PCT WORLD INTELLECTUAL PROPERT
International Burea

INTERNATIONAL APPLICATION PUBLISHED UNDER TI

WO 9606750A2

(51) International Patent Classification 6 : B60K 15/00 — A2

(11) International Publication Number: WO 96/06750

(43) International Publication Date: 7 March 1996 (07.03.96)

(21) International Application Number: PCT/US95/11024

(22) International Filing Date: 29 August 1995 (29.08.95)

(30) Priority Data:
08/297,232 29 August 1994 (29.08.94) US

(71)(72) Applicant and Inventor: STENGER, Gregory, J. [US/US]; 5883 Hathaway Road, Lebanon, OH 45036 (US).

(74) Agents: EBY, C., Richard et al.; Wood, Herron & Evans, 2700 Carew Tower, Cincinnati, OH 45202 (US).

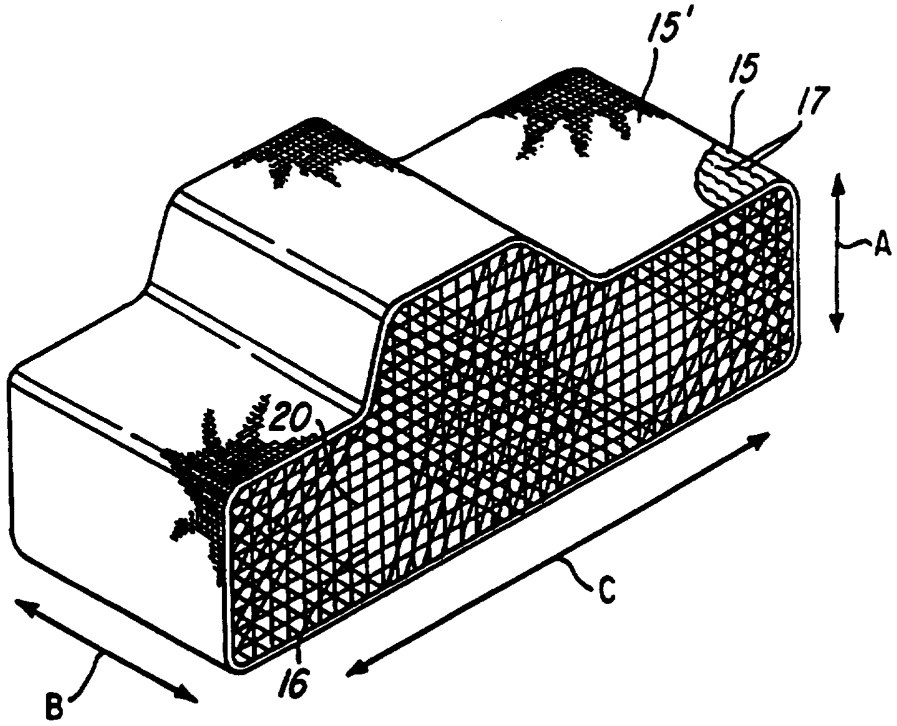
(81) Designated States: AM, AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, EE, ES, FI, GB, GE, HU, IS, JP, KE, KG, KP, KR, KZ, LK, LR, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, TJ, TM, TT, UA, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG), ARIPO patent (KE, MW, SD, SZ, UG).

Published
Without international search report and to be republished upon receipt of that report.

(54) Title: TANK FOR STORING PRESSURIZED GAS

(57) Abstract

A tank for storing a pressurized gas including walls of a layered material (15) and continuous unidirectional fibrous bundles of fibers (16) woven through the walls of layered material (15). The continuous unidirectional fibrous bundles (16) have first ends (17) that extend over a first wall of material (15), pass through the first wall of material (15), extend through the interior of the tank (11), pass through another wall of the material (15) and have second ends (17) that extend over the other wall of the material (15). Other bundles of fibers (18, 20) can be woven between different walls of the tank (11) in a similar pattern to produce complex three dimensional shapes.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria	GB	United Kingdom	MR	Mauritania
AU	Australia	GE	Georgia	MW	Malawi
BB	Barbados	GN	Guinea	NE	Niger
BE	Belgium	GR	Greece	NL	Netherlands
BF	Burkina Faso	HU	Hungary	NO	Norway
BG	Bulgaria	IE	Ireland	NZ	New Zealand
BJ	Benin	IT	Italy	PL	Poland
BR	Brazil	JP	Japan	PT	Portugal
BY	Belarus	KE	Kenya	RO	Romania
CA	Canada	KG	Kyrgystan	RU	Russian Federation
CF	Central African Republic	KP	Democratic People's Republic of Korea	SD	Sudan
CG	Congo			SE	Sweden
CH	Switzerland	KR	Republic of Korea	SI	Slovenia
CI	Côte d'Ivoire	KZ	Kazakhstan	SK	Slovakia
CM	Cameroon	LI	Liechtenstein	SN	Senegal
CN	China	LK	Sri Lanka	TD	Chad
CS	Czechoslovakia	LU	Luxembourg	TG	Togo
CZ	Czech Republic	LV	Latvia	TJ	Tajikistan
DE	Germany	MC	Monaco	TT	Trinidad and Tobago
DK	Denmark	MD	Republic of Moldova	UA	Ukraine
ES	Spain	MG	Madagascar	US	United States of America
FI	Finland	ML	Mali	UZ	Uzbekistan
FR	France	MN	Mongolia	VN	Viet Nam
GA	Gabon				

TANK FOR STORING PRESSURIZED GAS

Field of the Invention

The present invention relates generally to the construction of fuel tanks for storing gas and, more particularly, to an improved construction of a gas storage tank for natural gas powered vehicles.

Background of the Invention

For many years, there has been interest in developing and using alternative fuels for vehicles, and particularly, overland vehicles, for example, automobiles, buses, trucks, etc. Over that period of time, many such vehicles have been retrofitted to operate using natural gas. More recently, with increasingly stringent air pollution standards, fleets of vehicles that have been retrofitted to operate with natural gas are more common.

In currently retrofitted vehicles, the natural gas is often stored in a cylindrically shaped pressurized steel vessel or tank designed specifically for storing gases such as natural gas, propane, nitrogen, etc. under high pressure. The cylindrical shape of the tank provides a circular cross section about an axis which eliminates bending stresses and helps reduce the weight of the tank. Since the cylindrical steel natural gas storage tank is not suitable for and cannot be readily retrofitted in place of the vehicle's liquid fuel storage tank, the natural gas storage tank is often housed in the storage area or trunk of the vehicle, thereby eliminating or severely limiting the use of the trunk for other storage. Therefore, there is a need for a natural gas storage tank that can take the place of the vehicle's liquid fuel storage tank. Other gas storage tank designs and structures are known in the art.

For example, the Pechstein U.S. Patent No. 2,156,400 is directed to a spherical container for storing fluids such as gases and liquids. The spherical container has a foundation with at least three reinforcing supports adapted to transmit the forces exerted by the dead weight and the weight of the contents of the container upon the foundation. The container further includes lower struts connected at their ends to points on the inner wall of the container where the container rests on the supports to form at least one lower polygonal frame. The container further has upper struts connected at both ends to the inner wall of the container at points lying in its horizontal middle portion to form at least one upper polygonal frame. Inclined struts connect the corner points of the upper and lower polygonal frames to provide a self supporting framework which is adapted to transfer the loads due to the dead weight and the weight of the contents of the container directly upon the supports without substantially stressing the walls of the container.

The Albrecht U.S. Patent No. 2, 296,414 is directed to heavily reinforced storage tanks for liquids and gases that are present in high volume and have angular sides made of flat or curved plates. The storage tank has flat side, top and bottom walls of metal plates. A plurality of vertically spaced tiers of braces are set at angles to adjacent vertical walls. Each tier has a plurality of parallel, horizontal, equally spaced braces lying in a common plane. Each of the braces forms a triangular truss with adjacent vertical walls to cause the stresses in the bracing members and the wall plates to be compensating stresses.

The Pflederer U.S. Patent No. 3,368,708 is directed to a filament wound storage vessel capable of withstanding high internal pressures. The cylindrical wall of the tank is formed of helically wound, fibrous material impregnated with thermal setting resin serving to bond fibers together as an integral structure.

While all of the above known tanks are effective to confine a gas under high pressure, the designs of the tanks are directed to their particular application. For example, the design of the currently used steel cylindrical tank is directed to a tank that is intended to be portable and not permanently affixed to any particular structure. Therefore, the tank has specifications relating to its size, shape and weight that facilitate portability.

In contrast, the Pechstein '400 and Albrecht '414 patents are designed to store large volumes of pressurized gas and are not designed for portability. The Pflederer '708 patent is designed to have a removable head portion at one end which presents different design considerations and a different structure. None of the above tanks provide a tank structure that may be constructed in any desired shape as may be required for installation in a vehicle.

Summary of the Invention

The present invention provides a natural gas storage tank designed specifically for installation in motor vehicles. Further, the natural gas storage tank of the present invention has the capability of being constructed to any desired shape to fit the specifications and space limitations for installation in a motor vehicle.

More particularly, and in accordance with the principles of the present invention, a fuel tank for a vehicle powered by natural gas includes a three dimensional tank outer wall structure made of the fibrous composite material. The tank outer wall structure has an exterior surface and further has at least two walls bounding an interior. The fuel tank further includes a set of continuous, unidirectional, fibrous bundles extending in a repeating pattern over the exterior surface of the outer wall structure on the first wall, through the first wall, through the interior, through the second wall, and over the exterior surface of the outer wall structure on the second wall.

In another aspect of the invention, the first and second walls of the tank may be parallel or may be adjacent, intersecting walls. In another aspect of the invention, the tank includes a second set of continuous, unidirectional fibrous bundles extending in a repetitive pattern over the exterior surface of the wall structure on a third wall of the tank, through the third wall, through the interior, through a fourth wall of the tank and over the exterior of the fourth wall.

In still another aspect of the invention, the tank includes a third set of continuous unidirectional fibrous bundles extending in a similar repeating pattern over and through fifth and sixth walls of the tank. The first, second and third bundles of continuous fibers may extend through the interior of the tank in directions generally perpendicular to each other, or, in directions that are oblique to each other, or, in perpendicular and oblique combinations thereof. Therefore, advantageously, the walls of the tank may be adjacent

The pressurized natural gas tank construction of the present invention has the advantage of being light in weight and capable of confining the pressurized gas. The construction permits the tank to be made in any geometric shape and, preferably, in a noncylindrical, prismatic shape comprised of a number of intersecting generally flat faces or surfaces. Therefore, the walls of the tank can conform to any available space in a vehicle for a tank These and other objects and advantages of the present invention will become more readily apparent during the following detailed description together with the drawings herein.

Brief Description of the Drawings

FIG. 1 is a perspective view of a vehicle shown in phantom line and containing a the natural gas tank in accordance with the principles of the invention.

FIG. 2 is a fragmentary perspective view of the vehicle with the natural gas tank of the present invention mounted in a different orientation within the vehicle.

FIG. 3 is a perspective view of the tank of FIG. 2 with parts phantom and parts in cross-section taken generally along the line 3-3 of FIG. 2.

FIG. 4 is a fragmentary perspective view of a portion of the tank of the present invention with parts in cross-section illustrating an arrangement of fibers constituting a first fibrous network.

FIG. 5 is a fragmentary perspective view, similar to that of FIG. 4, with parts in cross-section illustrating two fibrous networks.

FIG. 6 is a fragmentary perspective view similar to those of FIGs. 4 and 5 illustrating a three-dimensional fibrous network.

FIG. 7 is a diagrammatic view illustrating the force vectors which operate on the tank internally due to the pressures exerted by the natural gas under high pressure.

FIG. 8 is a fragmentary cross-sectional perspective view of a portion of an embodiment of this invention illustrating the support of oblique walls and the use of obliquely oriented fibrous networks.

Detailed Description of the Invention

As will be apparent from Figs. 1 and 2, the vehicle 10 contains high pressure tank gas tank 11 which, as shown, is located in the rear of the vehicle. In Fig. 1, the tank is oriented with its B axis in a vertical direction, and its longitudinal C axis substantially perpendicular to the length of the vehicle. In Fig. 2, the tank has been rotated about its longitudinal C axis sot that its B axis in a horizontal direction. Attached to tank 11 is fill hose line 12 which is capable of handling the gaseous fuel under high pressure and engine fuel supply line 14 which is also capable of handling the gaseous fuel under pressure. Pressure can be reduced at the tank fitting by use of a pressure regulator. Located to the rear of high pressure tank 11 and connected to fill hose 12 is a receptacle 13 for adding additional natural gas or other fuel.

As will be apparent from FIGS. 3-8, fibrous composite layered material 15 constitutes the outer structural wall portion of high pressure tank 11. As is noted from FIGS. 3, 4, 5, 6 and 8, continuous, internal, unidirectional fibrous bundles 16 are arranged within tank 11 mainly along the A axis as illustrated in the drawings. Exposed portions 17 of fibrous bundles 16 are crossed over or stitched through the fibrous composite layered material 15 as shown in FIGS. 4, 5, 6 and 8, and can be covered with a protective layer or coating 15′.

The continuous unidirectional fibrous bundles 16 arranged mainly along the A axis serve to provide reinforcement substantially perpendicular to that of reinforcing fibrous bundles 18 and 20 shown in FIG. 6. The reinforcing fibrous bundles 16 pass through the multi-ply tank wall then exposed 17 along the exterior surface of the outer structural wall and then re-enter the tank through the wall. This pattern is repeated seriatim to provide the internal reinforcement mainly along the A axis resisting the internal pressure forces, which would otherwise tend to warp the tank away from its desired three-dimensional, noncylindrical structural configuration. The thickness of the wall 15 and the spacing of fibrous bundles 16 and 17 can be varied as desired. Protective covering 15′ can be a composite fibrous overwrap or layer or it can be a resinous coating. A liner material can be used on the interior surface to meet the permeation requirements for specific applications.

Continuous unidirectional fibrous bundles 18 are arranged mainly along the B axis as is shown in FIGS. 3, 5 and 6 and are crossed over/stitched through the walls 15 and emanate along the outer structural wall as 19.

As shown from FIG. 6, disposed along the C axis are reinforcing continuous unidirectional fibrous bundles 20 whose exposed ends 21 emanate from the interior of tank 11. These bundles pass through the multi-plies of the outer structural wall and are exposed on the exterior surface of the outer structural wall. The bundles then re-enter into the interior of tank 11 to serve as a lateral reinforcement, tying the multi-ply walls together so as to reinforce tank 11 from forces which would otherwise tend to push the tank out on all walls. The tanks of this invention are characterized as having a noncylindrical three-dimensional tank outer wall having an exterior surface and substantially opposed wall portions of fibrous composite wall material and reinforcing portions. These reinforcing portions are in the form of a first set of continuous, unidirectional fibrous bundles which traverse through the tank outer wall, and a second set of continuous unidirectional fibrous bundles running in a direction substantially perpendicular to the first set and, also passing through the tank outer wall. The first set and the second set of fibrous bundles exit and re-enter the tank outer wall to provide exposed portions on the exterior surfaces thereof. A protective layer covers the exterior surface of the tank outer wall and these exposed portions of the fibrous bundles.

As will be apparent from FIG. 7, the vector forces operating internally on the noncylindrical tank walls, which are of a multi-layered construction shown at 11, 15, exert substantially perpendicularly opposed forces. Forces from the fibrous bundles shown as 22, 23 balance the gas pressure forces shown as 24, 25. As will be apparent from FIG. 7, the respective pairs of forces 22, 24 and 23, 25 are in parallel but opposite directions.

The reinforcing fibrous bundles are depicted two dimensionally in axes A and C in FIG. 8. One or more additional sets of reinforcing fibrous bundles can be located so as to be at reinforcing positions other than substantially perpendicular with respect to substantially opposed outer structural wall portions. The fibrous reinforcing bundles can be placed at angles other than 90° to maintain complex shapes and/or to minimize the number and length of the internal reinforced fibrous bundles, therefore maximizing tank volume. Fibrous bundles which are not substantially perpendicular to a wall surface are designed to balance the forces such that the desired tank shape is maintained.

Such geometrically complex non-cylindrical fuel tanks in accordance with this invention are characterized by a structure having fiber bundles oriented in a crossing substantially perpendicularly intersecting pattern in combination with fiber bundles which are arranged at angles other than substantially ninety degrees compared with the substantially perpendicular fiber bundles. Such structure is illustrated in FIG. 8 and contains a complex geometric configuration having multiple plateaus connected by sloping spans and further characterized by rounded or sharply rounded edge surfaces.

In a lesser complex aspect, as shown in FIGS. 3, 5 and 6, the reinforcing structure illustrated involves plies of unidirectional tape or woven fabric having a crossing 90° intersecting pattern involving substantially perpendicular internal reinforcement. Thus the nature of the internal reinforcement and external reinforcement provided by these unidirectional bundles and woven or non-woven fabric containing them can be varied in accordance with the present invention depending upon the specific pressure loads and the exterior wall engineering configuration of the tanks 11.

Fabrication

The tanks of the present invention can be made by a variety of procedures, including, but not necessarily limited to, procedures wherein the exterior tank wall is laid up, and in an enveloping fashion, covers a temporary or fugitive core through which the internal fibers are then stitched, or three dimensionally braided in which case a fugitive core is not needed.

Again, the use of the terminology internal fibers, as used herein, includes bundles of glass, graphite, aramid, or steel fibers which are joined together by a thermoset or a thermoplastic resinous matrix material, or for steel fibers, the matrix material can be a lower melting point metal. The matrix material is capable of withstanding the solvents employed to remove the foam or other temporary, viz., fugitive, core on the one hand or is capable of withstanding the temperatures at which the foam or other temporary core material is pyrolyzed once the internal and external substantially perpendicular and non-perpendicular reinforcing fibers have been placed and solidified at their desired locations. Woven plies of pre-impregnated material stitched with pre-impregnated bundles of fibers can be formed by inflation followed by curing within assembled sections of a mold. Upon cooling or curing, the tank 11 achieves its solid, non-cylindrical, three-dimensional desired configuration.

Additionally, with respect to the fabrication of non-cylindrical fuel tanks 11 three-dimensional braiding techniques can be employed without the use of core or fugitive materials on which to construct the tanks 11. Braiding techniques permit the tank 11 to retain its shape while resisting the internal pressure forces acting thereon, such is illustrated for example in FIG. 7.

One such technique for braiding without a core is the use of a braided pre-form which has a thermoplastic resin previously incorporated therein. Such pre-resinified, pre-braided structures can then be heated up and inflated to its final shape with a gas or liquid. The orientation and length of the fibers in the braided pre-form determine its ultimate shape.

Alternatively, a gas material can be injected into the interior of the resinified pre-form after it is placed within a female cavity of a mold, e.g., a mold formed from sections, so that the injected gas operates to force the structure against the mold section into which ultimate shape tank 11 conforms. The heat can then be removed and the mold portions separated to result in the desired configuration.

The process used to attain functional rigidity of the tank is dependent on the matrix or resin material used. A thermosetting resin can be cured at room or elevated temperatures and a thermoplastic is final formed at elevated temperatures, then cooled.

The following nonlimiting example will further illustrate a storage tank constructed in accordance with the principles of the present invention.

EXAMPLE

First, a piece of one inch thick foam was cut into a six inch by six inch square. The edges of the foam were rounded, using a one-half inch router bit, thereby creating a foam square with smooth semicircular edges having a one-half inch radius and two opposed five inch by five inch surfaces. Notches were cut at the center of two opposed curved edges to receive metal inserts. The metal inserts were made from a two inch long, one inch diameter piece of aluminum rod that was sawed in half longitudinally to create an insert with a semicircular cross-section. A longitudinal center hole was drilled through the metal inserts, and the holes were tapped to accept a 0.125 inch diameter pipe. The metal inserts were then inserted into the notches so that their ends were flush with the surface of the curved edge.

Next, three plies of three ounce per square yard E-glass woven fabric were wrapped around the core, followed by three plies of twenty ounce E-glass woven fabric. The second set of plies of woven fabric was rotated ninety degrees with respect to first set of plies. The fabric covered foam core assembly was now ready to be stitched through the thickness. The stitches were made with a seventy pound tensile strength braided "KEVLAR" line in a grid pattern. The grid pattern had stitching along a first set of rows extending diagonally across the opposed surfaces. Stitches also extended along a second set of diagonal rows substantially perpendicular to the first set of rows. The stitches penetrated the fabric approximately every 0.125 inch, and the rows of stitches were separated by approximately 0.125 inches, thereby tying the two five inch by five inch surfaces together. The fabric was cut from around the tapped holes in the metal inserts and two 0.125 inch pipes were attached to the assembly. Epoxy resin was then squirted between the fabric and the foam, using a hypodermic needle. The resin was applied in this fashion to ensure the resin thoroughly saturated the fabric. The completed assembly was cured in one-half an hour and was allowed to post-cure for one week. Acetone was then used as a solvent to dissolve the foam core, thereby forming the tank interior.

A T-fitting with two Zerk fittings was connected to one of the two 0.125 inch pipes in the cured tank assembly. A 3,000 pounds per square inch ("psi") pressure gauge was attached to the opposite 0.125 inch pipe and was used to record pressure. Testing began by first filling the tank with grease through the Zerk fittings. When the tank pressure reached 600 psi, a small leak developed at one of the corners. The tank pressure was raised to 1,000 psi, and it took twenty-nine seconds for the pressure to drop from 1,000 psi to 500 psi. Pressure was again applied to the tank, and the internal fibers began to fail at approximately 1,300 psi. By increasing the number of stitches per square inch and/or by changing the type of fabric or material, it is believed that a tank can be fabricated in which an initial failure of the internal fibers will not occur until a pressure of 1,800 psi or more.

While the invention has been set forth by a description of the preferred embodiment in considerable detail, it is not intended to restrict or in any way limit the claims to such detail. Additional advantages and modifications readily appear to those who are skilled in the art. For example, the preferred embodiment of the invention is a noncylindrical fuel tank for storing pressurized natural gas for powering a vehicle. As will be appreciated, the construction of the present invention may be used in the construction of tanks of any geometric shape including cylindrical tanks. Further, tanks constructed in accordance with the present invention may be used to store any gas under pressure, for example, oxygen for aircraft emergency supply tanks, air for emergency rescue and scuba tanks, nitrous oxide or other anesthetic in medical environments, propane in a lighter weight, more portable container. In addition, tanks constructed in accordance with the present invention may be used for hydraulic accumulators, fire extinguisher, tankard trucks, gas storage tanks for industrial or commercial, etc.

The invention, therefore, in its broadest aspects, is not limited to the specific detail shown and described. Consequently, departures may be made from the details described herein without departing from the spirit and scope of the claims which follow.

CLAIMS

1. A tank for storing a gas under pressure comprising:

a three dimensional tank outer wall structure made of a fibrous composite material, the tank outer wall structure having first and second walls bounding an interior and an exterior surface; and

a first set of continuous, unidirectional fibrous bundles extending in a repeating pattern

over the exterior surface of the outer wall structure on the first wall,

through the first wall,

through the interior,

through the second wall, and

over the exterior surface of the outer wall structure on the second wall.

2. The tank of claim 1 wherein said fibrous bundles include glass fibers.

3. The tank of claim 1 wherein said fibrous bundles include graphite fibers.

4. The tank of claim 1 wherein said fibrous bundles include aramid fibers.

5. The tank of claim 1 wherein said fibrous bundles include steel fibers.

6. The tank of either claims 2, 3, or 4 wherein said bundles are joined together by a thermoset resinous matrix material.

7. The tank of claims 2, 3 or 4 wherein said bundles are joined together by a thermoplastic resinous matrix material.

8. The fuel tank of claim 1 further comprising a protective layer covering the exterior surface of the wall structure and portions of the fibrous bundles extending over the exterior surface.

9. A fuel tank as in claim 8 wherein said protective layer is a composite fibrous overlap.

10. A fuel tank as in claim 8 wherein said protective layer is a resinous coating.

11. The fuel tank of claim 8 further comprising:

third wall of the tank outer wall structure; and

a second set of continuous, unidirectional fibrous bundles extending in a repetitive pattern

over the exterior surface of the wall structure on the third wall,

through the third wall,

through the interior,

through the one of the first and second walls, and

over the exterior surface of the wall structure on the one of the first and second walls.

12. The fuel tank of claim 8 further comprising:

third and fourth walls of the tank outer wall structure; and

a second set of continuous, unidirectional fibrous bundles extending in a repetitive pattern

over the exterior surface of the wall structure on the third wall,

through the third wall,

through the interior,

through the fourth wall, and

over the exterior surface of the wall structure on the fourth wall.

13. The fuel tank of claim 12 further comprising:

fifth and sixth walls of the tank outer wall structure; and

a third set of continuous, unidirectional fibrous bundles extending in a repeating pattern of

over the exterior surface of the wall structure on the fifth wall,

through the fifth wall,

through the interior,

through the sixth wall, and

over the exterior surface of the wall structure on the sixth wall.

14. The fuel tank of claim 13 wherein the second set of fibrous bundles extend through the interior of the fuel tank in a direction substantially perpendicular to the first set of fibrous bundles.

15. The fuel tank of claim 14 wherein the third set of fibrous bundles extend through the interior of the fuel tank in a direction substantially perpendicular to the first and the second sets of fibrous bundles.

16. The fuel tank of claim 14 wherein the third set of fibrous bundles extend through the interior of the fuel tank in a direction substantially non-perpendicular to the first set of fibrous bundles.

17. The fuel tank of claim 14 wherein the third set of fibrous bundles extend through the interior of the fuel tank in a direction substantially non-perpendicular to the first and the second sets of fibrous bundles.

FIG-1

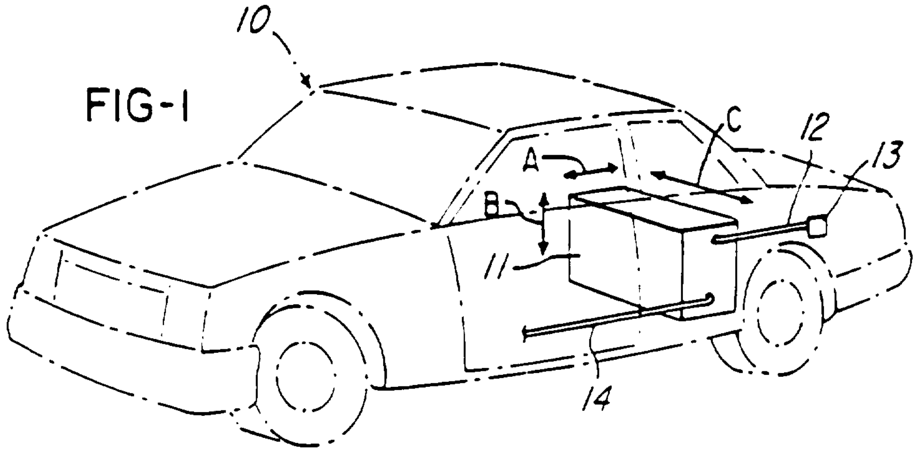


FIG-2

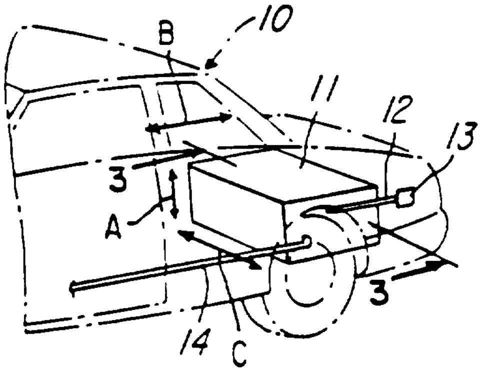


FIG-7

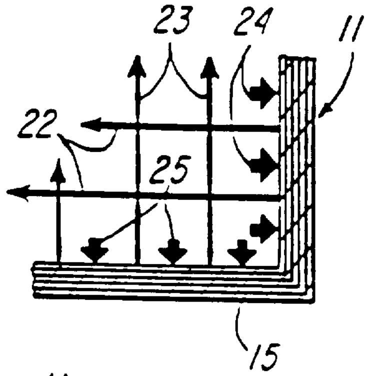


FIG-3

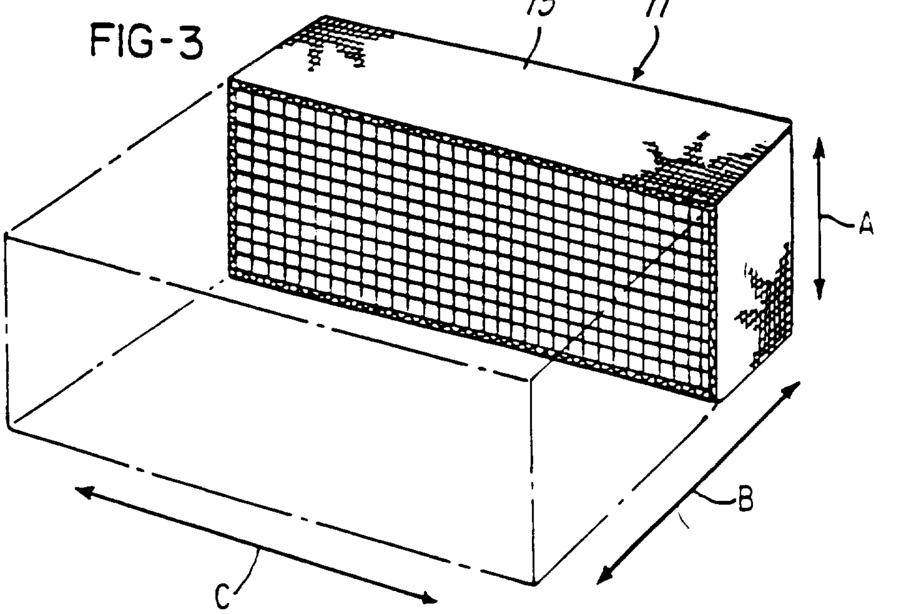


FIG-4

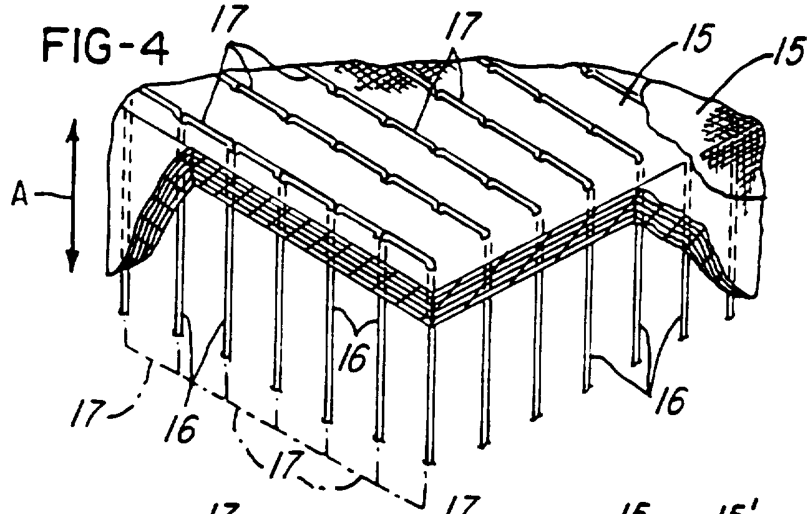


FIG-5

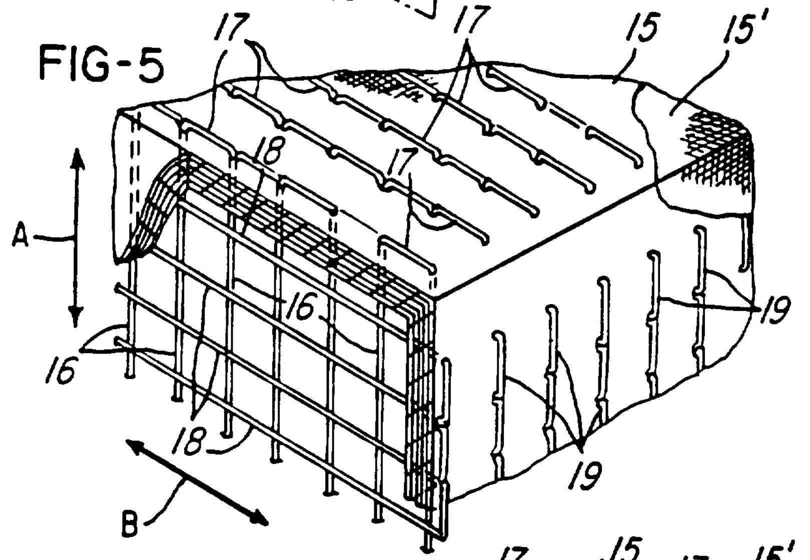


FIG-6

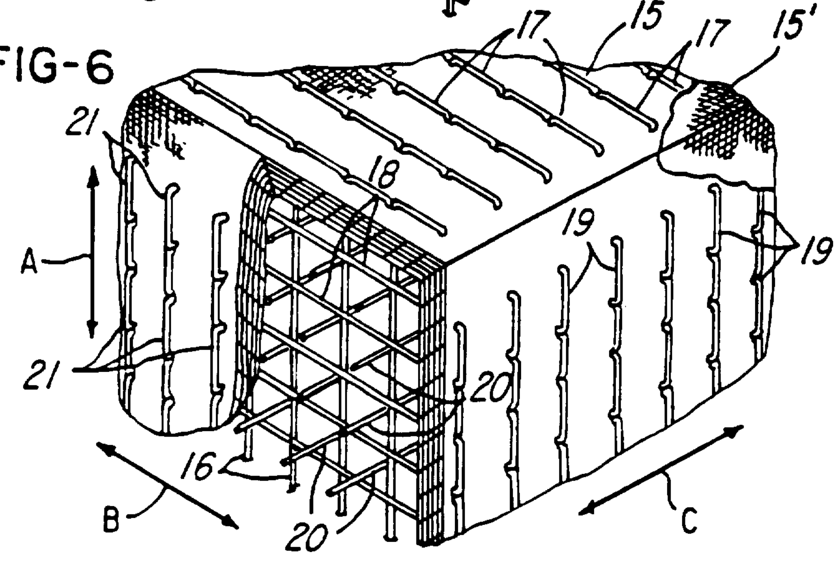


FIG-8