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(54) **METHOD OF FORMING AN ENHANCED-SURFACE WALL FOR USE IN AN APPARATUS**

VERFAHREN ZUR FORMUNG EINER WAND MIT VERSTÄRKTER OBERFLÄCHE ZUR
VERWENDUNG IN EINER VORRICHTUNG

PROCÉDÉ DE FORMATION D'UN PAROI À SURFACE AMÉLIORÉE POUR UTILISATION DANS
UN APPAREIL

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(56) References cited:
EP-A1- 0 603 108 GB-A- 2 457 333
JP-A- S56 136 241 US-A- 3 861 462
US-A- 4 092 842 US-A- 4 098 722
US-A- 6 026 892 US-A1- 2006 054 035
US-A1- 2007 122 590 US-A1- 2008 038 144

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Description

Technical Field

[0001] The present invention relates generally to methods of forming enhanced-surface walls for use in apparatuses (e.g., heat transfer devices, fluid-mixing devices, etc.) for performing a process, to enhanced-surface walls *per se*, and to various apparatuses incorporating such enhanced-surface walls.

Background Art

[0002] It is known to provide enhanced-surface walls for use in heat exchangers and fluid-mixing devices. Such walls typically have a plurality of characters impressed thereon to enhance the surface area, to improve fluid mixing, to promote turbulence, to break up the boundary layer adjacent the surface, to improve heat transfer, etc. JP S56 136241 appears to disclose a method of producing a fin for a heat exchanger, including passing fin material through two working rollers having projections on their surfaces. This method comprises the steps as defined in the preamble of claim 1. EP 0 603 108 appears to disclose a heat exchanger tube having a ribbed internal surface, in which the ribs are parallel to the longitudinal axis of the tube, and have a pattern of parallel notches impressed into them at an angle oblique to the longitudinal axis of the tube. GB 2 457 333 appears to disclose a metallic molded sheet having a corrugated surface in which two kinds of waveforms each having a sinusoidal cross section perpendicularly intersect each other without forming bent portions at the portions where the two kinds of waveforms perpendicularly intersect each other. US 4 098 722 appears to disclose a method including forming a sheet of material with a planar region and a region of first corrugations; superimposing second corrugations that are smaller than the first corrugations and laying the planar region onto the region with the first corrugations. US 4 092 842 appears to disclose a method of deeply embossing sheet material, including embossing a small-scale relief pattern across the entire sheet, and then deeply embossing spaced-apart protuberances into the sheet. US 6 026 892 appears to disclose a heat transfer tube with a cross-grooved inner surface, in which primary and secondary spiral grooves have respective helix angles within certain ranges.

[0003] US 5,052,476 A appears to disclose a heat transfer tube having U-shaped primary grooves, V-shaped secondary grooves, and pear-shaped tertiary grooves to increase turbulence and reflux efficiency. The tube is first formed as a plate, and is then rolled into a tube, after which its proximate ends are welded together. The depth of the secondary grooves is said to be 50-100% of the depth of the primary grooves.

[0004] US 5,259,448 A appears to disclose a heat transfer tube having rectangularly shaped main grooves and narrow secondary grooves that intersect the main

grooves at an angle. The device appears to be formed flat, rolled or curled, and then welded. The depth of the narrow grooves is said to be 0.02 millimeters (mm). The depth of the main grooves is said to be 0.20-0.30 mm.

[0005] US 5,332,034 A appears to disclose a heat exchanger tube having longitudinally-extending circumferentially-spaced ribs with parallel inclined notches to increase turbulence and to increase heat transfer performance.

[0006] US 5,458,191 A appears to disclose a heat exchanger tube having circumferentially-spaced helically-wound ribs with parallel inclined notches.

[0007] US 6,182,743 B1 appears to disclose a heat transfer tube with polyhedral arrays to enhance heat transfer characteristics. The polyhedral arrays may be applied to internal and external tube surfaces. This reference may teach the use of ribs, fins, coatings and inserts to break up the boundary layer.

[0008] US 6,176,301 B1 appears to disclose a heat transfer tube with polyhedral arrays having crack-like cavities on at least two surfaces of the polyhedrons.

[0009] US 2005/0067156 A1 appears to disclose a heat transfer tube that is cold- or forge-welded, and that has dimpled patterns thereon of various shapes.

[0010] US 2005/0247380 A1 appears to disclose a heat transfer tube of tin-brass alloys to resist formicary (i.e., ant-like) corrosion.

[0011] US 2009/0008075 A1 appears to disclose a heat transfer tube having arrays of polyhedrons, with the second array being arranged at an angle with respect to the first.

[0012] US 5,351,397 A appears to disclose a roll-formed nucleate boiling plate having a first pattern of grooves separated by ridges, and a second pattern of more-shallow grooves machined into the ridges. The second pattern depth is said to be about 10-50% of the depth of the first pattern.

[0013] US 7,032,654 B2 appears to disclose a heat exchanger having fins with enhanced-surfaces, and with holes in the fins.

[0014] US 4,663,243 A appears to disclose a heat exchanger surface having flamesprayed ferrous alloy enhanced boiling surfaces.

[0015] Finally, US 4,753,849 appears to disclose a heat exchanger tube with a porous coating to enhanced heat transfer.

Disclosure of the Invention

[0016] With parenthetical reference to the corresponding parts, portions or surfaces of one or more of the disclosed embodiments, merely for purposes of illustration and not by way of limitation, the present invention broadly provides: (1) improved methods of forming enhanced-surface walls for use in apparatuses (e.g., heat

[0017] transfer devices, fluid mixing devices, etc.) for performing a process, (2) to enhanced-surface walls *per se*, and (3) to various apparatuses incorporating such en-

hanced-surface walls.

[0018] In one aspect, the invention provides an improved method of forming an enhanced-surface wall (20) for use in an apparatus for performing a process, comprising the steps of: providing a length of material (21) having opposite initial surfaces (21a, 21b), the material having a longitudinal centerline (x-x) positioned substantially midway between the initial surfaces, the material having an initial transverse dimension measured from the centerline to a point on either of the initial surfaces located farthest away from the centerline, each of the initial surfaces having an initial surface density, the surface density being defined as the number of characters on an surface per unit of projected surface area; impressing secondary patterns (23a, 23b) having secondary pattern surface densities onto each of the initial surfaces to distort the material and to increase the surface densities on each of the surfaces and to increase the transverse dimension of the material from the centerline to the farthest point of such distorted material; and impressing primary patterns (25a, 25b) having primary pattern surface densities onto each of such distorted surfaces to further distort the material and to further increase the surface densities on each of the surfaces; characterized in that the step of impressing said primary pattern onto each of said surfaces further increases the dimension from said centerline to the farthest point of said further-distorted material; and the step of impressing said primary patterns onto said material does not reduce the minimum dimension of said further-distorted material, when measured from said centerline to any point on either of said further-distorted surfaces, below 50% of the minimum dimension of said material, when measured from said centerline to either of said initial surfaces; thereby to provide an enhanced-surface wall for use in an apparatus for performing a process.

[0019] Each secondary pattern surface density may be greater than each primary pattern surface density.

[0020] The step of impressing the secondary patterns onto each of the initial surfaces may include the additional step of: cold-working the material.

[0021] The step of impressing the primary patterns onto each of distorted surfaces may include the additional step of: cold-working the material.

[0022] The secondary patterns may be the same.

[0023] The secondary patterns may be shifted relative to one another such that a maximum dimension from the centerline to one distorted surface will correspond to a minimum dimension from the centerline to the other distorted surface.

[0024] The step of impressing the secondary patterns onto the material may increase the maximum transverse dimension of the material from the centerline to the farthest point of the distorted material of up to 135% of the maximum transverse dimension from the centerline to the farthest point on the initial surface.

[0025] The step of impressing the secondary patterns onto the material may increase the maximum transverse

dimension of the material from the centerline to the farthest point of the distorted material of up to 150% of the maximum transverse dimension from the centerline to the farthest point on the initial surface.

[0026] The step of impressing the secondary patterns onto the material may increase the maximum transverse dimension of the material from the centerline to the farthest point of the distorted material of up to 300% of the maximum transverse dimension from the centerline to the farthest point on the initial surface.

[0027] The step of impressing the secondary patterns onto the material may increase the maximum transverse dimension of the material from the centerline to the farthest point of the distorted material of up to 700% of the maximum transverse dimension from the centerline to the farthest point on the initial surface.

[0028] The step of impressing the secondary patterns onto the material may not reduce the minimum dimension of the material, when measured from any point on one of such distorted surfaces to the closest point on the opposite one of such distorted surfaces, below 95% of the minimum dimension from any point on one of the initial surfaces to the closest point on the opposite initial surface.

[0029] The step of impressing the secondary patterns onto the material may not reduce the minimum dimension of the material, when measured from any point on one of such distorted surfaces to the closest point on the opposite one of such distorted surfaces, below 50% of the minimum dimension from any point on one of the initial surfaces to the closest point on the opposite initial surface.

[0030] The primary patterns may be the same.

[0031] The primary patterns may be shifted relative to one another such that a maximum dimension from the centerline to one further-distorted surface will correspond to a minimum dimension from the centerline to the other further-distorted surface.

[0032] The step of impressing the primary patterns onto the material may not reduce the minimum dimension of the further-distorted material, when measured from the centerline to any point on either of the further-distorted surfaces, below 95% of the minimum dimension of the material, when measured from the centerline to either of the initial surfaces.

[0033] The opposite surfaces of the material may be initially planar.

[0034] The steps of impressing the patterns may include the steps of impressing the patterns by at least one of a rigidizing, stamping, rolling, pressing and embossing operation.

[0035] The method may further comprise the additional steps of: bending the enhanced-surface wall such that the proximate ends are positioned proximate to one another; and joining the proximate ends of the material together; thereby to form an enhanced-surface tube.

[0036] The step of joining the proximate ends of the material together may include the further step of: welding

the proximate ends of the material to join them together.

[0037] The method may further comprise the additional step of: providing holes through the material.

[0038] The method may further comprise the additional step of: installing the enhanced-surface wall in a heat exchanger.

[0039] The method may further comprise the additional step of: installing the enhanced-surface wall in a fluid-handling apparatus.

[0040] These and other objects and advantages will become apparent from the foregoing and ongoing written specification, the drawings and the appended claims.

Brief Description of the Drawings

[0041]

Fig. 1A is a schematic top plan view of a length of material showing the Secondary 1 and Primary 1 patterns being impressed thereon.

Fig. 1B is a side elevation of the structure schematically shown in Fig. 1A.

Fig. 2A is an enlarged top plan view of the Secondary 1 pattern, as shown in Figs. 1A-1B, impressed into the material.

Fig. 2B is an enlarged top plan view of the Primary 1 pattern impressed into a sheet of supplied material, the scale of Fig. 2B being the same as the scale of Fig. 2A

Fig. 2C is a top plan view of the superimposed Primary 1 and Secondary 1 patterns, as shown in Figs. 1A-1B, impressed into the material, the scale of Fig. 2C being the same as the scale of Figs. 2A-2B.

Fig. 3A is a greatly-enlarged fragmentary transverse vertical sectional view of the material prior to impressing the Secondary 1 patterns thereon, this view being taken generally on line 3A-3A of Fig. 1A.

Fig. 3B is a greatly-enlarged fragmentary transverse vertical sectional view thereof, taken generally on line 3B-3B of Fig. 2A, showing the Secondary 1 patterns impressed onto the material.

Fig. 3C is a greatly-enlarged fragmentary transverse sectional view, taken generally on line 3C-3C of Fig. 2B, showing the Primary 1 patterns impressed into the material.

Fig. 3D is a greatly-enlarged fragmentary transverse sectional view thereof, taken generally on line 3D-3D of Fig. 2C, showing the Primary 1 and Secondary 1 patterns impressed into the material.

Fig. 4 is a schematic transverse vertical sectional view thereof, showing how the Secondary 1 patterns are impressed into the material.

Fig. 5A is a schematic view, showing how the point-to-point wall thickness of a plain sheet is measured.

Fig. 5B is a schematic view, showing how the point-to-point wall thickness of the material is measured after the Secondary 1 patterns have been impressed therein.

Fig. 5C is a schematic view showing how the point-to-point wall thickness of the Primary 1 patterns is measured.

Fig. 5D is a schematic view showing how the point-to-point wall thickness of the finished enhanced-surface material is measured, this material having the super imposed Primary 1 and Secondary 1 patterns impressed thereon.

Fig. 6A is a schematic view showing how the area thickness of a plain sheet is measured.

Fig. 6B is a schematic view showing how the area wall thickness is measured after the Secondary 1 patterns have been impressed thereon.

Fig. 6C is a schematic view showing how the area wall thickness is measured after the Primary 1 patterns have been impressed thereon.

Fig. 6D is a schematic view showing how the area wall thickness of an enhanced-surface wall is measured after the Primary 1 and Secondary 1 patterns have been impressed thereon.

Fig. 7A is a top plan view showing another primary pattern, designated the Primary 2 pattern, impressed on a sheet.

Fig. 7B is a fragmentary transverse vertical sectional view thereof taken on line 7B-7B of Fig. 7A.

Fig. 7C is a fragmentary transverse horizontal sectional view thereof, taken generally on line 7C-7C of Fig. 7A.

Fig. 8A is a top plan view of a third primary pattern, designated the Primary 3 pattern, impressed on a sheet of material.

Fig. 8B is a fragmentary transverse vertical sectional view thereof, taken generally on line 8B-8B of Fig. 8A.

Fig. 8C is a fragmentary transverse horizontal sectional view thereof, taken generally on line 8C-8C of Fig. 8A.

Fig. 9A is a top plan view of another primary pattern, designated the Primary 4 pattern, impressed into a sheet of material, this pattern having a character surface density of 0.5.

Fig. 9B is a view similar to Fig. 9A, but showing a variant form of the Primary 4 pattern having a character surface density of 1.0.

Fig. 9C is a view similar to Figs. 9A and 9B, but showing another variant form of the Primary 4 pattern having a character surface density of 2.0.

Fig. 10A is a top plan view of another primary pattern, designated the Primary 5 pattern, impressed on a sheet of material.

Fig. 10B is a fragmentary transverse vertical sectional view thereof, taken generally on line 10B-10B of Fig. 10A.

Fig. 10C is a fragmentary transverse horizontal sectional view thereof, taken generally on line 10C-10C of Fig. 10A.

Fig. 11A is a top plan view of another secondary pattern, designated the Secondary 2 pattern, im-

pressed into the material, this view showing the individual characters as being somewhat oval-shaped. Fig. 11B is a fragmentary transverse vertical sectional view thereof, taken generally on line 11B-11B of Fig. 11A.

Fig. 11C is a fragmentary transverse horizontal sectional view thereof, taken generally on line 11C-11C of Fig. 11A.

Fig. 12A is a top plan view of another secondary pattern, designated the Secondary 3 pattern, impressed onto a length of material, this view showing the individual characters as being somewhat lemon-shaped.

Fig. 12B is a fragmentary transverse vertical sectional view thereof, taken generally on line 12B-12B of Fig. 12A.

Fig. 12C is a fragmentary transverse horizontal sectional view thereof, taken generally on line 12C-12C of Fig. 12A.

Fig. 13A is a top plan view of another primary pattern, designated the Primary 6 pattern, impressed into a length of material.

Fig. 13B is a fragmentary transverse vertical sectional view thereof, taken generally on line 13B-13B of Fig. 13A.

Fig. 14A is still another example of a criss-crossed directional primary pattern, designated the Primary 7 pattern, impressed on a length of material, this pattern being directional in both the longitudinal and transverse directions.

Fig. 14B is fragmentary transverse vertical sectional view thereof, taken generally on line 14B-14B of Fig. 14A.

Fig. 14C is a fragmentary transverse horizontal sectional view thereof, taken generally on line 14C-14C of Fig. 14A.

Fig. 15A is a fragmentary view of another pebble-like non-directional pattern, designated as Secondary 4 pattern, impressed on a length of material.

Fig. 15B is a fragmentary transverse vertical sectional view thereof, taken generally on line 15B-15B of Fig. 15A.

Fig. 15C is a fragmentary transverse horizontal sectional view thereof, taken generally on line 15C-15C of Fig. 15A.

Fig. 16A is a top plan view of yet another honeycomb-like non-directional pattern, designated Secondary 4 pattern, impressed on the length of material.

Fig. 16B is a fragmentary transverse vertical sectional view thereof, taken generally on line 16B-16B of Fig. 15A.

Fig. 16C is a fragmentary transverse horizontal sectional view thereof, taken generally on line 16C-16C of Fig. 16A.

Fig. 17 is a schematic view of one process for making enhanced-surface tubes.

Fig. 18A is a side elevation of a round tube having an optional coating on its outer surface.

Fig. 18B is a right end elevation of the round tube shown in Fig. 18A.

Fig. 18C is an enlarged detail view of the round tube, taken within the indicated circle in Fig. 18B, and particularly showing the coating on the outer surface of the tube.

Fig. 19A is an isometric view of a rectangular tube.

Fig. 19B is a fragmentary transverse vertical sectional view, taken generally on line 19B-19B of Fig. 19A, of the rectangular tube.

Fig. 19C is an enlarged detail view of a portion of the wall of the rectangular tube, this view being taken within the indicated circle in Fig. 19B.

Fig. 20A is a side elevation of a U-shaped tube.

Fig. 20B is a slightly-enlarged fragmentary transverse vertical sectional view thereof, taken generally on line 20B-20B of Fig. 20A.

Fig. 20C is a further-enlarged detail view of a portion of the tube wall, this view being taken within the indicated circle of Fig. 20B.

Fig. 21A is a side elevation of a helically-wound coil formed of a round tube having enhanced inner and outer surfaces.

Fig. 21B is a top plan view of the coil shown in Fig. 21A.

Fig. 21C is an enlarged fragmentary vertical sectional view thereof, taken generally on line 21C-21C of Fig. 21A, showing the tube in the coil.

Fig. 21D is a further-enlarged detail view, taken within the indicated circle of Fig. 21C, showing of a portion of the tube wall.

Fig. 22 is a schematic view of one process for making an enhanced-surface fin.

Fig. 23A is a front elevation of a first enhanced-surface fin having primary and secondary patterns impressed thereon, and having cooler tube and flow-through openings.

Fig. 23B is a fragmentary vertical sectional view thereof, taken generally on line 23B-23B of Fig. 23A.

Fig. 24A is a front elevation of a second enhanced-surface fin having primary and secondary patterns impressed thereon, and having cooler tube and flow-through openings.

Fig. 24B is a fragmentary vertical sectional view thereof, taken generally on line 24B-24B of Fig. 24A.

Fig. 25A is a front elevation of a third enhanced-surface fin having cooler tube openings and smaller flow-through openings.

Fig. 25B is a front elevation of a fourth enhanced-surface fin having cooler tube openings and intermediate flow-through openings.

Fig. 25C is a front elevation of a fifth enhanced-surface fin having cooler tube openings and larger flow-through openings.

Fig. 25D is a front elevation of a sixth enhanced-surface fin having cooler tube openings and one combination of smaller, intermediate and larger flow-through openings.

Fig. 25E is a front elevation of a seventh enhanced-surface fin having cooler tube openings and another combination of smaller, intermediate and larger flow-through openings.

Fig. 26 is a schematic view of an improved heat exchanger having an enhanced-surface heat transfer tube therewithin.

Fig. 27A is a bottom plan view of an improved fluid cooler having enhanced-surface tubes therewithin.

Fig. 27B is a fragmentary horizontal sectional view thereof, taken generally on line 27B-27B of Fig. 27A.

Fig. 27C is a side elevation of the improved cooler shown in Fig. 27A, with the cover in place.

Fig. 27D is a fragmentary vertical sectional view thereof, taken generally on line 27D-27D of Fig. 27C, showing a bottom plan view of one of the fins.

Fig. 27E is an enlarged detail view of a portion of one of the fins, this view being taken within the indicated circle of Fig. 27D.

Fig. 28 is a schematic view of a fluid flow vessel incorporating enhanced surfaces therewithin.

Fig. 29A is a top plan view of a heat exchanger plate incorporating enhanced surfaces therewithin.

Fig. 29B is an enlarged detail view of a portion of the heat exchanger plate, this view being taken within the indicated circle in Fig. 29A.

Description of the Preferred Embodiments

[0042] At the outset, it should be clearly understood that like reference numerals are intended to identify the same structural elements, portions or surfaces consistently throughout the several drawing figures, as such elements, portions or surfaces may be further described or explained by the entire written specification, of which this detailed description is an integral part. Unless otherwise indicated, the drawings are intended to be read (e.g., cross-hatching, arrangement of parts, proportion, degree, etc.) together with the specification, and are to be considered a portion of the entire written description of this invention. As used in the following description, the terms "horizontal", "vertical", "left", "right", "up" and "down", as well as adjectival and adverbial derivatives thereof (e.g., "horizontally", "rightwardly", "upwardly", etc.), simply refer to the orientation of the illustrated structure as the particular drawing figure faces the reader. Similarly, the terms "inwardly" and "outwardly" generally refer to the orientation of a surface relative to its axis of elongation, or axis of rotation, as appropriate. Unless otherwise indicated, all dimensions set forth in the present specification, and in the accompanying drawings, are expressed in inches.

[0043] Referring now to the drawings, and more particularly to Figs. 1-3 thereof, the present invention broadly provides an improved method of forming an enhanced-surface wall 20 for use in an apparatus for performing a process. The apparatus may be a heat transfer device, a type of fluid mixing apparatus (either with or without a

pertinent heat exchange function), or some other form of apparatus.

[0044] This application discloses multiple embodiments of enhanced-surface walls having various primary and/or secondary patterns. The first embodiment is illustrated in Figs. 1A-6D, the second in Figs. 7A-7C, the third in Figs. 8A-8C, the fourth in Figs. 9A-9C, the fifth in Figs. 10A-10C, the sixth in Figs. 11A-11C, the seventh in Figs. 12A-12C, the eighth in Figs. 13A-13B, the ninth in Figs. 14A-14C, the tenth in Figs. 15A-15C, and the eleventh in Figs. 16A-16C. These various patterns may be used in various combinations with one another, and are not exhaustive of all patterns falling within the scope of the appended claims.

[0045] One process of making an enhanced-surface tube is schematically shown in Fig. 17, and several variations of such tubes are depicted in Figs. 18A-21D.

[0046] One process for making an enhanced-surface fin is schematically shown in Fig. 22, and several variations of such fins are shown in Figs. 23A-25E.

[0047] An improved heat exchanger incorporating the enhanced-surface tubes is schematically shown in Fig. 26.

[0048] A cooler incorporating such enhanced-surface fins is depicted in Figs. 27A-27E.

[0049] Another fluid flow vessel incorporated enhanced surfaces is depicted in Fig. 28.

[0050] Finally, an improved plate having various enhanced surfaces is shown in Figs. 29A-29B.

[0051] These various embodiments and applications will be described *seriatim* herebelow.

First Embodiment (Figs. 1A-6D)

[0052] The improved method broadly begins with providing a length of material, of which a fragmentary portion is generally indicated at 21. This material may be a piece of plate-like stock, may be unrolled from a coil, or may have some other source or configuration. The material may be rectangular having planar upper and lower initial surfaces 21a, 21b, respectively, and may have a longitudinal transverse centerline x-x positioned substantially midway between these initial surfaces. As shown in Fig. 3A, the thickness of the material between initial surfaces 21a-21b may be about 0.035 inches, and the nominal spacing from the centerline to either of the surfaces may therefore be about 0.0175 inches.

[0053] The leading edge of the material in this first embodiment is then passed rightwardly (in the direction of the indicated arrow in Fig. 1A) between a pair of upper and lower first rolls or dies 22a, 22b, respectively, which impress the Secondary 1 patterns into the upper and lower surfaces, respectively, of the material. The upper and lower surfaces of the material after the Secondary 1 patterns have been impressed thereon are indicated at 23a, 23b respectively. The material is then translated rightwardly between a second pair of upper and lower rolls or dies 24a, 24b respectively, which impress Primary 1

patterns onto the upper and lower surfaces, respectively of the material.

[0054] Figs. 2A and 3B show the shape and configuration of the material after the Secondary 1 patterns have been impressed thereon. The Secondary 1 patterns have the shape of an array of interlocking paving blocks when seen in top plan (Fig. 2A), but have undulating or sinusoidal shapes when seen in cross-section (Fig. 3B).

[0055] Figs. 2B and 3C show the shape of the Primary 1 patterns if such patterns were impressed into a sheet of plain stock material, without the Secondary 1 patterns impressed thereon. As shown in Figs. 2B and 3C, the Primary 1 patterns are in the form of a series of repeating step-like functions. In Figs. 2B and 3C, the upper surface of the material is indicated at 25a, and the lower surface thereof is indicated at 25b.

[0056] Thus, the material exiting the second dies has the Primary 1 and Secondary 1 patterns superimposed and impressed thereon. These upper and lower surfaces of the material containing the superimposed Primary 1 and Secondary 1 patterns are indicated at 26a, 26b, respectively.

[0057] As shown in Figs. 3A-3B, the step of impressing the Secondary 1 patterns onto the material increases the minimal initial area wall thickness of the material from about 0.035 inches to about 0.045 inches. As shown in Figs. 3A and 3C, the step of impressing the Primary 1 patterns into the initially supplied material would increase the initial area wall thickness from about 0.035 inches to about 0.050 inches. However, as shown in Fig. 3D, when the Primary 1 patterns are superimposed on the Secondary 2 patterns, the thickness of the material, as distorted by the Secondary 1 patterns (i.e., 0.045 inches), is further distorted to a dimension of about 0.052 inches.

[0058] In the accompanying drawings, Figs. 2A-2C are drawn to the same scale (as indicated by the 6.0 x 6.0 dimensions thereon), and are enlarged with respect to the structure shown in Fig. 1A. Figs. 3A-3D are also drawn to the same scale, which is further-enlarged with respect to the scale of Figs. 2A-2C, and is greatly enlarged with respect to the scale of Figs. 1A-1B.

[0059] Fig. 4 shows how the Secondary 1 patterns are impressed into the material. To this end, the top and bottom rolls 22a, 22b impart the undulating sinusoidal Secondary 1 patterns that are vertically aligned with one another such that the peak of one is aligned with the valley of the other. The material 21 is only partially deformed by the two rolls. Thus, the material will have a series of dimple-like concavities indicated at 27, separated by intermediate arcuate convexities, severally indicated at 28. In an alternative process, the material could be fully deformed, or "coined", between the upper and lower rolls.

[0060] In the preferred embodiment, the steps of impressing the primary and secondary patterns into the material has the effect of cold-working the material. However, in an alternative process, the material could be heated, and the process could include the step of hot-working the same. The secondary patterns may be the same, or

may be different from one another. The step of impressing the secondary pattern onto the material increases the maximum transverse dimension of the material from the centerline to the farthest point of the distorted material of up to 135% in one case, 150% in another case, 300% in a third case, and 700% in a fourth case, of the maximum transverse dimension from the centerline to the farthest point of the initial surfaces. The steps of impressing the primary and secondary patterns into the material does not materially reduce the minimum dimension of the material, when measured from any point on one of the distorted surfaces to the closest point on the opposite one of the distorted surfaces, below 95% in one case, and 50% in a second case, of the minimum dimension from any point on one of the initial surfaces to the closed point on the opposite initial surface.

[0061] The primary patterns impressed into the opposite sides of the material may be the same, or may be different. The step of impressing the primary patterns into the material does not reduce the minimum dimension of the further-distorted material, when measured from the centerline to any point on either of the further-distorted surfaces, below 95% of the minimum dimension of the material, when measured from the centerline to either one of the initial surfaces.

[0062] The primary patterns impressed into the opposite sides of the material may be the same, or may be different. The step of impressing the primary patterns into the material does not reduce the minimum dimension of the further-distorted material, when measured from the centerline to any point on either of the further-distorted surfaces, below 50% of the minimum dimension of the material, when measured from the centerline to either one of the initial surfaces.

[0063] In one aspect, the step of impressing the primary patterns onto each of the surfaces may further increase the dimension from the centerline to the farthest point of the further-distorted material.

[0064] The initial surfaces may be planar or may be supplied with some pattern or patterns impressed thereon. The step of impressing the primary and secondary patterns onto the material may be by a rigidizing operation, a stamping operation, a rolling operation, a pressing operation, an embossing operation, or by some other type of process or operation. Similarly, the material may be supplied with cooler tube openings and/or with flow-through openings of whatever pattern is desired.

[0065] The method may further include the additional step of bending the enhanced-surface wall such that the proximate ends are positioned adjacent one another, and joining the proximate ends of the material together, as by welding to form an enhanced-surface tube. The method may include the further step of providing holes through the material.

[0066] As indicated above, the enhanced-surface wall may be installed in heat exchanger, in some type of fluid-handling apparatus or in still other forms of apparatus as well.

[0067] The primary patterns may be directional or non-directional. The enhanced-surface wall complies with at least one of the following ASME/ASTM designations: A249/A, A135, A370, A751, E213, E273, E309, E1806, A691, A139, A213, A214, A268, A 269, A270, A312, A334, A335, A498, A631, A671, A688, A691, A778, A299/A, A789, A789/A, A789/M, A790, A803, A480, A763, A941, A1016, A1012, A1047/A, A250, A771, A826, A851, B674, E112, A370, A999, E381, E426, E527, E340, A409, A358, A262, A240, A537, A530, A435, A387, A299, A204, A20, A577, A578, A285, E165, A380, A262 and A179. Each of the foregoing designations is hereby incorporated by reference.

[0068] The material may be provided with a coating (e.g., a plating, etc.) on at least a portion of one of its initial surfaces, or such initial surface(s) may be chemically treated (e.g., electro-polished, etc.). Such coating and/or chemical treatment may be applied before, during or after the formation of the enhanced surfaces thereon. As used herein, the term "portion" includes a range of from 0-100%.

[0069] The invention also includes an enhanced-surface wall formed by the foregoing method.

[0070] Figs. 5A-5D show how the point-to-point wall thickness is measured during various stages of the method. As used herein, the term "point-to-point wall thickness" means the thickness of the material from a point on one surface thereof to the closest point on the opposite surface thereof. Thus, Fig. 5A shows a micrometer as measuring the initial thickness between planar surfaces 21a, 21b. Fig. 5B shows the micrometer as measuring the wall thickness after the Secondary 1 patterns have been impressed thereon. This view schematically shows two measuring orientations, one being of the vertical thickness and the other being at an angle, such that the lesser of the two measured thicknesses may be used. Fig. 5C shows how the point-to-point wall thickness would be measured when the primary pattern is impressed into the material. Finally, Fig. 5D shows the micrometer as measuring the point-to-point wall thickness of the material after the Primary 1 and Secondary 1 patterns have been impressed thereon. Here again, the lesser of the two measured thicknesses is used as the measure of the minimum wall thickness. These two illustrations of the orientation of the micrometer are not exhaustive of all possible orientations thereof.

[0071] Fig. 6A-6D shows how the area thickness of the material is measured at various stages during the performance of the method. The thickness is measured by measuring the peak-to-peak distance of the opposed surfaces, and, usually, by encompassing several peaks along each of the two surfaces. Thus, Fig. 6A shows the micrometer as measuring the thickness of the initially-supplied material having planar upper and lower surfaces 21a, 21b, respectively. Since these surfaces are planar, the micrometer can simply measure the distance therebetween. Fig. 6B shows the micrometer as measuring the thickness of the material after the Secondary 1 pattern

has been impressed thereon. Note that the micrometer is measuring the peak-to-peak thickness of the amplitudes of both surfaces. Fig. 6C shows the micrometer as measuring the thickness of the material if the Primary 1 patterns were to be impressed on the initially-supplied material. In this view, the micrometer is again measuring the peak-to-peak thickness across multiple characters impressed on the surfaces. Finally, Fig. 6D shows the micrometer as measuring the wall thickness of the material after the Primary 1 and Secondary 1 patterns have been impressed thereon.

[0072] Because the "point-to-point wall thickness" means the thickness of the material from a point on one surface thereof to the closest point on the opposite surface thereof, it is sometimes required to measure such dimension both vertically and at various angles to determine which is the minimum thickness. However, because the "area thickness" refers to a peak on one surface to a peak on the opposite surface dimension, this can usually be measured vertically. The "area thickness" preferably encompasses multiple peaks on each surface.

Second Embodiment (Figs. 7A-7C)

[0073] A second primary pattern, designated the Primary 2 pattern, is illustrated in Figs. 7A-7C, and is generally indicated at 30. This pattern somewhat resembles a raised honeycomb, and has an upper surface 31a and a lower surface 31b. This pattern is directional in the vertical direction, but non-directional in the horizontal direction. The vertical and horizontal transverse cross-sections are shown in Figs. 7B-7C.

Third Embodiment (Figs. 8A-8C)

[0074] Figs. 8A-8C show another furrow-like primary pattern, designated the Primary 3 pattern. This pattern is generally indicated at 32. This pattern is directional in the vertical direction, but is non-directional in the horizontal direction. The vertical and horizontal transverse cross-sections are shown in Figs. 8B-8C. This pattern has sinusoidal undulations, albeit of different periods, in each of the two orthogonal transverse directions on its upper and lower surfaces.

Fourth Embodiment (Figs. 9A-9C)

[0075] Figs. 9A-9C show another secondary pattern designated the Secondary 2 pattern. This pattern comprises of a series of dimple-like indentations on one surface, and vertically-aligned convexities on the opposite surface. These dimples can be staggered or in-line, as desired. This pattern is generally indicated at 34 in Fig. 9A, and is shown as having an upper surface 35a.

[0076] Figs. 9B-9C show density variations on the pattern shown in Fig. 9A. In Fig. 9A, the pattern is indicated at 34', and the upper surface is indicated at 35a'. The surface density of the dimple-like characters in pattern

34 shown in Fig. 9A is 0.5 of that for the modified pattern 34' shown in Fig. 9B, and 0.25 of that for the further-modified pattern 34'' shown in Fig. 9C. Thus, the surface density of the dimple-like characters in Fig. 9B is twice that shown in Fig. 9A. Similarly, surface density of the dimple-like characters in Fig. 9C is twice the surface density of the characters in Fig. 9B, and four times the surface density of the characters shown in Fig. 9A.

[0077] Figs. 9A-9C are drawn to the same scale, as indicated by the 6.0 x 6.0 dimensions.

Fifth Embodiment (Figs. 10A-10C)

[0078] Figs. 10A-10C show another chevron-like primary pattern designated the Primary 4 pattern. This pattern is non-directional in both the horizontal and vertical directions. The pattern is generally indicated at 36, and has upper and lower surfaces 38a, 38b.

Sixth Embodiment (Figs. 11A-11C)

[0079] Figs. 11A-11C show another form of secondary pattern designated the Secondary 2 pattern, impressed into the material. In this form, the individual dimples or characters are somewhat oval-shaped. Note that the period of the dimples is different in the two orthogonal directions, as shown in Figs. 11B-11C. This pattern is generally indicated at 39, and is shown as having upper and lower surfaces 40a, 40b, respectively.

Seventh Embodiment (Figs. 12A-12C)

[0080] Figs. 12A-12C show still another type of secondary pattern, designated the Secondary 3 pattern. The dimples or characters of this pattern appear to be somewhat lemon-shaped. Here again, note that the periods of the patterns is different in each of the two orthogonal transverse directions, as shown in Figs. 12B-12C. This pattern is generally indicated at 41, and is shown as having upper and lower surfaces 42a, 42b, respectively.

Eighth Embodiment (Figs. 13A-13B)

[0081] Figs. 13A-13B are used to illustrate a directional pattern, designated the Primary 6 pattern. This pattern is generally indicated at 43, and is shown as having upper and lower surfaces 44a, 44b, respectively. Note that the pattern appears to have a series of step functions on its opposite surfaces, as shown in Fig. 13B. Note also, and the characters are aligned such that each projection on one surface corresponds with an indentation on the other surface. This pattern is directional in the horizontal direction, but not in the vertical direction.

Ninth Embodiment (Figs. 14A-14C)

[0082] Figs. 14A-14C show a criss-crossed pattern designated the Primary 7 pattern, impressed on the ma-

terial. This pattern is generally indicated at 45, and is shown as having an upper surface 46a and a lower surface 46b. This pattern is directional (i.e., not interrupted) in both the horizontal and vertical directions. Note that the period of the characters is the same in both orthogonal transverse directions.

Tenth Embodiment (Figs. 15A-15C)

[0083] Figs. 15A-15C show an irregular pebble-like, albeit repeating, non-directional secondary pattern impressed on the material. This pattern is designated the Secondary 4 pattern. This pattern is generally indicated at 48, and has upper and lower surfaces 49a, 49b, respectively. The cross-sections in the orthogonal axes are shown in Figs. 15B-15C, respectively. In Figs. 15B-15C, note that the indentation on one surface is vertically aligned with a projection on the other surface. This pattern is non-directional in the sense that the pattern is interrupted in each of the horizontal and vertical directions. As used herein, the term "directional" with respect to a pattern means that the lines of the pattern are continuous and not interrupted along a direction, whereas the term "non-directional" means that the lines of the pattern are interrupted along a direction, even though the pattern may repeat.

Eleventh Embodiment (Figs. 16A-16C)

[0084] Figs. 16A-16C show still another honeycomb-like non-directional secondary pattern, designated the Secondary 5 pattern impressed on a material. This pattern is generally indicated at 50, and is shown as having upper and lower surfaces 51a, 51b, respectively. This pattern is non-directional in the vertical and horizontal directions.

Method of Making an Enhanced-Surface Tube (Fig. 17)

[0085] Fig. 17 depicts one method of making a round tube having enhanced surfaces. According to this process, a coil 52 having the primary and secondary patterns (and, optionally, whatever cooler tube and flow-through openings are desired) is unwound. The leading edge of the material passes through a series of rollers and roller dies, severally indicated at 53, within which the planar sheet material is rolled into a round tube with the two longitudinal edges being arranged closely adjacent, or, preferably, abutting, one another. The rolled tube is then passed through a preheating unit 54 and a welding unit 55 to weld the longitudinal edges together. The welded tube is then passed through a secondary heating unit 56 to anneal the weld and the material, and is then cooled in a cooling unit 58. The cooled welded tube is then passed through a deburrer to smooth the weld edges, and is further advanced rightwardly by rollers 60, 60.

Round Tube (Figs. 18A-18C)

[0086] Tubes may have many different shapes and cross-sections. Figs. 18A-18C depict a length of welded round tube that may be manufactured by the process indicated in Fig. 17. The tube, generally indicated at 62, is shown as having primary and secondary patterns. As best shown in Fig. 18B, tube 62 has a thin-walled circular transverse cross-section.

[0087] The tube outer wall is also shown as having a coating 63 thereon. This coating may be a plating, or some other form of coating or lamination. This coating is optional and may be provided on any of the enhanced surfaces disclosed herein. The coating can be provided on the inner or outer surface of a tube, as desired.

Rectangular Tube (Figs. 19A-19C)

[0088] As noted above, not all tubes have a round transverse cross-section. Some tubes have oval-shaped cross-sections, polygonal cross-sections, or the like.

[0089] Figs. 19A-19C depict a tube 64 having a generally-rectangular transverse cross-section, with primary and secondary patterns on its inner and outer surfaces. This tube may, if desired, be formed with a coating or may be chemically treated.

U-Shaped Tube (Figs. 20A-20C)

[0090] Figs. 20A-20C depict a round tube which is bent to have a U-shape, when seen in elevation. This tube, generally indicated at 65, has primary and secondary patterns on its inner and outer surfaces.

Coil formed of Round Tube (Figs. 21A-21D)

[0091] Figs. 21A-21D depict a helically-wound coil formed from a length of round tubing. This coil, generally indicated at 66, has primary and secondary patterns on its inner and outer surfaces.

Method of Making an Enhanced-Surface Fin (Fig. 22)

[0092] Fig. 22 is a schematic view of one process for forming enhanced-surface fins. In this process, a coil 68 of material with primary and secondary patterns is unrolled. The leading edge of the material passes around idler rollers 69a, 69b, c9c, and is then passed between an opposed pair of roller dies 70a, 70b, which punch or form various holes (e.g., cooling tube holes and/or flow-through holes in whatever pattern is desired) in the material. The leading edge is then passed through a second pair of roller dies 71a, 71b, which form flanges on the material. The leading edge is then passed under a cut-off shear 72, where individual fins, severally indicated at 73, are cut from the roll material. These fins are moved rightwardly by the action of rollers 74.

Fins Having Cooler Tube Openings and Flow-Through Openings (Figs. 23A-25E)

[0093] Figs. 23A-25E show different forms of improved fins having different combinations of primary and secondary patterns, and having cooler tube openings and variously-sized flow through openings.

[0094] A first form of fin is generally indicated at 75 in Figs. 23A-23B. In this first form, the individual characters of the primary and secondary patterns are indicated at 76', 76", respectively. The cooling tube openings (i.e., the openings in the fins to accommodate passage of various cooling tubes (not shown)) are severally indicated at 77, and the relatively-small flow-through openings are severally indicated at 78.

[0095] A second form of fin is generally indicated at 79 in Figs. 24A-24B. In this second form, the individual characters of the primary and secondary patterns are again indicated at 76', 76", respectively. The cooling tube openings and the relatively-small flow-through openings are again indicated at 77, 78, respectively. Notice that second fin 78 is thinner, and more deeply distorted than first fin 75.

[0096] Five different fins are illustrated in Figs. 25A-25E. In each of these figures, the cooling tube openings or holes are indicated at 77. The salient difference between these five figures lies in the size and configuration of the flow-through openings. In Fig. 25A, a third form of fin, generally indicated at 79, is shown as having a plurality of smaller-sized flow-through openings, severally indicated at 80. In Fig. 25B, a fourth form of fin, generally indicated at 79', is shown as having intermediately-sized flow-through openings, severally indicated at 80'. In Fig. 25C, a fifth form of fin, generally indicated at 79", is shown as having larger-sized flow-through openings, severally indicated at 80". Fig. 25D illustrates a sixth form of fin having various vertical columns of small, intermediate and large flow-through holes. Fig. 25E illustrates a seventh form of fin having another combination of small, intermediate and large flow-through holes. In each of these cases, the fin has primary and secondary patterns.

Improved Heat Exchanger (Fig. 26)

[0097] An improved heat exchanger, generally indicated at 81, is shown in Fig. 26 as having an outer shell 82. A serpentine enhanced-surface heat transfer tube 83 extends between a hot inlet and a hot outlet on the shell. Cold fluid is admitted to the shell through a cold inlet, and flows around the tube toward a cold outlet, through which it exits the shell. The inlet and outlet connections and/or the tube geometry may be changed, as desired.

Improved Cooler (Figs. 27A-27E)

[0098] Figs. 27A-27E depict an improved cooler, generally indicated at 84. This cooler is shown as having a plurality of enhanced-surface tubes, severally indicated

at 85, that penetrate a bottom 86 and that rise upwardly through a plurality of vertically-spaced fins, severally indicated at 88. The tubes wind through the fins in a serpentine manner. Here again the fluid connections and/or the tube geometry may be changes, as desired. Each fin is shown as having a plurality of cooler tube openings 89 to accommodate passage of the tubes. Each fin has primary and secondary patterns, and may optionally have a number of flow-through openings in whatever pattern is desired.

[0099] Fig. 27A depicts a plan view of the cooler bottom. Fig. 27B is a fragmentary vertical sectional view of the cooler, taken generally on line 27B-27B of Fig. 27A, and shows the tubes as passing upwardly and downwardly through aligned cooler tube openings in the fins. Fig. 27C is a side elevation of the cooler. Fig. 27D is a fragmentary horizontal sectional view through the cooler, taken generally on line 27D-27D of Fig. 27C, and shows a bottom plan view of one of the fins. Finally, Fig. 27E is an enlarged detail view of the lower right portion of the fin, this view being taken within the indicated circle in Fig. 27D.

Improved Fluid-Flow Vessel (Fig. 28)

[0100] An improved fluid-flow vessel is generally indicated at 90 in Fig. 28. This vessel is shown as including a process column, generally indicated at 91, that includes a plurality of vertically-spaced enhanced surface walls, severally indicated at 92. Vapor rises upwardly through the column by sequentially passing through the various walls, and liquid descends through the column by also passing through the various walls. Vapor at the top of the column passes via conduit 93 to a condenser 94. Liquid is returned to the uppermost chamber within the column by a conduit 95. At the bottom of the process column, collected liquid is supplied via a conduit 96 to an enhanced-surface reboiler 98. Vapor leaving this reboiler is supplied to the lowermost chamber of the column via a conduit 99.

Improved Heat Exchanger Plate (Figs. 29A-29B)

[0101] Fig. 29A depicts an improved heat exchanger plate, generally indicated at 100. A plurality of such plates may be stacked on top of one another, and adjacent plates may be sealingly separated by a gasket (not shown) to define flow passageways therebetween. Fig. 29B shows that portions of the heat exchanger plate may have enhanced surfaces thereon so as to facilitate heat transfer. Fig. 29B clearly shows that the illustrated portion of the plate may have primary patterns 101 and secondary patterns 102.

[0102] Therefore, the present invention broadly provides an improved method of forming an enhanced-surface wall for use in an apparatus for performing a process.

Modifications

[0103] The present invention contemplates that many changes and modifications may be made. For example, while it may be preferred to form the material of stainless steel, other types of material(s) (e.g., various alloys of aluminum, titanium, copper, etc. or various ceramics) may be used. The material may be homogenous or non-homogenous. It may be coated or chemically treated, either before, during or after the method described herein. As illustrated above, the primary and secondary patterns may have a variety of different shapes and configurations, some regular and directional, and others not. The same types or configurations of characters may be used in the primary and secondary patterns, with the difference residing in the depth and/or surface density of such characters. The various heat transfer devices disclosed herein may be complete in and of themselves, or may be portions of larger devices, which may have shapes other than those shown.

[0104] Therefore, while the improved method and apparatus has been shown and described, and several modifications and changes thereof discussed, persons skilled in this art will readily appreciate the various additional changes and modification may be made, as defined and differentiated by the following claims.

Claims

1. A method of forming an enhanced-surface wall (20) for use in an apparatus for performing a process, comprising the steps of:

providing a length of material (21) having opposite initial surfaces (21a, 21b), said material having a longitudinal centerline (x-x) positioned substantially midway between said initial surfaces (21a, 21b), said material (21) having an initial transverse dimension measured from said centerline (x-x) to a point on either of said initial surfaces (21a, 21b) located farthest away from said centerline (x-x), each of said initial surfaces (21a, 21b) having an initial surface density, said surface density being defined as the number of characters on an surface per unit of projected surface area;

impressing secondary patterns having secondary pattern surface densities onto each of said initial surfaces (21a, 21b) to distort said material (21) and to increase the surface densities on each of said surfaces (21a, 21b) and to increase the transverse dimension of said material (21) from said centerline (x-x) to the farthest point of such distorted material (21); and
impressing primary patterns having primary pattern surface densities onto each of such distorted surfaces to further distort said material (21)

and to further increase the surface densities on each of said surfaces (21a,21b);

characterized in that

the step of impressing said primary pattern onto each of said surfaces (21a,21 b) further increases the dimension from said centerline (x-x) to the farthest point of said further-distorted material; and

the step of impressing said primary patterns onto said material does not reduce the minimum dimension of said further-distorted material, when measured from said centerline (x-x) to any point on either of said further-distorted surfaces, below 50% of the minimum dimension of said material, when measured from said centerline (x-x) to either of said initial surfaces (21a,21b); thereby to provide an enhanced-surface wall for use in an apparatus for performing a process.

2. The method as set forth in claim 1 wherein each secondary pattern surface density is greater than each primary pattern surface density. 20
3. The method as set forth in claim 1 wherein the step of impressing said secondary patterns onto each of said initial surfaces includes the additional step of: cold-working said material (21). 25
4. The method as set forth in claim 1 wherein the step of impressing said primary patterns onto each of distorted surfaces includes the additional step of: cold-working said material (21). 30
5. The method as set forth in claim 1 wherein said secondary patterns are the same. 35
6. The method as set forth in claim 5 wherein said secondary patterns are shifted relative to one another such that a maximum dimension from said centerline (x-x) to one distorted surface will correspond to a minimum dimension from said centerline (x-x) to the other distorted surface. 40
7. The method as set forth in claim 1 wherein the step of impressing said secondary patterns onto said material increases the maximum transverse dimension of said material from said centerline to the farthest point of said distorted material of up to 135% of the maximum transverse dimension from said centerline to the farthest point on said initial surface. 45
8. The method as set forth in claim 1 wherein the step of impressing said secondary patterns onto said material (21) increases the maximum transverse dimension of said material from said centerline to the farthest point of said distorted material of up to 150% of the maximum transverse dimension from said centerline (x-x) to the farthest point on said initial surface 50

(21a,21 b).

9. The method as set forth in claim 1 wherein the step of impressing said secondary patterns onto said material (21) increases the maximum transverse dimension of said material from said centerline (x-x) to the farthest point of said distorted material of up to 300% of the maximum transverse dimension from said centerline (x-x) to the farthest point on said initial surface (21a,21b). 5
10. The method as set forth in claim 1 wherein the step of impressing said secondary patterns onto said material (21) increases the maximum transverse dimension of said material from said centerline (x-x) to the farthest point of said distorted material of up to 700% of the maximum transverse dimension from said centerline (x-x) to the farthest point on said initial surface (21a,21b). 10
11. The method as set forth in claim 1 wherein the step of impressing said secondary patterns onto said material does not reduce the minimum dimension of said material (21), when measured from any point on one of such distorted surfaces to the closest point on the opposite one of such distorted surfaces, below 95% of the minimum dimension from any point on one of said initial surfaces (21a,21b) to the closest point on the opposite initial surface (21a,21b). 15
12. The method as set forth in claim 1 wherein the step of impressing said secondary patterns onto said material (21) does not reduce the minimum dimension of said material (21), when measured from any point on one of such distorted surfaces to the closest point on the opposite one of such distorted surfaces, below 50% of the minimum dimension from any point on one of said initial surfaces (21a,21b) to the closest point on the opposite initial surface (21a,21b). 20
13. The method as set forth in claim 1 wherein said primary patterns are the same. 25
14. The method as set forth in claim 13 wherein said primary patterns are shifted relative to one another such that a maximum dimension from said centerline (x-x) to one further-distorted surface will correspond to a minimum dimension from said centerline (x-x) to the other further-distorted surface. 30
15. The method as set forth in claim 1 wherein the step of impressing said primary patterns onto said material (21) does not reduce the minimum dimension of said further-distorted material, when measured from said centerline (x-x) to any point on either of said further-distorted surfaces, below 95% of the minimum dimension of said material, when measured from said centerline (x-x) to either of said initial surfaces (21a,21b). 35

faces (21a,21b).

16. The method as set forth in claim 1 wherein the opposite initial surfaces of said material (21) are planar. 5
17. The method as set forth in claim 1 wherein the steps of impressing said patterns includes the step of impressing said patterns by at least one of a stamping and rolling operation. 10
18. The method as set forth in claim 1, and further comprising the additional steps of:
 - bending said enhanced-surface wall (20) such that the proximate ends are positioned proximate to one another; and 15
 - joining the proximate ends of said material (21) together; thereby to form an enhanced-surface tube (62,64,65). 20
19. The method as set forth in claim 18 wherein the step of joining the proximate ends of said material together, includes the further step of: 25
 - welding the proximate ends of said material to join them together.
20. The method as set forth in claim 1, and further comprising the additional step of: 30
 - providing holes through said material.
21. The method as set forth in claim 1, and further comprising the additional step of: 35
 - installing said enhanced-surface wall in a heat transfer device.
22. The method as set forth in claim 1, and further comprising the additional step of: 40
 - installing said enhanced-surface wall in a fluid-handling apparatus.

Patentansprüche

1. Verfahren zum Ausbilden einer Wand (20) mit verbesserter Oberfläche zur Verwendung in einer Vorrichtung zum Durchführen eines Prozesses, umfassend die folgenden Schritte: 45
 - Bereitstellen einer Länge an Material (21) mit gegenüberliegenden anfänglichen Flächen (21a, 21b), wobei das Material eine Längsmittellinie (x-x) aufweist, die im Wesentlichen mittig zwischen den anfänglichen Flächen (21a, 21b) positioniert ist, wobei das Material (21) eine anfängliche Querabmessung aufweist, die von der Mittellinie (x-x) zu einem Punkt auf einer der anfänglichen Flächen (21a, 21b) gemessen ist, der 50

am weitesten von der Mittellinie (x-x) entfernt angeordnet ist, wobei jede der anfänglichen Flächen (21a, 21b) eine anfängliche Flächendichte aufweist, wobei die Flächendichte als die Anzahl an Merkmalen auf einer Fläche pro Einheit eines projizierten Flächenbereichs definiert ist; Aufprägen von sekundären Mustern mit sekundären Musterflächendichten auf jede der anfänglichen Flächen (21a, 21b), um das Material (21) zu verformen und um die Flächendichten an jeder der Flächen (21a, 21b) zu erhöhen und um die Querabmessung des Materials (21) von der Mittellinie (x-x) zu dem entferntesten Punkt eines solch verformten Materials (21) zu erhöhen; und Aufprägen von primären Mustern mit primären Musterflächendichten auf jede der verformten Flächen, um das Material (21) weiter zu verformen und um die Flächendichten auf jeder der Flächen (21a, 21b) weiter zu erhöhen; **dadurch gekennzeichnet, dass** der Schritt des Aufprägens der primären Muster auf jede der Flächen (21a, 21b) die Abmessung von der Mittellinie (x-x) zu dem entferntesten Punkt des weiter verformten Materials weiter erhöht; und der Schritt des Aufprägens der primären Muster auf das Material die Mindestabmessung des weiter verformten Materials, von der Mittellinie (x-x) zu einem beliebigen Punkt auf einer der weiter verformten Flächen gemessen, nicht unter 50 % der Mindestabmessung des Materials, von der Mittellinie (x-x) zu einer der anfänglichen Flächen (21a, 21b) gemessen, reduziert; um dadurch eine Wand mit verbesserter Oberfläche zur Verwendung in einer Vorrichtung zum Durchführen eines Prozesses bereitzustellen.

2. Verfahren nach Anspruch 1, wobei jede sekundäre Musterflächendichte größer als jede primäre Musterflächendichte ist.
3. Verfahren nach Anspruch 1, wobei der Schritt des Aufprägens der sekundären Muster auf jede der anfänglichen Flächen den folgenden zusätzlichen Schritt umfasst: Kaltumformen des Materials (21).
4. Verfahren nach Anspruch 1, wobei der Schritt des Aufprägens der primären Muster auf jede der verformten Flächen den folgenden zusätzlichen Schritt umfasst: Kaltumformen des Materials (21).
5. Verfahren nach Anspruch 1, wobei die sekundären Muster dieselben sind.
6. Verfahren nach Anspruch 5, wobei die sekundären

- Muster relativ zueinander derart verschoben werden, dass eine maximale Abmessung von der Mittellinie (x-x) zu einer verformten Fläche einer Mindestabmessung von der Mittellinie (x-x) zu der anderen verformten Flächen entsprechen wird.
- 5
7. Verfahren nach Anspruch 1, wobei der Schritt des Aufprägens der sekundären Muster auf das Material die maximale Querabmessung des Materials von der Mittellinie zu dem entferntesten Punkt des verformten Materials auf bis zu 135 % der maximalen Querabmessung von der Mittellinie zu dem entferntesten Punkt auf der anfänglichen Fläche erhöht.
- 10
8. Verfahren nach Anspruch 1, wobei der Schritt des Aufprägens der sekundären Muster auf das Material (21) die maximale Querabmessung des Materials von der Mittellinie zu dem entferntesten Punkt des verformten Materials auf bis zu 150 % der maximalen Querabmessung von der Mittellinie (x-x) zu dem entferntesten Punkt auf der anfänglichen Fläche (21a, 21b) erhöht.
- 15
9. Verfahren nach Anspruch 1, wobei der Schritt des Aufprägens der sekundären Muster auf das Material (21) die maximale Querabmessung des Materials von der Mittellinie (x-x) zu dem entferntesten Punkt des verformten Materials auf bis zu 300 % der maximalen Querabmessung von der Mittellinie (x-x) zu dem entferntesten Punkt auf der anfänglichen Fläche (21a, 21b) erhöht.
- 25
10. Verfahren nach Anspruch 1, wobei der Schritt des Aufprägens der sekundären Muster auf das Material (21) die maximale Querabmessung des Materials von der Mittellinie (x-x) zu dem entferntesten Punkt des verformten Materials auf bis zu 700 % der maximalen Querabmessung von der Mittellinie (x-x) zu dem entferntesten Punkt auf der anfänglichen Fläche (21a, 21b) erhöht.
- 30
11. Verfahren nach Anspruch 1, wobei der Schritt des Aufprägens der sekundären Muster auf das Material die Mindestabmessung des Materials (21), von einem beliebigen Punkt auf einer der verformten Flächen zu dem nächsten Punkt auf der gegenüberliegenden der so verformten Flächen gemessen, nicht unter 95 % der Mindestabmessung von einem beliebigen Punkt auf einer der anfänglichen Flächen (21a, 21b) zu dem nächsten Punkt auf der gegenüberliegenden anfänglichen Fläche (21a, 21b) reduziert.
- 35
12. Verfahren nach Anspruch 1, wobei der Schritt des Aufprägens der sekundären Muster auf das Material (21) die Mindestabmessung des Materials (21), von einem beliebigen Punkt auf einer der so verformten Flächen zu dem nächsten Punkt auf der gegenüber-
- 40
- liegenden der so verformten Flächen gemessen, nicht unter 50 % der Mindestabmessung von einem beliebigen Punkt auf einer der anfänglichen Flächen (21a, 21b) zu dem nächsten Punkt auf der gegenüberliegenden anfänglichen Fläche (21a, 21b) reduziert.
- 45
13. Verfahren nach Anspruch 1, wobei die primären Muster dieselben sind.
- 50
14. Verfahren nach Anspruch 13, wobei die primären Muster relativ zueinander derart verschoben werden, dass eine maximale Abmessung von der Mittellinie (x-x) zu einer weiter verformten Fläche einer Mindestabmessung von der Mittellinie (x-x) zu der anderen weiter verformten Fläche entsprechen wird.
- 55
15. Verfahren nach Anspruch 1, wobei der Schritt des Aufprägens der primären Muster auf das Material (21) die Mindestabmessung des weiter verformten Materials, von der Mittellinie (x-x) zu einem beliebigen Punkt auf einer der weiter verformten Flächen gemessen, nicht unter 95 % der Mindestabmessung des Materials, von der Mittellinie (x-x) zu einer der anfänglichen Flächen (21a, 21b) gemessen, reduziert.
16. Verfahren nach Anspruch 1, wobei die gegenüberliegenden anfänglichen Flächen des Materials (21) planar sind.
17. Verfahren nach Anspruch 1, wobei die Schritte des Aufprägens der Muster den Schritt Aufprägen der Muster durch mindestens eines eines Stanz- und eines Walzvorgangs umfasst.
18. Verfahren nach Anspruch 1 und ferner umfassend die zusätzlichen Schritte
Biegen der Wand (20) mit verbesserter Oberfläche derart, dass die nahe gelegenen Enden nahe zueinander positioniert sind; und
Zusammenfügen der nahe gelegenen Enden des Materials (21) ;
um dadurch eine Röhre (62, 64, 65) mit verbesserter Oberfläche auszubilden.
19. Verfahren nach Anspruch 18, wobei der Schritt des Zusammenfügens der nahe gelegenen Enden des Materials den folgenden weiteren Schritt umfasst:
Schweißen der nahe gelegenen Enden des Materials, um sie zusammenzufügen.
20. Verfahren nach Anspruch 1 und ferner umfassend den folgenden zusätzlichen Schritt:
Bereitstellen von Löchern durch das Material.
21. Verfahren nach Anspruch 1 und ferner umfassend den folgenden zusätzlichen Schritt:

Einbauen der Wand mit verbesserter Oberfläche in eine Wärmeübertragungsvorrichtung.

22. Verfahren nach Anspruch 1 und ferner umfassend den folgenden zusätzlichen Schritt:
Einbauen der Wand mit verbesserter Oberfläche in eine Fluidbehandlungsvorrichtung.

Revendications

1. Procédé de formation d'une paroi (20) à surface améliorée destinée à être utilisée dans un appareil servant à effectuer un processus, comportant les étapes consistant à :

mettre en place une longueur de matériau (21) présentant des surfaces initiales (21a, 21b) opposées, ledit matériau présentant un axe médian longitudinal (x-x) positionné sensiblement à mi-chemin entre lesdites surfaces initiales (21a, 21b), ledit matériau (21) présentant une dimension transverse initiale mesurée dudit axe médian (x-x) à un point sur l'une ou l'autre desdites surfaces initiales (21a, 21b) située le plus loin dudit axe médian (x-x), chacune desdites surfaces initiales (21a, 21b) présentant une densité surfacique initiale, ladite densité surfacique étant définie comme le nombre de caractères sur une surface par unité d'aire de surface projetée ;

empreindre des motifs secondaires présentant des densités surfaciques de motifs secondaires sur chacune desdites surfaces initiales (21a, 21b) pour déformer ledit matériau (21) et pour accroître les densités surfaciques sur chacune desdites surfaces (21a, 21b) et pour accroître la dimension transverse dudit matériau (21) dudit axe médian (x-x) au point le plus éloigné dudit matériau (21) déformé ; et

empreindre des motifs primaires présentant des densités surfaciques de motifs primaires sur chacune desdites surfaces déformées pour déformer davantage ledit matériau (21) et pour accroître davantage les densités surfaciques sur chacune desdites surfaces (21a, 21b) ;

caractérisé en ce que

l'étape consistant à empreindre ledit motif primaire sur chacune desdites surfaces (21a, 21b) accroît davantage la dimension dudit axe médian (x-x) au point le plus éloigné dudit matériau davantage déformé ; et

l'étape consistant à empreindre lesdits motifs primaires sur ledit matériau ne réduit pas la dimension minimum dudit matériau davantage déformé, mesurée dudit axe médian (x-x) à un point quelconque sur l'une ou l'autre desdites surfaces davantage déformées, au-dessous de

50% de la dimension minimum dudit matériau, mesurée dudit axe médian (x-x) à l'une ou l'autre desdites surfaces initiales (21a, 21b) ; pour réaliser ainsi une paroi à surface améliorée destinée à être utilisée dans un appareil servant à effectuer un processus.

2. Procédé selon la revendication 1, chaque densité surfacique de motifs secondaires étant supérieure à chaque densité surfacique de motifs primaires.

3. Procédé selon la revendication 1, l'étape consistant à empreindre lesdits motifs secondaires sur chacune desdites surfaces initiales comprenant l'étape supplémentaire consistant à : travailler ledit matériau (21) à froid.

4. Procédé selon la revendication 1, l'étape consistant à empreindre lesdits motifs primaires sur chacune des surfaces déformées comprenant l'étape supplémentaire consistant à : travailler ledit matériau (21) à froid.

5. Procédé selon la revendication 1, lesdits motifs secondaires étant les mêmes.

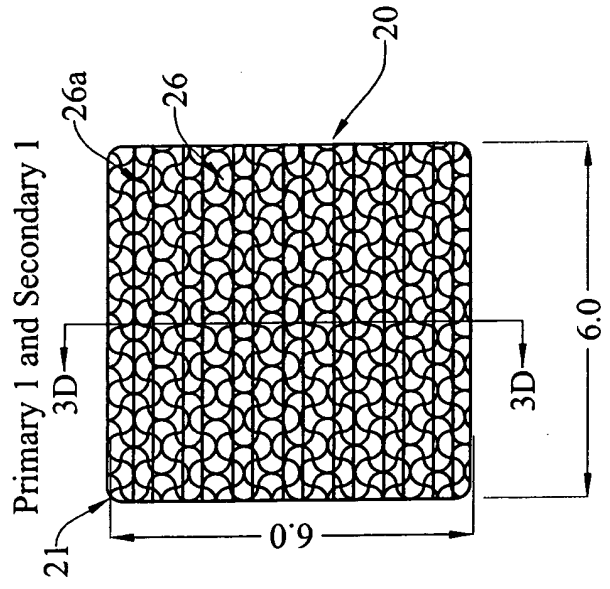
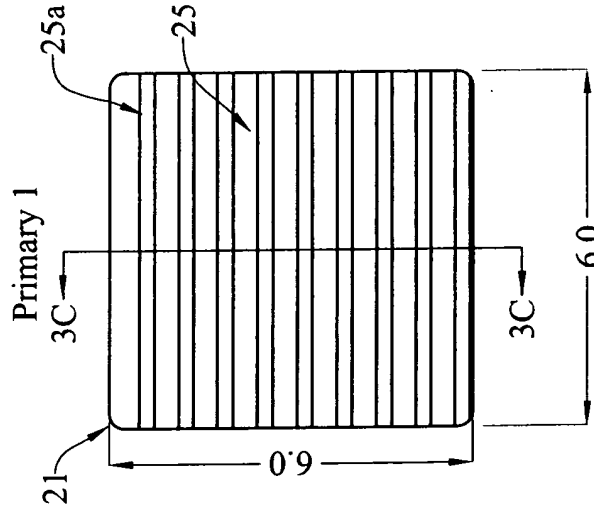
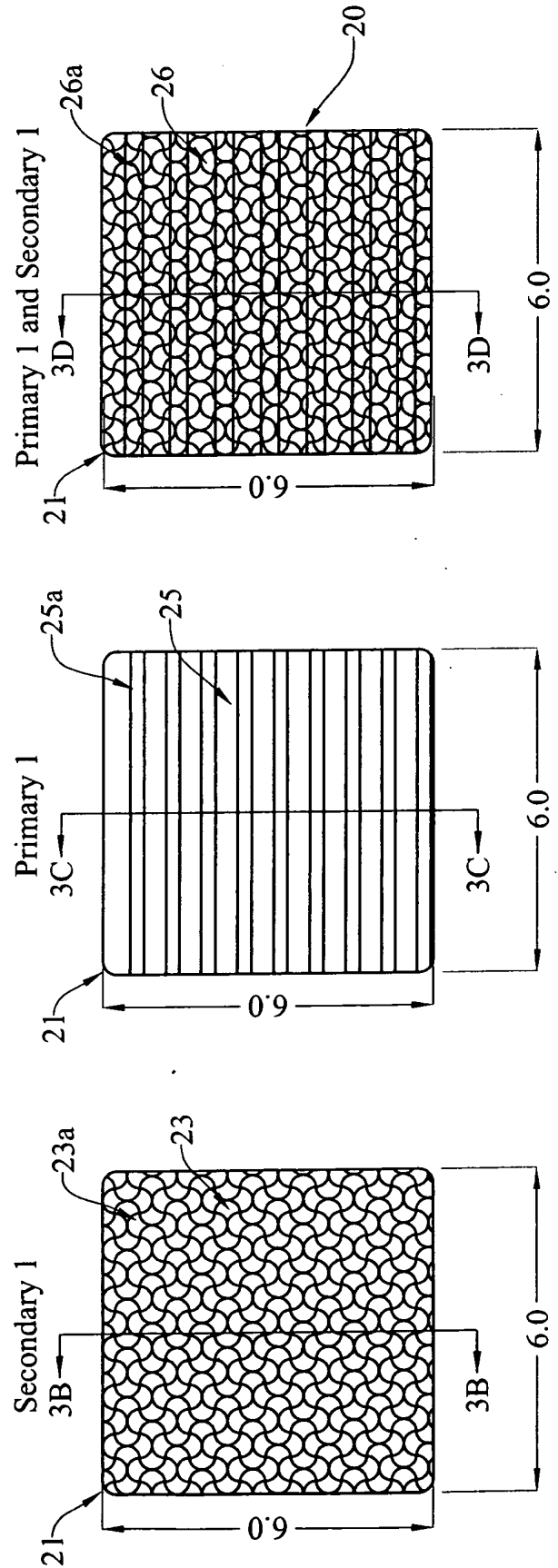
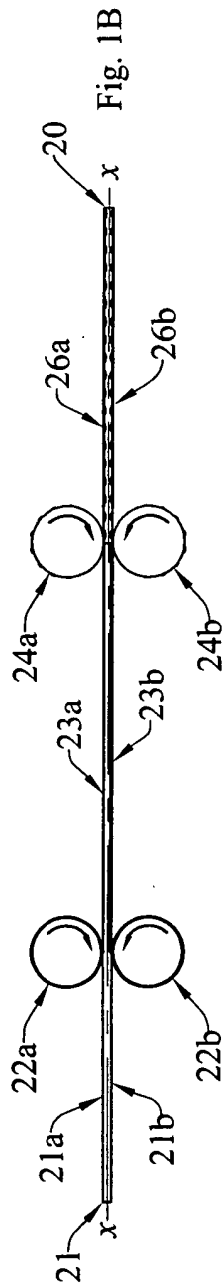
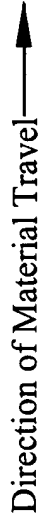
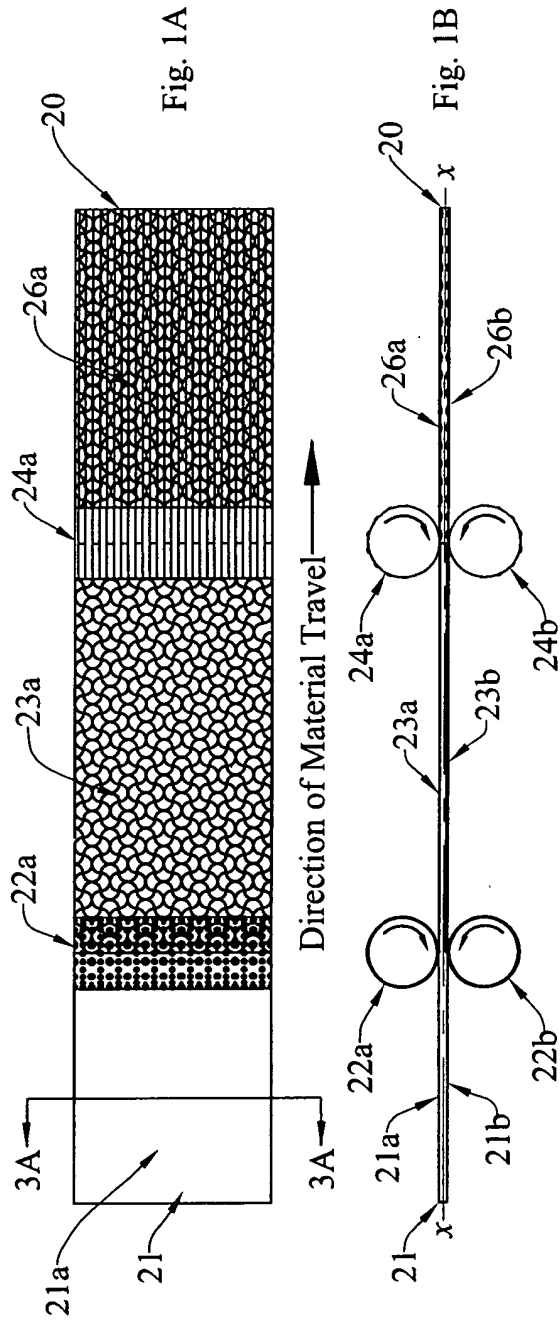
6. Procédé selon la revendication 5, lesdits motifs secondaires étant décalés les uns par rapport aux autres de telle façon qu'une dimension maximum dudit axe médian (x-x) à une surface déformée corresponde à une dimension minimum dudit axe médian (x-x) à l'autre surface déformée.

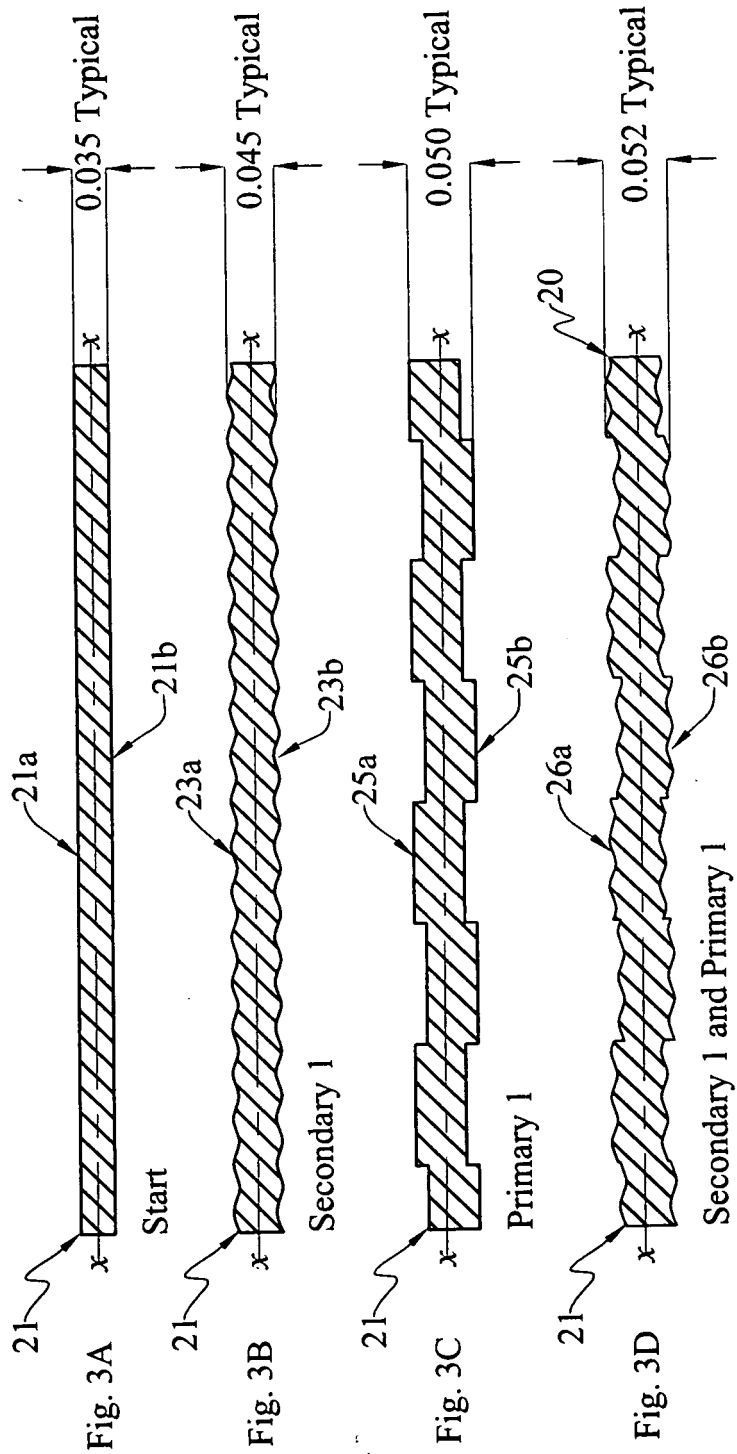
7. Procédé selon la revendication 1, l'étape qui consiste à empreindre lesdits motifs secondaires sur ledit matériau accroissant la dimension transverse maximum dudit matériau dudit axe médian au point le plus éloigné dudit matériau déformé jusqu'à 135% de la dimension transverse maximum dudit axe médian au point le plus éloigné sur ladite surface initiale.

8. Procédé selon la revendication 1, l'étape qui consiste à empreindre lesdits motifs secondaires sur ledit matériau (21) accroissant la dimension transverse maximum dudit matériau dudit axe médian au point le plus éloigné dudit matériau déformé jusqu'à 150% de la dimension transverse maximum dudit axe médian (x-x) au point le plus éloigné sur ladite surface initiale (21a, 21b) .

9. Procédé selon la revendication 1, l'étape qui consiste à empreindre lesdits motifs secondaires sur ledit matériau (21) accroissant la dimension transverse maximum dudit matériau dudit axe médian (x-x) au point le plus éloigné dudit matériau déformé jusqu'à 300% de la dimension transverse maximum dudit axe médian (x-x) au point le plus éloigné sur ladite surface initiale (21a, 21b).

10. Procédé selon la revendication 1, l'étape qui consiste à empreindre lesdits motifs secondaires sur ledit matériau (21) accroissant la dimension transverse maximum dudit matériau dudit axe médian (x-x) au point le plus éloigné dudit matériau déformé jusqu'à 700% de la dimension transverse maximum dudit axe médian (x-x) au point le plus éloigné sur ladite surface initiale (21a, 21b). 5
11. Procédé selon la revendication 1, l'étape qui consiste à empreindre lesdits motifs secondaires sur ledit matériau ne réduisant pas la dimension minimum dudit matériau (21), mesurée d'un point quelconque sur une desdites surfaces déformées au point le plus proche sur la surface opposée parmi lesdites surfaces déformées, au-dessous de 95% de la dimension minimum d'un point quelconque sur une desdites surfaces initiales (21a, 21b) au point le plus proche sur la surface initiale (21a, 21b) opposée. 10
12. Procédé selon la revendication 1, l'étape qui consiste à empreindre lesdits motifs secondaires sur ledit matériau (21) ne réduisant pas la dimension minimum dudit matériau (21), mesurée d'un point quelconque sur une desdites surfaces déformées au point le plus proche sur la surface opposée parmi lesdites surfaces déformées, au-dessous de 50% de la dimension minimum d'un point quelconque sur une desdites surfaces initiales (21a, 21b) au point le plus proche sur la surface initiale (21a, 21b) opposée. 20
13. Procédé selon la revendication 1, lesdits motifs primaires étant les mêmes. 25
14. Procédé selon la revendication 13, lesdits motifs primaires étant décalés les uns par rapport aux autres de telle façon qu'une dimension maximum dudit axe médian (x-x) à une surface davantage déformée corresponde à une dimension minimum dudit axe médian (x-x) à l'autre surface davantage déformée. 30
15. Procédé selon la revendication 1, l'étape qui consiste à empreindre lesdits motifs primaires sur ledit matériau (21) ne réduisant pas la dimension minimum dudit matériau davantage déformé, mesurée dudit axe médian (x-x) à un point quelconque sur l'une ou l'autre desdites surfaces davantage déformées, au-dessous de 95% de la dimension minimum dudit matériau, mesurée dudit axe médian (x-x) à l'une ou l'autre desdites surfaces initiales (21a, 21b). 35
16. Procédé selon la revendication 1, les surfaces initiales opposées dudit matériau (21) étant planes. 40
17. Procédé selon la revendication 1, les étapes consistant à empreindre lesdits motifs comprenant l'étape consistant à empreindre lesdits motifs par une opération d'emboutissage et/ou de laminage. 45
18. Procédé selon la revendication 1, et comportant en outre les étapes supplémentaires consistant à : 50
- cintrer ladite paroi (20) à surface améliorée de telle façon que les extrémités proches soient positionnées à proximité l'une de l'autre ; et joindre les extrémités proches dudit matériau (21) ensemble ; pour former ainsi un tube (62, 64, 65) à surface améliorée.
19. Procédé selon la revendication 18, l'étape qui consiste à joindre les extrémités proches dudit matériau ensemble comprenant l'étape supplémentaire consistant à : 55
- souder les extrémités proches dudit matériau pour les joindre ensemble.
20. Procédé selon la revendication 1, et comportant en outre l'étape supplémentaire consistant à : pratiquer des trous à travers ledit matériau.
21. Procédé selon la revendication 1, et comportant en outre l'étape supplémentaire consistant à : installer ladite paroi à surface améliorée dans un dispositif de transfert de chaleur.
22. Procédé selon la revendication 1, et comportant en outre l'étape supplémentaire consistant à : installer ladite paroi à surface améliorée dans un appareil de traitement de fluide.





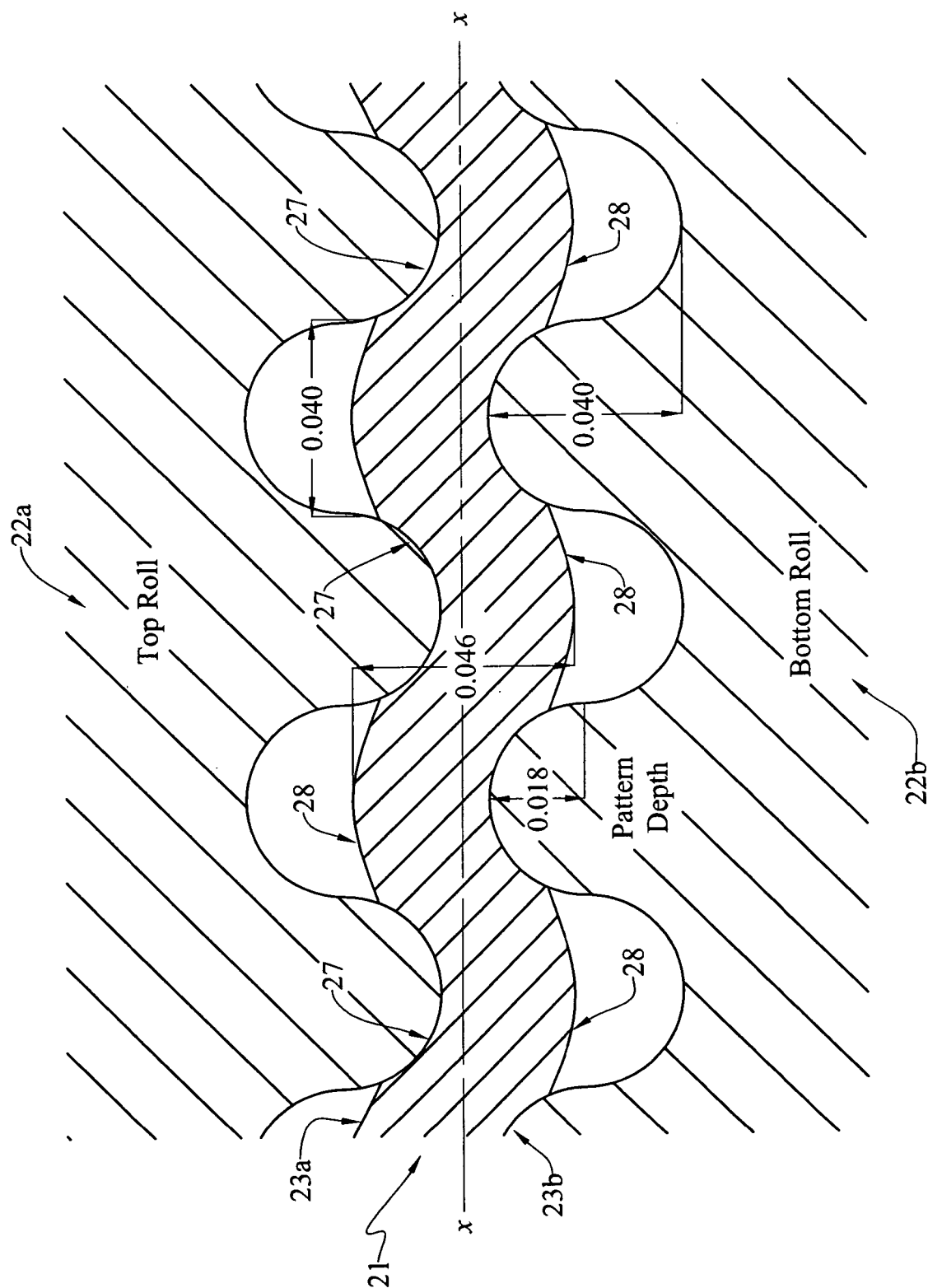


Fig. 4

Point-to-Point Wall Thickness
of an Enhanced Sample
Formed from Plain Sheet

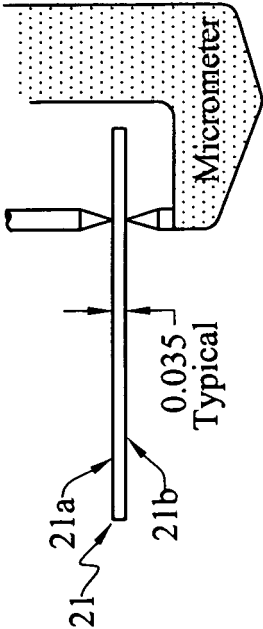


Fig. 5A

Point-to-Point Wall Thickness
of an Enhanced Sample
Formed from Plain Sheet
(Primary 1)

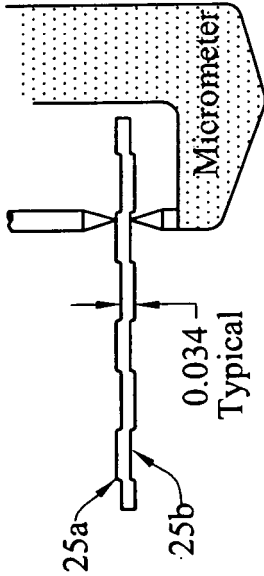


Fig. 5C

Point-to-Point Wall Thickness
of an Enhanced Sample
Formed from Plain Sheet
(Secondary 1)

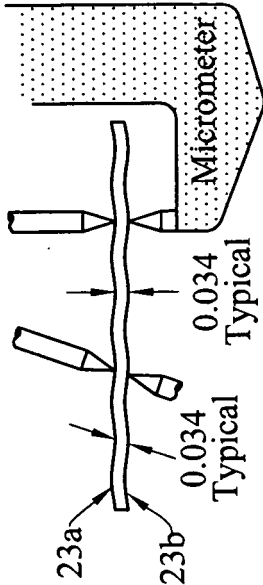


Fig. 5B

Point-to-Point Wall Thickness
of an Enhanced Sample
Formed from Plain Sheet
(Primary 1 and Secondary 1)

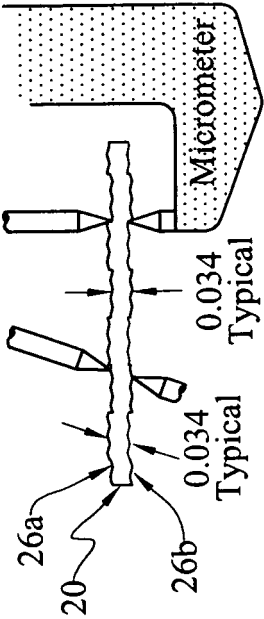


Fig. 5D

Area Wall Thickness
of an Enhanced Sample
Formed from Plain Sheet

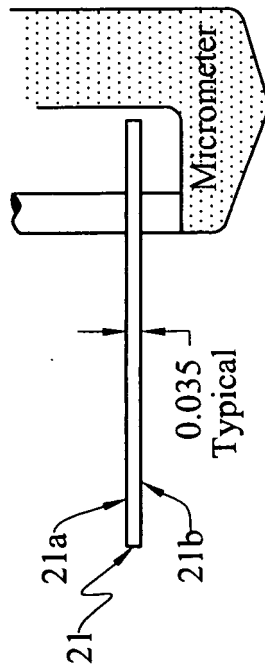


Fig. 6A

Area Wall Thickness
of an Enhanced Sample
Formed from Plain Sheet
(Primary 1)

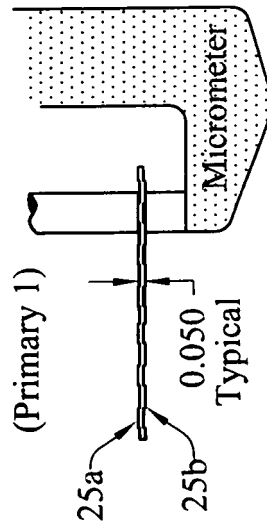


Fig. 6C

Area Wall Thickness
of an Enhanced Sample
Formed from Plain Sheet
(Secondary 1)

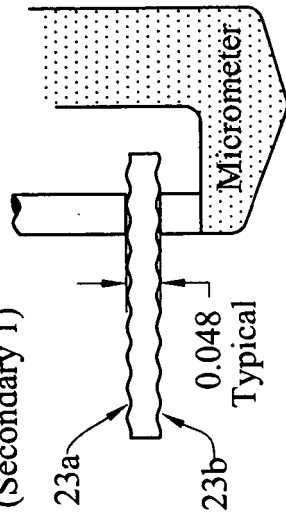


Fig. 6B

Area Wall Thickness
of an Enhanced Sample
Formed from Plain Sheet
(Primary 1 and Secondary 1)

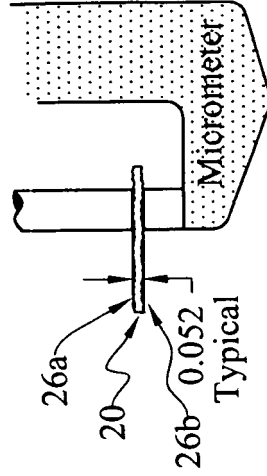
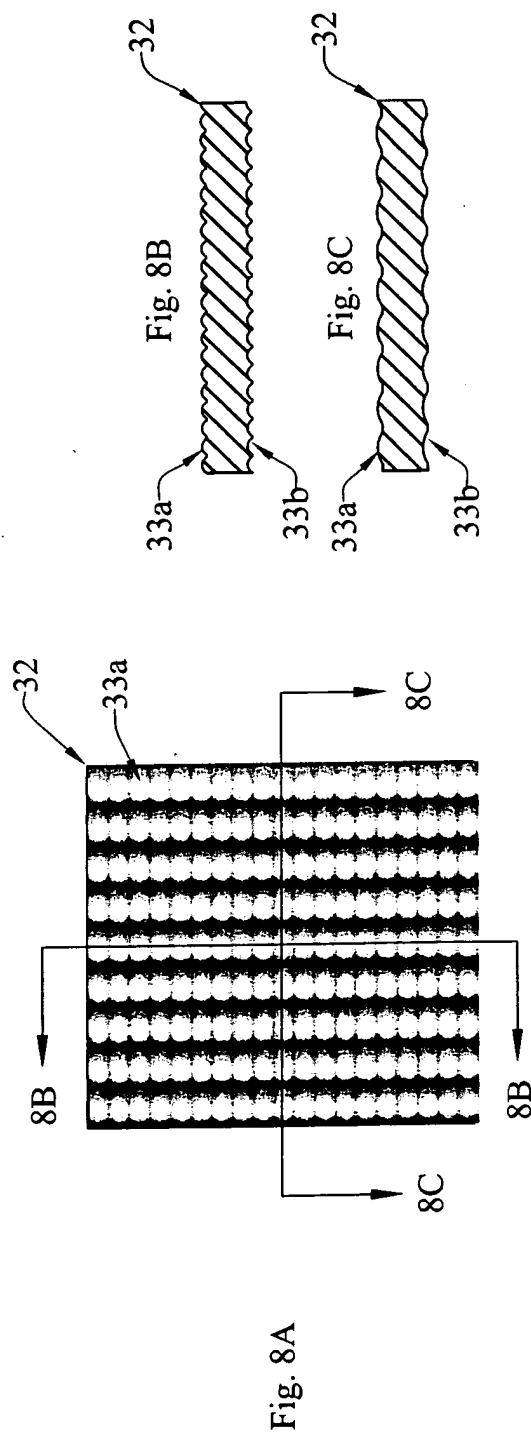
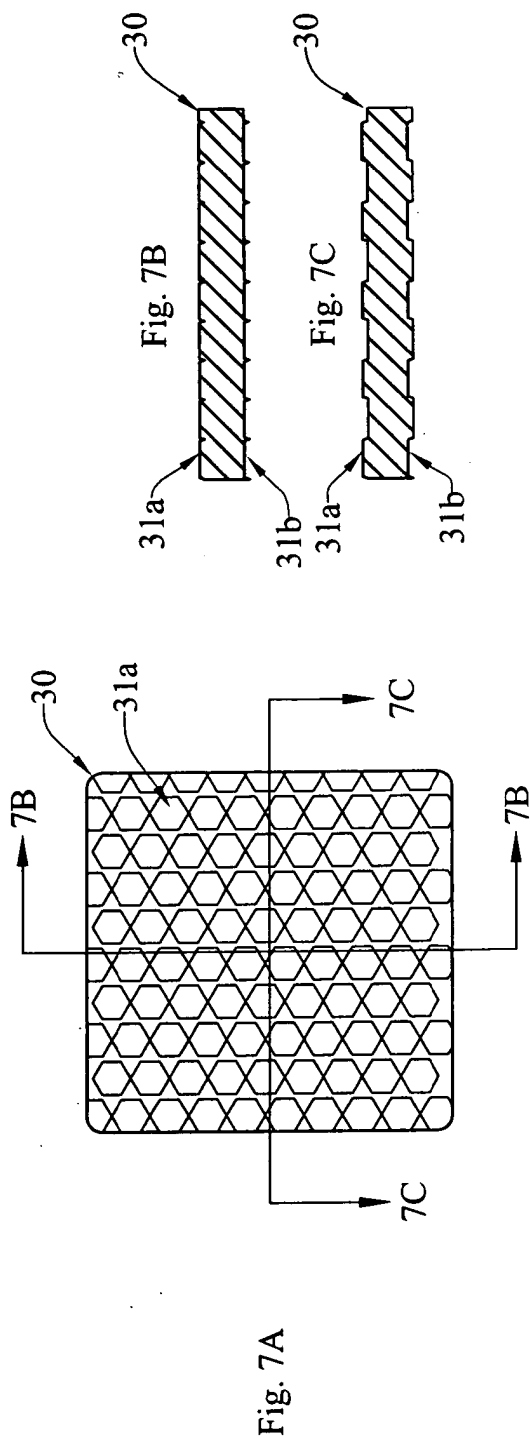


Fig. 6D

Primary Patterns



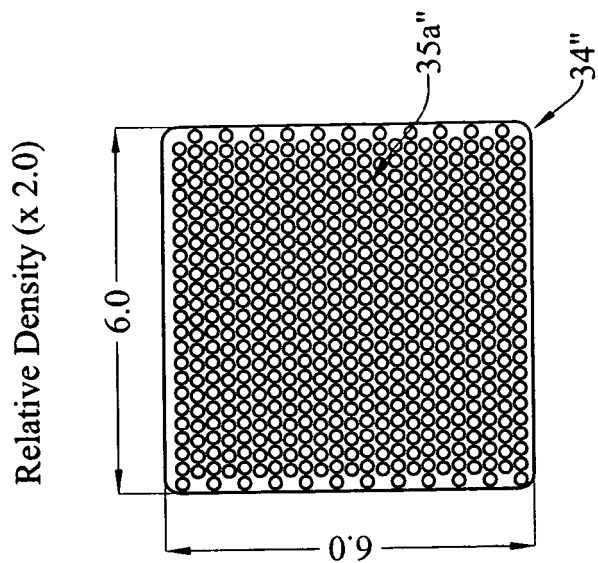


Fig. 9C

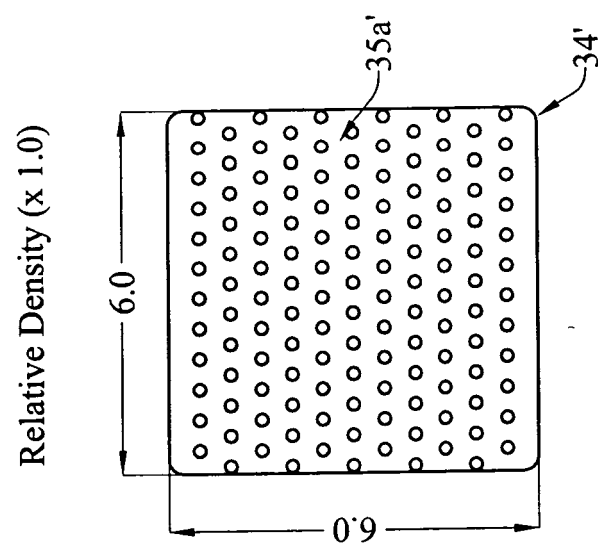


Fig. 9B

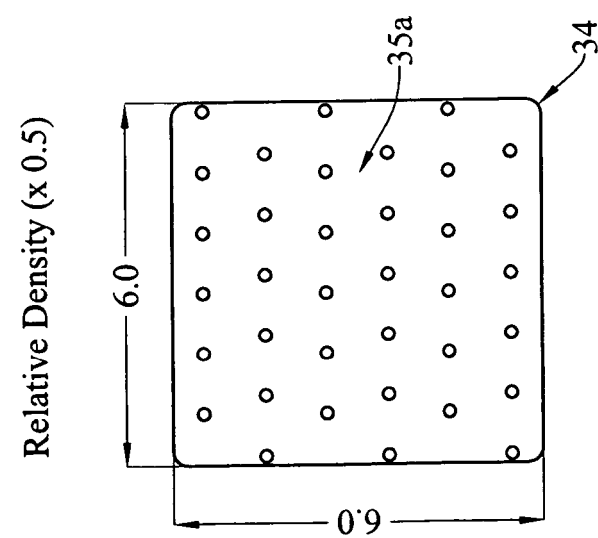
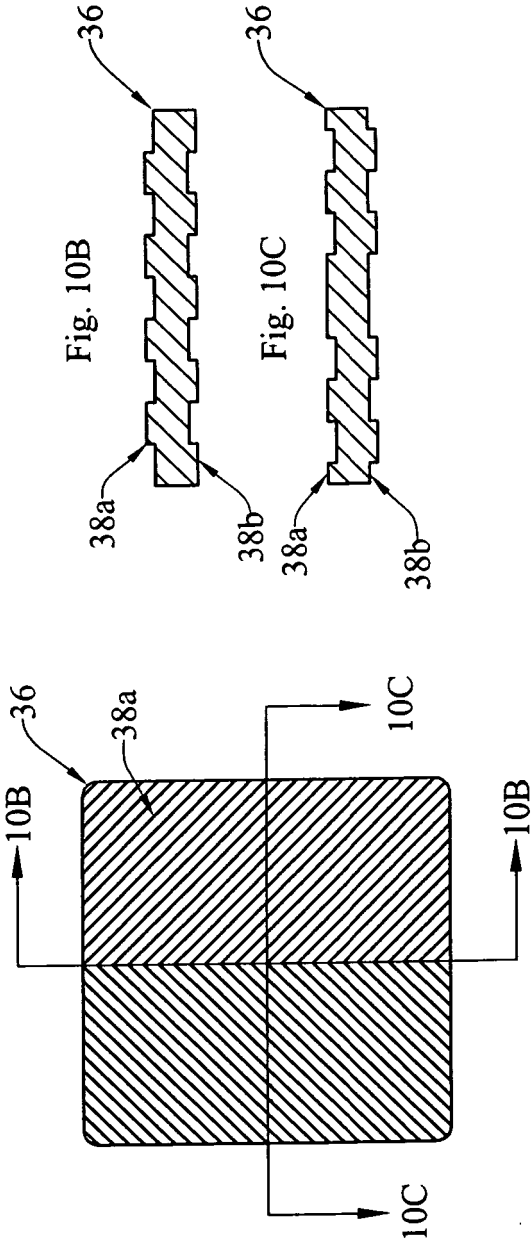
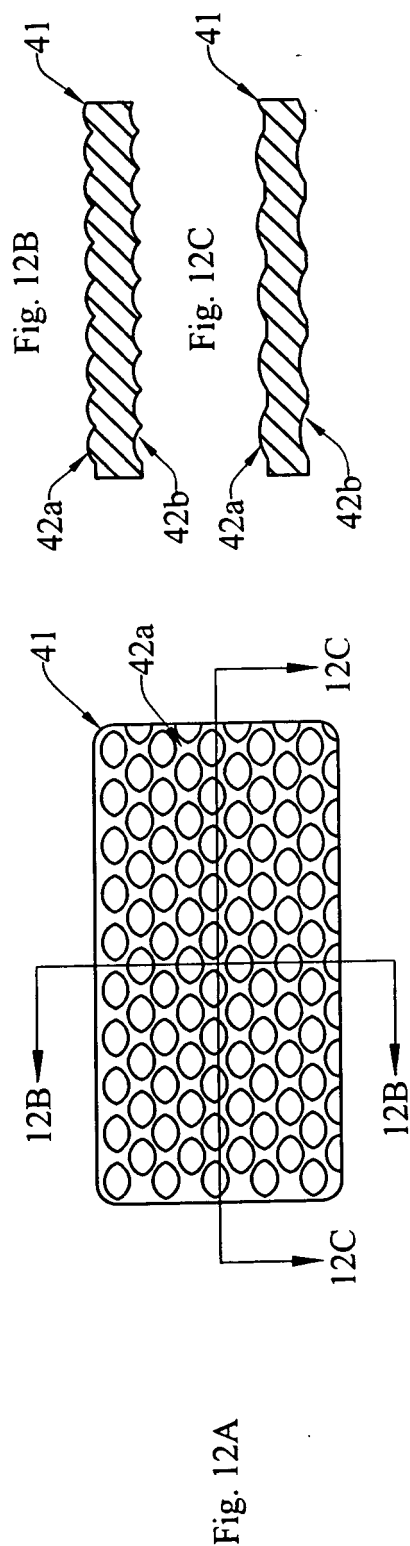
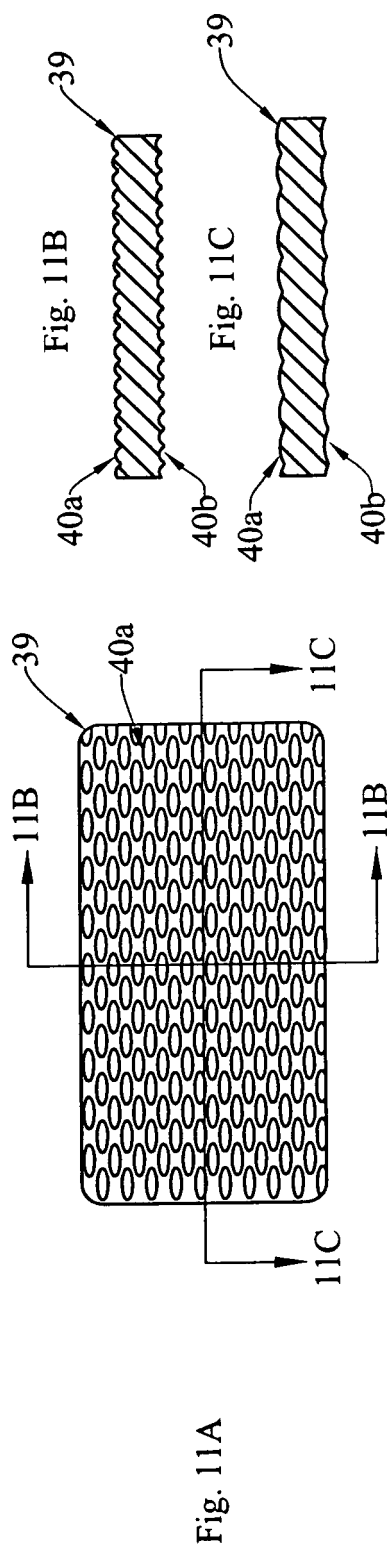


Fig. 9A

Primary Patterns



Secondary Patterns



Directional Patterns

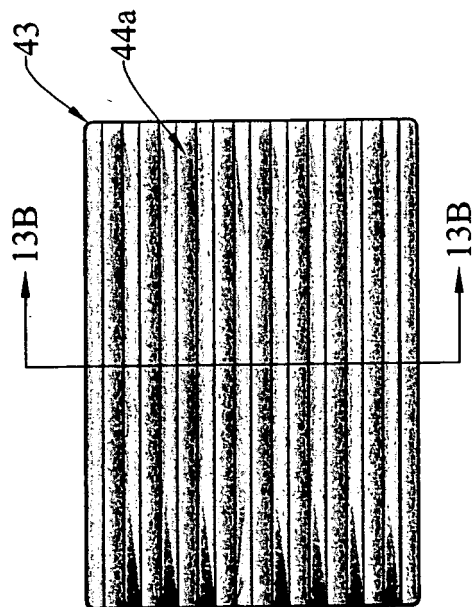


Fig. 13A

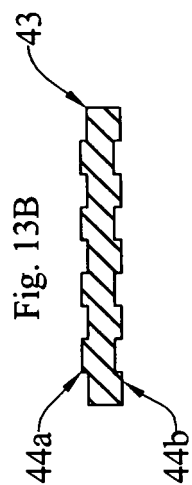


Fig. 13B

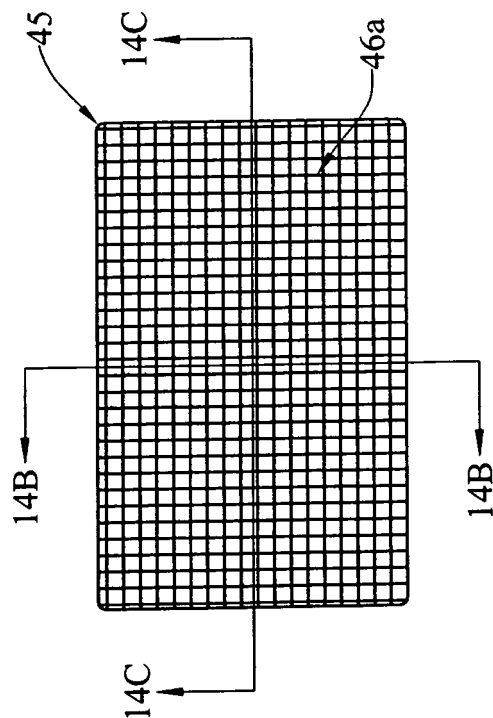


Fig. 14A

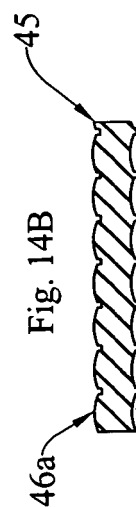


Fig. 14B

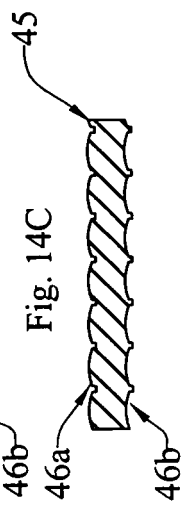
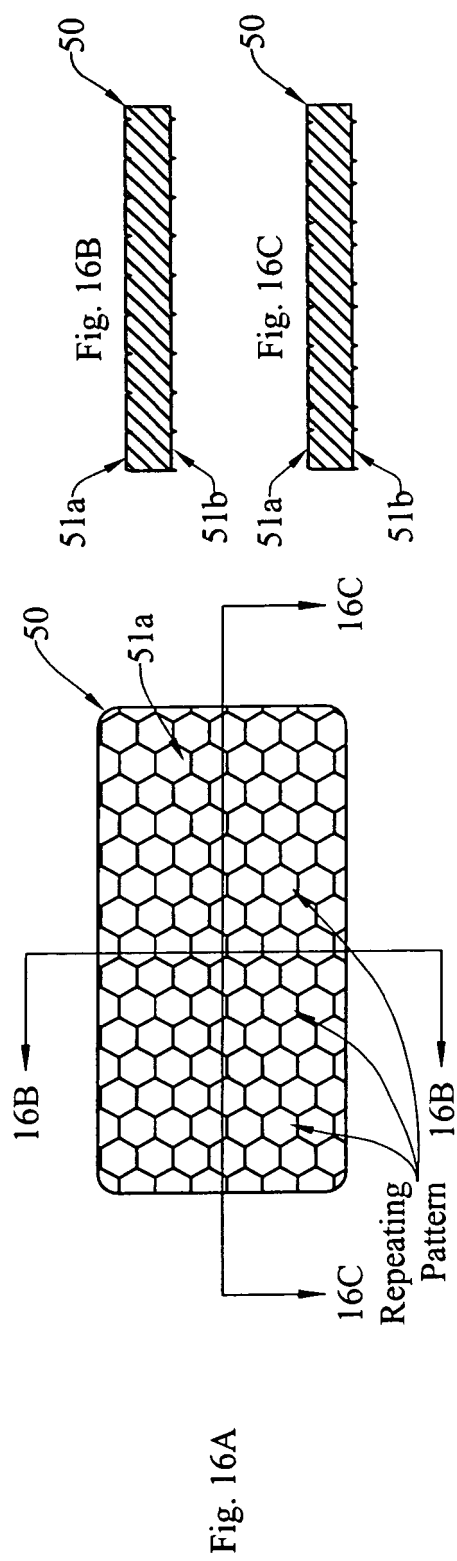
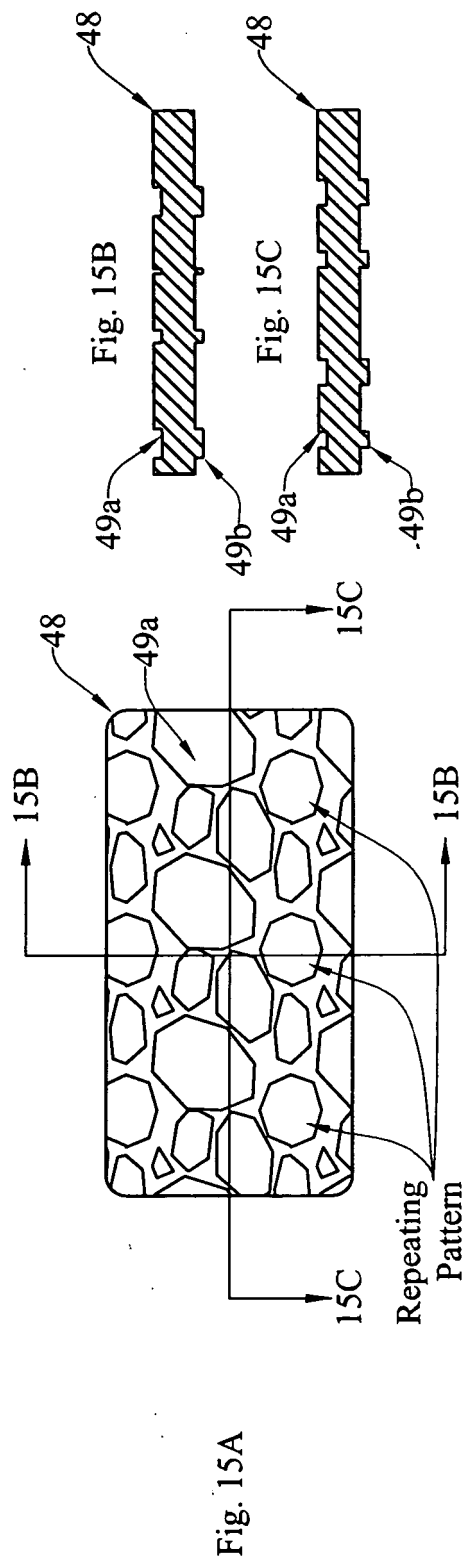


Fig. 14C

Non-Directional Patterns



Enhanced-Surface Tube Making Process

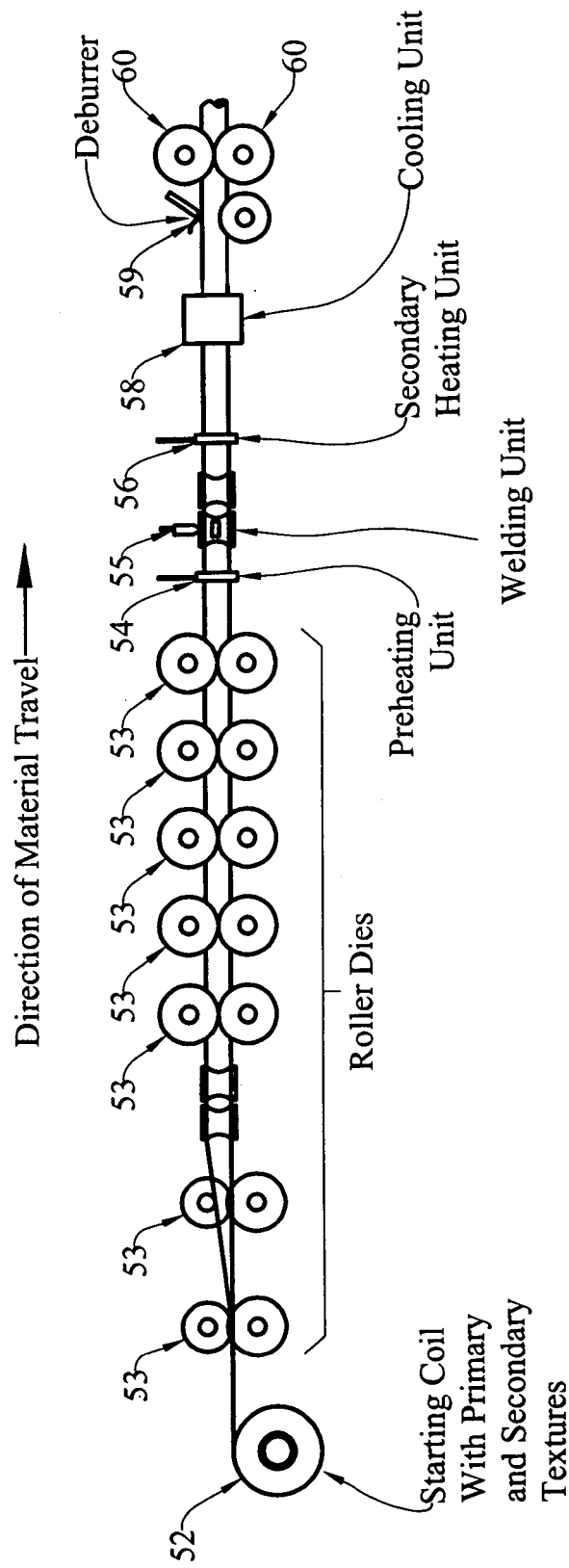


Fig. 17



Fig. 18A

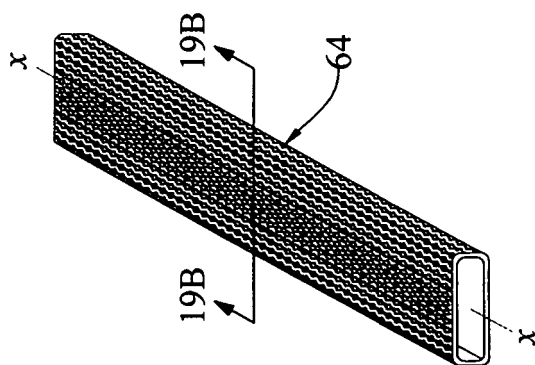


Fig. 19A

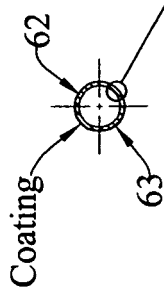


Fig. 18B

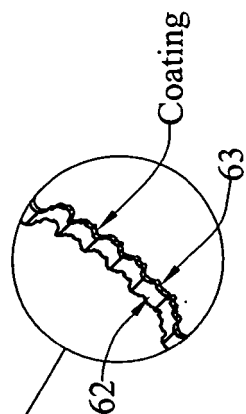


Fig. 18C

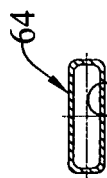


Fig. 19B

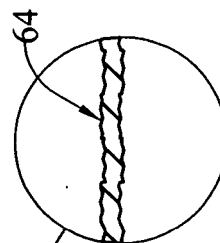


Fig. 19C

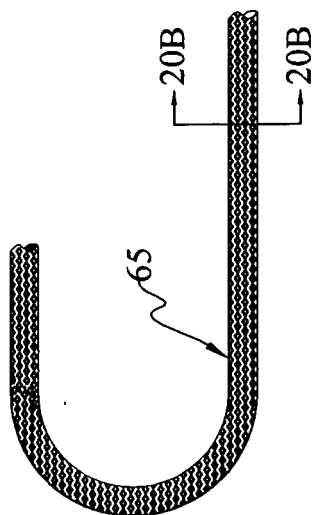


Fig. 20A

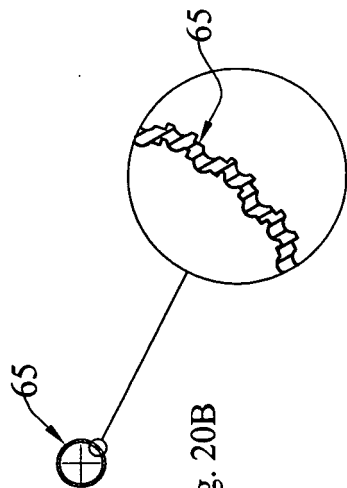


Fig. 20B

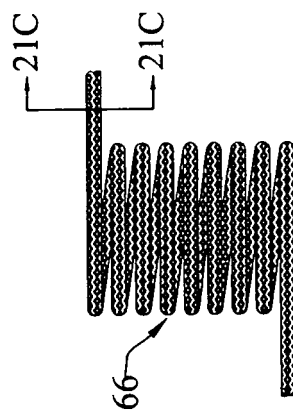


Fig. 20C

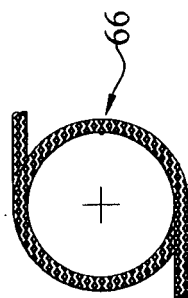


Fig. 21B

Fig. 21A

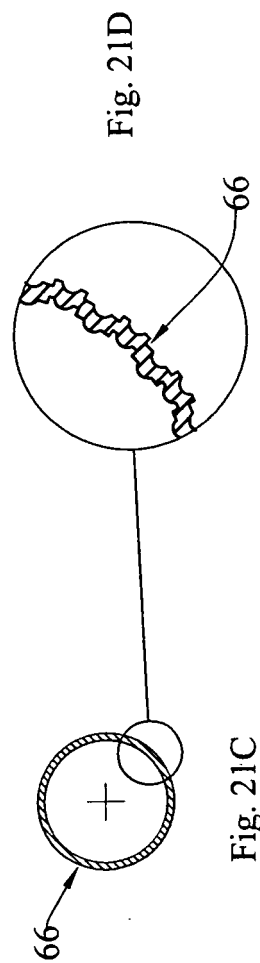


Fig. 21C

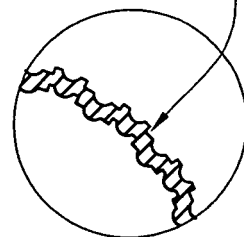


Fig. 21D

Enhanced-Surface Fin Making Process

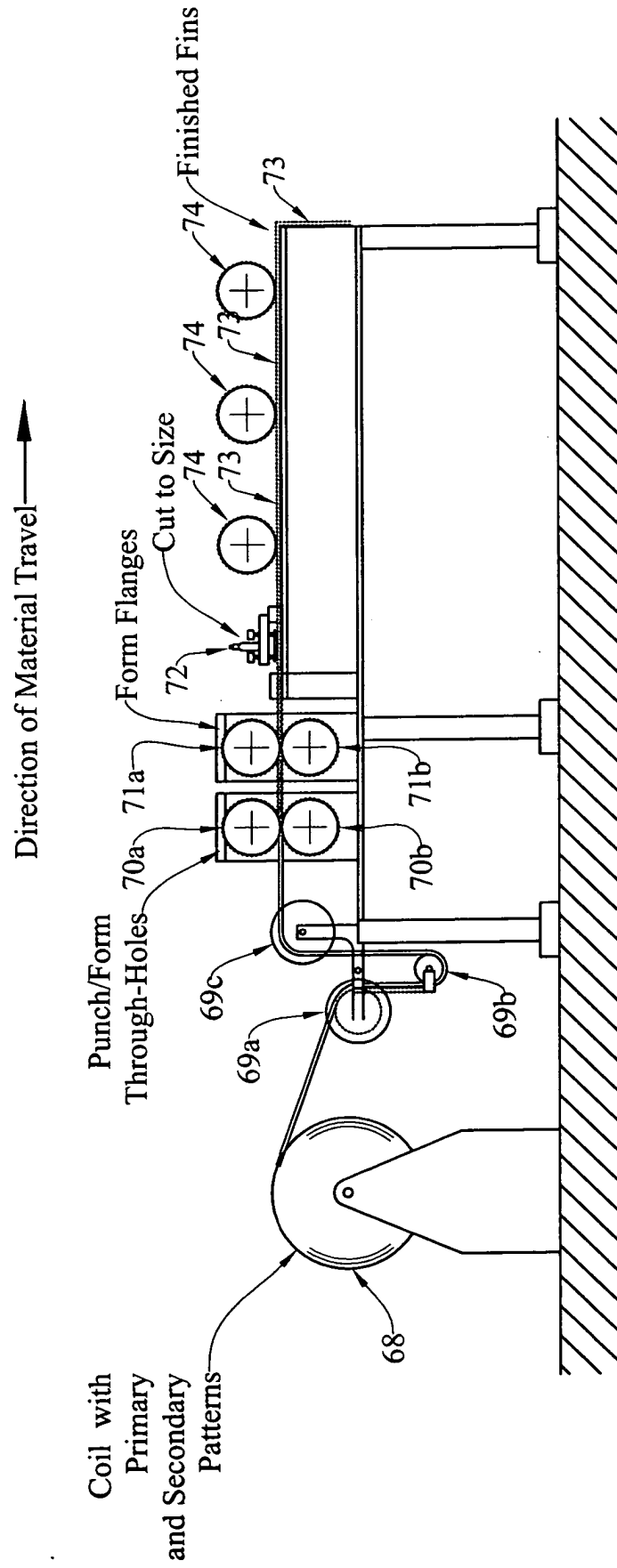
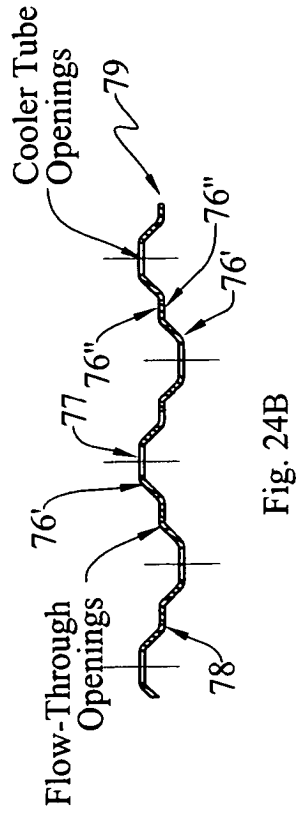
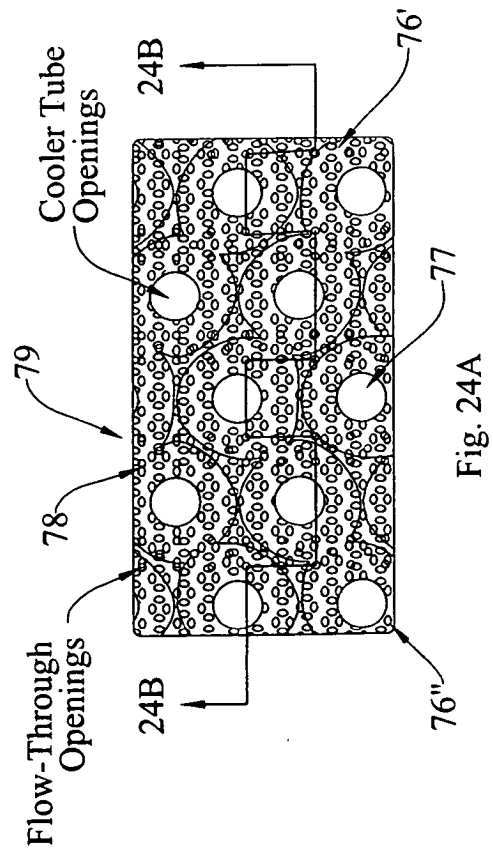
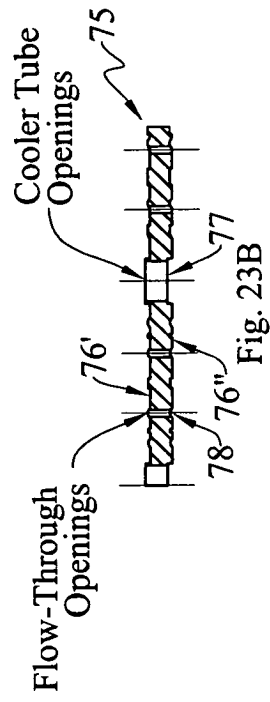
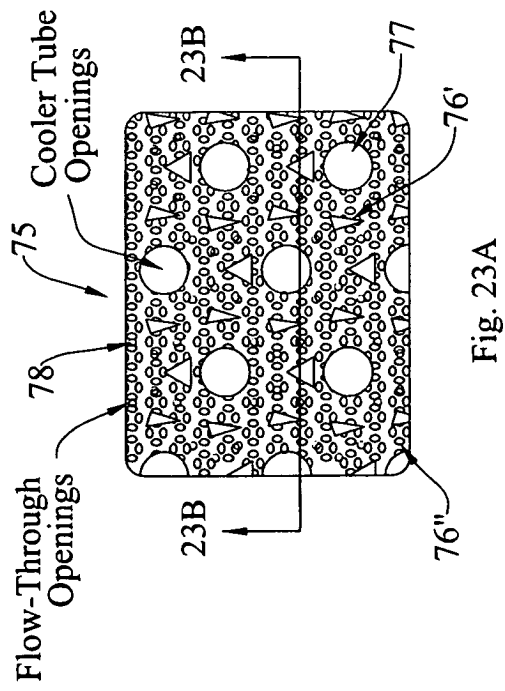
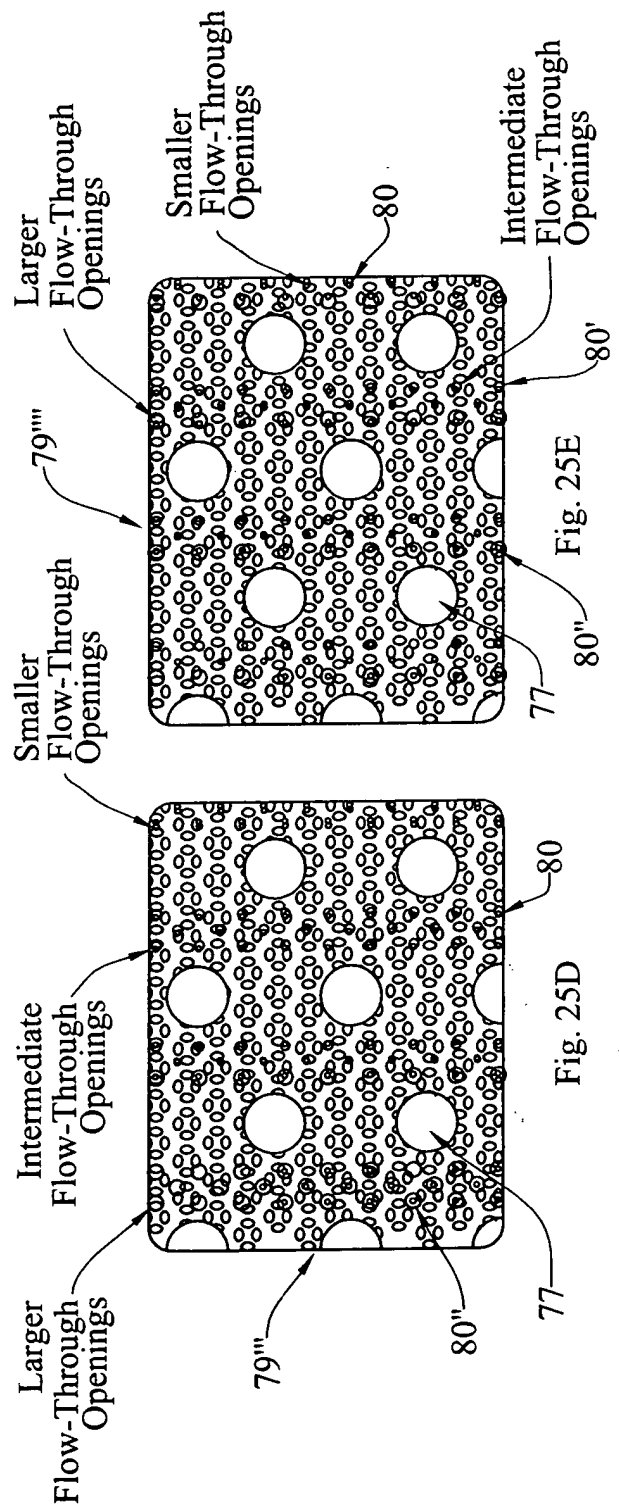
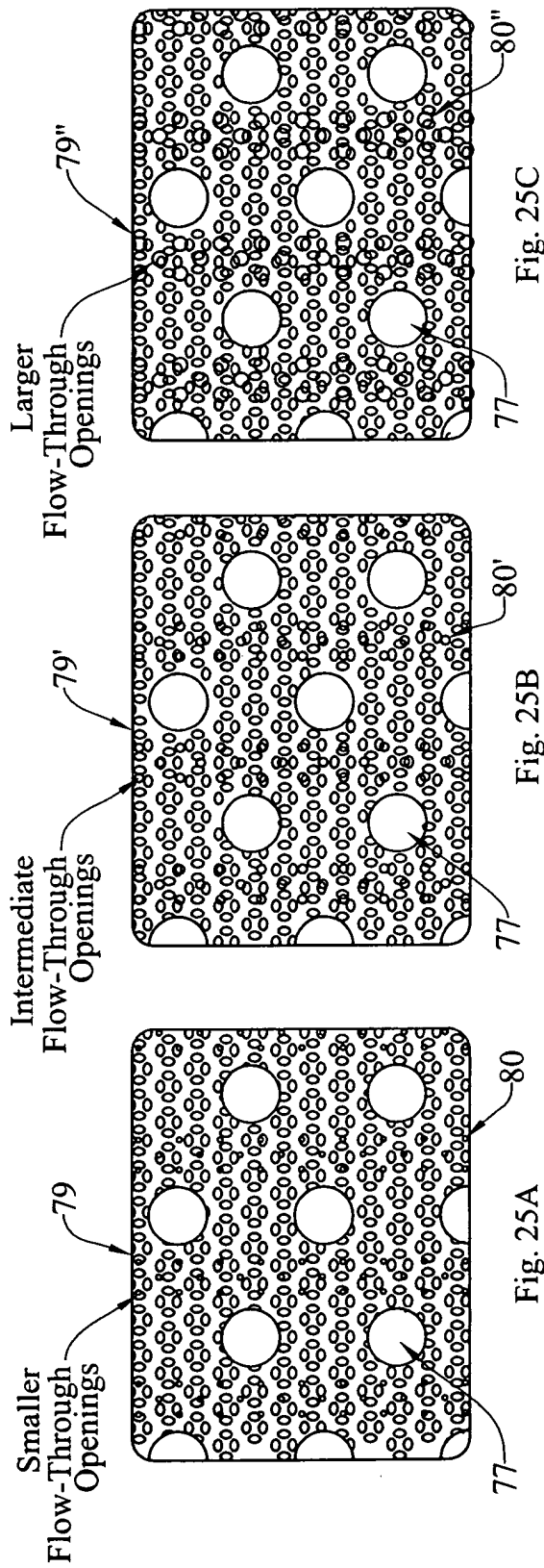


Fig. 22





Improved Heat Exchanger

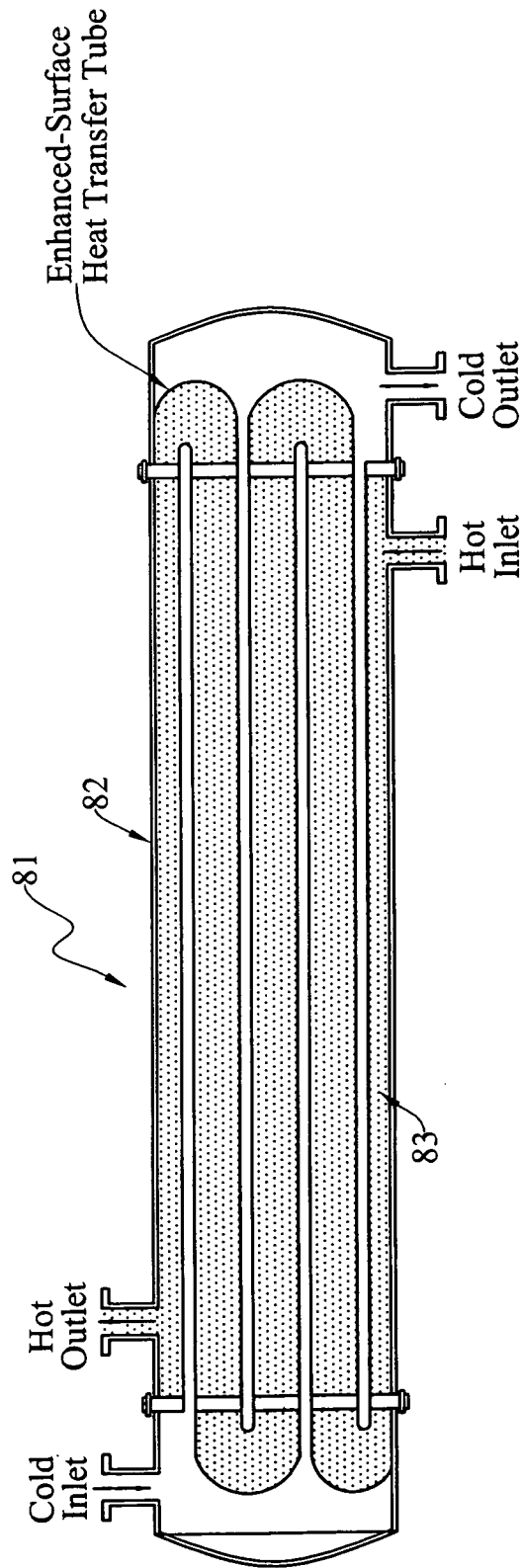


Fig. 26

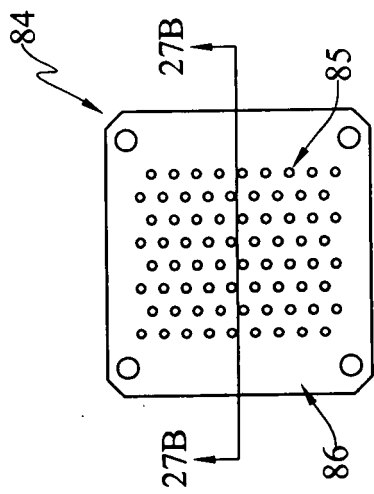


Fig. 27A

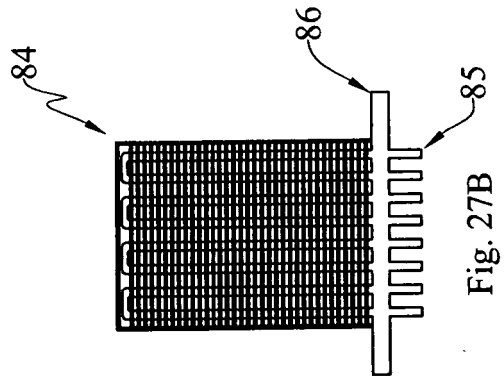


Fig. 27B

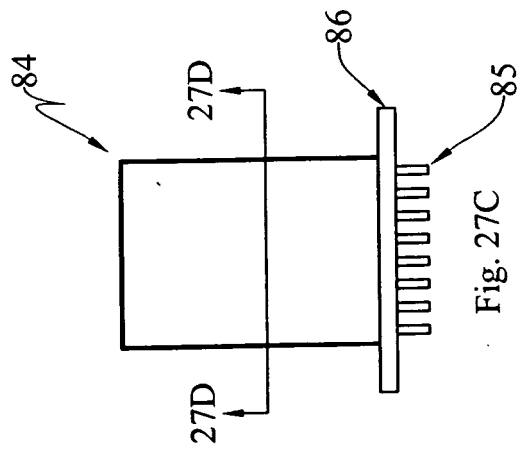


Fig. 27C

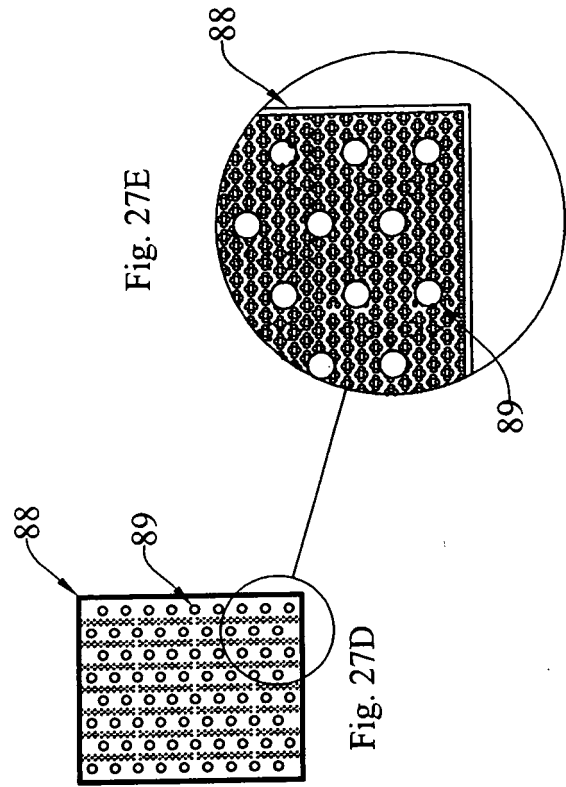


Fig. 27E

Fig. 27D

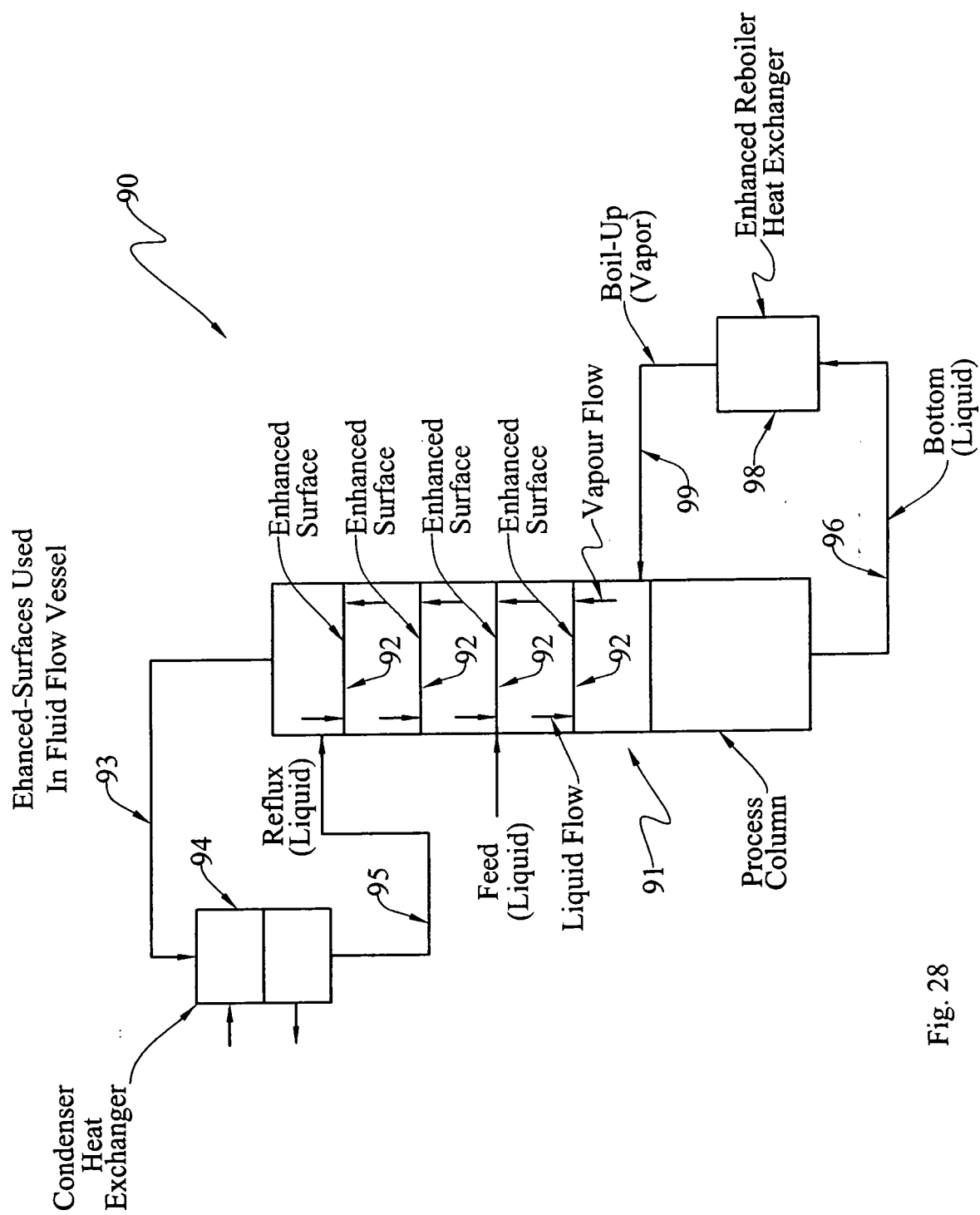


Fig. 28

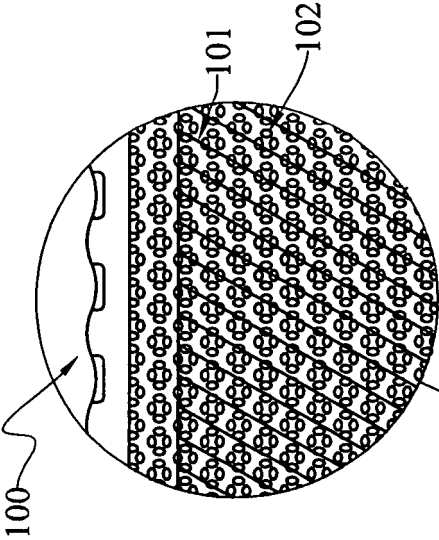


Fig. 29B

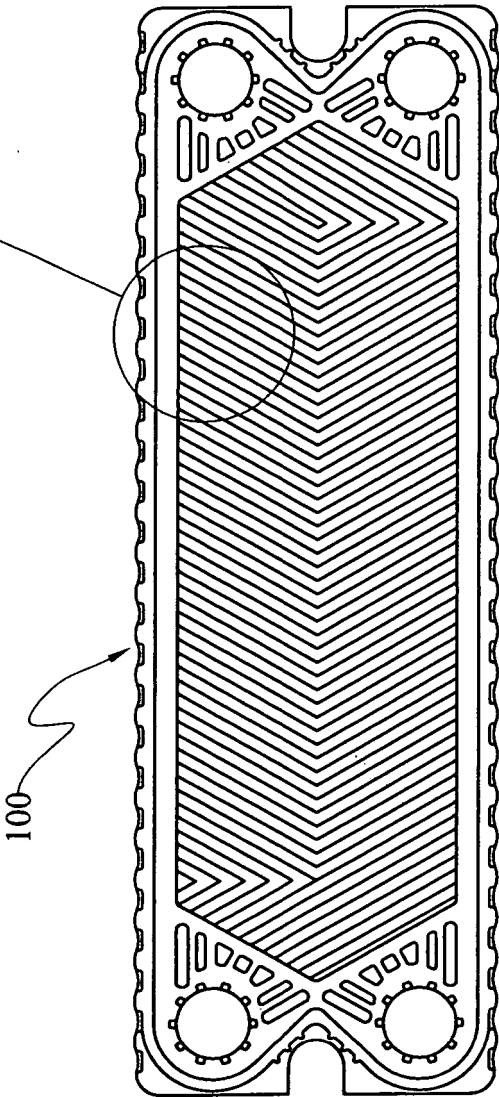


Fig. 29A

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- JP S56136241 A [0002]
- EP 0603108 A [0002]
- GB 2457333 A [0002]
- US 4098722 A [0002]
- US 4092842 A [0002]
- US 6026892 A [0002]
- US 5052476 A [0003]
- US 5259448 A [0004]
- US 5332034 A [0005]
- US 5458191 A [0006]
- US 6182743 B1 [0007]
- US 6176301 B1 [0008]
- US 20050067156 A1 [0009]
- US 20050247380 A1 [0010]
- US 20090008075 A1 [0011]
- US 5351397 A [0012]
- US 7032654 B2 [0013]
- US 4663243 A [0014]
- US 4753849 A [0015]