United States Patent [19]

Becker

[11] **3,756,310**

[45] **Sept. 4, 1973**

[54] **REGENERATOR**

[75] Inventor: **Rudolf Becker,** Munich, Germany

[73] Assignee: **Linde Aktiengesellschaft,** Hollriegelskreuth, Germany

[22] Filed: **Feb. 22, 1971**

[21] Appl. No.: **117,670**

[30] **Foreign Application Priority Data**

Feb. 20, 1970 Germany .... P 20 07 956.5

[52] **U.S. Cl.** **165/4,** 165/10, 62/15

[51] **Int. Cl.** **F28d 17/02**

[58] **Field of Search** 165/4, 8, 10; 62/13–15; 263/51

[56] **References Cited**

UNITED STATES PATENTS

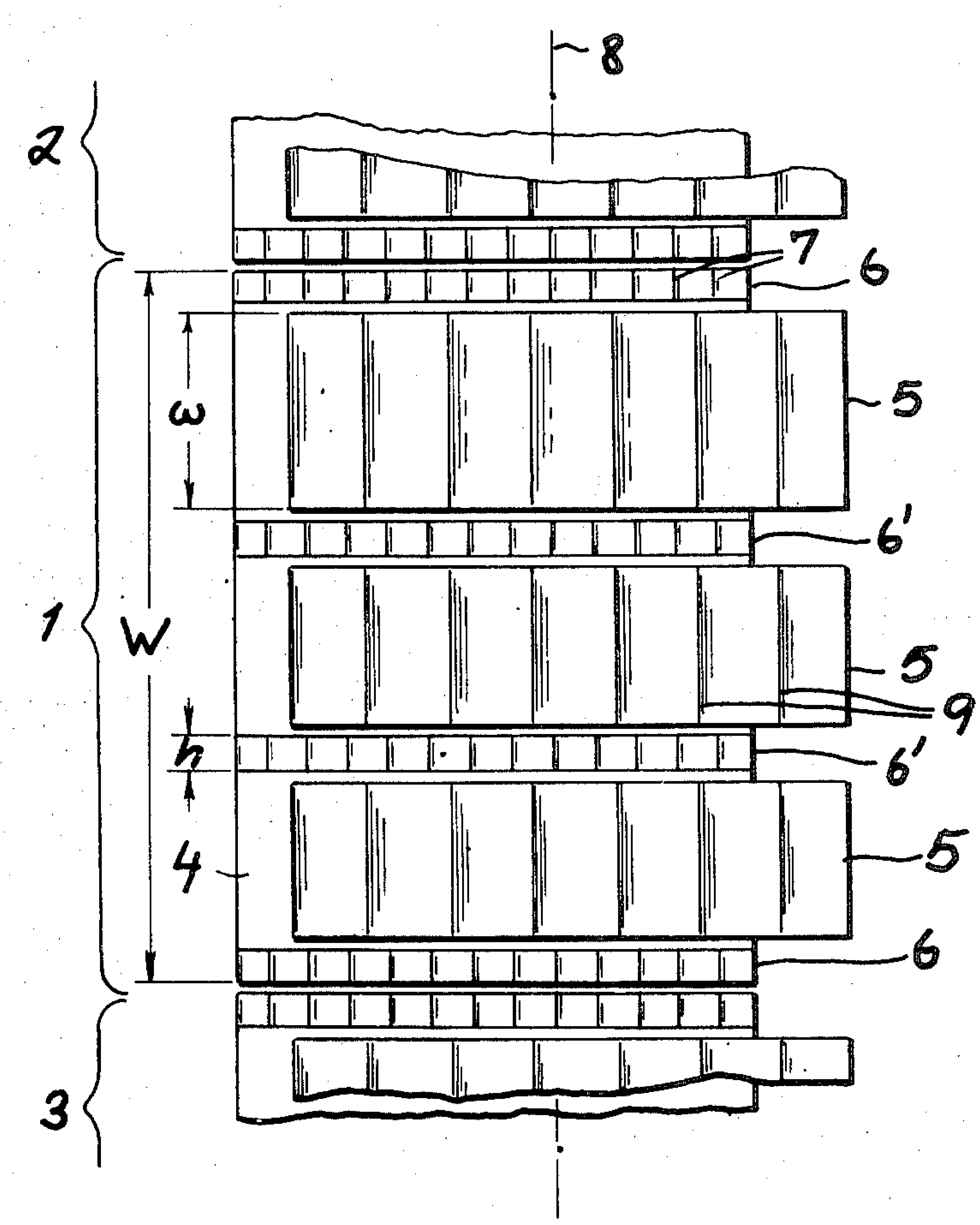
R19,140	4/1934	Frankl	165/10
3,183,963	5/1965	Mondt	165/10
3,262,490	7/1966	Olson	165/10

Primary Examiner—Albert W. Davis, Jr.
Attorney—Karl F. Ross

[57] **ABSTRACT**

A regenerator for effecting heat exchange between two fluids, one of which transfers heat to a mass within the regenerator while the other abstracts heat from this mass. The regenerator is provided with a portion in which a fluid, e.g. water, is condensed. The regenerator has stacked matrices, hurdles, baffles or stages of the heat-absorbing material which comprise corrugated sheets with the corrugations of the several stages being inclined at different angles to the axis of the regenerator. The angle between the longitudinal axis of the regenerator and the direction of the corrugation in the condensation stage is less than that in other stages.

5 Claims, 8 Drawing Figures



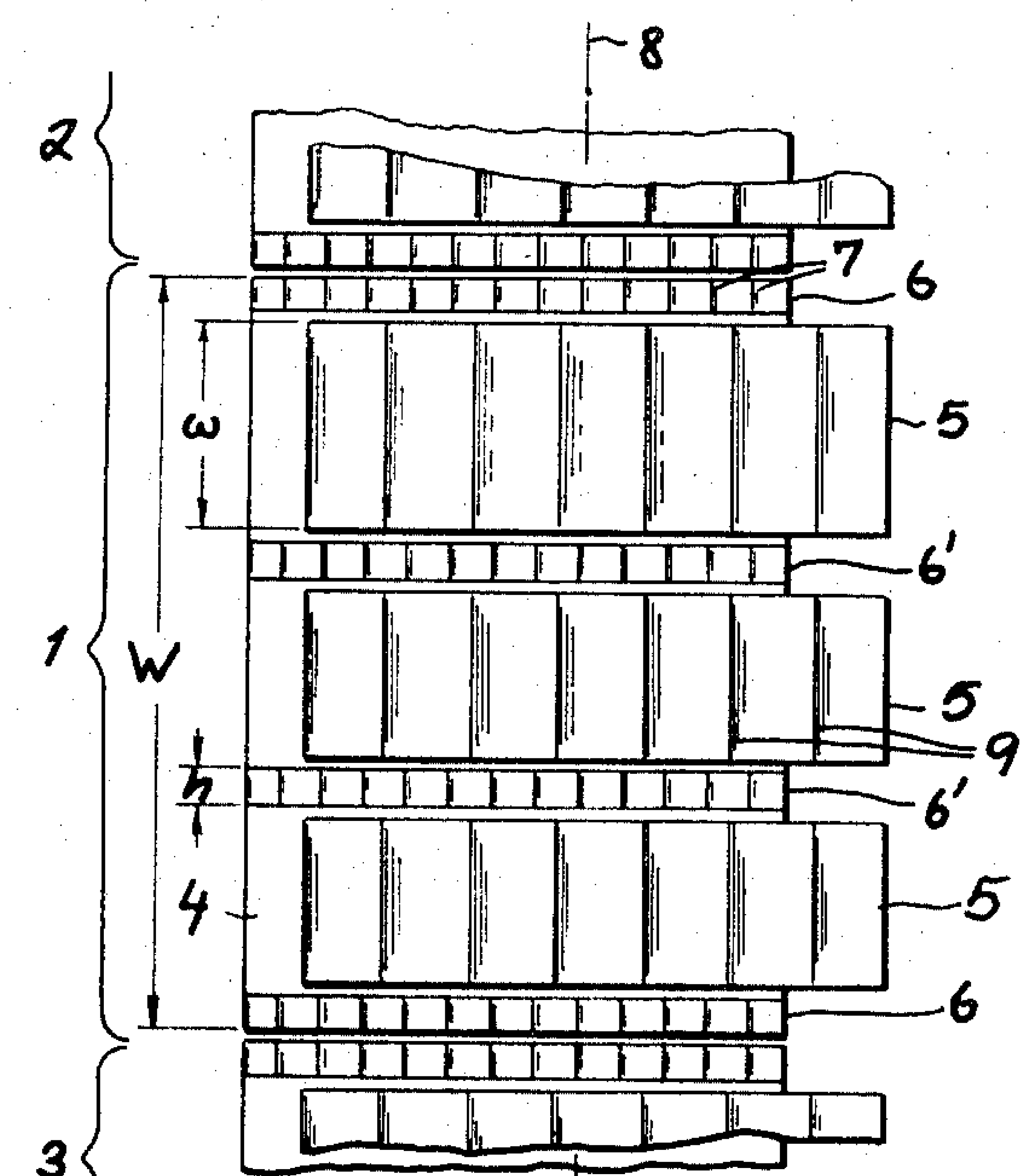


FIG. 1

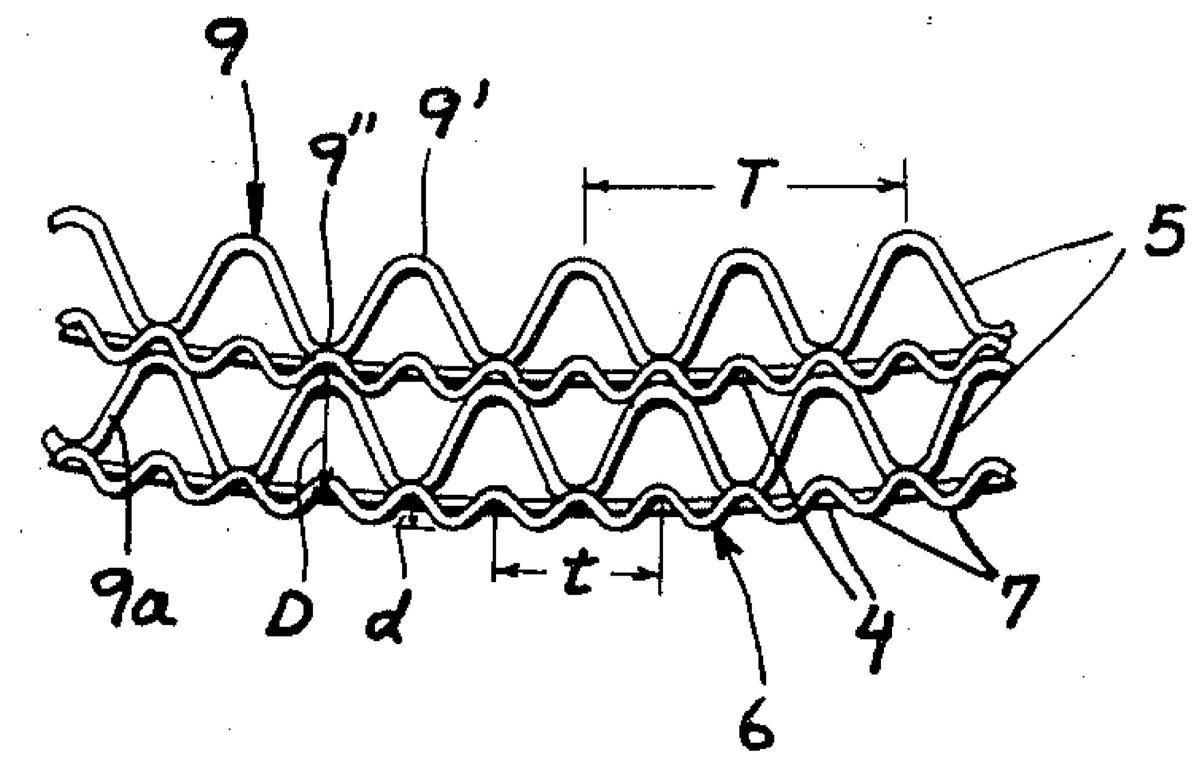
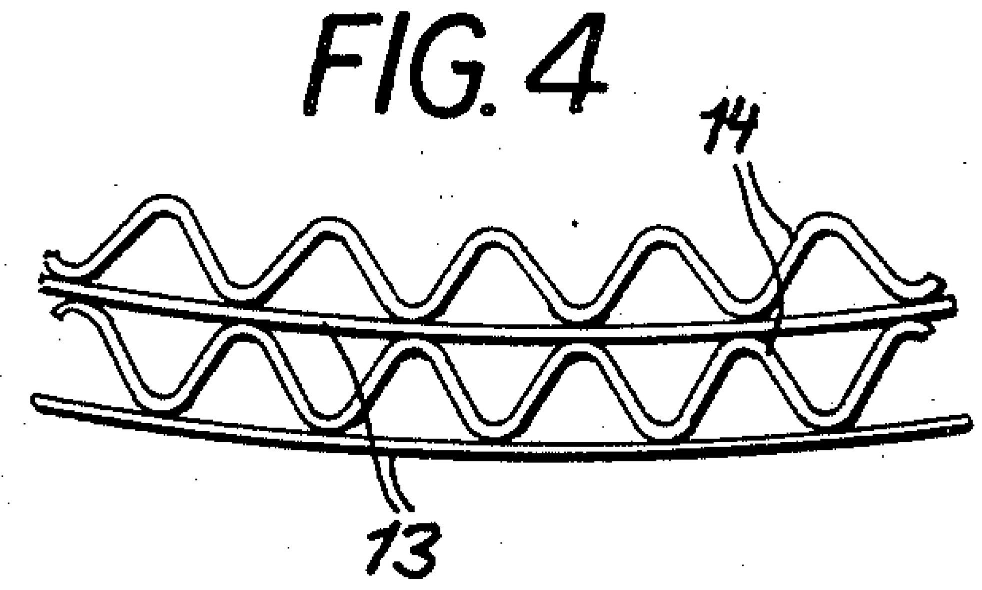


FIG. 2

FIG. 4



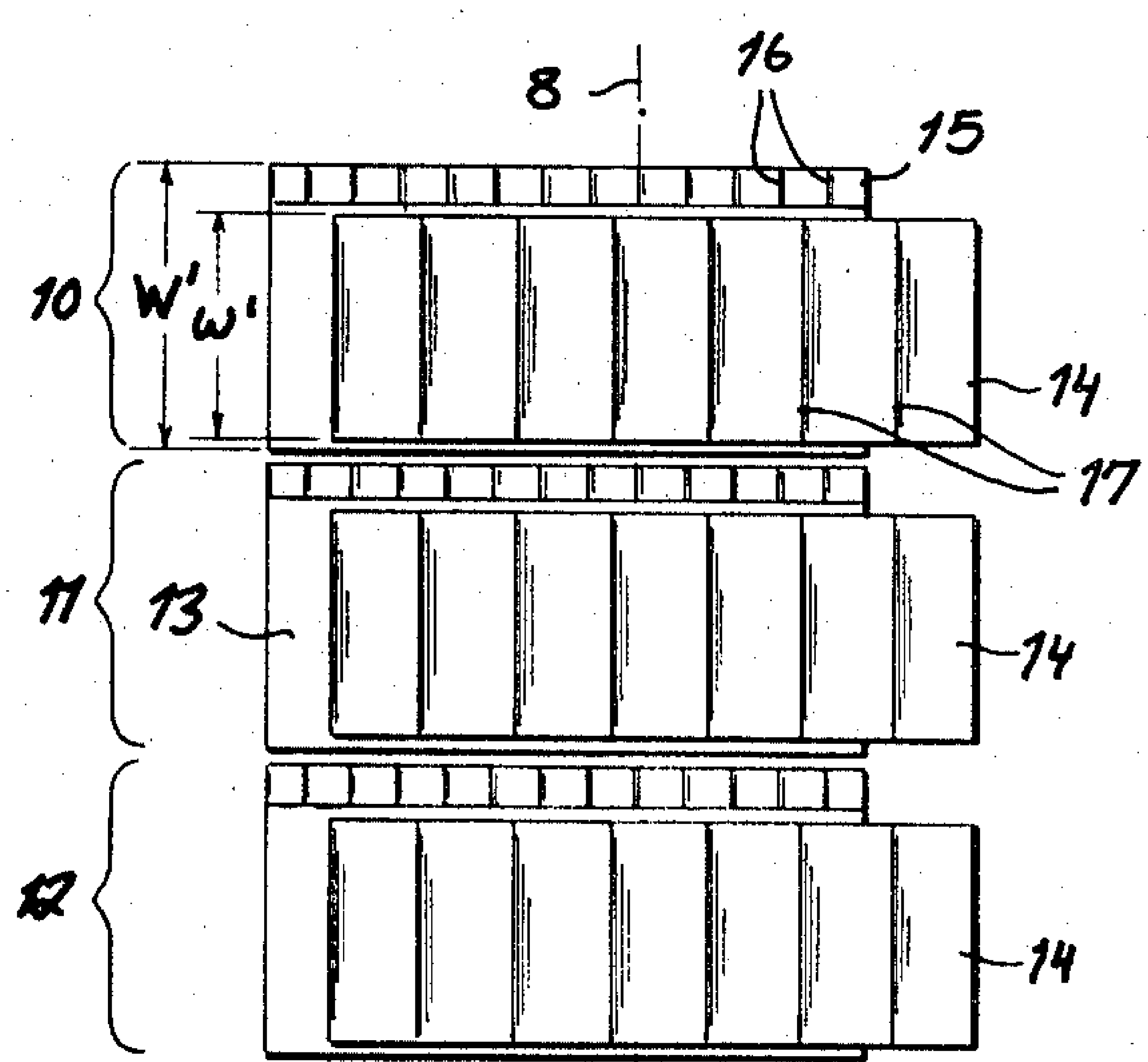


FIG. 3

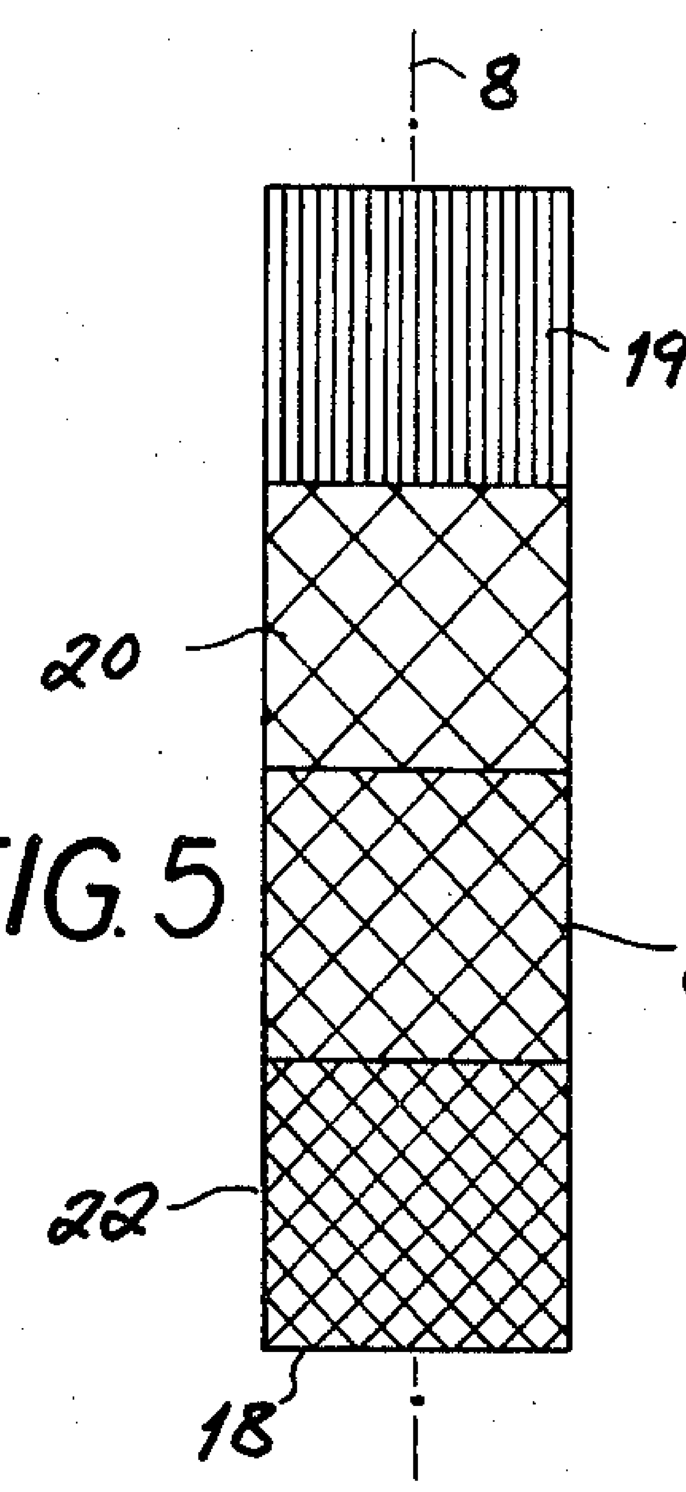


FIG. 5

INVENTOR:
Rudolf Becker

BY

Karl F. Ross
Attorney

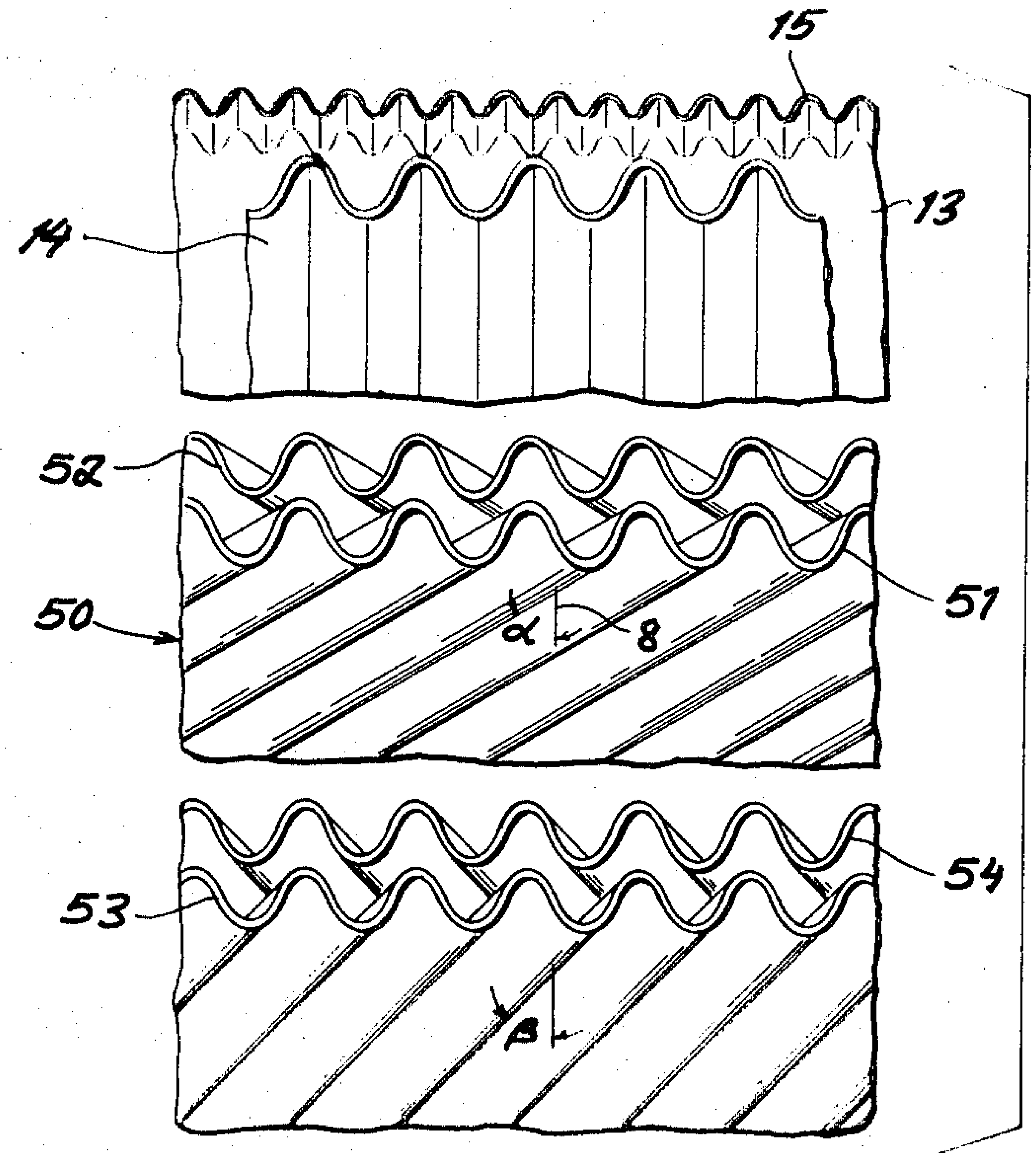


FIG. 6

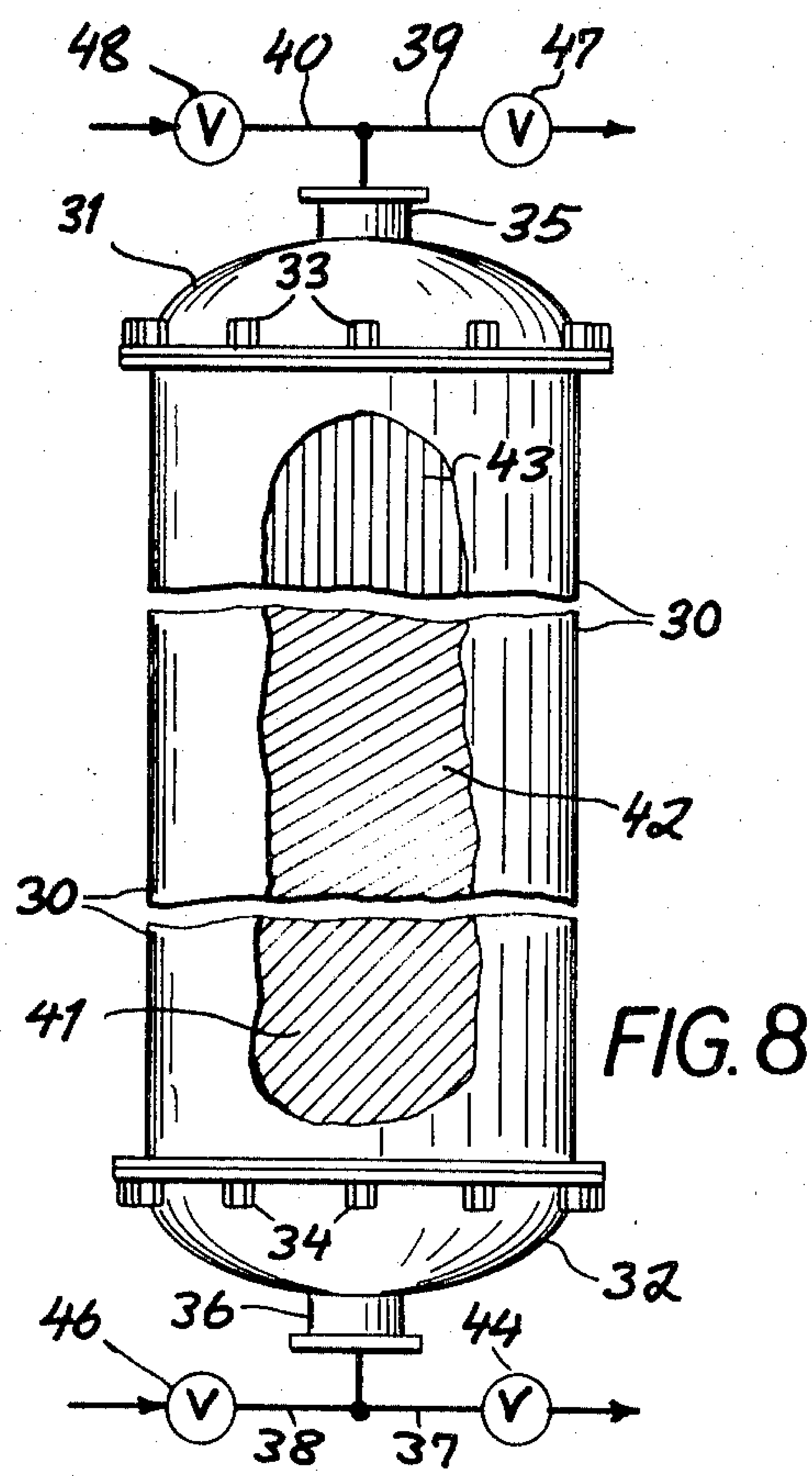


FIG. 8

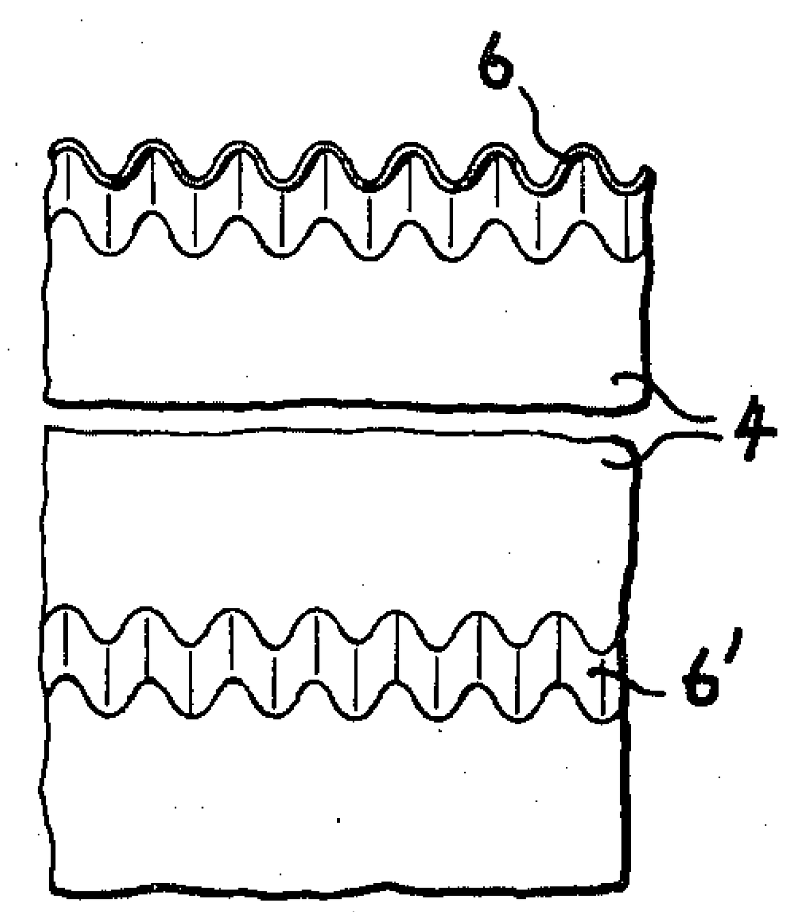


FIG. 7

Rudolf Becker
INVENTOR.

BY

Karl G. Ross
Attorney

REGENERATOR

FIELD OF THE INVENTION

The present invention relates to a regenerator and, more particularly, to a heat exchanger of the type in which heat or cold is stored in a heat-storage mass and is transferred to a fluid traversing the regenerator and having at least a condensable component.

BACKGROUND OF THE INVENTION

While the heat-exchange art is old and highly developed, indirect heat exchangers for use at low temperatures and even at high temperatures can be classified into two broad categories. The first category is a multicompartment heat exchanger in which heat transfer between the fluids which traverse respective compartments is effected through a thermally conductive wall which may be a plate, tube or the like. In this indirect heat exchanger, the fluids are passed in countercurrent or concurrent flow through the chambers simultaneously and efforts are made to facilitate heat conduction through the wall. In the other broad category of heat exchangers, hereinafter described as regenerators, a first fluid transfers heat or cold to a heat-storage mass, whereupon the other fluid is passed through the same chamber into contact with this mass and abstracts heat and cold therefrom. The principal difference between these two systems is the relationship of the fluid flow to time. In the first-mentioned system, the fluids are passed simultaneously through respective chambers separated by the thermally conductive wall whereas, in the regenerator, the fluids are passed successively into contact with the same heat-exchange surface of a heat storage mass. The principles of regenerator operation and the use of regenerators are described in U.S. Pat. No. 3,477,496.

Regenerators are commonly used in low-temperature applications wherein, for example, a relatively cold fluid from an air rectification plant, is passed through the regenerator to abstract heat from the heat-storage mass and transfer cold to the latter. It may be noted that the cooling of a heat-exchange mass will be described hereinafter as the abstraction of heat from or transfer of cold to the mass. Subsequently, a fluid to be cooled, e.g., the fluid to be subjected to rectification, may be passed through the regenerator to transfer heat to the mass while being cooled as a consequence. Frequently, at one stage in the heat exchanger, condensation of impurities, e.g., moisture, in this second fluid is effected.

It has been proposed to provide regenerators operating under the above-described principles and for the purposes set forth, with stages, baffles, hurdles or matrices of heat-storage material in the form of laminations of corrugated plates or sheets, e.g. as strips of corrugated sheet metal, the heat-storage mass of each stage or hurdle being spirally coiled or disposed in the form of nested cylinders. In matrices of the latter type, it has been proposed to incline the corrugation to the axis of the heat exchanger at an angle of, say, 45° in one layer and at a similar angle but in the opposite direction for another layer. The interwound corrugated strips thus have corrugations extending at approximately right angles to one another. It has also been proposed, in connection with such prior regenerators, to arrange the several stages or to so dimension the heat-storage mass such that the mass density (i.e., the mass of heat-

storage material per unit volume of the regenerator) increases from the hot to the cold end of the regenerator. The reason for this adjustment of the mass density is that the specific heat of the heat-storage material decreases at lower temperatures and hence is less at the cold end of the regenerator than at the warm end.

Regenerators of the aforedescribed type, with packings or hurdles of corrugated strips and like latticework systems have the disadvantage that, because high mass densities are required in the condensation zone (e.g., at the stage of the regenerator at which condensation of a condensable fluid, generally water, occurs) to compensate for the transfer of the latent heat of condensation, the flow cross-section must be markedly reduced and, therefore, the efficiency of the regenerator is lowered. In this connection, it might be mentioned that a reduced flow cross-section is associated with a proportionately large increase in the flow velocity and a large drop in the fluid pressure across the condensation stage which are both disadvantageous. To compensate, it is common practice to increase the length of the condensation stage which has the disadvantage that the volume of this stage is increased together with losses occurring in switchover from one fluid to the other. Finally, it should be observed that an increased length of the condensation zone invariably involves still higher pressure drops thereacross.

OBJECTS OF THE INVENTION

It is, therefore, the principal object of the present invention to provide an improved regenerator of relatively simple and inexpensive construction, adapted to obviate the disadvantages enumerated above.

A more specific object of the invention is to provide a packed regenerator using corrugated strips, which is characterized by low gas velocities and, consequently, low pressure drops thereacross.

Still another object of the invention is to provide an improved regenerator for the purposes described which operates more efficiently, occupies a smaller volume and is less expensive than most conventional regenerators designed for the same effective heat transfer.

SUMMARY OF THE INVENTION

These objects and others, which will become apparent hereinafter, are attained in accordance with the present invention, with a system which markedly reduces the pressure drop at least in the condensation stage or zone; according to the invention, the mass density of the heat-storage mass in the condensation zone is made relatively high by providing the heat-storage mass in this zone as a stack of hurdles, baffles or the like of corrugated sheet metal, especially corrugated strips in which the corrugations run generally parallel to the axis of the regenerator and in the principal direction of fluid flow therethrough, the corrugations also extending in the width of the sheet metal strips which may be thicker in the condensation zone to provide the greater mass density. However, the present invention provides that, whereas the corrugations of other portions of the regenerator may be inclined to a greater or lesser extent with respect to the axis of the regenerator and thus have lesser or greater flow resistance, the corrugations in the condensation zone are of a reduced inclination and preferably are substantially parallel to the axis; consequently, the more densely packed condensation zone has a decreased flow resistance in combination.

According to a more specific feature of the invention, the entire regenerator is packed with stages, baffles or hurdles of corrugated strips, advantageously in packages of nested concentric turns or a spiral package and spaced vertically with the condensation zone being formed by one or more such packages at the top of the generally cylindrical regenerator. In this preferred construction of the regenerator, the other stages or zones of the regenerator are provided with corrugated strips whose corrugations advantageously are inclined to the axis of the regenerator at angles of 45° to 60°, inclusively, while the corrugations in the condensation zone are inclined at 0° to the axial direction, i.e., are parallel thereto, Furthermore, in the other zones leading to the condensation zone, the corrugations of adjacent strips may be inclined to one another and in opposite directions to the axis so that a crosswise arrangement of the corrugations is provided in each zone.

It has been found to be advantageous to increase the mass density in the region of the condensation zone by introducing between the successive layers of corrugated strips, substantially smooth sheet-metal plates or strips, the thickness and number of which is selected in accordance with the mass density desired.

It has been found to be especially advantageous to make the smooth strips between the corrugated strips somewhat wider than the latter, i.e., to dimension the smooth strips to have a width (running in the axial direction of the regenerator) which is greater than that of the corrugated strips whose corrugations run likewise in this direction. In one embodiment of the invention, the smooth strip has a width which is two to 15 times greater than the width of the corrugated strips associated therewith so that, along each flank of the smooth strip, a number of corrugated strips may be provided. Advantageously, in this embodiment and in embodiments where the smooth strip is only say 1 to 10 percent greater in width than the corrugated strip (preferably 3 to 10 percent), the upper and/or lower edges of the smooth strip are formed with a series of grooves (corrugations) running in the axial or longitudinal direction and advantageously with a lesser corrugation period or higher undulation frequency than the corrugations of the corrugated strips. This band of grooves and alternating crests, preferably deformed symmetrically on opposite sides of the smooth sheet, serves to support each hurdle or heat-exchange unit upon the lower unit or to carry the next higher unit. When the smooth strip is a multiple or more of the width of a single strip, similar grooves or corrugations are provided in a band between the corrugated strips so as to constitute spacing members. The width (in the direction of the axis of the regenerator) of these corrugated spacer bands is relatively small, i.e., a minor fraction of the width of the corrugated strip.

It has already been observed that each smooth strip may be from 1 to 10 percent wider than the associated corrugated strip, with this extra width serving to provide the spacer bands or chains or channels. In this case, the spacer bands may constitute 0.5 to 5 percent of the width of the corrugated strip and the spacer bands are used to separate the independent heat exchange units from one another. Since the channels or grooves of the spacer bands extend parallel to the troughs of the corrugations of the corrugated strips, there is a minimum pressure drop across the assembly and an optimum flow velocity of the gas therethrough.

It has already been observed that the mass density, i.e., the mass of fluid-permeable heat exchange material per unit volume of the regenerator, can be readily established simply by modifying the depths of the corrugations and the thicknesses of the sheet-metal strips, i.e., the smooth sheet metal strip and the corrugated sheet metal strips. The mass density is greatest in the region of the condensation zone and then drops toward the warm end of the heat exchanger. It has been found to be advantageous, however, to provide a relatively dense arrangement at the hot end of the heat exchanger to compensate for reduced efficiency and it is, accordingly, a feature of the invention to provide the packing units such that the maximum mass density is at the condensation zone, the mass density decreases immediately adjacent this zone or in an intermediate portion of the regenerator, and finally the mass density increases again toward the cold end of the regenerator opposite the condenser zone. In this way, the heat exchange compensates for the latent heat transfer in the condensation zone as well as for the lower efficiency of the hot end of the regenerator. Since the condensation zone does not have to be lengthened in the manner of earlier regenerator, there is no increased loss upon switchover of the regenerator from one fluid to another.

DESCRIPTION OF THE DRAWING

The above and other objects, features and advantages of the present invention will become more readily apparent from the following description, reference being made to the accompanying drawing, in which:

FIG. 1 is a diagrammatic elevational view of a portion of a regenerator in accordance with the present invention, showing only the orientation and configuration of the heat storage mass;

FIG. 2 is an end view of this assembly;

FIG. 3 is a view similar to FIG. 1 illustrating another embodiment of the invention;

FIG. 4 is a bottom end view of arrangement of FIG. 3;

FIG. 5 is a diagram showing the several stages of the regenerator;

FIG. 6 is a fragmentary perspective view illustrating other aspects of the invention;

FIG. 7 is a diagrammatic elevational view of the smooth strip of FIG. 1; and

FIG. 8 is a vertical elevational view, partly broken away, of a regenerator embodying the present invention.

SPECIFIC DESCRIPTION

Referring first to FIG. **8**, a regenerator embodying the instant invention may be seen to comprise a cylindrical housing **30** closed at the top and bottom by domes **31** and **32**, respectively, held in place by flange bolts **33** and **34**. The usual fittings **35** and **36** are provided to communicate with the interior of the regenerator the fitting **36** communicating with a supply line **37** of one fluid and a line **38** for the other fluid. Similarly, lines **39** and **40** are provided for the fitting **35**. As shown diagrammatically in FIG. **8**, the interior of the regenerator is stacked with heat-exchange masses **41**, **42** and **43**, constructed as described in connection with FIGS. **1–5**, the latter mass defining the condensation zone. In normal operation, the heat exchanger is cooled by opening valves **44** and **45** to permit a cold fluid to pass through the heat exchanger, thereby transferring cold to the heat-exchanger masses therein and abstracting heat from the system. In the second cycle, the valves **44** and **45** are closed but valves **46** and **47** are opened to conduct the warm fluid through the heat exchanger, thereby cooling the latter. Condensation occurs in the zone of heat-storage unit **43** and the condensate may be removed by sublimation in the next half cycle as gas is passed through the regenerator to cool the same.

Referring now to FIG. **1**, it will be seen that the regenerator zones may comprise cylindrical or spiral windings of smooth sheet metal strips and corrugated sheet metal strips which are assembled into disk-like heat-storage units or matrices diagrammatically represented at **1, 2** and **3.** These matrices, hurdles or assemblies each have a structure best seen in FIGS. **2** or **6** and are stacked in the vertical direction parallel to the axis **8** of the regenerator within the housing so that each assembly **1, 2** or **3** constitutes one of the heat-exchange zones or a number of such assemblies constitutes the heat-exchange zone.

The hurdle or matrix **1** is flanked at the top and bottom by matrices **2** and **3**, respectively. The matrix **1** comprises the smooth sheet-metal strip **4** and three vertically spaced corrugated sheet metal strips **5** with vertically extending corrugations represented at **9.** The corrugations **9** thus lie parallel to the axis **8.** At the upper and lower ends of the smooth sheet-metal strip **4,** which may have a width $15w \geq W \geq 2w$ where w is the width of the corrugated strip **5**, there are provided bands or chains **6** of vertical channels **7** in the form of corrugations. Similar bands are provided at **6'** to space the corrugated strips **5** apart. The corrugated bands **6** and **6'** may be separate members fixed to the smooth sheet **4** or may be deformed directly therein. The channels or corrugations **7**, of course, lie parallel to the axis **8.**

The bands or chains **6** of the channel **7** increase the overall structural strength of the hurdle and serve to pass each hurdle from the underlying and overlying bands of adjacent hurdles. The hurdle **1** is thus formed by the cylindrical intercoiling of a smooth sheet metal strip with three corrugated sheet metal strips so that the corrugated strips flank the opposite sides of each smooth strip **4** as shown in FIG. **2.** The corrugations **9** of the corrugated strips comprise crests **9'** which alternate with troughs **9''** and are offset from the corrugation **9a** of the other side of the sheet metal strip **4** by one-half of the undulation period T which may be about twice the undulation period t of the corrugated bands **7.** However, the corrugation depth D of the strips **5** is advantageously at least four times greater than the corrugation depth d of the band. The corrugated strips **5** should have a thickness of 0.3 to 2.0mm, and a width w of 20 to 50mm. The smooth strip **4** should have a width of 100 to 400mm and a thickness of 0.1 to 0.5mm. The height h of the bands **6'** between the corrugated strips **5** and, therefore, the spacing of the corrugated strips **5** may be 0.5 to 5.0mm. FIG. **2** shows only two turns of the strips **4** and **5.** It will be understood, however, that the entire regenerator cross-section (FIG. **8**) is generally filled with turns of the strips of each stage.

In FIG. **3**, using the same format as in FIG. **1**, the condensation stage of the regenerator is shown. Here, the individual hurdles, packages, heat-storage units or matrices **10, 11** and **12** are axially stacked, each of the hurdles comprising a smooth sheet-metal strip **13** coiled with a respective corrugated strip **14.** The smooth strip **13** has a width W' which is slightly greater (by 1 to 10 percent, preferably 3 to 10 percent) than the width w' of the corrugated strip **14** whose channels or corrugations are represented at **17** and are parallel to the axis **8** of the regenerator. At least at one of the edges projecting beyond the corrugated strip **14**, the smooth strip **13** is formed with a band or chain **15** of channel **16** in the form of corrugations. Of course, a simple corrugated band may be applied to the smooth strip **13**, e.g. by welding, if desired, although it is preferred to deform the smooth strip along its edge to form this band. The bands **15** are each interposed between a respective hurdle **12, 11, 10** . . . and the next higher hurdles **11, 10** . . . and form spacers between them. A plurality of such matrices form the condensation zone. When viewed in the direction of arrow IV (FIG. **3**), the assembly has the configuration illustrated in FIG. **4.** Between each two turns of the corrugated strip **14**, a single turn of the smooth strip **13** can be seen. It will be understood that, with small diameters of the matrix, bands **6, 15** of channel **7, 16** may be omitted and the strips **4** and **13** made with the same width as the corrugated strip **5, 14** or an exact multiple of the width thereof.

In FIG. **5**, an overall diagram of the regenerator has been illustrated, the cold end being represented at **18.** The condensation zone is thus located in the region of the warm end and is shown at **19** in the form of a water condenser whose corrugations or channels run parallel to the axis **8** of the regenerator. Preferably, smooth strips are provided between the corrugated strips as described with respect to FIGS. **1–4.** The condensation zone is disposed above zones **20, 21** and **22** in which the matrices have corrugations which are inclined to the longitudinal axis of the regenerator. In these matrices, the smooth strip can be omitted and a pair of corrugated strips coiled together so that their corrugations cross one another as represented by the cross-hatching in FIG. **5.** The mass density of the regenerator varies from the cold end to the condenser and is greatest at the condenser. In the stage **20**, immediately following the condenser, the mass density is much larger and the corrugations may be inclined at angles of 60° to the axis **8.** In the stages **21** and **22** in which the mass density increases from one to the other, the corrugations may run at angles of 45° to 60° to the axis **8.** The thickness of the corrugated strip in the condensation zone preferably ranges between 0.3 and 2.0mm while the thickness of the smooth strips ranges from 0.1 to 2.0mm. The corrugated strips of the remaining zones **20** through **22** may be 0.1 to 0.5mm in thickness. This is shown in greater detail in FIG. **6** in which the smooth sheet **13** with the corrugated band **15** can be seen to be flanked by the corrugations **14.** The corrugations **50** of the corrugated strip **51** of zone **20** are inclined at the angle α to the axis **8** where α equals 60° and are juxtaposed with the corrugated strips **52** inclined in the opposite direction. The strips **53** and **54** of the coils of zone **21** are seen to be inclined at angles β of 45° to the axis of the regenerator.

I claim

1. A regenerator comprising an elongated housing; respective fluid-permeable masses of heat-storage material stacked along the axis of said housing and defining respective zones therealong including a condensation zone at one end of said housing; and means for passing fluids through said housing, at least some of said masses of said heat-storage material comprising respective matrices of a plurality of turns of corrugated sheet-metal strips, the corrugations of the strips of said condensation zone including with said axis angles less than those included with said axis by the corrugations of others of said zones, said matrices of said condensation zone having a greater mass density than the matrix of such zones, the corrugations of the matrix of said condensation zone being substantially parallel to said axis and the corrugations of the matrices of the other zones being inclined at angles between 45° and 60° inclusive to said axis, said matrix of said condensation zone including between successive turns of said corrugated strip, at least one turn of a relatively smooth sheet-metal strip, the mass density of said matrices of said other zones being lower proximal to said condensation zone but higher relatively distal therefrom.

2. A regenerator comprising an elongated housing: respective fluid-permeable masses of heat-storage material stacked along the axis of said housing and defining respective zones therealong including a condensation zone at one end of said housing; and means for passing fluids through said housing, at least some of said masses of said heat-storage material comprising respective matrices of a plurality of turns of corrugated sheet-metal strips, the corrugations of the strips of said condensation zone including with said axis angles less than those included with said axis by the corrugations of others of said zones, said matrices of said condensation zone having a greater mass density than the matrix of another of such zones, the corrugations of the matrix of said condensation zone being substantially parallel to said axis and the corrugations of the matrices of the other zones being inclined at angles between 45° and 60° inclusive to said axis, said matrix of said condensation zone including between successive turns of said corrugated strip, at least one turn of a relatively smooth sheet-metal strip, said relatively smooth strip having a width in the direction of said axis ranging between two and 15 times the width of the corrugated strips flanking same and is provided with a band of channels separating said corrugated strips from further corrugated strips forming said matrix of said condensation zone.

3. A regenerator comprising an elongated housing; respective fluid-permeable masses of heat-storage material stacked along the axis of said housing and defining respective zones therealong including a condensation zone at one end of said housing; and means for passing fluids through said housing, at least some of said masses of said heat-storage material comprising respective matrices of a plurality of turns of corrugated sheet-metal strips, the corrugations of the strips of said condensation zone including with said axis angles less than those included with said axis by the corrugations of others of said zones, said matrices of said condensation zone having a greater mass density than the matrix of another of such zones, the corrugations of the matrix of said condensation zone being substantially parallel to said axis and the corrugations of the matrices of the other zones being inclined at angles between 45° and 60° inclusive to said axis, said matric of said condensation zone including between successive turns of said corrugated strip, at least one turn of a relatively smooth sheet-metal strip, said relatively smooth strip having a width in the direction of said axis between 3 and 10 percent greater than the width of corrugated strips flanking same and is formed along at least one edge with a band of channels separating said matrix from another matrix of similar construction.

4. The regenerator defined in claim 2 wherein the mass density of said matrices of said other zones is lower proximal to said condensation zone but is higher relatively distal therefrom.

5. The regenerator defined in claim 3 wherein the mass density of said matrices of said other zones is lower proximal to said condensation zone but is higher relatively distal therefrom.

* * * * *