

Jan. 23, 1968

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3,364,548

METHOD FOR PRODUCING AN ELECTROFORMED HEAT EXCHANGER

Filed Dec. 8, 1964

7 Sheets-Sheet 1

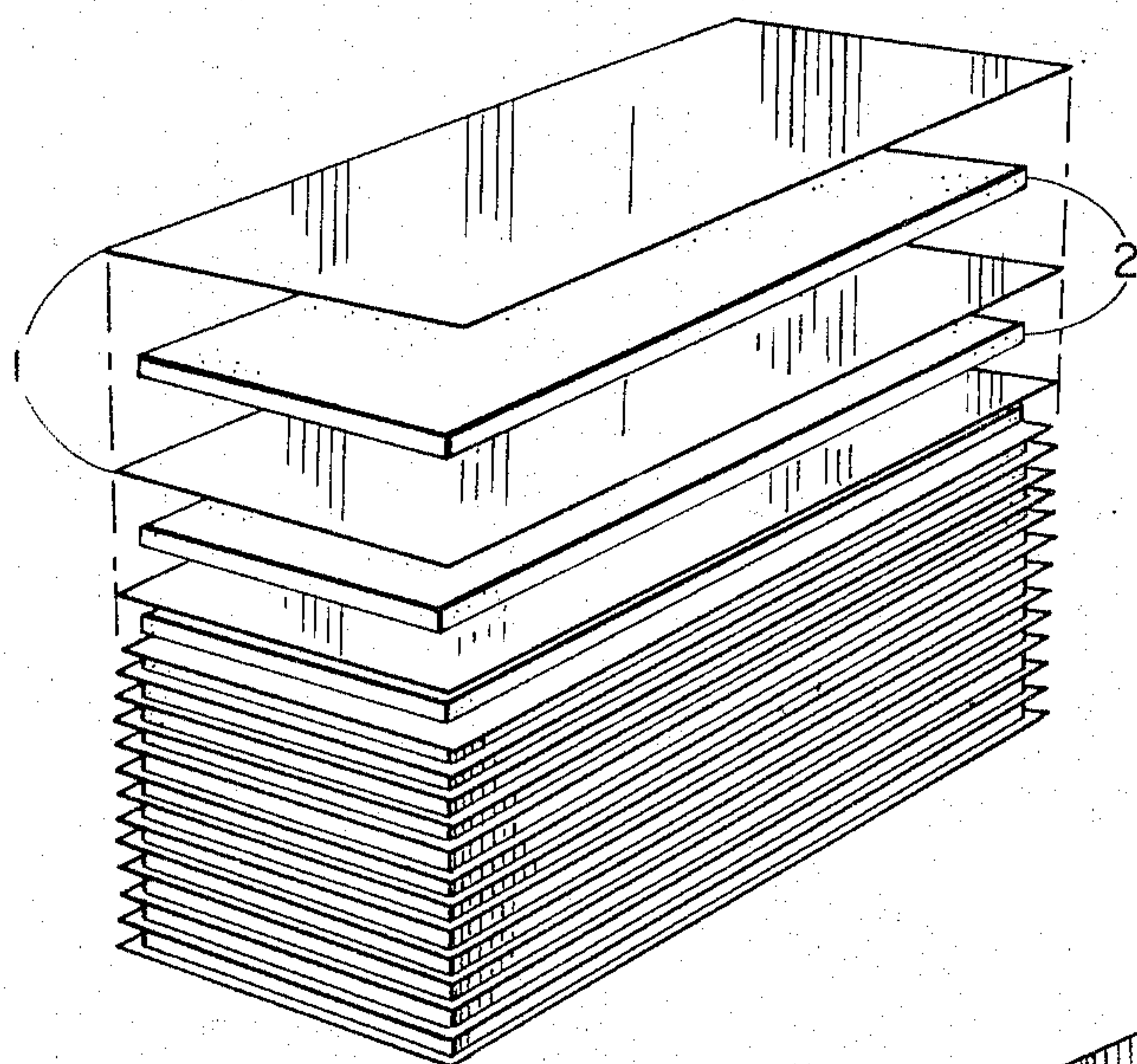


FIGURE 1

FIGURE 2

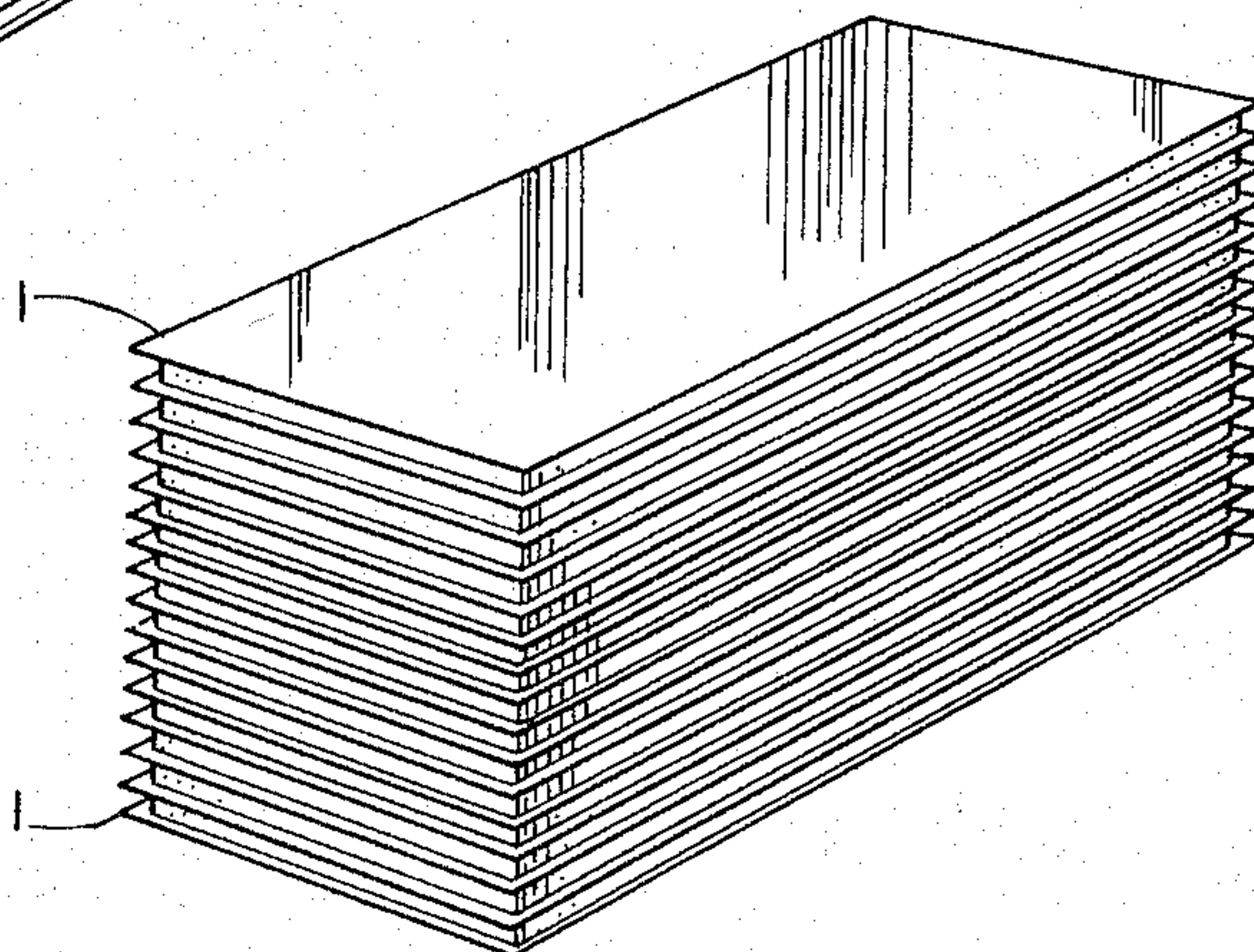
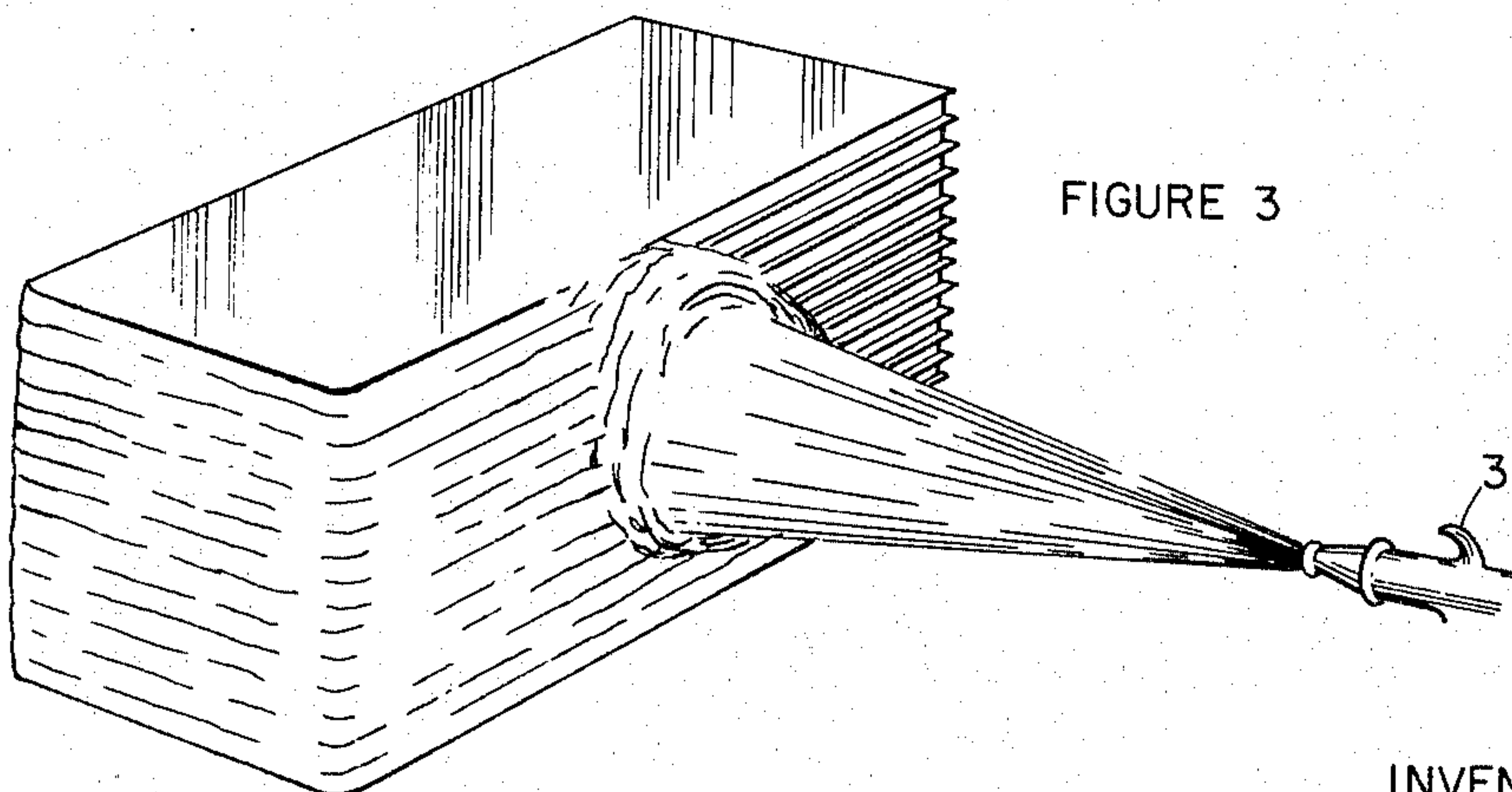


FIGURE 3



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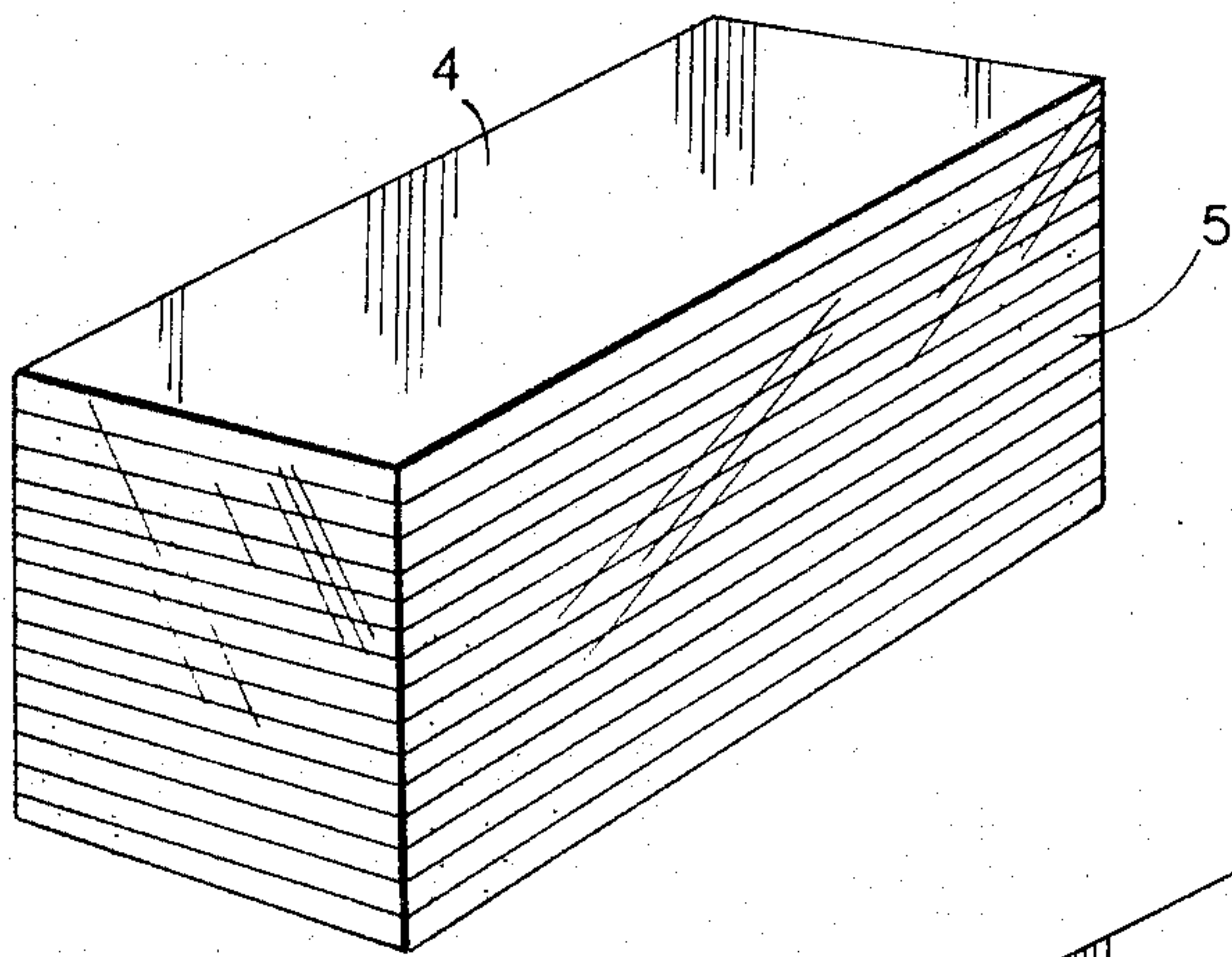


FIGURE 4

FIGURE 5

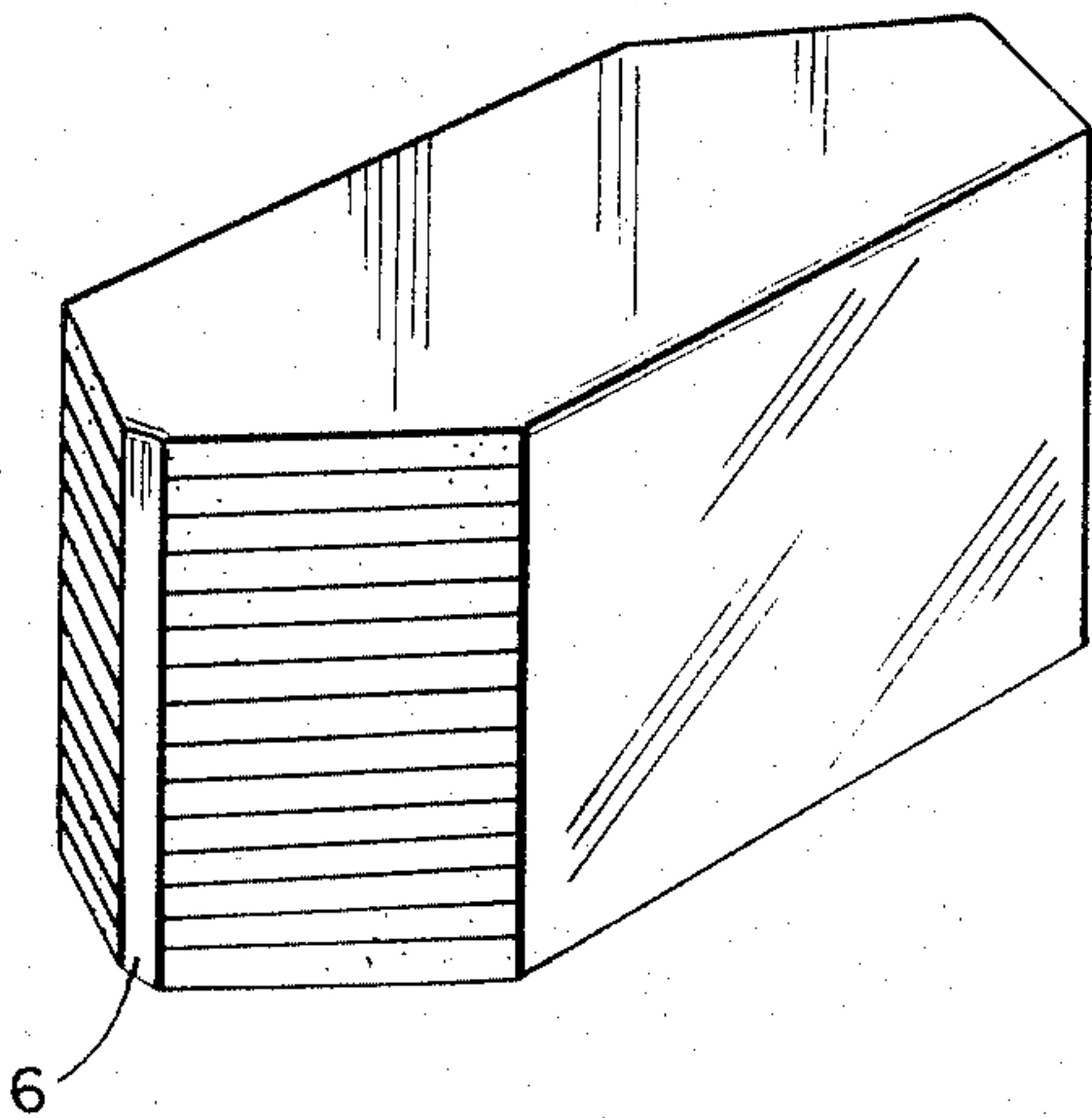
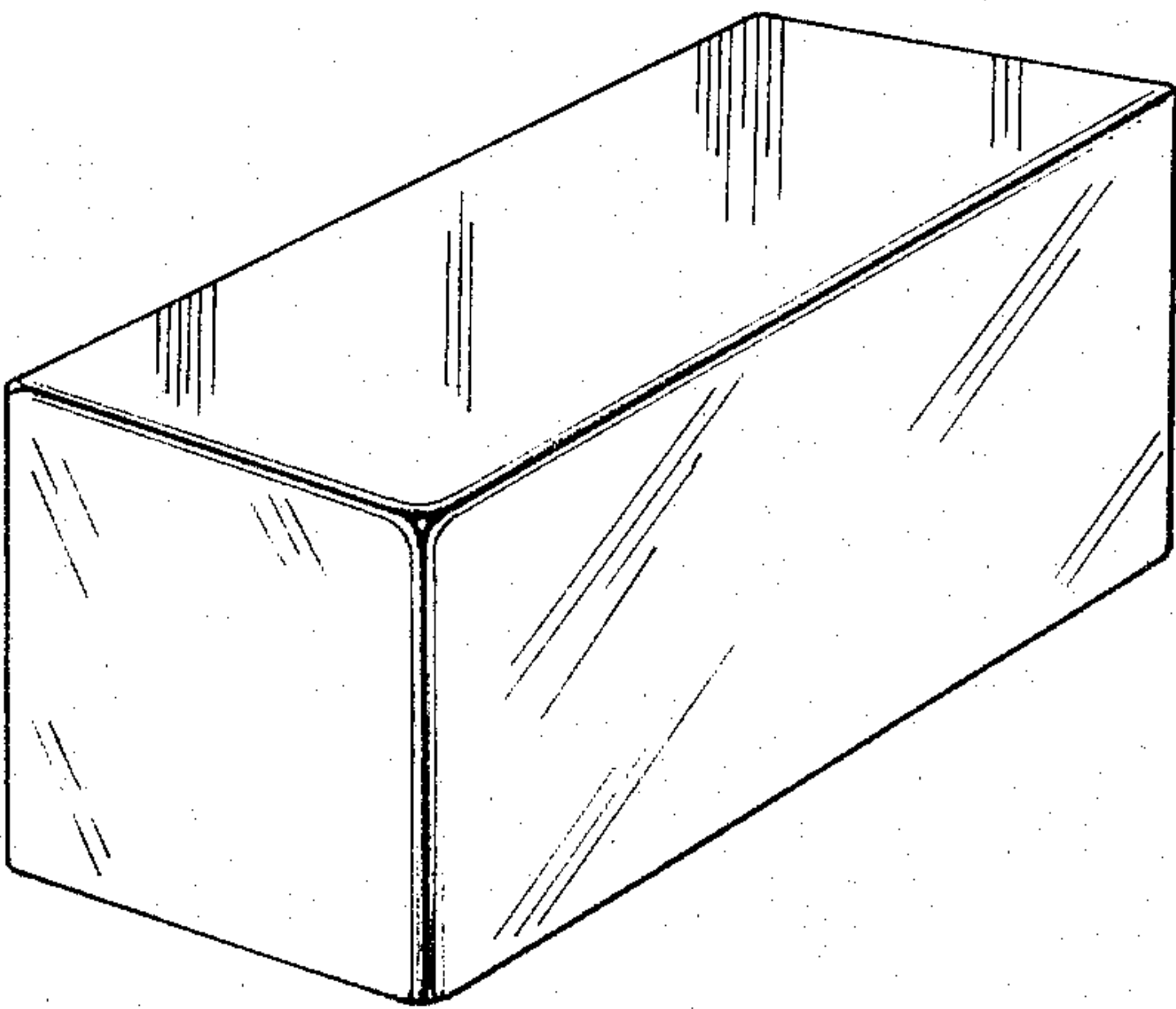


FIGURE 6

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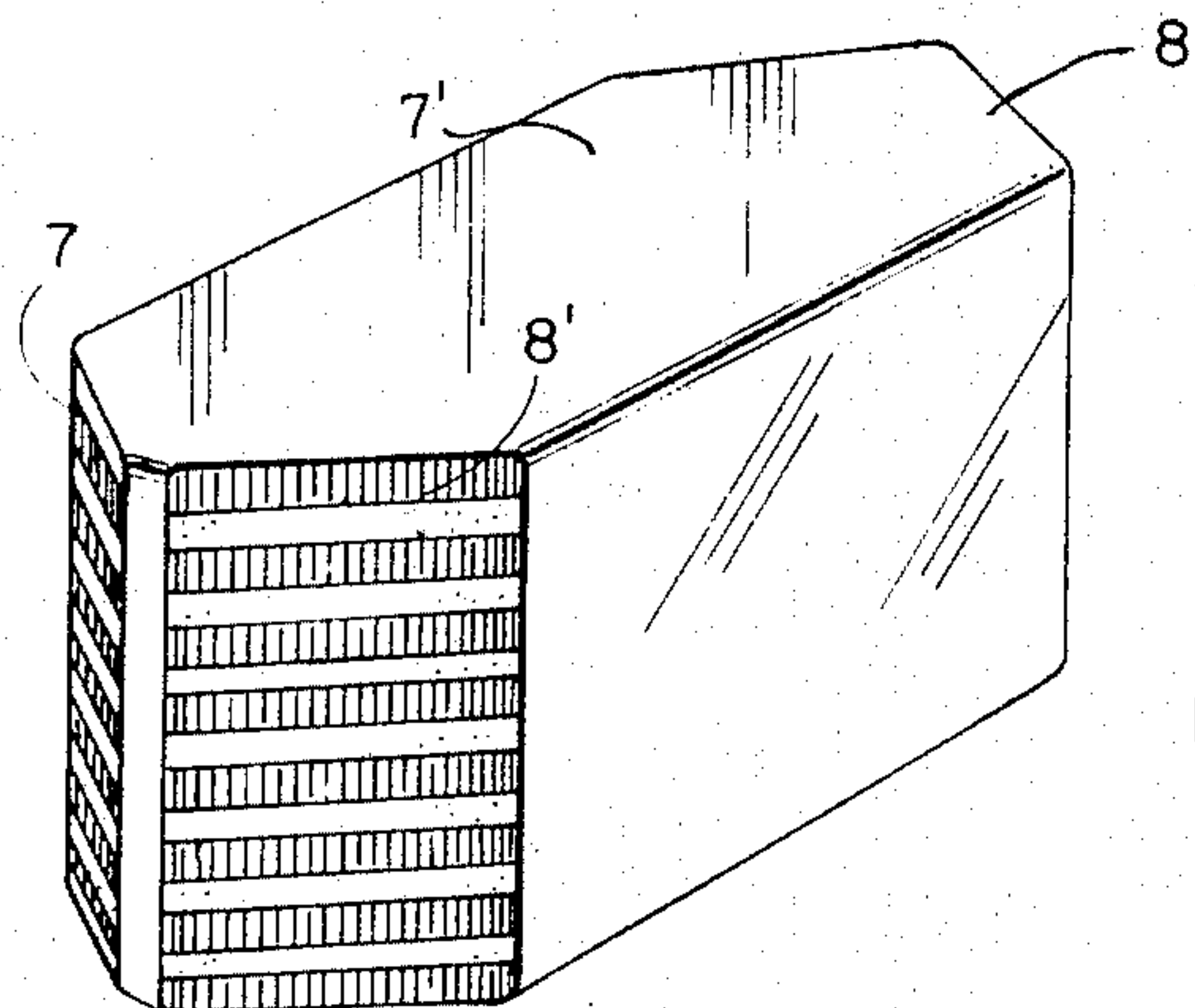


FIGURE 7

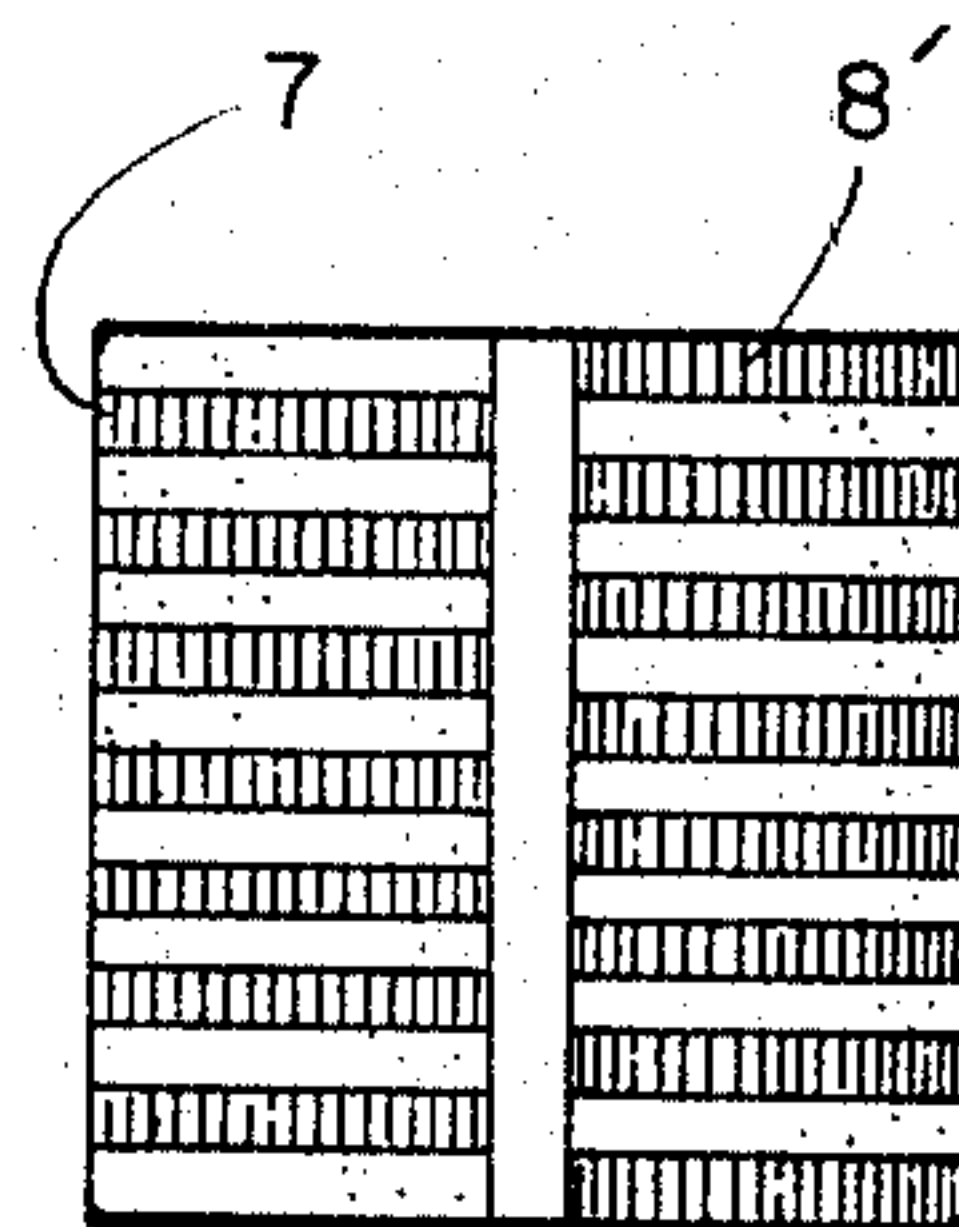


FIGURE 7A

FIGURE 8

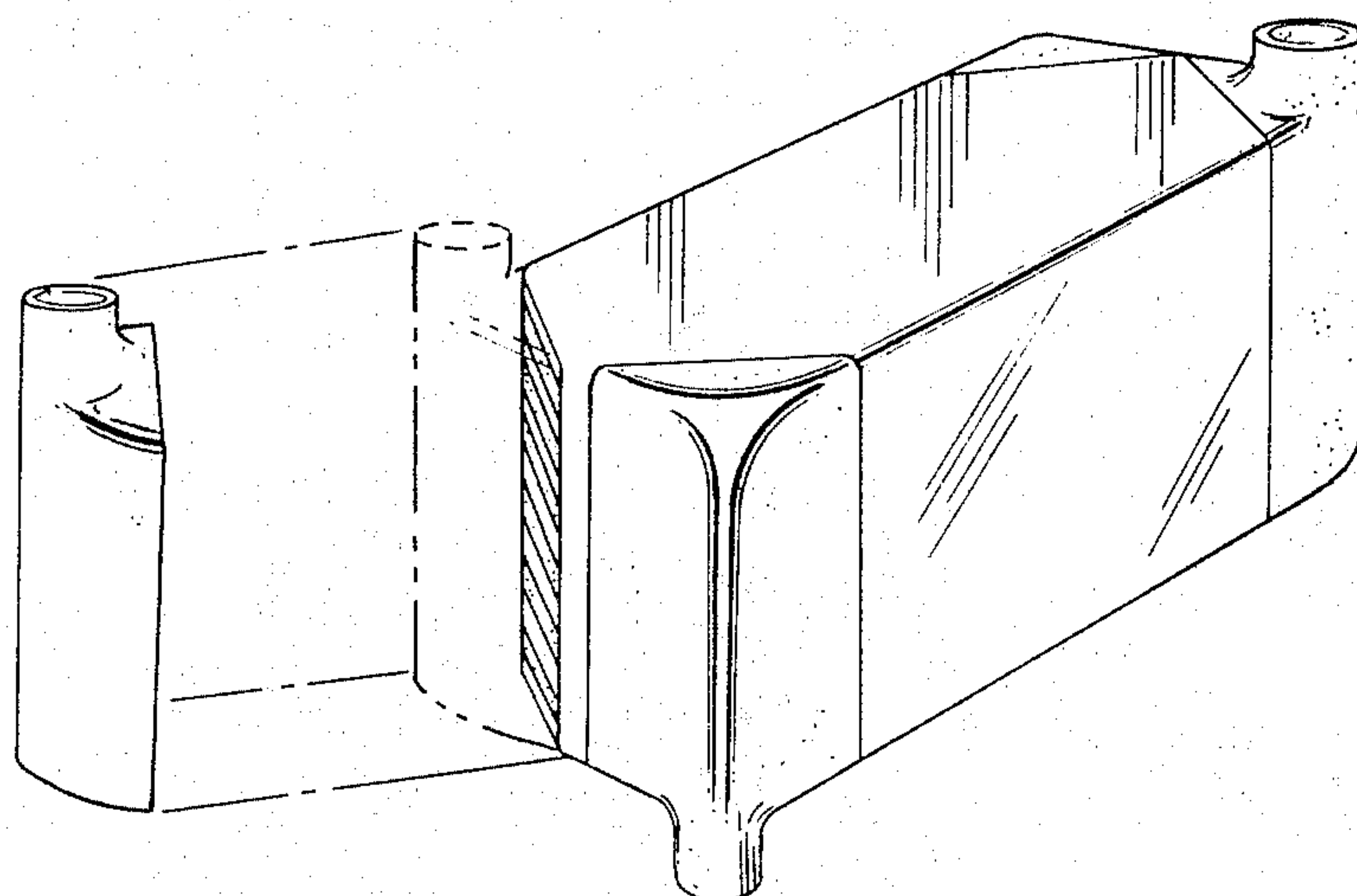
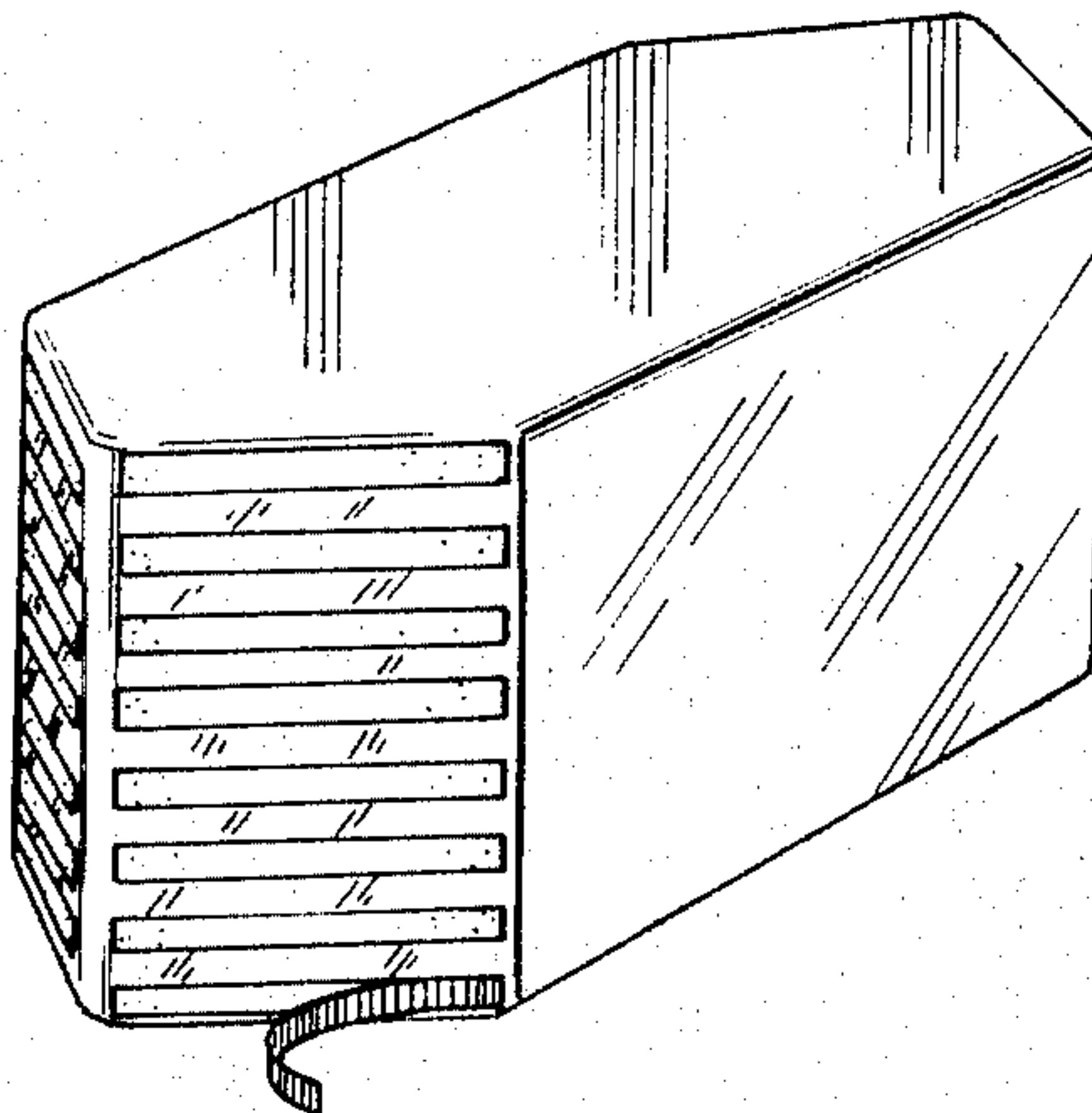


FIGURE 9

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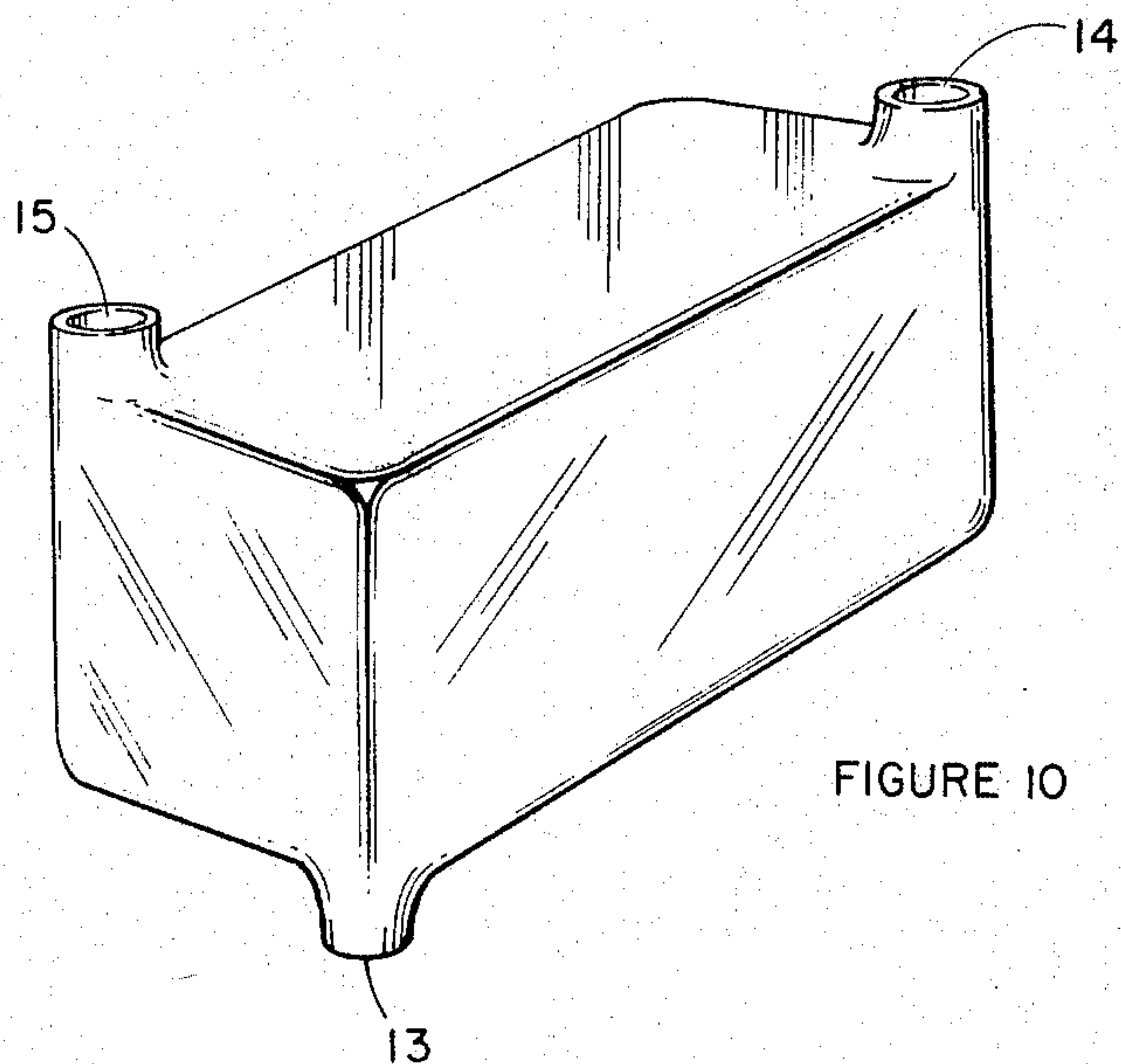
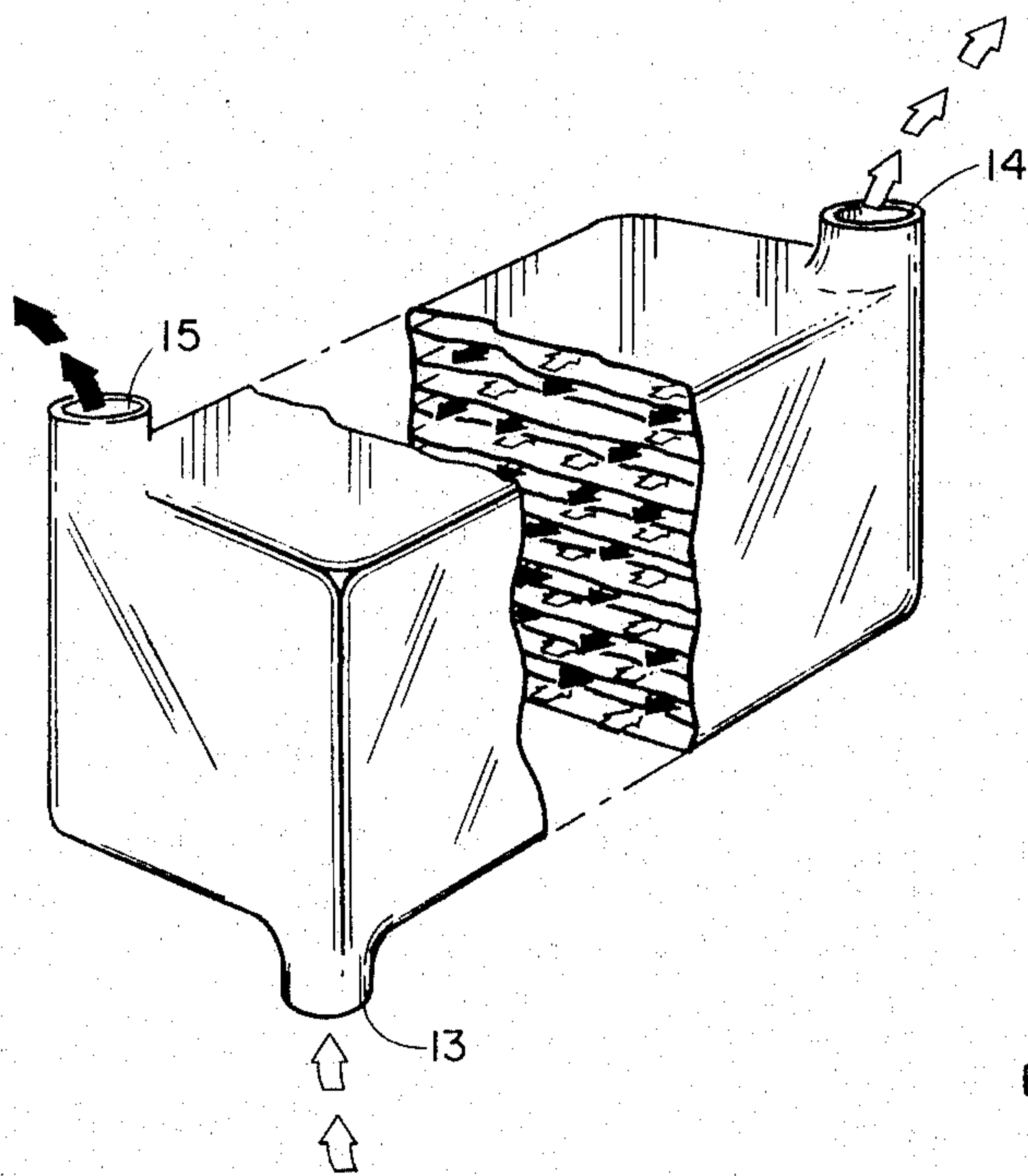


FIGURE 10

FIGURE 11



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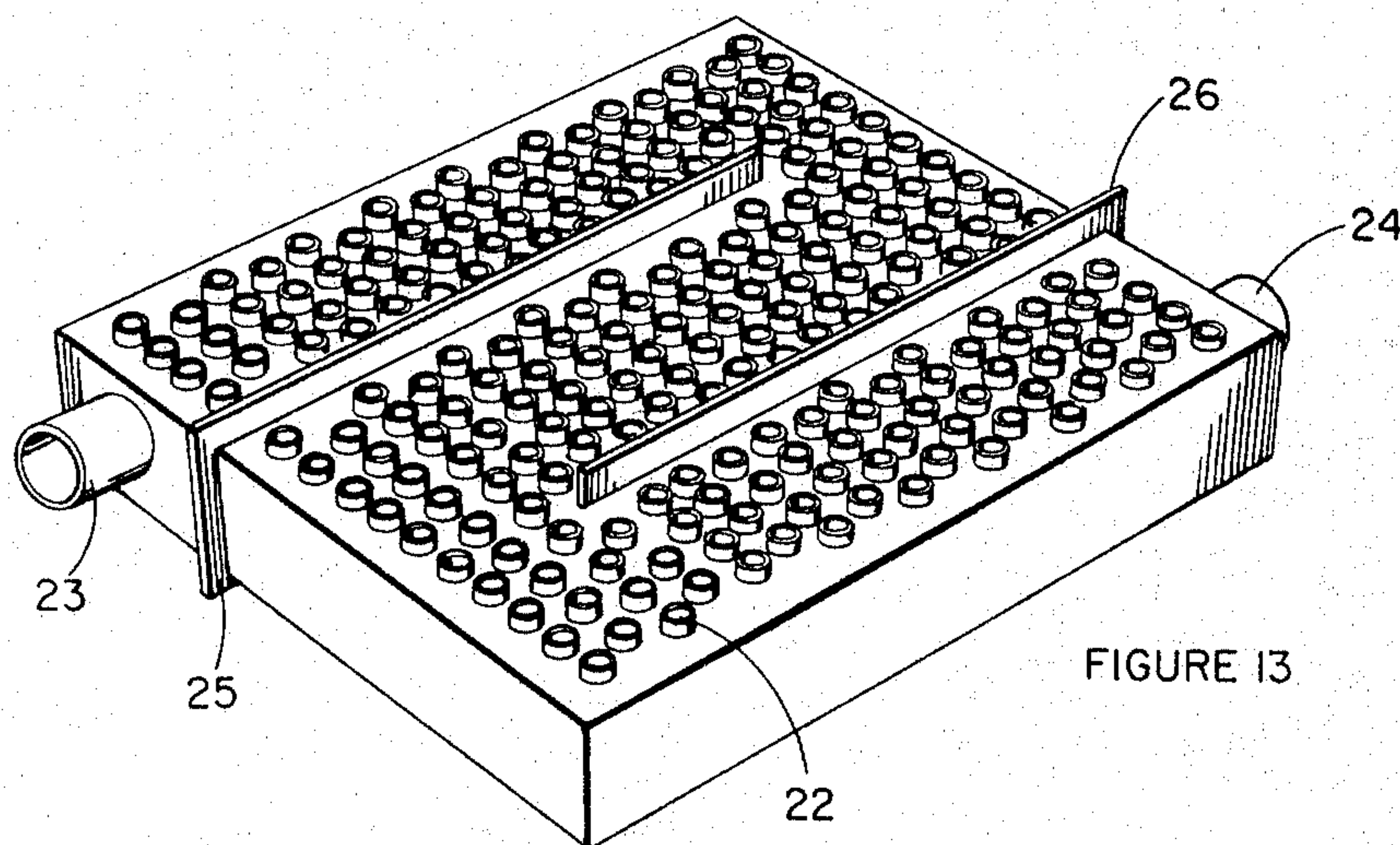
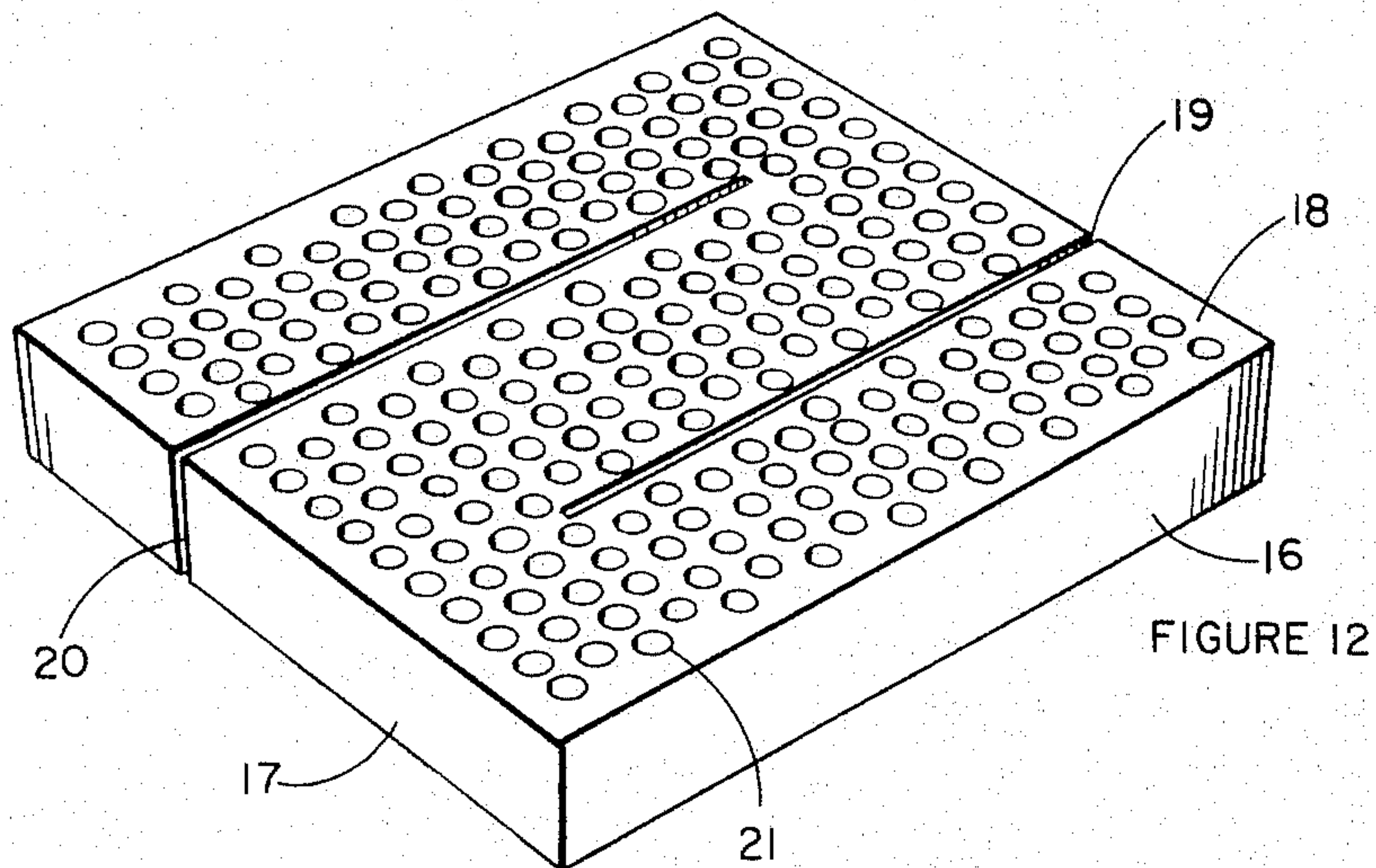
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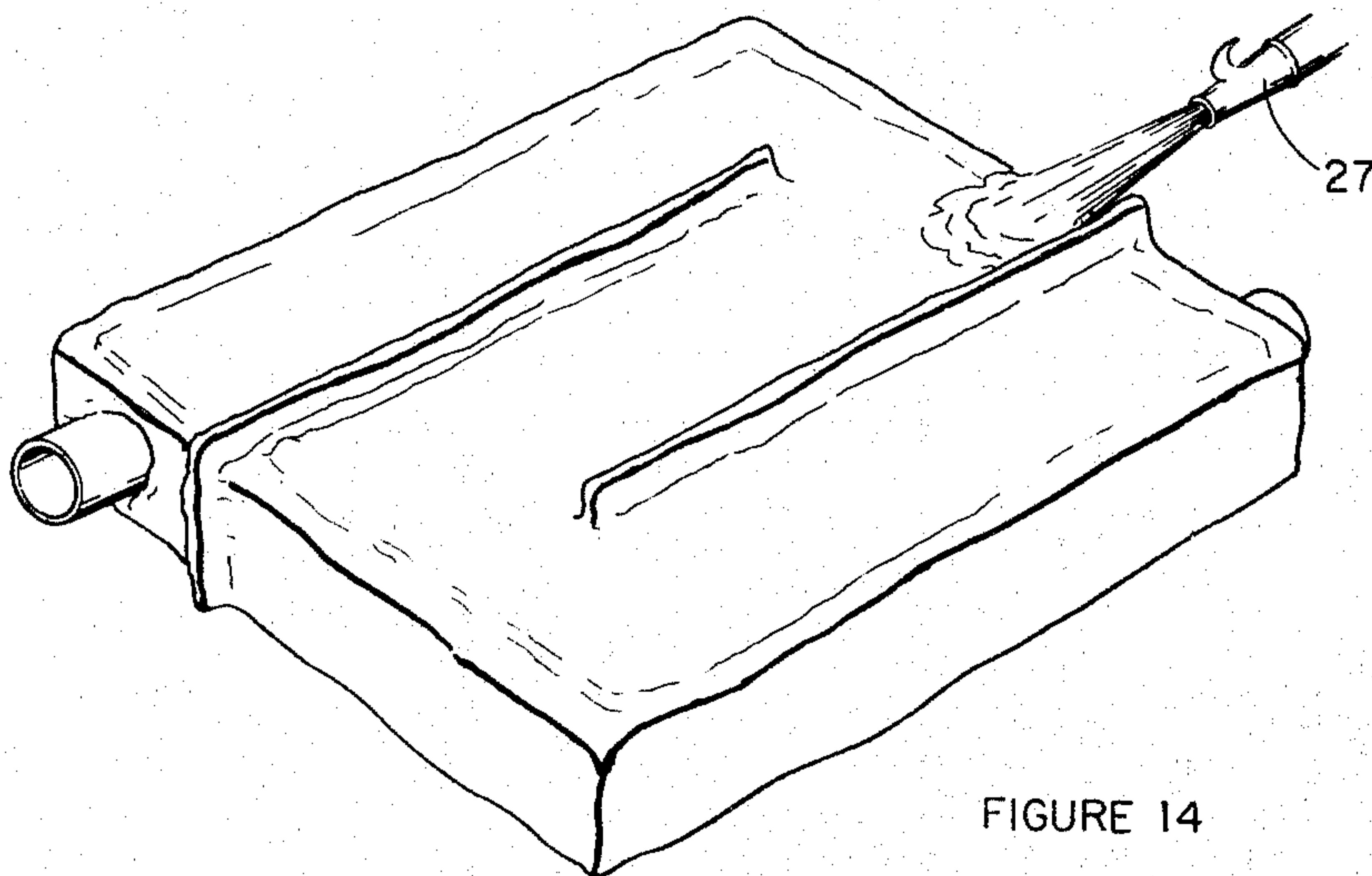


FIGURE 14

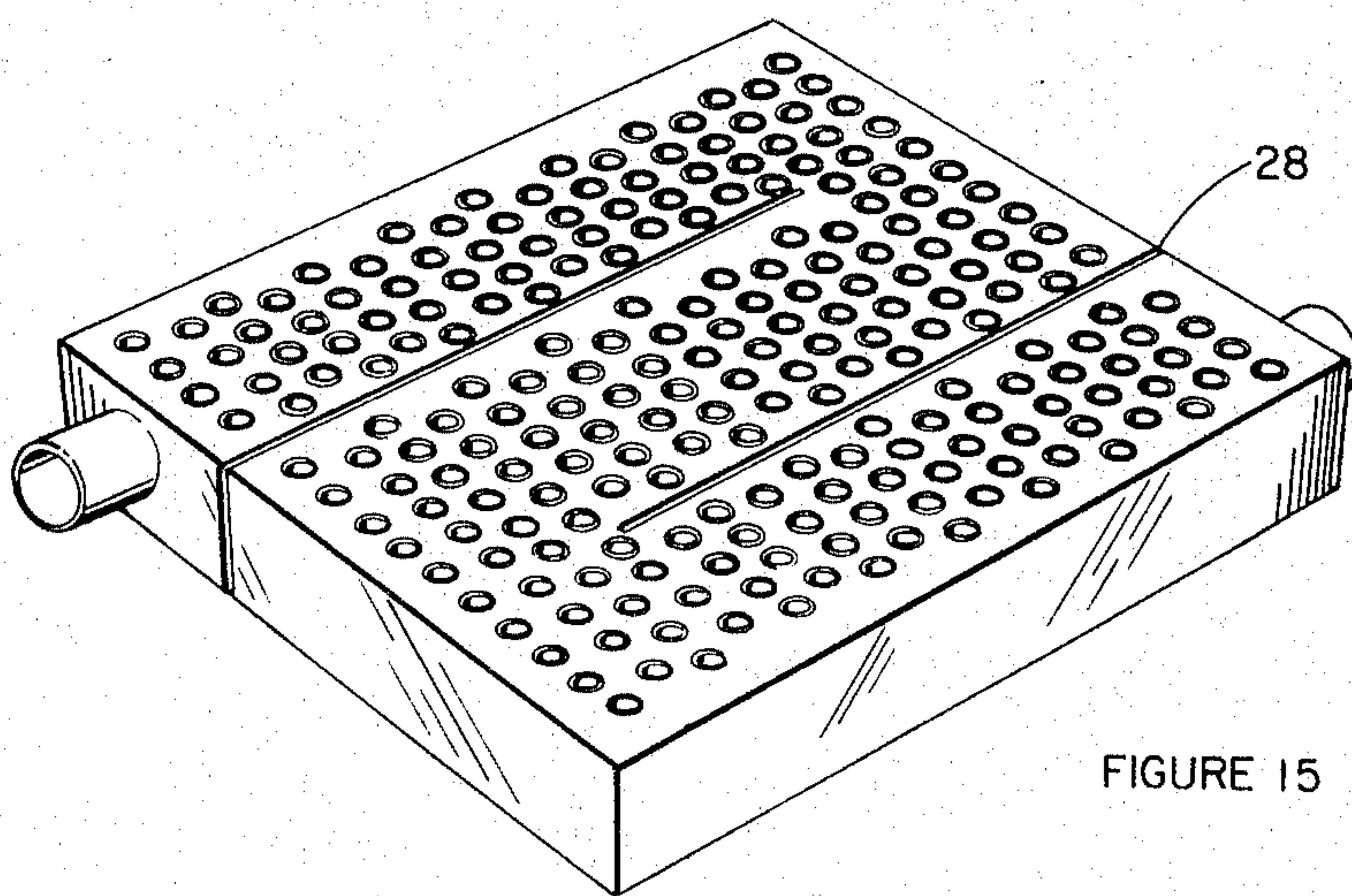


FIGURE 15

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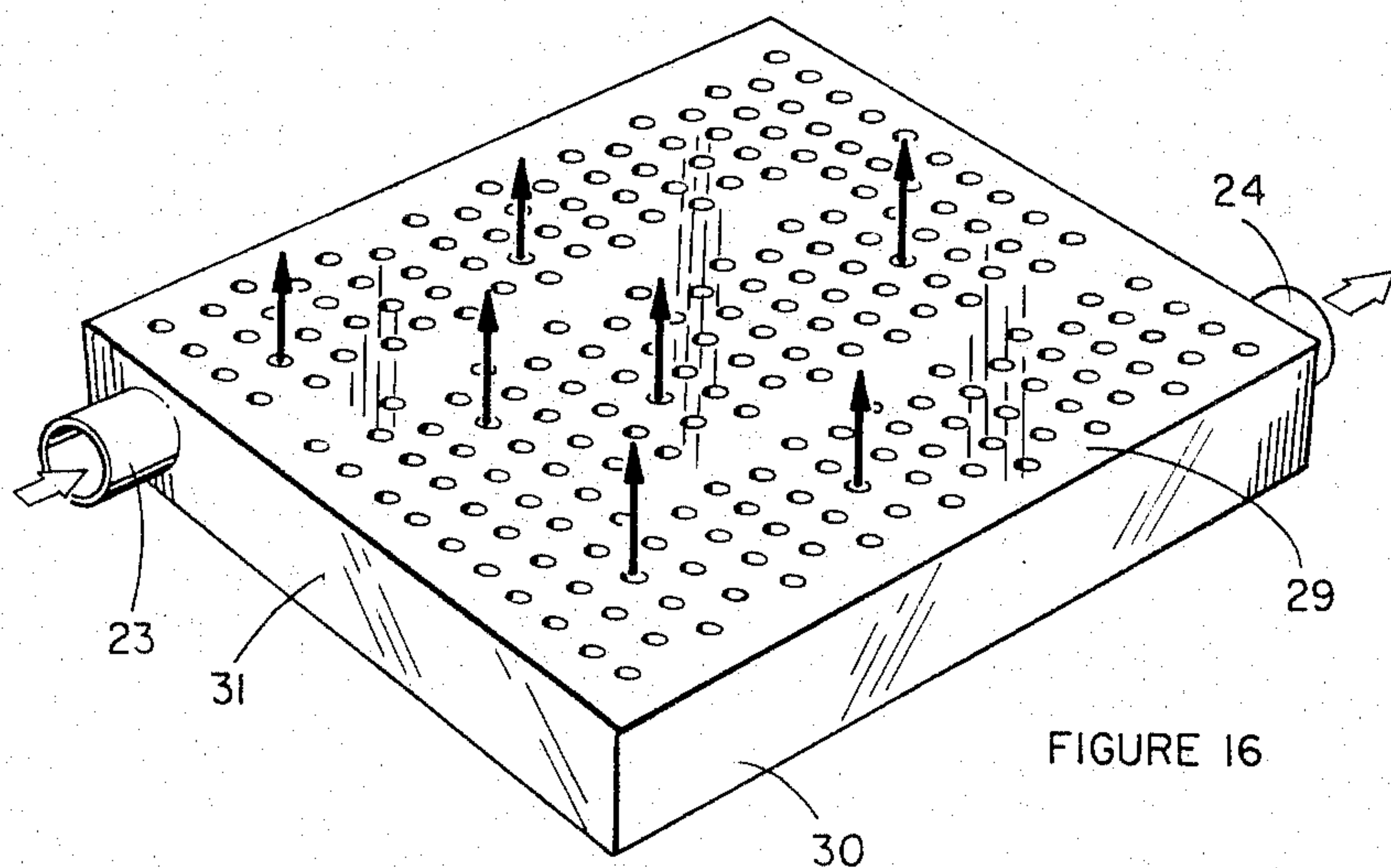


FIGURE 16

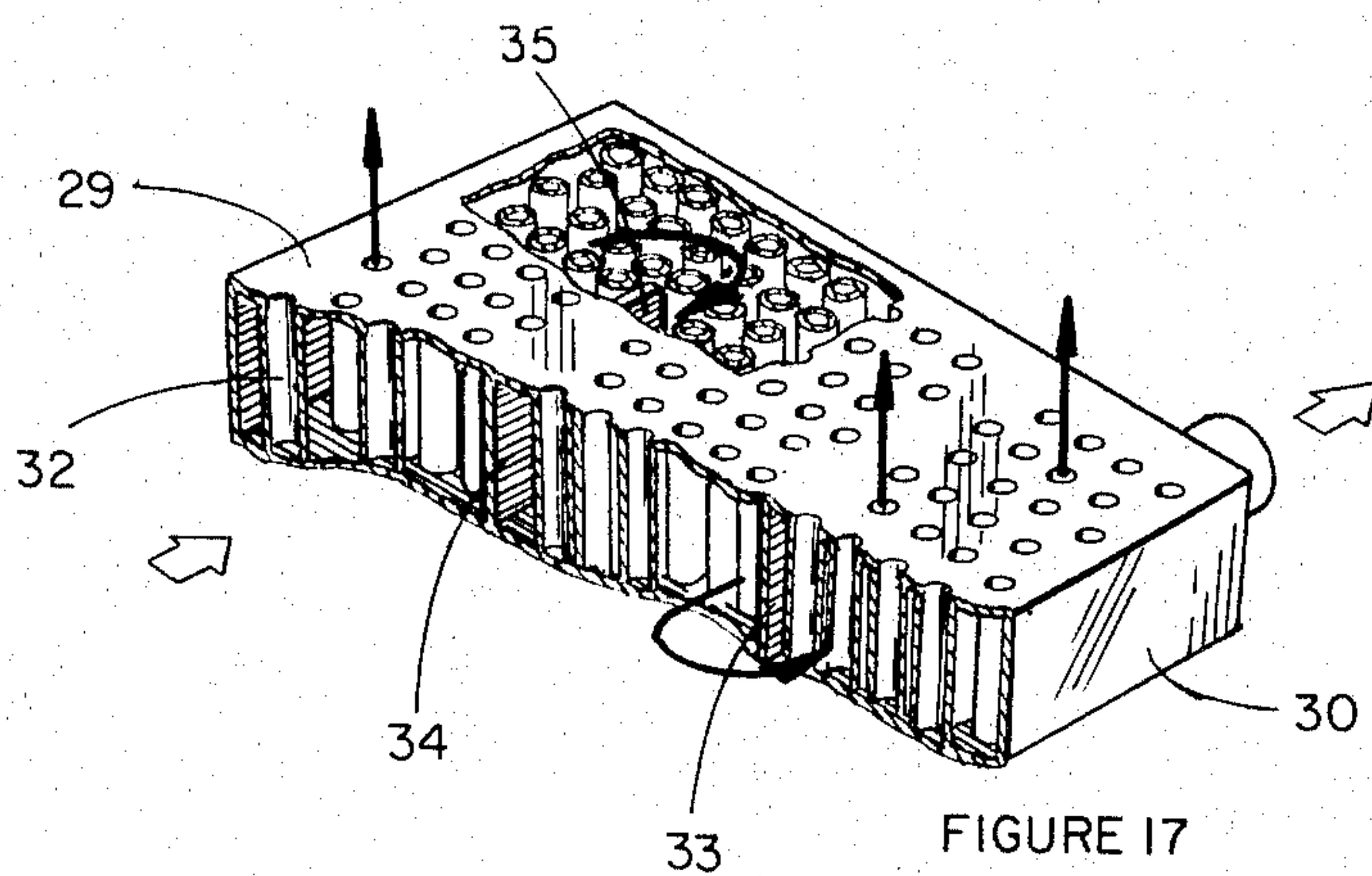


FIGURE 17

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METHOD FOR PRODUCING AN ELECTRO-FORMED HEAT EXCHANGER

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11 Claims. (Cl. 29—157.3)

ABSTRACT OF THE DISCLOSURE

This disclosure concerns a process for the fabrication of articles such as fluid-to-fluid heat exchangers which have at least two separate passages which are in close thermal contact. The method described involves the use of sacrificial tooling which is chemically dissolved after the construction material is deposited by metal spray or electroplating. The method allows complex multi-chamber construction without welding or other heat processes and permits maximum strength in compact, thin-wall assemblies. The method also eliminates the need for expensive jigs and other tooling.

This invention relates to heat exchangers and more particularly to high performance heat exchangers which have the greatest rate of heat exchange per unit of volume.

Heat exchangers are very extensively used in process industries, in connection with power generating systems and frequently, in very sophisticated forms, in modern military equipment.

Prior art heat exchangers of the liquid-to-liquid and liquid-to-gas types (the types with which the present invention is primarily concerned) have been constructed in a variety of forms and designs. The use of tubing formed into a labyrinth immersed in a vessel is a common and well known simple type of heat exchanger.

Most high performance liquid-to-liquid heat exchangers are necessarily built on the counter flow principle. That is to say that, given a hot fluid to be cooled and a cooler fluid to absorb the heat, the cooler fluid coolant would begin to come into thermal contact with the heat exchanging elements at a point where the fluid to be cooled is just leaving the heat exchanger. After the coolant is warmed by heat absorption as the process of cooling the hot fluid progresses, the coolant contacts the cooling elements carrying the hot fluid at progressively higher temperature locations until the last contact of the coolant with the hot fluid to be cooled is made as the hot fluid enters the heat exchanger and the coolant leaves the heat exchanger. Obviously, if the direction of flow of the coolant and hot fluid through the heat exchanger are in the same direction, the temperature rise of the coolant becomes a limiting factor in connection with the terminal temperature of the hot fluid as it leaves the heat exchanger. Thus the important concept of counter flow is applied to the present invention.

In prior art heat exchangers, the effort to maximize the amount of heat exchange surface usually resulted in the evolution of a device which was both expensive and difficult to manufacture. For example, where large amounts of series or parallel tubing are employed, many welded, brazed or soldered joints become necessary. Not only are these manufacturing processes time consuming and therefore costly, but to the extent that they involve the application of heat to materials such as copper (which are so desirable for use in heat exchanger applications because of their high thermal conductivity) these metals are annealed to a condition of relative softness and greatly decreased strength. Thus if a prior art heat exchanger

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is to be used under conditions of substantial applied pressure to one or both of the fluid components, this fact must be taken into consideration in the stress design of the heat exchanger elements. The result usually is greater weight and thickness of material. The further result is therefore an increase of size and weight. Accordingly, the general objective of the present invention was the development of a heat exchanger of a high order of thermal performance in a minimum package and at a comparatively low cost without complex tooling.

In evolving the present invention, it was realized that the more nearly the two fluid components can be brought into perfect thermal contact, the greater will be the overall thermal efficiency of the exchanger. It will readily be realized that if the coolant fluids were constrained into thin planer cross sections of flow separated only by thin conductive membranes a greatly improved thermal efficiency should be possible. In maintaining these separation membranes at minimum thickness it is therefore exceedingly important that a method of fabrication be devised which would not result in the annealing of the membrane material. Heat exchangers made in accordance with the structure and method of the present invention have been found to be highly efficient not only on an absolute performance basis but also in terms of rate of heat exchange per unit volume.

In explaining the present invention typical drawings which will be explained in terms of typical materials are presented.

FIGURE 1 depicts the sheet metal stacking operation which is the first step of the process.

FIGURE 2 illustrates the completed stack resulting from the process of FIGURE 1.

FIGURE 3 illustrates the second or aluminium spraying step of the process.

FIGURE 4 illustrates the third step of the process namely the machining of the laminated edges.

FIGURE 5 illustrates the fourth step of the process which comprises an overall copper plating operation.

FIGURE 6 illustrates the fifth step in the operation which is the wedge-machining of the small end faces.

FIGURE 7 illustrates the masking or sixth step in the process.

FIGURE 8 illustrates the seventh and eighth step of replacing and unmasking.

FIGURE 9 illustrates the ninth step, the emplacement of manifold mandrels.

FIGURE 10 illustrates the tenth step in which the assembly is again plated.

FIGURE 11 is a cutaway of a finished heat exchanger showing flow of hot and cold fluids.

FIGURE 12 is a combination mandrel and expendable jig for a second embodiment of the present invention.

FIGURE 13 illustrates a stacking or assembly step for a second embodiment.

FIGURE 14 illustrates the aluminium spraying step for the second embodiment.

FIGURE 15 shows the machining step for the second embodiment.

FIGURE 16 illustrates the replating step for the second embodiment.

FIGURE 17 depicts a midsection cutaway of a finished item according to the second embodiment.

A full understanding of the structure of the present invention as well as of the unique fabrication process is thought to be best achieved as the detailed description of the fabrication process progresses.

In the drawings, FIGURES 1 through 11 illustrate the first embodiment which is a liquid-to-liquid heat exchanger, whereas FIGURES 12 through 17 illustrate a second embodiment according to the present invention.

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This second embodiment is intended mainly for liquid-to-gas heat exchanges although it is not limited to that application. The said first embodiment will be fully described before further reference is made to the second embodiment.

Referring now to FIGURES 1 and 2, it will be noted that a multiple sandwich of alternating copper and aluminium sheets is first assembled. The copper sheets illustrated by the numeral 1 typically are thin sheets of number 110 copper alloy in the hardened condition having 266 B.t.u./hr./sq. ft./degree Fahrenheit/ft. conductivity. This particular copper is one which has a very high thermal conductivity and a tensile strength in mill condition high as 55,000 p.s.i. The aluminium sheets 2 are slightly smaller in both flat dimensions than the copper sheets so that their edges are slightly indented within the stack as will be obvious from FIGURE 2. The aluminium sheet thickness is chosen in accordance with the desired fluid flow cross-sectional thickness. Since every other aluminium sheet corresponds to a fluid flow area for one of the two fluids passing through the heat exchanger, it is possible for alternate aluminium sheets to be of a first thickness and the remaining ones to be of a second thickness. Since fluid flow paths will ultimately replace the aluminium sheets, the result of such a variation in aluminium sheet thickness would be a larger overall flow cross-section for one of the two fluids as compared to the other. Such an expedient might be desirable, as for example when there is an unlimited coolant supply and maximum cooling of a hot fluid is sought, or when the specific heats of the two fluids differed widely. In such a case it may be desirable to have the rate of flow or the fluid cross-sectional area, or both, greater in connection with the fluid of the lower specific heat. In a particular model of a heat exchanger according to the present invention, copper strips 12 inches long by 1 inch wide and .010 inch in thickness were used. Altogether 15 of such copper strips were separated by 14 strips of aluminium each slightly smaller in the flat dimensions as compared to the copper sheets and each .060 inch in thickness, thereby leaving copper sheets on the outside locations. Proceeding now to FIGURE 3 the entire assembly is sprayed along the laminated edges of FIGURE 2 with a soft aluminium alloy preferably containing little or no alloying elements. In this way the spaces between the projecting edges of the copper sheets are filled with aluminium. While this operation is proceeding the sandwich is necessarily held tightly together in some type of clamping mechanism (not shown). Once the aluminium spraying operation of FIGURE 3 is completed however, the entire assembly may be unclamped as it will now be held together by the sprayed aluminium material. The appearance of the result of FIGURE 3 is that of a rectangular block of sprayed aluminium on two of the sides and the ends, with copper showing on the remaining two opposite faces. The aluminium spray gun 3 might be any commercially available metal spray gun loaded to spray aluminium. The "Metco" metal spray gun is satisfactory for this operation.

In FIGURE 4 the surface 4 and its opposite number on the bottom of the block would be the remaining copper surfaces exposed to view after the completion of the operation of FIGURE 3. FIGURE 4 illustrates the approximate appearance of the block after the aluminium sprayed sides and ends have been machined smooth so that the edges of the copper sheets inside are exposed. The extent of this machining operation is not sufficient to remove any substantial amount of the sprayed aluminium material which was deposited between the projecting edges of the copper sheets. As an additional step in connection with the assembly as it appears in FIGURE 4 a relatively short dip is effected in an aqueous solution of muriatic acid or hot sodium hydroxide. Either of these two chemicals vigorously attacks the aluminium while leaving the copper substantially untouched. Thus the aluminium is

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etched away from the exposed copper edges. The depth of this etching process has been found to be on the order of .010 to .030 for an exchanger of the indicated size of the model.

As a further intermediate step, the assembly is washed to neutralize the etching chemical, preferably sandblasted to remove any copper discoloration or surface corrosion and then washed again and de-greased in order to prepare it for the plating tank.

It should be noted that in applying the electrode to the assembly for the plating operation, care should be exercised so that the electrode does not grip at or near the exposed copper strip edges.

Referring now to FIGURE 5, the assembly is seen after it has been electroplated with a .030 to .040 thickness of copper. It will be realized that the copper plating reaches into the voids created between the copper edges by the etching thereby gripping the copper sheets with the full strength of the deposited copper material. Referring now to FIGURE 6 the ends of the assembly have been machined into two wedge shapes. The ends are not machined to a direct point however. A small strip of copper typically shown at 6 in FIGURE 6 is left at each end. Obviously this machining operation removes all of the spray deposited aluminium material within the areas of the four cuts made and illustrated. There is still an adequate amount of spray deposited aluminium on the remaining laminated edges now covered by the copper plating, and the assembly may therefore be expected to remain as a firmly joined laminated block.

The thickness of plating to be applied in order to obtain the appearance of FIGURE 5 will depend upon the overall strength service environment i.e. the mechanical ruggedness required of the unit as well as the internally applied pressure contemplated. Referring now to FIGURE 7 and 7a, it will be noted that the aluminium edges on either end are alternately masked in the manner shown in FIGURE 7a. As either end of the block of FIGURE 7 is viewed directly it should resemble FIGURE 7a on one end and the mirror image (complement) of 7a on the other end. It will later be seen as the unit is manifolded that the fluid flow is thus from 7 to 7' and from 8 to 8' as shown on FIGURE 7. The masking contemplated in FIGURE 7 is preferably accomplished through the use of thin strips of polyethylene film with adhesive, taking care that the masks are tight to the aluminium. Masking can also be done with brush applied lacquer and removal by solvent. Thus it will be seen from FIGURE 7a that the appearance alternates between masking strips and bare strips of aluminium. The masking strips must not overlap the copper edges since in FIGURE 8 the entire assembly has again been copper plated and the masks thereafter removed. During this plating step the new copper must adhere to the exposed copper edges well to prevent internal leaks in the final product. The appearance of the end of the assembly contemplated in FIGURE 8 is then one of alternating copper plated aluminium edges and bare aluminium edges.

Referring now to FIGURE 9, four shaped aluminium mandrels are affixed to the edges of the FIGURE 8 assembly. These mandrels typically at 9 in FIGURE 9 may be fabricated of pure soft aluminium by a process such as die casting. They may be of thin wall construction but must be closed at 10, 11, 12 and at the other manifold mandrel corresponding portion which is the diagonally opposite number of 9 on FIGURE 9. Aluminized plaster or plastic could be used as an alternative for an aluminium mandrel in the step of FIGURE 9. A material should not be used which will be difficult to etch or dissolve away however.

FIGURE 10 represents the appearance of the entire unit after it has been completely copper plated with the manifold mandrels in place. The use of a small amount of adhesive along the edges of the manifold mandrel in order to hold it in place for the plating operation of

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FIGURE 10 is not objectionable provided that in the ultimate step when the unwanted material is dissolved away a suitable solvent can be used to remove this adhesive. Once the final copper plating is effected, the mandrel ends at 13, 14 and 15 in FIGURE 10 are opened either by drilling or by machining off the closed ends to open them. Another dip in the acid or sodium hydroxide solution is next accomplished. In this way all of the aluminium within the assembly including the original aluminium sheets and the aluminium manifold mandrel are completely dissolved leaving an all copper assembly as shown in the cutaway view of FIGURE 11. In accordance with the masking and plating operation of FIGURES 7 and 8 the manifolds are now automatically joined so as to produce a flow situation depicted by FIGURE 11. If it is assumed that a hot fluid is represented by the arrows entering at 13 in FIGURE 11 this flow will be divided among alternate laminar flow paths and discharged at 14. The interleaving flow paths are connected to manifold 15 and its opposite number not shown.

Proceeding now to FIGURE 12 a description will be given of the second embodiment. In this second embodiment it will be assumed that an exchange of heat is desired between a flowing gas and a flowing liquid. In general the second embodiment operates much like a fire-tube boiler in that the gas passes through a plurality of tubes in parallel, and the fluid is circulated around the full length and perimeter of the tubes.

Referring now to FIGURE 12 it may be assumed that a solid block of aluminium has been drilled through with a plurality of holes of which 21 is typical. Symmetrically placed saw cuts 19 and 20 have also been made.

Mass production methods for producing the block of FIGURE 12 are readily available and are well known. For the sake of economy of material, it is also possible to construct the block of FIGURE 12, which actually serves as a mandrel and assembly jig, from two thin pre-punched plates, one of which would form the top surface 18 visible in FIGURE 12 and an identical opposite plate would form the bottom of the block. Thin sheet side members, of which 16 and 17 are typical, could then be welded or even cemented in place as shown thereby producing a hollow box structure.

Proceeding now to FIGURE 13, the slots 19 and 20 each receive a slightly oversize copper sheet as at 25 and 26 in FIGURE 13. Each of the holes 21 now receives a copper tube slightly longer than the thickness of the block mandrel. The use of a small amount of adhesive cement is entirely appropriate to hold the tubes 22 and the plates 25 and 26 in place pending the next operation, although tight fits in the holes and saw cuts could be depended upon to hold these parts in place. Hollow cylindrical copper intake and exhaust conduits 23 and 24 will require some adhesive to hold them in place however. The end product of the step of FIGURE 13 is then the aluminium mandrel and jig block of FIGURE 12 with all of the holes 21 filled by copper tubes 22 and copper plates and conduits 25, 26—23, 24 respectively in place as shown.

In FIGURE 14 the assembly of FIGURE 13 is aluminium sprayed in a step which is a counterpart of FIGURE 3 in connection with the first embodiment.

FIGURE 15 envisions a machining step of the two surfaces through which the smaller copper tubes are exposed and is comparable to the step of FIGURE 4.

In FIGURE 16 the entire assembly is electroplated with copper in a step comparable to FIGURE 5. It is assumed that the mouth of each of the copper tubes including the larger conduits 23 and 24 have been suitably plugged with a material to which the plating will not adhere. It should also be noted that immediately prior to plating the same preparation steps as in connection with FIGURES 4 and 5 are assumed, including the short etching step whereby the edges of the copper tubes are left projecting by a very small amount above the alumin-

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ium surface 29 before the copper plating is applied. In this way the plating which is deposited over the surface 29 as well as 30, 31 and for that matter over 23 and 24 will effect a strong union with each of the tubes. After this plating operation, the assembly is substantially finished except for the dissolving of the aluminium block mandrel by the same method as described in connection with the first embodiment.

FIGURE 17 illustrates the manner in which the liquid and gas might be expected to flow. Liquid admitted at 23 would flow past the first third of the copper tubes and would be constrained from lateral flow by the baffle 34. It would then round the corner of the baffle 35 and flow between the baffles 34 and 33 until it again reversed direction and flowed over the remaining third of the tubes between 33 and sidewall 30. A typical outside tube 32 would be expected to be emplaced so as to clear a side wall opposite 30 by approximately the same amount as it clears any adjacent companion tube.

The fundamental similarity between the process of forming the two embodiments will readily be noted in the machining operation of FIGURE 15. For example, it is expected that not all of the sprayed aluminium is to be removed from the machined surfaces for the same reasons as discussed in connection with FIGURE 4. It is assumed also that whatever material is used as a non-conductive plug such as cork, rubber or plastic for temporarily blocking the tubes 22 remains substantially in place during the machining step of FIGURE 15 and the plating step of FIGURE 16 but is removed before the application of the aluminium dissolving chemical.

From the foregoing description it will be obvious to one skilled in the art that various modifications and variations are possible and can be practiced without further invention. For example, the original metal sheets can be shaped other than rectangularly. They may even assume a complex curved shape or some other form factor.

It will also be understood that in the first embodiment the surfaces from which the intake and discharge ports (as for example in FIGURE 10) 13, 14 and 15 are emplaced could be corrugated for strength in a direction such that ridges of the corrugations run perpendicular to the long dimension of the unit. Each of the 1 and 2 sheets (FIGURE 1) would in that event be individually corrugated. In this way additional strength against internal pressure could be achieved. Corrugation of the side surfaces of the typical second embodiment such as at surface 30 could also be effected. The corrugations in that case would also be expected to have their ridges normal to the long dimension of side 30. The wedge shaped cuts of FIGURE 6 are convenient, but no critical angles or cut widths are suggested by the illustration.

Obviously the ports or conduits 23 and 24 as of FIGURE 16 could be masked or coated prior to the plating operation to avoid excessive buildup of plating material thereon if so desired.

Concerning materials, virtually any plateable material can be used in lieu of the copper and another metal could replace the aluminium interleaves, spray metal and manifold mandrels. The etching chemical must be such that it would dissolve the aluminium substitute without substantially attacking the copper substitute. Many non-ferrous metals including the noble metals could be chosen to provide suitable metal pairs and a general knowledge of chemistry would permit the proper choice of an etching chemical.

Many additional possibilities will suggest themselves in respect to materials used. Among other things, whenever the copper plating of either embodiment is to be undertaken, a thin plating of gold rhodium or some other selected plateable metal of exceptional nobility could first be applied. If the copper plating already discussed is then applied over the noble metal flashing or plating, fluid contact surfaces could then display the advantage of the noble metal coating where corrosive fluids are involved.

The copper sheets in the stack of the first embodiment and all the copper tubes of the second embodiment would need to be preplated or flashed with the noble metal to be used in order to complete the interior surface of noble metal in the finished product.

One of the most important results of the present invention was the development of the unique process described which permits the retention of mill hardness and strength in the copper (or other material) which forms the final product. Heat, as has been pointed out before, deteriorates these qualities of the metal and therefore the device of the present invention is thereby greatly superior to any design calling for the use of heat to weld, braze, or even solder. The retention of maximum metal strength than allows minimum metal thickness and correspondingly more efficient heat transfer. Bi-metal or galvanic corrosion within the present invention is not a factor because the metal "seen" by the fluids is all the same element.

While it has been contemplated that copper plates and tubes used in the fabrication of the embodiments of the present invention would normally be desired to be in their fully work hardened and most thermally conductive condition, this is not a requirement of the process. If, for some special purpose softer alloys were desired, the process will be found to be fully applicable.

In presenting the present invention with drawings depicting typical shapes and configurations, it is pointed out that the inventor does not thereby wish to be limited to the scope of his invention. The drawings are illustrative only and in accordance with the broad concepts of the invention, what is claimed is:

1. The process for producing a multi-chambered fluid tight vessel including at least two independent fluid flow chambers in close thermal contact with each other comprising: embedding a plurality of thin wall elements of a first metal in a mass of a second metal to the extent that only the extremities of said elements protrude from said mass of second metal, said second metal being capable of being selectively etched and removed from said first metal; masking a plurality of areas about the periphery of said mass with a material to which electroplating will not adhere, said masking being applied so as to correspond to areas of accessibility to said fluid flow chambers; electroplating said mass with metal substantially the same as said first metal; removing said masking material thereby to provide access openings; and bathing said plated mass in a chemical agent which does not appreciably react with said first metal but which reacts with said second metal to completely dissolve all of said second metal.

2. The invention set forth in claim 1 in which said first metal is copper and said second metal is aluminum.

3. The method of constructing a fluid-to-fluid heat exchanger comprising the steps of: stacking at least three sheets of a first metal separated from each other by interleaving sheets of a second metal, said sheets of second metal being slightly smaller in the flat dimensions than said sheets of first metal, said second metal being one capable of being selectively etched and removed from said first metal; spraying more of said second metal as a binder into the indentations produced around the edges of said sheets of second metal, thereby to produce a cohesive assembly; machining said sprayed portions flat and to an extent to exhibit flush edges of both of said metals and etching said second metal slightly away; plating said assembly with a continuous layer of said first metal; machining at least one surface perpendicular to said sheets on each of two opposite faces of said assembly, thereby exposing the cross-sections of all of said sheets of first and second materials; alternately masking at least some of said exposed sheets of said second metal, replating said assembly with said first metal and thereafter remov-

ing said masking; manifolding said machined surfaces and dissolving all of said second metal from said assembly with a chemical which attacks said second metal but not said first metal.

4. The process for producing a device of the character described composing the steps, in order, of: arranging and separating a plurality of congruent relatively thin wall members of a plateable first metal by means of separator members of a second metal, said second metal being capable of being selectively etched and thereby removed from said first metal; spraying an additional quantity of said second metal over said thin wall members and said separator members to produce a firmly held mass; machining said mass sufficiently to expose the extremities of said thin wall members flush with the surface of said sprayed second metal; etching said machined mass with a chemical agent which dissolves said second metal but not said first metal to produce the effect of indenting the residue of said sprayed second metal away from the edges of said first metal; masking a predetermined area of the exposed surface of said residue of sprayed second metal with a masking material to which electroplated material will not adhere; electroplating said mass with a third metal, said third metal being of a type which is not etched by said chemical agent and which is capable of bonding to said first metal during said electroplating; removing said masking material; and dissolving all of said remaining second metal by a second application of said chemical agent.

5. The invention set forth in claim 4 in which said manifolding is accomplished by affixing a hollow manifold mandrel of said second metal to said machined surfaces and again plating said assembly with said first metal.

6. The invention set forth in claim 4 in which said machined surfaces are two in number on each of two opposite ends of said assembly, and said masking is accomplished so as to produce two sets of interleaved through passages when said second metal is dissolved away.

7. The invention set forth in claim 4 further defined in that said first and third metals are substantially the same material.

8. The invention set forth in claim 4 further defined in that an initial step is included of plating said thin wall members with a thin layer of a fourth metal chemically less active than said first metal, and an intervening step of plating said mass with said fourth metal is also included before said step of plating with said third metal.

9. The invention set forth in claim 4, further defined in that said first and third metals are metals having a high order of heat conductivity such as copper and said second metal is aluminum containing no substantial quantities of alloying elements.

10. The method invention set forth in claim 9 in which said chemical agent is a hot alkaline compound such as sodium hydroxide.

11. The method invention set forth in claim 9 in which said chemical is an acid such as muriatic acid.

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