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KOBE STEEL, LTD.
**Features**

The Diffusion-bonded Compact Heat Exchanger (DCHE) is a compact type heat exchanger noted for the following features.

**Excellent pressure and temperature resistance**
Up to 100 MPa or 900°C with optimization of the material and channel size.

**Remarkable compact size**
90% reduction in plot area compared with multitubular heat exchangers, with high heat transfer performance.

**High corrosion resistance**
Using stainless steel and other materials, the heat exchanger can be used in a wide range of applications.

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**Application Examples**

1. **Cooler for compressor**
   A multitubular heat exchanger for the nitrogen compressor was replaced with the DCHE. As a result, the DCHE could be made significantly more compact, approximately 10% in volume and less than 15% in weight, compared with a multitubular heat exchanger of the same heat transfer performance and pressure loss. Also, the overall heat transfer coefficient increased to 200%. This means that the energy efficiency is improved.

   **Comparison of a multitubular heat exchanger and DCHE (with the same pressure loss)**

<table>
<thead>
<tr>
<th>Item</th>
<th>Multitubular Heat Exchanger</th>
<th>DCHE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size (m³)</td>
<td>100%</td>
<td>10%</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>100%</td>
<td>15%</td>
</tr>
<tr>
<td>Heat-transfer Area (A)</td>
<td>100%</td>
<td>70%</td>
</tr>
<tr>
<td>Overall Heat Transfer Coefficient (U)</td>
<td>100%</td>
<td>200%</td>
</tr>
<tr>
<td>Loss of Pressure (ΔP)</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

   **Multitubular heat exchanger**
   Φ650×4200 TL-TL (5500 kg)

   **DCHE**
   330×350×650 (750 kg)

2. **Heat Exchanger for Hydrogen Station**
   Heat exchangers for hydrogen station require compactness and reliability for operational fluctuation. DCHE achieves the same performance in less than 5% the plot area compared with a multitubular heat exchanger. The reliability of DCHE has been confirmed with stress simulation and a fatigue test under a high-pressure conditions using actual test pieces.

   **Fatigue Test Conditions**

<table>
<thead>
<tr>
<th>Media</th>
<th>Test 1</th>
<th>Test 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>20 (°C)</td>
<td>40 (°C)</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0.6 - 92 MPa</td>
<td>0.6 - 92 MPa</td>
</tr>
<tr>
<td>Pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycle</td>
<td>1,000,000</td>
<td>70,000</td>
</tr>
</tbody>
</table>

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**Overview**

The Diffusion-bonded Compact Heat Exchanger (DCHE) is a compact heat exchanger with excellent heat transfer performance and high pressure resistance. In a DCHE, several hundreds of plates are stacked, each with flow passages. Significant features are the flow passage size and joining. Flow passage diameters are each several millimeters in size, to ensure a large heat transfer area per unit volume of at least 1000 m²/m³. The joining is accomplished by diffusion bonding, which offers high pressure resistance up to 100 MPa.

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**Applications**

The key words of DCHE are "excellent pressure and temperature resistance," "remarkable compact size" and "high corrosion resistance." Owing to these features, DCHE is applicable in such applications as:

- **Limited space, such as offshore facilities**
  Examples: Inter-coolers and after-coolers for compressors

- **Installed at a height, requiring compactness and lightness**
  Examples: Vaporizers and condensers used on towers such as distilling columns

- **Severe operating conditions**
  (e.g., high pressure, large temperature differences among fluids, operational fluctuations)
  Examples: Coolers for high-pressure hydrogen stations

**Applicable Materials:** SS-304, SS-304L, SS-316, SS-316L etc.

**Applicable Codes:** ASME Section VIII Div. 1 High Pressure Gas Safety Law (Japan), etc.
**Features**

Stacked Micro Channel Reactor (SMCR®) is a large-capacity micro channel reactor noted for the following features:

- **Improved chemical operation efficiency**
  High mass transfer performance can be achieved.

- **Large capacity (more than 10,000 channels in one unit)**
  Several tens of thousands of tons throughput per year

- **Excellent heat transfer performance**
  Precise temperature control is possible.

- **Quick scale-up of the process from laboratory to commercial plant**
  Numbering-up technique makes it easy to scale up.

**What is a Micro Channel Reactor?**

A micro channel reactor is a reactor that consists of numerous channels with small diameters of less than a few millimeters.

The micro channel structure provides the following benefits.

**Benefits of Micro channel reactor**

- Higher chemical operation efficiency
- Homogeneous mixing
- Precise temperature control
- Continuous operation
- Quick phase separation

Micro channel reactors have been attracting attention due to their excellent thermal and mass transfer performance.

However, micro channel reactors have been applicable only for limited uses, such as the small production of pharmaceuticals and other high value-added goods.

One of the issues limiting use is the very limited capacity of micro channel reactors.

Although increasing the number of channels (Numbering-up) can be a solution for increasing the capacity, it is difficult to lay out numerous channels (1,000 to 10,000 or more) efficiently in the equipment and distribute fluids to the channels uniformly.

**Details**

While plate-type micro reactors have been proposed previously, there have been no reactors able to achieve the large capacity applicable for mass production. Kobe Steel applied its manufacturing technology for brazed aluminum heat exchangers (ALEX) to develop stacked multichannel reactors, SMCR®, as a large-capacity micro channel reactor.

SMCR® consists of plates that have parallel multi-channels on both sides and a through-hole connecting the channels on both sides of the plate. This structure enables the efficient arrangement of numerous channels and allows uniform fluid distribution and mixing in each of channels. As SMCR® features excellent heat-transfer performance and due to its structure, it is able to stack heat transfer layers with reaction layers. As a result, precise temperature control of the reaction layer is possible.

In addition, depending on the combination of channel configurations of the mixing part, T-shaped mixing or Y-shaped mixing can be employed.

**Example of Shift from Two-dimensional to Three-dimensional Structure**

<table>
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<tbody>
<tr>
<td><strong>Two-dimensional Structure</strong></td>
</tr>
<tr>
<td><strong>Three-dimensional Structure</strong></td>
</tr>
</tbody>
</table>

**Conceptual Image of Channel Cross Section**

- **Heat Transfer Channel**
- **Mass Transfer**
- **Mid-point Mixing and Extraction**
- **Basic Channel Shapes**

**Example of Shift from Two-dimensional to Three-dimensional Structure (conceptual image of channel layout)**
Using this structure, stable slug flows* can be formed.

* Slug flow is a flow pattern where immiscible fluids are alternately arranged in channels. This is a characteristic flow pattern of a micro channel reactor and is characterized by the large specific interfacial area.

Advantages

SMCR® construction offers these advantages:

- Uniform distribution of fluids to multi channels
- Various flow conditions (slug flow, two-layer flow, annular flow, etc.)
- Arbitrary mixing structures (T-junction, Y-junction, etc.)
- Handling multiple fluids in a single unit.
- Charge and discharge of fluids partway along each channel.
- Choice of materials (Ni alloy steel, stainless steel, aluminum alloy, ceramic, etc.)

Applications

The following are examples of application.

- **Extraction Process**
- **Absorption Process**
- **Reaction Process**

(Applicable Phases: gas-liquid, liquid-liquid, etc.)

*A SMCR® brings micro channel reactor benefits to conventional processes such as in the large capacity chemical industry. In addition, SMCR® can be used withstanding pressure performance of up to 100 Mpa and heat resistance performance of up to the 900°C due to diffusion bonding.*

**Examples of Applications**

**Conventional Equipment**

When processing for a total of 2 hours by stirring (1 hour) and separating (1 hour) 3m³ in total with 1.5m³ of the raw material and 1.5m³ of the extraction solvent.

- **Equipment Specifications**
  - Size: φ1600 x 2000L mm, 1 installation (Volume: 0.21m³)
  - Motor: 600W x 500H x 700L mm, 1 installation

**Advantage**

- Continuous processing is possible.
- Amount of extraction solvent used can be reduced.
- Significant effects with a large number of extraction stages.

**Test Example [Extraction]**

A test to extract 0.1 wt% of the phenol in dodecane in water was performed using a conventional stirring-type reactor and SMCR®. With SMCR® installed in Kobe Steel’s bench test unit, the number of channels and stacked layers was varied to confirm the increasing throughput achieved by the increased number of channels. As a result, the extraction performance of the SMCR® was high regardless of the number of channels or stacking, and we were able to verify that equilibrium extraction was achieved in 1/100 of the time taken using the stirring-type reactor.

**Product Development and the Process up to Provision**

The following depicts regular product development and the process up to provision. Please contact with Kobe Steel for more details.

* SMCR® Micro Channel Reactor

**Examples of Applications**

**Conventional Equipment**

Using an SMCR®, a continuous extraction process was conducted for two hours with a residence time of one minute.

- **Equipment Specifications**
  - Size: φ1600 x 2000L mm, 1 installation (Volume: 0.21m³)
  - Motor: 600W x 500H x 700L mm, 1 installation

**Advantage**

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