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(54) **ANGLED TUBE FINS TO SUPPORT SHELL SIDE FLOW**

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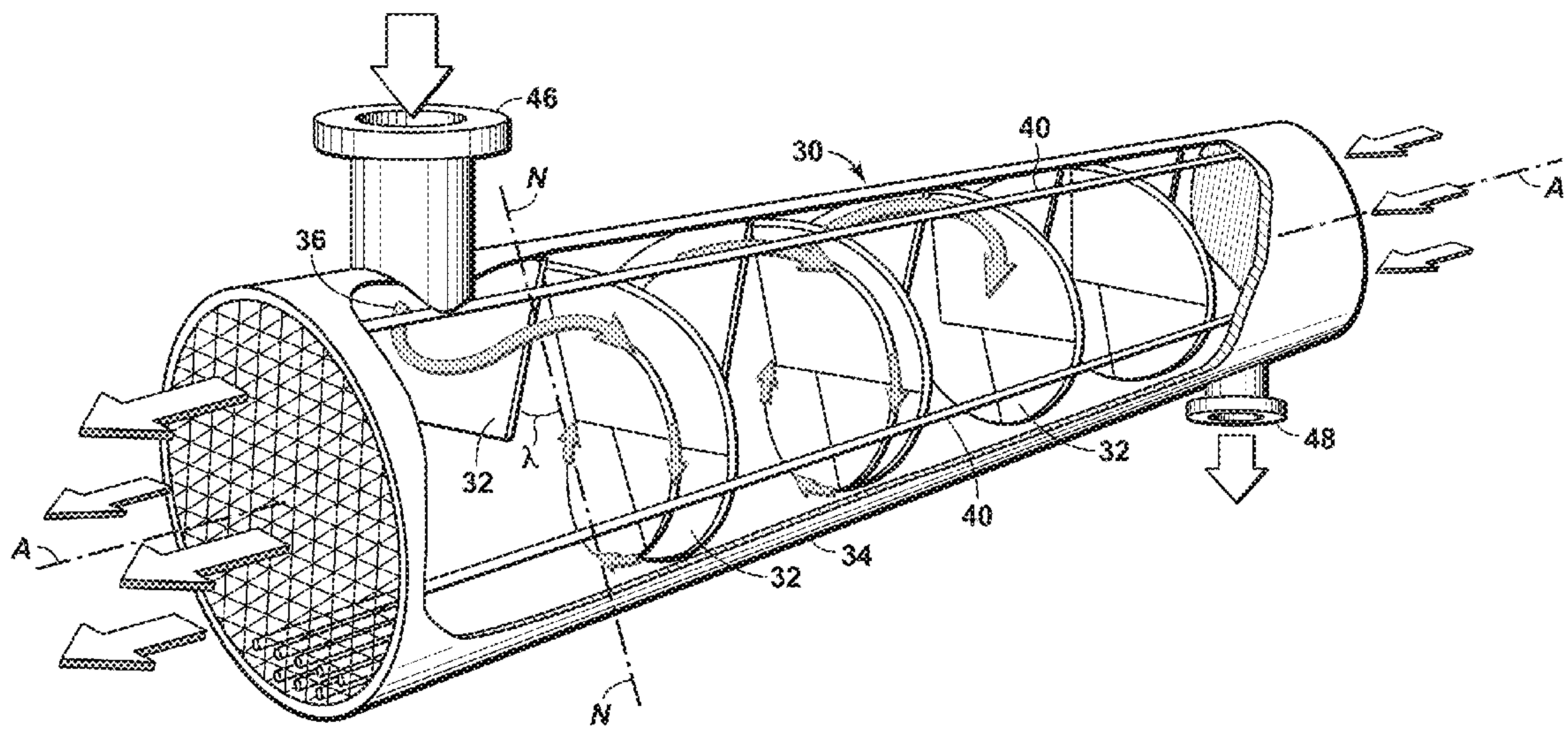
(57) **ABSTRACT**

A heat exchanger, including: a shell configured to have an inlet and an outlet for a first fluid; baffles disposed in the shell, wherein the baffles are configured to guide the first fluid into a helical flow pattern, and at least some of the baffles are disposed in a helical pattern with a helix angle; a tube disposed in the shell, wherein the tube extends along a longitudinal axis of the shell, the tube passes through the baffles, and the tube is configured to facilitate an exchange of thermal energy between a second fluid within the tube and the first fluid; and fins fixedly attached to an outer surface of the tube, wherein at least some of the fins are angled to match the helix angle of the at least some of the baffles.



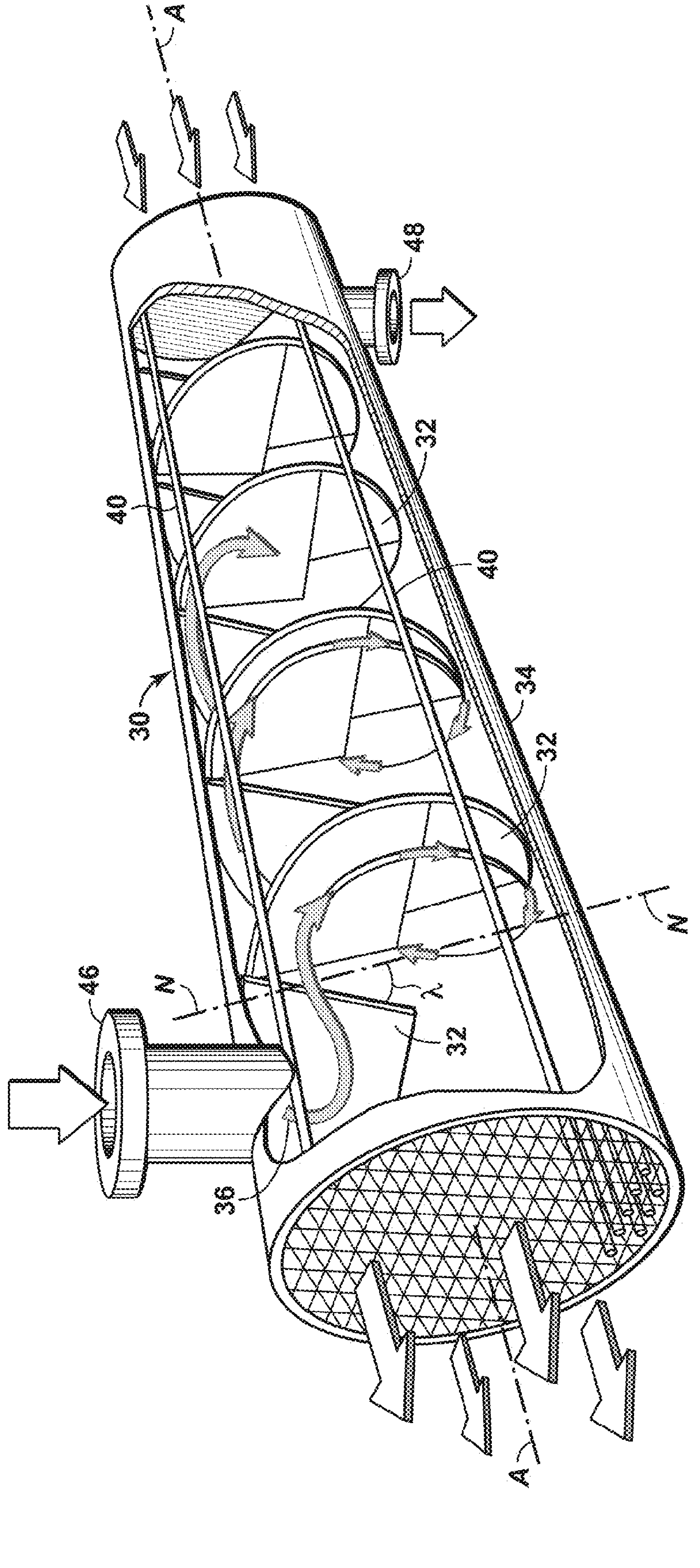


FIG. 1A

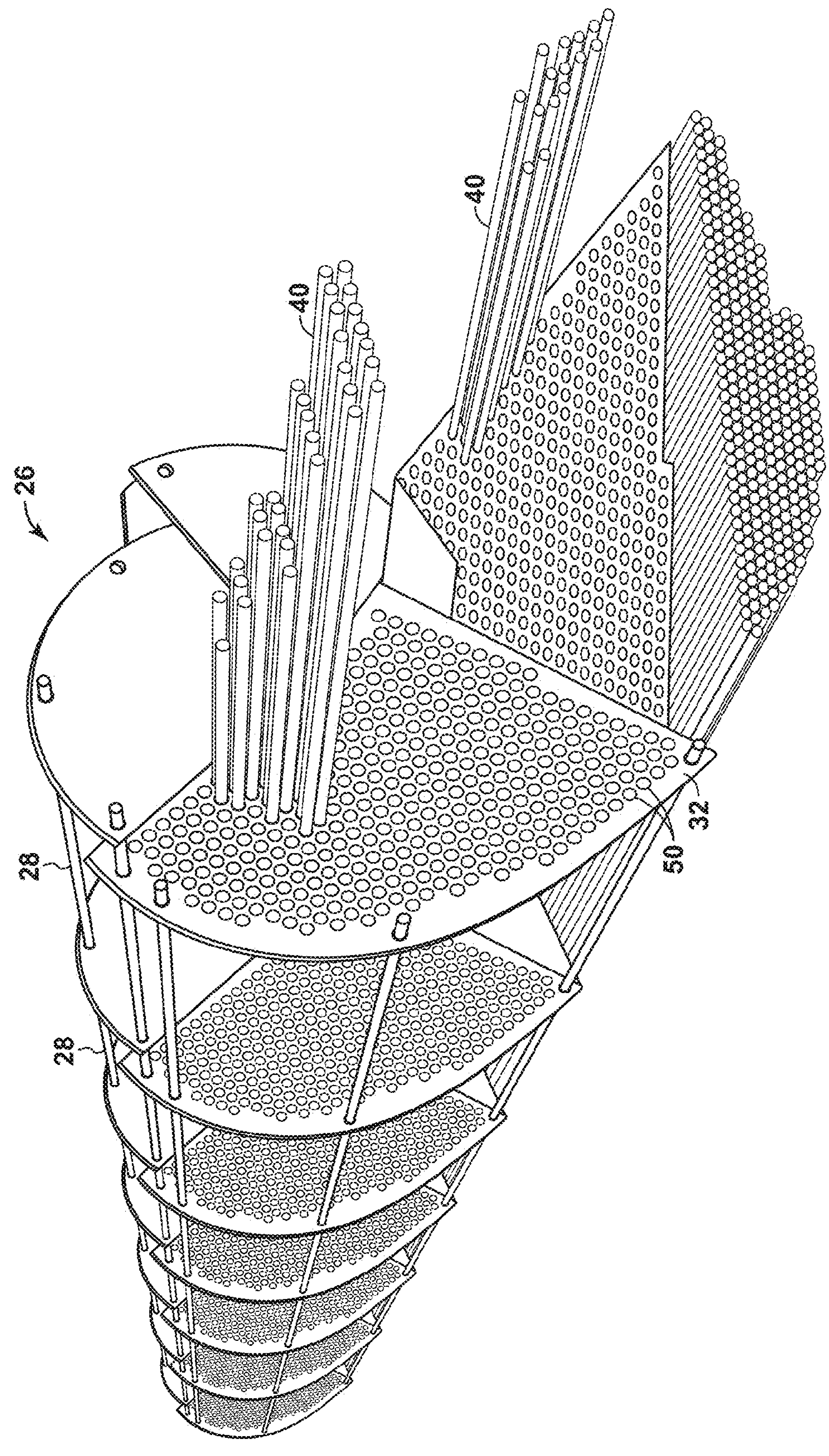


FIG. 1B

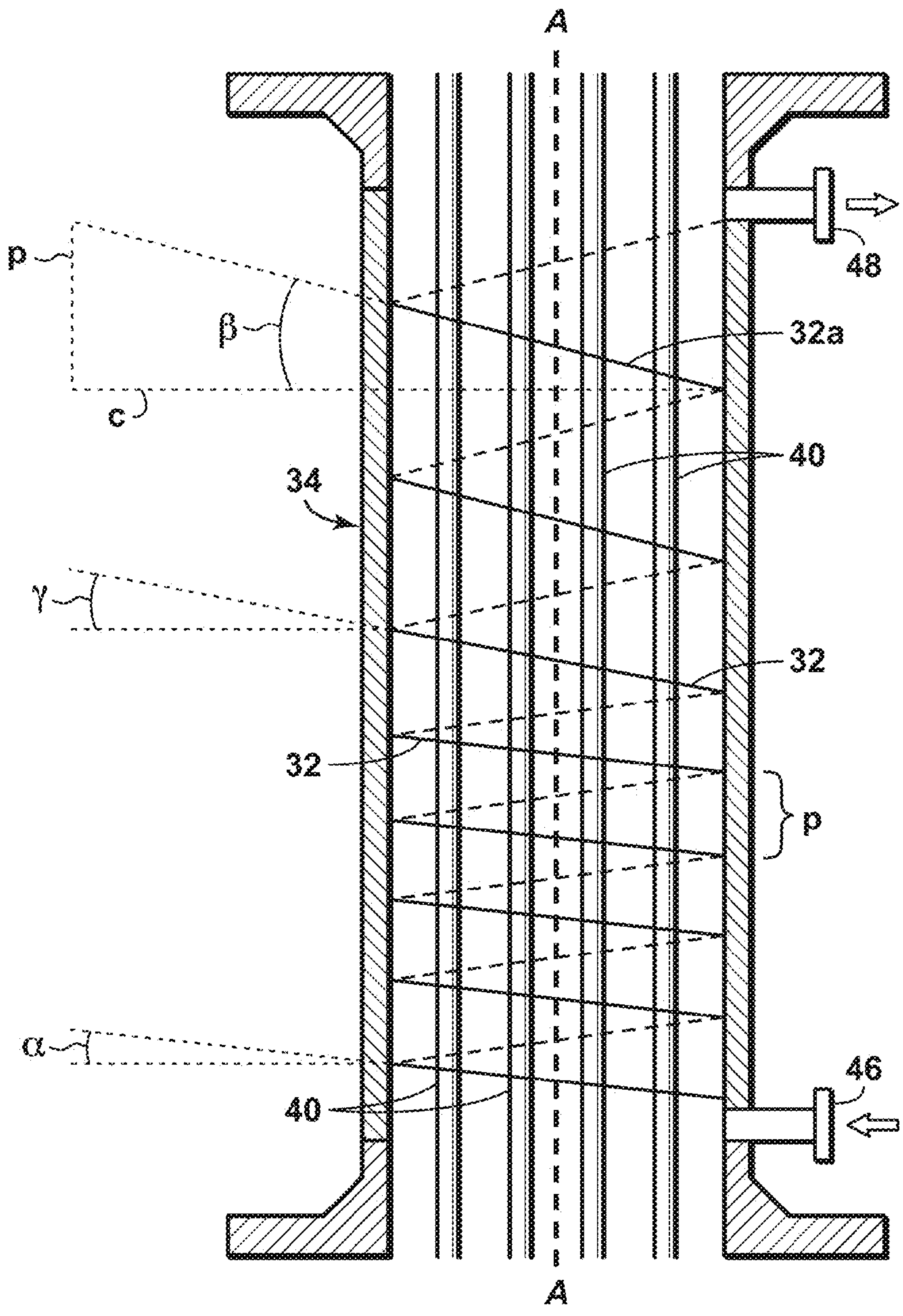


FIG. 2

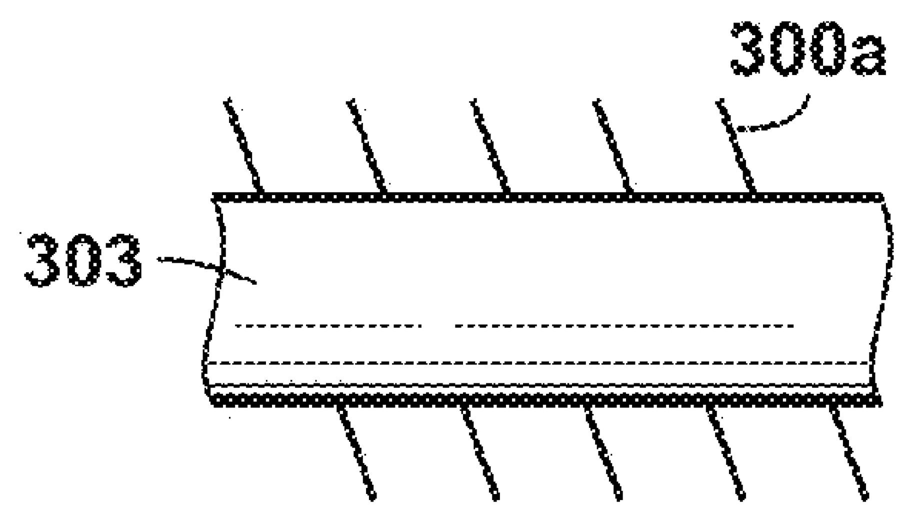


FIG. 3A

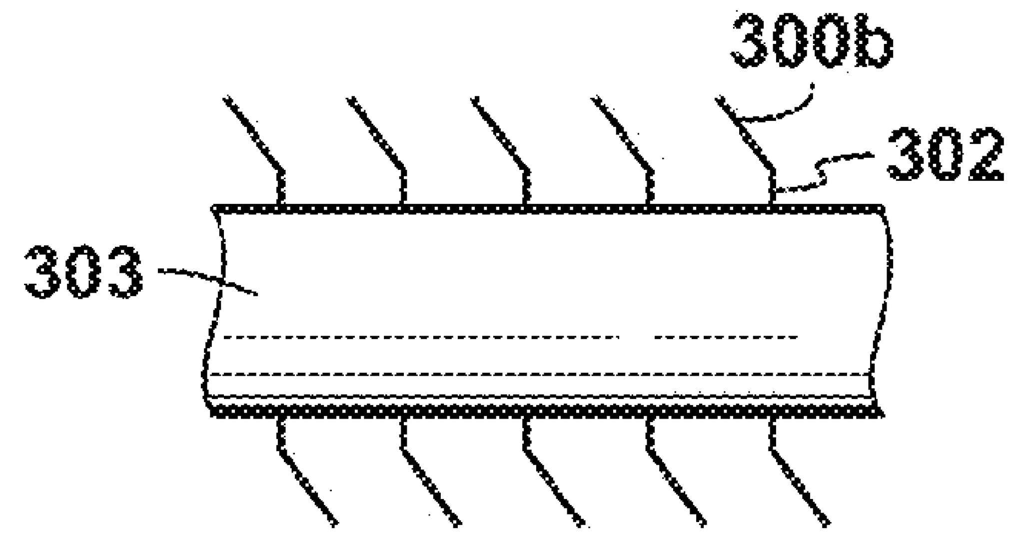


FIG. 3B

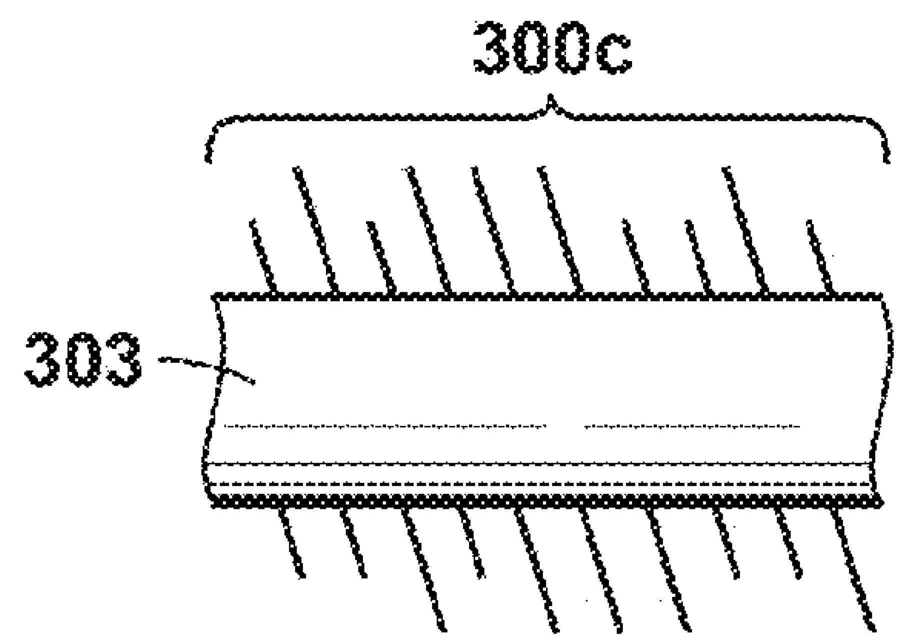


FIG. 3C

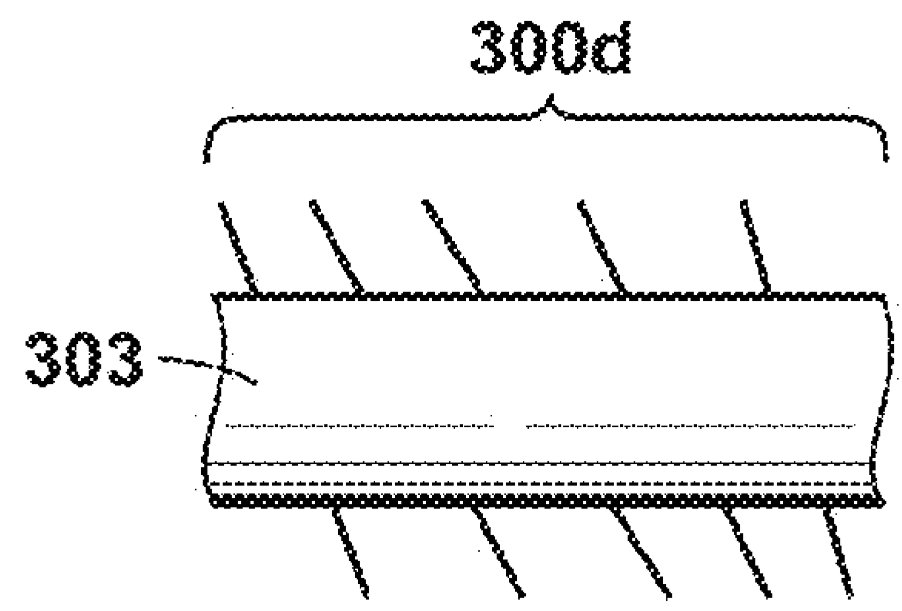


FIG. 3D

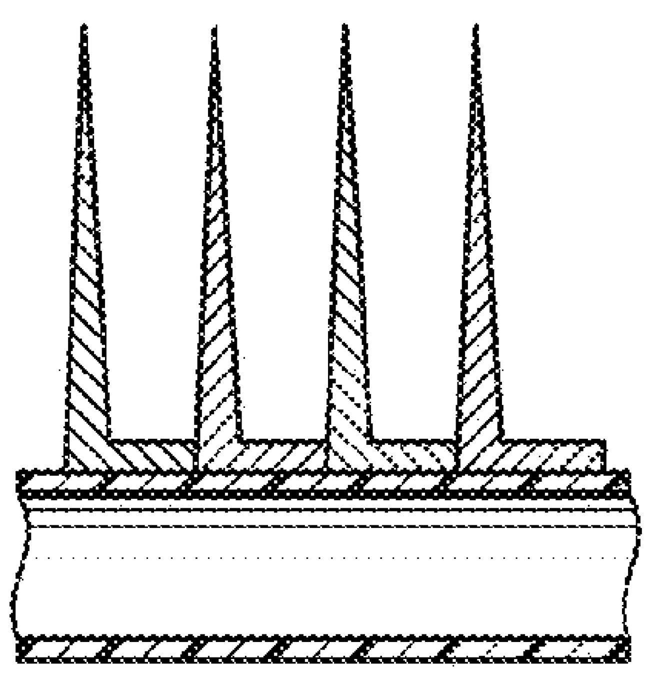


FIG. 4A

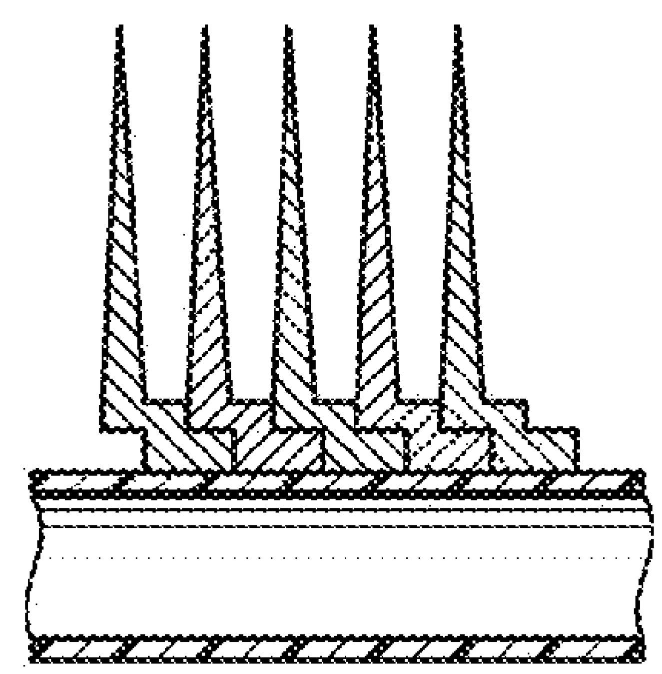


FIG. 4B

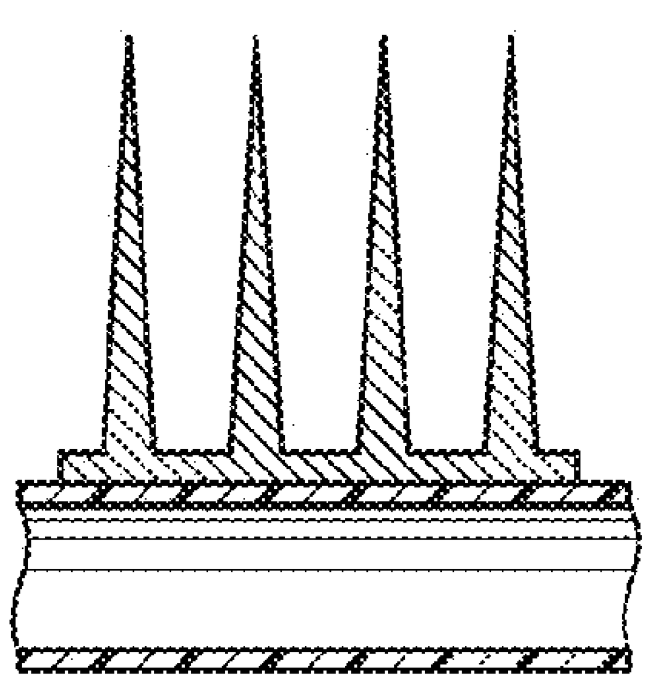


FIG. 4C

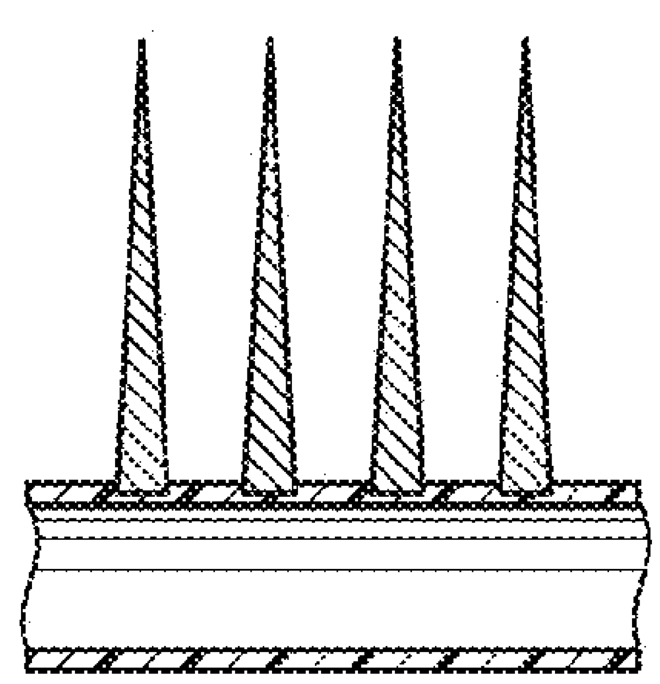


FIG. 4D

ANGLED TUBE FINS TO SUPPORT SHELL SIDE FLOW

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the priority benefit of U.S. patent application No. 62/026,953 filed Jul. 21, 2014 entitled ANGLED TUBE FINS TO SUPPORT SHELL SIDE FLOW, the entirety of which is incorporated by reference herein.

TECHNOLOGICAL FIELD

[0002] Exemplary embodiments described herein pertain to heat exchangers. More specifically, some exemplary embodiments described herein pertain to a shell-and-tube heat exchanger, wherein the tube is fitted with angled fins.

BACKGROUND

[0003] This section is intended to introduce various aspects of the art, which may be associated with exemplary embodiments of the present invention. This discussion is believed to assist in providing a framework to facilitate a better understanding of particular aspects of the present invention. Accordingly, it should be understood that this section should be read in this light, and not necessarily as admissions of prior art.

[0004] A shell-and-tube heat exchanger is a class of heat exchangers typically employed in oil refineries and other large chemical processes. A shell-and-tube heat exchanger includes a shell (a large pressure vessel) with a bundle of tubes inside it. One fluid runs through the tubes and another fluid flows over the tubes (through the shell) to transfer heat between the two fluids. The term tube bank is often used, in the literature, to denote a crossflow situation and bundle to indicate longitudinal flow, however this convention is far from universal.

[0005] A shell-and-tube heat exchanger may contain a bundle of tubes with baffles that induce and support a helical flow of the shell side fluid from the inlet to the outlet of the unit. CB&I Lummus provides a shell-and-tube heat exchanger based on this technology. Helical baffles currently exist in single-helix and double-helix configurations. A triple-helix configuration may also exist. The tubes comprising the tube bundle of a helical baffle heat exchanger resemble that of a conventional tube bundle: plain, internally finned, externally finned, straight, or U-tube.

[0006] Two fluids, of different starting temperatures, flow through the shell-and-tube heat exchanger. One flows through the tubes (the tube side) and the other flows outside the tubes but inside the shell (the shell side). Heat is transferred from one fluid to the other through the tube walls, either from tube side to shell side or vice versa. The fluids can be either liquids or gases on either the shell or the tube side. In order to transfer heat efficiently, a large heat transfer area should be used, leading to the use of many tubes.

[0007] U.S. Pat. No. 8,613,308 "Process for Transferring Heat or Modifying a Tube in a Heat Exchanger" describes a vertically oriented shell-and-tube heat exchanger equipped with either helical baffles or expanded metal baffles. The vertically oriented tubes possess internal rifling that may be spiral in nature. The outer fins are understood to be integral with the tube material and oriented ninety degrees (90°) from the longitudinal plane of the tubes. These fins are not claimed to assist or to enhance the shell side fluid flow through the helical or expanded metal baffles. U.S. Pat. No. 8,613,308 is incorporated herein by reference in its entirety.

[0008] U.S. Pat. No. 5,092,038 "Method of Manufacturing Spiral Heat Exchanger Tubes with an External Fin" describes a method of fabricating a heat exchanger that possesses helical ridges and other convoluted circumferential surfaces for enhanced heat transfer. Conventional fins may be added to the complex surface of the twisted fin tube by conventional means. The patent describes an integral helical fin and additional circumferential surfaces that are formed by twisting/deforming the tube material during formation of the tube. These fins are integral with the tube, that is, of the same metal of which the tube is made. As such, the heights of such fins typically range from 0.5 to 3.0 mm. These are commonly called "low-fins." The height of these low-fins is limited by the amount of metal available on the circumference of the tube and the required minimum wall thickness required for mechanical viability of the tube in service. While the patent does describe the addition of high-fins onto the surface of the twisted fin tube surface, these high-fins remain oriented 90° from the longitudinal plane of the tube. U.S. Pat. No. 5,092,038 is incorporated herein by reference in its entirety.

[0009] U.S. Pat. No. 4,699,211 "Segmental High Performance Shell and Tube Heat Exchanger" describes a concept in which the successive baffles of a conventional segmental baffle arrangement are rotated at angles other than 180°. U.S. Pat. No. 4,699,211 is incorporated herein by reference in its entirety.

[0010] U.S. Pat. No. 2,384,714 A "Tubular Heat Exchanger" describes what appears to be one of the first helical baffle applications within a shell-and-tube type heat exchanger. An additional novel concept appears to be the "nesting" of the tubes which are then connected to a manifold residing directly within the heat exchanger vessel. The patent does not discuss enhancements on the outside of the tube surface to enhance shell side flow. U.S. Pat. No. 2,384,714 is incorporated herein by reference in its entirety.

[0011] Other background information regarding heat exchangers can also be found in U.S. Pat. Nos. 8,613,308, 5,092,038, and 6,827,138, and U.S. patent publication 2009/0301699, each of which is incorporated herein by reference in its entirety.

SUMMARY

[0012] A heat exchanger, including: a shell configured to have an inlet and an outlet for a first fluid; baffles disposed in the shell, wherein the baffles are configured to guide the first fluid into a helical flow pattern, and at least some of the baffles are disposed in a helical pattern with a helix angle; a tube disposed in the shell, wherein the tube extends along a longitudinal axis of the shell, the tube passes through the baffles, and the tube is configured to facilitate an exchange of thermal energy between a second fluid within the tube and the first fluid; and fins fixedly attached to an outer surface of the tube, wherein at least some of the fins are angled to match the helix angle of the at least some of the baffles.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] While the present disclosure is susceptible to various modifications and alternative forms, specific example embodiments thereof have been shown in the drawings and are herein described in detail. It should be understood, however, that the description herein of specific example embodiments is not intended to limit the disclosure to the particular forms disclosed herein, but on the contrary, this disclosure is to cover all modifications and equivalents as defined by the appended claims. It should also be understood that the drawings are not necessarily to scale, emphasis instead being placed upon clearly illustrating principles of exemplary embodiments of the present invention. Moreover, certain dimensions may be exaggerated to help visually convey such principles.

[0014] FIG. **1**A is an elevational cut-away view of an exemplary shell of a heat exchanger.

[0015] FIG. **1**B is a perspective view of a baffle cage with tube bundles.

[0016] FIG. **2** shows an example of how baffles plates can be arranged within the heat exchanger.

[0017] FIGS. **3**A, **3**B, **3**C, **3**D illustrate exemplary cross-sections of tubes with external fins.

[0018] FIGS. **4**A, B, C, and D depict the various techniques to attach fins to the outer circumference of the tube surface.

DETAILED DESCRIPTION

[0019] Exemplary embodiments are described herein. However, to the extent that the following description is specific to a particular, this is intended to be for exemplary purposes only and simply provides a description of the exemplary embodiments. Accordingly, the invention is not limited to the specific embodiments described below, but rather, it includes all alternatives, modifications, and equivalents falling within the true spirit and scope of the appended claims.

[0020] Exemplary embodiments of the present technological advancement introduce the concept of employing angled external fins on tubes such that they are no longer perpendicular to the longitudinal axis of the tube (or parallel to a normal of the longitudinal axis of the tube) and that the established external fin angle matches that of the angle of the helical baffle arrangement so as to better promote the establishment and maintenance of a uniform helical flow along the shell side of a helically-baffled heat exchanger. "Match", as used herein, does not require that the angle of the fins be identical to the baffle angle. Rather, the angle of the fin matches the baffle angle if it is within +/−5 degrees.

[0021] Referring to FIG. **1**A, a helically baffled heat exchanger **30** is configured with a plurality of quadrant shaped segment baffle plates **32** each positioned at an angle λ relative to a normal N-N to a longitudinal axis A-A of a shell **34**. The baffle quadrant plates **32**, (hereafter referred to as baffles), thus guide a shell side cross flow **36** into a helical pattern and at a reduced unsupported pipe spans between the baffles. The result is true cross flow on the shell side with effective conversion of available pressure drop to heat transfer and reduced risk due to minimized vibration of tubes **40** traversed by another fluid. There are no dead spots along the cross flow **36** for fouling, and wasted energy of eddies or back mixing is substantially eliminated. Although the baffles **32**, as shown in the accompanying drawings, are flat, the opposite sides of each baffle may be curved to guide the cross flow **36** along the helical pattern.

[0022] FIG. **1**B provides an example of the helical baffle plates **32** with tubes **40** passing through baffle holes **50**. As used herein, baffle refers to a device to direct the shell side fluid across tubes for optimum heat transfer. Baffles are installed on the shell side to provide a higher heat transfer rate due to increased turbulence and to support the tubes, thus reducing the change of damage due to vibration.

[0023] As illustrated in FIG. **1**B, a baffle cage **26**, which can be a combination of successive baffles or quadrant plates **32** positioned at the angle λ and interconnected by a plurality of tie rods **28**, serves as a support for multiple tubes **40** and as a helical guide for the cross flow **36**. A bundle or coil of tubes **40** can form the assembly of the heat exchanger that transfers energy between the source and load fluids.

[0024] While the exemplary embodiment of FIG. **1**B illustrates a baffle cage formed of discontinuous plates, the baffle can be formed from continuous or discontinuous plates disposed to form a helix. The helix angle of the baffles **32** can be determined, for example, by unwinding the helix, forming a two-dimensional representation of the helical pattern. As illustrated in FIG. **2** for baffle cage **26**, the helix angle is determined as the arctangent of the shell circumference C divided by the pitch p (longitudinal distance transversed by a baffle arc extending 360°. The pitch is equal to p=C* tan (B), where B is the helix angle. Therefore the helix angle is arctan (p/C).

[0025] The pitch (or baffle-pitch) is the center-to-center distance between baffles, and this can be adjusted to vary the crossflow velocity. In practice the baffle pitch is not normally greater than a distance equal to the inside diameter of the shell or closer than a distance equal to one-fifth the diameter or 50.8 mm (2 in) whichever is greater. The baffle pitch can be constant or vary over the length of the heat exchanger.

[0026] FIG. **2** shows baffles plates **32** arranged within the heat exchanger such that the baffles at one end of the heat exchanger have a different helix angle than baffles at an opposite end of the heat exchanger. As illustrated in FIG. **2**, heat exchanger **30** is equipped with helical baffles **32**. Baffles **32** proximate shellside inlet **46** may have a helix angle α. Baffles **32***a* proximate shellside outlet **48** may have a helix angle β with respect to longitudinal axis A-A of shell **34**.

[0027] In some embodiments, baffles intermediate shellside fluid inlet **46** and outlet **48** may have a helix angle γ intermediate that of helix angles α,β. For example, the helix angles of baffles **32** may gradually increase or decrease from inlet **46** to outlet **48**, depending on the type of service (e.g., condensing, evaporating, etc.). In other embodiments, the helix angles for baffles **32** may undergo one or more step changes.

[0028] α,β, and γ can all be equal, in which case the helix angle is constant (see, FIG. **1**A for example).

[0029] The tubes **40** are fitted with external fins in order to increase the heat-transfer area (fins not shown in FIGS. **1**A, **1**B and **2** for clarity). As used herein, fin is a projection on a tube in a shell and tube heat exchanger used for increasing heat transfer. The fin can be flattened, include ridges, be perforated, or have other geometric enhancements. Low-fins are integral with the tube and made of the same material as the tube. As there is only so much tube wall material from which to form a low-fin, low-fins -extend for a short distance above the tube surface. High-fins are not integral with the tube material, but are rather fixedly attached to the outer surface of the tube. While a high-fin may be of the same material as the tube,—they are typically not (for example, stainless steel tubes with aluminum fins). A high-fin, not being formed from the tube material itself, allows the manufacture of taller fins (e.g., 9 mm to 32 mm, or more) as well as additional geometric enhancements (grooves, dimples, perforations, etc.).

[0030] FIGS. **3**A-**3**C illustrate exemplary cross-sections of tubes **40** with external fins **300***a-c*. In FIG. **3**A, fins **300***a* are angled to match the angle of the baffle, and the height of the fins remains constant over the entire surface of the tube **303**. The angles of helical baffles are typically range from 15 to 40 degrees. In FIG. **3**A, the density of the fins (number of fins per unit length of the tube) remains constant over the entire external surface of the tube **303**. In FIG. **3**B, the fins **300***b* are also angled to match the angle of the baffle and have a constant height, but are displaced in a radial direction of the tube via member **302**. FIG. **3**C illustrates an example in which fins **300***c* have heights and densities that vary over the entire surface of the tube **303**.

[0031] The fins **300***a-c* do not need to be integral with the tube material, can have a different composition than the tube material, and can have heights ranging from 9.0 to 32.0 mm. These are commonly called "high-fins." The height of high-fins is not limited as that of low-fins. High-fins are not typically of the same material as that of the tube **303** to which they are connected. In the embodiment of FIG. **3**C, fins **300***c* can all be high-fins or a mixture of high-fins and low-fins.

[0032] In FIGS. **3**A-**3**C, the angle of the fins remains constant over the entire surface of the tube. In FIG. **3**D, the angle of the fins **300***d* varies over the entire external surface of the tube in order to match a varying baffle angle (i.e., FIG. **2** with different helix angles α, β, and γ). When the fin angles and baffle angles vary, a "match" can be determined by comparing a fin to a baffle plate on one or both sides of the fin.

[0033] The present technological advancement can enhance heat transfer performance. Angled fins that match the helical angle of the baffle plates provide enhanced heat transfer by improving the helical flow on the shell-side. The outer surface of tubes **40** can be smooth, contoured, otherwise enhanced, or fabricated to employ a combination of these attributes for enhanced shell side fluid flow and heat transfer performance. The circumference of tubes **40** can be circular, oval, wavy, otherwise enhanced, or fabricated to employ a combination of these attributes for enhanced shell side fluid flow and heat transfer performance. The inside surface of tubes **40** may be smooth, wavy, otherwise enhanced, or fabricated to employ a combination of these attributes for enhanced tube side fluid flow and heat transfer performance.

[0034] Moreover, the various characteristics in FIGS. **3**A-**3**D can be mixed and matched in order to be combined in various ways that are self-evident to those of ordinary skill in light of the teachings of the present disclosure. The angled external fins specifically promote and enhance the shell side fluid helical flow pattern through a tube field (or tube bundle) within a shell-and-tube heat exchanger employing helical baffle technology by varying fin angle, height, density, metallurgy, or base tube arrangement and other surface enhancements.

[0035] FIGS. **4**A-D depict the various techniques to attach fins to the outer circumference of the tube surface. In FIG. **4**A, the fins have an L-shaped connection to the outer-surface of the tube. In FIG. **4**B, the fins have an overlap L-shaped connection to the outer-surface of the tube and an adjacent fin. In FIG. **4**C, the fins are extruded. In FIG. **4**C, the fin material is wrapped around the base tube and then pressed during fabrication such that the fin is extruded from the material wrapped around the tube, not from the tube material itself. In FIG. **4**D, the fins are embedded in the outer-surface of the tube.

[0036] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal language of the claims.

What is claimed is:

1. A heat exchanger, comprising:

a shell configured to have an inlet and an outlet for a first fluid;

baffles disposed in the shell, wherein the baffles are configured to guide the first fluid into a helical flow pattern, and at least some of the baffles are disposed in a helical pattern with a helix angle;

a tube disposed in the shell, wherein the tube extends along a longitudinal axis of the shell, the tube passes through the baffles, and the tube is configured to facilitate an exchange of thermal energy between a second fluid within the tube and the first fluid; and

fins fixedly attached to an outer surface of the tube, wherein at least some of the fins are angled to match the helix angle of the at least some of the baffles.

2. The heat exchanger of claim **1**, wherein the angle of the fins is constant over an entire outer surface of the tube.

3. The heat exchanger of claim **2**, wherein the helix angle of the at least some of the baffles is constant.

4. The heat exchanger of claim **1**, wherein the helix angle of the at least some of the baffles varies and matches a varying angle of the fins.

5. The heat exchanger of claim **1**, wherein a height of the fins is constant over an entire outer surface of the tube.

6. The heat exchanger of claim **1**, wherein a height of the fins varies over an entire outer surface of the tube.

7. The heat exchanger of claim **1**, wherein a number of fins per unit length of the tube is constant over an entire surface of the tube.

8. The heat exchanger of claim **1**, wherein a number of fins per unit length of the tube varies over an entire surface of the tube.

9. The heat exchanger of claim **1**, wherein the outer surface of the tube is configured to enhance shell side fluid flow and heat transfer performance.

10. The heat exchanger of claim **9**, wherein the outer surface of the tube is smooth, contoured, or includes smooth sections and contoured sections.

11. The heat exchanger of claim **1**, wherein the tube is configured to have a cross-section that is configured to enhance tube side flow and heat transfer performance.

12. The heat exchanger of claim **11**, wherein an inside surface of the tube is smooth, wavy, or includes smooth sections and wavy sections.

13. The heat exchanger of claim **1**, further comprising a plurality of tubes that include fins angled to match the helical angle.

14. The heat exchanger of claim **1**, wherein a metallurgy of the fins is constant over an entire outer surface of the tube.

15. The heat exchanger of claim **1**, wherein a metallurgy of the fins varies over an entire outer surface of the tube.

16. The heat exchanger of claim **1**, wherein the fins are high fins that with a height of 9.0 to 32.0 mm.

17. The heat exchanger of claim **1**, wherein the fins have a different composition than the outer surface of the tube.

* * * * *