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R. C. STEELE

3,018,087

HEAT TRANSFER PANEL

Filed April 11, 1958

Fig. 1.

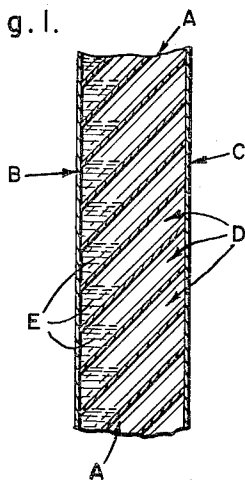


Fig. 2.

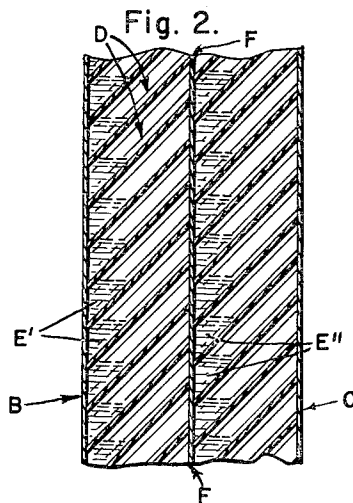


Fig. 3.

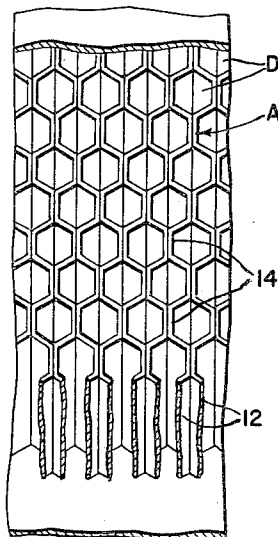


Fig. 5.

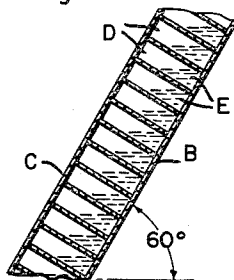


Fig. 6.

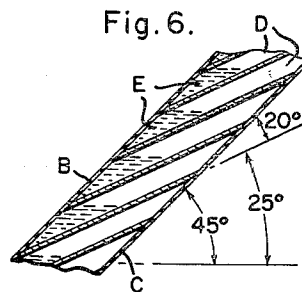
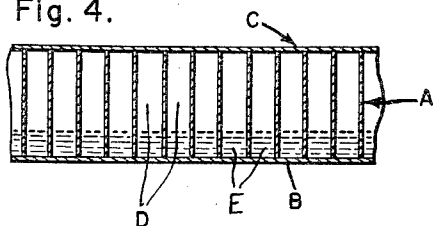


Fig. 4.



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3,018,087

HEAT TRANSFER PANEL

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This invention relates to a panel structure having a different coefficient of heat transfer in one direction through its thickness than in the opposite direction.

A primary object and feature of the invention is to provide a panel structure which will transfer heat from one side to its other side at a faster rate than it will transfer heat in the opposite direction when temperatures on opposite sides of the panel are reversed.

The present invention is particularly adaptable for panel or wall construction in buildings, storage tanks, refrigeration compartments, transportation vehicles, containers and other industrial thermodynamic and heat transfer applications where it may be desired to transfer heat more rapidly in one direction than in the other. By way of example, and not by way of limitation, it is contemplated that the present invention may be employed in the construction of liquid storage tanks in areas such as the southwest portions of the United States, or in desert areas where the temperatures in the day under the heat of the sun may substantially exceed 100° F., where at night, the temperatures may drop to 60° F., or below. In any such installation, it is desirable to insulate the interior of the tank against evaporation loss due to heat during the hot period of the day. It is also desirable to dissipate the stored or latent heat within the tank to the outside atmosphere during the colder outside nighttime periods. As will more fully appear, a storage tank having its roof and vertical walls constructed in accordance with the teachings of the present invention is adapted to provide a good insulator between the heat of the sun and the interior of the tank during the day, but at the same time provide a means for fairly rapidly transferring stored heat within the tank to outside atmosphere when there occurs a substantial temperature differential between the inside and outside of the tank and in which the outside temperature drops a substantial amount below the warmer contents of the tank.

Another object is to teach how, through the selection of an appropriate heat transfer liquid having a known boiling or rapid vaporization point and freezing point, the maximum low temperature of heat transfer through the panel by convection and condensation of the liquid molecules may be regulated and limited. As will more fully appear, the panel is arranged to transfer heat in one direction only by convection of vaporized molecules of the liquid.

The foregoing and other objects will be appreciated upon a reading of the following written description and an understanding of the accompanying drawings wherein:

FIG. 1 is a fragmentary vertical sectional view of a panel constructed according to one embodiment of the invention;

FIG. 2 is a fragmentary vertical sectional view of a modified structure comprising a plurality of the embodiments of FIG. 1 connected in series;

FIG. 3 is a fragmentary front elevational view of the embodiment of FIG. 1 with one of the face sheets removed exposing the honeycomb corestock;

FIGS. 4, 5 and 6 are all fragmentary sectional views showing further modifications of the invention.

The invention comprises, essentially, a cellular honeycomb core A with sheets or faces B and C bonded or otherwise attached to its opposed cellular faces to hermetically seal the individual cells D. Liquid indicated at E partially fills each cell.

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Core A consists of a plurality of corrugated or sinusoidally curved webs 12 bonded node to node at longitudinally spaced intervals as indicated at 14 to form a hexagonal cellular core of honeycomb. The particular method and means for assembling the honeycomb core forms no part of the present invention, although, reference may be made to U.S. Patents Nos. 2,610,934 and 2,734,843 as exemplary instruction in that art.

Core A is preferably formed of a material having a relatively low coefficient of heat conductivity such as synthetic resin impregnated glass or textile cloth, or paper, numerous types of which are available commercially and are well known in the art.

Sheets B and C are bonded to the opposed cellular faces of core A.

Sheets B and C are formed of a suitable material having heat conductive properties as the particular application of the invention may dictate. In addition, surfaces of components A, B and C may be colored light or dark to affect the rate of heat transfer through the panel as will more fully appear.

Each cell D of the core is partially filled with a volatile liquid E having a known boiling point appropriate for use within the range of anticipated temperatures and temperature differentials in connection with which the invention is to be used. Generally speaking, the normal boiling point of the liquid used may be reduced and controlled by creating a partial vacuum within the cells at the time the panel is fabricated and hermetically sealed by application of the face sheets B and C to the core A.

FIGS. 1 through 3 disclose an embodiment showing the unidirectionally extending axes of the honeycomb cells B obliquely disposed relative to sheets B and C. The embodiments of FIGS. 1 through 3 are particularly adaptable to provide vertical panel surfaces. FIG. 4 discloses a panel constructed with the axes of the cells disposed perpendicularly to the flat planes of the face sheets B and C, and this type of construction is adaptable to provide a horizontal panel structure embodying the invention.

The operation and function of the invention will now be described:

In general, it may be observed that the coefficient or rate of heat transfer through the thickness of the fabricated panel structure is substantially greater in the direction of side B to side C than in the reverse direction of from side C to side B, assuming in each measurement of heat transfer that the same temperature differential on opposite sides of the panel would exist, although reversed according to the direction of heat transfer.

The following factors in connection with the heat transfer properties of the panel A may be observed. Firstly, rate of heat transfer by conduction would be equal regardless of the direction of heat transfer through the panel. In this regard the honeycomb core material will conduct heat at the same rate in either direction. As above noted, it is considered preferable although perhaps not essential, that in most applications it will be desirable to make the honeycomb core out of a relatively good heat insulating material to minimize heat transfer in either direction by conduction.

Heat will also be transferred through the thickness of the panel by radiation of heat from opposite interior surfaces of the face sheets. If the sheets B and C are made of the same material and are treated similarly, the rate of heat transfer by radiation will be the same in either direction, although the rate of transfer by radiation in the panel structure shown in FIG. 4 will be substantially higher than the rate of transfer by radiation in the panel structure shown in FIGS. 1-3. This is because the angularity of the cells in the FIGS. 1-3 struc-

ture will function to baffle direct radiant heating between the sheets B and C.

The third, and most significant, way by which heat is transferred through the panel structure embodying the invention is by convection. If the cells D are vacuumized, or partially vacuumized, it is apparent that comparatively little air molecule heat transfer will occur. However, if it be assumed that there is a substantial temperature differential between sides B and C of the panel, and in which the temperature at side B is substantially higher than the temperature at side C, there will occur a relatively rapid convection transfer of heat due to the evaporation and condensation of the liquid E. More specifically, if it is assumed that the temperature on side B of the panel is at least equal to the boiling or rapid vaporization point of liquid E, it is apparent that said liquid E will function to evaporate molecules which will circulate to and condense upon the colder surfaces of face sheet C. Each molecule as it condenses on the surface C will transfer (by conduction) heat to the latter. The condensed particles of liquid will then gravitationally flow down the cell walls to the reservoir or pool of liquid whereupon the cycle of evaporation and condensation repeats itself.

When the temperature differential on opposite sides of the panel are reversed and specifically, when the temperature on side C elevates to equal or above the temperature on side B of the panel, the transfer of heat by vapor convection and condensation will cease.

The principles of operation of the invention may be illustrated by the following laboratory experiment:

The core was constructed using a $\frac{3}{16}$ " cell size, 1.0" thick hexagonal honeycomb core fabricated from 112 weave glass cloth and impregnated to 7.0 lbs./cu. ft. density with heat resistant modified phenolic resin such as Cincinnati Testing Laboratory CTL-91LD resin. A panel was made using face sheets of 0.020" gauge 20/20-4T3 aluminum Alclad 2024-T3 alloy coated on their inner surfaces and bonded to opposite sides of the core by heat resistant epoxy polyamide resin. The core was oriented 60° to horizontal, with each cell about one-fourth filled with water, in the manner indicated in FIG. 5.

Using conventional thermal conductivity apparatus and measuring the heat flow from B to C with the hot side B at 221° F. and the cold side C at 117° F., the thermal conductivity of the panel was 0.458 B.t.u.-ft./hr.-ft.² per ° F. When the heat flow was reversed, the flow from C to B with the hot side at 225° F. and the cold side C at 112° F., resulted in a heat conductivity measurement of 0.221 B.t.u.-ft./hr.-ft.² per ° F.

From the foregoing it was concluded that in the above experiment, the test panel transferred heat about twice as fast in one direction as in the other.

By way of further example, another panel was fabricated using a $\frac{3}{16}$ " cell size, 0.602" thick hexagonal honeycomb core fabricated from 0.101 weave glass cloth at 2.5 lbs./cu. ft. density. The panel was made using face sheets of 0.10" thickness window pane glass coated on their inner surfaces and bonded to opposite sides of the core by a mixture of polyamide and epoxy resin. The core was oriented at 50° to the horizontal with each cell containing ten drops of water.

Using conventional thermal conductivity testing apparatus, and measuring the heat flow from B to C with hot side at 196° F. and cold side at 105° F., the heat conductivity of the panel was 0.201 B.t.u.-ft./hr.-ft.² ° F. The flow from C to B with cold side at 101° F. and hot side at 230° F., was .0828 B.t.u.-ft./hr.-ft. ° F.

From the foregoing it was concluded that in the above experiment, the test panel transferred heat about two and one-half times as fast in one direction as in the other.

Applying the principles of operation and function ascribed to the invention hereinabove, the following example of how the invention may be practically utilized is given.

As earlier pointed out, it is contemplated that the present invention might have considerable practical utility if used as the lid and wall structures of petroleum or other liquid storage tanks located in areas where there occurs very considerable day and night temperature variation such as desert conditions where the daytime temperatures may substantially exceed 100° F., and where the nighttime temperatures may drop to 60° F., or below. In any such storage tank application where it would be desirable to insulate the tank from daytime heat and prevent evaporation of the contents as much as possible, the interior surfaces of the tank would be considered as the side B surface of panel A, whereas the exterior of the tank would correspond in relative location to side C of the panel. It is appreciated that during the hot daytime periods, the honeycomb core material would function as a relatively good heat insulator and would minimize heat transfer from the relatively hotter outside to the relatively cooler inside of the tank. However, during the cooler night time periods where the temperature may drop to 60° F., or below, and further assuming that the interior contents of the tank may be to 80°-90° F., the latent heat in the tank would be fairly rapidly transferred to the outer face sheet due to the continuous evaporation and condensation of the liquid E in the manner previously described. In temperature ranges noted here, the liquid E should have a boiling or rapid vaporization point of perhaps around 70° F., or even lower. Water might be used if the cells D of the honeycomb were substantially vacuumized.

The embodiment of the invention shown in FIG. 2 indicates how two or more of the panel structures embodying the invention may be connected in series in the event it is desirable to utilize such an arrangement in any given heat transfer application. For example, it may be necessary or advisable to provide multi-layers of core and face skins to alter the heat characteristics of the panel.

In FIG. 2 the center sheet or plate F will function as the condensing surfaces for liquid E' and will function as the heat surfaces for heating to rapid vaporization or boiling point liquid E''. It is seen that the heat source for liquid E'' is derived from heat loss transferred to sheet F from condensation of vapor molecules from liquid E'. Thus, it is apparent that the vaporization or boiling point of liquid E'' must be below the condensation temperature of liquid E'.

It is also possible to control and limit the maximum low temperature at which any panel embodying the invention will continue to transfer heat by evaporation and condensation from the hot side to the cold side. This is accomplished by selecting and using a heat transfer liquid that will freeze at the temperature which is determined to be the maximum low transfer temperature of the panel. To illustrate the above, assume that it is not desired to cool the contents of refrigeration car compartment below a certain low temperature of, for example 32° F. even should the actual outside temperature drop well below this maximum low heat transfer temperature. In such event, water, having a freezing point of 32° F. and hermetically sealed in vacuumized cells of the panel core, would be suitable because after sufficient heat was transferred to bring the inner panel side B into approximate temperature equilibrium with the cold (sub-freezing) outer side C of the panel, the water would freeze into ice and in such state would not transfer further heat by convection and condensation.

The term "maximum low heat transfer temperature" as used herein means the predetermined low temperature below which it is not desired to transfer heat by convection and condensation of the heat transfer molecules. Manifestly, the panel will continue to conduct a certain amount of heat by conduction and radiation whenever there is a temperature differential on opposite sides of the panel.

As previously indicated FIG. 5 shows an arrangement

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in which the axes of the honeycomb cells C are perpendicular to the face sheets B and C. However, the composite panel is oriented at an oblique angle, such as 60°, with reference to horizontal and with the heat transfer liquid E normally filling the lower regions of the cells D. It is appreciated that the panel arrangement shown in FIG. 5 might be used in a pitched roof construction or in other types of inclined panel installations and where it is desirable to transfer heat more rapidly in the direction of B to C than C to B.

FIG. 6 illustrates a panel in which the axes of the honeycomb cells D are disposed at an acute angle with reference to the face skins B and C as for example 20°. When the panel is oriented at a substantially greater angular inclination from horizontal (such as 45°) than the angle between the cell axes and the face sheets B and C, the heat transfer liquid E will gravitate to the B side of the panel. The heat flow transfer characteristics of the panel of FIG. 6 will be the reverse of the heat flow characteristics of the panel shown in FIG. 5. It is contemplated that the FIG. 6 embodiment may be employed in solar energy installations where the B side of the panel is subjected to direct rays of sunlight which will cause the liquid E to boil or vaporize at a rapid rate and condense on the relatively cooler surfaces of the inside panel C. During the day the panel would operate to transfer solar heat rapidly through the panel in the direction of B to C. During nighttime periods when side B becomes cooler than side C, the insulating properties of the panel will minimize loss of stored heat through the panel from side C to side B according to the principles hereinabove explained.

The rate of heat transfer of a panel of any of the above types from side B to side C may be varied by the selection and use of different types of heat transfer liquids having different thermal conductivities. The selection of a particular type of transfer liquid will depend in some measure at least on the application of use to which the panel is put and upon the temperature ranges and temperature differentials in connection with which the panel is to operate. The panel characteristics may also be enhanced by maintaining both the outside and inside surfaces of sheet C light colored to minimize heat absorption from the outside, and radiation of heat from sheet C to sheet B. The interior and exterior surfaces of sheet B may be blackened to increase the heat transfer qualities from the hot side of the panel to liquid E via sheet B. It is contemplated that various types of volatile heat transfer liquids such as aqueous salts or brine solutions, oils, alcohol, and other liquids, particularly those with relatively low boiling points, may be found suitable for use in various applications of the invention, it being understood that the scope of the invention is not considered to be limited to any particular type or category of heat vaporizable transfer liquids.

Although the present invention has been described

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in some detail by way of illustration and example for purposes of clarity of understanding, it is understood that certain changes and modifications may be made within the spirit of the invention and the scope of the claims appended hereto.

What is claimed:

1. A panel structure characterized by its ability to transfer heat more rapidly in one direction through its thickness than in the opposite direction: a sandwich structure comprising a section of cellular core defining unidirectionally extending open ended cells through its thickness, and first and second flat parallel substantially vertically disposed face sheets affixed to opposite sides of said section closing and hermetically sealing opposite open ends of said cells; a volatile liquid only partially filling each cell; the axes of said unidirectionally extending cells obliquely angularly disposed from horizontal to cause said liquid in each cell to normally gravitationally flow and form into a pool in contact with the interior surface of said first face sheet and out of contact and spaced from the interior surface of said second face sheet; the interior of said second face sheet defining a potential condensing surface for vaporized molecules of the liquid in each partially filled cell.

2. A panel structure characterized by its ability to transfer heat more rapidly in one direction through its thickness than in the opposite direction: a sandwich structure comprising a section of cellular core defining unidirectionally extending open ended cells through its thickness, and first and second flat parallel face sheets affixed to opposite sides of said section closing and hermetically sealing opposite open ends of said cells; a volatile liquid only partially filling each cell; the axes of said unidirectionally extending cells disposed in an oblique angle relative to the flat planes of said face sheets; said sandwich structure positioned with said face sheets disposed generally in a vertical plane and with the axes of said cells inclined substantially out of horizontal to cause said liquid in each cell to normally gravitationally flow and form into a pool in contact with the interior surface of the face sheet closing the lower end of each cell and out of contact and spaced from the interior surface of the face sheet closing the upper end of each said cell; the interior of the sheet closing the upper ends of the cells defining a potential condensing surface for vaporized molecules of the liquid in each partially filled cell.

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