

Heat transfer enhancement pipe as well as cracking furnace and atmospheric and vacuum heating furnace including the same

Technical Field

5 The invention relates to the field of fluid heat transfer technology, in particular to a heat transfer enhancement pipe as well as a cracking furnace and an atmospheric and vacuum heating furnace including the same.

Background

10 The heat transfer enhancement pipe refers to a heat transfer element capable of enhancing fluid heat transfer between the interior and the outside of the pipe, that is, enabling unit heat transfer area to transfer as much heat as possible per unit time. The heat transfer enhancement pipes are used in many industries, such as thermal power generation,
15 petrochemical, food, pharmaceutical, light industry, metallurgy, navel architecture, etc. The cracking furnace is an important equipment in petrochemical industry, therefore the heat transfer enhancement pipe has been widely used in the cracking furnace.

For a heat transfer enhancement pipe, there is a flow boundary layer
20 between the fluid flow body and the pipe wall surface, and the heat transfer resistance is large. At the same time, due to the extremely low flow velocity in the boundary layer, coke is gradually deposited and adhered to the inner surface of the furnace pipe during the cracking process to form a dense coke layer, which coke layer is extremely large in
25 heat transfer resistance. Therefore, the maximum resistance of the heat transfer pipe in the radiation section of the cracking furnace is in the boundary layer region of the inner wall of the pipe.

US5605400A discloses to enhance heat transfer by providing a fin on the internal wall of the heat transfer enhancement pipe. The fin not only
30 increases surface area of the heat transfer enhancement pipe but also increases turbulent kinetic energy inside the pipe. The fin is in the form of a distorted blade. The fin is usually arranged in the interior of the heat

transfer enhancement pipe to thin the boundary layer of the fluid via rotation of the fluid itself, thereby achieving the purpose of heat transfer enhancement. Although the heat transfer enhancement pipe with fin has a relatively good heat transfer enhancement effect, cracks can often occur
5 between the fin and the pipe wall of the heat transfer enhancement pipe due to high stress at the welding site during operation, since the fin is connected with the pipe wall of the heat transfer enhancement pipe by welding. Especially in long-term operation combined with ultra-high temperature environment, it is more likely for cracks to occur between the
10 fin and the pipe wall of the heat transfer enhancement pipe, thereby shortening service life of the heat transfer enhancement pipe.

Therefore, it is necessary to reduce thermal stress of the heat transfer enhancement pipe to increase service life of the heat transfer enhancement pipe, while ensuring heat transfer effect of the heat transfer enhancement
15 pipe.

Summary of the Invention

Objects of the present invention are to overcome issues of short service life of the heat transfer enhancement pipe existing in the prior art
20 and to provide a heat transfer enhancement pipe capable of reducing its own thermal stress and thereby increasing service life of the heat transfer enhancement pipe.

In order to achieve the above objects, the present invention is intended to reduce stress at the connection of the fins with the pipe wall by
25 providing a heat insulator or a heat insulating layer at the outside of the pipe body to reduce the temperature of the pipe wall.

In one aspect, the present invention provides a heat transfer enhancement pipe including a pipe body of tubular shape with an inlet for entering of a fluid and an outlet for said fluid to flow out, internal wall of
30 the pipe body is provided with a fin protruding toward the interior of the pipe body and spirally extending in an axial direction of the pipe body, wherein at least one of a heat insulator and a heat insulating layer is

provided at the outside of the pipe body.

Preferably, a heat insulator is provided at the outside of the pipe body at least partially surrounding the external circumference of the pipe body.

Preferably, a heat insulating layer is provided on the external surface
5 of the pipe body.

On the other aspect, the present invention provides a cracking furnace or an atmospheric and vacuum heating furnace comprising a radiation chamber, in which at least one furnace pipe assembly is installed; the furnace pipe assembly comprises a plurality of furnace pipes arranged in
10 sequence and heat transfer enhancement pipe communicating adjacent furnace pipes, the heat transfer enhancement pipe is heat transfer enhancement pipe as described as above.

Brief Description of the Drawings

15 Fig.1 is a structural schematic view of the heat transfer enhancement pipe according to a preferred embodiment of the present invention, viewed from the inlet of the pipe body, wherein the fin has a rectangular cross section; the transition angle is 30° .

Fig.2 is a cross-sectional structural schematic view of the heat
20 transfer enhancement pipe shown in Fig. 1.

Fig.3 is a perspective structural schematic view of the heat transfer enhancement pipe according to another preferred embodiment of the present invention, viewed from the inlet of the pipe body, wherein the fin has a trapezoidal cross section; the transition angle is 35° .

25 Fig.4 is a cross-sectional structural schematic view of the heat transfer enhancement pipe shown in Fig. 3.

Fig.5 is an end view of the heat transfer enhancement pipe according to another preferred embodiment of the present invention.

Fig.6 is a cross-sectional structural schematic view of the heat
30 transfer enhancement pipe shown in Fig. 5.

Fig.7 is a side perspective schematic view of the heat transfer enhancement pipe according to another preferred embodiment of the

present invention, wherein the cross-section of the fin is trapezoidal-shaped viewed from aside.

Fig.8 is a side perspective schematic view of the heat transfer enhancement pipe according to another preferred embodiment of the present invention, wherein the cross-section of the fin is triangular-shaped viewed from aside.

Fig.9 is an end view of the heat transfer enhancement pipe according to another preferred embodiment of the present invention.

Fig.10 is a cross-sectional structural schematic view of the heat transfer enhancement pipe shown in Fig. 9.

Fig.11 is an end view of the heat transfer enhancement pipe according to another preferred embodiment of the present invention.

Fig.12 is a cross-sectional structural schematic view of the heat transfer enhancement pipe shown in Fig. 11.

Fig.13 is a cross-sectional structural schematic view of the heat transfer enhancement pipe according to another preferred embodiment of the present invention.

Fig.14 is a structural schematic view of a furnace pipe assembly in the cracking furnace according to a preferred embodiment of the present invention.

Fig.15 is a perspective schematic view of the heat transfer enhancement pipe according to a preferred embodiment of the present invention, wherein a heat insulator is provided at the outside of the pipe body, the fin has a trapezoidal cross section, the transition angle is 30° .

Fig.16 is a cross-sectional structural schematic view of the heat transfer enhancement pipe shown in Fig. 15.

Fig.17 is a perspective schematic view of the heat transfer enhancement pipe according to another preferred embodiment of the present invention, wherein a heat insulator is provided at the outside of the pipe body, the fin has a trapezoidal cross section, the transition angle is 35° .

Fig.18 is a cross-sectional structural schematic view of the heat

transfer enhancement pipe shown in Fig. 17.

Fig.19 is a perspective schematic view of a heat transfer enhancement pipe according to another preferred embodiment of the present invention, wherein a heat insulator is provided at the outside of the pipe body, the fin
5 has a trapezoidal cross section, the transition angle is 40° .

Fig.20 is a cross-sectional structural schematic view of the heat transfer enhancement pipe shown in Fig. 19.

Fig.21 is a perspective schematic view of a heat transfer enhancement pipe according to another preferred embodiment of the present invention,
10 wherein the connecting part supported between the pipe body and the heat insulator is the second connecting part.

Fig.22 is a perspective schematic view from another angle of the heat transfer enhancement pipe shown in Fig. 21.

Fig.23 is a perspective schematic view of the heat transfer
15 enhancement pipe according to another preferred embodiment of the present invention, wherein a heat insulator is provided at the outside of the pipe body, the fin has a trapezoidal cross section, the number of intervals arranged at the fin is 1, the transition angle is 35° .

Fig.24 is a cross-sectional structural schematic view of the heat
20 transfer enhancement pipe shown in Fig. 23.

Fig.25 is a perspective schematic view of the heat transfer enhancement pipe according to another preferred embodiment of the present invention, wherein a heat insulator is provided at the outside of the pipe body, the fin has a trapezoidal cross section, the transition angle is
25 35° , and the top surface of the fin facing the central axis of the pipe body is formed as the third transition surface of concave shape.

Fig.26 is a cross-sectional structural schematic view of the heat transfer enhancement pipe shown in Fig. 25.

Fig.27 is a cross-sectional structural schematic view of the heat
30 transfer enhancement pipe according to a preferred embodiment of the present invention, wherein a heat insulating layer is provided on the external surface of the pipe body, the fin has a trapezoidal cross section,

the number of intervals arranged at the fin is 1, the transition angle is 35°.

Fig.28 is a local structural schematic view of the heat transfer enhancement pipe shown in Fig. 27, wherein a heat insulating layer is provided on the external surface of the pipe body, which includes a metal alloy layer, an oxide layer, and a ceramic layer sequentially stacked at the external surface of the pipe body.

Description of the Reference Numbers

1- heat transfer enhancement pipe; 10- pipe body; 100- inlet; 101- outlet; 11- fin; 110- first end surface; 111- top surface; 112- side wall face; 113- smooth transition fillet; 114- through hole; 115- second end surface; 120- side wall; 12-interval; 13 -hole; 14- heat insulator; 140- straight pipe section; 141- first tapered pipe section; 142- second tapered pipe section; 15- gap; 160- first connecting piece; 161- second connecting piece; 162 - connecting rod; 17 - heat insulating layer; 170- metal alloy layer; 171- ceramic layer; 172- oxide layer; 2-furnace pipe.

Detailed Description of Embodiments

In the present invention, without indicated on the contrary, words such as “up”, “down”, “left”, and “right” used herein to define orientations generally refer to and are understood as orientations in association with the drawings and orientations in actual application; “interior” and “external” is relative to the axis of the heat transfer enhancement pipe.

In addition, the height of the fin refers to the height or distance between the top surface of the fin facing the central axis of the pipe body and the internal wall of the pipe body. The axial length of the fin refers to the length or distance of the fin along the central axis in the side view.

The present invention proposes to provide a heat transfer enhancement pipe in a furnace pipe assembly to enhance heat transfer, thereby reducing or preventing formation of coke layer. As shown in Fig.14, a plurality of furnace pipe assembly are provided in a radiation chamber of a cracking furnace, each furnace pipe assembly is provided with heat transfer enhancement pipes 1. In each furnace pipe assembly,

two heat transfer enhancement pipes 1 disposed at intervals along the axial direction of the furnace pipe 2. Each heat transfer enhancement pipe 1 has an internal diameter of 65 mm. In each furnace pipe assembly, the axial length of the furnace pipe 2 between two adjacent heat transfer enhancement pipes 1 is 50 times the internal diameter of the heat transfer enhancement pipe 1. It is to be understood that, the number and interval of the heat transfer enhancement pipes 1 may vary depending on particular applications, without departing from the scope of the present invention.

As shown in Figures 1-8, the heat transfer enhancement pipe 1 includes a pipe body 10 of tubular shape having an inlet 100 for entering of a fluid and an outlet 101 for said fluid to flow out. The internal wall of the pipe body 10 is provided with fin 11 protruding towards the interior of the pipe body 10 and spirally extending in an axial direction of the pipe body.

The fins 11 may extend continuously or in sections. When the fins 11 extend in sections, the fins 11 include a plurality of the fin sections divided by intervals 12. Similarly, when the fins 11 extend continuously, the fins 11 may be considered to include a single fin section. Therefore, the fins 11 have one or more fin sections extending spirally in the axial direction of the pipe body 10. It is to be understood that the length of each fin section may be the same or different. In addition, each fin section includes a first end surface facing the inlet 100 and a second end surface facing the outlet 101. At least one of the first end surface and the second end surface of at least one of the fin sections is formed as a transition surface along a spirally extending direction. In order to facilitate the distinction, in the present application, the first end surface 110 closest to the inlet 100 is referred to as the first transition surface; the second end surface 115 closest to the outlet 101 is referred to as the second transition surface; the first end surface and the second end surface defined by the side walls 120 of the intervals 12 are referred to as the fourth transition surface. When the first end surface and/or the second end surface of the plurality of the fin sections are transition surfaces, the transition surfaces

formed by the first end surface and/or the second end surface of each fin section may be the same or different .

In addition, it should be noted that the transition surface may be a curved face or a flat face. The curved face may be convex or concave.

5 Preferably, the curved face is concave to further improve the heat transfer effect of the heat transfer enhancement pipe and to further reduce the thermal stress of the heat transfer enhancement pipe. In addition, the transition surface can also reduce the impact force of the fluid on the fins. "Transition angle" refers to the angle between the transition surface or the
10 tangent plane of the transition surface (when the transition surface is a curved face) and the tangent plane of the pipe wall at the connection position. The transition angle extends at an angle greater than or equal to 0° and less than 90° .

According to one example, the outside of the pipe body 10 is
15 provided with a heat insulator 14 at least partially surrounding the external circumference of the pipe body 10. By providing the outside of the pipe body 10 with heat insulator 14 at least partially surrounding the external circumference of the pipe body 10, heat transfer between high-temperature gas and the external wall of the pipe body 10 is impeded to reduce
20 temperature of the external wall of the pipe body 10, thereby reducing temperature difference between the pipe body 10 and the fin 11, so as to effectively reduce thermal stress of the heat transfer enhancement pipe 1, extend service life of the heat transfer enhancement pipe 1, and correspondingly increase the allowable temperature of the heat transfer
25 enhancement pipe 1. When applying the aforementioned heat transfer enhancement pipe 1 to a cracking furnace, long-term stable operation of the cracking furnace can be ensured. Since the fins 11 are arranged in the interior of the pipe body 10, the fluid entering into pipe body 10 can turn into a swirling flow; due to its tangential velocity, the fluid can destroy the
30 boundary layer and reduces the rate of coking. It is to be understood that the heat insulator 14 can completely surround the external circumference of the pipe body 10 at the circumference of the pipe body 10, i.e. at 360°

around the external circumference of the pipe body 10; the heat insulator 14 can also partially surround the external circumference of the pipe body 10 at the circumference of the pipe body 10, e.g. at 90° around the external circumference of the pipe body 10; of course, the heat insulator 14 can
5 surround the external circumference of the pipe body 10 with a suitable angle according to actual needs; it should be noted that, when applying the aforementioned heat transfer enhancement pipe 1 to a cracking furnace and providing the heat insulator 14 that partially surrounds the external circumference of the pipe body 10 at the outside of the pipe body 10, it is
10 preferable to provide the heat insulator 14 at a heated surface of the pipe body 10. In addition, the heat insulator 14 can preferably be arranged at the outside of the pipe body 10 that is provided with the fins, so that the fins are not easily cracked away from pipe body 10, and service life of the heat transfer enhancement pipe 1 can be increased.

15 As shown in Figures 15-26, heat insulator 14 can be tubular and is preferably sleeved on the outside of the pipe body 10, so as to further reduce temperature of the pipe wall of the pipe body 10, thereby further reducing heat stress of the heat transfer enhancement pipe 1. As for the shape and structure of the heat insulator 14, they are not specifically
20 limited: as shown in Fig. 15, heat insulator 14 can be cylindrical; or as shown in Fig. 17, heat insulator 14 can be elliptical.

In addition, as shown in Fig. 19 and Fig. 20, heat insulator 14 can abut on the external surface of the pipe body 10; as shown in Fig. 22 and Fig. 23, heat insulator 14 can also be sleeved on the outside of the pipe
25 body 10; and gap 15 can be left between heat insulator 14 and the external wall of the pipe body 10. By leaving gap 15 between heat insulator 14 and the external wall of the pipe body 10, temperature of the pipe wall of the pipe body 10 in use is further reduced, thereby further reducing thermal stress of the heat transfer enhancement pipe 1.

30 In order to further improve structural stability of the heat transfer enhancement pipe 1, a connector that connects heat insulator 14 and pipe body 10 can be arranged there-between, wherein the structural form of the

connector is not specifically limited as long as it can connect heat insulator 14 with pipe body 10. As shown in Fig. 23, the connector can include a first connecting piece 160 that can extend in an axial direction parallel to pipe body 10; as shown in Fig. 21, the connector can include a second
5 connecting piece 161 that can extend spirally along the external wall of the pipe body 10; as shown in Fig. 15 and Fig. 17, the connector can include a connecting rod 162 with both ends thereof connectable to the external wall of the pipe body 10 and the internal wall of the heat insulator 14, respectively. It is also to be understood that any two or more of the
10 connectors of the above three structures can be optionally arranged between heat insulator 14 and pipe body 10. Preferably, the connector is prepared and obtained from hard materials such as 35Cr45Ni or from soft materials such as ceramic fiber.

As shown in Figures 15, 16, and 18, heat insulator 14 can include a
15 straight pipe section 140, and a first tapered pipe section 141 and a second tapered pipe section 142 that are connected to the first end and the second end of straight pipe section 140, respectively, wherein the first tapered pipe section 141 is tapered in a direction from close to the first end to away from the first end; the second tapered pipe section 142 is tapered in a
20 direction from close to the second end to away from the second end. Heat insulator 14 is arranged as the above structure, so that not only temperature of the pipe wall of the pipe body 10 is effectively decreased, but also temperature variation in the axial direction of the pipe body 10 is relatively uniform, while thermal stress of the heat transfer enhancement pipe 1 is
25 also reduced.

Further, the angle formed between the horizontal surface and the external wall surface of the first tapered pipe section 141 is preferably 10-80°; specifically, the angle formed between the horizontal surface and the external wall surface of the first tapered pipe section 141 can be 20°,
30 30°, 40°, 50°, 60°, or 70°. The angle formed between the horizontal surface and the external wall surface of the second tapered pipe section 142 is preferably 10-80°; similarly, the angle formed between the

horizontal surface and the external wall surface of the second tapered pipe section 142 can be 20°, 30°, 40°, 50°, 60°, or 70°.

Further, the extension length of the heat insulator 14 in the axial direction of the pipe body 10 is preferably 1-2 times the length of the pipe body 10. Setting the axial length of the heat insulator 14 within the above range can further decrease temperature of the pipe wall of the pipe body 10 in use and further reduces thermal stress of the pipe body 10.

In addition, the first end surface 110 of the fin 11 closest to the inlet 100 is formed as the first transition surface in a spirally extending direction. By providing on the internal wall of the pipe body 10 with fin 11 protruding towards the interior of the pipe body 10 and by forming the first end surface 110 of the fin 11 closest to the inlet 100 as the first transition surface in a spirally extending direction, it thereby enables the heat transfer enhancement pipe to have a good heat transfer effect, while thermal stress of the heat transfer enhancement pipe 1 can be reduced, e.g., maximum thermal stress reduction of the heat transfer enhancement pipe 1 can generally be over 50% (as shown in the tables below) and the ability to resist local over-temperature of the heat transfer enhancement pipe 1 is correspondingly improved, so as to increase service life of the heat transfer enhancement pipe; furthermore, the first end surface 110 forming as the first transition surface has a relatively strong turbulent effect on the fluid in pipe body 10 and reduces coking phenomenon.

The aforementioned heat transfer enhancement pipe 1 is suitable for heating furnaces and also for cracking furnaces. The aforementioned heat transfer enhancement pipe 1 can be installed in cracking furnaces such as ethylene cracking furnaces, so that the fluid in transit can enter into pipe body 10 of the heat transfer enhancement pipe 1 through inlet 100; afterwards, under the influence of the fin 11, the fluid becomes a swirling flow; due to its tangential velocity, the fluid can destroy the boundary layer, reduces the rate of coking, and extends service cycle of the cracking furnaces; meanwhile, since the first end surface 110 of the fin 11 closest to the inlet 100 is formed as the first transition surface in a spirally extending

direction, thermal stress of the heat transfer enhancement pipe 1 is thereby reduced and service life of the heat transfer enhancement pipe 1 extended. Wherein Fig. 4 clearly shows the first transition surface forming in the spirally extending direction; that is to say, the first end surface 110 is sloped in the spirally extending direction. Additionally, it should be noted that the fluid in the heat transfer enhancement pipe 1 is not specifically limited and can be selected according to actual application environment of the heat transfer enhancement pipe 1.

In addition, the first transition surface can be formed as a first curved face. The first curved face can be either convex or concave shape; preferably, the first curved face is of concave shape so as to further improve heat transfer effect of the heat transfer enhancement pipe 1 and further reduce thermal stress of the heat transfer enhancement pipe 1. Specifically, the first curved face can be a partial paraboloid taken from a paraboloid. In addition, the transition angle of the first transition surface can be greater than or equal to 0° and less than 90° , so as to further reduce thermal stress of the heat transfer enhancement pipe 1 and greatly increase service life of the heat transfer enhancement pipe 1. The transition angle of the first transition surface can be 10° , 15° , 20° , 25° , 30° , 35° , 38° , 40° , 45° , 50° , 55° , 60° , 65° , 70° , 75° , 80° , or 85° .

In order to further reduce thermal stress of the heat transfer enhancement pipe 1, the second end surface of the fin 11 closest to the outlet 101 can be formed as the second transition surface in a spirally extending direction; wherein the second end surface 110 is sloped in the spirally extending direction, so as to correspondingly increase service life of the heat transfer enhancement pipe. In addition, the second transition surface can be formed as a second curved face. The second curved face can be either convex or concave shape; preferably, the second curved face can be of concave shape. In addition, the transition angle of the second transition surface can be greater than or equal to 0° and less than 90° , so as to further reduce thermal stress of the heat transfer enhancement pipe 1 and greatly increase service life of the heat transfer enhancement pipe 1.

The transition angle of the second transition surface can be 10° , 15° , 20° , 25° , 30° , 35° , 38° , 40° , 45° , 50° , 55° , 60° , 65° , 70° , 75° , 80° , or 85° .

As shown in Fig. 12, the top surface 111 of the fin 11 facing the central axis of pipe body 10 can be formed as the third transition surface, so as to reduce thermal stress of the heat transfer enhancement pipe 1 without affecting heat transfer effect of the heat transfer enhancement pipe 1. It is further preferred for the third transition surface to be concave. Specifically, the third transition surface takes form of a paraboloid.

Preferably, two opposite side wall faces 112 of the fin 11 gradually approach to each other in a direction from the internal wall of pipe body 10 to the center of pipe body 10; that is to say, each of the side wall faces 112 can be inclined, so as to enable fin 11 to enhance disturbance to the fluid entering into pipe body 10 and improve heat transfer effect, while further reducing thermal stress of the heat transfer enhancement pipe 1. It is also understood that the cross section of the fin 11, which is the cross section taken from a plane parallel to a radial direction of pipe body 10, can substantially be trapezoidal or trapezoidal-like. Of course, the cross section of the fin 11 can substantially be rectangular.

In order to reduce thermal stress of the heat transfer enhancement pipe 1, a smooth transition fillet 113 can be formed at the connection of at least one of two opposite side wall faces 112 of the fin 11 with the internal wall of pipe body 10. Further, the radius of smooth transition fillet 113 is greater than 0 and less than or equal to 10 mm. Setting the radius of smooth transition fillet 113 within the above range can further reduce thermal stress of the heat transfer enhancement pipe 1 and increase service life of the heat transfer enhancement pipe 1. Specifically, the radius of smooth transition fillet 113 can be 5 mm, 6 mm, or 10 mm.

In addition, the angle formed by each of the side wall faces 112 and the internal wall of pipe body 10 at the connection with each other can be 5° to 90° ; that is to say, the angle between the tangential planes of each of the side wall faces 112 and the internal wall of pipe body 10 at the connection with each other can be 5° to 90° ; setting the angle within the

above range can further reduce thermal stress of the heat transfer enhancement pipe 1 and increase service life of the heat transfer enhancement pipe 1. The angle formed by each of the side wall faces 112 and the internal wall of pipe body 10 at the connection with each other can
5 be 20°, 30°, 40°, 45°, 50°, 60°, 70°, or 80°.

In order to reduce thermal stress of the heat transfer enhancement pipe 1, the height of the fin 11 is preferably greater than 0 and less than or equal to 150mm; for example, the height of the fin 11 can be 10 mm, 20 mm, 30 mm, 40 mm, 50 mm, 60 mm, 70 mm, 80 mm, 90 mm, 100 mm,
10 110 mm, 120 mm, 130 mm, or 140 mm.

The heat transfer enhancement pipe 1 includes a pipe body 10 of tubular shape having an inlet 100 for entering of a fluid and an outlet 101 for said fluid to flow out. The internal wall of pipe body 10 is provided with fin 11 protruding towards the interior of pipe body 10 and spirally
15 extending in an axial direction of the pipe body, wherein a height of the fin 11 gradually increases from one end in at least a part extension of the fin. In the example shown in Fig.8, the height of the fin 11 gradually increases in an extending direction from the inlet 100 to the outlet 101; however, it is to be understood that, the height of the fin 11 may also gradually
20 increases in an extending direction from the outlet 101 to the inlet 100. In addition, the height of the fin 11 may also gradually increases in a direction from both ends to the middle. By providing on the internal wall of pipe body 10 with fin 11 protruding towards the interior of pipe body 10 and by causing the height of the fin 11 to gradually increase in the
25 extending direction from the inlet 100 to the outlet 101, it thereby enables the heat transfer enhancement pipe to have a good heat transfer effect, while thermal stress of the heat transfer enhancement pipe 1 can be reduced and the ability to resist local over-temperature of the heat transfer enhancement pipe 1 is correspondingly improved, so as to increase service
30 life of the heat transfer enhancement pipe; furthermore, the height of the fin 11 gradually increasing in the extending direction from the inlet 100 to the outlet 101 has a relatively strong turbulent effect on the fluid in pipe

body 10 and reduces coking phenomenon.

In order to further reduce thermal stress of the heat transfer enhancement pipe 1, a ratio of the height of the highest part of the fin 11 to the height of the lowest part of the fin 11 is 1.1-1.6:1. For example, the
5 ratio of the height of the highest part of the fin 11 to the height of the lowest part of the fin 11 is 1.2:1, 1.3:1, 1.4:1 or 1.5:1.

Effects of the present invention will be further illustrated through examples and comparative Examples in the following.

Example 11

10 A plurality of furnace pipe assemblies are arranged in a radiation chamber of a cracking furnace. The heat transfer enhancement pipes 1 are arranged in three of the furnace pipe assemblies. Two heat transfer enhancement pipes 1 are arranged in each furnace pipe assembly at intervals along axial direction of the furnace pipe 2. Each heat transfer
15 enhancement pipe 1 has an internal diameter of 65 mm. In each furnace pipe assembly, the axial length of the furnace pipe 2 between two adjacent heat transfer enhancement pipes 1 is 50 times the internal diameter of the heat transfer enhancement pipe 1. The structure of each of the heat transfer enhancement pipes 1 is as follow: heat insulator 14 of cylindrical shape is
20 arranged on the outside of the pipe body 10; heat insulator 14 completely surrounds the external circumference of the pipe body 10 and leaves gap 15 with the external wall of the pipe body; heat insulator 14 is connected with pipe body 10 through connecting rod 162; two fins 11 are arranged on the internal wall of the pipe body 10 with their two ends respectively
25 formed as the first transition surface and the second transition surface of concave shapes in a spirally extending direction as shown in Fig. 4; the transition angle of the first transition surface is 30°; the transition angle of the second transition surface is 30°; the cross section of each fin 11, i.e. the cross section taken from a surface in the radial direction parallel to
30 pipe body 10, is substantially trapezoidal; the angle formed by each side wall face 112 and the internal wall of the pipe body 10 is 45°; each side wall face 112 and the internal wall of the pipe body 10 form a smooth

transition fillet; as viewed from the direction of inlet 100, two fins 11 take shapes of clockwise spirals; two fins 11 are enclosed at the center of the pipe body 10 to form hole 13 extending in the axial direction of the pipe body 10; the ratio of the diameter of hole 13 to the internal diameter of the pipe body 10 is 0.6; the rotation angle of each of the fins 11 is 180°; the distortion ratio of each of the fins 11 is 2.5, wherein the outlet temperature of the cracking furnace is 820-830°.

Example 12

Example 12 is the same as Example 11 except that: heat insulator 14 is elliptical; the transition angle of the first transition surface is 35°; the transition angle of the second transition surface is 35°. Other conditions remain unchanged.

Example 13

Example 13 is the same as Example 11 except that: heat insulator 14 is attached to the external wall of the pipe body 10; the transition angle of the first transition surface is 40°; the transition angle of the second transition surface is 40°. Other conditions remain unchanged.

Comparative Example 11

A heat transfer enhancement pipe of the prior art is arranged, wherein the outside of the pipe body is not provided with a heat insulator; the interior of the pipe body is provided with only one fin 11 that extends spirally in the axial direction of the pipe body and separates the interior of the pipe body into two mutually non-communicating chambers, with the remaining conditions unchanged.

Respective test results of the cracking furnaces in the examples and the comparative Example after operating under same conditions are shown in Table 1 below.

Table 1

Test items No.	Heat transfer load/W	Pressure drop/MPa	Maximum thermal stress/MPa	Service life/year
Example 11	94620	0.10835	40	6-7
Example 12	94620	0.10835	30	7-8
Example 13	95650	0.10835	30	7-8
Comparative Example 11	89889	0.12085	110	4-5

It can be known from the above that providing the heat transfer enhancement pipe provided by the invention in the cracking furnace increases heat transfer load, significantly increases heat transfer efficiency, and significantly reduces pressure drop, while reducing maximum thermal stress of the heat transfer enhancement pipe and significantly increasing service life of the heat transfer enhancement pipe.

According to another example of the present invention, a heat insulating layer 17 is provided on the external surface of the pipe body 10. By providing the heat insulating layer 17 on the external surface of the pipe body 10, heat transfer between high-temperature gas and the pipe wall of the pipe body 10 is impeded to reduce temperature of the pipe wall of the pipe body 10, thereby reducing temperature difference between the pipe body 10 and the fin 11, so as to effectively reduce thermal stress of the heat transfer enhancement pipe 1, extend service life of the heat transfer enhancement pipe 1. It also improves high temperature resistance performance, thermal shock performance, and high-temperature corrosion resistance performance of the heat transfer enhancement pipe 1 because of the arrangement of the heat insulating layer 17. When applying the aforementioned heat transfer enhancement pipe 1 to a cracking furnace, long-term stable operation of the cracking furnace can be ensured. Since the fins are arranged in pipe body 10, the fluid entering into pipe body 10 can turn into a swirling flow; due to its tangential velocity, the fluid can

destroy the boundary layer and reduces the rate of coking. In addition, heat insulating layer 17 can preferably be arranged at the outside of the pipe body 10 that is provided with the fins, so that the fins are not easily cracked away from pipe body 10, and thermal stress of the heat transfer enhancement pipe 1 can be reduced.

Preferably, heat insulating layer 17 can include a metal alloy layer 170 arranged on the external surface of the pipe body 10 and a ceramic layer 171 arranged on the metal alloy layer 170. Through providing metal alloy layer 170 on the external surface of the pipe body 10 and ceramic layer 171 on the metal alloy layer 170, the heat insulating effect of the heat insulating layer 17 can be improved to further decrease thermal stress of the heat transfer enhancement pipe 1.

It is to be understood that metal alloy layer 170 can be prepared and formed by metal alloy materials including M, Cr, Al, and Y, wherein M is selected from one or more of Fe, Ni, Co, and Al; when M is selected from two or more metals therein, such as Ni and Co, metal alloy layer 170 can be prepared and formed by metal alloy materials including Ni, Co, Cr, Al, and Y; when metal alloy layer 170 contains Ni and Co, heat insulating ability of the heat insulating layer 17 can be further improved, and oxidation resistance and hot corrosion resistance of the heat insulating layer 17 are improved. As for the content of each metal in the metal alloy materials, it can be configured according to actual needs with no particular requirement. For example, the weight fraction of Al can be 5-12%, and the weight fraction of Y can be 0.5-0.8%, so that the robustness of the heat insulating layer 17 can be improved, while reducing oxidation rate of metal alloy layer 170; the weight fraction of Cr can be 25-35%. In addition, it should also be noted that the metal alloy materials can be sprayed on the external surface of the pipe body 10 to form metal alloy layer 170 by employing low pressure plasma, atmospheric plasma, or electron-beam physical vapor deposition. Thickness of metal alloy layer 170 can be 50 to 100 μm ; specifically, thickness of metal alloy layer 170 can be 60 μm , 70 μm , 80 μm , or 90 μm .

In order to further improve oxidation resistance of the heat insulating layer 17 and extend service life of the heat insulating layer 17, additive materials can be added to the metal alloy materials for preparing metal alloy layer 170, that is, metal alloy layer 170 can be prepared and formed after mixing the metal alloy materials with the additive materials, wherein the metal alloy materials include M, Cr, Al, and Y, wherein M is selected from one or more of Fe, Ni, Co, and Al; the additive materials are selected from Si, Ti, Co, or Al_2O_3 ; as for the amount of addition of the additive materials, it can be added according to actual needs with no particular limitations, wherein the metal alloy materials have already been described in the above, and will not be described in details herein again.

In addition, ceramic layer 171 can be prepared and formed by one or more materials from yttria-stabilized zirconia, magnesia-stabilized zirconia, calcia-stabilized zirconia, and ceria-stabilized zirconia. When ceramic layer 171 is formed by two or more materials from the above, any two or more of the above materials can be mixed and then form into ceramic layer 171 after mixing. Specifically, when selecting yttria-stabilized zirconia as the material for ceramic layer 171, ceramic layer 171 can have a relatively high thermal expansion system, for example, it can reach up to $11 \times 10^{-6} \text{ K}^{-1}$; ceramic layer 171 can also have a relatively low thermal conductivity coefficient of $2.0\text{-}2.1 \text{ Wm}^{-1}\text{K}^{-1}$; while ceramic layer 171 also has good thermal shock resistance. It should also be noted that when selecting yttria-stabilized zirconia as ceramic layer 171, the weight fraction of yttrium oxide is 6-8%. In order to further improve heat insulating performance of the heat insulating layer 17, cerium oxide can also be added to the above materials forming ceramic layer 171; specifically, the amount of addition of cerium oxide can be 20-30% of the total weight of yttria-stabilized zirconia; further, the amount of addition of cerium oxide can be 25% of the total weight of yttria-stabilized zirconia. Similarly, one or more materials of yttria-stabilized zirconia, magnesia-stabilized zirconia, calcia-stabilized zirconia, and ceria-stabilized zirconia can be sprayed onto the external surface of metal alloy surface 170 to form ceramic layer 171

by employing methods of low pressure plasma, atmospheric plasma, or electron-beam physical vapor deposition. In addition, the thickness of ceramic layer 171 can be 200-300 μm ; for example, the thickness of ceramic layer 171 can be 210 μm , 220 μm , 230 μm , 240 μm , 250 μm , 260 μm , 270 μm , 280 μm , or 290 μm . It should be noted that when the heat transfer enhancement pipe 1 is in use, the Al in metal alloy layer 170 reacts with the oxygen in ceramic layer 171 to form a thin and dense aluminum-oxide protective film, thereby protecting pipe body 10.

In order to improve peeling resistance of the heat insulating layer 17, an oxide layer 172 can be arranged between metal alloy layer 170 and ceramic layer 171, wherein oxide layer 172 is preferably prepared and formed by alumina, silica, titania, or a mixture of any two or more materials from alumina, silica, and titania. Preferably, alumina is selected for preparing and forming oxide layer 172 to improve heat insulating performance of the heat insulating layer 17. Similarly, the above oxide materials can be sprayed onto the surface of metal alloy layer 170 to form oxide layer 172 by employing methods of low pressure plasma, atmospheric plasma, or electron-beam physical vapor deposition. In addition, the thickness of oxide layer 172 can be 3-5 μm ; for example, the thickness of oxide layer 172 can be 4 μm .

Additionally, the porosity of the heat insulating layer 17 can be 8 to 15%.

In order to effectively reduce temperature of the pipe wall of the pipe body 10 and to make temperature variation in the axial direction of the pipe body 10 relatively uniform while also to reduce thermal stress of the heat transfer enhancement pipe 1, heat insulation layer 17 can include a straight section, and a first tapered section and a second tapered section that are connected to the first end and the second end of the straight section, respectively, wherein the first tapered section is tapered in a direction from close to the first end to away from the first end; the second tapered section is tapered in a direction from close to the second end to away from the second end. It is to be understood that the thickness of the

heat insulating layer 17 is thinner near the ends; the thickness of the heat insulating layer 17 can gradually decrease by a value of 5-10%. In order to further reduce thermal stress of the heat transfer enhancement pipe 1, heat insulating layer 17 is thicker at positions corresponding to the fins.

5 In addition, all of the features of the fin 11 of the examples with regard to the heat insulator 14 are suitable for the examples with regard to the heat insulating layer 17.

Effects of the present invention will be further illustrated through Examples and comparative Examples in the following.

10 Example 21

Example 21 is the same as Example 11, except that: the heat insulator 14 is replaced with the heat insulating layer 17, the heat insulating layer 17 includes a 70 μm thick metal alloy layer 170, a 4 μm thick oxide layer 172, and a 240 μm thick ceramic layer 171 sequentially arranged at the external
15 surface of the pipe body 10; wherein the metal alloy layer 170 is spray-formed from metal alloy materials having weight fraction of 64.5% Ni, 30% Cr, 5% Al, and 0.5% Y via atmospheric plasma spray method; the oxide layer 172 is formed by spraying aluminum oxide to the surface of metal alloy layer 170 by a selected method of low pressure plasma spray;
20 the ceramic layer 171 is formed by spraying yttria-stabilized zirconia mixed with cerium oxide of 25% weight fraction of the yttria-stabilized zirconia; in the yttria-stabilized zirconia, the weight fraction of cerium oxide is 6%.

Example 22

25 Example 22 is the same as Example 21, except that: in heat insulating layer 17, metal alloy layer 170 is prepared and formed by metal alloy materials having weight fraction of 64.2% Ni, 30% Cr, 5% Al, and 0.8% Y, respectively; ceramic layer 171 is formed by yttria-stabilized zirconia; in the yttria-stabilized zirconia, the weight fraction of yttrium oxide is 8%.
30 Other conditions remain unchanged.

Comparative Example 21

Comparative Example 21 is the same as Comparative Example 11, i.e.:

the heat transfer enhancement pipe of the prior art is arranged (the external surface of the pipe body is not provided with heat insulating layer), wherein the outside of the pipe body is not provided with heat insulating layer; the interior of the pipe body is provided with only one fin that
 5 extends spirally in the axial direction of the pipe body and separates the interior of the pipe body into two mutually non-communicating chambers, with the remaining conditions unchanged.

Respective test results of the cracking furnaces in the Examples and the comparative Example after operating under same conditions are shown
 10 in Table 2 below.

Table 2

Test items No.	Heat transfer load/W	Pressure drop/MPa	Temperature difference between the fin and the pipe wall of the pipe body/°C	Maximum thermal stress/MPa	Service life/year
Example 21	94700	0.10780	20-25	40	6-7
Example 22	94620	0.10820	20-25	40	6-7
Comparative Example 21	88080	0.12090	35-40	110	4-5

It can be known from the above that providing the heat transfer enhancement pipe provided by the invention in the cracking furnace
 15 increases heat transfer load, significantly increases heat transfer efficiency, and significantly reduces pressure drop, while reducing maximum thermal stress of the heat transfer enhancement pipe and significantly increasing service life of the heat transfer enhancement pipe.

Preferred embodiments of the present invention have been described
 20 in detail above in association with the drawings; however, the present invention is not limited thereto. Various simple alterations of the technology of the present invention including combinations of each

specific technological feature in any suitable ways can be made in the scope of the technology contemplated in the present invention. To avoid unnecessary repetitions, the present invention will not illustrate further on various possible combinations. However, these simple alterations and
5 combinations should be regarded as contents disclosed by the present invention and fall into the scope protected by the present invention.

CLAIMS

1. A heat transfer enhancement pipe (1) comprising a pipe body (10) of tubular shape having an inlet (100) for entering of a fluid and an outlet (101) for said fluid to flow out; internal wall of the pipe body (10) is provided with a fin (11) protruding towards interior of the pipe body (10), the fin (11) spirally extends in an axial direction of the pipe body (10), wherein at least one of a heat insulator (14) and a heat insulating layer (17) is provided at outside of the pipe body (10).

2. The heat transfer enhancement pipe according to claim 1, characterized in that a heat insulator (14) at least partially surrounding the external circumference of the pipe body (10) is provided at the outside of the pipe body (10).

3. The heat transfer enhancement pipe according to claim 2, characterized in that the heat insulator (14) has a tubular shape, the heat insulator (14) is sleeved on the outside of the pipe body (10).

4. The heat transfer enhancement pipe according to claim 3, characterized in that a gap (15) is left between the heat insulator (14) and external wall of the pipe body (10).

5. The heat transfer enhancement pipe according to claim 4, characterized in that a connector for connecting the heat insulator (14) and the pipe body (10) are arranged between the heat insulator (14) and the pipe body (10).

6. The heat transfer enhancement pipe according to claim 5, characterized in that the connector is selected from one or more of the following three structures: the connector includes a first connecting piece (160) that extends in an axial direction parallel to the pipe body (10); the connector includes a second connecting piece (161) that extends spirally along the external wall of the pipe body (10); the connector includes a connecting rod (162) with its two ends respectively connected to the external wall of the pipe body (10) and the internal wall of the heat insulator (14).

7. The heat transfer enhancement pipe according to claim 2, characterized in that the heat insulator (14) comprises a straight pipe section (140), and a first tapered pipe section (141) and a second tapered pipe section (142) respectively connected to the first end and second end of the straight pipe section (140), wherein the first tapered pipe section (141) is tapered in a direction from close to the first end to away from the first end; the second tapered pipe section (142) is tapered in a direction from close to the second end to away from the second end.

8. The heat transfer enhancement pipe according to claim 1, characterized in that a heat insulating layer (17) is provided on the external surface of the pipe body (10).

9. The heat transfer enhancement pipe according to claim 8, characterized in that the heat insulating layer (17) comprises a metal alloy layer (170) arranged on the external surface of the pipe body (10) and a ceramic layer (171) located on the metal alloy layer (170).

10. The heat transfer enhancement pipe according to claim 9, characterized in that the heat insulating layer (17) comprises an oxide layer (172) arranged between the metal alloy layer (170) and the ceramic layer (171).

11. The heat transfer enhancement pipe according to claim 10, characterized in that the thickness of the oxide layer (172) is 3-5 μm ; and/or the oxide layer (172) is prepared and formed by alumina, silica, titania, or a mixture of any two or more materials from alumina, silica, and titania.

12. The heat transfer enhancement pipe according to claim 9, characterized in that the thickness of the metal alloy layer (170) is 50-100 μm ; and/or the metal alloy layer (170) is prepared and formed by metal alloy materials including M, Cr, Al, and Y, wherein M is selected from one or more of Fe, Ni, Co, and Al.

13. The heat transfer enhancement pipe according to claim 12, characterized in that the metal alloy layer (170) further comprises additive materials selected from Si, Ti, Co, or Al_2O_3 .

14. The heat transfer enhancement pipe according to claim 9, characterized in that the thickness of the ceramic layer (171) is 200 to 300 μm ; and/or the ceramic layer (171) is prepared and formed by one or more materials of yttria-stabilized zirconia, magnesia-stabilized zirconia, 5 calcia-stabilized zirconia, and ceria-stabilized zirconia.

15. The heat transfer enhancement pipe according to claim 8, characterized in that the heat insulating layer (17) comprises a straight section, and a first tapered section and a second tapered section respectively connected to the first end and second end of the straight 10 section, wherein the first tapered section is tapered in a direction from close to the first end to away from the first end; the second tapered section is tapered in a direction from close to the second end to away from the second end.

16. The heat transfer enhancement pipe according to claim 1, 15 characterized in that a height of the fin (11) gradually increases from one end in at least a part spiral extension of the fin.

17. The heat transfer enhancement pipe according to claim 1, characterized in that a first end surface (110) of the fin (11) facing the inlet (100) is formed as a first transition surface in a spirally extending 20 direction.

18. The heat transfer enhancement pipe according to claim 1, characterized in that a second end surface of the fin (11) facing the outlet (101) is formed as a second transition surface in a spirally extending direction.

25 19. The heat transfer enhancement pipe according to claim 1, characterized in that a top surface (111) of the fin (11) facing a central axis of the pipe body (10) is formed as a third transition surface of concave shape.

20. A cracking furnace or atmospheric and vacuum heating furnace, 30 comprising a radiation chamber, in which at least one furnace pipe assembly is installed; the furnace pipe assembly comprises a plurality of furnace pipes (2) arranged in sequence and a heat transfer enhancement

pipe communicating adjacent furnace pipes (2); the heat transfer enhancement pipe is the heat transfer enhancement pipe (1) according to any one of the claims 1-19.