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(71) Applicant: ABB LUMMUS GLOBAL, INC. [US/US]; 1515 Broad Street, Bloomfield, NJ 07003 (US).

(72) Inventors: LLOYD, Jonathan; Obere Gasse 4, CH-5400 Baden (CH). GRIFFIN, Timothy; Bachtalstrasse 15, CH-5408 Ennetbaden (CH). KRANZMANN, Axel, Ewald; Uhlandstrasse 23, D-70182 Stuttgart (DE). SCHUH, Lothar; Handschuhsheimer Strasse 13, D-68723 Plankstadt (DE). MURRELL, Lawrence, Lee; 1229 McDonough Street, South Plainfield, NJ 07008 (US). OVERBEEK, Rudolf, A.; 32 Lexington Court, Chatham, NJ 07928 (US).

(74) Agents: SQUIRE, William et al.; Carella, Byrne, Bain, Gilfillan, Cecchi, Stewart & Olstein, 6 Becker Farm Road, Roseland, NJ 07068 (US).

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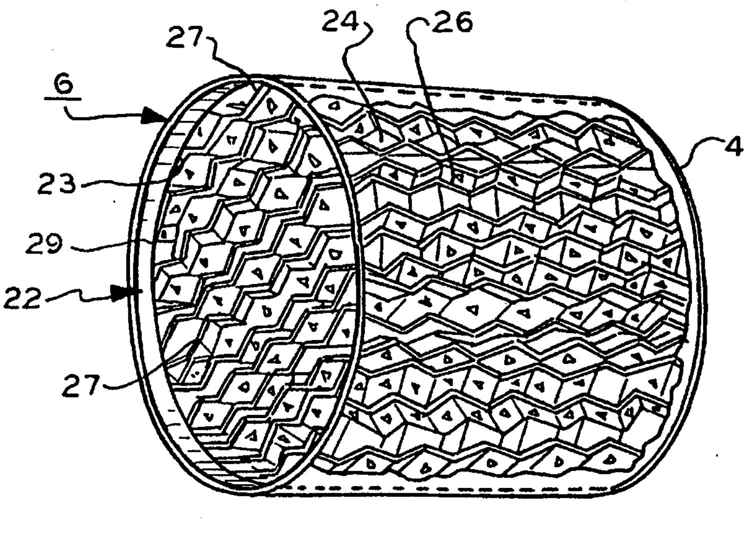

(57) Abstract

A combustion engine catalytic converter comprises porous mesh sheet material made of metal fibers having a diameter of about 1–30 microns coated with a catalyst and formed into corrugations, the material having a void volume of preferably about 80–95 %. Adjacent sheets have corrugations in one example at 45° in opposite directions relative to the gas inlet and outlet flow directions. The sheets create turbulence creating a pressure drop across the sheet material and causing exhaust gas to flow through the sheet material interstices in contact with the catalyst in the interstices. The material is light weight, has low mass and exhibits good cold start up heating in less than 1 minute. The pressure drop across the converter, with turbulence in the gas flow, is comparable to honeycomb prior art converter structures exhibiting laminar flow, uses less catalyst, is more efficient and is lighter. Various embodiments are shown employing vortex generators for providing turbulence in addition to the zigzag corrugated channel orientation or to provide tortuous channel paths for the gas flow to create the desired turbulence.

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EXHAUST GAS CATALYTIC CONVERTER

This invention relates to combustion engine catalytic converters, and more particularly, to catalytic converters for use with automotive engines.

CROSS REFERENCE TO RELATED APPLICATIONS AND PATENTS

Of interest are commonly owned copending U.S. applications Application Serial No. 09/181,186 entitled "Method and Apparatus for Making Catalyst carrier device Element" filed October 28, 1998 in the name of Vogt et al., Application Serial No. 09/002539 entitled "Catalyst carrier device and Element Therefor" filed January 2, 1998 in the name of Paikert et al. corresponding to PCT/US98/27699 filed December 29, 1998, Application Serial No. 09/156,023 entitled "Coated Products" filed in the name of Schuh et al. on September 17, 1998, Application Serial No. 09/156,023 entitled "Coated Products" filed September 17, 1998 in the name of Schuh et al., and Application Serial No. 60/087,474 entitled "Structured Packing and Element Therefor" filed May 29 1998 in the name of Overbeek et al.

Also of interest are U.S. Pats. Nos. 4,939,113 , 4,965,243 and International Application No. PCT/US95/01849 Publication No. WO 95/35152, which disclose catalysts for automotive combustion engine exhaust three way catalytic converters. Also of interest are U.S. Pats. Nos. 5,304,330, 5,080,962; 5,102,745 and 5,096,663 which disclose making mesh material. All of the foregoing applications and patents are incorporated in their entirety by reference herein.

Catalytic converters for automotive combustion engines are available, typically about 120 mm in diameter, in two basic constructions. One construction employs ceramic honeycomb monolithic elements comprising Mg-Al-oxide, known as Cordierite, a trademark of Corning Corporation. This material has a relatively low thermal coefficient of expansion to preclude thermal shock damage to the structure. The material is available as an extrudate. The honeycomb structure comprises a large number of parallel conduits through the material, typically about 400 conduits per square inch. A catalyst is deposited on the surface of the structure in the conduits. The conduits are parallel to provide laminar gas flow through the structure. Turbulence in the conduits is believed undesirable by conventional wisdom in the prior art in that such turbulence creates a back pressure, that is, it creates a relatively large pressure drop across the structure. This pressure drop or back pressure causes combustion engines to lose efficiency and creates a loss of power output, which is undesirable. The problem with such a structure is that it also exhibits inefficient utilization of the catalyst. The catalyst is coated as a washcoat on the surfaces of the material in the conduits. There is inefficient catalytic action between the catalyst and the flowing gases because the narrow straight channels of the monolith result in a build-up of a laminar layer which reduces gas-catalyst mass-transfer. This inefficiency requires costly excessive catalyst to be utilized in order for the converter to meet its required conversion levels. For example, 90 grams of catalyst is used on typical catalytic converters. Further, the structure is relative bulky and heavy, e.g., 1180 grams.

A second type of catalytic carrier comprises Fe-Cr-alloy with approximately 5% Al, which forms a protective alumina scaling on the metal surface upon response to oxygen-containing atmosphere at elevated temperature. This layer prevents the oxidation of the alloy at temperatures as high as 1000°C. Common foils of the alloy, about 40-50 micron thickness, are corrugated with linear corrugations extending along the material in parallel. A second sheet of overlying foil is then wrapped with the corrugated foil into a spiral structure having a longitudinal axis. The corrugations all form parallel channels in the longitudinal direction. The foils are relatively tightly wrapped to produce a high weight, high mass honeycomb-like structure. The thermal mass is less than that of the ceramic structure and may have about 800 channels per square inch of transverse area. However, this structure also employs laminar flow to minimize the pressure drop through the structure.

The limitations of the foregoing honeycomb monolithic structures include a relatively high mass (which translates into a relatively high thermal mass) of the carrier. (600-1200g/liter) with no possibility for dramatic weight reduction. High thermal mass is undesirable. High mass results in slow light-off. Light-off refers to the time it takes for the mass to reach the operating temperature, e.g., 300°C, of the catalyst coated on the monolithic structure. This is also referred to as the cold start-up period of an engine. The monolith structure due to its thermal mass is slow to heat up to the desired temperature during cold start-up. This slow light-off in automotive applications results in poor catalytic reaction and thus poor conversion of certain undesirable polluting gas components, e.g., NOx, unconverted HC, and CO. The pollutants are formed during the start up periods of cold engines when the catalyst is not at its critical temperature. Thus, until the catalyst reaches its operating temperature, high and unacceptable pollution levels in the exhaust gas are present. This is obviously undesirable. Reducing the mass by reducing wall thickness as a solution is limited. The current minimum thickness of the metal foils is limited to about 40 microns.

A further limitation of prior art catalytic converter monolith structures is the limited catalytic active surface area. This is the total geometric surface area available in the interior conduits of the structure. The surface area can be increased by reducing the size of the channels, i.e., the cross sectional area, but this will increase the pressure drop along the converter length and is believed not desirable as noted above. What is desired is a very low pressure drop across the structure between its inlets and outlets.

There are currently developments for producing catalytic converters employing metal foils as thin as 20 microns employing turbulence enhancers in an effort to induce improved reaction of the catalyst with the gas or new coating technologies for the catalyst to also enhance such reactions. Further, work is being done by others to increase the number of flow channels in the order of 1000-1200 channels per square inch of transverse area of converter structure. However, such structures still exhibit relatively high thermal mass and low mass transfer which result in relatively inefficient catalytic operation.

The present inventors recognize a need for an improved catalytic converter which will overcome the problems noted above with the prior art monolithic converter structures.

A combustion engine catalytic converter for reacting with certain components of the engine exhaust gas when flowing in a given direction according to the present invention comprises a housing having an engine exhaust gas receiving chamber; a porous material in the chamber having pores exhibiting a plurality of interstices in fluid communication with each other and externally the material, the received gas for flowing externally and within the interstices and a catalyst secured to the material for reacting with the gas components as the received gas flows through the chamber and through the interstices.

In one aspect, the porous material comprises sintered metal fiber and in another aspect, the porous material comprises sheet material. Preferably, the catalyst is secured to the material within the interstices.

In a further aspect, the sheet material includes a plurality of vortex generators.

In a still further aspect, the sheet material is corrugated, the corrugations of each sheet being parallel, the corrugations of adjacent sheets being inclined relative to each other, the corrugations of adjacent sheets forming fluid channels in fluid communication with each other .

Preferably, the corrugations form gas flow channels oriented within a range of 0° to about a 75° angle of inclination relative to the given direction of flow.

In a still further aspect, the porous material is formed into a plurality of sheets, each sheet having a plurality of parallel channels, means for coupling the plurality of sheets with their channels parallel, each sheet including a plurality of vortex generators extending into each of the channels for forming each said channel into a substantially tortuous fluid path for the gas flowing in the given direction.

Preferably the material is about at least 85% void and the fibers are preferably about 1-50 microns in diameter, more preferably from 8 to 25 microns in diameter.

A combustion engine catalytic converter in a further aspect comprises a housing having an exhaust gas receiving chamber; a plurality of sheets of material in the chamber, each sheet including a plurality of corrugations, the corrugations being inclined to the given direction to create turbulence in the flowing gas in said chamber, and a catalyst secured to the material for reacting with said gas components. Preferably, the corrugation side walls are flat and subtend an angle of about 30-150° relative to each other.

In a further aspect, the longitudinal length of the corrugations of adjacent sheets are oriented at an angle relative to each other, the corrugations of adjacent sheets forming fluid channels in fluid communication with each other.

In a further aspect, vortex generators are included in the corrugated sheets and preferably comprise tabs bent from the plane of the associated sheet material forming through holes in the sheet material.

In a further aspect, the porous material is formed into a plurality of sheets, each sheet having a plurality of parallel channels. Means are included for coupling the plurality of sheets with their channels parallel, each sheet including a plurality of vortex generators extending into each of the channels for forming each channel into a substantially tortuous fluid path for the gas flowing in the given direction.

In a further aspect, the metal fibers and catalyst are heated in a reducing atmosphere, preferably hydrogen, such that fiber contact points within the material attach by sintering of the fibers.

In yet a further aspect, the metal fibers and catalyst are heated by flowing an electric current through the material in a flowing gas atmosphere to attach the fibers at contact points within the material by sintering.

In another aspect, the metal fibers and catalyst are heated by flowing an electric current through the structure to efficiently heat up the structure to react at a certain temperature with the exhaust gas.

A combustion engine catalytic converter according to a still further aspect of the present invention comprises a housing having a gas receiving chamber and catalyst means in the chamber for reacting with the gas components and arranged to create a turbulent flow of the gas through the chamber while maintaining the pressure drop through the chamber of a certain value sufficiently low to create a back pressure to the engine of equal or less than the certain value.

A combustion engine catalytic converter in a still further aspect comprises a housing having a gas receiving chamber for receiving the exhaust gas and a carrier including a catalyst in the chamber, the catalyst for reacting with the received gas components in the chamber when the catalyst is at a certain temperature, the carrier exhibiting a sufficiently low thermal mass with respect to the thermal energy transmitted to the carrier by the gas in thermal contact therewith at least the certain temperature so that the carrier exhibits the certain temperature in less than about 1 minute.

IN THE DRAWING:

FIGURE 1 is a perspective view of a catalytic converter according to an embodiment of the present invention;

FIGURE 2 is a perspective view of the central converter portion of the converter of FIGURE 1;

FIGURE 3 is a more detailed perspective view of the portion of FIGURE 2 with the outer cover shown transparent for purposes of illustration;

FIGURE 4 is a perspective view of a plurality of corrugated converter elements of FIGURE 3 laid out in side-by-side relation;

FIGURE 5 is a more detailed perspective view of a portion of one of the corrugated elements of FIGURE 4 used in the embodiment of FIGURES 1-3;

FIGURE 6 is an isometric view of a representative sheet material forming the element of FIGURE 4 prior to formation of the corrugations in the element;

FIGURE 7 is an isometric view of a portion of an element formed by the sheet of FIGURE 6 after corrugations and vortex generators are formed therein;

FIGURE 7a is a more detailed view one of the vortex generators of FIGURE 7 taken at region 7a;

FIGURE 8 is an end view of a portion of the element of FIGURE 7;

FIGURE 8a is a more detailed view of a portion of the element of FIGURE 8 taken at region 8a;

FIGURE 9 is a plan view of an intermediate stage of processing the sheet of FIGURE 6 according to a second embodiment of an element after the vortex generators of FIGURES 7-8 are formed and prior to formation of the corrugations;

FIGURE 10 is an isometric view of a portion of the sheet of FIGURE 9;

FIGURE 11 is an end elevation view of the portion of FIGURE 10 taken along lines 11-11;

FIGURE 12 is a photomicrograph of the material forming the sheet material of an element of the present invention showing enlarged detail of the material structure;

FIGURE 13 is a side elevation sectional view of an apparatus for forming the sheet material of FIGURE 9;

FIGURE 14 is a plan sectional view of the apparatus of FIGURE 13;

FIGURE 15 is a side elevation sectional generally diagrammatic view of the apparatus of FIGURE 16 taken along lines 15-15;

FIGURE 16 is a generally diagrammatic plan view of an apparatus for forming the corrugations of the sheet material of FIGURES 4, 5 and 7, 8 ;

FIGURE 17 is a generally diagrammatic side elevation sectional view of the apparatus of FIGURE 18 taken along lines 17-17;

FIGURE 18 is a generally diagrammatic plan view of the apparatus of FIGURE 17 in a stage after forming the sheet material corrugations of FIGURES 4, 5 and 7, 8;

FIGURE 18a is an isometric view of a representative finger employed in the embodiments of FIGURES 15-18;

FIGURE 19 is an isometric view of a further embodiment of a catalytic converter catalyst support structure;

FIGURE 20 is a plan view of a portion of an element used in the structure of FIGURE 19;

FIGURE 21 is a front elevation view of the element of FIGURE 20 taken along lines 21-21; and

FIGURES 22-27 are charts useful for explaining certain principles of the present invention.

In FIGURE 1, catalytic converter 2 comprises a metal housing 4 including a circular cylindrical section 6, a forward frusto-conical section 8 and a rear conical section 10. Converter 2 section 6 contains a catalyst carrier 22 (FIGURE 3) coated with a catalyst which reacts with exhaust gases from an automotive, for example, combustion engine (not shown) for conversion of hydrocarbons and other pollutant components to neutral non-polluting gases. Section 6 may be about 120 cm diameter and 150 cm in length in this embodiment. Other embodiments may be of different dimensions according to a given implementation. Forward section 6 is connected to pipe 12 which terminates at its front end in flange 14. Flange 14 connects to the combustion engine exhaust pipe (not shown) for receiving the engine exhaust gases in direction 16. The converter 2 rear section 10 is connected to pipe 18 which terminates at flange 20 for connection to the gas discharge portion of the exhaust system (not shown).

In FIGURE 2, the central circular cylindrical section 6 of the housing 4 includes a catalytic conversion catalyst-carrier 22 shown in more detail in FIGURE 3. The section 6 includes a circular cylindrical liner 23 (not shown) of porous mesh sheet material formed of metal microfibers of the type described in more detail below. The sheet material liner 23 provides vibration damping and frictionally secures the carrier 22 axially in place in the housing 4 during assembly. The liner may optionally have a catalyst material of the type and in the manner described below. The housing 4 may be stainless steel and formed as a sheet material joined by welding at a longitudinal edge 25. The housing 4 in section 6 when welded, compresses the liner 23 against the carrier 22. A metal screen 31 is affixed to each of the opposite axial ends of the carrier 22. A split ring 29 is welded to the interior of the housing 4 external the screens 31 sandwiching the screens 31 and carrier 22 there between.

In FIGURE 3, the section 6 housing 4 and liner 23 are shown transparent for purpose of illustrating the carrier 22 carried in the interior thereof. Carrier 22 comprises an assembly of corrugated catalyst-carrier elements 24, 26 and so on. Each of the elements 24, 26 are fabricated of the identical sheet material composition as the liner 23, but differ in peripheral dimensions from each other to form the circular cylindrical shape of the housing 4 section 6 core. The elements 24, 26 have the same axial longitudinal length from the left to right in the drawing, but have differing transverse widths across the diametrical dimension to accommodate the circular cavity of the housing 4 section 6 inside of the liner 23. The elements 24, 26 are identically formed and comprise identically shaped corrugations 27. See the aforementioned Application Serial No. 09/181,186 mentioned in the introductory portion herein for a description of an apparatus fully incorporated by reference herein for making the elements 24, 26. This apparatus is briefly described herein in respect of FIGURES 13-18 below.

The corrugations 27, while angular in transverse section, may also be of rounded undulations or of other shapes as desired for a given implementation. In this implementation, the carrier 22 is for use with combustion engine exhaust gases, for example, for treating NOx, HC and CO components of the gas.

In FIGURE 6, sheet 28, forming the elements 24, 26 (and liner 23, FIGURE 2) is planar and cut to size from a relatively larger sheet, e.g., 3 by 4 foot sheet (0.91 m x 1.22 m) (not shown). Sheet 28 comprises porous sintered stainless steel or other metal fibers as described below in more detail. The sheet 28 has a high surface area to void volume for example, a void volume preferably in the 85% to 95% range discussed below. The sheet 28 provides a catalyst support comprising a porous mesh-like structure. The term "supported on the mesh" as used herein includes coating the catalyst on the mesh as well as entrapping the catalyst in the interstices of the mesh, or combinations thereof.

The catalyst material may include any known combustion engine exhaust catalyst material. By way of example such material may include a particulate gamma alumina support dispersed on or in the mesh. The catalyst metals may be selected from the group consisting of palladium, the combination of platinum plus rhodium, and mixtures of platinum, palladium and rhodium dispersed on the particulate support of gamma alumina as disclosed in Pat. No. 4,939,113.

In the alternative, the catalyst may be deposited on the mesh as a slurry containing a platinum group element, active alumina, cerium oxide, a barium compound and a zirconium compound and calcining the support as disclosed in Pat. No. 4,965,243. In a further alternative, the catalyst may comprise multiple layers, for example, a first and second layer. The first layer comprises a support, at least one palladium component, optionally a minor amount of platinum, optionally an oxygen storage composition, e.g. cerium oxide or a zirconium crude-cerium oxide composition, optionally a zirconium component, optionally at least one alkaline earth metal component and optionally at least one rare earth metal component selected from the group consisting of lanthanum metal components and neodymium metal components. The second layer comprises a support, a platinum component, a rhodium component, an oxygen storage composition comprising a diluted oxygen storage component and optionally a zirconium component as disclosed in Pat. Application No. WO 95/35152.

The catalyst that is employed also may be one that is commercially available and while it may be of the type as described more fully for example in the aforementioned Pat. Nos. 4,965,243; 4,939,113 and PCT Application No. WO 95/35152 incorporated by reference in their entirety herein, it may be of any other automotive combustion engine exhaust catalytic converter composition as known in this art.

More particularly, the mesh-like material forming the carrier 22 and liner 23 comprises fibers or wires, such as a wire or fiber mesh, a metal felt or gauze, metal fiber filter and so on. The mesh-like structure may be comprised of a single layer, or may include multiple layers where there may be one layer of wires; e.g., a knitted wire structure or a woven wire structure, and preferably comprises a plurality of wires or fibers to form a three dimensional network of materials. In one embodiment, the support structure comprises a plurality of layers or sheets of fibers that are oriented randomly in the layers. One or more metals may be used in producing a metal mesh. Alternatively the mesh fibers may be formed from or include materials other than metals alone or in combination with metals; e.g. carbon or metal oxides or a ceramic.

In a preferred embodiment wherein the mesh-like structure comprises a plurality of layers of fibers to form the three dimensional network of materials, the thickness of such support is at least five microns, and generally does not exceed ten millimeters. In accordance with a preferred embodiment, the thickness of the network is at least 50 microns and more preferably at least 100 microns and generally does not exceed about 2 millimeters and preferably 1 mm.

In general, the thickness or diameter of the fibers which form the plurality of layers of fibers is less than about 500 microns, preferably less than about 150 microns and more preferably less than about 30 microns. In a preferred embodiment, the thickness or diameter of the fibers is from about 1 to about 30 microns and preferably 8-25 microns.

The three dimensional mesh-like structure may be produced as described in U.S. Pat. Nos. 5,304,330, 5,080,962; 5,102,745 or 5,096,663 incorporated by reference herein. It is to be understood, however, that such mesh-like structure may be formed by procedures other than as described in the aforementioned patents.

The mesh-like structure that is employed in the present invention (without a catalyst on the mesh) has a void volume which is at least 45%, and is preferably at least 55% and is more preferably at least 65% and still more preferably is at least about 90%. In general, the void volume does not exceed about 95%. The term "void volume" as used herein is determined by dividing the volume of the structure which is open by the total volume of the structure (openings and mesh material) and multiplying by 100. The particular description of the mesh-like sheet 28 is also described in the aforementioned Application Serial No. 60/116,649 filed January 21, 1999 and incorporated in its entirety by reference herein.

The sheet 28 is coated by the catalyst employing know deposition processes. The supported catalyst which is supported on the mesh-like structure may be present on the mesh-like support as a coating on the wires or fibers that form the mesh-like structure and/or may be present and retained in the interstices of the mesh-like structure.

In one embodiment, wherein the catalyst supported on a particulate support the catalyst is present as a coating on the mesh-like structure, the mesh-like structure may be initially coated with a particulate support, followed by addition of the catalyst to the particulate support present as a coating on the mesh-like structure. The particle support for the catalyst may include alumina, silica, zirconia, ceria, titania, barium oxide and mixtures thereof. Examples of specific compositions are disclosed in the aforementioned Pat. Nos. 4,9065,243; 4,939,113, and PCT Application No. WO 95/35152. Alternatively, the catalyst supported on a particulate support may be coated onto the mesh. The particulate support with or without catalyst may be coated on the mesh structure by a variety of techniques, e.g., dipping or spraying. After coating the particulate support without catalyst onto the mesh, the particulate support is impregnated with a solution containing the catalyst precursors and is treated thermally to obtain the catalyst.

In one embodiment, wherein the mesh-like structure is comprised of a plurality of layers of metal fibers, the particulate support with or without catalyst may be coated onto the mesh-like catalyst support by an electrophoretic coating procedure, as described in U.S. Application Serial Number 09/156,023, filed on September 17, 1998 incorporated by reference herein. In such a procedure, a wire mesh-like structure is employed as one of the electrodes, and the particulate support, such as an alumina support of the requisite particle size, with or without catalyst, (which may include alumina in the form of a sol to promote the adherence of larger particles to the wire mesh) is suspended in a coating bath. A potential is applied across the electrodes, one of which is the mesh-like structure formed from a plurality of layers of fibers, and the mesh-like structure is electrophoretically coated with the alumina support with or without catalyst. If the alumina support does not include a catalyst, the catalyst then can be added to the catalyst structure by impregnating with or dipping the structure (which contains the alumina coating) into an appropriate solution that contains the catalyst and possibly one or more promoters.

As hereinabove indicated, the supported catalyst may be supported on the mesh material by entrapping or retaining the particulate support in the interstices of the mesh. For example, in producing a mesh-like structure comprised of a plurality of layers of randomly oriented fibers, the particulate support may be included in the mix that is used for producing the mesh-like structure whereby the mesh-like structure is produced with the particulate support retained in the interstices of the mesh. For example, such mesh-like structure may be produced as described in the aforementioned patents, and with an appropriate support being added to the mesh that contains the fibers and a binder, such as cellulose. The catalyst or support, entrapped within the interstices of the metal fibers and the binder is subsequently, heated in a reducing atmosphere such as hydrogen such that the fibers attach to each other by sintering action at the fiber contact points within the porous material. In the alternative, the metal fibers and catalyst or support may be heated by flowing an electric current through the material in a flowing gas atmosphere so as to cause the fibers to attach to each other at fiber contact points within the porous material. In the case the produced mesh structure includes the particulate support retained in the mesh structure, the particulate support retained in the mesh structure is impregnated with the catalyst precursors and treated thermally to obtain the catalyst.

A photomicrograph of the wire mesh in one embodiment is shown in FIGURE 12. This photograph shows a top plan view of a 20 micron, 90% void 79% Fe16% Cr 5% Al alloy fiber sheet of a 0.7 mm thickness electrophoretically coated with a three-way catalyst catalyst. The total weight of catalyst per weight of metal and catalyst is, in this case, 20%.

In one example, the fibers are about 8-12 microns in diameter and are employed in sheets of about 0.5 mm thick with 95% voids. The material has the consistency of paper or felt, is delicate and can be readily permanently deformed and/or damaged. The sheets are 1m x 1m and corrugated as described above. These sheets are cut to size for corrugating the material. The material is then cleaned in a solvent, e.g., acetone, to remove contamination and dried in heated air. Optionally, the material may be heat treated at 400-700°C in air to preoxidize the surface of the metal fibers. The catalyst coating is applied in a slurry process, a catalyst carrier or wherein the catalyst is suspended in water (colloidal suspension, slip) and the metal fiber sheet is immersed into the slurry. Because the slurry must penetrate the entire mesh structure (coat the fibers in the void volume), the wetting behavior must be appropriate. Heat treatment provides good wetting properties because a slight oxidation layer on the fibers provides the desired wetting action. However, depending on the material, wetting can be acceptable without heat treatment in accordance with the manufacturing process of the fiber sheets and the fiber wetting characteristics.

After heat treatment, contamination needs to be avoided with careful handling of the sheet material.

The coating is applied in the slurry containing the catalytic powder. The slurry contains the catalytic powder of a composition as described in the catalyst related patents and International Application noted in the introductory portion. Preferably, this slurry is deposited as a thin coating, e.g. 1-10 microns, onto the micro fibers. This deposition can be by an electrophoretic process described more fully in copending Application Serial No. 09/156,023 noted in the introductory portion and incorporated by reference herein. After the electrophoretic coating is applied, the sheets are dried in hot air and heat treated to provide bonding of the catalyst coating on the fibers. The sheet material is heated to about 200-900°C during this heat treating in accordance with the nature of the coating. For example, when a catalyst is directly deposited on to the fibers, a heat treatment of 500°C may be employed. This provides the desired attachment of the coating onto the fiber surfaces and may not affect the properties of the catalyst.

After final heat treatment, the single corrugated sheets are assembled to the catalytic converter housing. This is done, for example, with a static mixing arrangement. The sheets are pressed together in the steel tube housing 4, FIGURE 2.

To form the corrugations, sheet 28, FIGURE 6, is rectangular or diamond polygon shape in accordance with a given implementation. The peripheral dimensions are determined according to the desired size, for example, to fit within the cylindrical housing 4 of section 6. All of the elements 8, 10 in the housing section 6 are arranged parallel. Thus the elements are dimensioned accordingly.

The sheet 28 is formed with two notches 30, 32, holes 34 at opposite edges. These notches and holes are for aligning the sheet for further processing in a mating die forming apparatuses described in the aforementioned Application Serial No. 09/181,186 and described below in connection with FIGURES 13-18. The location and angle of the notches is important for aligning the corrugations to be formed to the sheet perimeter dimensions in the apparatuses of FIGURES 13-18.

The sheet 28 of FIGURE 6 is processed in an apparatuses shown and described below in FIGURES 13-18 for forming corrugations 50 in the sheet 28 to form element 1884. The corrugations are formed by adjacent side walls 51, 51' and 53, 53' and so on. The corrugations define roots 57 and crests 59. The side walls are inclined preferably at an angle α (FIGURE 8) of about 90°. The roots and crests extend in a linear direction parallel to axis 61.

The elements 24, 26, 54, 56 and so on, FIGURES 3 and 4, are oriented with their axes 61 at alternating angles φ, FIGURE 25, to the flow direction 16, FIGURE 1, of the gases through the housing 4. In FIGURE 25, the flow direction corresponds to direction 16, FIGURE 1. The wave direction corresponds to the axis 61 of the elements. The defined angle φ of pattern is the angle between the axes 61 and the flow direction 16. In FIGURE 25 the angle φ is shown as having values of 0 to 90° and in the flow diagram as being at 45°. This means that adjacent elements are oriented with their corrugations at the angle 2φ relative to each other and to the direction 16, the angle φ being the defined angle of the pattern. The preferred channel angles φ of 45° to the axial flow direction 16 of the gas, FIGURE 25, left hand side of the figure, provides adjacent sheets oriented with their channels oriented at 2φ or 90° relative to each other.

The corrugations form gas channels there through. These channels are in fluid communication with each other at the edges of the elements at the housing 4 circumferential surface. The flow pattern angle φ may be at any desired value according to a given implementation. The gas entering the housing 4 in direction 16 enters into the channels of the elements and then is diverted at angle φ initially then at 90° thereto in the adjacent element and so alternating at right angles in the direction of flow. This creates a turbulence in the flow which is contrary to conventional wisdom in the art of combustion engine catalytic converters. There are no parallel channels through the converter housing 4 producing laminar flow in this arrangement. The exhaust pipe 12 may be widened from about 50 mm to about 120 mm diameter and about 150 mm long in section 6, FIGURE 2, in this embodiment.

Turbulence is believed undesirable in that it is believed to create undesirable back pressure or an undesirably high pressure drop across the converter. The prior art honeycomb and similar structures create laminar flow to provide reduced pressure drop across the converter. High pressure drop causes loss of engine power. In the various FIGURES 22-27, MEC refers to the mesh corrugated sheet elements constructed and oriented according to the present invention employing mesh material described above and as shown in FIGURE 12. Preferably the catalyst is "supported on the mesh" which includes entrapping the catalyst as well as coating the catalyst on the wires or fibers.

This provides increased surface area of catalyst exposed to gases when the gases flow through the interstices. Some turbulent flow is required to have sufficient gas flow through the mesh interstices. This increased surface area of catalyst increases the efficiency of the converter 2, and requires less catalyst per converter as compared to prior art 400 channel per inch honeycomb structures with laminar flow channels.

Comparing the surface area of a solid sheet to a 95% porous 0.5 mm thick sheet of 10 micron fibers MEC material forming element 44, FIGURE 5, it can be calculated that the MEC material has five times more surface area than the solid sheet due to the large surface area of the fibers. Increased surface area is provided by increasing the thickness of the MEC material, decreasing the fiber diameter and decreasing the porosity. If only 50% of the fibers are completely coated, there is still 2.5 times more exposed surface as compared to a coated solid sheet. The prior art catalytic converters all provide materials with solid surfaces rather than porous material with through pores.

By way of example, assuming a prior art monolithic substrate has a sheet surface area of about 500 m^2/m^3, the converter with the MEC material of about the same overall dimensions has an effective area of 2500 m^2/m^3. Frontal blockage of the section 6 elements, FIGURE 2, is generally only about 10-20% of the total frontal area defined by the housing 4 in section 6, depending upon the thickness of the sheet employed.

Ceramic substrates have relatively thick walls 0.2-0.5 mm thick. A typical square shaped monolith has an effective area of 2000 m^2/m^3 100% coated with catalyst, with about 200-400 cells per square inch with surface area ranging from 1500 to 3000 m^2/m^3. Frontal area blockage is about 25-30%. A more advanced prior art converter uses thin metal sheets, 40–70 microns thick of sinusoidal wave corrugations, 1 mm high, each layer separated by a flat metal sheet. This has an effective area of about 2000-4000 m^2/m^3 and a frontal blockage of about 10-20%, depending on the sheet thickness employed and the number of cells per square inch.

Conversion in automotive catalysts is intrinsically fast, but is gas-solid mass-transfer limited. All prior art converters exhibit laminar flow. The mass-transfer in a laminar flow is an order-of-magnitude less than in turbulent flow and, therefore, catalyst is used inefficiently. The crossed corrugations of the elements of section 6, FIGURE 2, create turbulent flow and higher mass-transfer than laminar flow arrangements, thus enhancing catalyst effectiveness. The effect of higher mass-transfer is particularly pronounced once light-off is achieved. Further, or separately, turbulence can be created using turbulence generators such as vortex generators described in connection with FIGURES 7-8 below. Prior to light-off, major benefits of the coated wire mesh are the shorter time to light-off and the high internal surface area which allows higher conversions even during relatively inefficient operation.

In present converters employing monolith converters, the converter is not run in the turbulent regime because for a channel that is wide enough for turbulent flow at a sufficiently low pressure drop so much surface area is lost, that a sufficient conversion rate cannot be achieved. In the present invention mesh structure, if the regime is turbulent, the catalyst in the central portions of the material thickness will be utilized. In addition, the surface area of the exposed fibers is sufficiently large to obtain the desired conversion rate. If gas enters the material pores, it has to be replaced by gas from the channel regions. There must be a small pressure differential between the channels to utilize the catalyst in the central, i.e., interior, portions of the material. Therefore, turbulence has to be created to obtain the desired pressure drop and resulting mass transfer. There is no gas communication between channels in a monolith.

The mesh material forming the elements typically weighs half per cm^3 , $0.2 g/cm^3$ without a coating than a corresponding typical monolith substrate ($0.5 g/cm^3$). This amounts to a decrease in 300 g for a typical converter. The mesh material is, therefore, considerably lighter than such monoliths.

The pressure loss in a monolith increases almost linearly with increase mass flow, which is a characteristic of laminar flow, as compared to the pressure loss in the corrugated MEC structure which rises quadratically with mass flow rate due to turbulent characteristics (see FIGURE 26). In this figure, one MEC material is uncoated and is corrugated at a 45° wave angle. One structure is made from metal sheet and is corrugated at a 45° angle, the ceramic honeycomb material is at 400 channels per square inch, a second MEC material is uncoated and corrugated at 60° wave angle (See FIGURE 25 for wave direction angle φ for the angle referred to in this discussion), and one set of data represents a calculated polynome for MEC corrugated material at 60 ° wave angle. As seen in FIGURE 26, the 45° angle has a non-linear pressure drop comparable to the linear drop of a honeycomb structure in a certain velocity regime

Thus for certain flow rates , the pressure loss is best in the MEC corrugated structure with channels at 45 degrees to the flow direction while at higher flow rates the pressure loss may be better in the monolith structure. The measured cross-over point for the above described structures is 5m/s. But of course other factors such as material thickness, number of elements, porosity, coating thickness and so on also have a bearing on the characteristics of the structure, particularly in the case of the monolith, where the frontal area will be reduced significantly upon coating.

Light-off time, the time it takes for the elements of the converter to reach operating temperature, e.g., about 300-350° C, during cold start-up, is much shorter with the MEC material corrugated MEC elements of FIGURES 2-4 than with monolithic structures. The heat capacity of ceramic is about 900J/kgK, while the heat capacity of steel and nickel is about 460 J/kgK, the heat capacity of a metal-foil system (400 channels/inch) is 375 J/K*Liter and the thermal capacity of the microwire mesh converter of comparable overall dimensions is 80-100 J/K* liter. The bulk density of the MEC elements is 2.5 times less than the average ceramic substrate presently used, and heat up time is therefore reduced by about 5 times. This results in light up of less than 1 minute for a converter with the MEC elements as compared to over 2 minutes for a conventional converter. This gives a significant reduction in the cold-start phase where NOx, HC and CO are emitted with minimal or no conversion. The high thermal conductivity of the metal fibers as compared to the ceramic monolith, coupled with the presence of turbulent rather than laminar flow, will result in a more uniform temperature profile across the MEC material.

To further reduce light-off time, the fibers and the catalyst may be heated at initial start up of the engine by flowing an electric current through the material to efficiently heat up the structure to react at a certain temperature with the exhaust gas.

Typical catalyst materials for the exhaust gases include noble metals such as platinum, palladium and rhodium combined with rare earth, ceria, zirconia, etc. Typical emissions to be converted include NOx, CO and HC. Some conventional converters employ a warm-up catalyst or absorber catalyst to absorb hydrocarbons during warm up of engine and converter.

A converter of the present invention may weigh about 150g/liter as compared to 800g/liter of a metal-monolith converter. The accessible catalytic active surface of coated fibers of the present invention may be about 3 m^2 per liter volume.

In one embodiment, the microwires comprise 20 micron thick wires of Fe-Cr-Al alloy with a voidness of 90%, sheet thickness of 0.8 mm. This results in a carrier structure that has a geometric surface of 0.3 m2/liter structure volume and 3.8 m2 internal fiber surface. A conventional monolith foil-surface is about 3 m2/liter structure volume. The volumetric activity of a catalyst system depends upon the accessible active surface. Such a structure can have higher internal surface areas when the fibers get smaller in diameter. This increases the area coated by the catalyst per unit volume. Conventional converters exhibit a geometric foil-surface of 3 m2/liter of structure volume. See Table I for examples of values for a microwire mesh converter material.

Table I

Fiber diameter liter of	Fiber surface	Fiber surface per Catalytic converter 150 g fibers/liter
20 micron	26 m2/kg	3.9m2
10 micron	52 m2/kg	7.8m2
5 micron	105m2/kg	16m2

As can be concluded from Table I, reducing the diameter of the fibers increases the volumetric activity of a converter significantly. This may result in either a better performing converter and/or a reduced size for the converter.

An apparatus 69 for forming the corrugations and, optionally, vortex generators, is shown in FIGURES 13 and 14. In the embodiment of Figs 7-8, the aforementioned Application Serial No. 09/181,186 and the drawings thereof are referred to for the following description in addition to FIGURES 13 and 14 herein. In FIGURE 13, the sheet 28 is placed between two respective upper and lower spring loaded die plates 58 and 60 having opposing sets of corresponding linear ridges 62 and 64 (not visible in the upper die plate due to the small scale of the figure), respectively, (See the aforementioned patent application for more detailed drawings) and cutting dies 64 and 66. The cutting dies 64 and 66 are form the vortex generators and the ridges 62 and 63 form grooves in the sheet 28 in a manner to be discussed below. The grooves assist in formation of the corrugations. It should be understood, however, that the sheet 28 may be formed without vortex generators and formed with only the corrugations. The charts of FIGURES 22-27 to be discussed below relate to a corrugated sheet 28 without vortex generators.

The apparatus 69 initially forms the sheet 28 surface features comprising grooves and vortex generators. The apparatus includes a base assembly 70 including a base 72, a pair of cylindrical guide and support posts 74 fixed to the base 72 and an upper assembly 76. The upper assembly 76 is supported on the posts by bearing assemblies 78. The upper assembly 76 is selectively displaceable in the vertical directions 80 by an operating device which may be a manually operated lever, a pneumatic or motor operated device or other power source (not shown). A pneumatic device can provide an air cushion for providing a damping action.

The base assembly 70 includes a fixed plate 82 fixed to the base 72 by locating guide pins 82 and bolts 84. An array of guide pins 84 are secured fixed to the base 72 and pass through the plate 82. The guide pins 84 each are slidably mounted in a mating sleeve 88. The sleeves 88 are press fit in mating bores in the lower movable die plate 60. The sleeves 88 each have a shoulder 90 abutting the die plate 60. The sleeves guide and locate the movable die plate 60 relative to the fixed plate 82 as the die plate displaces vertically in directions 80.

An array of four bolt pins 92 are secured to the fixed plate 82 and pass through a chamber 94 in the fixed plate. The pins 92 also are in mating bores in die plate 60. A compression spring 96 is in each chamber 94 and urge the die plate 60 vertically upwardly, direction 80'. Pins 85 mate in and slide in bores in sleeves 88 for guiding the plate 60 during its displacement.

An array of triangular cutter dies 66 are fixed in corresponding bores 67 to the fixed plate in an array. The cutter dies form vortex generators 36, 36' (FIGURES 9-11) in the sheet 28 (FIGURE 6) in the process of forming an intermediate stage sheet 28'. As mentioned, the vortex generators are optional, depending upon a given implementation. The vortex generators 36, 36' are mirror image triangular tabs projecting from the plane of the sheet material of sheet 28' in alternating fashion, for example. The generators 36, 36' are arranged in parallel linear arrays in accordance with a given design configuration of the elements. The orientation, shape, number and configuration of the generators is in accordance with a given implementation, and are shown by way of example in the figures. For example, in FIGURE 5, element 1884 comprises two rows of vortex generators 46, 48 on one side of a corrugation 50 and two rows of generators 46', 48' on a second side of corrugation 50. The generators 46, 46' extend in one direction from the sheet material such as the single row of generators 38, FIGURE 8 and the generators 48, 48' extend in an opposite direction such as the single row of generators 40, FIGURE 8, on a corrugated sheet forming elements 24, 26 (FIGURE 3).

A vortex generator cutter 66 comprises a first cylindrical shank which fits in a bore 67 and may be press fitted fixedly attached in the bore 67 to the fixed plate 82. Extending from the first shank is a second shank, which is triangular in plan view. The cutter edge tapers at one side of the second shank and the edge tapers at a different taper at a second side of the second shank forming a tapering cutting surface having a further tapering edge. The three tapering cutting edges project above the fixed plate 82. The cutters are secured to the fixed plate 82 in the desired array for generating the vortex generators 36, 36', FIGURE 9. The second shanks and attached cutting edges extend above the fixed plate 82.

The movable lower die plate is slidably attached to the guide pins for vertical displacement. The movable lower plate is resiliently supported on springs 96. The movable plate 60 is normally in a vertical upper quiescent position. The movable plate 60 also has a plurality of bores 98 in an array, each bore accommodating a separate cutter die second shank. The cutting edges of the cutter dies 66 are just below the top surface

100 of the movable lower plate 60 in the normal upper quiescent position of the plate. The lowermost sheet material processing position of the movable lower plate permits the cutting edges to protrude above the movable plate top surface 100. The amount that the movable plate 60 is displaced is determined by the gap between the fixed and movable plates. The movable plate has four raised peripheral triangular mesa regions 102 relative to the top surface 100 containing the cutters. The raised regions 102 form the top surface 100 into a diamond shaped recess for receiving the microwire sheet material.

The movable plate 60 top surface 100 preferably has an array of upstanding linear ridges 62 extending therefrom. The ridges 62 are parallel and are equally spaced, with an array of cutter dies 66 aligned between adjacent ridges and with the cutter dies also linearly aligned in a direction normal to the ridges. The ridges 62 have a height h preferably about 0.4 mm or about 50% of the thickness of sheet 28. The ridges 62 have a thickness of preferably about 0.4 mm in this embodiment. The ridges have a preferably curved edge with parallel sides. However, the ridges may have other shapes such as rectangular or triangular in end view or transverse section.

The ridges 62 are used to form depressed groove surface features in the sheet material 28'. In particular, the ridges form foldline creases or channels 38 in the underside of the sheet 28', FIGURES 9-11. The ridges 62 penetrate into the sheet 28' an amount that just equals the height of the ridges above the top surface 100 of the movable plate 60. The broad surface of the sheet 28 just touches the movable die plate 60 surface 100 without any compression and deformation of the sheet 28 material in the region between the ridges 62 and the resulting crease foldline channels 38. The guide pins guide the movable plate 60 during its displacement.

In the alternative, the channels 38, FIGURES 9-11, may be formed by cutting devices (not shown). In this case the ridges on the movable die plate are optional. A second apparatus (not shown) holds the sheet material. Slots (not shown) in the second apparatus permits cutting devices to cut the channels in the material without compression distortion of the material.

The amount of travel of the movable die plate 60 is such that the cutting edges of the cutter dies 66 protrude above the surface 100 of the plate 60 a distance to penetrate through the sheet 28 and form the vortex generators 36, 36'. This travel amount is set by the gap between the fixed and movable die plates 82, 60.

The upper assembly 76, FIGURE 13, as shown in the aforementioned Application No. 09/181,186 and comprises a support base plate 104 having a recess 106 for receiving a mechanism (not shown) for selectively displacing the support plate 104 vertically, directions 80. A lever (not shown) is manually operated to displace the assembly 76 in directions 80. The base plate 104 slidably displaces vertically via bearing assemblies 78 along the posts 74. The assembly 76 normal quiescent position is in its uppermost position direction 80'.

Upper die plate 58 is a movably resiliently secured to upper base plate 104 for relative displacement in directions 80. An array of bores 68 are in the upper die plate 58. The bores are aligned vertically with the cutter dies 66 in the lower movable die plate. The bores 68 are dimensioned and located to receive the cutter dies 66 in the lower movable die plate. A second portion of bores similar to those bores in the upper movable plate are in the lower movable die plate 60 to receive cutter dies 64 fixed to the fixed upper support base plate 104. A second portion of upper cutter dies identical to the lower cutter dies are fixed to the relatively fixed upper plate 104. The cutter dies in the lower movable die plate 60 generate vortex generators 36, and the cutter dies in the upper plate 58 generate vortex generators 40, FIGURES 9-11. The cutter dies preferably penetrate into aligned bores of the opposing upper and lower movable die plates.

The upper die plate 58 is resiliently secured to the relatively fixed base plate 104 by bolt guide pins and mating compression springs 106. A further upper fixed plate 115 is fixed to base plate 104. An array of locating pins 107 and guide pins 108 and sleeves 110 identical to the respective pins and sleeves of the lower assembly locate and guide the movable upper die plate 58 relative to the upper plates 104 and 115. Locating pins and bolts 112, 114 are fixed to the upper fixed plate 104 for locating and securing the upper movable die plate 58 to the upper fixed plate 104.

The upper movable die plate 58 surface 116 has an array of ridges 63 (not visible in the figure due to the scale of the drawing) depending therefrom toward the lower movable die plate 60. The ridges 63 are linear and parallel and are equally spaced, the same spacing as ridges 62 of the lower plate 60, but alternating therewith vertically. These ridges 63 also form surface features, e.g., channels 42, FIGURE 11, in the sheet material 28 and are optional, in the alternative, should cutter devices (not shown) be used to cut the channels 42. An array of cutter dies 64 in the upper assembly 76 are aligned between adjacent ridges 63. The cutter dies 64 are also linearly aligned in a direction normal to the ridges of the upper movable plate 58. The ridges 63 of the upper plate have a height preferably about 0.4 mm or about 50% of the thickness of sheet 28, FIGURE 6. The ridges 63 have a thickness also of preferably about 0.4 mm in this embodiment. The ridges have a preferably curved edge with parallel sides. However, the ridges may have other shapes such as rectangular or triangular in end view or transverse section. The ridges of the lower and upper movable die plates are preferably are identical.

The ridges may have other dimensions, the heights and widths being given by way of example only for a given sheet material. The height may be set to minimize the degree of compression and the thickness set at a value to minimize the surface area magnitude of the sheet material 28 that is compressed.

The upper movable die plate 58 has four raised triangular peripheral mesa regions 118 relative to a medial surface 116. The raised regions form the medial surface into a diamond shaped recess for receiving the sheet of microwire mesh material. The raised regions 118 overly and are aligned with the raised regions 102 on lower movable die plate 60. The recesses of the upper and lower plates form a single chamber when the plates 58 and 60 abut at the raised regions. The chamber is sufficiently vertically thick such that the sheet 28 placed in the so formed combined chamber is not compressed by movable die plate recessed surfaces when closed to form the vortex generators 36, 40, FIGURE 11, and crease channels 38, 42 (FIGURE 11). The crease or foldline channels 42 are formed by the ridges 63 in the upper movable die plate 58. The medial surfaces containing the cutter dies barely touch the sheet 28' during the formation of the creases and vortex generators. The abutting regions of the upper and lower die plates limit the depth of penetration compression of the ridges 62 and 63 into the sheet 28 forming the creases 38, 42, FIGURE 11. This depth can be adjusted, if desired by providing adjustment screws (not shown). In the alternative, shims (not shown) may be placed in these mesa regions to also adjust the amount of penetration of the ridges into the sheet 28 to form the desired crease foldlines 38 and 42.

The mesa regions 102 and 118 of the lower and upper die plates are provided a height value above the plane of respective medial sheet material receiving chamber forming surfaces 100 and 116 to limit the amount of travel of the upper die plate 58 during its vertical displacement toward the lower die plate during formation of the sheet 28', FIGURE 11. This is so that the ridges of the die plates penetrate into the sheet 28' an amount that just equals the height of the ridges. That is, when the mesa regions abut, the depth of penetration of the ridges into the sheet 28' is limited and simultaneously precludes compressive deformation of the sheet 28' between the localized distortion regions at the crease foldlines.

In this way, the broad surface 52, FIGURES 9-11, of the sheet 28' just touches and lays against the movable die plate surfaces during formation of the foldline channels 38 and 42 and vortex generators 36 and 40. This contact is without any compression and deformation of the sheet 28' material in the region between the ridges and the foldline channels 38 and 42. The vortex generators 40 are in alternating rows with the vortex generators 36, alternating on opposite sides of the sheet 28', FIGURES 9-11. While one row of generators is disposed between adjacent foldline channels 38 and 42 which also alternate in vertical orientation as seen in FIGURE 11, more rows or more or fewer generators and rows may be provided according to a given implementation as seen in FIGURE 5 discussed above. The difference between the generators 40, 40' and 36, 36' is their relative orientation..

What is important is that the lower and upper die plates 58, 60 are set to just contact the sheet 28 when the foldline channels and vortex generators are fully formed. This eliminates possible deformation of the frangible mesh sheet 28' during such formation that might otherwise occur.

The sheet 28, FIGURE 6, is located in the fixtures of the ridge and vortex generating apparatus 69 by notches 30, 32 (FIGURE 6) and a pair of mating guide pins in the movable lower die plate. The notches 30, 32 and holes 34, FIGURE 6, in the sheet 28 are formed by other apparatus (not shown) during the cutting of the sheet 28 from larger sheets. No deformation of the sheet 28 occurs during such formation and cutting. Different size sheets 28 are formed for use in the converter section 6, FIGURES 1 and 2. This is illustrated in FIGURE 4 showing elements 24, 26 and other elements 54, 56 and so on of differing overall perimeter dimensions but otherwise formed of identical structures as shown in Figs, 9-11. Holes 34 permit an operator to properly orient the final formed sheets 28', FIGURE 10.

The sheets 28', FIGURES 9-10, are now ready for formation of the corrugations 27, FIGURES 3, 7 and 8. It should be understood that if only corrugations are desired, only creases 38 and 42 are formed in the sheet material. The corrugations 27 are in linear rows of preferably identical transverse widths, W, FIGURE 8. Preferably the corrugations 27 are at an angle α of about 90°, but may be at other angles as desired.

Each corrugation 27 is formed by a strip containing vortex generators 38, 38' in a row or vortex generators 40, 40' in another row. The generators 38 face in one direction and the generators 40 face in the opposite direction from the surface of the formed sheet 28", FIGURES 7 and 8.

Apparatus 120, FIGURES 15 and 16, as shown in more detail in the aforementioned copending Application Serial No. 09/181,186 incorporated by reference herein, forms the corrugations 27, FIGURES 7-8. The apparatus 120 forms the corrugations 27 without any permanent deformation of the sheet 28". Such deformation includes compression, creases, wrinkles or other deformation of the frangible material between any of the foldline channels 38 and 42, FIGURE 11.

The apparatus 120 includes an upper corrugation forming assembly 122 and a lower corrugation forming assembly 124. The upper and lower assemblies mate and cooperate to form the corrugations 27 in the sheet 28", FIGURE 6. A controller (not shown) pneumatically lifts the upper assembly vertically from lower assembly via block 151 and post. The controller releases the upper assembly 122 which falls by its weight via the force of gravity toward lower assembly 124. This falling action is dampened by a pneumatic action of a controller operator (a piston for example, not shown), which provides an air cushion.

The upper assembly 122 includes an upper plate 134 and has two sets 126 and 128 of mirror image identical corrugation forming respective parallel plate members 130, 132, slidably secured to and beneath plate 134 at opposite ends of the plate 134. The sets of members 130, 132 are coplanar with each other. There are five corrugation forming plate members 130, 132 in each set. Each member comprises a planar metal sheet, e.g., sheet 136, with linear right angle sheet material rigid fingers 138. A central finger 140 is fixed to plate 134 between the two sets 126 and 128 of fingers 142, 143, 144, 145 and 146 of one set 126 and 147-150 and 138 of the other set 128. All of the fingers are equally spaced from each other the same spacing as the foldline channels 42, FIGURE 11. Each finger depends from a corresponding different plate member of members 130 and 132 and is dimensioned to be received in a corresponding foldline channel 42 of the sheet 28', FIGURE 9.

Each finger extends transversely the same extent, e.g., completely across the corresponding corrugation forming member in and out of the drawing FIGURE 15. The fixed finger 147 also has the same transverse extent as the other fingers. Each finger, e.g., finger 147, has a planar sheet metal shank 152, FIGURE 18a, that tapers to its depending edge 154. The edge has a transverse width the same as that desired for the foldline channels 42, the edges 154 engaging the foldline channels 42. The fingers all depend that distance in which their depending edges 154 are all coplanar for engaging the foldline channels 42 uniformly in the same plane. The members 130 and 132 of each set slide horizontally relative to each other transversely the vertical direction in opposite directions 156.

One set 128 of fingers 147-150 and 138 engage the channels 42 on the right half of the sheet 28' FIGURE 11 and slide to the left in the drawing, directions 156, and the other set 126 of fingers engaging the left half channels 42 and slide to the right. Both sets of fingers are in their most separated position in the horizontal directions 156 with their respective fingers most distal to the central fixed finger 140. In this position the fingers are also the furthermost apart vertically. This is the open position.

When the fingers are closed so that the spacing there between is the smallest in directions 156 and vertically, this is the closed position which is shown in FIGURES 17 and 18.

In similar fashion as in the upper assembly 122 , the lower assembly 124 includes a lower plate 125 and two sets of five each of mirror image identical respective corrugation forming plate members 158 and 160 slidably secured to plate 125. Each set of members has a corresponding set of five fingers 158' and 160', respectively. One finger is attached to each plate member. The plate members 158 and 160 are respectively horizontally slidably secured relative to each other and coplanar with each other. There are five corrugation forming plate members in each lower assembly 124 set. These lower plate members 158 and 160 are substantially similar to and correspond to the plate members 130 and 132 of the upper assembly 122 in that each member comprises a planar metal sheet with respective linear right angle fingers 158' and 160' at an inner member edge closest to the central region between the plate members in directions 156

There is no central finger in the lower sets of fingers of assembly 124. All of the fingers 158' and 160' are equally spaced from each other the same spacing as the foldline channels 38, FIGURE 11, in the open position. Each finger extends upwardly from its plate member 158 or 160 and is dimensioned to be received in a corresponding foldline channel 38 of the sheet 28', FIGURE 11.

Each finger extends transversely the same extent in and out of the drawing figure, e.g., completely across the corresponding corrugation forming members 158 and 160 The fingers all extend vertically upwardly that distance in which their extended edges are all coplanar for engaging the sheet 28' foldline channels 38, FIGURE 11, uniformly in the same plane in the open position.

Projections (not shown) receive the respective end notches 30 and 32, FIGURES 6 and 9, of the sheet 28'. These projections align the foldline channels in the sheet 28' exactly over the edges 154 (FIGURE 18a) of the respective corresponding fingers of the lower finger assembly. In this way the fingers 158' and 160' each engage a corresponding foldline channel 38 of the sheet 28'. This also aligns the foldline channels 42 with the overlying fingers of the upper finger assembly 122.

The fingers of the upper assembly 122 are aligned vertically medially between the fingers of the lower assembly 124, FIGURE 15. This is to align the fingers with the corresponding foldline channels 38 and 42 in the sheet 28', FIGURES 9-11. The fingers of the upper and lower corrugation forming assemblies have sufficient height spacing so as to receive the vortex generators 36 and 40, FIGURE 11, there between during folding of the sheet 28'.

The members 158 and 160 of each set of fingers are selectively slid horizontally in opposite directions 156 relative to each other from the open position of FIGURE 15 to the closed position of FIGURE 17. A corrugation forming member finger set corresponding to set 128 can slide to the left in the drawing, FIGURE 11, and the other set, set 126, can slide to the right. Both sets are in the closed position of FIGURE 17 when the corrugations are fully formed. When the fingers are located so that the spacing there between is the greatest in the opposite horizontal and vertical directions, they are in the open position for engaging the channels 38, FIGURE 11.

A pair of levers 162 and 164 are connected by pivot pins 166 to the respective plates 134 and 125. Each of the lower and upper finger members 130, 136 and 158, 160 are slidably connected to the respective upper and lower base plates 134 and 125. The levers are interconnected by a crank mechanism (not shown) which comprises a set of links (not shown) connected to pivots 165.. The links are threaded and include an adjustment screw sleeve (not shown) with a nut at one end of the sleeve for adjustably receiving the threaded link and a ball socket at the sleeve other end attached to each lever and to a crank. Rotation of the links about their longitudinal axes provides threaded adjustment of the link length between the levers 162 and 164. A pneumatic motor (not shown) rotates the crank. A controller (not shown) selectively drives the motor.

A stop device (not shown) adjacent each lever limits the associated lever rotation. A linear array of five pins 168 and 170, respectively, are attached vertically to each lever 162 and 164 adjacent to its corresponding pivot 166. Each pin 168 or 170 passes through and engages a corresponding elongated hole of the respective corrugation forming finger members 130, 132 and 158, 160 of the upper assembly 122 and lower assembly 124. In addition, a cam pin 172 rides against a ramp surface 174 of a vertically inclined ramp in the upper plate 134 for permitting the upper fingers to simultaneously vertically displace toward the lower fingers as they horizontally displace toward each other to the position of FIGURE 17.

The crank mechanism (not shown) as it rotates in response to the motor simultaneously opens and closes the levers 162 and 164. Normally the levers are in the quiescent open position (FIGURE 15) so that the planes of the edges of the fingers of the upper and lower corrugation forming assemblies are spaced apart and just engaged with the foldline channels of the sheet 28'.

In the closed position, FIGURES 17 and 18, these planes of the finger edges are situated as depicted in FIGURE 17 forming an interdigitated relation among the fingers. This latter position is after the sheet 28' is folded as in FIGURE 7. These two different open and closed vertical positions are set by the cammed position of the camming pins 172 abutting the ramps 174.

The upper assembly 122 has bearings 176. Supports 178 support posts 180 are attached to bearings 176. Posts 180 are mounted on supports 182.

In operation, the upper assembly 122 is lifted by the piston operator (not shown) in response to the operation of the controller. The levers 162 and 164 are in the open position (FIGURE 15). The fingers of the corrugation forming member of the upper and lower sets 126, 128 and 158' and 160' , are spread apart the maximum amount corresponding to the spacing of the foldline channels 38 and 42 in the sheet 28' (FIGURE 11). The sheet 28' is then place over the fingers of the lower sets 158' and 160' engaged with the foldline channels 38 (FIGURE 11). This alignment is assisted by placing the notches 30 and 32, FIGURE 6, of the sheet 28' into the projections (not shown) at the distal end fingers of each set. At the same time the controller is not operating the lever motor so that the levers 162 and 164 remain open.

The controller opens a valve to the operator (not shown) to release a piston not shown. The piston permits the upper assembly 122 to drop by its own weight via gravity. When the assembly 122 reaches the lowermost position, the camming pin 172 comes to rest at the base of the ramp 174. At this time the fingers are all fully engaged in the corresponding foldline channels of the sheet 28'.

No compressive load is on the sheet 28' in the regions between the fingers or at the fingers because the spacing between the fingers is set to correspond exactly to the thickness of the sheet 28'. Thus no compressive deformation of the sheet 28' occurs at any location between the folds during the folding process.

At this time the controller starts the operation of the lever crank motor. The crank displaces the levers 162 and 164 to rotate toward one another to the position of FIGURE 18 from the position of FIGURE 16. As the levers rotate, the pins 168 and 170, FIGURE 16, also rotate about pins 166. Because the pins 168 and 170 are different radial distances from the levers, each pin will rotate a different angular extent about the pivot 166.

Each corrugation member of members 132, 130, 158 and 160 being engaged with a different pin 168 or 170 is translated in directions 156 by that corresponding pin toward the center of the finger assemblies. The members at the opposing sets move in opposing relation simultaneously toward one another. At the same time, the camming pins 172 ramp along the corresponding ramps 174 due to the weight of the upper assembly. This ramping action gradually displaces the upper assembly vertically toward the lower assembly until the fingers reach their interdigitated position of FIGURE 17.

This interdigitated movement folds the sheet 28' at the foldline channels to produce the corrugations of FIGURE 8. This folding action occurs with no compressive loading on the sheet outside the foldline channels. The spacing is such between the upper and lower assemblies during the folding action such that no contact is made on the sheet 28' in the regions between the foldline channels. This precludes damaging the previously formed vortex generators and the sheet 28' in this region.

Since the compressive loading only occurs at the previously deformed foldline channels, the porosity of the remaining portions of the sheet 28' remains without deleterious deformation.

The apparatus 120 may be provided with different finger corrugation forming members in the upper and lower assemblies 122 and 124 to accommodate different size sheets 28. The apparatus forms the corrugations 27, FIGURE 3, without any permanent deformation of the sheet 28'. Such deformation includes compression, creases, wrinkles or other deformation of the material between any of the foldline channels 38 and 42, FIGURE 11.

The charts of FIGURES 22-27 are self explanatory as to their contents. In FIGURE 22, a plot of Reynolds number vs. friction factor shows the effect of wave orientation of the corrugations of the mesh MEC material on the pressure drop. The increase in friction factor means that the pressure drop will increase as the channels are placed at a shallower angle to the flow, as defined in FIGURE 25. In addition, it can be seen that the porous material employed will exhibit a similar behavior as a flat sheet of the same thickness. Literature correlation describing the behavior as a flat sheet can be employed to describe the behavior of the MEC catalytic support mesh material. FIGURE 23 shows the measured pressure drops at the outlet of the converters at different flow rates of 5, 10 and 20 meters/second at 700 K. The calculation of the pressure drop as a function of the Reynolds number were computed for a 400 cpsi (channels per square inch) conventional catalytic converter monolith structure and packing employing the MEC material with corrugations at 60° relative orientation. The length of the converters was 0.15 m.

In FIGURE 26, a comparison is made between a 60° MEC structure and a standard 400 cpsi honeycomb, both of 150 mm length. Experimental data has been extrapolated to higher velocities based on the assumption of laminar flow in the honeycomb and turbulent flow in the MEC structure, which has been indicated in previous experiments. It is shown that the pressure drop of a 60° MEC packing is roughly the same as for a 400 cpsi honeycomb at a flow velocity (based on an empty tube) of 16 m/s, well above that corresponding to typical full load operation of an internal combustion engine. Thus, the 60° MEC should exhibit significantly lower pressure drop than a honeycomb at standard operating conditions.

Due to the presence of turbulence in the MEC structures, the gas-solid mass transfer at a given pressure drop is typically one order-of-magnitude greater than in the honeycomb. Thus, the catalyst surface area present in the MEC is more efficiently utilized than in the honeycomb, and thus greater conversion can be achieved for a given pressure drop with the MEC as indicated in FIGURE 24. Here, calculations are made of the conversion in MEC and standard honeycomb packings, using literature correlations for Sh (Focke, W.W. et al., "The Effect of Corrugation Inclination Angle on the Thermohydraulic Performance of Plate Heat Exchangers", *Int. J. Heat Mass Transfer*, **28 (8)**, 1469-1479, 1985) and experimental data from pressure drop measurements. Calculations were performed for a flow velocity of 10 m/s (based on empty tube) and a gas temperature of 700 K. In these calculations, it is assumed that the reactions are limited by the bulk mass transport in the main channels. Since it is assumed that the internal fiber surface area does not play a role here at steady state operation at high catalyst temperature, this is considered to be a rather conservation calculation. Due to the high turbulence intensity, it is interesting to see that the MEC more effectively converts the exhaust gas despite the much larger channel dimension.

A conventional honeycomb structure in actual tests on six automotive engines exhibits, for example, a pressure drop of 200 mbar and an MEC mesh device employing 60 degree corrugation angles exhibits a pressure drop of 120 mbar as an average of measured values in six automotive units employing a catalyst of 40g in the MEC mesh material and 90 g in the honeycomb. The tests were performed on 5 liter VH Porsche 928 engines at 5700 rpm. Operating temperature was 850°C.

The plot of FIGURE 26 shows the pressure drop per meter of module as a function of gas flow rate v (m/s) as measured for a 400 cell per square inch (cpsi) honeycomb and for 45 and 60 degree channel orientation MEC mesh material. For the honeycomb, the specific pressure drop is linear, which indicates that the flow in the channels is laminar. For the MEC mesh material structures the flow exhibits specific pressure drops that are non-linear for a large range of flow rates, indicating turbulent flow in the channels.

FIGURE 24 shows good correlation of 45 degree corrugation orientation of the MEC material pressure drop to that of honeycomb 400 cpsi ceramic structure.

FIGURE 27 shows that the corrugated MEC mesh material without vortex generators provides good conversion for a 150 mm length converter section 6, FIGURE 2, even though it has less mass, less catalyst material and exhibits turbulent flow as compared to the honeycomb material. This is unexpected based on conventional wisdom in this art. Typically a catalytic converter volume of about 750 ml corresponds to a combustion engine of about 1000 ccm cylinder capacity.

FIGURES 19-20 illustrate a further embodiment of a catalytic converter device structure formed of the MEC mesh sheet material. The converter catalyst carrier device 186 is shown square but in practice may be circular cylindrical to fit within the section 6 housing 4, FIGURE 2. The elements of the device 186 in this case are of different sizes to accommodate the cylindrical housing as discussed above in connection with the element of Figs 2-4. The device 186 must have vortex generators which create turbulence in parallel channels rather as compared to the zig-zagging crossed channels of the adjacent elements of the FIGURE 2 embodiment. The parallel channels of the device 186 are all tortuous and do not provide parallel gas flow paths.

In FIGURE 19, device 186 comprises an array of identical catalyst carrier device elements 188, 190, 192 and 194 which are part of a larger array. In practice more or fewer elements may be used according to a given implementation. For example, device 186 may include more than nine such elements. Also, the elements are shown in a square array. This configuration is also by way of illustration. In practice, the array may also be rectangular, circular or any other desired shape in a plan view in the flow direction 16, of the converter carrier device of FIGURE 1. Preferably, the array is circular as in FIGURES 2 and 3.

The elements conform to the housing 4 interior shape to fill the interior volume of section 6, FIGURE 1. Each element 188, 190, 192 and 194 is formed from an identical substrate blank of porous metallic MEC microfibers in a manner similar to that as described above herein. Reference is made to the aforementioned PCT Application No. PCT/US98/27699 for a more detailed description of the elements.

Each element includes a plurality of right angle corners formed at fold lines such as fold lines 196. A first top row 197 of identical tabs 198 including a first top row of identical corresponding through square holes 200 are in each element 188, 190, 192 and 194. The tabs 198 are in channels 210, 212, 214 and so on of each element. These tabs extend in and out of the drawing FIGURE 21 and toward the top and bottom of the figure in FIGURE 20 in opposite directions. Each element has a tab 198 and hole 200 in the first row 197 disposed in channel wall 209 and walls parallel to wall 209 such as walls 211. Tabs 198 form vortex generators. The holes 200 of each row are adjacent the tab tips 222 of that row, FIGURE 21. The tabs 198 are each located in a channel such as channels 210, 212 and 214. The tabs in adjacent opposite facing channels such as channels 210 and 212 face in corresponding opposite directions in those channels. In FIGURE 20, the tab tips 222 are shown oriented facing toward the top and bottom of the drawing figure in opposite directions for the tabs attached to parallel walls 209, 230 and so on. Reference numerals in these figures with primes and multiple primes represent identical parts in corresponding different rows.

Each tab 198 has a first edge 216, FIGURE 21, coextensive with a channel corner formed by a fold line in the sheet material, such as corners 202, 204, 208, and so on. Each tab 198 has a second edge 218 which emanates at a second channel corner 220 formed by a fold line and inclined relative to the corners 202 and 220 terminating at a distal end segment tip 222. The edges 216 and 218 of each tap 198 terminate at one tab end at fold lines 226 lying in plane 228. The tip 222 has an edge that is coextensive with edge 216, both of which edges are straight and lie on a channel corner at a fold line, such as corner 230, FIGURES 20 and 21.

The tab 198 edges 216 and 218 both emanate from a common transverse plane 228, FIGURE 21, as do all of the edges of the tabs 198 of row 197. Each tip 222, which is optional, preferably is square or rectangular, but may be other shapes as well according to a given implementation. Holes 200 are slightly larger than the tips 222 so as to permit a tip 222 to pass there through as seen by tip 222''''' at the bottom of FIGURE 19 and as shown by the projection of the tips 222 from each channel in FIGURE 20. All of the tabs 198 and holes 200 of row 197 are aligned in a row that is parallel to plane 228.

A second row 199 of identical tabs 198' and square holes 200' are formed in each element. The tabs and holes of row 199 are oriented at right angles to the orientation of the tabs and holes of row 197. These tabs and holes extend from and are in alternating channel walls also alternating with respect to the walls from which tabs 198 and holes 200 extend and are located in. For example, tabs 198' of row 199 are in channel side walls 213 and 215 and so on at right angles to walls 209 and 211. These tabs 198' extend in a direction to the right and left in the drawing FIGURES 19, 20 and 21.

Additional rows 201 and 205 of tabs and holes, FIGURE 21, with corresponding primed reference numerals are aligned parallel to row 197, are oriented in the same direction and are aligned in the same channels such as channels 210 and 212 and so on. For example, tabs 198" are in row 201, and tabs 198"" are in row 205. An additional bottom row 207 of tabs 198""' and holes 200""' are aligned in a row parallel to row 199, are oriented in the same direction and are aligned in the same channels. Additional intermediate row 203 of tabs 198"' and holes 200"' are aligned in a row parallel to the other rows, are oriented in the opposite direction as the tabs of rows 199 and 207 and are aligned in the same channels. The row 199 is between rows 197 and 201 and row 203 is between row 201 and 205. More or fewer such rows and channels may be provided according to a given implementation. The resulting channels in FIGURE 19 are square in plan view as shown in FIGURE 20 with the adjacent elements enclosing the channels.

The element 188, as are all of the elements, is formed by bending the blank substrate material along the fold lines and so on in alternating opposite directions. This forms the blank into a channeled quasi-corrugated structure employing tooling similar to that described above in connection with FIGURES 13 and 14. The device 186 has identical preferably square in plan view channels. The channels are formed in the different elements and face in alternating opposite directions in each element. Thus channels 210 and 214 and so on formed by element 188 face toward the viewer in FIGURE 21 and channels 212, 217 and so on face in the opposite direction away from the viewer into the drawing figure. All of the elements of catalyst carrier device 186 are constructed similarly with identical channels.

The tabs 198 in row 197 are bent out of the plane of the figure in opposite directions in alternate but parallel walls forming the channels. Thus the tabs of channels 210, 214 and so on are bent in the same direction, e.g., out of the drawing plane toward the viewer, FIGURE 21. The tabs in channels 212 and 217 are bent in the opposite direction out of the plane of the figure away from the viewer. A similar alternating bending direction sequence is provided the tabs of the lateral side walls of each channel such as tabs 198' and 198 "' and 198""'.

The tabs in plan view along the channel 210 length, from the top of the figure to the bottom, in FIGURES 19 and 21, interrupt each of the channels, as best seen in FIGURE 20, and thus form a solely tortuous path through each of the channels for the gases. No open continuous linear fluid path is available along any of the channel lengths. The tortuous blocking interruption of the linear channels by the tabs is best seen in FIGURE 20. Each channel has an uppermost tab 198, FIGURE 21, a next lower tab 198' and then a still next lower tab 198" and so on. As shown in FIGURE 20, a portion of each of the tabs overlies a portion of the other tabs in the channel. In the plan view of FIGURE 20, each channel is totally blocked by the tabs, as are all of the channels, in the direction normal to the plane of the figure. Thus no linear fluid path is present along the length of each channel 66 presenting only turbulence to the gas flow. Also, each tab in a given channel has one edge thereof adjacent to and abutting a channel wall.

The holes 200 each receive a tip 222 of a corresponding tab. For example, in FIGURES 19 and 20, a tip 222 of each tab extends through a hole 222 into adjacent channel. The tab tips thus extend through the corresponding holes 200 of the channel thereof into a next adjacent channel for all of the tabs.

Thus, the tabs of each element are employed for substantially cooperating with only the channels of that element to provide the desired tortuous fluid paths. The tabs of each element are substantially independent of the channels of the adjacent elements. This is notwithstanding that the tips 222 each pass through the hole 200 of the common wall of an adjacent element into the adjacent element channel. For example, a tip 222 passes through the common channel wall 232, FIGURE 19, of elements 190 and 192.

The tabs are bent away partially or not at all from the plane of the blank material for those walls of the channels next adjacent to the housing, e.g., housing 4 FIGURE 2, which walls that may abut or are next to the housing. Thus the tabs at the edges of the structure array may not extend beyond the structure so as to not interfere with the housing interior walls. Holes 200 in these edge surfaces are also not necessary.

The holes and openings in the walls created by the formation of the tabs provide fluid communication among the channels in directions transverse the fluid flow direction of the device 186. Of course, the openings in the sheet material formed by bending the tabs out of the plane of the sheet material provide major fluid communication between the channels in a transverse direction. These openings and holes 200 are formed in all four walls of each interior channel.

The elements may be secured together by spot welding the corners of the channels at the upper and bottom array ends. The welding is optional as the elements may be dimensioned to fit closely into the converter housing section 6, FIGURE 2, and held in place to the housing by friction or by other means (not shown) such as fasteners or the like. The elements may also be secured together first by any convenient fastening devices or bonding medium.

It should be understood that the number of tabs in a channel and their relative orientation is given by way of example. For example, only one set of tabs, such as tabs 198''' extends from the corresponding lateral side wall into a channel. In practice, more than one tab could extend from each side wall into each channel. Also, the sequence of tab orientation, e.g., which tabs extend from a given wall in a longitudinal sequence along the channel length, is also by way of example, as other orientations may be used according to a given need.

Further, the length of the elements and the catalyst carrier device array channels may vary from that shown. The channel lengths are determined by the factors involved for a given implementation as determined by the gases, volumes and pressures thereof, flow rates, and other related parameters required to perform the desired conversion process.

In operation, the mesh material provides high surface area (area per unit volume), relatively uniform distribution of gases throughout the converter, and uniform contacting of the involved surfaces. The microfiber substrate material forming the device 186 provides enhanced contact of the catalyst surfaces through its surface texture and the relatively large interstices between the fibers.

The preferred micro fiber mesh material which, e.g., can be provided by the sintered fiber sheet material of the catalyst carrier device elements provides relatively high catalyst surface area with optimum access to the catalyst by the gases. The fibers are coated with the catalyst and/or the catalyst particles are trapped in the porous network of the sheet material. Where relatively rapid chemical reactions are employed, utilization of the internal surface area of the porous material is dependent upon the rate of transport of the gases to these surfaces. The mass transport is faster in the case of driven forced flow (convection) than by mere concentration of gradients (diffusion). The intended optimum device, therefore, provides optimum cross flow of the fluids with low pressure drop there across.

To optimize conversion, the pressure drop is maintained relatively low as discussed above. This is provided by relatively high void space per unit volume, low friction (good aerodynamic characteristics) and prevention of undesirable stagnant gas pockets.

It will occur to one of ordinary skill that various modifications may be made to the disclosed embodiments which are given by way of illustration and not limitation. It is intended that the appended claims define the invention.

What is claimed is:

1. A combustion engine catalytic converter for reacting with certain components of engine exhaust gas flowing in a given direction comprising:

a housing having an engine exhaust gas receiving chamber;

a porous material in the chamber having pores exhibiting a plurality of interstices in fluid communication with each other and externally the material, said received gas for flowing externally and within said interstices; and

a catalyst secured to the material for reacting with said gas components as the received gas flows through the chamber and through the interstices.

2. The converter of claim 1 wherein the porous material comprises sintered metal fibers.

3. The converter of claim 1 wherein the porous material comprises sheet material.

4. The converter of claim 1 wherein the catalyst is secured to the material within said interstices.

5. The converter of claim 3 wherein the sheet material includes a plurality of vortex generators.

6. The converter of claim 3 wherein the sheet material is corrugated, the corrugations of each sheet being parallel, the corrugations of adjacent sheets being inclined relative to each other, the corrugations of adjacent sheets forming fluid channels in fluid communication with each other .

7. The converter of claim 6 wherein the corrugations form gas flow channels oriented within a range of 0° to about a 75° angle of inclination relative to the given direction.

8. The converter of claim 1 wherein the porous material is formed into a plurality of sheets, each sheet having a plurality of parallel channels, means for coupling the plurality of sheets with their channels parallel, each sheet including a plurality of vortex generators extending into each said channel for forming each said channel into a substantially tortuous fluid path for said gas flowing in said given direction.

9. The converter of claim 1 wherein the material is about at least 85% voids.

10. The converter of claim 2 wherein the fibers are about 1-50 microns in diameter.

11. A combustion engine catalytic converter for reacting with certain components of engine exhaust gas flowing in a given direction comprising:

a housing having an exhaust gas receiving chamber;

a plurality of sheets of material in the chamber, each sheet including a plurality of corrugations, the corrugations being inclined to the given direction to create turbulence in the flowing gas in said chamber; and

a catalyst secured to the material for reacting with said gas components.

12. The converter of claim 11 wherein the corrugations are each defined by planar side walls lying in planes oriented at an angle relative to each other.

13. The converter of claim 12 wherein the corrugation side walls subtend an angle of about 30-150° relative to each other.

14. The converter of claim 12 wherein the longitudinal length of the corrugations of adjacent sheets are oriented at an angle relative to each other, the corrugations of adjacent sheets forming fluid channels in fluid communication with each other.

15. The converter of claim 14 wherein the corrugations are oriented within a range of 0° to about a 75° angle of inclination relative to the given direction.

16 The converter of claim 11 wherein each said sheet comprises a porous material having pores exhibiting a plurality of interstices and said catalyst is secured to the material within and externally the interstices for reacting with said gas components as the gas flows through the chamber from the engine.

17. The converter of claim 16 wherein the porous material comprises sintered metal fibers.

18. The converter of claim 11 wherein each of the sheets of material includes a plurality of vortex generators.

19. The converter of claim 18 wherein the vortex generators comprise tabs bent from the plane of the associated sheet material forming through holes in the sheet material.

20. A combustion engine catalytic converter for reacting with certain components of engine exhaust gas, the engine exhibiting reduced power output in the presence of back pressure of at least a certain value from said gas, said converter comprising:

a housing having a gas receiving chamber; and

catalyst means in the chamber for reacting with said gas components and arranged to create a turbulent flow of said gas through the chamber while maintaining the pressure drop through the chamber of a value sufficiently low to create a back pressure to said engine of less than said certain value.

21. The converter of claim 20 wherein the catalyst means comprises a catalyst carrier comprising sheet material forming gas flow channels and means for creating turbulence of said gas flowing in said channels.

22. The converter of claim 20 wherein the catalyst means comprises a catalyst carrier comprising a plurality of contiguous sheets of sheet material each sheet formed into a plurality of linear corrugations forming gas flow channels, and means for creating turbulent gas flow in said channels, the corrugations of adjacent sheets forming fluid channels in fluid communication with each other.

23. The converter of claim 22 wherein the means for creating turbulent gas flow comprises vortex generators in each said channel for forming substantially tortuous gas flow paths through said channels.

24. The converter of claim 22 wherein the means for creating turbulent gas flow comprises orienting the channels of adjacent sheets in different angles relative to each other and providing fluid communication between the channels of said adjacent sheets.

25. The converter of claim 24 wherein the corrugations form gas flow channels oriented within a range of 0° to about a 75° angle of inclination relative to the given direction.

26. The converter of claim 21 wherein the carrier material is porous material comprising sintered metal fibers.

27. The converter of claim 22 wherein the carrier material is porous material comprising sintered metal fibers.

28. The converter of claim 22 wherein the corrugations form gas flow channels oriented within a range of 0° to about a 75° angle of inclination relative to the given direction.

29. The converter of claim 27 wherein the material is about at least 85% voids.

30. A combustion engine catalytic converter for reacting with certain components of engine exhaust gas comprising:

a housing having a gas receiving chamber for receiving said exhaust gas; and

a carrier including a catalyst in the chamber, the catalyst for reacting with said received gas components in said chamber when the catalyst is at a certain temperature, said carrier exhibiting a sufficiently low thermal mass with respect to the thermal energy transmitted to the carrier by said gas in thermal contact therewith at at least said certain temperature so that the carrier exhibits said certain temperature in less than about 1 minute.

31. The converter of claim 30 wherein the carrier comprises a porous material having pores exhibiting a plurality of interstices through which said gas may flow.

32. The converter of claim 31 wherein the catalyst is secured to the material within and externally the interstices for reacting with said gas components as the gas flows through the chamber and through the interstices from the engine.

33. The converter of claim 30 wherein the material is porous sheet material.

34. The converter of claim 33 wherein the sheet material includes a plurality of vortex generators.

35. The converter of claim 33 wherein the sheet material is corrugated, the corrugations of each sheet being parallel, the corrugations of adjacent sheets being inclined relative to each other, the corrugations of adjacent sheets forming fluid channels in fluid communication with each other.

36. The converter of claim 33 wherein the material is about at least 85% voids.

37. The converter of claim 30 wherein the carrier has a Nusselt number of at least about 15.

38. The converter of claim 2 wherein catalyst is secured to the metal fibers in the interstices and the fibers and catalyst are heated in a reducing atmosphere such that fibers attach to each other by sintering at contact points within the porous material.

39. The converter of claim 2 wherein the metal fibers and catalyst are heated by flowing an electric current through the material in a flowing gas atmosphere so as to cause the fibers to attach to each other at fiber contact points within the porous material.

40. The converter of claim 2 wherein the fibers and the catalyst are heated by flowing an electric current through the material to efficiently heat up the structure to react at a certain temperature with the exhaust gas.

41. The converter of claim 38 wherein the reducing atmosphere is hydrogen.

FIG. 1

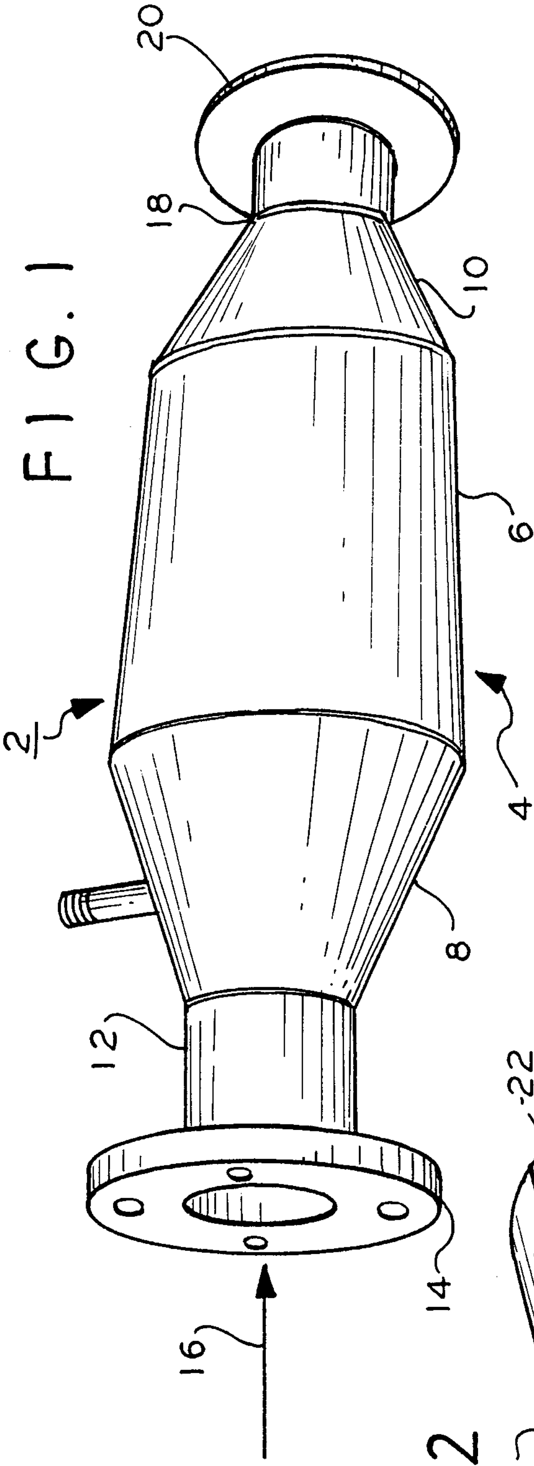


FIG. 2

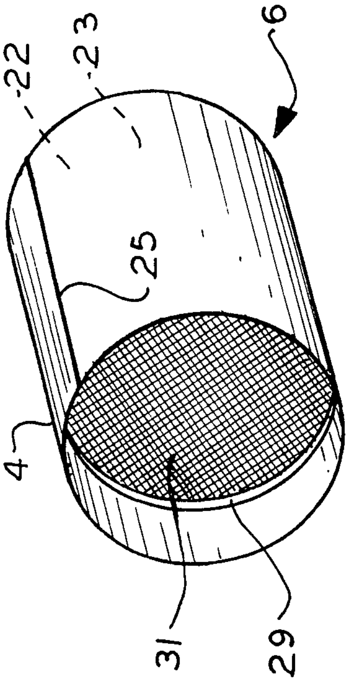


FIG. 3

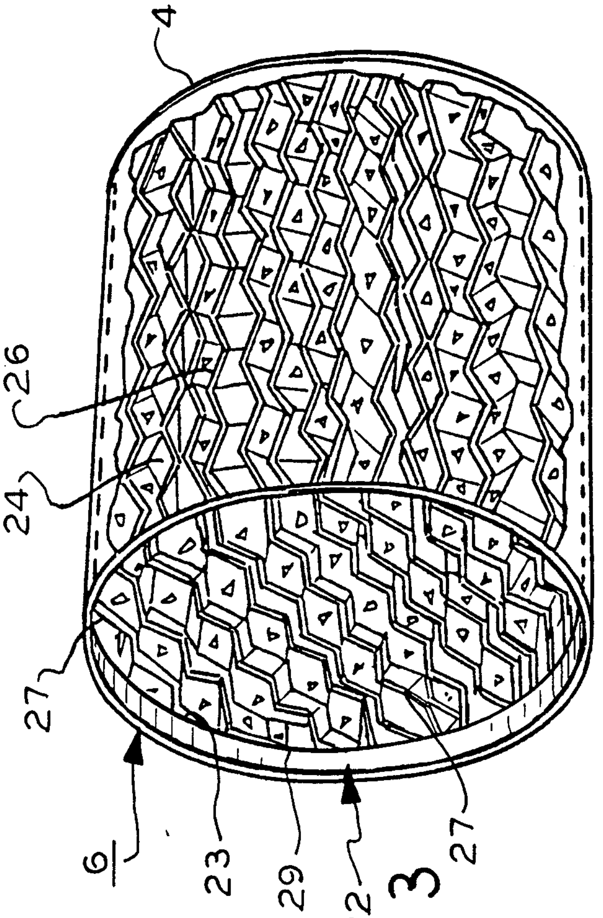


FIG. 4

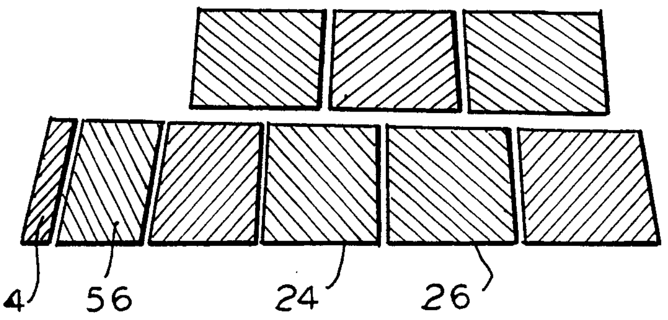


FIG. 5

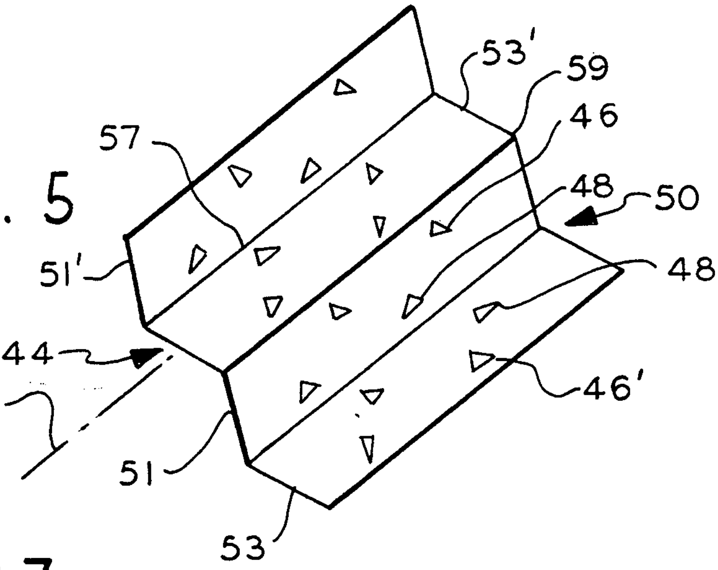


FIG. 27

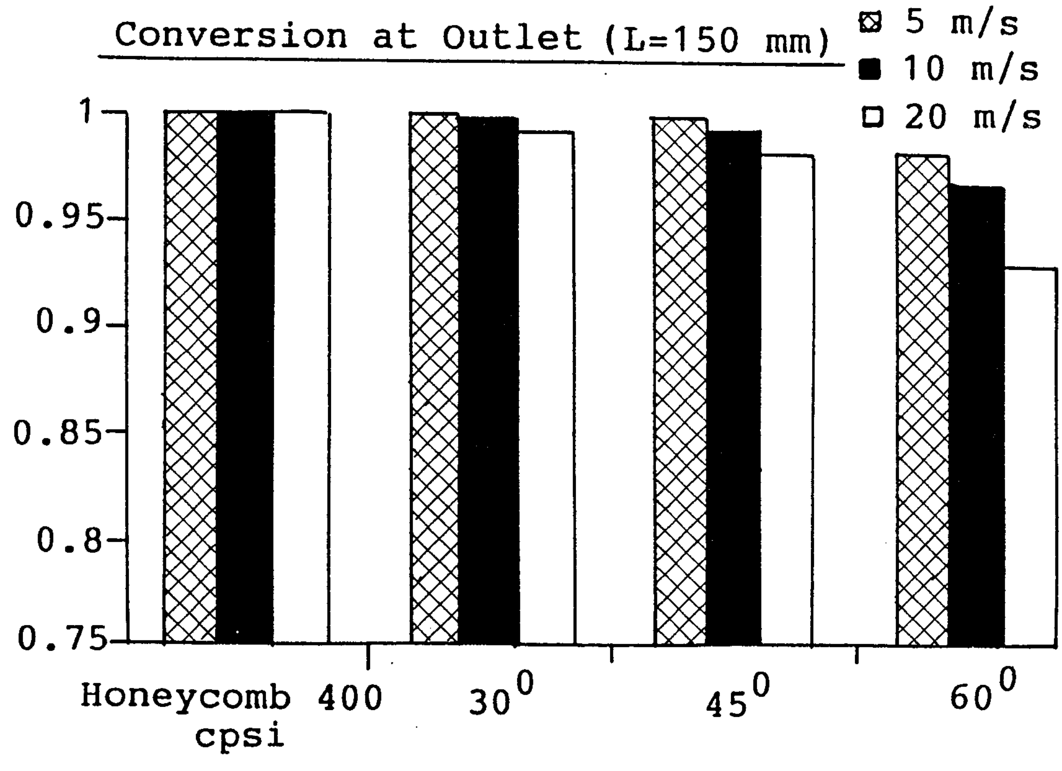
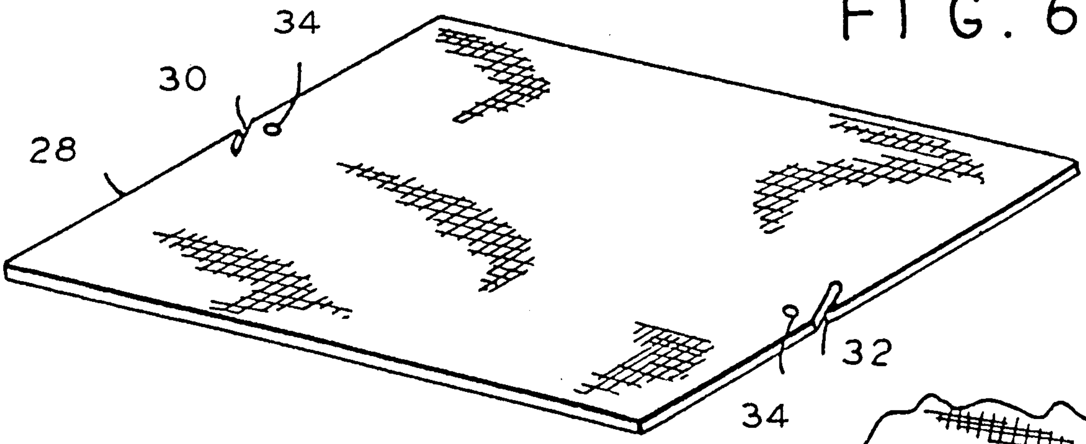


FIG. 6



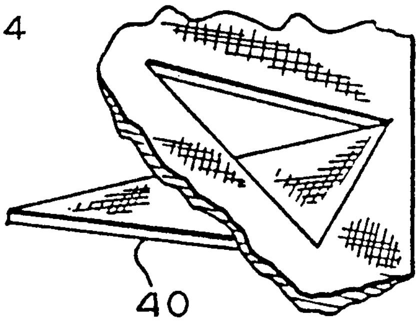


FIG. 7a

FIG. 7

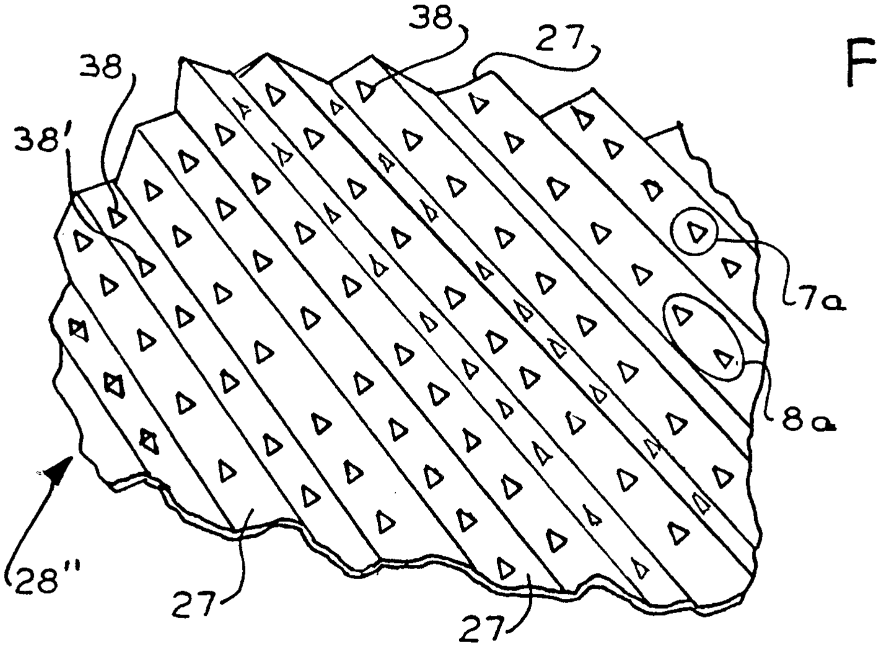


FIG. 8a

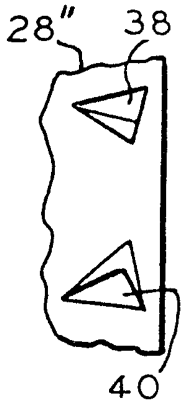


FIG. 8

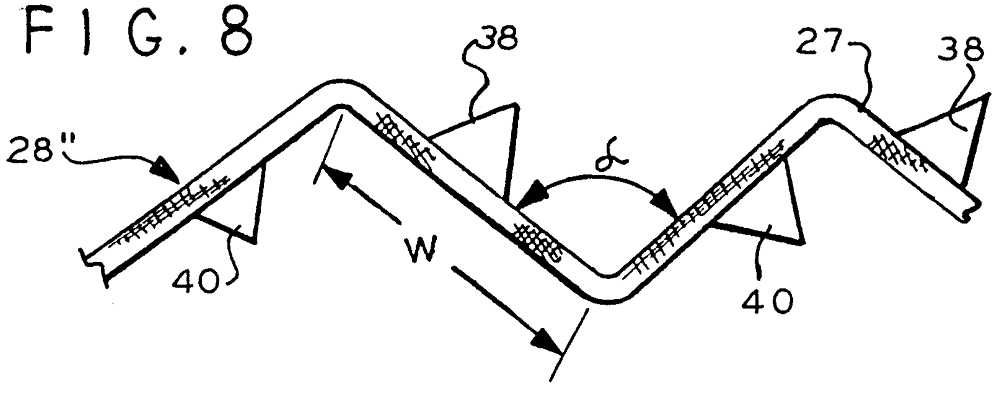


FIG. 9

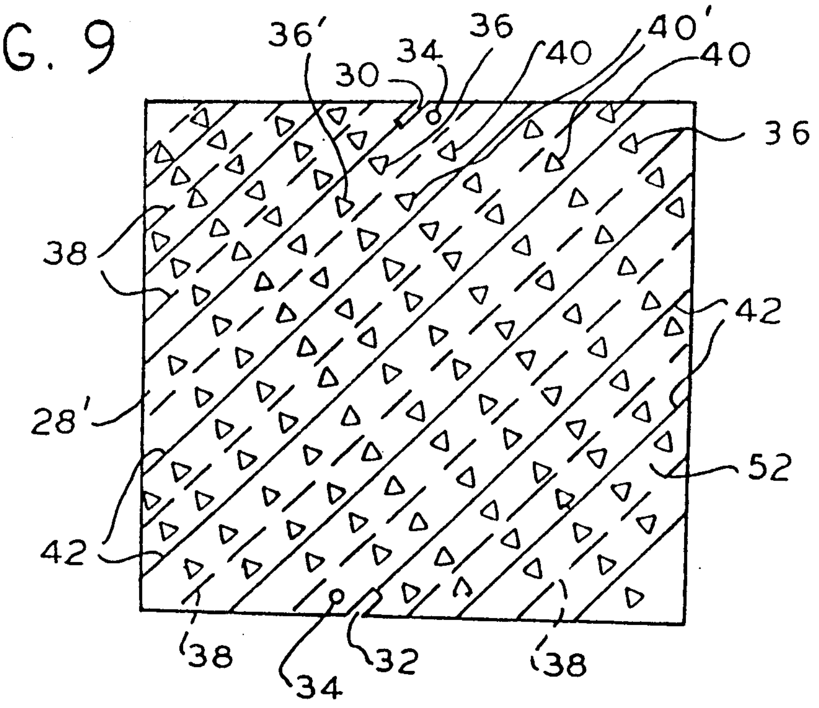
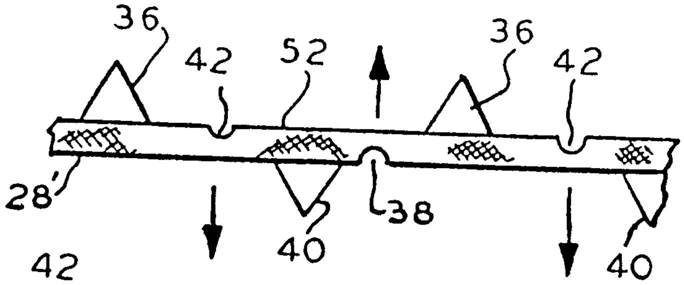


FIG. 11



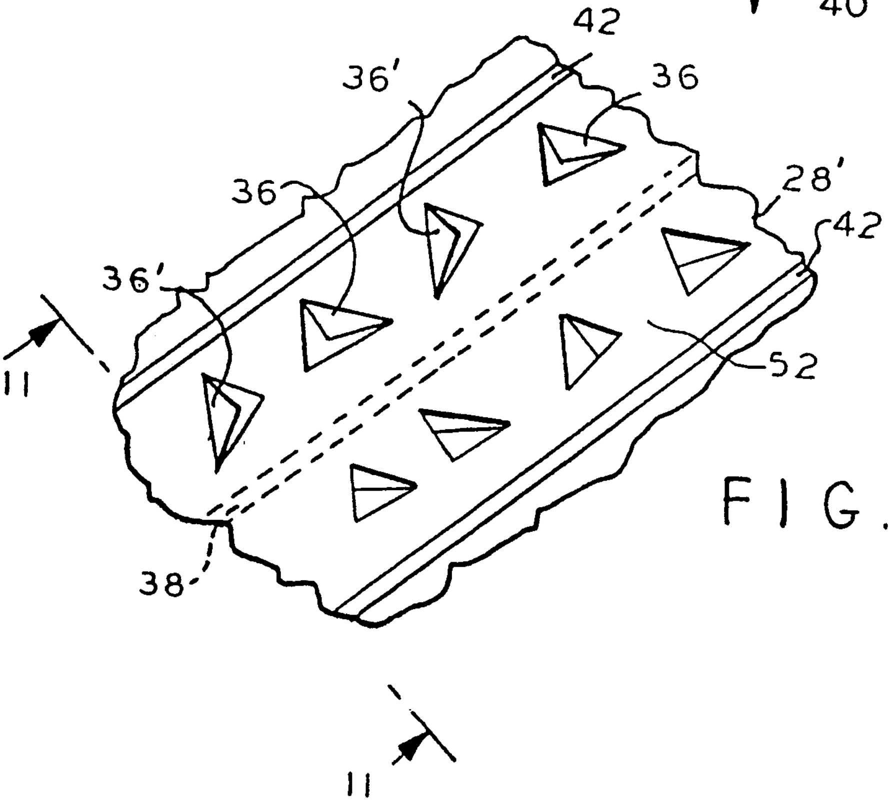


FIG. 10

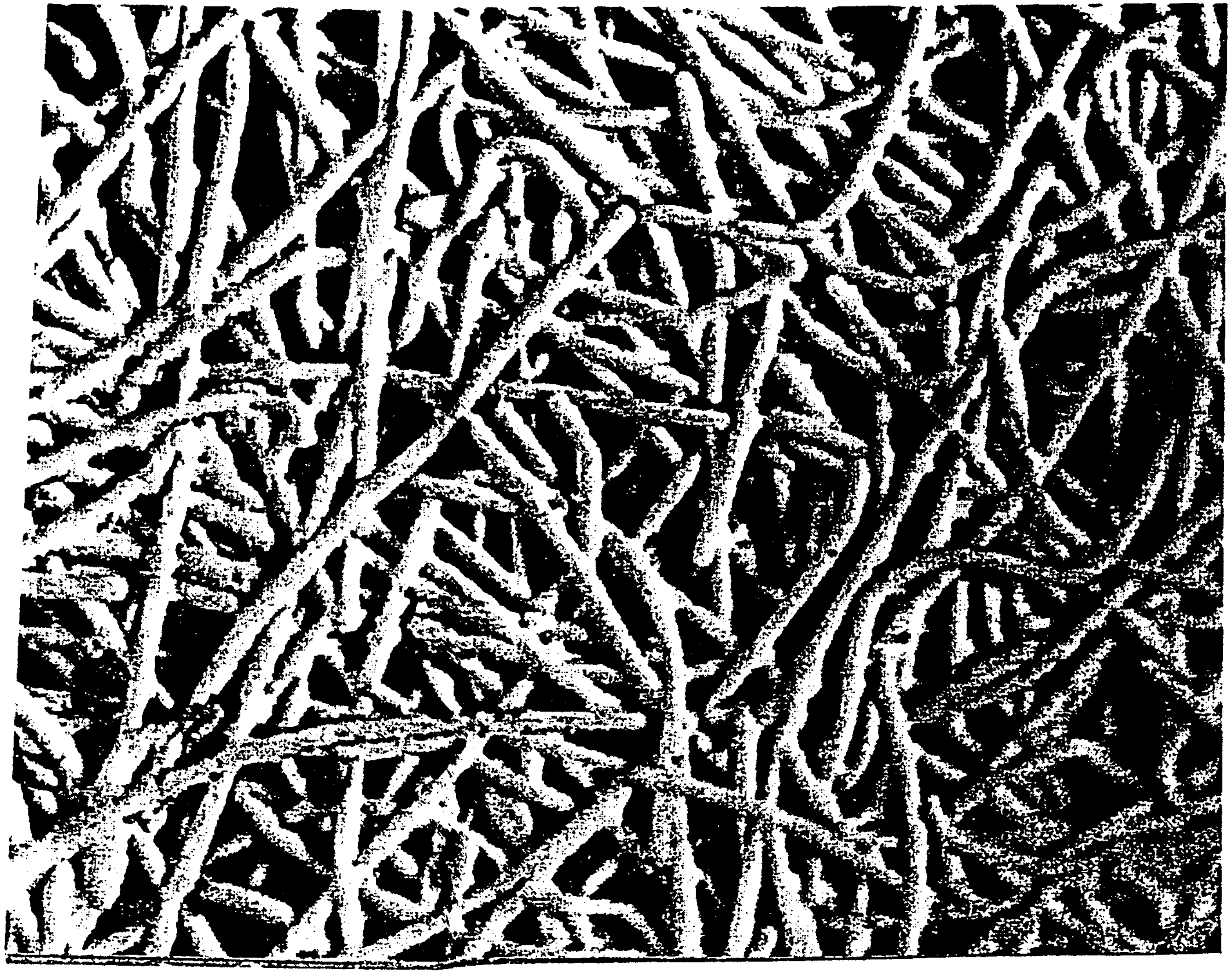
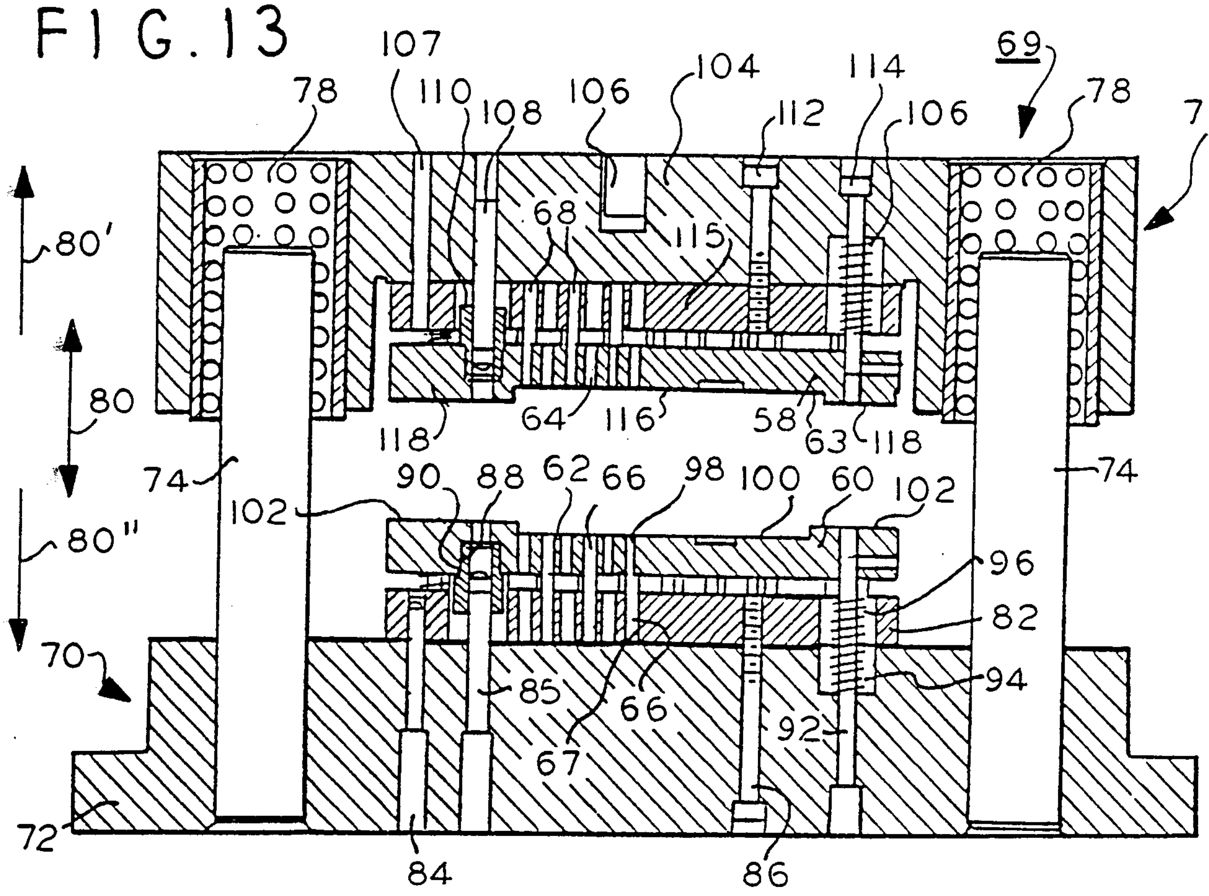


FIG. 12

FIG.13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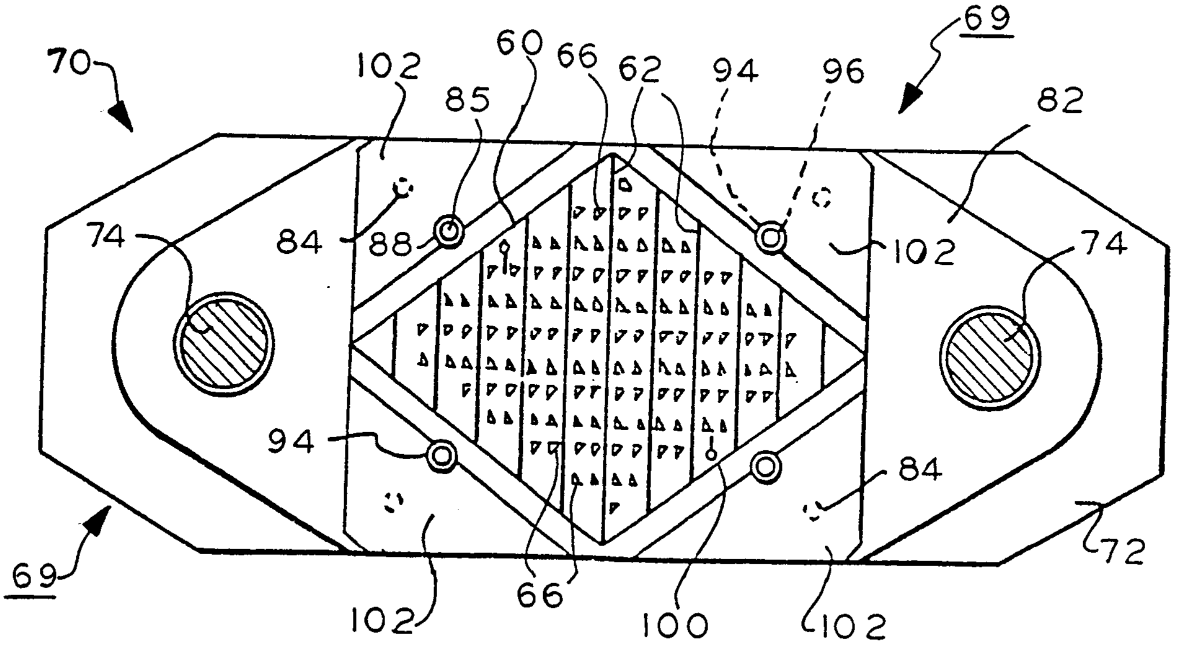
92
72
84
86

FIG.14


70
102
60
66
62
94
96
69
85
82
74
84
88
102
74
94
84
69
102
66
100
102
72

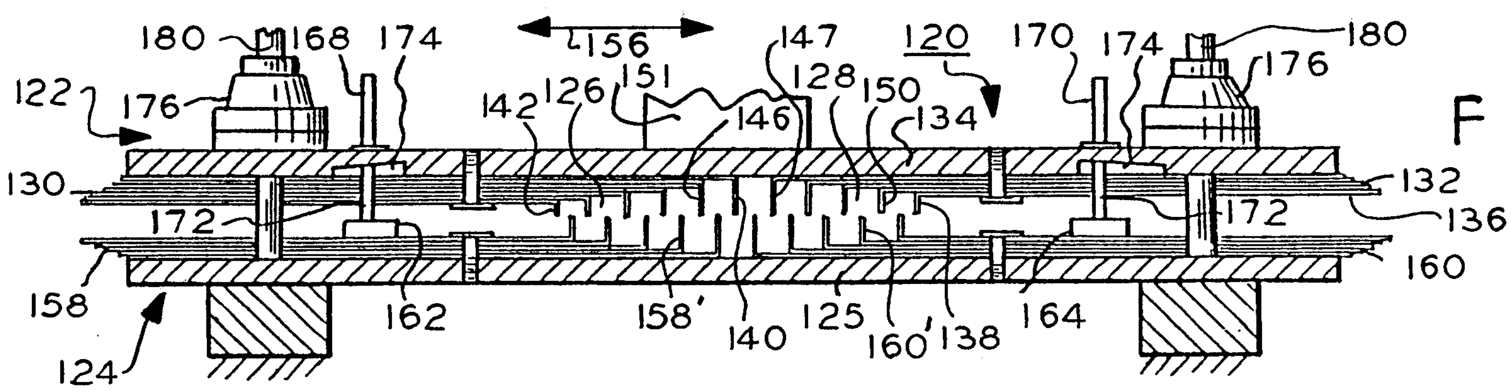

180
168
174
156
147
120
170
174
180
122
176
151
126
142
146
128
150
134
176
130
132
172
172
136
158
162
158'
140
125
160'
138
164
160
124

FIG. 15

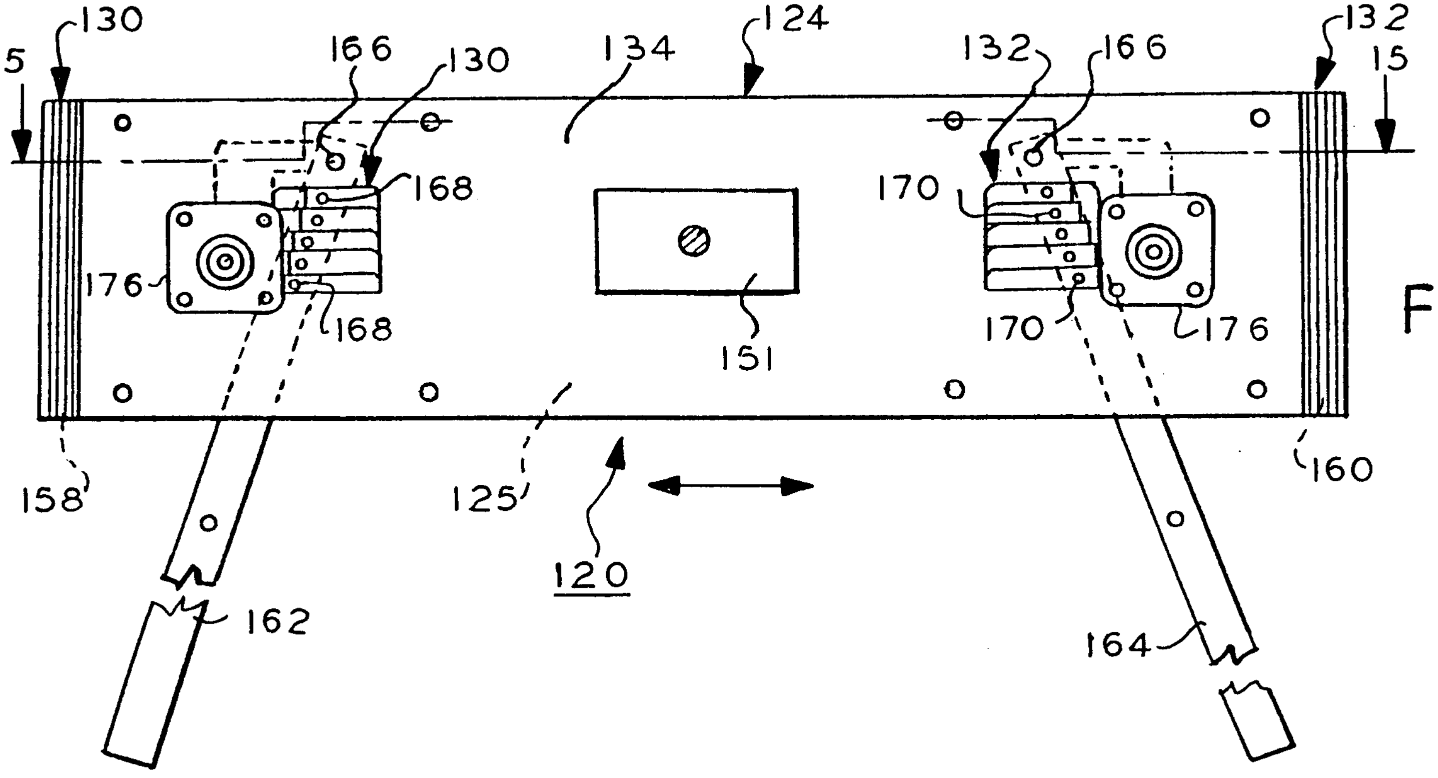

130
15
166
130
134
124
132
166
132
15
168
170
176
168
151
170
176
158
125'
120
160
162
164

FIG. 16

FIG. 17

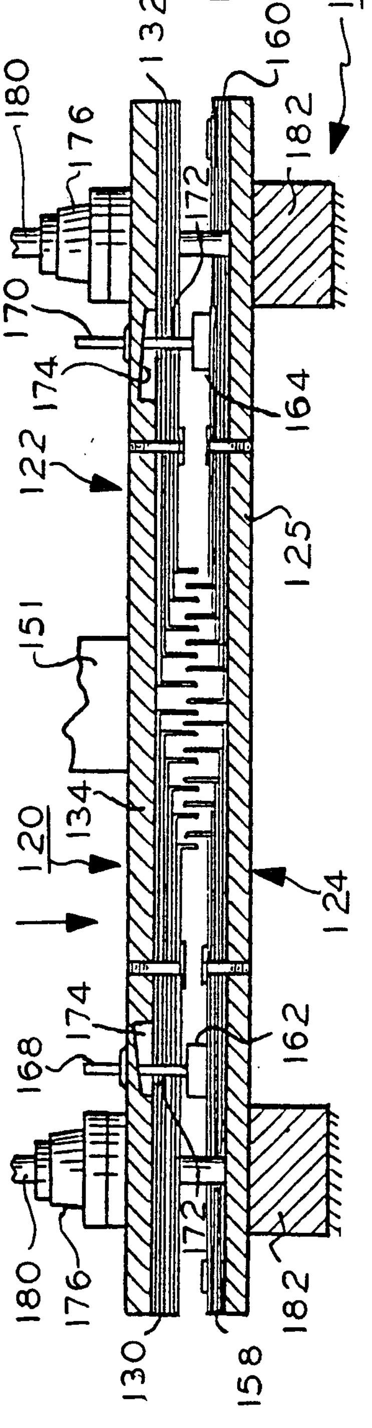


FIG. 18

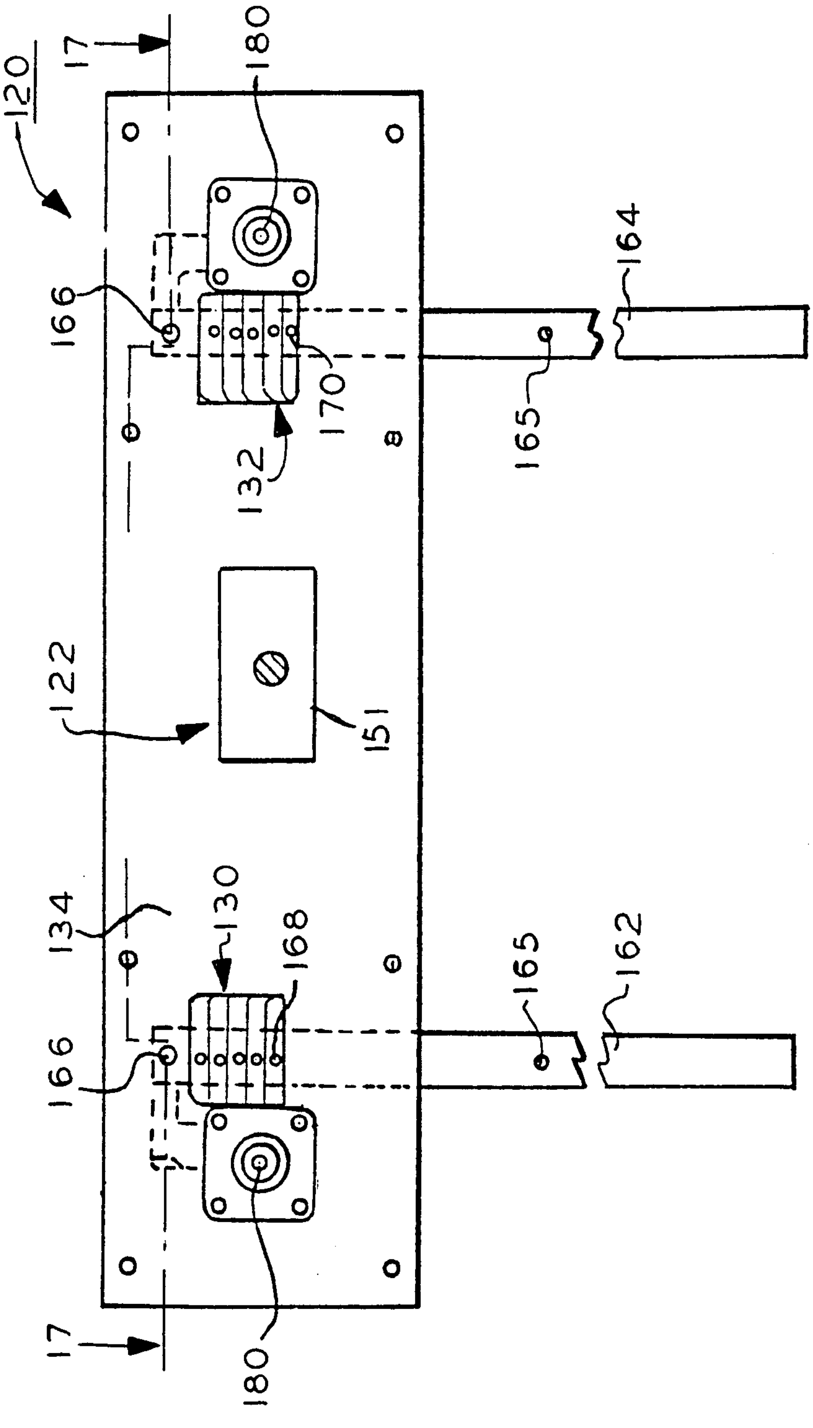
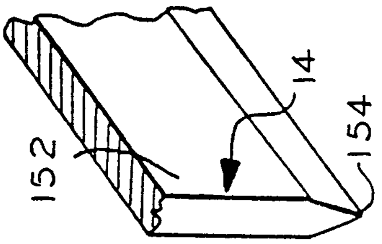


FIG. 18a



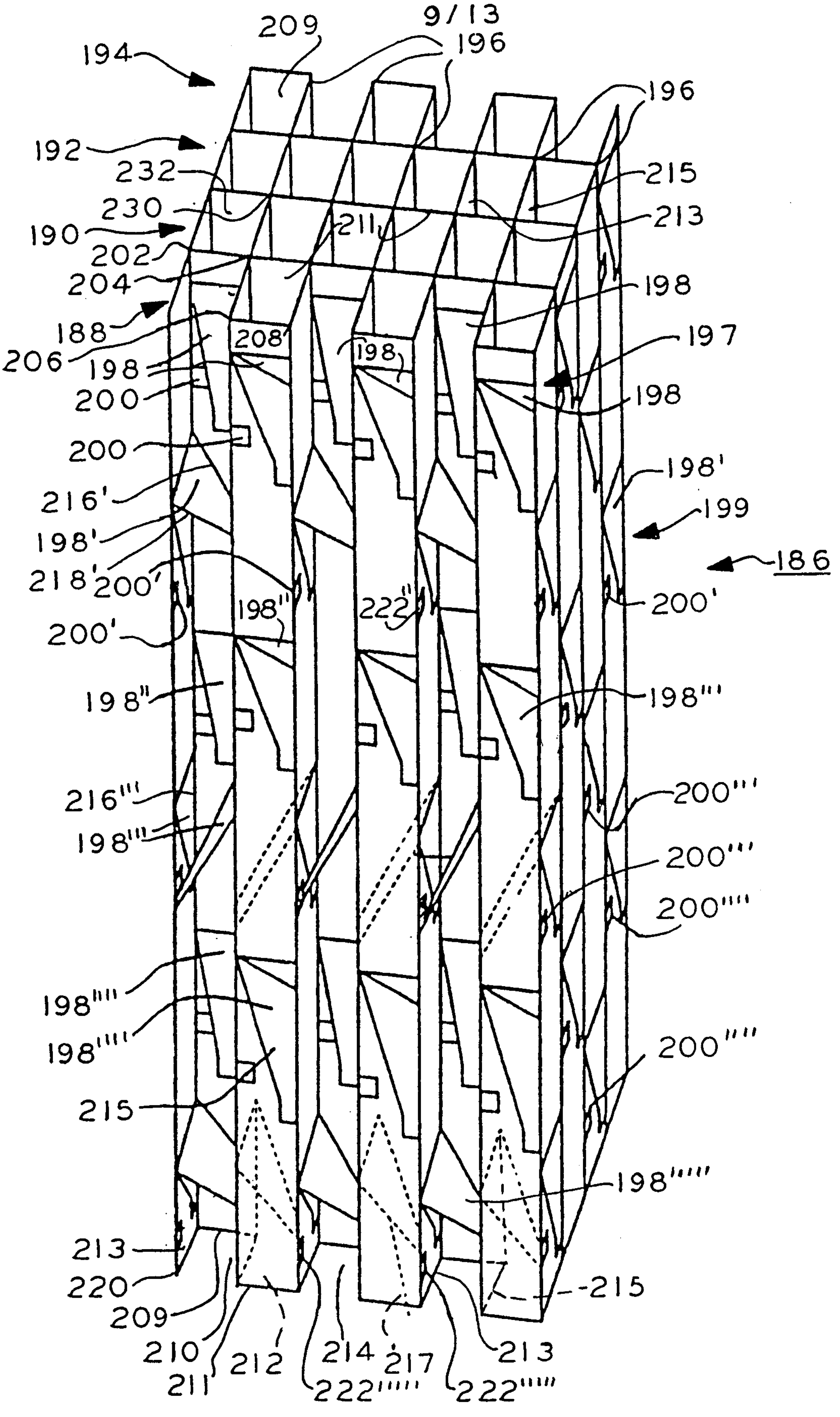

209
196
194
196
192
232
215
230
213
190
211
202
204
198
188
208'
198
197
206
198
200
198
200
198'
216'
199
198'
186
218'
200'
200'
198''
222''
200'
198''
198'''
216'''
200'''
198'''
200'''
200''''
198''''
198'''''
200''''
215
198''''''
213
220
215
209
213
210
212
214
217
211
222'''''
222'''''

FIG. 19

FIG. 20

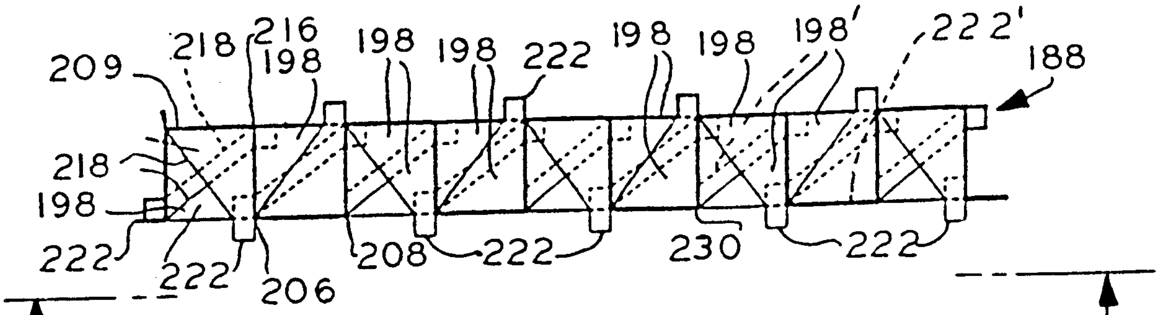

209
218
216
198
198
198
222
198
198
198'
222'
188
218
198
222
222
206
208
222
230
222
21
21

FIG. 21

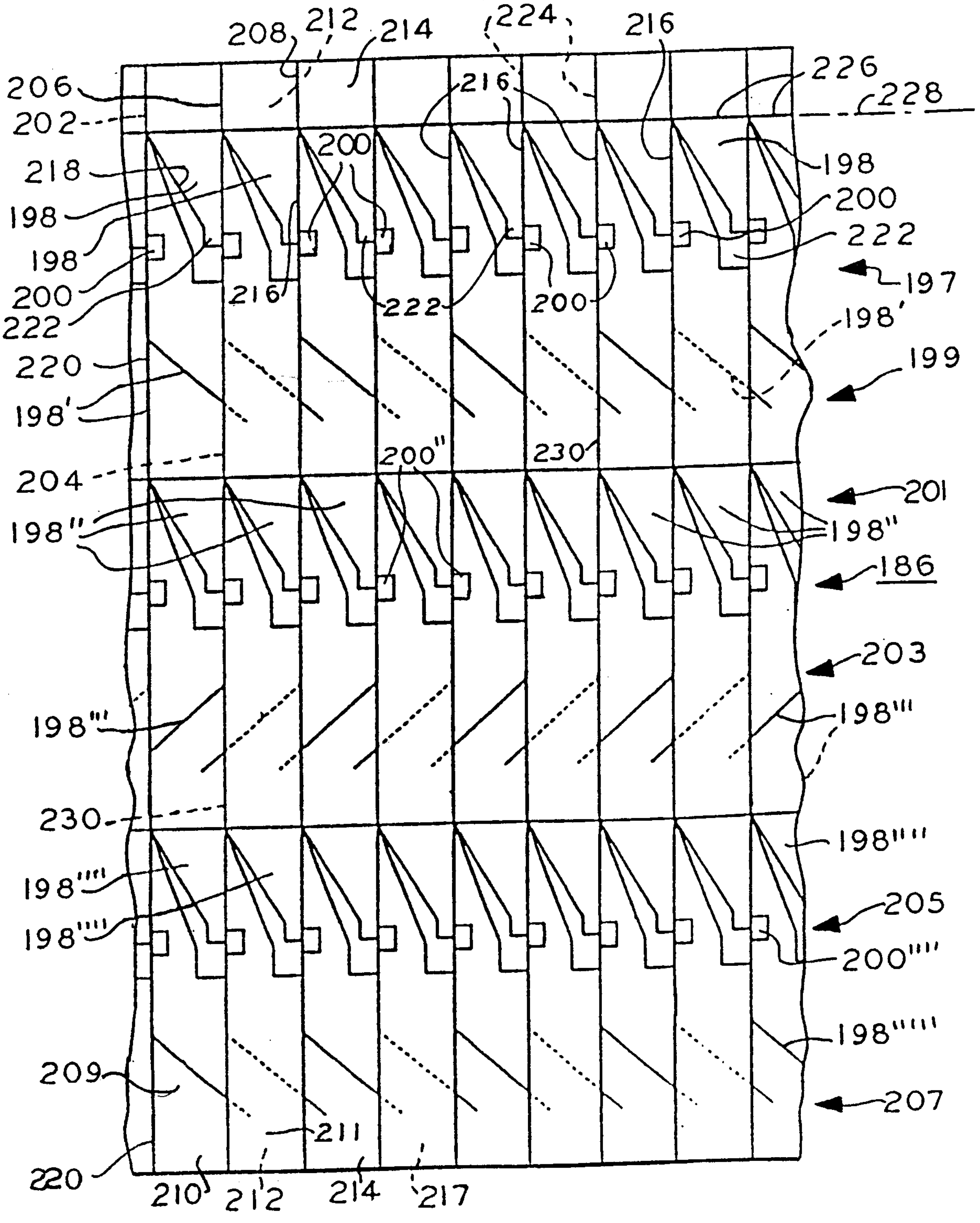

208
212
214
224
216
226
228
206
202
216
200
218
198
198
198
200
222
216
222
200
198
200
222
197
198'
199
220
198'
200''
230
204
201
198''
198''
186
203
198'''
198'''
230
198''''
198''''
198''''
205
200''''
198'''''
209
207
211
220
210
212
214
217

FIG. 22

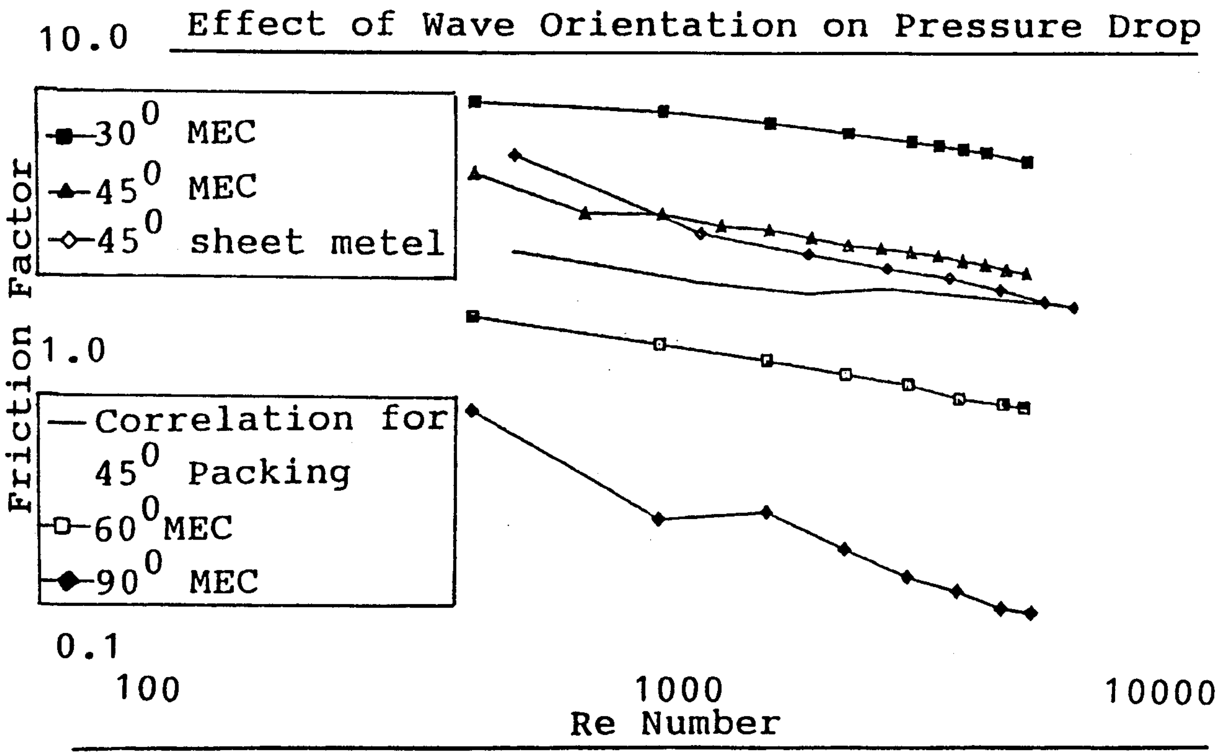
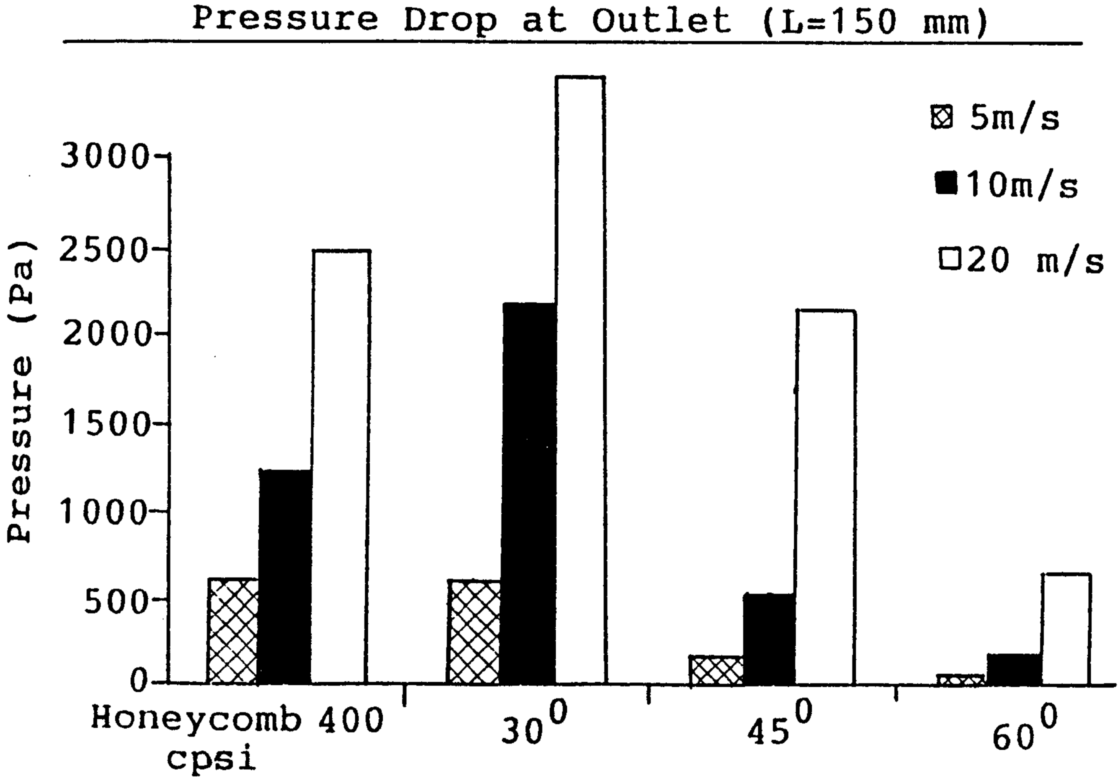
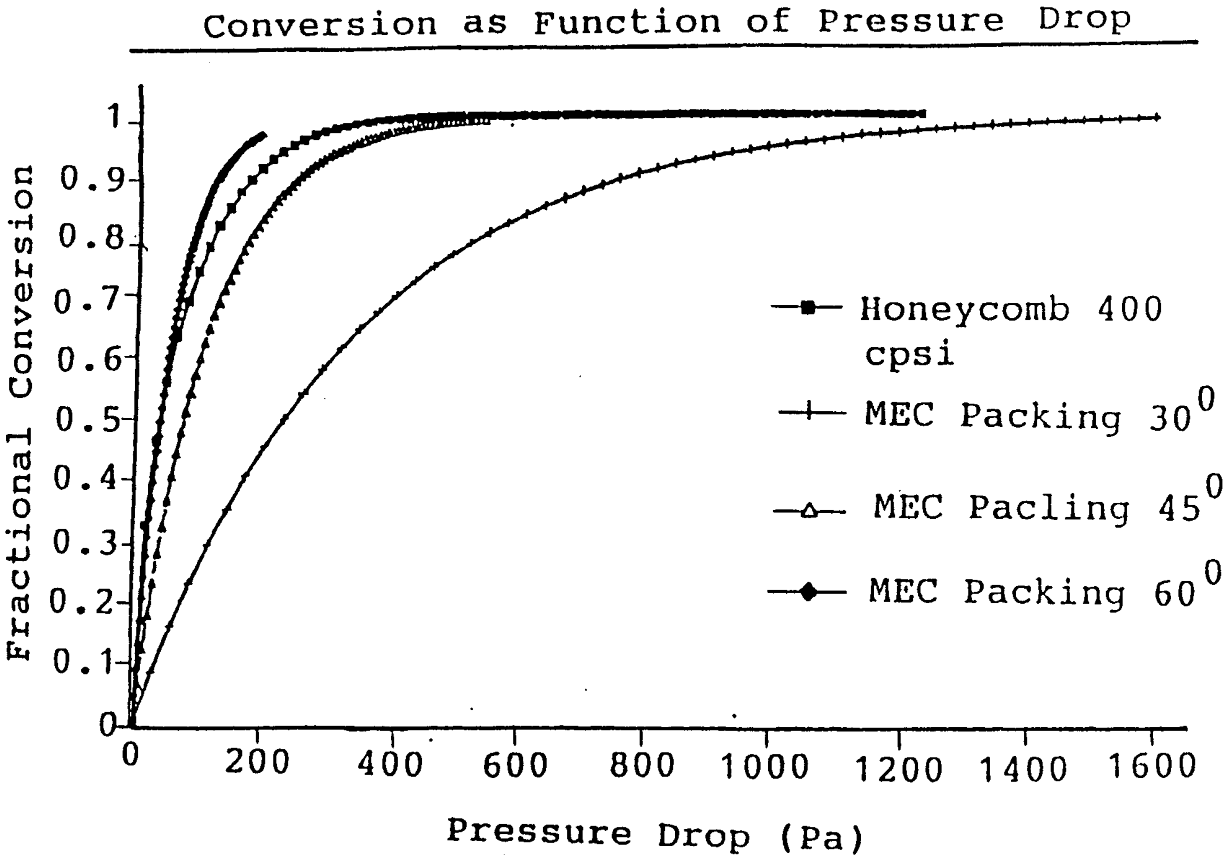

Effect of Wave Orientation on Pressure Drop
10.0
1.0
0.1
Friction Factor
100
1000
10000
Re Number
30⁰ MEC
45⁰ MEC
45⁰ sheet metel
Correlation for 45⁰ Packing
60⁰MEC
90⁰ MEC

FIG. 23


Pressure Drop at Outlet (L=150 mm)
Pressure (Pa)
3000
2500
2000
1500
1000
500
0
5m/s
10m/s
20 m/s
Honeycomb 400 cpsi
30⁰
45⁰
60⁰


Conversion as Function of Pressure Drop

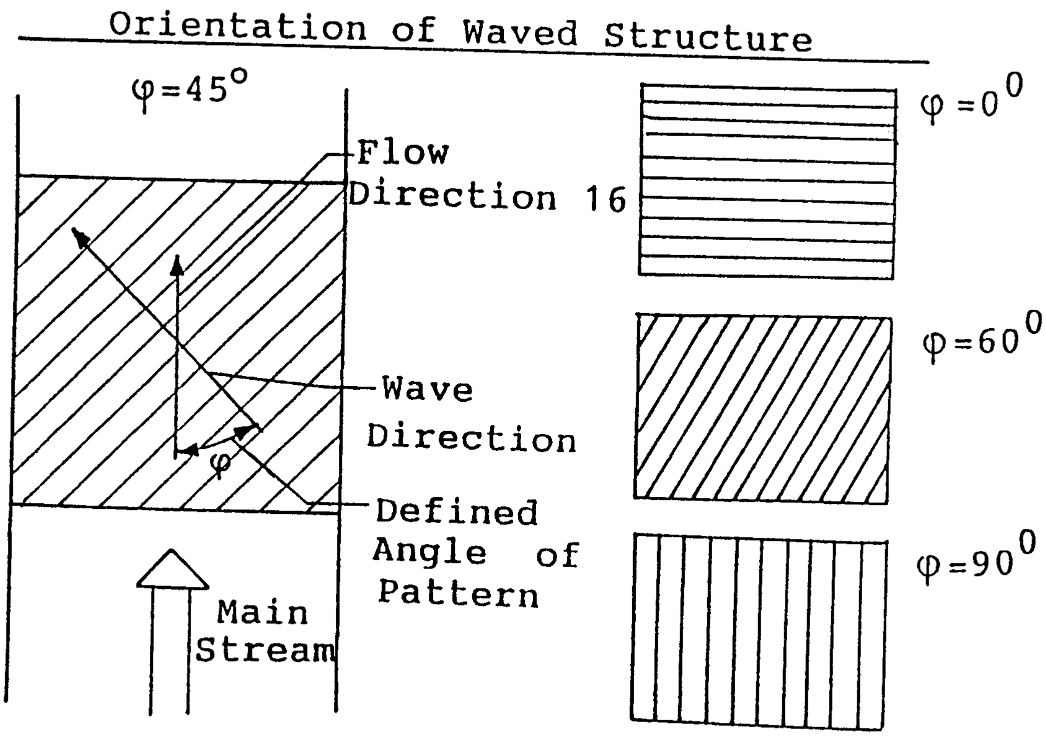
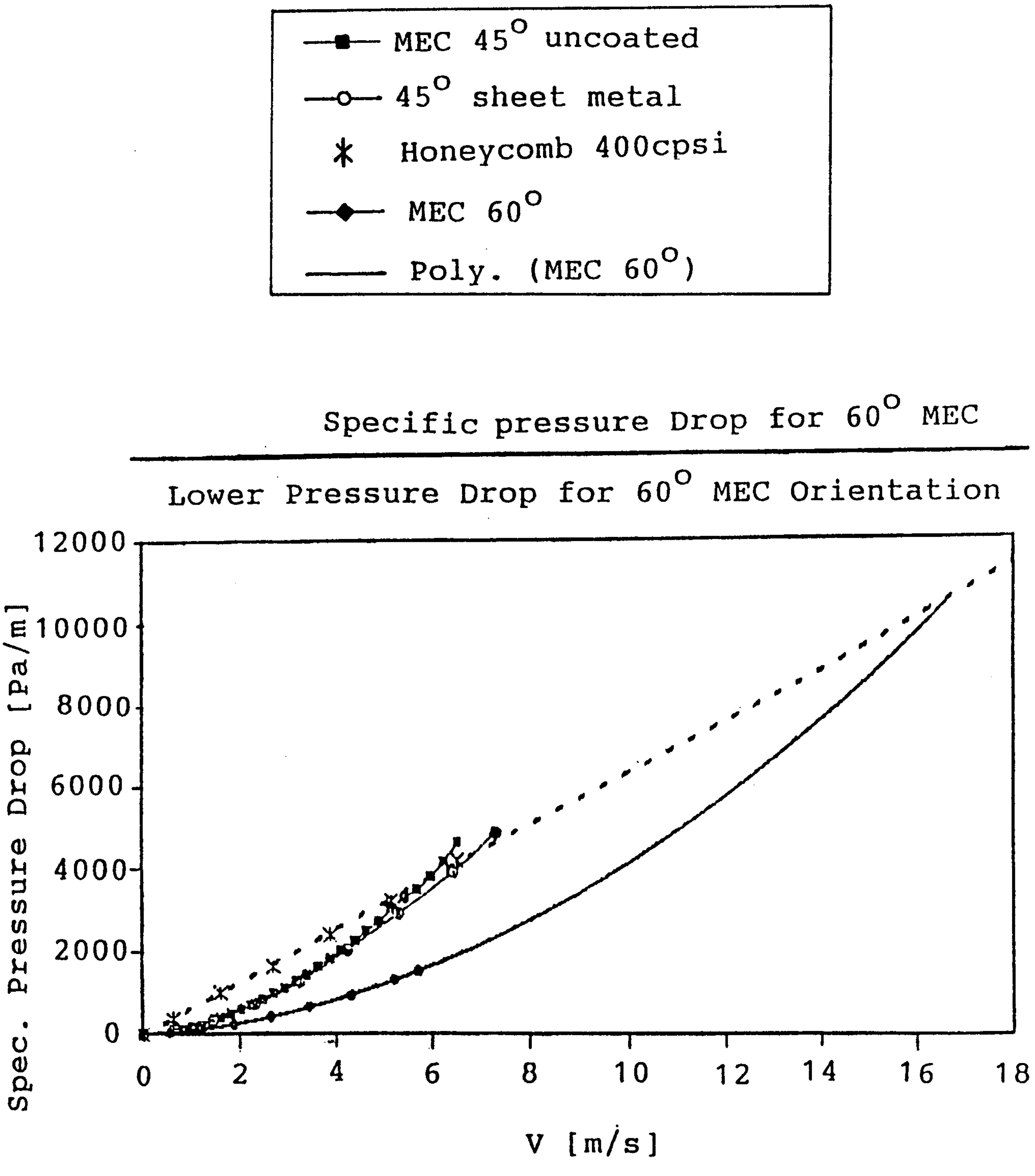

Orientation of Waved Structure

FIG. 26


MEC 45° uncoated
45° sheet metal
Honeycomb 400cpsi
MEC 60°
Poly. (MEC 60°)
Specific pressure Drop for 60° MEC
Lower Pressure Drop for 60° MEC Orientation
Spec. Pressure Drop [Pa/m]
12000
10000
8000
6000
4000
2000
0
0
2
4
6
8
10
12
14
16
18
V [m/s]

INTERNATIONAL SEARCH REPORT

Ir nal Application No
PCT/US 00/06137

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 F01N3/28 B01J19/32 F01N3/20

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 F01N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
E	WO 00 24506 A (ABB LUMMUS GLOBAL INC) 4 May 2000 (2000-05-04) cited in the application page 2, line 3 - line 12 page 12, line 10 -page 13, line 20; figures 1-9	1-6,8,9, 11,12, 16-24, 26,27, 29-36
X	DE 42 06 812 A (NISSAN MOTOR) 17 September 1992 (1992-09-17)	1,3-5, 20-23, 30-34
Y	column 3, line 17 -column 4, line 29; figures	2,6-8, 11-15, 18,19, 24-28, 35,38, 40,41

-/--

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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"E" earlier document but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search
15 June 2000

Date of mailing of the international search report
27/06/2000

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Fax: (+31-70) 340-3016

Authorized officer
Sideris, M

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In ›nal Application No
PCT/US 00/06137

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
Y	US 5 425 236 A (HAERLE HANS A) 20 June 1995 (1995-06-20) claims 1,6; figures	2,8,26, 27
Y	DE 39 23 094 A (LTG LUFTTECHNISCHE GMBH) 17 January 1991 (1991-01-17) claims 1,10,11,18-20; figures	6,7, 11-15, 18,19, 24,25, 28,35
Y	US 5 165 899 A (DELAUNAY CHRISTOPHE ET AL) 24 November 1992 (1992-11-24) column 5, line 14 - line 43	2,38,41
Y	WO 98 42963 A (KOMIYAMA TOMONARI ;NIPPON OIL CO LTD (JP); SHINTO KOGYO CO LTD (JP) 1 October 1998 (1998-10-01) & EP 0 903 476 A (NIPPON OIL CO) page 3, line 56 -page 4, line 5 page 13, line 21 - line 45; figure 36	2,40
A	US 5 651 946 A (DEKUMBIS ROGER ET AL) 29 July 1997 (1997-07-29)	

4

INTERNATIONAL SEARCH REPORT

Information on patent family members

Int ial Application No
PCT/US 00/06137

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		ES 2101996 T	16-07-1997
		JP 7163889 A	27-06-1995