KOBE STEEL, LTD.

MACHINERY BUSINESS

Sales & Marketing Department
Energy & Nuclear Equipment Division
TEL: +81-3-5739-6663/FAX: +81-3-5739-6980 9-12, Kita-Shinagawa 5-chome, Shinagawa-ku, Tokyo 141-8688, Japan

Engineering Section
Takasago Equipment Plant
Energy & Nuclear Equipment Division
TEL: +81-79-445-7214/FAX: +81-79-445-7239 3-1, Araicho Shinhama 2-chome, Takasago, Hyogo 676-8670, Japan

E-mail: dche@kobelco.com
smcr@kobelco.com

URL: http://www.kobelco.co.jp/english/machinery/

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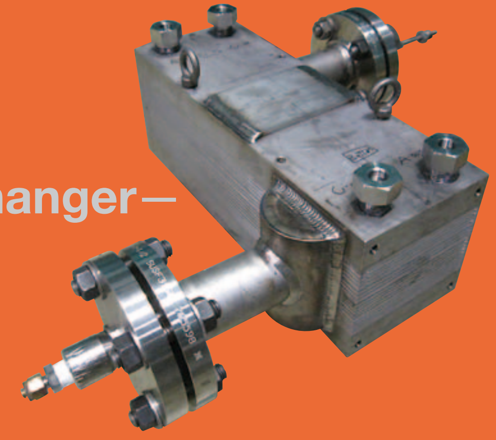
KOBELCO

DCHE

—Diffusion Bonded Compact Heat Exchanger—

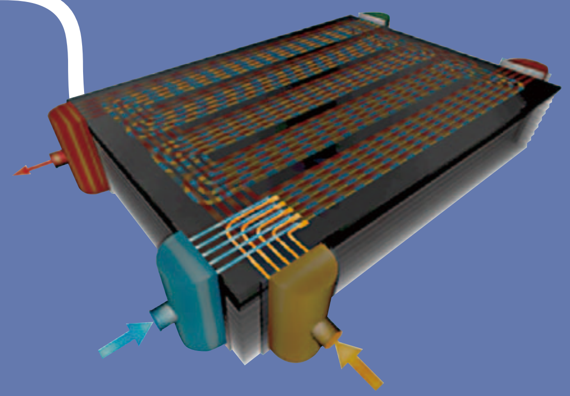
Micro Channel Heat Exchanger



SMCR®

—Stacked Multi-Channel Reactor—

Micro Channel Reactor



KOBE STEEL, LTD.

DCHE

Micro Channel Heat Exchanger

Diffusion Bonded **C**ompact **H**eat **E**xchanger

Features

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

Excellent pressure and temperature resistance

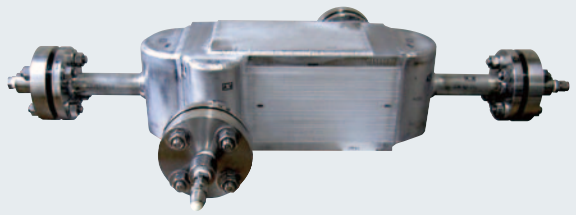
Up to 100 MPa or 900°C with optimization of the material and channel size.

Remarkable compact size

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

High corrosion resistance

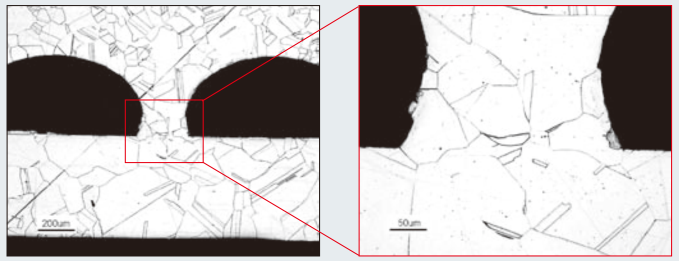
Using stainless steel and other materials, the heat exchanger can be used in a wide range of applications.



Outside view of Diffusion-bonded Compact Heat Exchanger

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 m^2/m^3. The joining is accomplished by diffusion bonding, which offers high pressure resistance up to 100 MPa.



Cross-sectional observation of diffusion bonding (SS-304L)

*Diffusion bonding is defined as
"a method for joining comprising the steps of closely sticking base materials together and pressing these materials against each other at a temperature not exceeding their melting points, while suppressing their plastic deformation to a minimum, so as to cause the diffusion of atoms at the joining interface to complete the bonding."

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

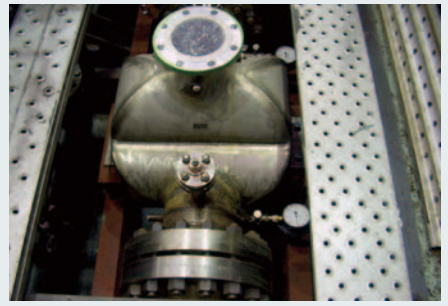
Applicable Materials: SS-304, SS-304L, SS-316, SS-316L etc.
Applicable Codes: ASME Section VIII Div. 1 High Pressure Gas Safety Law (Japan), etc.

Application Examples

❶ 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.

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



DCHE
330×350×650 (750kg)

Example of Application as Rear Cooler
Designed pressure of 9 MPaG, inspected under high pressure gas specified quipment inspection rules

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

Item		Multitubular Heat Exchanger	DCHE
Size	(m^3)	100%	10%
Weight	(kg)	100%	15%
Heat-transfer Area	(A)	100%	70%
Overall Heat Transfer Coefficient	(U)	100%	200%
Temperature Difference	(dT)	100%	70%
Loss of Pressure	(dP)	100%	100%

❷ 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

	Test 1	Test 2
Media	Water	Hydrogen
Temp.	20 [°C]	−40 [°C]
Pressure	1.0-86.5 [MPa]	0.6-92 [MPa]
Cycle	1,000,000	70,000

Example of integration with dispenser

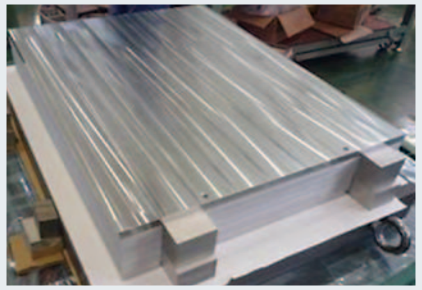
SMCR®

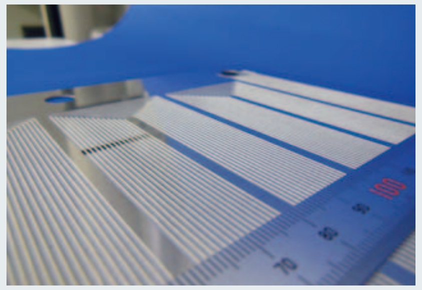
Stacked Multi-Channel Reactor

Micro Channel Reactor

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

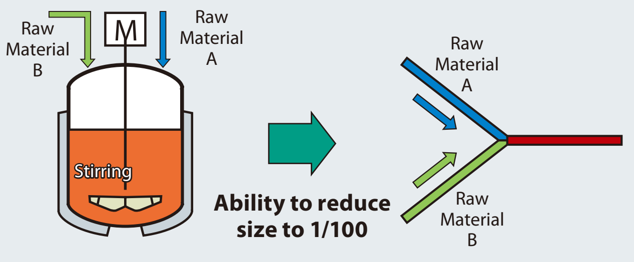
Numbering-up technique makes it easy to scale up.

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

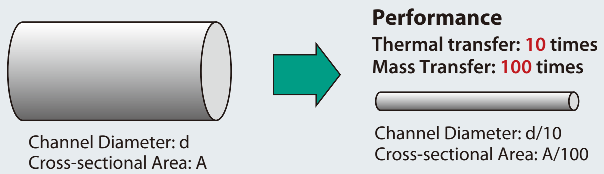
- Higher chemical operation efficiency
- Homogeneous mixing
- Precise temperature control
- Continuous operation
- Quick phase separation



[Conventional Reactor]

[Micro Reactor]
(Reactor with internal diameters of several millimeters or less)

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.



[Conventional Reaction Field]

[Micro Channel]

Heat Transfer: $C_p \Delta T_f \propto \frac{h}{d}$

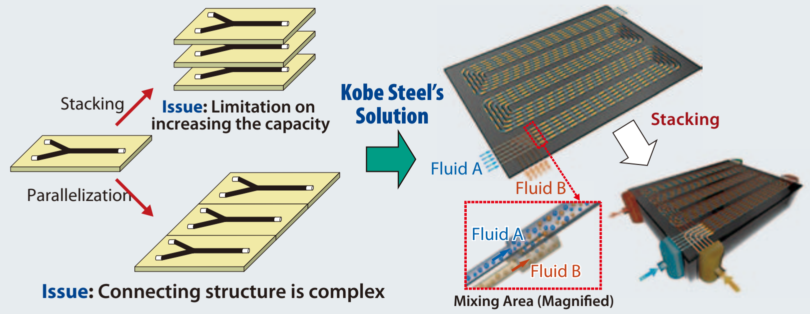
Mass Transfer: $t \propto \frac{d^2}{D}$

C_p : Specific Heat
t : Diffusion Time
D : Diffusion Coefficient
T_f : Fluid Temperature
h : Heat Transfer Coefficient
d : Hydraulic equivalent diameter

Details

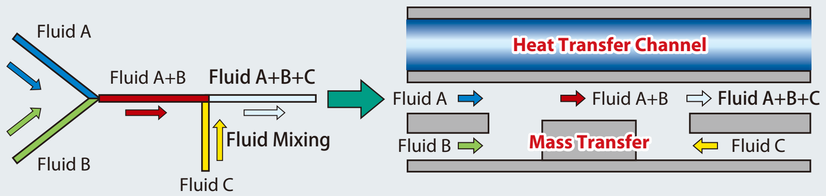
SMCR® Structure

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.



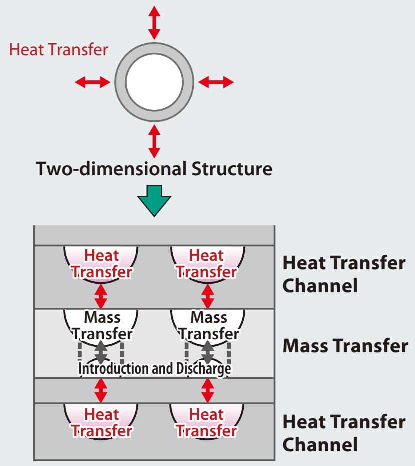
The Issues of Micro Reactors and The Solution

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.

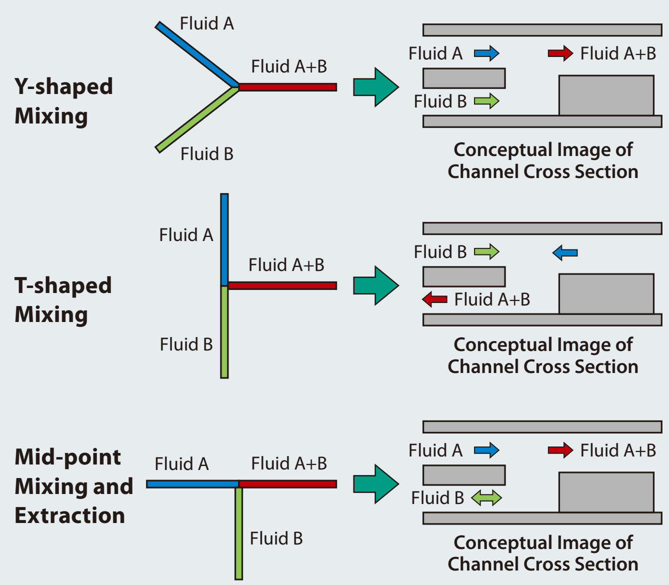


Example of Shift from Two-dimensional to Three-dimensional Structure

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 (conceptual image of channel layout)



Basic Channel Shapes

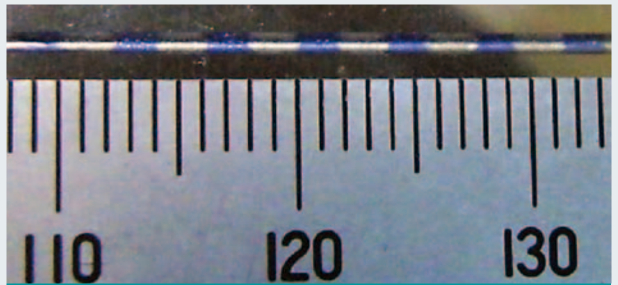
SMCR®

Micro Channel Reactor

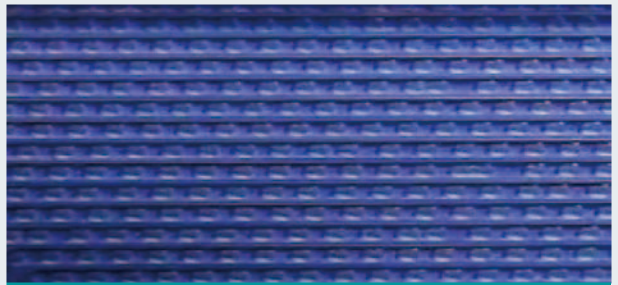
Stacked Multi-Channel Reactor

Using this structure, stable slug flows* can be formed.

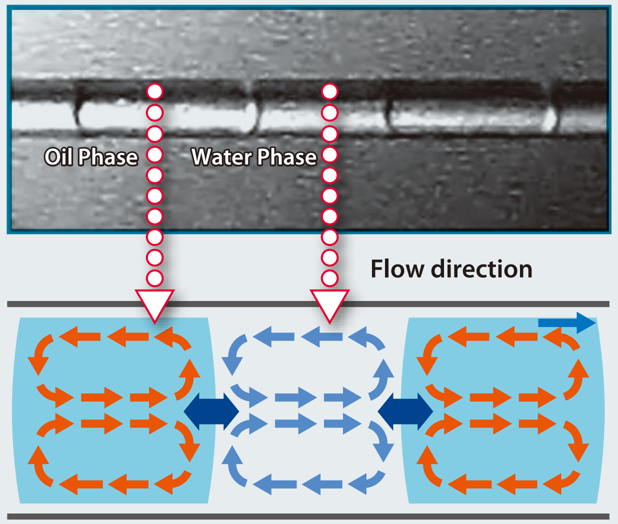
* Slug flow is a flow pattern where immiscible fluids are alternatly arranged in channels. This is a characteristic flow pattern of a micro channel reactor and is characterized by the large specific interfacial area.



Example of liquid-liquid slug flow (single channel)



Example of gas-liquid slug flow (15 channels)



Conceptual Image of Slug Flow

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.)

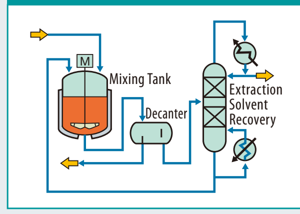
*SMCR brings micro channel reactor benefits to conventional processes such in the as large capacity chemical industry. In addition, SMCR® can be used with withstanding pressure performance of up to 100 Mpa and heat resistance performance of up to the 900°C due to diffusion bonding.

Effect examples

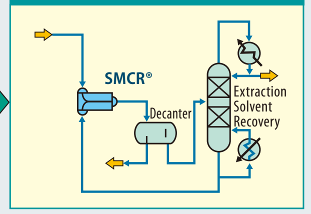
- Reduction of the plot area.
- Easy to apply, the multi-stage system has many mixings and separating parts.
- A smaller number of extraction stages compared to batch reactors.
- High mass transfer performance makes it possible to reduce the amount of extraction solvent.

Examples of Applications

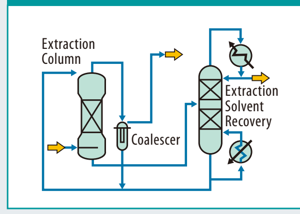
Example of a Conventional Stirring-type Extraction System



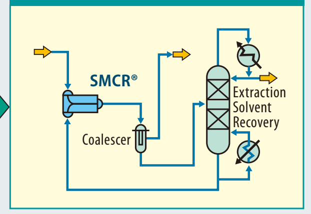
Example of SMCR® Extraction System



Example of Conventional Extraction Column System



Example of SMCR® Extraction System

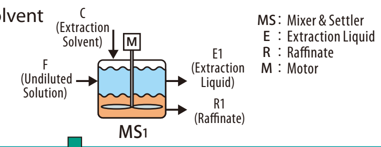


Conventional Equipment

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

Equipment Specifications

Size: φ1600 x 2000L mm, 1 installation (Volume: $4m^3$)



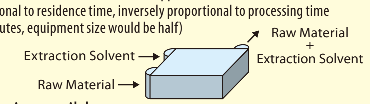
SMCR Equipment

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

Equipment Specifications

Size: 600W x 500H x 700L mm, 1 installation (Volume: $0.21m^3$ ← approx. 1/20 the size)
→ Equipment size is proportional to residence time, inversely proportional to processing time
(If residence time was 0.5 minutes, equipment size would be half)

Loss of pressure: 1 bar



Advantages

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

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.