

TITLE OF THE INVENTION

HEAT EXCHANGE TUBES

FIELD OF INDUSTRIAL APPLICATION

The present invention relates to heat exchange
5 tubes which are outstanding in heat transfer efficiency
and useful, for example, as thermal cracking reactor
tubes in ethylene plants (ethylene cracking tubes).

BACKGROUND OF THE INVENTION

In thermal crackers for producing ethylene, a
10 hydrocarbon material such as naphtha, natural gas or
ethane is fed to a reactor tube as a fluid mixture
(about 700° K in temperature) with steam and heated to
a specified temperature (about 1090° K) with heat
supplied from outside while being passed through the
15 tube at a high velocity (e.g., about 0.1 to 0.8 second
to flow through the reactor tube when the tube is about
10 to about 13 m in length), whereby olefins such as
ethylene, propylene and the like are produced by
thermal cracking.

20 It is required for the thermal cracking
operation to effect efficient heat transfer to the fluid
passing through the tube at a high velocity and to
rapidly heat the fluid to the reaction temperature range
up to the central portion thereof. At the same time,

unnecessary heating to a high temperature beyond the cracking temperature range must be avoided to the greatest possible extent. The reason is that if the hydrocarbon material is retained in a high temperature range beyond the cracking temperature range for a long period of time, the material becomes converted into lighter fractions (for example, methane and free carbon) to excess or the cracked product undergoes polycondensation or like reaction, consequently reducing the yield of the desired product greatly while permitting the deposition of free carbon on the tube inner surface to result in the disadvantage of necessitating more frequent decoking.

To assure the reactor tube of an improved heat transfer efficiency and to heat up the fluid inside the tube rapidly, it is conventional practice to decrease the bore diameter of the tube (for example, to not larger than 40 mm) and increase the heat transfer surface area relative to the content volume. Further heat exchange tubes have been proposed which, as shown in FIG. 12, are formed with a corrugated inner wall surface, with ridges and furrows extending helically or in parallel to the tube axis, thus shaped ingeniously in cross section and thereby given an increased heat transfer area (Unexamined Japanese Patent Publications

No. 173022/1983 and No. 127896/1989).

Although a decrease in the diameter of the reactor tube is effective for transferring heat to the fluid inside the tube more efficiently, it is then
5 required that an increased number of reactor tubes be installed in the cracker to compensate for the decrease in the tube diameter if the apparatus is to remain unchanged in ethylene production capacity. This renders
10 the apparatus more cumbersome to operate and maintain while the decrease in the tube diameter entails the drawback that free carbon is liable to become deposited on the tube wall in a shortened period of time.

The reactor tube of FIG. 12 wherein the inner wall surface is corrugated merely achieves an improvement in heat transfer efficiency generally corresponding to the increase in the tube wall inner surface area and can not be expected to attain a remarkably improvement in any other function over usual tubes (having
15 a smooth inner wall surface with no corrugation).

20 In view of the foregoing problems, the present invention provides a novel heat exchange tube which achieves a remarkably improved efficiency in transferring heat to the fluid flowing therethrough without necessitating a reduction in its inside diameter
25 and which is rapidly heatable for the fluid to a required

temperature up to its central portion, the tube being adapted for use in thermal crackers for producing ethylene to make it possible to greatly increase the production capacity thereof and render the apparatus compact in design and easy to operate and maintain.

SUMMARY OF THE INVENTION

The heat exchanger tube of the present invention is characterized in that fins positioned in a direction intersecting the axis of the tube are formed on the inner surface of wall of the tube in one or a plurality of regions or all regions arranged from an inlet end of the tube to an outlet end thereof axially of the tube, the fins having a suitable pitch.

The fins are formed by a helical projection extending helically on the tube wall inner surface axially of the tube, or are each in the form of an annular projection circumferentially extending on the tube wall inner surface around the axis of the tube.

The region or regions where the fins are to be formed in the interior of the tube from the inlet end to the outlet end, the angle of intersection of the fins with the tube axis, the fin pitch, etc. are suitably determined in accordance with specific conditions such as the operating conditions of the heat exchange tube, heat transfer efficiency required,

permissible range of pressure losses, etc.

The fins formed on the tube wall inner surface in a direction intersecting the tube axis (at right angles therewith or obliquely) act as
5 agitating elements on the fluid inside the tube, causing heat to be transferred through the tube wall to the fluid inside the tube with an improved efficiency as the effect of the turbulence formed by agitation.

Thus, unlike the conventional heat exchange
10 tube which is improved in heat transfer efficiency by an increase of heat transfer area of the tube wall, the present invention depends solely on the formation of turbulence by the agitating action of the fins on the fluid inside the tube to produce a great fluid
15 mixing effect and thereby realize a uniform temperature distribution of the fluid radially from the tube wall to the tube axis over the entire cross section and rapid heating to the required temperature.

Although ensuring rapid heating of the fluid
20 inside the tube, the fins formed on the tube wall inner surface are responsible to an increase in the pressure loss of the fluid, whereas a high heat transfer efficiency can be achieved by effective agitation while suppressing the pressure loss within limits not
25 objectionable to the actual operation by designing the

fins in conformity with the inside diameter of the tube, for example, by suitably determining the angle of intersection of the fins with the tube axis and the fin pitch.

5 BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a view in axial section of a tube having fins formed by a helical projection;

FIG. 2 is a view in axial section of a tube having fins each in the form of an annular projection;

10 FIG. 3 is a development of the inner surface of wall of the tube having the helical projection;

FIG. 4 is a development of the inner surface of wall of the tube having the annular projections;

15 FIG. 5 is a diagram in axial section showing an example of distribution of fins on the inner surface of a tube wall;

FIG. 6 is a diagram in axial section illustrating another example of distribution of fins on the inner surface of a tube wall;

20 FIG. 7 is a diagram showing a temperature distribution of a fluid inside a heat exchange tube having fins;

FIG. 8 is a diagram showing a temperature distribution of the fluid inside a heat exchange tube
25 having no fins;

FIG. 9 is a diagram showing a temperature distribution of the fluid inside a heat exchange tube having no fins;

FIG. 10 is a graph showing the fluid temperatures at the axial portions of the tubes shown in FIGS. 7 and 9;

FIG. 11 is a graph showing the fluid pressures inside the same tubes; and

FIG. 12 is a view in cross section showing a conventional example of heat exchange tube.

DETAILED DESCRIPTION OF THE INVENTION

FIGS. 1 and 2 show examples of arrangements of fins formed on the inner surface of a tube wall according to the invention. Indicated at 10 in FIG. 1 is a tube, at 10a the axis of the tube, and at 10s the inner surface of wall of the tube. Fins 20 are formed by a helical projection helically extending on the tube wall inner surface axially of the tube. FIG. 2 shows fins 20 each in the form of an annular projection circumferentially extending on the tube wall inner surface around the tube axis 10a.

FIG. 1 shows an example wherein the fins are made continuous in the form of a single helical projection, whereas such fins may be formed by a plurality of helical projections.

FIG. 3 is a development of the tube having the fins 20 formed by the helical projection to show the helical pattern on the tube wall inner surface. Indicated at θ is the angle of intersection of the fin 20 with the tube axis 10a, at p the pitch of fins 20, and at S the circumference ($= \pi D$ where D is the inside diameter of the tube). The pitch p of the fins 20 which are formed by a single helical projection is equal to the distance of axial advance of a point in the helical projection for a complete turn about the tube axis, i.e., lead L ($= \pi D / \tan \theta$). The pitch p of helical fins 20 as formed by a plurality of helical projections can be optionally determined as the spacing (axial distance) between the adjacent helical projections.

FIG. 4 is a development of the inner surface of wall of the tube having the fins which are annular projections. The angle of intersection, θ , of the fin is 90 degrees, and the pitch p is an optional value determined as an axial spacing between the adjacent fins 20.

The fins on the tube wall inner surface are formed in one region along the axial length of the tube from an inlet end 10₁ thereof to its outlet end 10₂, or in a plurality of regions arranged axially of the tube as shown in FIG. 5. (The drawing shows an example

wherein the fins are formed in three regions A_1 , A_2 and A_3 arranged from the tube inlet end 10_1 to the outlet end 10_2 .) Alternatively, the fins are formed over the entire region A of the tube from the inlet
5 end 10_1 to the outlet end 10_2 .

The fins inside one tube are those formed by a helical projection or those comprising annular projections, or a combination of the two types. For example, annular projection fins are provided in
10 the region A_1 , and helical projection fins in the regions A_2 and A_3 in FIG. 5. Thus, helical projections and annular projections are selectively combined as desired.

The fins 20 on the tube wall inner surface
15 serve as elements for agitating the fluid inside the tube to transfer heat to the fluid with an improved efficiency, and at the same time, become a factor to increase the pressure loss of the fluid, whereas a rapid heating effect due to the improved heat transfer
20 efficiency can be assured while suppressing the increase in the pressure loss by suitably determining, for example, the pitch p and the intersection angle θ of the fins in conformity with the inside diameter of the tube.

Varying the fin pitch p from region to region
25 inside the tube is an effective method of assuring

balance between the improvement in heat transfer efficiency and the suppression of pressure loss. For example, in the case where fins are provided in discrete regions arranged axially of the tube as shown in FIG. 5, the fin pitch in an optional one of the regions is made different from the fin pitch of the region adjacent thereto, and the different pitches p are repeated axially of the tube. In the case where fins are formed in almost the entire region of the tube as shown in FIG. 6, the entire region can be divided into a plurality of consecutive subregions, with every two adjacent subregions made different from each other in fin pitch p to repeat the different pitches p axially of the tube.

With the tube formed with fins in some regions or in the entire region thereof, the fin pitch p_1 of an upstream portion of the tube from the inlet end to an intermediate portion thereof is made relatively small, and the fin pitch p_2 of a downstream portion of the tube is made relatively large ($p_1 < p_2$). This assures the upstream portion of rapid heating due to a strong agitating action while suppressing an increase in the pressure loss in the downstream portion extending to the outlet end. When it is desired to rapidly heat the fluid in the downstream portion of the tube by

vigorous agitation, the relation between the upstream portion and the downstream portion as to the fin pitch is reversed ($p_1 > p_2$).

The height h of the fins (see FIGS. 1 and 2) is suitably determined, for example, in conformity with the inside diameter D of the tube. The heat transfer efficiency can be improved by agitation while suppressing the increase in the pressure loss, by making the fins formed in different positions inside the tube, for example, in the adjacent regions, different in height h , or by giving a relatively large height h to the fins in the upstream portion (or the downstream portion) of the tube and making the fins in the downstream portion (or the upstream portion) small in height.

In order to rapidly heat up a gas fluid passed through the ethylene producing reactor tube at a high velocity, it is desired to form fins in at least three regions along the axis of the tube or over the entire length of the tube. When the reactor tube is up to about 150 mm in inside diameter D , it is suitable that the tube be about 20 to about 350 mm in pitch p , at least about 15 degrees in intersection angle θ and about 1 to about 15 mm in fin height h . In the case where fins are provided in a plurality of discrete regions along the tube axis, each of these regions

preferably has an axial length of at least about 1 m,
and the adjacent regions are spaced apart by a distance,
for example, of about 50 to about 2000 mm. In the case
where fins are formed in almost the entire region of
5 the tube and when the entire region is divided into a
a plurality of consecutive subregions which are made
different from one another, for example, in pitch p ,
each subregion may have an axial length of at least
about 1 m. The fins have a thickness t which is
10 determined within the limits of about 5 to about 10 mm,
for example, according to the inside diameter of the
tube.

Given below are examples of reactor tubes
for producing ethylene which have fins formed by a
15 helical projection with consideration given to a
balance between rapid heating and pressure loss
suppression.

- Reactor tube about 150 to 100 mm in inside diameter D
intersection angle θ : $40-85^\circ$, pitch p : 20-150 mm.
20 Reactor tube about 100 to 50 mm in inside diameter D
intersection angle θ : $25-65^\circ$, pitch p : 50-300 mm.
Reaction tube up to about 50 mm in inside diameter D
intersection angle θ : $25-45^\circ$, pitch p : 50-300 mm.

Also given below are examples having fins
25 which are annular projections (90 degrees in intersection

angle θ) in place of helical projection fins.

Reactor tube about 150 to 100 mm in inside diameter D
pitch p: 50-150 mm.

Reactor tube about 100 to 50 mm in inside diameter D
5 pitch p: 100-350 mm.

Reactor tube up to about 50 mm in inside diameter D
pitch p: 100-350 mm.

Fins are formed in these reactor tubes in various modes described above, for example, by varying
10 the pitch p or fin height h from region to region axially of the tube.

Examples

A tube (test tube A) formed with fins on the tube wall inner surface according to the invention was
15 subjected to a thermal fluid analysis under conditions simulating the operating conditions of reactor tubes for producing ethylene with the result to be described below. The arrangement of fins formed and the analysis conditions are as follows.

20 (1) Tube wall

Inside diameter D: 60 mm, length: 10 m.

(2) Arrangement of fins

Fins each comprising an annular projection were formed in almost the entire region of the tube
25 from the inlet end to the outlet end as shown in

FIG. 6 (fin height h 3 mm, thickness t 5 mm).

The fin pitch p was 100 mm in an upstream portion (over about 40% of the entire length of the tube from its inlet end) and 300 mm in a downstream portion (over about 60% of the tube length).

(3) Tube wall temperature: 1300° K

(4) Fluid inside the tube

Flow rate: 100 m/s (residence time 0.1 sec)

Temperature (inside the inlet end): 700° K

10 Coefficient of kinematic viscosity: $102.7 \text{ mm}^2/\text{s}$

Reynolds number: 48685

FIG. 7 shows the temperature distribution of the fluid inside the test tube A as determined by the fluid analysis. The temperature zone for the thermal cracking reaction for producing ethylene is a region a
15 (1093-1120 $^{\circ}$ K).

A tube having no fins (test tube B, the same as the test tube A with respect to the inside diameter D and tube length) was subjected to a fluid analysis
20 under the same conditions as above. FIG. 8 shows the temperature distribution of the fluid inside the tube determined.

FIGS. 7 and 8 reveal the following. The test tube B (FIG. 8) having no fins has a great
25 temperature gradient radially of the tube. It is after

passing through about $4/5$ of the entire length of the tube B (position x_2) that the fluid in the vicinity of the tube reaches the temperature region a required for the thermal cracking reaction. On the other hand, the finned test tube A (FIG. 7) has a very small temperature gradient radially of the tube. By the time the fluid passes through about $2/5$ of the tube length (position x_1), the fluid reaches the temperature region a needed for the thermal cracking reaction and is heated up so rapidly as to reach a temperature region i.

FIG. 9 shows the result obtained by using another tube (test tube C) having no fins like the test tube B for heating under substantially the same conditions as the test tube A. The test tube C was 38 mm in inside diameter D. FIG. 10 shows fluid temperatures at the axial portions of the test tube C and the test tube A. The test tube C having no fins on its inner surface is equivalent to the finned test tube A in heat transfer efficiency but the inside diameter ($D = 38$ mm) of the tube C is much smaller than the inside diameter ($D = 60$ mm) of the tube A. This means that as an advantage of the fins provided on the tube wall inner surface, the finned tube can be given a greatly increased inside diameter for use as a tube of large diameter unlike the tube having no

fins.

FIG. 11 shows variations in the pressure of fluid along the tube axis (pressure losses with the tube inlet end taken as a reference point) as measured for the test tube A (with fins) and the test tube C (with no fins). The test tube A is greater than the test tube C in pressure losses but is still maintained at a loss level not objectionable to the thermal cracking operation. When desired, the test tube A can be made equivalent to the test tube C with respect to pressure variations at the outlet end by slightly lowering the velocity of the fluid through the tube.

Incidentally, FIG. 11 shows that the pressure gradient of the test tube A is much smaller at the right side (downstream side) of point I than at the left side (upstream side) thereof. This change in the gradient corresponds to a difference in the fin pitch p . (The pitch p is small at the upstream side and great at the downstream side.) Thus, the difference in the fin pitch p between the upstream side of the tube and the downstream side thereof is effective for reducing the increase in pressure loss while insuring a high heat transfer efficiency by the agitating action of fins.

The ethylene producing reactor tube which is

improved in heat transfer efficiency by the provision of fins on its inner surface makes it possible to greatly increase the production capacity of the thermal cracker and to render the cracker compact in design and easy to operate and maintain. Since the fluid inside the tube can be rapidly heated to a thermal cracking temperature up to the central portion of the tube, the fluid can be fed through the tube at as high a velocity as is the case with a tube of reduced diameter, and the increased tube diameter and high-velocity feeding of the fluid result in the advantage of affording a greatly increased production capacity when the equipment remains unchanged in scale.

Furthermore, it becomes possible to greatly shorten the length of the tube without impairing the production capacity. For example, a comparison of the test tube A of FIG. 7 with the test tube B of FIG. 8 reveals that the latter requires a residence time for the fluid inside the tube to pass through about $4/5$ of the entire tube length when the fluid is to be heated to the thermal cracking temperature up to the axial portion of the tube, whereas in the latter case, a residence time corresponding to about $2/5$ of the entire tube length permits the fluid to be heated to the cracking temperature up to the axial portion.

This suggests that for use as a reactor tube for producing ethylene, the former test tube can be shortened to about one-half of the latter or shorter in length while remaining equivalent to the latter in ethylene
5 production capacity, consequently making it possible to compact the thermal cracker in design.

Further unlike conventional reactor tubes which are improved in thermal transfer efficiency by a decrease in diameter, the tube of the invention can
10 be assured of a high thermal transfer efficiency although having a relatively large diameter, so that the same production capacity can be provided by a smaller number of tubes than in the prior art. For example, the increase in diameter from the test tube
15 C (38 mm in diameter D) to the test tube A (60 mm in diameter D) reduces the number of reactor tubes to be installed in the cracker to one half or smaller.

The heat exchange tube of the present invention is prepared from a tubular body made of a
20 heat-resistant alloy (such as 25Cr-20Ni (SCH22), 25Cr-35Ni (SCH24) or Incolloy) which is selected according to the use and operating conditions by forming fins of heat-resistant alloy on the inner surface of wall of the tubular body by overlaying
25 such as powder plasma-arc welding, or inert gas arc

welding with use of a consumable or non-consumable electrode. The fins are formed as a helical projection or annular projections by rotating the tubular body about its axis and continuously or intermittently
5 moving the welding torch axially of the tubular body for the welding operation.

The heat exchange tube of the present invention achieves an exceedingly high heat transfer efficiency as the uniform agitating-mixing effect
10 produced on the fluid inside the tube by the fins on the tube wall inner surface, and is assured of this high efficiency even when having a large diameter without necessitating a reduction in the tube diameter. Accordingly when used as the reactor tube of the
15 thermal cracker for the production of ethylene, the tube gives a greatly increased capacity to the cracker because the fluid can be fed therethrough at a high velocity and because of the increased tube diameter, renders the cracker compact in design
20 when the tube has a shortened length and makes the cracker easy to operate and maintain through a reduction in the number of tubes installed in the cracker.

Additionally, the heat exchange tube of the
25 present invention is also useful, for example, as a

boiler tube for producing steam, superheater tube for
municipal refuse incinerators for generating
electricity, radiant tube for heat-treating furnaces
for steel materials, preheater tube for manufacturing
5 reduced iron, etc. Because of the high heat transfer
efficiency, the present tube makes the equipment
increased in capacity, compact in construction and
easier to operate and maintain.



What is claimed is:

1. A heat exchange tube characterized in that fins positioned in a direction intersecting the axis of the tube are formed on the inner surface of wall of the tube in one or a plurality of regions or all
5 regions arranged from an inlet end of the tube to an outlet end thereof axially of the tube, the fins having a suitable pitch.

2. A heat exchange tube as defined in claim 1 wherein the fins are formed in at least three regions arranged from the inlet end to the outlet end axially of the tube, and the pitch of the fins in an optional
5 one of the regions is different from the pitch of the fins in the region adjacent to the optional region.

3. A heat exchange tube as defined in claim 1 wherein the fins are formed in almost all regions arranged from the inlet end to the outlet end axially of the tube, and the pitch of the fins in an optional
5 one of consecutive regions included in the regions is different from the pitch of the fins in the region adjacent to the optional region.

4. A heat exchange tube as defined in claim 1 wherein the pitch of the fins in an upstream portion of the tube from the inlet end approximately to the middle of the tube is greater than the pitch of the



5 fins in a downstream portion of the tube approximately from the middle of the tube to the outlet end.

5. A heat exchange tube as defined in claim 1 wherein the pitch of the fins in an upstream portion of the tube from the inlet end approximately to the middle of the tube is smaller than the pitch of the
5 fins in a downstream portion of the tube approximately from the middle of the tube to the outlet end.

6. A heat exchange tube as defined in claim 1 wherein each of the fins is an annular projection circumferentially extending on the tube wall inner surface in a direction intersecting the tube axis
5 at right angles therewith.

7. A heat exchange tube as defined in claim 1 wherein the fins are formed by a helical projection helically extending on the tube wall inner surface axially of the tube.

8. A heat exchange tube as defined in claim 1 wherein the fins are provided in the plurality of regions or said all regions arranged from the inlet end to the outlet end axially of the tube and comprises
5 in desired combination annular projections circumferentially extending on the tube wall inner surface in a direction intersecting the tube axis at right angles therewith and a projection or projections helically



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extending on the tube wall inner surface axially of
10 the tube.

9. A heat exchange tube as defined in claim 1
wherein the tube is up to 150 mm in inside diameter,
20 to 350 mm in fin pitch, 15 to 90 degrees in the
angle of intersection of the fin with the tube axis,
5 and 1 to 15 mm in fin height.

10. A heat exchange tube as defined in claim 1
wherein each of the regions is at least 1 m in axial
length.

11. A heat exchange tube as defined in claim
1 which is a reactor tube for producing ethylene.