An enhanced heat transfer tube with discrete bidirectionally inclined ribs (DBIR-tube) provides enhanced convective heat transfer both in laminar and turbulent flow regions. The inner surface of the tube is formed with bidirectionally inclined ribs, each being in the form of discrete strip-like protrusions which respectively form a certain angle with respect to the axis of the tube and incline in two directions. With the hydrodynamic inner diameter of the tube represented by “d”, each bidirectionally inclined rib has a height less than or equal to 0.2d, a circumferential width less than or equal to 0.5d, and an axial length less than or equal to 2d. A certain angle formed between the axis of each rib and the axis of the tube is ±5° to ±85°, the positive sign meaning that the internal rib is orientated in a right hand declining direction, and the negative sign meaning that the internal rib is orientated in a left hand declining direction.
Fig. 3
AN ENHANCED HEAT TRANSFER TUBE WITH DISCRETE BIDIRECTIONALLY INCLINED RIBS

TECHNICAL FIELD

[0001] The invention relates to an enhanced heat transfer tube with discrete bidirectionally inclined ribs, which belongs to the field of enhanced heat transfer and heat exchanger.

BACKGROUND ART

[0002] Shell-and-tube type heat exchangers have extensively and greatly application in areas such as petroleum engineering, chemical engineering, and power engineering. Smooth circular tubes, which have the advantages of easy manufacturing, high reliability and low cost, are generally used in shell-and-tube type heat exchangers. However, ordinary shell and tube heat exchangers using circular tubes are bulky and material-cost, due to their weak heat transfer. In order to overcome these shortages, a variety of enhanced heat transfer tubes have been adopted for substituting smooth circular tubes. Various enhanced convective heat transfer tubes have been invented in recent 30 years based on wall surface disturbing enhancement techniques. Especially, rough surface enhanced tubes, such as spirally grooved tubes, transverse grooved tubes and micro finned tubes, made by rolling have been successfully and widely used in engineering. In addition, inserts, such as twisted-tape inserts and spring inserts, also have lots of applications. Most of the existing enhanced tubes suffer from high flowing resistance or pressure drop, fouling (dust accumulating) in the backflow areas near the grooves or ribs, as well as low efficiency and high cost in tube manufacturing.

DISCLOSURE OF THE INVENTION

[0003] An object of the invention is to solve the problems found from the prior art by provide a new type of enhanced heat transfer tube, named by enhanced heat transfer tube with discrete bidirectionally inclined ribs (for simplification, the tube is called as “DBIR-tube” below), which includes a plurality of bidirectionally inclined ribs on the tube wall, with the ribs being in the form of discrete strip-like protrusions which respectively form a certain angle with respect to the axis of the tube and incline in two directions. Longitudinal vortex flows, especially near the tube wall, can be induced by the bidirectionally inclined ribs disposed periodically on the tube wall. As a result, the heat transfer is significantly enhanced. The DBIR-tube of the present invention is made on the basis of the Field Synergy Principle of convective heat transfer (c.f. Guo Z. Y., Mechanism and Control of Convective Heat Transfer—Coordination of Velocity and Heat Flow Field, Chinese Science Bulletin, 46(7): 596-599 April 2001.). An enhanced heat transfer is obtained from the improvement of the synergy between the velocity field and the temperature gradient field with less additional pressure drop. Theoretical analysis based on Field Synergy Principle shows that the longitudinal vortex flow is the most effective way for enhancing heat transfer. The invented DBIR-tube has better heat transfer performance and less friction loss in turbulent regions and transition regions than traditional spirally grooved tubes, transverse grooved tubes, spirally finned tubes and rough finned tubes. As a result, it can overcome the disadvantages of the existing enhancing techniques.

[0004] According to the present invention, an enhanced heat transfer tube with discrete bidirectionally inclined ribs (DBIR-tube) is provided, wherein the inner surface of the tube is formed with bidirectionally inclined ribs including left hand inclined ribs and right hand inclined ribs, with the ribs being in the form of discrete strip-like protrusions which respectively form a certain angle with respect to the axis of the tube and incline in two directions, and wherein, if the hydrodynamic inner diameter of the tube is represented by “D”, each inclined rib has a height less than or equal to 0.2 D, a circumferential width less than or equal to 0.5 D, and an axial length less than or equal to 2 D.

[0005] Preferably, a certain angle formed between the axis of each rib and the axis of the tube is ±5° to ±85°, wherein the positive sign means that the internal rib is orientated in a right hand declining direction, and the negative sign means that the internal rib is orientated in a left hand declining direction.

[0006] Preferably, the shape of the cross section of the rib is in the form of one or combined more of circular arch, rectangle, triangle, circular sector, streamline, and any combination of curve line and straight line.

[0007] Preferably, the axis of the rib is in the form of one or combined more of straight line, zigzag line, arch line, spiral line, and curve line.

[0008] Preferably, the inner surface of the tube is in the form of one or combined more of smooth surface, spiral rib surface, and low rib surface.

[0009] Preferably, the outer surface of the tube is in the form of one or combined more of grooved surface, smooth surface, spiral rib surface, low rib surface, and finned surface.

[0010] Compared with the existing techniques, the present invention has the virtues of significant enhanced heat transfer, low additional pressure loss and simple manufacturing process. In the turbulent flow region, the heat transfer coefficient of the DBIR-tube is 80% to 150% higher than that of the smooth tube, and 30% higher than that of the transverse grooved tube (one best enhanced tube), while the pressure loss is 20% to 50% lower than that of the transverse grooved tube. With regard to the convection heat transfer happened in transition regions, the heat transfer effect is also greatly improved. Compared with the transverse grooved tube, the DBIR-tube is of good anti-fouling performance because there is no back flow (transverse vortex flow) formed near the bidirectionally inclined ribs and there is no stagnant area formed inside the tube.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 is a schematic view of the structure of a DBIR-tube of the present invention.

[0012] FIG. 2 is a sectional view taken along line A-A of FIG. 1.

[0013] FIG. 3 is an enlargement view of part B of FIG. 2.

[0014] FIG. 4 is a circumferentially part-deployed schematic view of another DBIR-tube of the present invention.

[0015] FIG. 5 is a circumferentially part-deployed schematic view of still another DBIR-tube of the present invention.
DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0016] The enhanced heat transfer tube with discrete bidirectionally inclined ribs (DBIR-tube) of the present invention comprises a plurality of bidirectionally inclined ribs on the inner surface of the tube wall, with the ribs being in the form of discrete strip-like protrusions which respectively form a certain angle with respect to the axis of the tube and incline in two directions. Generally, the height of each bidirectionally inclined rib is no more than (less than or equal to) 0.2 d, the circumferential width of it is no more than 0.5 d, and the axial length of it is no more than 2 d, wherein d is the hydrodynamic inner diameter of the tube. The term “discrete” used herein means discontinued, which differs from the case in spirally grooved tubes (continuously spiral), spirally finned tubes (continuously spiral), and transverse tubes (circumferentially continuously). Meanwhile, the “bidirectionally inclined rib” refers to a non-even or rough surface element (strip-like protrusion) having a certain length. The DBIR-tubes can be made by mould pressing or rolling of ordinary smooth tubes, low finned tubes, and spirally finned tubes, etc., and it can also be made during the process of forming seamless tubes by rolling or the process of forming seamless tubes by weld-jointing. Due to the plurality of discrete bidirectionally inclined ribs, longitudinal vortex flows and/or other secondary flows will be induced in the inventoried DBIR-tube, and the vortex flows and secondary flows are mainly appeared near the tube wall, so that the turbulent flow heat transfer in the turbulent regions and the convective heat transfer in the transition regions are enhanced.

The First Embodiment

[0017] FIG. 1 shows the structure of a DBIR-tube of the present invention. The inner surface of the tube is provided with a plurality of discrete, two-direction helical protrusions (named as internal discrete double helical ribs or internal discrete bidirectionally inclined ribs). The outer surface of the tube is provided with a plurality of discrete double helical grooves.

[0018] In FIGS. 1 and 2, reference numeral 1 designates the discrete double helical ribs, and reference numeral 2 designates the discrete double helical grooves, with the helical ribs and the corresponding helical grooves being formed simultaneously during processing. In FIG. 1, reference sign “d” designates the hydrodynamic inner diameter of the tube, reference sign “P” designates the axial length of each internal inclined rib, and reference sign “C” designates the helical angle of the internal inclined ribs. In FIG. 3, reference sign “h” designates the height of the internal inclined ribs. The tubes of the invention meet the condition of $P=0.3 \text{ d}, h=0.05 \text{ d}, \text{ and } C=\pm 45^\circ$, wherein the positive sign (+) means that the internal rib is orientated in a right hand declining direction, and the negative sign (−) means that the internal rib is orientated in a left hand declining direction.

The Second Embodiment

[0019] FIG. 4 shows the structure of another DBIR-tube of the present invention in a circumferentially part-deployed schematic view. The inner surface of the tube is provided with a plurality of discrete, two-direction helical protrusions (discrete bidirectionally inclined ribs or discrete double inclined ribs). The outer surface of the tube is smooth, without any protrusion or groove.

[0020] In FIG. 4, reference numeral 3 designates the discrete bidirectionally inclined ribs, which are asymmetrical disposed. Each pair of inclined ribs, composed of an inclined rib which is orientated in a right hand declining direction and a circumferentially neighboured inclined rib which is orientated in a left hand declining direction, form a vortex generator. In each cross-section of the tube, there are two vortex generators formed by four inclined ribs. In FIG. 4, reference sign “C” designates the helical angle of the internal inclined ribs, and $C=\pm 50^\circ$, wherein the positive sign (+) means that the internal rib is orientated in a right hand declining direction, and the negative sign (−) means that the internal rib is orientated in a left hand declining direction. Streamlines designated by reference numeral 4 schematically show the longitudinal vortex flows generated near the tube wall. Since the longitudinal vortex flows are mainly created near the tube wall, heat transfer may be enhanced in both laminar and turbulent flow regions. The discrete inclined ribs nearly do not create any transverse vortex flow in the fluid flowing through the tube, and do not significantly reduce the flowing area of the tube. As a result, the flowing resistance or pressure loss is much lower than that of traditional spirally grooved tubes, transverse grooved tubes and spirally finned tubes.

The Third Embodiment

[0021] FIG. 5 shows the structure of yet another DBIR-tube of the present invention in a circumferentially part-deployed schematic view. The inner surface of the tube is provided with a plurality of discrete, two-direction helical protrusions (bidirectionally inclined ribs). The outer surface of the tube is provided with a plurality of discrete double helical grooves.

[0022] In FIG. 5, reference numeral 5 designates the discrete double helical ribs which are symmetrically arranged, and reference numeral 6 designates the discrete double helical grooves which are also symmetrically arranged. On the inner surface, each pair of inclined ribs, composed of an inclined rib which is orientated in a right hand declining direction and a circumferentially neighboured inclined rib which is orientated in a left hand declining direction, form a vortex generator. Within a small circumferential segment of the tube, which has an axial length of less than 0.5 d, there are three vortex generators formed by six inclined ribs.

[0023] Preferred manufacturing methods of the DBIR-tube include rolling or mould pressing. A preferred rolling process of the DBIR-tube with bidirectionally inclined helical ribs on the inner surface and bidirectionally inclined helical grooves on the outer surface is carried out in the following way. Specifically, a tube is formed by processing rollers, the forming surfaces of which are provided with discrete bidirectionally inclined low-profile protrusions; when the tube is formed by rolling, discrete helical bidirectionally inclined grooves are formed on the outer surface under the extrusion forces of the low-profile protrusions, and in the meantime, discrete bidirectionally inclined ribs are formed on the inner surface. On the other hand, two manufacturing processes are preferred for forming the DBIR-tube with discrete helical bidirectionally inclined ribs on the inner
surface and being smooth on the outer surface. The first one is similar to that of the traditional enhanced heat transfer tube with inner spirally fins and being smooth on the outer surface, and the second one is further processing (for example, cold drawing) the DBIR-tube with helical bidirectionally inclined ribs on the inner surface and helical bidirectionally inclined grooves on the outer surface obtained previously by rolling or mould pressing as discussed above. As a result of the discontinuousness of the bidirectionally inclined ribs, the manufacturing efficiency of the rolling or mould pressing process of DBIR-tube is several times higher than that of the spirally finned tubes, the transverse grooved tubes and the spirally finned tubes. Therefore, the manufacturing cost is greatly reduced.

What is claimed is:

1. An enhanced heat transfer tube with discrete bidirectionally inclined ribs, wherein the inner surface of the tube is formed with bidirectionally inclined ribs including left hand inclined ribs and right hand inclined ribs, with the ribs being in the form of discrete strip-like protrusions which respectively form a certain angle with respect to the axis of the tube and incline in two directions, and wherein, if the hydrodynamic inner diameter of the tube is represented by “d”, each bidirectionally inclined rib has a height less than or equal to 0.2d, a circumferential width less than or equal to 0.5d, and an axial length less than or equal to 2d.

2. The enhanced heat transfer tube with discrete bidirectionally inclined ribs of claim 1, wherein a certain angle formed between the axis of each rib and the axis of the tube is 5° to ±85°, wherein the positive sign means that the internal rib is orientated in a right hand declining direction, and the negative sign means that the internal rib is orientated in a left hand declining direction.

3. The enhanced heat transfer tube with discrete bidirectionally inclined ribs of claim 1, wherein the shape of the cross section of the rib is in the form of one or combined more of circular arch, rectangle, triangle, circular sector, streamline and any combination of curvilinear and straight line.

4. The enhanced heat transfer tube with discrete bidirectionally inclined ribs of claim 1, wherein the axis of the rib is in the form of one or combined more of straight line, zigzag line, arch line, spiral line and curve line.

5. The enhanced heat transfer tube with discrete bidirectionally inclined ribs of claim 1, wherein the inner surface of the tube is in the form of one or combined more of smooth surface, spiral rib surface, and low rib surface.

6. The enhanced heat transfer tube with discrete bidirectionally inclined ribs of claim 1, wherein the outer surface of the tube is in the form of one or combined more of grooved surface, smooth surface, spiral rib surface, low rib surface, and finned surface.

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