Upscaling processes for new battery raw materials from laboratory into industrial production

ONEJOON GmbH
Agenda

1. Introduction
   ONEJOON Group

2. Motivation –
   What drives us

3. From Laboratory into
   Industrialization

4. Case Studies -
   new anode materials

5. Improving performance
   for CAM

6. Discussion
ONEJOON - Your Partner for Thermal Production Systems

- Represented in 4 countries with 9 locations worldwide
- 240 employees worldwide (2020)
- More than 100 design engineers, researchers and developers
- Quality made by ONEJOON with own factories in Germany, Korea and China
- Ongoing Culture of Innovation ensured by German and Korean Test Center and Research & Development Department
- Experienced Project Management Team with Project Sizes up to 50 Mio €
- Thermal Process Equipment up to 3000 °C and turnkey Thermal Process Production lines
- Pioneer in electric high temperature furnaces
  Established in year 1888
Onejoon Core Teams around the globe can handle local projects on their own with an organisation of Sales, Project Management, Basic Engineering, Commissioning, Site Management and Service.
Factories and Facilities

Headquarter of ONEJOON Co. Ltd. in Suwon, Korea

Headquarter of ONEJOON GmbH in Bovenden, Germany

ONEJOON GmbH, Office Germany South

Production of ONEJOON GmbH in Bovenden, Germany

Test Center of ONEJOON GmbH in Bovenden, Germany

Production of ONEJOON (Zheijiang) Co.Ltd., China
Cathode Active Material
Powder Process Engineering & Equipment

Example for NCM622 2-firing process

1st Firing Process
1. Big Bag Unloading
2. Raw material hoppers
3. Weighing (e.g. loss in weight feeder)
4. Ploughshare or vertical mixer
5. Ribbon mixer
6. Permanent Magnetic Separator
7. Auger Filling System
8. Kiln System A
9. Roll Mill (double)
10. Bag Filter Hopper
11. Ribbon Mixer
12. Air Classifier Mill
13. Bag Filter Hopper
14. Ribbon Mixer
15. Permanent Magnetic Filter
16. Ultrasonic Sieve
17. Electro Magnet Filter
18. Ribbon Mixer
19. Packing Station

2nd Firing Process
20. Bag Filter Hopper
21. Ribbon Mixer + hoppers (CAM1 + Additives)
22. Weighing
23. Ploughshare or vertical mixer
24. Ribbon mixer
25. Permanent Magnetic Separator
26. Auger Filling System
27. Kiln System B
28. Roll Mill (double)
29. Bag Filter Hopper
30. Ribbon Mixer
31. Air Classifier Mill
32. Bag Filter Hopper
33. Ribbon Mixer
34. Permanent Magnetic Filter
35. Ultrasonic Sieve
36. Electro Magnet Filter
37. Ribbon Mixer
38. Packing Station

Hoppers, Vibration Feeders, Chutes, Knockers, Filters, Dehumidifiers, MSR, etc. not shown in list
Thermal Processes
this is our Expertise
## Battery Materials Overview & Onejoon Focus

### Onejoon Focus

<table>
<thead>
<tr>
<th>Process</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mining</td>
<td>Mining of minerals</td>
</tr>
<tr>
<td>Materials Processing</td>
<td>Processing of minerals into raw materials used in Li-ion chemistry</td>
</tr>
<tr>
<td>Component Production</td>
<td>Manufacturing of active and inactive cell components like anode/cathode, materials, binders, electrolyte and separator</td>
</tr>
<tr>
<td>Cell Production</td>
<td>Production and assembly of individual battery cells</td>
</tr>
<tr>
<td>Module Production</td>
<td>Configuration of cells into larger modules that include some electronic management</td>
</tr>
<tr>
<td>Pack Assembly</td>
<td>Stacking of modules together with battery management systems that manage power, charging and temperature</td>
</tr>
<tr>
<td>Vehicle Integration</td>
<td>Integration of the battery pack into the vehicle including the battery-car interface (connectors, converters)</td>
</tr>
<tr>
<td>In-Vehicle Use</td>
<td>Use during specified in-vehicle lifetime</td>
</tr>
<tr>
<td>2nd Use</td>
<td>Battery refurbishment and re-use for stationary applications</td>
</tr>
<tr>
<td>Recycling</td>
<td>Deconstruction for recycling of components and materials</td>
</tr>
</tbody>
</table>

**Image:** Diagram illustrating the battery materials process from mining to recycling with specific focus on Onejoon's areas of interest.
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Motivation for future material processing

Lifetime Sustainability: Well to Wheel CO2 emissions

![CO2 Emission Graph](image)

Fig. 9 'Well to wheel' lifecycle CO₂ emission comparisons (From presentation: 'The Powertrain of the Future - The Challenge of CO₂ and Emission Compliance', Michael Reissig, AVL List GmbH)
Motivation for future material processing

Lifetime Sustainability: Lifecycle CO2 emissions

Fig. 10 Lifecycle CO₂ emission comparisons, including ‘cradle to grave’ data.
Motivation: Current Production of Graphites

Acheson Process / Lengthwise Graphitization

Source: Saint Gobain

Mining

Source: anfre
Target for a sustainable production of raw materials

- Considerable reduction of the energy consumption and emissions –
  Improvement of the lifetime sustainability of e-vehicles

- High control over temperature and atmosphere –
  Improving the yield

- Control over the material properties and
  Improving of the average quality level

- Control over the exhaust properties –
  Continuous exhaust treatment

- Reduction of manual operation steps –
  Integration into an automated production system

Keep challenging your own solution - continuous review of the complete process
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Problem of Upcaling Production

Many of promising new processes fail during industrial upscaling due to their complexity.
From lab into large scale production

- Increasing batch size
- Multiplying batch conditions

Laboratory → Pilot → Production
From Laboratory to industrial scale production

ONEJOON

Concept for Pilot Scale ➔ Concept for Industrial Scale

Process Review ➔ Simulation

Test Center ➔ Concept for Pilot Scale

CUSTOMER

Vision Material & Process ➔ Laboratory ➔ Pilot Line ➔ Industrial Line
Where furnace suppliers come into account

Corporate Research & R&D - Groups

R&D - Groups
Institutes & Laboratories

Process

Material

Production

Classical Furnace supplier

Corporate Engineering
Plant Engineering
Proof of Concept
what does it take....?
Test Kiln „Multifunctional Kiln“

Technical Highlights:
- Versatile functions
- Gas preheating and Gas humidification
- Cooling zones at the inlet and outlet
- Use as conveyor belt or push-through oven possible

Technical Details:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Atmosphere</td>
<td>Air, inert gas, burnable gas</td>
</tr>
<tr>
<td>Temperature-Zone 1-3</td>
<td>Up to 700°C</td>
</tr>
<tr>
<td>Temperature-Zone 4-6</td>
<td>Up to 1,100°C</td>
</tr>
<tr>
<td>Number of separately</td>
<td>6</td>
</tr>
<tr>
<td>controllable heating</td>
<td></td>
</tr>
<tr>
<td>zones</td>
<td></td>
</tr>
<tr>
<td>Heated length per kiln segment</td>
<td>Approx. 4400mm</td>
</tr>
<tr>
<td>Muffle profile</td>
<td>Width approx. 500mm</td>
</tr>
<tr>
<td></td>
<td>Height approx. 200mm</td>
</tr>
</tbody>
</table>
What can we adjust

Inlet Cooling Zone:

Outlet Cooling Zone:

Process variables:

- Amount of powder /layer thickness
- Process atmosphere (Nitrogen, ...)
- Inlet position gas and direction of gas flow
- Flow rate gas (1-20 Nm³/hr)
- Gas/powder ratio
- Dwell time and temperature zone 1 & 2 independant
- Heating and cooling rates (within physical limits)
Current Testing Portfolio: subject to continuous adoption
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Graphite and Carbon for anode materials

Carbon and Graphite

- Natural graphite
- Petrocoke based
- Polymer based
- Deposition based
- Bio material based

Silicon composites
Furnace or Reactor? Processing of Anode Material.

Typical processes
- Drying
- Vapor release
- Pyrolysis
- Carbonization
- Activation
- Passivation
- Deposition
- Graphitization
- ……
Concepts for Anode Materials
based on experience from different industries.
Concept Characteristics:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept Complexity</td>
<td>high</td>
</tr>
<tr>
<td>Gas Tightness</td>
<td>difficult to achieve</td>
</tr>
<tr>
<td>Temperature Profile</td>
<td>very high flexibility</td>
</tr>
<tr>
<td>Atmosphere Profile</td>
<td>high flexibility</td>
</tr>
<tr>
<td>Reaction Control</td>
<td>depending on carrier / saggar</td>
</tr>
<tr>
<td>Possible Max Temperature</td>
<td>limited due to roller material</td>
</tr>
<tr>
<td>Energy Efficiency</td>
<td>low</td>
</tr>
</tbody>
</table>
Pusher Furnace

Concept Characteristics:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept Complexity</td>
<td>medium</td>
</tr>
<tr>
<td>Gas Tightness</td>
<td>very good</td>
</tr>
<tr>
<td>Temperature Profile</td>
<td>reasonable flexibility</td>
</tr>
<tr>
<td>Atmosphere Profile</td>
<td>reasonable flexibility</td>
</tr>
<tr>
<td>Reaction Control</td>
<td>depending on carrier / saggar</td>
</tr>
<tr>
<td>Possible Max Temperature</td>
<td>high</td>
</tr>
<tr>
<td>Energy Efficiency</td>
<td>medium</td>
</tr>
</tbody>
</table>
Rotary Furnace

Concept Characteristics:

<table>
<thead>
<tr>
<th>Concept Characteristic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept Complexity</td>
<td>medium</td>
</tr>
<tr>
<td>Gas Tightness</td>
<td>difficult to achieve</td>
</tr>
<tr>
<td>Temperature Profile</td>
<td>very limited flexibility</td>
</tr>
<tr>
<td>Atmosphere Profile</td>
<td>low</td>
</tr>
<tr>
<td>Reaction Control</td>
<td>very good</td>
</tr>
<tr>
<td>Possible Max Temperature</td>
<td>limited due to drum material</td>
</tr>
<tr>
<td>Energy Efficiency</td>
<td>high</td>
</tr>
</tbody>
</table>
## Tube Furnace

### Concept Characteristics:

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept Complexity</td>
<td>medium</td>
</tr>
<tr>
<td>Gas Tightness</td>
<td>very good</td>
</tr>
<tr>
<td>Temperature Profile</td>
<td>limited</td>
</tr>
<tr>
<td>Atmosphere Profile</td>
<td>limited</td>
</tr>
<tr>
<td>Reaction Control</td>
<td>limited</td>
</tr>
<tr>
<td>Possible Max Temperature</td>
<td>very high</td>
</tr>
<tr>
<td>Energy Efficiency</td>
<td>high</td>
</tr>
</tbody>
</table>
**Recirculation Furnace**

---

**Concept Characteristics:**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept Complexity</td>
<td><strong>high</strong></td>
</tr>
<tr>
<td>Gas Tightness</td>
<td><strong>good</strong></td>
</tr>
<tr>
<td>Temperature Profile</td>
<td><strong>very high flexibility (batch)</strong></td>
</tr>
<tr>
<td>Atmosphere Profile</td>
<td><strong>very high flexibility (batch)</strong></td>
</tr>
<tr>
<td>Reaction Control</td>
<td><strong>very high for flat carriers</strong></td>
</tr>
<tr>
<td>Possible Max Temperature</td>
<td><strong>low</strong></td>
</tr>
<tr>
<td>Energy Efficiency</td>
<td><strong>low</strong></td>
</tr>
</tbody>
</table>

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[Side View](#)

[Front View](#)
Case Study 1

Customer Requirements:
• Throughput,  e.g. 4000 tons/a
• Process      pyrolysis
• Temperature  1,000 °C
• Atmosphere   innert gas
• Focus        excellent temperature control and waste gas control

Case study:
• Rotary furnace  not possible due to metal contamination and long process time
• Roller furnace  problem of condensation
• Pusher furnace  tests showed this is the preferred solution, allowing long process times and good vapor removal
Tests in our test center: relevant aspects

Inlet Cooling Zone:

Outlet Cooling Zone:

Gas input options (partly preheated)
Off-gas (to combustion chamber)

Process parameter to be varied:
- Tray design and filling height
- Temperature profile - typical 1 to 2 dwell temperatures
- Ramp rate (slow, intermediate or fast)
- Dwell time (from minutes to hours)
- Process gas composition
- Process gas flow (direct /counterflow or mixed)
- Input of process gas either cold (position A, B, E) or pre-heated (position C and D)
- Off-gas in either of the 2 ports (F and /or G)
- Short or long cooling zones
Tests in our test center: relevant aspects

Thermocouple in powder to measure product temperature during test

Muffle to guide gas flow close to product
Example of temperature profile in the furnace

Inlet Cooling Zone:

Outlet Cooling Zone:

---

Zone 1  Zone 2  Zone 3  Zone 4  Zone 5  Zone 6
Examples of different Saggar materials for material transport

Stainless steel
Titanium
Ceramic
Graphite

Simulation of Heat Transfer

Effect of Heat Transfer
reaction completed
reaction not completed

Effect of Gas Saturation
reaction completed
reaction not completed
Concept for the production of carbon for batteries
Concept for the production of carbon for batteries

Temperature profile

![Diagram of production process](image1)

![Sample material](image2)
Case study 2 – out of the box approach

Customer Requirements:
- Throughput, e.g. 1000 tons/a
- Process: proprietary chemical reaction
- Temperature: 900 °C
- Atmosphere: Highly flammable gasses
- Reactivity: excellent gas – powder interaction

Case study:
- Rotary furnace: limited due to dust release
- Roller furnace: limited due to gas flow limitation and condensation
- Pusher furnace: possible – but study showed complexity of gas injection and off gas
- Recirculation furnace: Simulation and tests proofed concept to provide high reaction efficiency
Example of the reactor
Simulation
Simulation: Concept of the reactor
Influence of reaction heat to product temperature

Exothermic reaction under a specific atmosphere
Gap between powder and next tray: 15 mm
Flow velocity: 0.5 m/s
Initial temperature gas & product: 450 °C

Mean temperature of powder: 449.5 °C

ΔT: 12K
Influence of reaction heat to product temperature

Exothermic reaction under a specific atmosphere
Gap between powder and next tray: 7.5 mm
Flow velocity: 0.5 m/s
Initial temperature gas & product: 450 °C

Mean temperature of powder: 451 °C

\[ \Delta T: 20K \]
Influence of reaction heat to product temperature

Exothermic reaction under a specific atmosphere
Gap between powder and next tray: 7.5 mm
Flow velocity: 1.0 m/s
Initial temperature gas & product: 450 °C

ΔT: 11K

Mean temperature of powder: 451.5 °C
Influence of reaction heat to product temperature

Exothermic reaction under a specific atmosphere
Gap between powder and next tray 7.5 mm
Flow velocity 2.0 m/s
Initial temperature gas & product: 450 °C

ΔT: 6K

Mean temperature of powder: 449 °C
Mean temperatures during cooling phase

- Reactive atmosphere
- Average product temperature after 1.5 hours: 92°C
- Average ΔT between Trays and Product: ca. 2K

T range = 85 - 120°C
Mean temperatures during cooling phase

- N2 atmosphere
- Average product temperature after 1.5 hours: 111°C
- Average product temperature after 1.8 hours: ~92°C
- Average ΔT between Trays and Product: ca. 0.5K

T range = 100 - 150°C
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NEW Development Pusher Kiln
Principle & Advantages

General

↑ Throughput (kg/h)
↓ Investment ($/kg)
↓ Footprint (m²)
↓ Energy consumption (KWh/kg)
↓ Process gas consumption (Nm³/h)

Process

↑ Temperature uniformity
↑ Adjustability and controllability
↑ Same condition situation for all saggars
↑ Process gas pre-heating (possible)
↑ Product homogeneity and quality
Series of experiments have been done for validation of concept to optimise and validate the CFD simulation model (flow & heating)
NEW Development Pusher Kiln
Testing and Simulation

Temperature and local gas pressure are almost independent of saggar position.
NEW Development Pusher Kiln
Current Product with Double Lane)
Battery Pusher Kiln Benefits

- Onejoon mass production kiln:
  - Almost no upscaling drawbacks!
  - ca. ~ 400 % increase of production capacity
  - ca. ~ 70 % reduce of kiln’s footprint
  - ca. ~ 23 % reduce of energy consumption
  - ca. ~ 27 % reduce of Oxygen consumption
  - up to 1 Mio €/a saving in production costs*

* PSK 6x7 compared with a 43.7 m 4x2 RHK; 5 kg filling; 8 ct/kWh; 15 ct/m3 \(O_2\)

thus exploiting almost the full potential of CAM powder

Satisfying OEM Targets → longer driving ranges and saving costs!
New battery materials – What is needed?

- Chemistry between the developing parties
  - Open relationship with mutual respect and understanding of cultures

- Extensive Process and Concept Expertise
  - Extensive experience in regard of special atmosphere processes
  - Wide concept know how
  - Experience with production scale up
  - Test center with good test capabilities

- Global Company
  - Manufacturing operations in the main production regions
  - Service capabilities worldwide

Capability to listen to the challenges presented by the producer in order to provide the best solution !!!
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