduced, cross-section and air circulation are optimized, and the hot air used for debinding is recirculated. Compared to conventional continuous sintering furnaces, optimized design reduces radiation loss and saves up to 40 % of energy during sintering. A modularized design shortens lead times and accelerates project completion. Only twelve months are needed from order to start of production.

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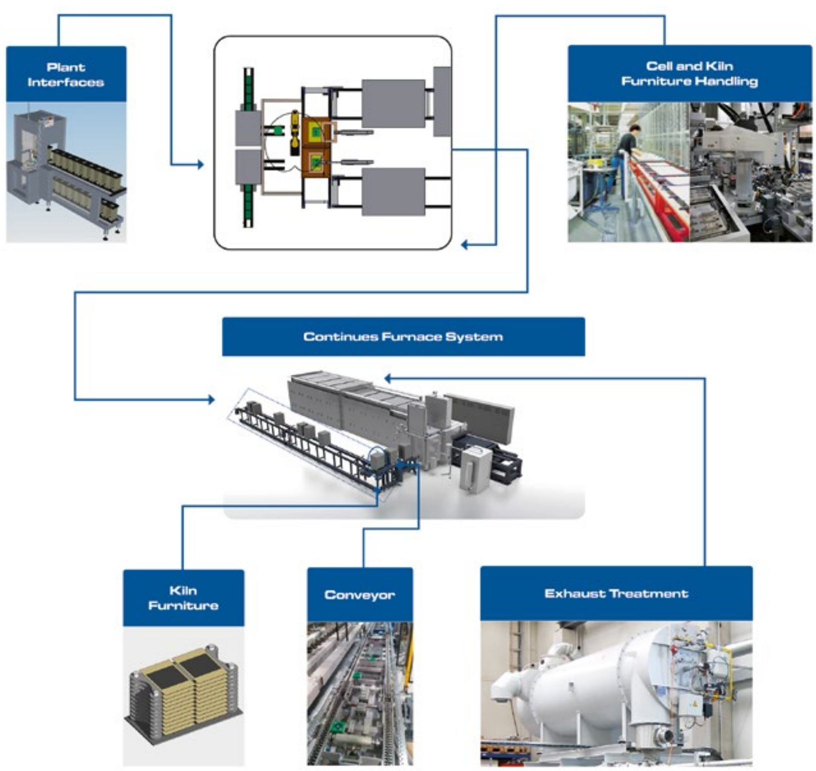

Figure 4 The turnkey production system includes cell handling, kiln furniture design, and exhaust gas treatment. (© Onejoon)