Modeling of Kobe's High Performance heat exchangers and Microchannel reactors
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  (ALEX: Brazed Aluminum Plate fin Heat Exchanger)
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  (SMCR: Stacked Multi-Channel Reactor)
Over 40 years experience as major manufacturer of compact heat exchanger (ALEX=Brazed Aluminum Plate-fin type).

Extensive range of technologies to design and fabricate heat exchangers of this type.

Has now developed the micro or milli channel heat exchanger (like PCHE (Printed Circuit Heat Exchanger) and MCR (Microchannel Reactor) based on this technology.
Printed Circuit Heat Exchanger (PCHE)
**Micro channel Heat Exchanger**
(*PCHE: Printed Circuit Heat Exchanger*)

**<Application>**
- a) Gas cooler for offshore use
- b) Special use for high pressure, high temperature or large temperature difference

**<Features>**
- a) can withstand high pressure (over 50MPaG)
- b) High thermal performance (approximately 1/10th of Shell & Tube type)

**<Fabrication step>**
- Plate
- Chemical Etching
- Form the Channel
- Stacking
- Diffusion bonding

- Image of channel
- Cross sectional view of diffusion bonding
- Outside view of core block with header & nozzle

**Note:** KSL can fabricate this equipment based on ASME code with stamp (2010E+2011a).
Design and rating software for heat exchanger

<Design Software>

KSL's own software and technique

<Rating software (Aspen PlateFin)>

- Stream by stream simulation and thermosyphon
- Detailed layer by layer simulation (including stacking arrangement)
- Crossflow exchanger simulation (single or multi-pass)

Note- Fin performance or channel data were measured by KSL and the data are linked to Aspen PlateFin.
Comparison between ALEX and PCHE for PlateFin

All design parameters for ALEX and PCHE are basically the same.

Hence heat transfer and pressure drop performance will be calculated using the same design tool as for ALEX.

Fin = Channel,
pt: pitch of fin
h: height of fin,
tF: thickness of fin
tB: thickness of side bar
Operation condition for Multi-Stage Compressor is simulated by HYSYS. The some operation condition are checked by the link between HYSYS and Aspen PlateFin.
Performance check of PCHE
(After cooler for Compressor)

Design Pressure: 8MPaG (Hydrostatic test: 12MPaG)
Code: Japanese High Pressure Gas Safety Law (with stamp)

KSL tests confirm the mechanical and thermal performance of this PCHE to be superior to S&T.

*Performance calculation & Rating : KSL's own software and technique (PCHE:S&T) Volume: 1:10, Weight: 1:8

Shell & Tube
Φ 650 × 4200TL-TL (5500kg)

PCHE
330X350X650 (700kg)
Microchannel reactor
(Stacked Multi-channel reactor)
**Microchannel Reactor**  
*(SMCR: Stacked Multi-Channel Reactor)*

**SMCR** is the stacked multi-channel reactor for the large capacity use, it is very easy to build the 'numbering-up' (multi-channel of one unit) by using the channel arrangement of third dimension.

→ *Improve batch operation to continuous operation for large capacity*

- **Mixer type (batch operation)**
  
  - A fluid
  - B fluid
  - C fluid

- **Continuous**

- **<2 dimensional>**
  - Y shape tube (Existing MCR)

- <3 dimensional>
  - Plate type (SMCR)

  - A fluid → A+B fluids → A+B+C fluids
  - B fluid
  - C fluid

- **Thermal control (Heat transfer)**

- **Cross sectional view of channel**

- **<Application>**
  
  a) Extraction
  
  b) Polymerization (Highly exothermic reaction)
  
  c) Reaction (liquid & liquid, liquid & gas and others)

  ⇒ It will be very important to estimate thermal performance of each reaction.
Conceptual design - Large capacity Microchannel Reactor

Stacked plate (b+a+b+a+b: plate and thermal control) will be bonded to one block.

Chanel number

\[
\text{channel} / \text{plate} \times \text{stacked number}
\]

(Feature)

Each stream has uniform pressure drop, so maldistribution is minimized. Due to this, a large capacity Micro channel reactor can be designed and fabricated.
Testing results for extraction use of SMCR

Testing device

- No deterioration of extraction ratio by using SMCR
- Residence time of SMCR can reduce 1/100 of Mixer type

KSL will use HYSYS and Aspen PlateFin to simulate the thermal performance and mass-transfer of SMCR by same concept of PCHE.
Conclusion

• Based on BAHX technologies, Kobe steel is now developing Microchannel heat exchangers and reactors for some applications such as cooler for compressor, extraction and reaction use.

• The heat transfer is most important issue for design of these equipment.

• The channel shape information of PCHE can be changed to the fin shape by using same hydraulic diameter and free flow area.

• Kobe steel presented the design method for the Microchannel equipment by using PlateFin.

• The process data such as some stage compressor or extraction process from HYSYS are linked to Aspen PlateFin.

• We reported the design result by PlateFin and the operation test results of this compressor cooler.

• And also, we introduced Large capacity Microchannel reactor and the importance of HYSYS and Aspen PlateFin to simulate the thermal and mass-transfer performance.
For reference
Bonding strength check

Bursting test of sample core by diffusion bonding

Bonding quality was confirmed by bursting test.

→ Bursting pressure was over 100MPaG.
(Channel size: 2mmx1mm, pitch 2.3mm, material: stainless steel)
Fabrication flow of PCHE (Printed circuit Heat Exchanger)

Core Body
- SS304 or 316L (Plate)
  - Material → Chemical Etching and others → Stacking
- SS304 or 316L (End Plate)
  - Material → Milling

Header & nozzle
- SS304 or 316L
  - Material → Cutting and bending → Welding → Welding

Bonding (Diffusion bonding or brazing)
performed by KSL or sub vendor (Certificate folder)

Inspection (Hydrostatic test, leak test and others)

Packing & Shipping

Material → Stacking → Bonding → Welding → Inspection → Packing & Shipping
Bonding method and material is selected based on the channel size, corrosion resistance, required strength and other relevant factors.
New Requirements in ASME for diffusion bonding

There were the special requirement for Diffusion bonding in Code Case(2437-1, 2621-1). But these requirements are limited to the special application.

Based on the customers requests, the general requirements are specified in ASME 2011a as follows, ASME Sec. VIII Div.1 “Diffusion bonding” at Mandatory Appendix-42 Sec. IX “Diffusion Welding” in QW-185

Requirement for production tests (only key issues):

aa) Test block shall be a minimum of a 200mm x200mmx 50 interface planes
bb) free from cracks and shall show no incomplete bond or porosity on or adjacent to the bond lines
cc) After the bonding, mechanical properties (TS,YS Hardness) shall match the ASME requirements (same as base metal).

Further more, M.A.W.P. (Maximum Allowable Working Pressure) for the device will be decided by the results of the bursting test in UG-101.
MAWP (Maximum Working Pressure) will be decided based on bursting test (ASME UG-101).
MAWP (Maximum Working Pressure) will be decided based on bursting test (ASME UG-101).
### Bursting Test Results based on ASME

<table>
<thead>
<tr>
<th>Test Specimen No.</th>
<th>Bursting test pressure or Hydrostatic test pressure at which the test was stopped</th>
<th>Tensile Strength</th>
<th>Character of Failure &amp; Location</th>
<th>Pressure gauge &amp; Recorder used to the test</th>
</tr>
</thead>
<tbody>
<tr>
<td>BT-2</td>
<td>99.76 MPa</td>
<td>Specified minimum</td>
<td>485 MPa</td>
<td>NKIS1015, NKIS1034, NKIH18</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Average actual</td>
<td>536.5 MPa</td>
<td></td>
</tr>
</tbody>
</table>

Therefore the maximum allowable working pressure of the diffusion bonding core shall be computed as follow in accordance with ASME CODE SECT. VIII UG101.

\[
P = \frac{B}{4} \times \frac{S_{\mu}E}{S_{\mu\text{avg}}}
\]

where
- \( B \) = bursting test pressure, or hydrostatic test pressure at which the test was stopped, MPa
- \( E \) = efficiency of welded joint, if used.
- \( S_{\mu} \) = specified minimum tensile strength at room temperature, MPa
- \( S_{\mu\text{avg}} \) = average actual tensile strength of test specimens at room temperature, MPa.

\[
P = \frac{99.76}{4} \times \frac{485}{536.5} = 22.5 \text{ MPa}
\]
After the bonding, we confirmed that mechanical properties (TS, YS Hardness) matched the ASME requirements (same as base metal).

<table>
<thead>
<tr>
<th>Tensile Tests (QW-153/App.42 6.2 (a))</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimen</td>
<td>Width/Diameter (μm)</td>
</tr>
<tr>
<td>PTPT-6 No.1 (V)</td>
<td>Φ 6.38</td>
</tr>
<tr>
<td>PTPT-6 No.2 (V)</td>
<td>Φ 6.38</td>
</tr>
<tr>
<td>PTPT-6 No.3 (V)</td>
<td>Φ 6.39</td>
</tr>
<tr>
<td>PTPT-6 No.1 (H)</td>
<td>Φ 6.38</td>
</tr>
<tr>
<td>PTPT-6 No.2 (H)</td>
<td>Φ 6.37</td>
</tr>
<tr>
<td>PTPT-6 No.3 (H)</td>
<td>Φ 6.38</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Hardness Tests (App.42 6.2 (a))</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Type</td>
<td>Results</td>
</tr>
<tr>
<td>Rockwell B PTPT-6 No.1 (V)</td>
<td>64.0</td>
</tr>
<tr>
<td>Rockwell B PTPT-6 No.2 (V)</td>
<td>64.2</td>
</tr>
<tr>
<td>Rockwell B PTPT-6 No.3 (V)</td>
<td>64.9</td>
</tr>
</tbody>
</table>
Demo heat exchanger based on ASME code

Demo heat exchanger (size 150Wx150Hx300mm)