or cold. In this case, a reactive fluid such as a combustion gas is supplied to the heat medium flow channel, and the heat or cold generated by its reaction is transferred to the reaction fluid in the reaction flow channel. Japanese Patent Application Laid-Open No. 2002-143675 (Patent Literature 1) describes a plate fin-type reactor with a structure in which catalytic combustion chambers and reforming chambers are alternately stacked, and discloses that the catalytic combustion chambers and the reforming chambers include fins, respectively, on which a combustion catalyst or a reforming catalyst is supported.

[0004]

In the reactor of Patent Document 1, the reaction progresses on both of the side that supplies heat and the side that demands heat, and a good heat balance is therefore needed between the catalytic combustion and the reforming. To address this, Patent Literature 1 describes use of catalyzing fins of different properties to control the reaction rates.

CITATION LIST

PATENT LITERATURE

[0005]

Patent Document 1: Japanese Patent Application Laid-Open No. 2002-143675

SUMMARY OF INVENTION

TECHNICAL PROBLEMS

[0006]

In a basic heat exchange-type reactor, the heat or cold supplied to the reaction fluid is only the heat or cold of the heat medium and does not contain the heat of reaction. The heat balance can therefore be easily adjusted by controlling the flow rate of the heat medium. However, even when the heat balance is proper, the temperature profile along the direction of flow in the reaction flow channel often shows local abrupt changes. For example, in a case where an exothermic reaction

temperature distribution is in a suitable state, it is necessary to make an adjustment for thermal migration inside the reactor in advance with the use condition taken into consideration. It is difficult to make such an adjustment with conventional reactors, and improvements are desired that enable local changes in heat transfer performance.

[0008]

The present disclosure solves such problems, and an object thereof is to provide a heat exchange-type reactor in which a temperature distribution can be adjusted in advance to a suitable state by adjusting thermal migration from a heat medium to a reaction fluid in the reactor in accordance with use conditions, and the temperature distribution can be easily re-adjusted as necessity arises.

SOLUTION TO PROBLEMS

[0009]

To solve the above problems, the present inventors have conducted an earnest research on thermal migration from a heat medium flow channel to a reaction flow channel, and found a simple configuration capable of easily adjusting the temperature distribution of a reaction flow channel by local adjustment of thermal migration utilizing members constituting the reactor. As a result, the present inventors have reached the technique of the present disclosure. The technique of the present disclosure can be provided as a simple system capable of easily adjusting the temperature distribution inside a reactor by utilizing a heat transfer promoter that promotes the heat transfer. With this applied to an existing reactor, it is possible to re-adjust the temperature distribution to an appropriate state in accordance with the state of implementation.

[0010]

According to an aspect of the present disclosure, a reactor is summarized as comprising: a heat exchanging body that includes therein a heat medium flow channel in which a

heat medium flow channel side, for explaining the operation of the heat transfer promoter.

DESCRIPTION OF EMBODIMENTS

[0015]

In a heat exchange-type reactor, the temperature distribution, i.e. temperature profile, in a heat medium flow channel and a reaction flow channel from the entrance to the exit changes due to the condition of the heat transfer from the heat medium flow channel to the reaction flow channel, and it also changes due to other factors. Specifically, the temperature profile changes also due to the temperature of a heat medium supplied and its flow rate, the reaction rate of a reaction fluid and the heat of the reaction, the type of a reaction catalyst to be used and its reaction properties, and so on.

[0016]

When an exothermic reaction of a reactant is caused to progress by cooling with use of a low-temperature heat medium (coolant), even if the theoretical amount of heat generation by the progress of the reaction can be balanced with the amount of heat removal, there may be a case where an abrupt temperature rise occurs in the temperature distribution in the reaction flow channel in the vicinity of the entrance as a result of starting the exothermic reaction. If the temperature rise is significant, the temperature recovery with the cooling will be delayed, so it is necessary to set long the reaction time and the reaction flow channel. Similarly, in the case where an endothermic reaction is caused to progress by heating with use of a high-temperature heat medium, a delay in reaction progress may occur due to an abrupt temperature decrease. In addition, an excessively large local temperature difference may cause partial thermal denaturation of the structural material of the heat exchanging body. It is therefore desirable to eliminate extreme fluctuations in the temperature profile. In order to mitigate these abrupt temperature

heat exchange-type reactors, fins of a single type are mounted as the heat transfer promoters, and therefore the heat transfer promoting effect is uniform across the entire apparatus. Specifically, the heat transfer performance is uniform from the entrance to the exit, and no local change is made to any part of the flow channel.

[0018]

With regard to this, the present disclosure utilizes a heat transfer promoter constituted by an assembly of a plurality of partial heat transfer promoters which can be recombined. In the basic configuration of the heat transfer promoter, the plurality of partial heat transfer promoters are of the same type, that is, the heat transfer is enhanced substantially equally over the entire heat transfer promoter by uniform heat transfer performance. By replacing at least one of them with another partial heat transfer promoter of a different type, it is possible to locally change the heat transfer performance of the heat transfer promoter in the replaced portion, thereby adjusting the amount of heat transfer there. Therefore, based on a temperature distribution obtained by measurement performed in a pilot reaction or by a simulation, the heat transfer can be adjusted by replacing a partial heat transfer promoter so as to make smooth the temperature change at and around the place showing abrupt temperature fluctuation (such as a region at which the reaction starts) on the temperature profile along the flow direction in the heat transfer wall surrounding the reaction flow channel. Moreover, it is possible to optimize the heat balance such that there is no excess or shortage in amount of heat, by adjusting the balance of the heat transfer performance so that the temperature profile line has a desired gradient. Hence, an efficient reactor can be provided. The temperature distribution in the reactor can be changed in various ways by changing the position at which the heat transfer performance of the heat transfer promoter is changed. Thus, the temperature distribution in the reactor can be adjusted as

appropriate in accordance with necessity that is not limited to suppression of temperature changes and improvement of the temperature gradient. In other words, changing the heat transfer performance of the heat transfer promoter can be utilized as a way to solve various heat-related problems inside the reactor, and the reactor can be adjusted to a good condition by adjusting the temperature distribution as appropriate anytime in accordance with changes in reaction conditions or characteristics of the reactor.

[0019]

Hereinbelow, embodiments of the present disclosure will be described in detail as mere examples with reference to the drawings. The flow of a heat medium and a reaction fluid in a reactor will be described with reference to FIG. 1 to FIG. 3, and heat transfer promoters and catalytic bodies disposed in heat medium flow channels and reaction flow channels will be described using FIG. 4 and FIG. 5. Also, FIG. 6 and FIG. 7 will be referred to for description of partial heat transfer promoters constituting each heat transfer promoter. It is noted that illustration of the heat transfer promoters and the catalytic bodies is omitted in FIG. 1 to FIG. 3. The dimensions and the materials as well as the specific numerical values and so on described in the embodiments are mere examples for facilitating the understanding of the disclosed content, and are not intended to limit the present disclosure unless otherwise noted. Also, in the description and the drawings, redundant description of elements having substantially the same function and configuration will be omitted by denoting them with the same reference sign, and illustration of elements that are not directly related to the present disclosure will be omitted.

[0020]

A reactor 1 illustrated in the drawings is a heat exchange-type reactor and has a heat exchanging body 3 as its main component. In the following embodiments, the heat exchanging body 3 is described as a plate-type heat exchanging

are prevented in this way. It is noted that although the heat exchanging body 3 can be configured by simply using at least one first heat transfer body 7 and at least one second heat transfer body 9, the larger the number of the first heat transfer bodies 7 and second heat transfer bodies 9, the higher the heat exchange performance. In this embodiment, a plurality of the first heat transfer bodies 7 and second heat transfer bodies 9 are used, the number of the second heat transfer bodies 9 is larger than the number of the first heat transfer bodies 7 by one, the second heat transfer bodies 9 are located at the uppermost and lowermost positions, and the first heat transfer bodies 7 are held between the second heat transfer bodies. Covering the periphery of the heat exchanging body 3 with a housing or a heat insulating material so as to suppress heat radiation from the heat exchanging body 3 is preferable for the reactor 1 from the viewpoint of suppressing heat loss. A plurality of the heat exchanging bodies 3 may be covered with a single housing so that the reactor 1 is configured to include the plurality of heat exchanging bodies 3.

[0021]

The heat conductive material constituting each part of the heat exchanging body 3 can be a heat resistant metal such as iron-based alloys and nickel alloys. Specifically, heat resistant alloys such as iron-based alloys such as stainless steel and nickel alloys such as Inconel 625 (registered trademark), Inconel 617 (registered trademark), and Haynes 230 (registered trademark) can be given as examples. These heat conductive materials are preferable since they have durability (corrosion resistance) against the progress of the reaction in the reaction flow channel and combustion gases usable as the heat medium, but the material is not limited to these. Also, steel plated with an iron-based plating material, metal coated with a heat resistant resin such as fluororesin, carbon graphite, or the like may be used. The fixing members 10 for fixing the stack body are made of a material having heat

resistance and strength, and it is preferable that the material has low thermal conductivity in order to suppress the heat loss due to heat dissipation. In the case where the fixing members 10 are made of the same material as that of the heat exchanging body 3, they may be covered with a heat insulating material. Making the housing so as to be connected to the fixing members 10 on both sides is preferable from the viewpoint of suppressing heat dissipation.

[0022]

As illustrated in FIG. 2, each first heat transfer body 7, in which a groove is formed, includes a base portion 11, sidewall portions 13, intermediate wall portions 15, and an end wall portion 19. With the second heat transfer body 9 stacked on the first heat transfer body 7, the groove in the first heat transfer body 7 forms a reaction flow channel 17. The base portion 11 defines the bottom surface of the reaction flow channel 17. The sidewall portions 13, the intermediate wall portions 15, and the end wall portion 19 are provided to stand on the base portion 11 so as to define side surfaces of the reaction flow channel 17. The lower surface of the second heat transfer body 9 is the upper surface of the reaction flow channel 17. The sidewall portions 13 and the end wall portion 19 are provided along three ends of the first heat transfer body 7. The intermediate wall portions 15 are formed in parallel and at equal intervals between the sidewall portions 13 on the opposite sides. The reaction flow channel 17 includes a plurality of branch flow channels 17a, a merge channel 17b, and a discharge hole 17c. The branch flow channels 17a extend side by side at equal intervals with the intermediate wall portions 15 interposed therebetween. One ends of the branch flow channels 17a are connected by the merge channel 17b which lies perpendicular to them, while the opposite ends of the branch flow channels 17a are open to the outside. The discharge hole 17c penetrates through one of the side wall portions 13 of the first heat transfer body 7 at one end portion thereof so as to extend the merge channel 17b.

17a) in which the reaction fluid is caused to flow. The first heat transfer bodies 7 function as members that receive heat or cold supplied from the heat medium or the second heat transfer bodies 9 and supply it to the reaction fluid, while the second heat transfer bodies 9 function as members that supply heat or cold supplied by the heat medium directly to the reaction fluid and indirectly thereto through the first heat transfer bodies 7.

[0025]

As illustrated in FIG. 1, the reaction flow channels 17 and the heat medium flow channels 31 are formed in such a manner that the discharge holes 31c of the heat medium flow channels 31 are located, on one side surface of the heat exchanging body 3, at the end portion opposite to the discharge holes 17c of the reaction flow channels 17. An end plate 21 curved in a concave shape is attached in a detachable manner or in an openable-closable manner to the side surface of the heat exchanging body 3 on the side where the branch flow channels 17a of the reaction flow channels 17 are open. With the end plate 21 covering the side surface of the heat exchanging body 3, a space is formed between the heat exchanging body 3 and the end plate 21. An inlet port 23 is provided on the end plate 21. Thus, as the reaction fluid is supplied from the inlet port 23, the reaction fluid splits into the branch flow channels 17a of each reaction flow channel 17 out of the space between the end plate 21 and the heat exchanging body 3, then merges at the merge channel 17b, and is discharged from the discharge hole 17c. Similarly, an end plate 35 curved in a concave shape is also attached in a detachable manner or in an openable-closable manner to the side surface of the heat exchanging body 3 on the side where the branch flow channels 31a of each heat medium flow channel 31 are open, i.e. the opposite side from the end plate 21. With the end plate 35 covering the side surface of the heat exchanging body 3, a space is formed between the heat exchanging body 3 and the end plate 35. An inlet port 37 is provided in the center of the end plate

35. As the heat medium is supplied from the inlet port 37, the heat medium splits into the branch flow channels 31a of each heat medium flow channel 31 out of the space between the end plate 35 and the heat exchanging body 3, then merges at the merge channel 31b, and is discharged from the discharge hoe 31c. Thus, the heat medium flow channels 31 and the reaction flow channels 17 are formed such that the heat medium and the reaction fluid flow in parallel but opposite directions in the branch flow channels 17a and the branch flow channels 31a.

[0026]

Further, an elongated and hollow lead-out member 39 having an opening along its longitudinal direction is attached to the side surface of the heat exchanging body 3 so as to cover the discharge holes 17c of the reaction flow channels 17. As a result, a merge channel connecting the discharge holes 17c in the vertical direction is formed. Thus, the reaction fluid flowing in the reaction flow channels 17 passes through the discharge holes 17c into the lead-out member 39, in which the reaction fluid merges, and is discharged from a tubular outlet port 41 provided in the center of the lead-out member 39. Similarly, an elongated and hollow lead-out member 43 having an opening along its longitudinal direction is attached to the same side surface of the heat exchanging body 3 so as to cover the discharge holes 31c of the heat medium flow channels 31. As a result, a merge channel connecting the discharge holes 31c in the vertical direction is formed. Thus, the heat medium flowing in the heat medium flow channels 31 passes through the discharge holes 31c to thereby merge, and is discharged from a tubular outlet port 45 provided in the center of the lead-out member 43. It is noted that the direction of flow of the reaction fluid from the inlet port 23 to the outlet port 41 and the direction of flow of the heat medium from the inlet port 37 to the outlet port 45 can be changed in the opposite directions.

[0027]

The reaction fluid is a fluid containing a reactant being a reaction raw material. While flowing through the branch flow channels 17a of the reaction flow channels 17, the reaction fluid receives the heat or cold of the heat medium flowing through the heat medium flow channels 31 and is thereby heated or cooled, so that the reaction progresses and the reactant is transformed into a product. The arrows denoted by reference sign R in FIG. 2 indicate the direction of the reactant to flow, while the arrows denoted by reference sign P indicate the direction of the product to flow. The arrows denoted by reference sign M in FIG. 3 indicate the direction of the heat medium to flow. The heat exchanging body 3 has a counter-flow type structure in which the reaction fluid and the heat medium flow in the opposite directions.

[0028]

As illustrated in FIG. 4 and FIG. 5, the reaction flow channels 17 and the heat medium flow channels 31 in the heat exchanging body 3 are formed as hollow portions whose cross sections perpendicular to the flow direction are rectangular. In this embodiment, eight branch flow channels 17a or branch flow channels 31a are formed in a single first heat transfer body 7 or second heat transfer body 9. However, the numbers of the branch flow channels 17a and the branch flow channels 31a are not limited to this, and are determined as appropriate with the design requirements, heat transfer efficiency, and the like of the heat exchanging body 3 taken into consideration. In view of heat transfer, it is usually preferable to provide several tens of branch flow channels 17a or branch flow channels 31a at intervals of about 1.0 times the flow channel width. It is also preferable to provide the reaction flow channels 17 and the heat medium flow channels 31 such that the intervals between them in the vertical direction (height direction) are about 0.2 to 5.0 times the intervals between these flow channels in the transverse direction. Further, although six first heat transfer bodies 7 and seven second heat transfer bodies 9 are stacked in this embodiment, the configuration is not limited

to this. It is preferable to configure the stack body (heat exchanging body 3) with its height set close to its width so that its cross section perpendicular to the flow direction can be close to a square shape. It is noted that, although the grooves for forming the reaction flow channels 17 and the heat medium flow channels 31 in the illustrated embodiment are provided only on one side of the first heat transfer bodies 7 and the second heat transfer bodies 9, it is also possible to make a change such that grooves are provided on both sides of the first heat transfer bodies 7 and the second heat transfer bodies 9. Then the reaction flow channels 17 and the heat medium flow channels 31 are formed as combination of the upper and lower grooves in the stacked state.

[0029]

A catalyst body 51 that promotes the reaction of the reactant is inserted in each of the branch flow channels 17a of the reaction flow channels 17 and fixed in close contact therewith so as to be capable of removal and insertion. A heat transfer promoter 53 that promotes the transfer of heat or cold from the heat medium to the heat exchanging body 3 is inserted in each of the branch flow channels 31a of the heat medium flow channels 31 and fixed in close contact therewith so as to be capable of removal and insertion. It is noted that the catalytic bodies 51 and the heat transfer promoters 53 in the reaction flow channels 17 and the heat medium flow channels 31 are hatched without illustration of their structures in FIG. 4 and FIG. 5, and illustration of the catalytic bodies 51 and the heat transfer promoters 53 in some of the reaction flow channels 17 and the heat medium flow channels 31 is omitted in FIG. 4.

[0030]

Each catalyst body 51 is a member in which a catalyst that promotes the reaction of the reactant is carried on the surface of a structural material, and may be one obtained by supporting the catalyst on the structural material using a carrier. The catalyst is appropriately selected according to

the reaction to proceed in the reactor 1. In order to increase the area of contact with the reaction fluid, the catalyst body 51 (structural material) may be one curved round in a wavy shape like a corrugated plate, one bent in a zigzag shape, or the like. Moreover, the length of the catalyst body 51 preferably corresponds to the branch flow channel 17a of the reaction flow channel 17 but is not limited to this.

[0031]

On the other hand, each heat transfer promoter 53 is a heat conductive member that promotes the heat transfer between the heat medium and the heat exchanging body 3, i.e. a heatsink, and includes fins (protrusions in the shape of plates, pins, or the like protruding into the fluid). The fins act to increase the contact area with (the heat transfer area from) the heat medium, thereby lowering the thermal resistance and increasing the heat transfer rate from the heat medium. The heatsink is generally configured in a form in which a plurality of fins are integrally connected to bases as a single body, and the heat transferred from the heat medium to the fins is supplied through the bases to the heat exchanging body. Examples of commercially available heatsinks include ones obtained by arranging many fins in the shape of plates, pins, tubes, or the like side by side and joining them to a base plate, ones in a shape of corrugated plate, and the like. From such various heatsinks, one suitable for the dimensions and shape of the branch flow channel 31a of the heat medium flow channel 31 can be appropriately selected and used as the heat transfer promoter 53. The heat sink with a corrugated plate-like shape has a structure in which the amount of heat transfer is easy to calculate and which is advantageous in adjusting the heat transfer performance and is also hard to break during the work for insertion into or removal from the flow channel. As the heat transfer promoter 53, one that comes into close contact with the heat transfer wall surrounding the branch flow channel 31a is used in order to ensure heat transfer to the heat exchanging body 3. In this respect, a heat transfer promoter

53 that comes into surface contact with the heat exchanging body 3, such as a heat transfer promoter 53A in the shape of an angular corrugated plate illustrated in FIG. 6, or the like, is suitable for the heat transfer to the heat exchanging body 3. The heat transfer promoter 53A of FIG. 6 is formed in the shape of an angular corrugated plate, i.e. in the shape of a thin plate bent to define protrusions and grooves arranged alternately and extending side by side, and includes flat surfaces on the protrusion portions and the groove portions. Thus, the heat transfer promoter 53 inserted and fitted in the branch flow channel 31a is in close contact with each of the first heat transfer body 7 (or the lid body 8) and the second heat transfer body 9 at the flat surfaces of the protrusion portions and the groove portions, so that these portions function as bases while the other portions function as fins. In the structure of the heat transfer promoter 53 including base portions in surface contact with the heat exchanging body 3 as above, the thermal resistance between the fins and the heat exchanging body 3 is low, so that heat is easily transferred to the heat exchanging body 3. Accordingly, the heat transfer performance is better than that of the one in the shape of a wavy corrugated plate. Meanwhile, as illustrated as one embodiment in FIG. 6, inserting and fitting the heat transfer promoter 53A placed on a heat conductive thin flat plate 55 into the branch flow channel 31a of the heat medium flow channel 31 improves the tightness in contact with the first heat transfer body 7 and the second heat transfer body 9. However, the use of the flat plate 55 is optional, and the flat plate 55 may be omitted to simplify the structure. Examples of the heat conductive material for constituting the heat transfer promoter 53 and the flat plate 55 include metals such as aluminum, copper, stainless steel, and iron-based plated steel. Aluminum and copper are preferable since their heat conductivity is particularly high. Naval copper, aluminum brass, and the like are also preferable in the case of cold exchange using a coolant.

[0032]

The heat transfer promoter 53 is configured as an assembly of a plurality of replaceable partial heat transfer promoters joined to each other in their longitudinal direction (flow direction). This can be made by utilizing objects that are typically used as heat radiating fins or heatsinks. For example, the heat transfer promoter 53A of the embodiment illustrated in FIG. 6 can be made by forming an assembly by preparing a corrugated plate of substantially the same length as the branch flow channel 31a, equally dividing this into a plurality of partial corrugated plates 53a' of the same length (in the flow direction) (see FIG. 7(a)), and joining them as partial heat transfer promoters 53a to constitute an aggregate. This can be used as each heat transfer promoter 53 in FIG. 1 to FIG. 5. Corrugated plates have different heat transfer performance depending on the heat conductivity of the constituent material and the contact area with the heat medium. Thus, by dividing a different corrugated plate having the same width, length, and height but a different pitch or plate thickness into parts of the same length, it is possible to obtain partial heat transfer promoters of a different type (replacement bodies) which have a different heat transfer area and which the partial heat transfer promoters can be replaced with. Similarly, replacement bodies can also be obtained from a corrugated plate of the same shape made of a different material. By using such a replacement body to replace at least one partial heat transfer promoter with the replacement body, the heat transfer promoter 53 is constituted by partial heat transfer promoters of a plurality of types and the heat transfer performance of the heat transfer promoter 53 is locally changed at the replaced position. By preparing various types of replacement bodies having different heat transfer performances, flexibility in adjustment of the heat transfer performance is enhanced. Then, an experimental measurement or a simulation may be conducted based on the configuration of the heat transfer promoter 53 in which partial heat transfer

promoters having the same heat transfer performance are inserted and joined to each other in the branch flow channel 31a, to thereby study the temperature distributions in the flow direction at the wall portions (heat transfer walls) facing respectively the reaction flow channel 17 and the heat medium flow channel 31 of the first heat transfer body 7 and the second heat transfer body 9. Based on that result, a part or all of the partial heat transfer promoters may be appropriately replaced with a replacement body, and it is thus possible to adjust the temperature distribution by changing the heat transfer performance in this way. With such an operation, the temperature gradient (temperature change) in the temperature distribution of the wall portion facing the reaction flow channel 17 can be adjusted to a suitable one.

[0033]

Incidentally, the corrugated plate can be obtained by repeatedly performing a bending process on a thin plate material from one end to fold it. It is therefore possible to prepare a corrugated plate of a suitable shape as needed, by preparing a thin plate of a material that is selected as appropriate from the heat conductive materials as mentioned above; setting bending intervals in accordance with the length, width, and height of the branch flow channel 31a of the heat medium flow channel 31, so as to provide dimensions for being tightly fixed into the branch flow channel 31a; and performing a bending process to make perpendicular bends. A corrugated plate obtained after performing the bending process using a thin plate material of the same length as the branch flow channel 31a may be cut and divided by the length of the partial heat transfer promoter, or thin plate materials processed to have the length of the partial heat transfer promoter may be subjected to the bending process.

[0034]

To replace a partial heat transfer promoter with a replacement body, the partial heat transfer promoter is pulled out of the branch flow channel 31a which is opened by detaching

(or opening) the end plate 35. In this connection, an offset-type corrugated plate with cutouts created by shifting the phase of the corrugation can be utilized, and this may be divided into partial corrugated plates 53b' (see FIG. 7(b)), which can be used to form the partial heat transfer promoters and the heat transfer promoter 53, with easy operation for replacement. Specifically, with a straight pulling bar 57 with a bent tip as illustrated in FIG. 6, the partial heat transfer promoter can be easily pulled out by hooking the bar in a cutout portion of the partial heat transfer promoter. Such an easy replacement operation as above is possible also in the case of using a louver-type corrugated plate on which a louver is formed or a slit-type corrugated plate provided with slits, which is not limited to the case of offset type. Further, a heat transfer promoter formed of a basic corrugated plate as illustrated in FIG. 6 or of a wavy corrugated plate can also constitute the heat transfer promoter 53 in which the replacing operation is easy, by providing it with a small piece, a hole, a cutout, or the like that can be hooked on the pulling bar 57.

[0035]

The larger the number of partial heat transfer promoters (the shorter the length in the flow direction) constituting the heat transfer promoter 53, the higher the accuracy of adjustment of the heat transfer performance. Thus the number of partial heat transfer promoters (the length in the flow direction) can be determined as appropriate in accordance with the required adjustment accuracy. Also, in a case where accumulated data on the relation between the heat supplied from the heat medium and the temperature distribution indicates that the portion requiring frequent replacement is limited to a specific region, the heat transfer promoter 53 does not need to be constituted by partial heat transfer promoters of the same length (in the flow direction). For example, the heat transfer promoter 53 can instead be constituted by short partial heat transfer promoters and long partial heat transfer

promoters. In this case, the heat transfer promoter 53 may be constituted by joining the short and long partial heat transfer promoters such that the short partial heat transfer promoters are arranged at the specific region and the long partial heat transfer promoters are arranged at the other regions (of low replacement frequency). Replacement bodies may be formed to have the same length as the short partial heat transfer promoters.

[0036]

Also, in FIG. 6, the heat transfer promoter 53A and each partial heat transfer promoter 53a are formed of a stack of two corrugated plates of the same type. However, they may be formed of a single plate or a stack of three or more plates. They may be a stack of a plurality of corrugated plates of different types. Increasing the number of layers of corrugated plates (reducing the height of a single corrugated plate) increases the contact area of the heat transfer promoter 53 with the heat medium and accordingly enhances the heat transfer performance. Corrugated plates stacked in the vertical direction are likely to be unstable if they are in the same phase state. However, sandwiching and interposing a heat conductive thin flat plate 59 between the upper and lower corrugated plates as illustrated in FIG. 6 stabilizes them and thereby makes it easier for them to be inserted and fitted into the branch flow channel 31a of the heat medium flow channel 31. In this case, the flat plate 59 increases the contact area with the heat medium. Then, making the flat plate 59 from a material similar to that of the above-mentioned flat plate 55 enhances the heat transfer performance of the heat transfer promoter 53. The replacement operation will be easy if the length of the flat plate 59 (in the flow direction) is equal to that of a partial heat transfer promoter 53a.

[0037]

FIG. 7 specifically illustrates examples of partial heat transfer promoters which are different in heat transfer performance. FIG. 7(a) illustrates, as an example, a partial

corrugated plate 53a' constituting the partial heat transfer promoter 53a of FIG. 6, and the partial heat transfer promoter 53a can be formed by stacking two partial corrugated plates 53' with the flat plate 59 interposed therebetween. FIG. 7(b) illustrates an example of the case utilizing an offset-type corrugated plate. A partial heat transfer promoter is formed by stacking partial corrugated plates 53b' obtained by dividing an offset-type corrugated plate, with the flat plate 59 interposed therebetween. The pitch and height of each partial corrugated plate 53b' are the same as those of the partial corrugated plate 53a' in FIG. 7(a), but the phase is regularly shifted by 1/4 along the flow direction. In this case, since turbulence occurs at the positions where the phase is shifted, the pressure loss slightly increases but the heat transfer is improved. Accordingly, the heat transfer performance is higher than that of the partial corrugated plate 53a' which has no phase shift. In other words, the heat transfer performance also changes with the frequency at which the phase is shifted. Further, though illustration is omitted, corrugated plates with a small pitch and height, e.g. corrugated plates with 1/2 of the pitch and height of the partial corrugated plate 53a', may be used in this way to form a partial heat transfer promoter similarly by stacking four of these corrugated plates with the flat plate 59 interposed therebetween. Thus, using corrugated plates with a small pitch or height can enhance the heat transfer performance of the heat transfer promoter 53. Then, various partial heat transfer promoters with increased heat transfer performance can be obtained by decreasing at least one of the pitch and the height. Conversely, partial heat transfer promoters with decreased heat transfer performance can be obtained by increasing at least one of the pitch and the height. Meanwhile, FIG. 7(c) shows a partial heat transfer promoter 53c using the same partial corrugated plate 53b' as that in FIG. 7(b). However, the upper corrugated plate is shifted in pitch by 1/2 relative to the lower corrugated plate, and no flat plate is

interposed between the corrugated plates. Accordingly, the heat transfer performance of the partial heat transfer promoter 53c is low as compared to a case where the flat plate 59 is interposed. Thus, with a stacked configuration as illustrated in FIG. 7(c), it is possible to use the same corrugated plate to form a partial heat transfer promoter with decreased heat transfer performance, and it is also stable without a flat plate interposed. It is noted that, while the bending angle of the partial corrugated plates constituting the heat transfer promoters and the partial heat transfer promoters in FIG. 4 to FIG. 7 is substantially a right angle, the bending angle may be less than 90 degrees or more than 90 degrees. In that case, the cross section of each branch flow channel 31a is defined as a trapezoidal shape by the heat transfer promoter 53. If the internal bending angle is less than 90 degrees, the heat transfer performance increases due to reduction in the pitch, and, if the internal bending angle is more than 90 degrees, the heat transfer performance decreases due to increase in the pitch. It is also possible, with the internal bending angle of less than 90 degrees, to form a corrugated plate with which the cross section of the branch flow channel is defined in a triangle shape.

[0038]

As illustrated in FIG. 7, a partial heat transfer promoter (replacement body) with the same material but different heat transfer performance can be provided by changing the contact area with the heat medium based on the difference in shape of the corrugated plates to be used and/or the presence or absence of the intervening flat plate. Alternatively, a partial heat transfer promoter (replacement body) with different heat transfer performance may be formed by utilizing a different constituent material, since the heat transfer performance of a partial heat transfer promoter can vary with the heat conductivity of its constituent material.

[0039]

When a plurality of partial heat transfer promoters

having the same heat transfer performance are sequentially inserted and fitted in one of the branch flow channels 31a of the heat medium flow channels 31, the partial heat transfer promoters are linearly joined to each other and form a heat transfer promoter 53 inside the branch flow channel 31a. The heat transfer performance for transfer of heat or cold from the heat medium to the first heat transfer body 7 and the second heat transfer body 9 is uniform across the entire branch flow channel 31a. Assuming that the temperature distribution along the flow direction in the wall portion (heat transfer wall) of the first heat transfer body 7 or the second heat transfer body 9 facing the reaction flow channel 17 in the above state is a standard temperature distribution, replacing one of the partial heat transfer promoters with a partial heat transfer promoter (replacement body) with different heat transfer performance changes the amount of heat transfer to the first heat transfer body 7 and the second heat transfer body 9 at the replaced position in accordance with the heat transfer performance. As a result, the temperature of the first heat transfer body 7 and the second heat transfer body 9 at and around the replaced position changes, thereby changing the temperature distribution curve of the wall portion. For example, in a case of a heating system using a high-temperature heat medium, replacing a partial heat transfer promoter with a replacement body with higher heat transfer performance raises the temperature of the wall portion at the replaced position, whereas replacing a partial heat transfer promoter with a replacement body with lower heat transfer performance lowers the temperature of the wall portion at the replaced position. Then, based on the standard temperature distribution curve, it is possible to determine the position (replacement position) at which the heat transfer performance is to be changed and the degree of the change, by comparing the standard temperature distribution curve with a target temperature distribution curve. A replacement body is selected in accordance with the degree of the change in heat

transfer performance thus determined, and the partial heat transfer promoter at the replacement position is replaced with the replacement body. In this way, the temperature distribution curve can approximate the target temperature distribution curve, and the heat transfer promoter is constituted by partial heat transfer promoters of a plurality of types. The number of partial heat transfer promoters replaced with a replacement body is not limited to one. All partial heat transfer promoters may be replaced. By adjusting the temperature distribution curve in this manner such that it has a suitable temperature gradient with drastic temperature changes eliminated, it is possible to optimize the progress of the reaction.

[0040]

An example of adjustment of the temperature distribution curve as described above will be described below with reference to FIG. 8. FIG. 8 is a set of graphs obtained by calculating, based on a simulation, (a) the temperature distribution at the reaction flow channel side and (b) the temperature distribution at the heat medium flow channel side in the heat exchanging body 3 with the reaction fluid and the heat medium supplied therein, in the reactor 1 having the structure illustrated in FIG. 1 to FIG. 3. In the temperature distribution graphs of FIG. 8, the horizontal axes represent respectively the position along the direction of flow in the flow channel in terms of the distance [unit: m] from the entrance-side end of the branch flow channel 17a of the reaction flow channel 17. The vertical axes represent respectively the temperature [°C] at the reaction flow channel side (FIG. 8(a)) and the heat medium flow channel side (FIG. 8(b)) in the heat exchanging body 3. The temperature at the reaction flow channel side is calculated as the temperature of the wall portions of the base portion 11 and the base portion 25 of the first heat transfer body 7 and the second heat transfer body 9 facing their reaction flow channel 17. The temperature at the heat medium flow channel side is calculated as the

temperature of the wall portions of the base portion 11 and the base portion 25 of a first heat transfer body 7 and the second heat transfer body 9 facing their heat medium flow channel 31. Also, the calculations are performed by assuming, as reaction conditions, a case of supplying a reformed raw material prepared in advance (containing methane (main raw material), water, carbon monoxide, and carbon dioxide; temperature: 630°C) as the reaction fluid and a combustion gas (temperature: 875°C) as the heat medium. Incidentally, it is assumed that a catalyst body obtained by supporting a catalyst on the surface of a wavy structural member is inserted and fitted in each of the branch flow channels 17a of the reaction flow channels 17.

[0041]

In FIG. 8, reference signs D1 and D2 represent temperature distribution curves assuming a case (setting 1) where an assembly of partial heat transfer promoters joined to a length of 0.6 m is inserted and fitted as the heat transfer promoter 53 in each of the branch flow channels 31a of the heat medium flow channels 31, the partial heat transfer promoters each being formed as a stack of two partial corrugated plates 53b' in FIG. 7(b) with the flat plate 59 interposed therebetween. Reference signs D3 and D4 represent temperature distribution curves assuming a case (setting 2) where a 0.6 m-long assembly of partial heat transfer promoters joined to a length of 0.4 m and then the partial heat transfer promoters 53c in FIG. 7(c) joined to a length of 0.2 m is inserted and fitted into each of the branch flow channels 31a of the heat medium flow channels 31, the former partial heat transfer promoters each being formed as a stack of four partial corrugated plates having the same length as the partial corrugated plate 53b' in FIG. 7(b) but 1/2 of the pitch and height thereof.

[0042]

With setting 1, the heat transfer promoter 53 uniformly promotes the heat transfer over the entire flow channel, so that the temperature distribution at the heat medium flow

channel side is close to a linear temperature distribution. However, the temperature gradient is higher at the position exceeding 0.4 m (1/3 region on the upstream side) (the curve of reference sign D1 in FIG. 8(b)). Due to the balance between the temperature rise resulting from the heat transfer corresponding to this and the heat absorption resulting from the progress of the reaction, the temperature at the reaction flow channel side appears as the curve of reference sign D2 in FIG. 8(a) and the temperature gradient is higher at the position exceeding 0.4 m (1/3 on the downstream side). In contrast, with setting 2, the heat transfer promoter 53 is formed such that the heat transfer performance at 1/3 of the heat medium flow channel on the upstream side is lower than setting 1 while the heat transfer performance at 2/3 on the downstream side is higher than setting 1. Accordingly, the heat transfer is suppressed at the upstream side of the heat medium flow channel and the heat of the heat medium is transferred intensively at the downstream side of the heat medium flow channel (= the upstream side of the reaction flow channel). Hence, on the temperature distribution on the heat medium flow channel side, the temperature gradient over the region from 0 to 0.4 m (2/3 on the downstream side) is higher than setting 1, while the temperature gradient over the region exceeding 0.4 m (1/3 on the upstream side) is lower than setting 1, as illustrated by the curve of reference sign D3. Correspondingly, on the temperature distribution at the reaction flow channel side too, the temperature gradient over the region from 0 to 0.4 m (2/3 on the upstream side) is higher than setting 1, and the temperature gradient over the region exceeding 0.4 m (1/3 on the downstream side) is lower than setting 1, as illustrated by the curve of reference sign D4. Consequently, the temperature difference between the positions at 0.4 m and 0.6 m at the heat medium flow channel side decreases from approximately 106°C (setting 1) to approximately 78°C (setting 2), and the temperature difference at the reaction flow channel side decreases from approximately

95°C (setting 1) to approximately 76°C (setting 2).

[0043]

As described above, the temperature distribution along the flow channel in the heat exchanging body 3 may be studied and the performance of heat transfer from the heat medium flow channel 31 to the heat exchanging body 3 may be changed by unit of partial heat transfer promoter, by replacing a part or all of the partial heat transfer promoters constituting the heat transfer promoter 53. In this way, the temperature distributions at each heat medium flow channel and each reaction flow channel can be adjusted to be close to the ideal temperature distribution curves. The temperature distributions vary depending on the condition of the reaction, the condition of supply of the heat medium, properties of the catalyst, and so on. Then, it is possible to provide a reactor in which the temperature distributions are adjusted in advance to preferable states in accordance with these conditions. In this way, the reactor exhibits its performance well, and thus the load and the energy consumption during operation can be reduced and a longer usage life can be ensured. Usually, the partial heat transfer promoters are joined such that the length of the heat transfer promoter 53 corresponds to the length of the branch flow channel 31a of the heat medium flow channel 31. However, no partial heat transfer promoter is used in a configuration in which the heat transfer performance is set to the lowest level. Thus, in a setting utilizing such a configuration, the entire length of the heat transfer promoter 53 does not correspond to the length of the branch flow channel 31a but is smaller than the length of the branch flow channel 31a. It is noted that excessive increase in resistance to flow is not preferable not only in view of the heat transfer performance but also in view of the mechanical power for supplying the fluid. For this reason, the increase in resistance to flow due to the increase in the contact area with the heat medium and the like are preferably taken into consideration when the heat transfer promoter 53 is selected.

This also applies to the catalyst body 51.

[0044]

The above-described heat exchanging body 3 is usable as any of a liquid-liquid heat exchanger, a gas-gas heat exchanger, and a gas-liquid heat exchanger. Thus, the reaction fluid and the heat medium to be supplied into the reactor 1 of the present disclosure may be a gas or a liquid, respectively. The configuration of the reactor 1 of the present disclosure is applicable to a reactor in which its reaction flow channels have a large specific surface area per unit volume, or a so-called compact reactor, and the reactor 1 can be used to implement chemical syntheses with various thermal reactions (endothermic reactions, exothermic reactions). Examples of syntheses with such thermal reactions include syntheses with endothermic reactions such as the methane steam-reforming reaction presented by formula (1) below and the methane dry-reforming reaction presented by formula (2) below, and exothermic reactions such as the shift reaction presented by formula (3) below, the methanation reaction presented by formula (4) below, and the Fischer-Tropsch synthesis reaction presented by formula (5) below. The reaction fluids in these reactions are gaseous.

[0045]

$CH_4 + H_2O \rightarrow 3H_2 + CO$ … Formula (1)

$CH_4 + CO_2 \rightarrow 2H_2 + 2CO$ … Formula (2)

$CO + H_2O \rightarrow CO_2 + H_2$ … Formula (3)

$CO + 3H_2 \rightarrow CH_4 + H_2O$ … Formula (4)

$(2n+1)H_2 + nCO \rightarrow C_nH_{2n+2} + nH_2O$ … Formula (5)

[0046]

Other than the above reactions, the technique of the present disclosure may also be applied to execution of reactions such as acetylation reaction, addition reaction, alkylation reaction, dealkylation reaction, hydrogen dealkylation reaction, reductive alkylation reaction, amination reaction, aromatization reaction, arylation reaction, autothermal reforming reaction, carbonylation

reaction, decarbonylation reaction, reductive carbonylation reaction, carboxylation reaction, reductive carboxylation reaction, reductive coupling reaction, condensation reaction, decomposition (cracking) reaction, hydrogen decomposition reaction, cyclization reaction, cyclooligomerization reaction, dehalogenation reaction, dimerization reaction, epoxidation reaction, esterification reaction, exchange reaction, halogenation reaction, hydrogenation reaction, hydrogen halogenation reaction, homologation reaction, hydration reaction, dehydration reaction, dehydrogenation reaction, hydrogen carboxylation reaction, hydrogen formylation reaction, hydrogenolysis reaction, hydrogen metalation reaction, hydrosilylation reaction, hydrolysis reaction, hydrotreating reaction, isomerization reaction, methylation reaction, demethylation reaction, metathesis (substitution) reaction, nitration reaction, oxidation reaction, partial oxidation reaction, polymerization reaction, reduction reaction, reverse water gas shift reaction, sulfonation reaction, telomerization reaction, transesterification reaction, and trimerization reaction.

[0047]

A fluid containing a substance (reactant) such as a raw material to participate in a chemical reaction as listed above can be supplied as a reaction fluid to the reactor to synthesize a target product. The reaction fluid may contain a carrier that is not involved in the reaction. The carrier can be appropriately selected from the substances that do not affect the progress of the reaction, in consideration of the chemical reaction to be carried out. Carriers usable for a gaseous reaction fluid include gaseous carriers such as an inert gas or a low-reactive gaseous substance (at the temperature inside the reactor).

[0048]

Also, fluidic substances that do not corrode the constituent material of the reactor are usable as the heat medium. For example, liquid substances such as water and oil

bodies, can be replaced only at the deteriorated or clogged portion of the catalyst body. In other words, replacement of the whole catalyst body can be avoided. Accordingly, it is possible to minimize the amount of replacement of the catalyst body, and reduce the cost required for performance adjustment and maintenance of the reactor.

[0051]

In the present disclosure, the heat transfer promoter, whose heat transfer efficiency is locally changeable, can be attached to and detached from a heat medium flow channel as long as it extends linearly with one end opened. The heat transfer promoter is therefore applicable to reactors including a heat exchanging body with a structure in which straight reaction flow channels and heat medium flow channels extend side by side. Also, in the above embodiment, description has been given of the heat medium flow channels whose cross sections perpendicular to the flow direction are rectangular. However, the technique of the present disclosure is applicable to cases where the cross sections of the heat medium flow channels are of other shapes. In particular, in the case of forming the grooves for forming the heat medium flow channels in both surfaces of the first heat transfer body and the second heat transfer body and joining them together, heat medium flow channels in the shape of a circular cylinder or an elliptical cylinder can be easily formed by forming grooves in the shape of a circular semi-cylinder or an elliptical semi-cylinder. Thus temperature distribution adjustment as described above is possible by dividing a heat transfer promoter in conformity with such a shape into a plurality of partial heat transfer promoters.

[0052]

Although preferred embodiments of the present disclosure have been described above with reference to the accompanying drawings, the present disclosure is not limited to those embodiments. It is to be understood that various modifications and adjustments that those skilled in the art

CLAIMS

[Claim 1] A reactor comprising:

a heat exchanging body that includes therein a heat medium flow channel in which a heat medium is caused to flow, and a reaction flow channel in which a reaction fluid is caused to flow, to exchange heat between the heat medium and the reaction fluid; and

a heat transfer promoter that is provided in the heat medium flow channel and comes in close contact with the heat exchanging body in order to promote heat transfer between the heat medium and the heat exchanging body, the heat transfer promoter being constituted by an assembly of replaceable partial heat transfer promoters of a plurality of types which have heat transfer performances different from one another by type and which are joined to each other in a flow direction and can be recombined to locally change the heat transfer performance of the heat transfer promoter.

[Claim 2] The reactor according to claim 1, wherein the partial heat transfer promoters of the plurality of types have the same length in a flow direction and are joined linearly.

[Claim 3] The reactor according to claim 1 or 2, wherein the partial heat transfer promoters of the plurality of types include a fin.

[Claim 4] The reactor according to any one of claims 1 to 3, wherein each of the partial heat transfer promoters of the plurality of types is formed of a bent plate-shaped member.

[Claim 5] The reactor according to claim 4, wherein each of the partial heat transfer promoters of the plurality of types has a shape of a corrugated plate bent in such a manner as to be in surface contact with the heat exchanging body.

[Claim 6] The reactor according to claim 4, wherein each of the partial heat transfer promoters of the plurality of types has a shape of a corrugated plate bent at a substantially right angle.

[Claim 7] The reactor according to any one of claims 1 to 6, wherein each of the partial heat transfer promoters of the plurality of types includes at least one of a small piece, a hole, a cutout, a louver, and a slit which is hookable.

[Claim 8] The reactor according to any one of claims 1 to 7, wherein the partial heat transfer promoters of the plurality of types are different from each other in at least one of thermal conductivity of a constituent material and contact area with the heat medium.

[Claim 9] The reactor according to claim 5 or 6, wherein the shapes of the corrugated plates of the partial heat transfer promoters of the plurality of types are different from each other by type in at least one of pitch and height.

[Claim 10] The reactor according to any one of claims 1 to 9, further comprising:

a catalyst that promotes a reaction of the reaction fluid, in the reaction flow channel.

[Claim 11] The reactor according to any one of claims 1 to 10, configured in a counter-flow type or a parallel-flow type wherein the heat medium flow channel and the reaction flow channel are formed linearly and arranged in parallel to each other.