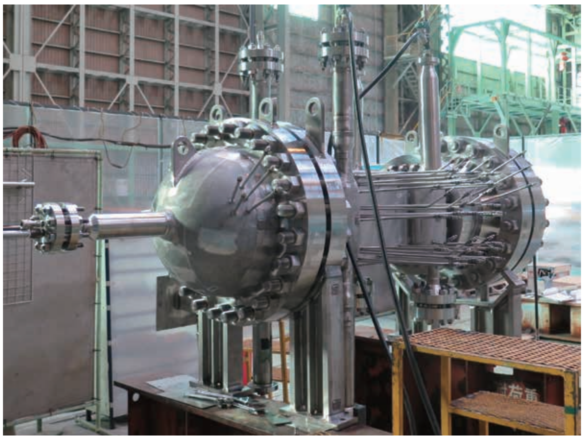
A Low-Carbon Smart Society Realized by Locally Distributed Production for On-Demand Use

Technological concept of compact reactor with innovative performance, and the element technologies that support it

A technology that achieves a "local production for local consumption" society has finally emerged. This technology enables reduction in transportation of materials that are difficult to handle, such as hydrogen, and efficient production of such materials in the required quantities when they are needed and where they are consumed. Compact reactor technology, which enables downsizing and efficient production of chemical process products, will bring about a revolution in the field of production and transportation.

SAKAKURA Shigeki
Business Development Department,
Resources, Energy & Environment Business Area,
IHI Corporation



Compact reactor capable of producing 8 000 Nm^3/d of hydrogen

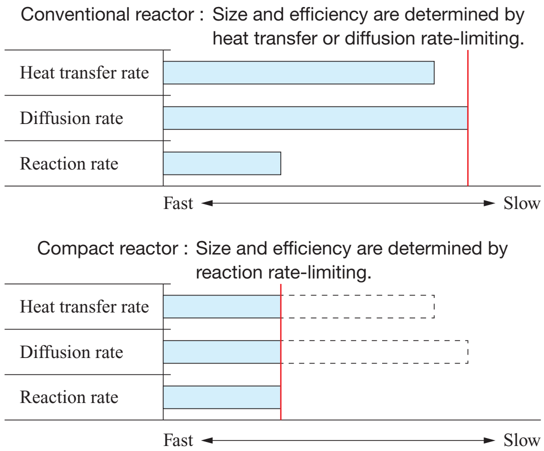
Example of modularized plant with two compact reactor systems

Movement toward a decentralized society

The world is undergoing a major transformation from a societal structure of mass consumption supported by enhancing efficiency through mass production and centralized production, to a smart society achieved by locally distributed production for on-demand use. It is well known that, with regard to electricity, attempts at creation of distributed and optimized systems have already begun through the construction of smart grids that utilize renewable energy and IoT. This trend is seen not only with respect to electricity but also for material (mass production), and the societal demand for distributed and optimized production is increasingly becoming intense.

However, petrochemical plants and other material production plants have been growing in size; for example, large-scale plants are usually constructed in coastal industrial areas where logistics infrastructure is already in place. As a result, with respect to reactors — which constitute the main equipment in plants — and other relevant equipment, there have currently not been technologies to enable distribution and optimization with higher production efficiency even at small capacity.

In North America, for example, shale natural gas is a widely



Schematic representation of principle to promote the chemical reaction in compact reactor

dispersed and distributed resource, but for natural gas in some inland areas where natural gas transport infrastructure like gas pipelines has not yet been developed, there is no means of industrially converting it to highly valued material in the natural gas yielding locality (local production); for this reason, although gas fields have been developed, many of them have not begun natural gas production. In other cases, for hydrogen and other products that are difficult to be transported and to be stored, there is no alternative but to transport them from the industrial production area to the area of demand, which entails high cost and the consumption of a large amount of energy.

The compact reactor is a small, efficient reactor that enables a shift from a society supported by conventional centralized large-scale production and delivery to a smart society where CO_2 emissions are reduced through decentralized compact, distributed, and optimized local production. Here, we describe the relevant technology concept and some element technologies that support it.

Utilizing 100% performance of catalyst potential

Within a reactor, a chemical reaction is induced to produce a chemical product from source material. To accelerate this reaction, the reactor is filled with catalyst and the temperature and pressure in the reactor is controlled so as to create an environment in which the catalytic reaction is highly activated. In this way, the chemical plant including the reactor is operated. Many chemical reactions generate or absorb heat as they proceed, and it is therefore important to appropriately remove or supply this heat during the course of the reaction. Generating a chemical reaction more efficiently in a smaller space is a key factor in developing small, efficient reactor technology.

A common means of producing a product efficiently with a reactor is to improve the catalyst or develop a new catalyst. However, this requires a large amount of experience and experimentation, and also necessitates the development of a catalyst respectively for each reaction (chemical process). Therefore, taking the reverse approach in thinking, our compact reactor technology focuses on maximizing the performance of the existing catalyst and making effective use of it.

IHI has delivered conventional large reactors and chemical plants all over the world. Based on the reactor fabrication technology and plant engineering technology that IHI has accumulated hitherto, together with the concept of the microchannel reactor, which promotes diffusion of materials and heat, we have developed a new reactor technology. This new technology enables downsizing and efficiency enhancement while ensuring quality and safety — which are the most important factors for society and customers — together with stability and ease of maintenance (such as catalyst replacement).

Significantly improved diffusion rate and heat transfer rate

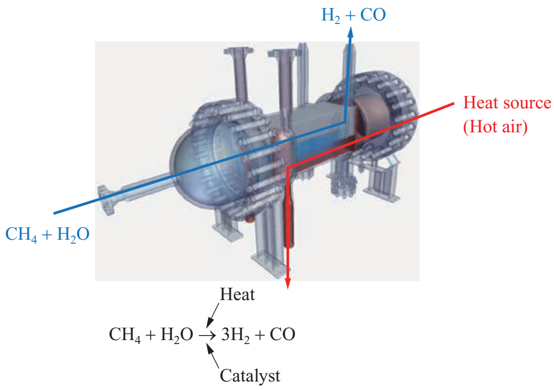
Promoting the chemical action that turns source material into products is important in enhancing efficiency. The rate of chemical action is determined mainly by three factors: ① reaction rate, ② diffusion rate, and ③ heat transfer rate. Factor ① represents the inherent ability of the catalyst to promote the reaction, and is strongly dependent on the kind of reaction and catalyst. Factor ② represents how efficiently the source material is supplied to the catalyst surface. Factor ③ represents the ability to receive and transmit the heat necessary for the reaction.

Hence, if the diffusion rate or heat transfer rate is insufficient, then the supply of source material or supply/removal of heat becomes a limiting factor, and promotion of the reaction is restricted. By improving these, it is therefore possible to promote the reaction using a state that makes maximum use of the inherent abilities of the catalyst.

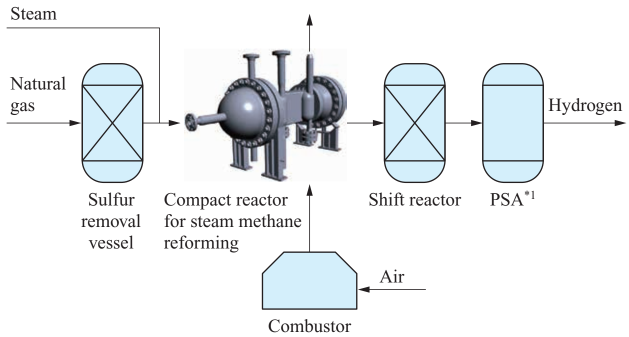
For this reason, our compact reactor technology has adopted two specific measures in order to apply the concept of the microchannel reactor and thereby increase diffusion rate and heat transfer rate. One is to apply structured catalyst in the reaction channel, and the other is to change the structure of the reactor to having stacked layers of channels with rectangular cross sections.

Superior performance of structured catalyst

Structured catalyst is made by coating the surface of a formed metal sheet with catalyst. The shape of the structural material for the catalyst has been optimized using IHI's thermal fluid technology so as to promote diffusion of the source material flowing, promote heat transfer, and reduce pressure drop in the reaction channels. This structural material is made by forming a metal sheet uniformly with a die. The surface of the metal sheet is then coated uniformly with catalyst to form the structured catalyst. Installing uniform structured catalysts into each reaction channel of the compact reactor eliminates variations in amount of catalyst and variations in pressure drop between reaction



Compact reactor as Steam Methane Reformer (SMR) for hydrogen production



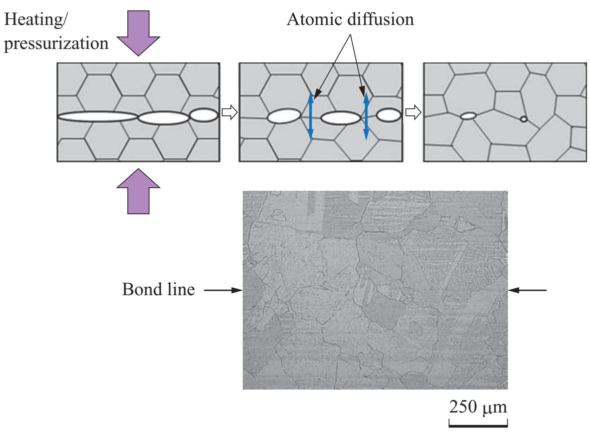
(Note) *1 : PSA (Pressure Swing Adsorption) type gas separation and refinement equipment

Process flow for hydrogen production plant with compact reactor for steam methane reforming

channels, and facilitates the maintenance process of catalyst installation and replacement. In addition, compared to conventional catalyst in the form of spherical or cylindrical pellets, the dead volume inside the catalyst shape that does not contribute to the reaction is reduced, thereby providing a larger catalyst surface area — which is important to the reaction — in each channel.

Reactor manufacturing technology that supports the layered structure

The compact reactor, which has a similar structure to a plate heat exchanger, consists of alternating reaction channel layers, which are filled with structured catalyst and in which the source material flows, and heating/cooling medium channel layers, in which a heating or cooling medium flows to control the temperature for reaction. This not only improves the heat transfer per unit volume of the reactor, but also reduces temperature variation over the cross section of each reaction channel, allowing all of the catalyst in each channel to function in an optimal environment. With regard to the cross section of the reactor, each reaction channel has a pair of heating or cooling medium channels, which prevents typical channels from becoming hot or cold spots. As a result, within the entire reactor, there are no channels where catalyst performance lowered.



Observation of structure of diffusion-bonded area

To use this layered reactor structure as a chemical process reactor, the structure — which functions as a pressure vessel — must have high structural strength that allows it to withstand a high-temperature and high-pressure environment. Diffusion bonding supported by IHI's structural and fabrication technologies is therefore applied to manufacturing the compact reactor. Diffusion bonding is a bonding method in which pressing load is applied to contacting metal surfaces heated to high temperature, causing atomic diffusion at the metal interface to bond the two metallic parts into one. This gives only a small amount of bonding deformation compared with other welding methods, and achieves both high dimensional accuracy and structural strength.

Application of compact reactor technology

Through the combination of layered reaction channels of high dimensional accuracy and structural strength, and uniformly manufactured structured catalyst installed in those channels, a remarkably compact, efficient reactor has been created that makes 100% use of catalyst performance.

Using these technologies, the size of a compact reactor can be reduced to one-tenth that of a conventional reactor. By consolidating plants consisting of such reactors into a modularized plant that can easily be transported by land, the plant can easily be installed even in inland areas, where installation and construction have hitherto been difficult.

As the first chemical process reactor with this compact reactor technology, IHI has developed a compact reactor as Steam Methane Reformer (SMR) that produces hydrogen or synthesis gas (a gas mixture of hydrogen and carbon monoxide) from natural gas (methane).

Applications of compact reactor

Compact reactor technology offers various possibilities. For example, possible applications of a compact SMR plant are as follows:

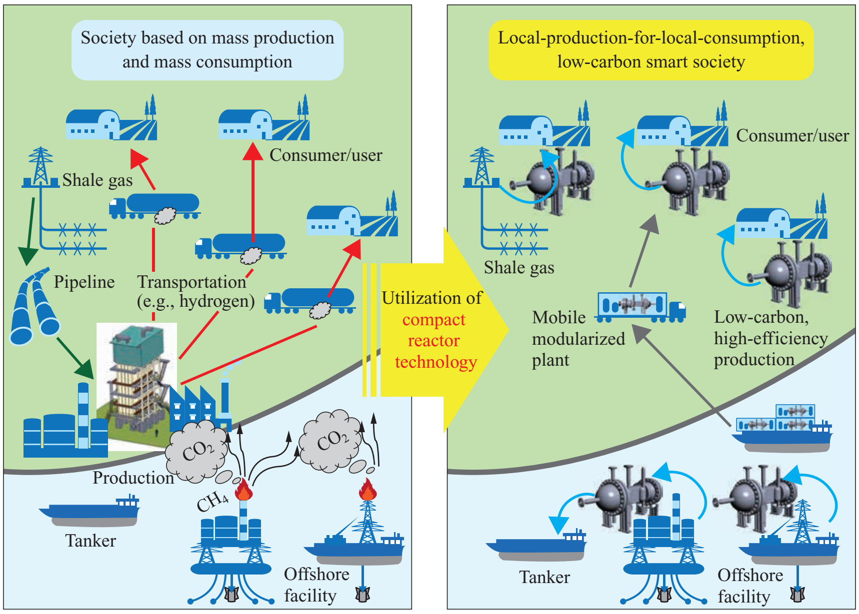
(1) Hydrogen can be produced in the area of demand, which eliminates transportation cost and transportation energy for hydrogen users who currently transport hydrogen from remote locations as compressed hydrogen or ultra-low-

temperature liquified hydrogen.

(2) Producers and/or consumers of ammonia, methanol and/or other products can directly produce and secure hydrogen or synthesis gases — which are raw materials for these products — in the area of demand.

(3) In areas where no pipeline has been installed, the owner of a natural gas resource can utilize the unused gas to produce hydrogen — or a subsequent product that needs hydrogen — in situ, thereby promoting effective utilization of that unused gas.

(4) Producers of sub-sea resources can reduce environmental burden by eliminating release into the atmosphere of associated gas generated by excavation (gas which is difficult to transport from offshore and therefore has to be discarded as flare gas). To achieve this, a small plant is installed on a offshore facility with limited installation area, and associated gas is used as source material to produce synthesis gas, which is then liquified on-site into methanol or synthetic petroleum. Liquification facilitates transportation/removal from the offshore facility, leading to a reduction in associated gas emissions.



Low-carbon smart society on local-production-for-local-consumption

A new society developed through compact reactor technology

Compact reactor technology makes it possible to install optimal plants in the areas of demand, even in locations where plant construction has hitherto been impossible, such as inland areas. Therefore, for hydrogen and other materials that cannot easily be transported and toxic materials whose transportation is restricted, there will be a switchover to efficient production in the area of consumption, thereby achieving a society free of wasteful energy consumption.

Item	Unit	Small-Size CR-H8	Medium-Size CR-H80
Generation capacity of hydrogen	$Nm^3/d-H_2$	8 000	80 000
Design pressure	MPa	2.0	
Design temperature	°C	865	
Reactor dimensions	m	1 × 1 × 3 	2 × 2 × 5 
Delivery style of compact reactor	—	Transportable modularized plant	

Lineup of compact reactor as steam methane reformer for hydrogen production

In addition, there have hitherto been resources that cannot be transported to large plants located in coastal industrial areas, and therefore have to be discarded or cannot be used; these can be converted in-situ into valuable products and easily transportable products, thereby achieving a society that does not unnecessarily burden the environment.

As a result, compact reactor technology, which is characterized by its downsizing and high efficiency, serves as a key technology for breaking away from the mass-production, mass-consumption (and mass-disposal) society that has hitherto existed, and establishing a distributed and optimized production society in which production is finely controlled through interregional networks that utilize IoT. Hence, through compact reactor technology and under the slogan of “local production for local consumption,” IHI aims to contribute to the achievement of a smart society characterized by low carbon and reduced CO_2 emissions.

Future challenges

Currently, performance data is being collected and verified at a hydrogen production test plant that uses a compact reactor for steam methane reforming. Going forward, in order to respond flexibly to the demands of customers and society, IHI will work to enlarge the range of capacity to which our compact reactor technology can be applied. In addition, we will work to apply compact reactor technology to chemical processes other than steam methane reforming.

Inquiries:
Business Development Department,
Resources, Energy & Environment Business Area,
IHI Corporation
Phone: +81-3-6204-7506
https://www.ihi.co.jp/en