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(54) Title: GLASS FIBER INSULATION PRODUCT
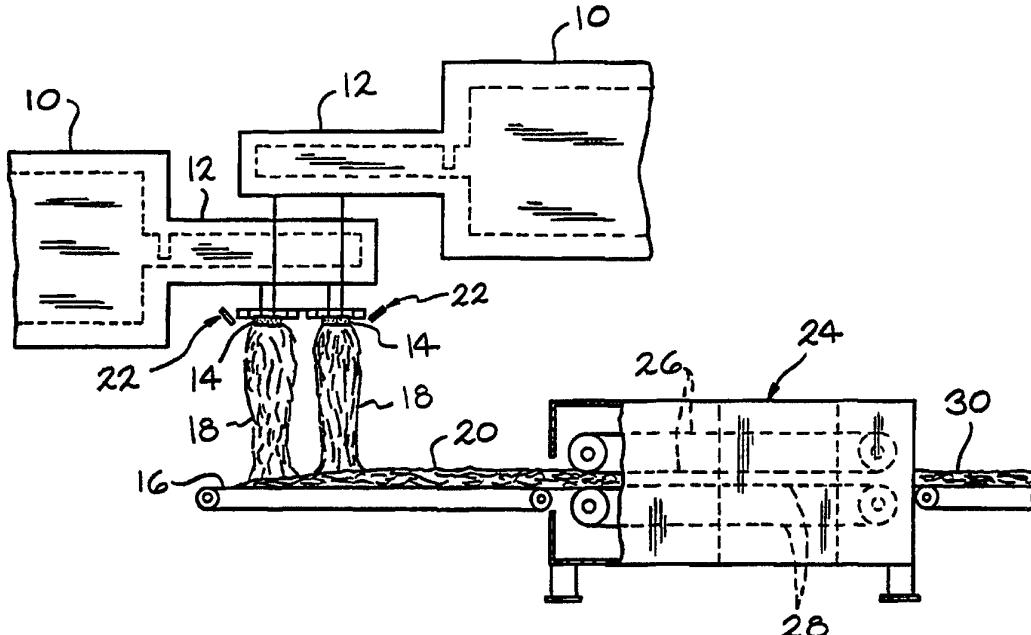
(57) Abstract

A glass fiber insulation product comprises irregularly shaped glass fibers of two different glasses having differing coefficients of thermal expansion, with the irregularly shaped dual-glass fibers exhibiting a substantially uniform volume filling nature, and providing improved recovery and thermal conductivity abilities even in the absence of a binder material.

GLASS FIBER INSULATION PRODUCT

TECHNICAL FIELD

This invention relates to wool materials of mineral
5 fibers and, more specifically, to insulation products of glass
fibers. The invention also pertains to the manufacture of the
insulation products of glass fibers.

BACKGROUND ART

10   Small diameter glass fibers are useful in a variety
of applications including acoustical or thermal insulation
materials. When these small diameter glass fibers are properly
assembled into a lattice or web, commonly called a wool pack,
glass fibers which individually lack strength or stiffness can
15 be formed into a product which is quite strong. The glass
fiber insulation which is produced is lightweight, highly
compressible and resilient. For purposes of this patent
specification, in using the terms "glass fibers" and "glass
compositions", "glass" is intended to include any of the glassy
20 mineral materials, such as rock, slag and basalt, as well as
traditional glasses. The common prior art methods for
producing glass fiber insulation products involve producing
glass fibers from a rotary process. A single molten glass
composition is forced through the orifices in the outer wall of
25 a centrifuge or spinner, producing primarily straight glass
fibers. The fibers are drawn downward by a blower. The binder
required to bond the fibers into a wool product is sprayed onto
the fibers as they are drawn downward. The fibers are then
collected and formed into a wool pack.
30   When forming insulation products of glass fibers,
the ideal insulation would have uniform spacing between the
fibers. Insulation is basically a lattice for trapping air
between the fibers and thus preventing movement of air. The
lattice also retards heat transfer by scattering radiation. A
35 more uniform spacing of fibers would maximize scattering and,
therefore, would have greater insulating capability.

In the production of wool insulating materials of
glass fibers, it becomes necessary to use fibers that are
relatively short. Long fibers tend to become entangled with

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each other forming ropes or strings. These ropes create a
deviation from the ideal uniform lattice and reduce the
insulating abilities of the glass wool. However, short fibers
that are straight form only a haphazard lattice, and some of
5 the fibers lie bunched together. It is clear that existing
glass wool insulating materials have significant non-
uniformities in the distribution of fibers within the product.
Thus, the ideal uniform lattice structure cannot be achieved.

Additionally, when using straight fibers it is
10 necessary to add an organic binder material to the fibers. The
binder is required to hold the product together by bonding at
the fiber to fiber intersections. Not only is the binder
itself expensive, but great pains must be taken to process
effluent from the production process due to the negative
15 environmental impact of most organic compounds. Further, the
binder must be cured with an oven using additional energy and
creating additional environmental cleanup costs.

Another problem with existing insulation products
is that some of the glass fibers irritate human skin upon
20 contact, particularly if the fibers are too large in diameter.
Also, if the glass fibers are fragile, breakage of the fibers
can cause the insulation products to be dusty.

In the shipping and packaging of insulation
products, high compressibility is preferred. It is desirable
25 to compress the wool for shipping and then have it recover
rapidly and reliably to the desired size. Current insulation
products are limited in the amount of compression possible
while still attaining adequate recovery. When the product is
compressed, the binder holds firm while the fibers themselves
30 flex. As the stress upon the fiber increases due to excessive
compression, the fiber breaks.

Attempts have been made in the prior art to produce
non-straight glass fibers. In a mechanical kink process, glass
fibers are pulled from a textile bushing. While still at high
35 temperatures, the fibers are pulled by mechanical means through
a series of opposed gears or a crimping device to attenuate and
crimp them. The net result is a bundle of kinked glass fibers.

The major disadvantage to mechanical kinking is
that the fibers are not conducive to satisfactory glass wool

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production. Every fiber produced in this manner has a uniform
shape, defeating the purpose of the kink, because the glass
wool produced does not have a uniform distribution. Further,
because the process is non-rotary, it has an unsatisfactory low
5 throughput and the fibers produced are too coarse for wool
insulating materials.

Stalego in U.S. Patent No. 2,998,620 discloses
curly glass fibers of bicomponent glass compositions. Stalego
teaches producing staple curly fibers by passing two glass
10 compositions of differing thermal expansivity through the
orifices of a spinner. The glasses are extruded as a dual
glass stream in aligned integral relationship such that the
fibers curl naturally upon cooling due to the differing thermal
expansivity. However, Stalego discloses employing the curled
15 fibers in the processing of yarns such as being woven into
fabric or included as a reinforcement in fired pottery and
clays. Stalego does not disclose the use of curly fibers in
insulation products.

Tiede in U.S. Patent No. 3,073,005 discloses a non-
20 rotary process for making bicomponent curly glass fibers. The
fibers are made by feeding differing glass compositions to an
orifice in side by side contact such that the two glasses are
attenuated into a single fiber. Tiede discloses using the
glasses in fabric production as well as cushion and floatation
25 materials. Tiede does not disclose insulation products made
with curly glass fibers.

Slayter et al. in U.S. Patent No. 2,927,621 also
disclose the production of curly fibers. In Slayter, glass
fibers of a single glass composition are passed through opposed
30 contoured skirts after the fibers have been softened by hot
gases. The fibers then take on the shape of the contour of the
skirts. However, the thick, long fibers are unsuitable for
insulating materials. Rather, the produced fibers are employed
in filtering media, and additionally have a binder applied.

35 Accordingly, a need exists for an improved wool
insulating material with a uniform volume filling nature such
that the wool insulating material has improved recovery and
reduced thermal conductivity and can be employed without the
use of a binder material. Also, it would be beneficial to

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solve the irritation and dustiness problems of existing glass
fiber insulation products.

DISCLOSURE OF INVENTION

5   This need is met by the present invention whereby
insulation products are produced from mineral fibers which are
irregular in shape. By employing fibers that are irregular,
rather than straight, kinked or even curly, a more uniform
lattice structure can be achieved. This is referred to as
10   uniform volume filling. The increased uniformity will allow
higher recovery ratios. More importantly, uniform volume
filling results in significantly lower thermal conductivity.
Also, the greater entanglement of irregularly shaped fibers
could allow sufficient wool pack integrity without the use of
15   an organic binder. By sufficient integrity it is meant that
the fibers of the wool batt will remain entangled and not
separate when an 8 ft. (2.4 m) wool batt is suspended under its
own weight either along its length or along its width. These
are referred to as the machine direction and the cross
20   direction, respectively. However, if so desired, a binder
material may be added to provide additional strength to the
wool insulating material. Also, the irregular shape of the
fibers of the invention makes the product less prone to cause
irritation, and may make the product less dusty.
25   In accordance with the preferred embodiment of the
invention there is provided an irregularly shaped glass fiber
and an insulation product comprising irregularly shaped glass
fibers. The insulation product of irregularly shaped glass
fibers has a substantially uniform volume filling nature.
30   Further, the irregularly shaped glass fibers are preferably
binderless. The term "binderless" is intended to mean that
binder materials comprise less than or equal to 1% by weight of
the product. Further, the term "binder" is not meant to
include materials added for dust suppression or lubrication.
35   Each of the irregularly shaped glass fibers comprises two
distinct glass compositions with different coefficients of
thermal expansion. The difference in the coefficient of
thermal expansion between the two glass compositions is
preferably greater than about 2.0 ppm/$^\circ$C (parts per million),

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more preferably greater than about 4.0 ppm/$^{\circ}$C, and most
preferably greater than about 5.0 ppm/$^{\circ}$C.

      In accordance with a further aspect of the present
invention there is provided an insulation product of
5 irregularly shaped glass fibers, the insulation product having
a substantially uniform volume filling nature, wherein the
product has a recovered density within the range of from about
0.3 to about 0.6 pcf (pounds per ft^3) (4.8 to 9.6 Kg/m^3), after
compression to a compressed density of from about 6 to about 18
10 pcf (96 to 288 Kg/m^3).

      In accordance with another aspect of the invention
there is provided a wool insulating material comprising
irregularly shaped glass fibers with a substantially uniform
volume filling nature, wherein each of the irregularly shaped
15 glass fibers consists of at least a first glass composition and
a second glass composition. The first glass composition
generally varies within the range of from about 15 to about 85%
of the total glass content of each fiber. The second glass
composition comprises the balance of the glass content of each
20 fiber. A small fraction of the fibers may be single
composition.

BRIEF DESCRIPTION OF DRAWINGS

      Figure 1 is a schematic view in elevation of a heat
25 setting process by which the insulation of the present
invention may be produced.

      Figure 2 is a schematic view in perspective of a
direct formed process by which the insulation of the present
invention may be produced.

30   Figure 3 is a schematic view in perspective of an
embodiment of the insulation product of the present invention.

      Figure 4 is a cross-sectional view in elevation of
a fiberizer by which the fibers of the present invention may be
produced.

35   Figure 5 is a plan view of a portion of the spinner
of Figure 4, taken along line 5-5.

      Figure 6 is a schematic view in elevation of the
spinner of Figure 5 taken along line 6-6.

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Figure 7 is a schematic cross-sectional view of an irregular glass fiber of the invention having a 50:50 A/B glass ratio.

Figure 8 is a schematic view of an irregular glass
5 fiber having an A/B glass ratio of less than 50:50.

Figure 9 is a schematic view in perspective of a helical glass fiber of the prior art.

Figure 10 is a schematic view in perspective of an irregularly shaped glass fiber of the present invention in a
10 natural, unconstrained state.

Figure 11 is a schematic view in perspective of the fiber of Figure 10 in a stretched state.

Figure 12 is an artistically enhanced schematic view in perspective of the irregularly shaped glass fiber of
15 Figure 10.

Figure 13 is a graph of the magnitude of rotation R along the y-axis of both a helical fiber (112) and an irregularly shaped fiber (122), with fiber length (mm) indicated along the x-axis.

20

MODES FOR CARRYING OUT THE INVENTION

The insulation products of irregularly shaped glass fibers of the present invention can be produced from a rotary fiber forming and pack heat setting process as shown in Figure
25 1.

Referring to Figure 1, it can be seen that two distinct molten glass compositions are supplied from furnaces 10 via forehearths 12 to fiberizers 14. Veils of irregularly shaped glass fibers 18 produced by the fiberizers are collected
30 on conveyor 16 as wool pack 20 by means of a vacuum positioned beneath the conveyor. As the fibers are blown downward by air or gases to the conveyor by means of blowers 22 in the fiberizers, they are attenuated and assume their irregular shape.

35 The wool pack is then passed through oven 24 at heat setting temperatures from 700 to 1100°F (371 to 593°C). The heat setting temperature may be achieved either by retarding the cooling process after fiber forming to retain some of the heat from the fiber forming process, or by

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reheating the fibers in the heat setting oven. While passing
through the oven, the wool pack is shaped by top conveyor 26
and bottom conveyor 28, and by edge guides, not shown. While
in the oven, the glass fibers may be subjected to flows of hot

5   gases to facilitate uniform heating. After a period of up to
10 minutes, the wool pack then exits the oven as insulation
product 30.

When glass fibers are constrained by conveyors 26
and 28 into the shape of the insulation product, the fibers are

10 stressed in the manner of a compressed spring. When the
stressed fibers are subjected to heat setting temperatures, the
glass structure is relaxed, possibly by a creep mechanism,
resulting in the stress being substantially released. Once the
constraints are removed, the wool pack does not expand but

15 holds the desired shape. Since the fibers bend as they cool,
they become more entangled and enhance the insulation product's
structural integrity.

It is to be understood that heat setting is an
optional aspect of the present invention. Other fabrication

20 techniques for the insulation product include stitching,
needling, hydro-entanglement, and encapsulation.

Referring to Figure 2, a novel direct forming
process is described through which insulation products of the
present invention may be produced. Irregularly shaped glass

25 fibers are produced in fiberizer 40. Veils 42 of glass fibers
are blown downward by means of blowers in the fiberizer and are
collected at temperatures of up to 1100°F (593°C) on opposed,
downwardly converging collection conveyors 44. The collected
fibers are passed through a heat-setting oven, such as pack

30 formation and heat setting conveyors 46, where the fibers are
shaped into an insulation product at temperatures within the
range of from about 700°F to about 1100°F (371 to 593°C). The
heat setting oven, or heat setting conveyors, preferably define
a predetermined cross-sectional shape. The heat for heat

35 setting the fibers in the oven can be supplied by any suitable
means, such as by hot air ducts 47, connected to a supply of
hot gases, not shown, which are adapted to pass heated gases
transversely through the wool pack 48.

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In a particular aspect of the invention the
intercepting conveyors are perforated or foraminous, and gases
flowing with the veil of fibers are exhausted through the
intercepting conveyors to separate the gases from the fibers.
5   These gases contain considerable heat, and preferably a
substantial portion of the exhausted gases is channeled from
the intercepting conveyors via conduits 49 to the upper edge of
the intercepting conveyors to conserve the heat. Ideally, this
recirculation of exhausted gases would maintain the glass
10 fibers exiting the intercepting conveyor at a temperature
within the range of from about 400°F to about 900°F (204°C to
482°C). Waste hot gases from the oven could also be channeled
to the upper edge of the intercepting conveyors.

From the formation and heat setting zones of the
15 heat setting conveyors, the insulation product is passed to
encapsulation module 50 where the insulation product can be
encapsulated with any suitable type of film, such as film 52.
Further, the moving product can be cut into individual units,
such as insulation batts, prior to packaging. The product can
20 be packaged by any suitable means, such as roll up apparatus
54.

Referring to Figure 3, the insulation product of
the present invention can be in the form of wool batt 56
consisting of irregularly shaped glass fibers. The batt can be
25 covered by an exterior facing 58, many types of which are known
in the prior art.

As shown in Figure 4, spinner 60 is comprised of
spinner bottom wall 62 and spinner peripheral wall 64. The
spinner is rotated on spindle 66, as is known in the prior art.
30 The rotation of the spinner centrifuges molten glass through
the spinner peripheral wall into primary fibers 68. The
primary fibers are maintained in a soft, attenuable condition
by the heat of annular burner 70. In one embodiment of the
invention, an internal burner, not shown, provides heat to the
35 interior of the spinner. Annular blower 72, using induced air
74, is positioned to pull the primary fibers and further
attenuate them into secondary fibers 76, suitable for use in
wool insulating materials. The secondary fibers, or dual-glass

irregularly shaped glass fibers, are then collected for
formation into a wool pack.

     The interior of the spinner is supplied with two
separate streams of molten glass, first stream 78 containing
5 glass A and second stream 80 containing glass B. The glass in
stream 78 drops directly onto the spinner bottom wall and flows
outwardly with centrifugal force toward the spinner peripheral
wall to form a head of glass A. Glass B in molten glass stream
80 is positioned closer to the spinner peripheral wall than
10 stream 78, and the glass in stream 80 is intercepted by
horizontal flange 82 before it can reach the spinner bottom
wall. Thus, a build-up or head of glass B is formed above the
horizontal flange.

     As shown in Figure 5, the spinner is adapted with
15 vertical interior wall 84 which is generally circumferential
and positioned radially inwardly from the spinner peripheral
wall. A series of vertical baffles 86, positioned between the
spinner peripheral wall and the vertical interior wall, divide
that space into a series of compartments 88. Alternate
20 compartments contain either glass A or glass B.

     The spinner peripheral wall is adapted with
orifices 90 which are positioned adjacent the radial outward
end of the vertical baffle. The orifices have a width greater
than the width of the vertical baffle, thereby enabling a flow
25 of both glass A and glass B to emerge from the orifice as a
single dual-glass primary fiber. As can be seen in Figure 6,
each compartment 88 runs the entire height of spinner
peripheral wall 64 with orifices along the entire vertical
baffle separating the compartments. Other spinner
30 configurations can be used to supply dual streams of glass to
the spinner orifices.

     The irregularly shaped fibers of the present
invention are dual-glass fibers, i.e. each fiber is composed of
two different glass compositions, glass A and glass B. If one
35 were to make a cross-section of an ideal irregularly shaped
glass fiber of the present invention, one half of the fiber
would be glass A, with the other half glass B. In reality, a
wide range of proportions of the amounts of glass A and glass B
may exist in the various irregularly shaped glass fibers in the

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wool insulating material (or perhaps even over the length of an
individual fiber). The percentage of glass A may vary within
the range of from about 15 to about 85% of the total glass in
each of the irregularly shaped glass fibers with the balance of
5 total glass being glass B. In general, insulation products of
the irregularly shaped fibers will consist of fibers of all
different combinations of the percentages of glass A and glass
B, including a small fraction of fibers that are single
component.

10   A method for measuring the proportion of glass A to
glass B involves examining the cross-section of a multiplicity
of fibers. If the A/B ratio is 50:50, the interface 92 between
the two glasses, glass A 94 and glass B 96, will pass through
the center 98 of the fiber cross-section, as shown in Figure 7.
15 Usually the interface between the two glasses is a line which
does not pass through the center of the fiber cross-section.
As shown in Figure 8, interface 102 between glass A 104 and
glass B 106 does not pass through center 108 of the fiber.
        Cross-section photographs of fibers are obtained by
20 mounting a bundle of fibers in epoxy with the fibers oriented
in parallel as much as possible. The epoxy plug is then cross-
sectioned using a diamond saw blade, and one of the new
surfaces is polished using various grinding media. The
polished sample surface is then coated with a thin carbon layer
25 to provide a conductive sample for analysis by scanning
electron microscopy (SEM). The sample is then examined on the
SEM using a backscattered-electron detector, which displays
variations in average atomic number as a variation in the gray
scale. This analysis reveals the presence of two glasses by a
30 darker and lighter region on the cross-section of the fiber,
and shows the interface of the two glasses.
        The "deviation ratio" is the ratio (expressed in
percent) of r to R, where R is the radius of a fiber cross-
section and r is the closest distance from the fiber center to
35 the interface of the two glasses. Where the fiber cross-
section is not round, the radii are measured perpendicular to
the interface. Where the interface is curved, a straight line
interface is approximated.

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The deviation ratio is a measure of how far the A/B glass ratio is away from 50:50. The larger the deviation from 50:50, the larger r will be as a percent of R. It has been found that the average deviation ratio of the irregularly

5 shaped glass fibers of the invention is typically greater than about 5%, generally greater than about 15%, and in many cases greater than about 30%.

Dual-glass fibers have a curvilinear nature due to the difference in thermal expansion coefficients of the two

10 glasses. As a dual-glass fiber cools, one glass composition contracts at a faster rate than the other glass composition. The result is stress upon the fiber. To relieve this stress the fiber must bend. If no rotation of the fiber is introduced, a flat coil having a generally constant radius of

15 curvature will be produced, the coil being in one plane such as in a clock spring. Rotation of dual-glass fibers can be measured by reference to the interface along the fiber between the two glass components. In order to get out of the plane, some rotation must be introduced. Constant rotation of the

20 fibers will produce a helix having a constant pitch. The fiber making up the helix has a constant direction of rotation - either clockwise or counter-clockwise. The helix also has a generally constant radius of curvature. Figure 9 shows a 3-dimensional schematic projection of helical fiber 112 of the

25 prior art. As an aid to visualization, the shadow 114 of the fiber cast by an overhead light onto a flat surface has been added.

An irregularly shaped fiber of the invention differs from a helical fiber in that the rotation of the fiber

30 is not constant, but rather varies irregularly both in direction (clockwise and counter-clockwise) and in magnitude. The magnitude of rotation of a fiber is how fast the fiber rotates per unit length of the fiber. The curvature is generally constant as dictated by the difference in thermal

35 expansion coefficients and the A/B proportion. Figure 10 shows a 3-dimensional projection of an irregular fiber 122 of the invention. As an aid to visualization, the shadow 124 of the fiber cast by an overhead light onto a flat surface has been added. When fiber 122 is put under tension, the tensioned

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fiber 122A and shadow 124A illustrate that the irregularity of
the fiber is maintained, as shown in Figure 11.

Irregular fiber 122B, shown in Figure 12, is fiber
122 of Figure 10 artistically enhanced by exaggerating the
5   thickness and by adding segmentation lines to show better
perspective.

Due to a continuously changing attenuation
environment, each irregularly shaped fiber is twisted in a
unique way. No two fibers are exactly alike. The fiber's
10 final shape is one with a baseline curvature due to the dual-
glass nature, which is modified by the twisting, irregular
rotation of the plane of curvature caused by the continuously
changing or stochastic attenuation environment. The fiber has
a baseline curvature that is twisted through three dimensions.
15 It is generally not helical. The fiber's irregular nature
allows the irregularly shaped glass fibers to stand apart from
one another and achieve a uniform volume filling nature.
Additionally, wool insulation material made of irregularly
shaped glass fibers is less irritating (not as itchy) to the
20 skin as wool insulating materials made with primarily straight
fibers, and may not be as dusty.

The nature of the irregularly shaped fibers was
analyzed using a direction vector analysis. The set of
coordinates describing the path of an irregularly shaped fiber
25 in 3-D space was generated using photographs taken from two
different angles, 90° apart. The coordinates were adjusted to
give equal three dimensional distances between the data points
along the length of the fiber, resulting in adjusted coordinate
data points (ACD). Three vectors were computed for each of the
30 ACD's as follows:

$\overline{V}_i$ = Fiber direction vector (a unit
       vector directed from one ACD to
       the next)

35

$\overline{F}_i$ = First derivative vector of $\overline{V}_i$
       with respect to the distance
       interval between ACD's

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$\overline{S}_i$ = Second derivative vector of $\overline{V}_i$
with respect to the distance
between ACD's.

5

The magnitude of rotation R_i for any given ACD is
as follows:

$R_i = S_i \cdot U_i$ (vector dot product), where

10

$$\overline{U}_i = \frac{V_i \ X \ V_{i-1}}{\overline{V_i \ X \ V_{i-1}}} \text{ (vector cross product)}$$

15      $\overline{U}_i$ is a unit vector perpendicular to the plane
containing V_i and V_{i-1}.

The magnitude of rotation R (y-axis) can be plotted
as a function of distance along the length of the fiber (x-
axis) as shown in Figure 13. The graph shows the magnitudes of
20 rotation of the irregular fiber shown in Figure 10 (fiber A)
and the helical fiber shown in Figure 9 (fiber B). The data in
Figure 13 has been smoothed with a 5 point weighted moving
average to reduce noise accentuated by the derivatizing
process. As can be seen from the graph, the rotation of an
25 unconstrained irregularly shaped fiber of the invention (fiber
A) varies irregularly in magnitude and sign along the length of
the fiber. The crossover points (i.e. where the rotation
changes sign) occur at a frequency of about one per centimeter
for the five micron diameter fiber A. In contrast, the helical
30 fiber (fiber B) has zero crossover points during the same
length. It is expected that the number of crossover points per
centimeter of the irregular fibers of the invention for a 5
micron diameter fiber will be at least 0.3 and most likely
within the range of from about 0.5 to about 5.0. Another way
35 to quantify the irregularity of the fibers is to calculate the
average rotation magnitude and the standard deviation of the
rotation magnitudes along the length of the fibers. Referring
to Figure 13, the average value for the magnitude of rotation R
for the helical fiber (fiber B) is well above zero (or well
40 below zero for opposite rotation). The standard deviation of

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the magnitude of rotation R for the helix is smaller than the average value of the magnitude of rotation R. In Figure 13 the ratio of standard deviation to the average magnitude of rotation is 0.25 for the helical fiber (fiber B).

5   In contrast, for the irregularly shaped fiber of the invention (fiber A), the average magnitude of rotation R is very small, being generally close to zero. The standard deviation of the magnitude of rotation is at least comparable to the average magnitude of rotation R, if not significantly

10   larger than the average magnitude of rotation R. Preferably, the ratio is greater than about 0.75. More preferably, it is greater than 1.0 and most preferably it is greater than 5.0. The ratio of the standard deviation to the average magnitude of rotation for fiber A is 8.3.

15   The irregular shape of the fibers gives the wool insulating material a more uniform volume filling nature. The primarily straight fibers of the prior art are arranged haphazardly in the wool pack. They are not uniform in volume filling. By uniform volume filling it is meant the fibers have

20   a desire to spread out and fill the entire volume available to them in a uniform manner. A more uniform volume filling nature allows a more efficient use of glass fibers to resist the flow of heat.

          X-ray computer tomography (CAT scan) testing has

25   shown that the irregularly shaped fibers employed in the present invention, due to their natural desire to stand apart, give a much more uniform volume filling nature than prior art standard glass fibers. In CAT scan testing of the density of wool packs, the wool pack of standard glass fibers of the prior

30   art shows a standard deviation of roughly twice that of the pack of irregularly shaped fibers. Thus, there is a significantly lower amount of variation of density in the pack made of irregularly shaped fibers indicating a substantially uniform volume filling nature.

35   The uniform volume filling nature of a wool insulating material may be additionally indicated by measuring thermal conductivity. Building insulation products are quantified by their ability to retard heat flow. Resistance to heat flow or R value is the most common measure of an

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insulation product's ability to retard heat flow from a
structure. R-value is defined by the equation: R value = t/k,
where R-value is resistance to heat flow in hrft^{2o}F/Btu
(m^{2o}C/Watt); t is recovered thickness in inches (mm); and k is
5 thermal conductivity in Btu in/hrft^{2o}F (Watt/m^{o}C).

Thermal conductivity or k value is a measure of a
material's ability to conduct heat. Thus, the lower a
material's k value the better that material is as an insulator.
Also, the more uniform the lattice of the material, the greater
10 that material's insulation ability. Thus, thermal conductivity
can be a measure of the uniform volume filling nature of the
insulation material.

Insulation products of the present invention result
in a substantial reduction in k values from that of the prior
15 art at identical product density and fiber diameter. For wool
insulating material at a fixed product density, 0.3 to 0.6 pcf
(4.8 to 9.6 Kg/m^{3}), and fixed fiber diameter, wool batts of the
present invention show k values of from 10 to 17 k points lower
than those of the best standard products of the prior art. At
20 this density, one k point, or thousandths k, translates to
approximately 1/2% glass fiber density needed for equivalent
thermal performance. Thus, the wool insulating material of the
present invention requires approximately 5 to 8-1/2% less glass
than the prior art material to reflect the same k values and
25 generate an equivalent R value. A comparable weight savings
will be seen in medium and high density insulating materials.
Insulation products of the invention preferably exhibit
improved k values of less than about 0.300 Btu in/hrft^{2o}F
(0.0432 Watt/m^{o}C) at 0.5 pcf (8.0 Kg/m^{3}) and at an effective
30 fiber diameter of 5 microns. Most preferably, the improved k
values are less than about 0.295 Btu in/hrft^{2o}F (0.0425
Watt/m^{o}C) at 0.5 pcf (8.0 Kg/m^{3}) and at an effective fiber
diameter of 5 microns.

Insulation products are packaged in high
35 compression in order to ship more insulation in a defined
volume, such as a truck. At the point of installation the
insulation product is unpackaged and the product expands or
recovers. The thickness to which the insulation product

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recovers is referred to as the recovered thickness. A specific
thickness of insulating material is required to perform to a
specified R value.

   The ability of an insulation product to recover
5 depends upon both the uncompressed product density and the
density to which the product is compressed. Wool insulating
material can be generally classified into three broad
categories: light, medium and heavy density. Light density
insulation products are those with a product density within the
10 range of 0.3 to 0.6 pcf (4.8 to 9.6 Kg/m^3). Medium density
insulating materials are those with a product density of from
0.6 to 0.9 pcf (9.6 to 14.4 Kg/m^3). Heavy density wool
insulating materials are those higher than 1.0 pcf (16 Kg/m^3).

   The compressed density is the density to which the
15 wool batt can be compressed for shipping while still
maintaining a satisfactory recovery. If a product is
compressed to too high a density, a substantial portion of the
glass fibers may break. As a result, the product will not
recover to a satisfactory thickness. For prior art light
20 density insulation products of straight fibers, the maximum
practical compressed density is from about 3 to about 6 pcf (48
Kg/m^3 to 96 Kg/m^3), depending on the product density.

   Light density wool insulating materials of the
present invention produce dramatically improved recovery
25 properties. This increase in recovery ability is due to the
unique shape and properties of the irregularly shaped fibers.
Due to the binderless nature of the irregularly shaped glass
fibers of the present invention, one would expect them to slide
upon compression as do the binderless straight fibers of the
30 prior art. However, the irregularly shaped fibers cannot slide
very far because the irregular shape catches on neighboring
fibers, thereby preventing significant movement. Further,
there is no binder placing stress on the fibers near the
intersections. Rather, the irregularly shaped fibers of the
35 present invention twist and bend in order to relieve stress.
Thus, the fibers' positions are maintained and any available
energy for recovery is stored in the fiber. This stored energy
is released when the compression is removed and the fibers
return to their recovered position.

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The term recovery ratio in the present invention is
defined as the ratio of recovered density to compressed
density, after an insulation product is compressed to the
compressed density, unpackaged, and allowed to recover to the
5 recovered density, according to ASTM C167-90. For example, an
insulation product compressed to a density of 6 pcf (96 Kg/m^3)
which recovers to 0.5 pcf (8 Kg/m^3) has a recovery ratio of
12:1. Light density wool batts of the present invention may be
compressed to a compressed density within the range of about 6
10 to about 18 pcf (96 to 288 Kg/m^3) and recover to a recovered
density of within the range of about 0.3 to about 0.6 pcf (4.8
to 9.6 Kg/m^3). This is a recovery ratio within the range of
from 12:1 to about 50:1. Preferably, insulation products of the
invention will be compressed to a compressed density within the
15 range of from about 9 to about 18 pcf (144 to 288 Kg/m^3) and
recover to a recovered density within the range of from about
0.3 to about 0.6 pcf (4.8 to 9.6 Kg/m^3). Most preferably, the
light density insulation products are compressed to a density
of within the range of from about 9 to about 15 pcf (144 to 240
20 Kg/m^3) and recover to a recovered density of within the range
of from about 0.3 to about 0.5 pcf (4.8 to 8 Kg/m^3).

The effect of this dramatic increase in the amount
of compression that can be applied to light density insulation
products of the present invention while still maintaining a
25 satisfactory recovered density is significant. For standard
R19 insulation products, compressed density can be increased
from around 4 pcf (64 Kg/m^3) to about 12 pcf (192 Kg/m^3) by
employing irregularly shaped glass fibers of the present
invention. This translates to around 3 times as much
30 insulating material which can be shipped in the same volume
shipping container, such as a truck or rail car. The potential
savings in shipping cost is enormous. Additionally, the more
highly compressed insulation products provide benefits in
storage and handling for warehousing, retailing and installing
35 the product.

To achieve the unique irregularly shaped glass
fibers of the present invention, specific compositions
satisfying a number of restraints are required. The first

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constraint involves the coefficient of thermal expansion. There is no direct constraint on the values for the coefficient of thermal expansion of either glass A or glass B. Preferably, however, the coefficients of thermal expansion of glass A and

5 glass B, as measured on the individual glasses by standard rod techniques, differ by at least 2.0 ppm/°C.

Another constraint for satisfactory commercial production of irregularly shaped glass fibers is viscosity temperature, which is the temperature at which the glass

10 viscosity is 1000 poise as measured by a standard rotating cylinder technique. It is commonly referred to as the log3 viscosity temperature. The log3 viscosity temperature is preferably within the range of from about 1850°F (1010°C) to about 2050°F (1121°C), more preferably within the range of from

15 about 1900°F (1037°C) to about 2000°F (1093°C), and most preferably about 1950°F (1065°C).

An additional constraint of the glass is that of liquidus temperature. The liquidus of a glass is the highest temperature at which crystals are stable in the molten glass.

20 With sufficient time, a glass at a temperature below its liquidus will crystallize. Crystallization in the furnace can lead to the formation of solid particles which, once passed to the fiberizer, become lodged in the orifices of the spinner, plugging them. The difference between the log3 viscosity

25 temperature and the liquidus for each of glass A and glass B of the dual-glass composition in the present invention is preferably at least 50°F (28°C), and more preferably more than about 200°F (111°C) lower than the log3 viscosity temperature. If this constraint is not met, crystallization may occur in the

30 lower (i.e. colder) part of the spinner blocking the spinner's orifices.

A further constraint on the glass composition of the present invention is glass durability. Durability relates to two glass wool pack properties. The first is the ability of

35 the glass wool pack to recover when it is opened for installation. The second is the long term physical integrity of the glass wool pack. If the glass chemical durability is too low, upon installation the glass wool pack could fail to

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recover to its design thickness. Whether the wool pack fails
to fully recover or disintegrates too quickly, the result is a
failure of the wool pack to adequately insulate.

A useful measure of the chemical durability of a
5   glass fiber for an insulation application is obtained by
measuring the percent weight loss of 1 gram of 10 micrometer
diameter fibers after 2 hours in 0.1 liters of distilled water
at 205°F (96°C). The durability so measured depends strongly
on the composition of the glass fibers and, to a lesser,
10   extent, on the thermal history of the fiber. To assure
adequate performance of the wool pack, fibers of each of the
dual glass compositions should exhibit a weight loss in this
test of less than about 4% and preferably less than about 2.5%.
In addition to its strong dependence on glass composition, the
15   chemical durability of a glass fiber depends to a lesser extent
on its thermal history. Thus, for example, heating a glass
fiber for several minutes at 1000°F (538°C), will improve its
chemical durability somewhat. It is understood that the limits
on chemical durability disclosed here refer to measurements on
20   glass fibers with no heat treatment other than that employed in
their original attenuation. Since glass wool insulation
typically contains some fibers that are thin enough to be
respirable if they break into short lengths, it is possible
that some fibers may become airborne and be inhaled. In the
25   body, they will be exposed to physiological fluids. To the
extent that the dissolution rate of the fibers in the body
plays a role in the biological activity of inhaled fibers, it
may be preferable to produce glass fibers with a relatively
high dissolution rate in such fluids. The dissolution rate of
30   glass fibers is expressed as the dissolution rate constant
measured for fibers in simulated lung fluid at 98°F (37°C). It
depends strongly on the glass fiber composition and, to a
lesser extent, on its thermal history. It is preferable to use
glass compositions having a dissolution rate constant of at
35   least 100 ng/cm^{2}hr for all insulation fibers. Therefore the
dissolution rate constant for fibers of each of the dual glass
compositions is preferably at least 100 ng/cm^{2}hr. As with the
chemical durability, subsequent heat treatment of the fiber
will reduce its dissolution rate. It is understood that the

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100 ng/cm^{2}hr limit refers to fibers formed into a wool
insulation pack in the final product form.

The dual-glass compositions of the present
invention comprising one high-borate, low-soda lime-
5   aluminosilicate composition as glass A and one high-soda, low-
borate lime-aluminosilicate composition as glass B satisfy all
constraints necessary for a successful irregularly shaped
fiber. By high-borate, low-soda lime-aluminosilicate
composition, it is intended that the glass composition have a
10 borate content of within the range of about 14% to about 24% by
weight of the total components. By a high-soda, low-borate
lime-aluminosilicate composition, it is intended that the glass
composition have a soda content within the range of from about
14% to about 25% by weight of the total components.

15   Preferably, the first glass composition comprises
by weight percent from about 50 to about 61% silica or SiO_2,
from about 0 to about 7% alumina or Al_2O_3, from about 9 to
about 13% lime or CaO, from about 0 to about 5% magnesia or
MgO, from about 14-24% borate or B_2O_3, from about 0 to about
20 10% soda or Na_2O, and from about 0 to about 2% potassium oxide
or K_2O.

The second glass composition is preferably one
which comprises by weight percent from about 52 to about 60%
silica or SiO_2, from about 0 to about 8% alumina or Al_2O_3, from
25 about 6 to about 10% lime or CaO, from about 0 to about 7%
magnesia or MgO, from about 0 to about 6% borate or B_2O_3, from
about 14 to about 25% soda or Na_2O, and from about 0 to about
2% potassium oxide or K_2O. It is understood that in each
composition there will typically be less than about 1% total of
30 various other constituents such as, for example Fe_2O_3, TiO_2 and
SrO, not intentionally added to the glass, but resulting from
the raw materials used in the batch formulation.

More preferably, the dual-glass composition of the
present invention comprises a first glass composition
35 containing approximately 52-57% silica, 4-6% alumina, 10-11%
lime, 1-3% magnesia, 19-22% borate, 4-6% soda, 0-2% potassium
oxide, and a second glass composition containing approximately
57-65% silica, 2-6% alumina, 8-9% lime, 4-6% magnesia, 0-6%
borate, 15-21% soda, and 0-2% potassium oxide.

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Example 1

Irregularly shaped glass fibers of the present invention were produced in a batch-mode low throughput laboratory spinner according to the process of the present

5   invention. Test squares of wool batts were then produced from 50 grams of the fibers in an 8 x 8 inch (203 mm x 203 mm) sample. The recovery of these test squares was measured by comparing the recovered thickness to the compressed thickness. The compression was for one week at 12 pcf (192 Kg/m^3).

10   A standard bindered insulation product of the prior art showed a recovery ratio of 18:1. Standard binderless wool insulating material of the prior art showed a recovery ratio of 14.4:1. Binderless irregularly shaped wool insulating material of the present invention showed a recovery of from 32:1 to 34:1

15   for three samples tested.

Example 2

The thermal conductivity of wool insulating material at 0.5 pcf (8.0 Kg/m^3) and a diameter of 5 microns

20   were measured using ASTM test C518. For twenty samples tested, the average of a standard bindered wool batt was 0.308 k value. For twenty samples tested of the irregularly shaped wool insulating material of the present invention, the average was 0.291 k value, indicating a difference of 17 k points. As one

25   k point represents roughly 1/2% glass, the wool insulating material of the present invention requires 8-1/2% less glass than the prior art material to achieve the same R value.

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<u>CLAIMS</u>

1.   An insulation product comprising irregularly shaped glass fibers having a substantially uniform volume filling nature, the insulation product having a recovered density within the range of from about 0.3 to about 0.6 pcf (4.8 to 9.6 Kg/m^3) after compression of the insulation product to a compressed density within the range of from about 6 to about 18 pcf (96 to 288 Kg/m^3).

2.   The insulation product of claim 1 having a recovered density within the range of from about 0.3 to about 0.6 pcf (4.8 to 9.6 Kg/m^3) after compression of the product to a compressed density within the range of from about 9 to about 18 pcf (144 to 288 Kg/m^3).

3.   The insulation product of claim 2 wherein the irregularly shaped glass fibers comprise two distinct glass compositions with different coefficients of thermal expansion, the difference in the coefficient of thermal expansion between the two glasses being greater than about 2.0 ppm/$^{\circ}$C.

4.   The insulation product of claim 3 wherein the irregularly shaped glass fibers are binderless.

5.   The insulation product of claim 1 having a recovered density within the range of from about 0.3 to about 0.6 pcf (4.8 to 9.6 Kg/m^3) after compression of the product to a compressed density within the range of from about 9 to about 15 pcf (144 to 240 Kg/m^3).

6.   The insulation product of claim 5 wherein the irregularly shaped glass fibers comprise two distinct glass compositions with different coefficients of thermal expansion, the difference in the coefficient of thermal expansion between the two glasses being greater than about 2.0 ppm/$^{\circ}$C.

7.   The insulation product of claim 6 wherein the irregularly shaped glass fibers are binderless.

8.   The insulation product of claim 1 having a recovery ratio within the range of from about 12:1 to about 50:1.

9.   The insulation product of claim 8 wherein the irregularly shaped glass fibers comprise two distinct glass compositions with different coefficients of thermal expansion,

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the difference in the coefficient of thermal expansion between
the two glasses being greater than about 2.0 ppm/$^\circ$C.

5   10.   The insulation product of claim 9 wherein the
irregularly shaped glass fibers are binderless.

              11.   The insulation product of claim 1 wherein the
irregularly shaped glass fibers are binderless.

              12.   The insulation product of claim 11 wherein
the irregularly shaped glass fibers are sufficiently entangled
that the binderless insulation product has integrity upon
10 suspension under its own weight.

              13.   The insulation product of claim 1 wherein the
irregularly shaped glass fibers comprise two distinct glass
compositions with different coefficients of thermal expansion,
the difference in the coefficient of thermal expansion between
15 the two glasses being greater than about 2.0 ppm/$^\circ$C.

              14.   An insulation product comprising irregularly
shaped glass fibers, the insulation product having a recovered
density within the range of from about 0.3 to about 0.6 pcf
(4.8 to 9.6 Kg/m^3) after compression of the insulation product
20 to a compressed density within the range of from about 6 to
about 18 pcf (96 to 288 Kg/m^3).

              15.   The insulation product of claim 14 having a
recovered density within the range of from about 0.3 to about
0.6 pcf (4.8 to 9.6 Kg/m^3) after compression of the product to
25 a compressed density within the range of from about 9 to about
18 pcf (144 to 288 Kg/m^3).

              16.   The insulation product of claim 14 having a
recovered density within the range of from about 0.3 to about
0.6 pcf (4.8 to 9.6 Kg/m^3) after compression of the product to
30 a compressed density within the range of from about 9 to about
15 pcf (144 to 240 Kg/m^3).

              17.   The insulation product of claim 14 having a
recovery ratio within the range of from about 12:1 to about
50:1.

35   18.   The insulation product of claim 1 wherein the
irregularly shaped glass fibers are binderless.

              19.   The insulation product of claim 18 wherein
the irregularly shaped glass fibers are sufficiently entangled

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that the binderless insulation product has integrity upon
suspension under its own weight.

        20.   The insulation product of claim 14 wherein
the irregularly shaped glass fibers comprise two distinct glass
5 compositions with different coefficients of thermal expansion,
the difference in the coefficients of thermal expansion between
the two glasses being greater than about 2.0 ppm/$^{\circ}$C.

FIG. 1

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FIG. 2

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FIG. 3

FIG. 4

FIG. 5

FIG. 6

FIG. 7


FIG. 8

FIG. 9

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FIG. 10

FIG. 11

122A

124A

FIG.12
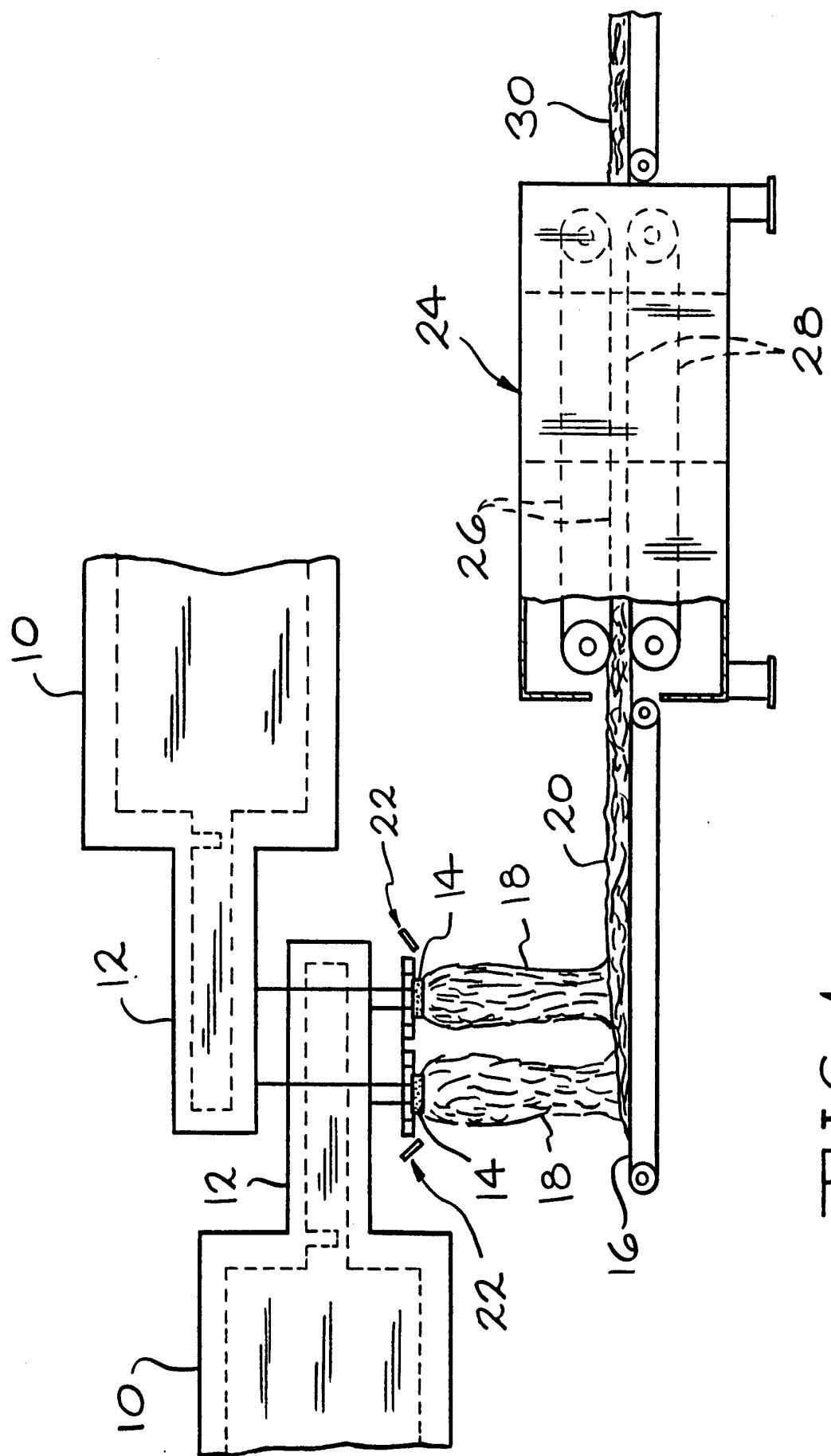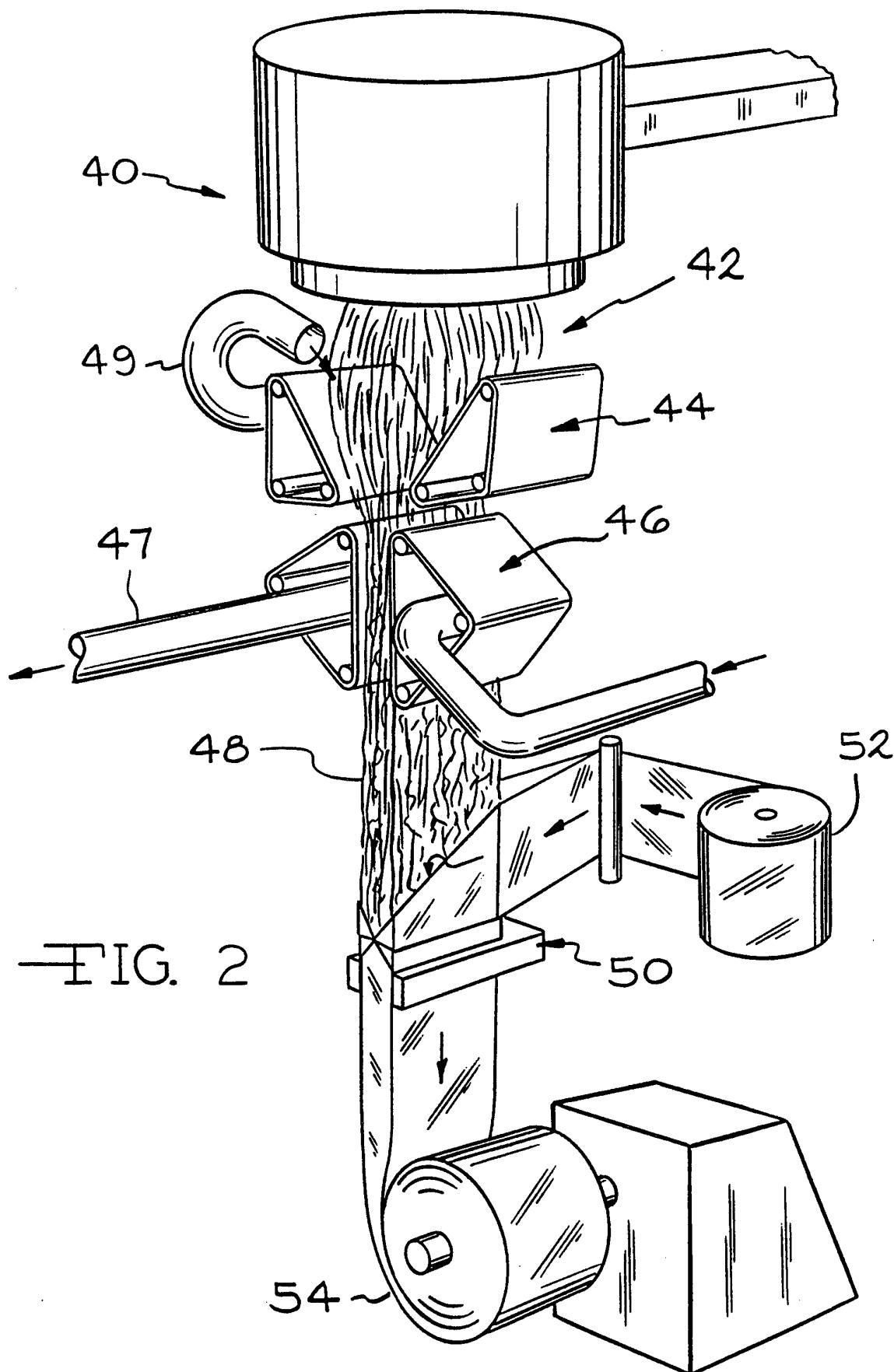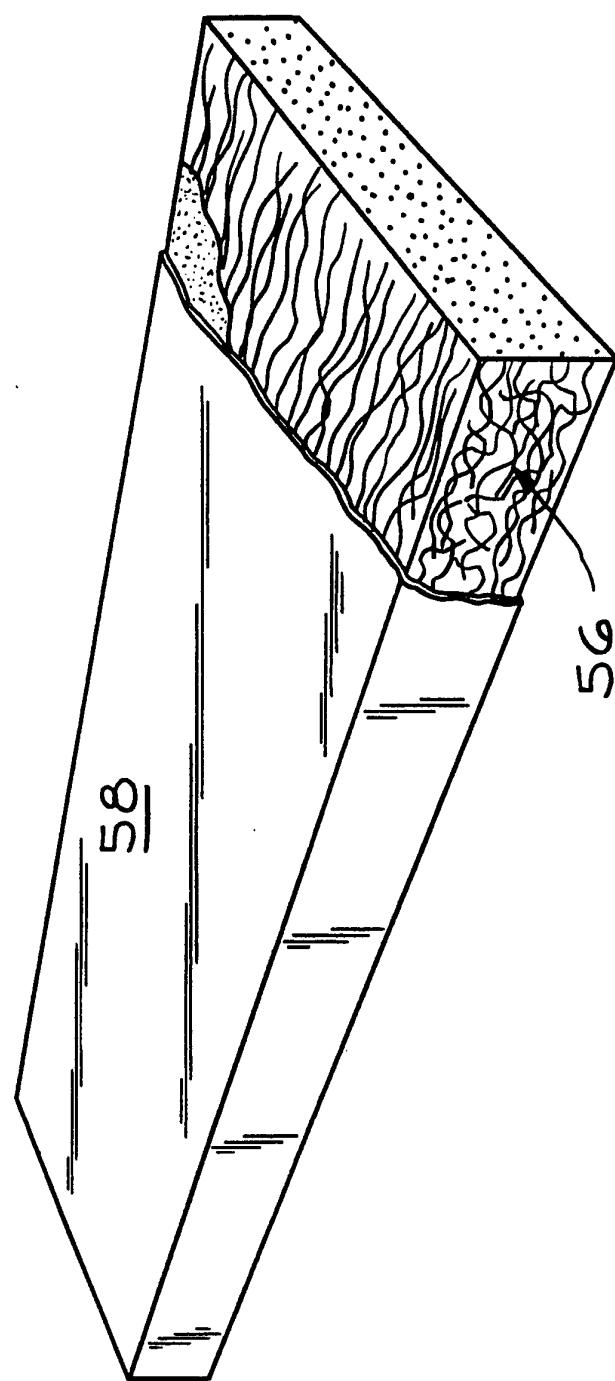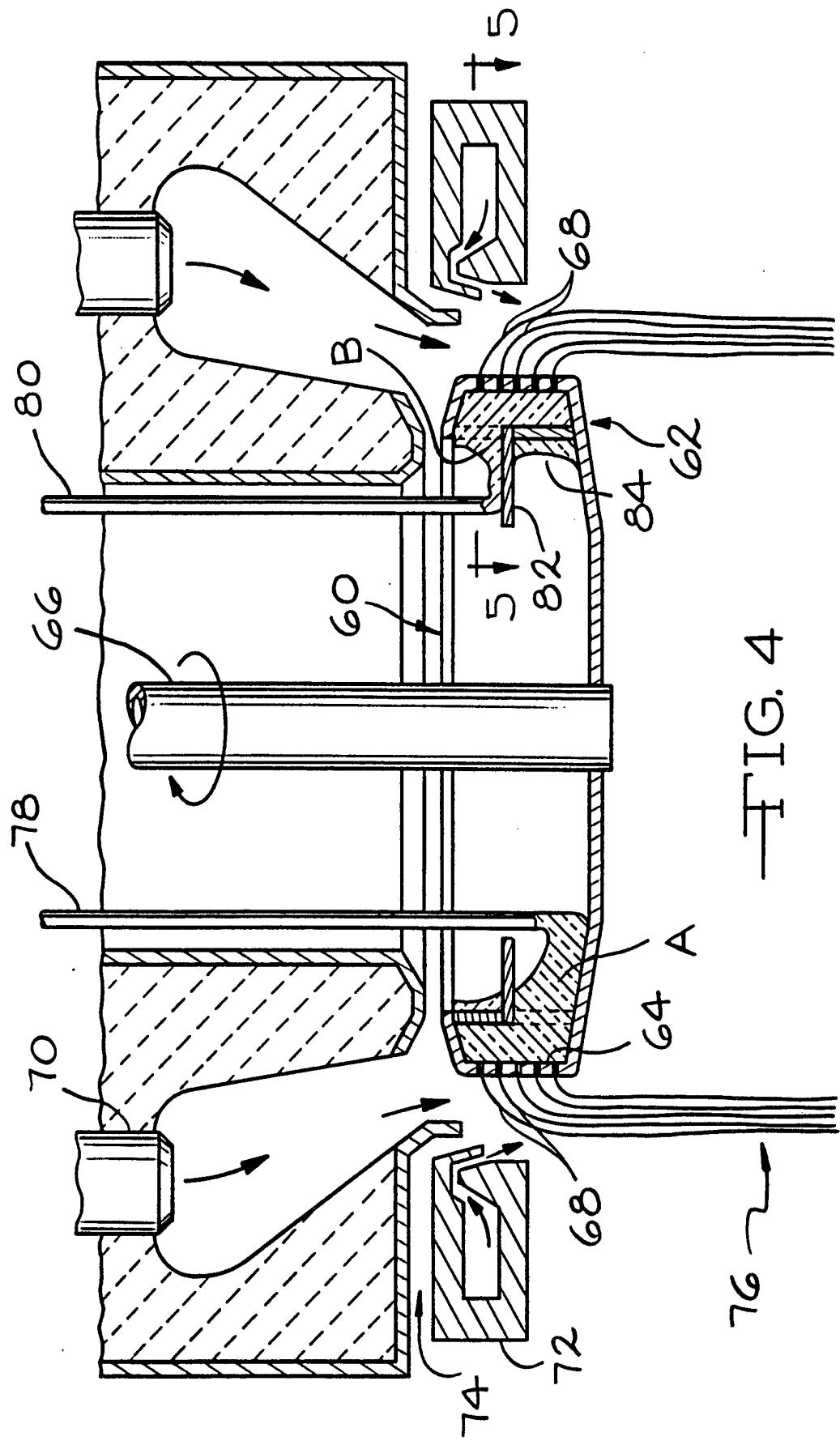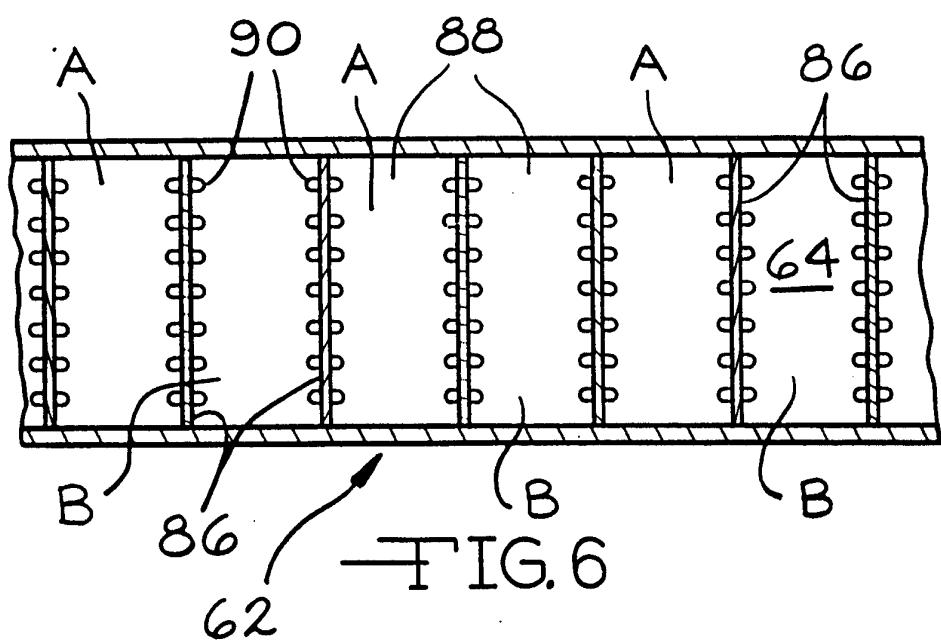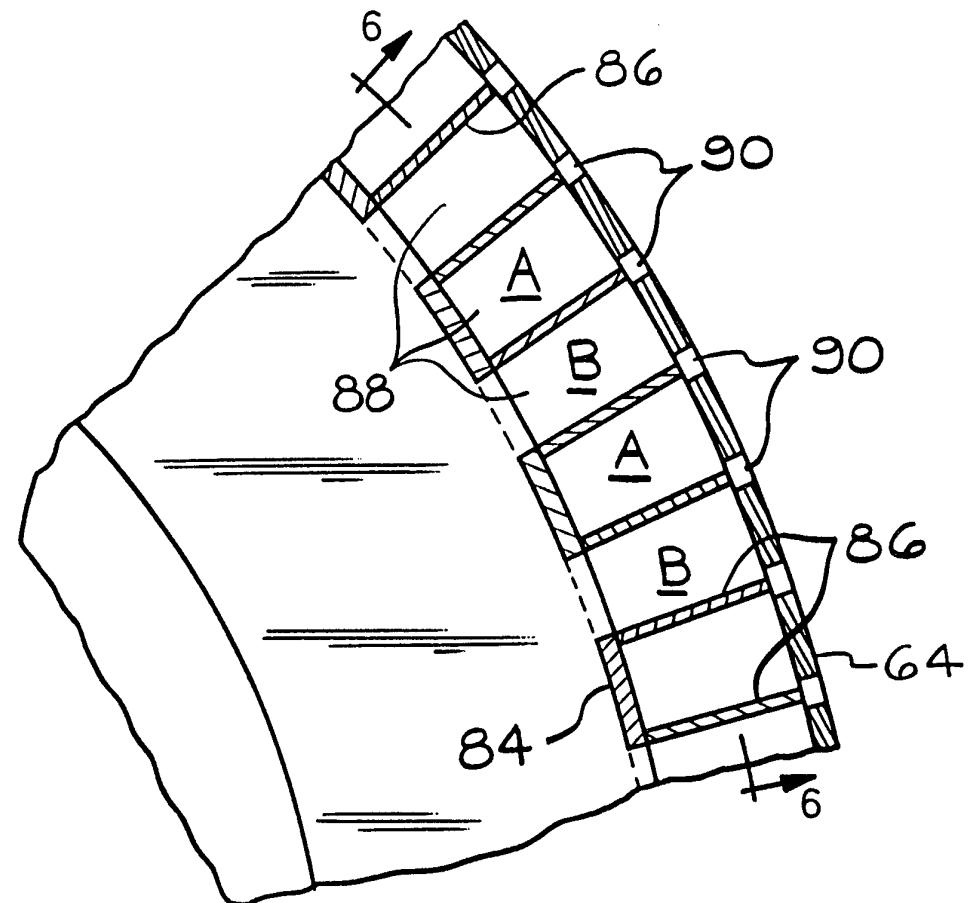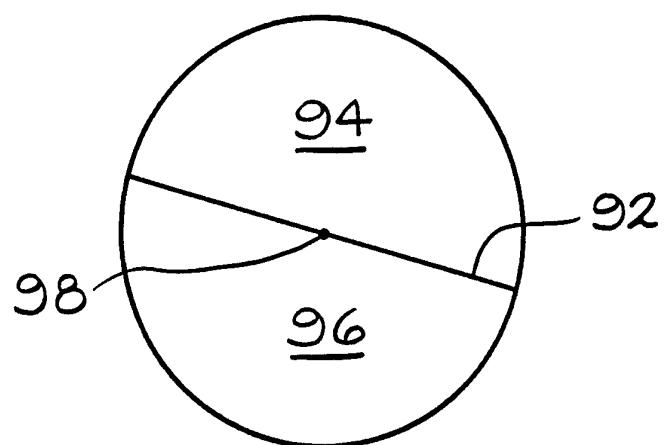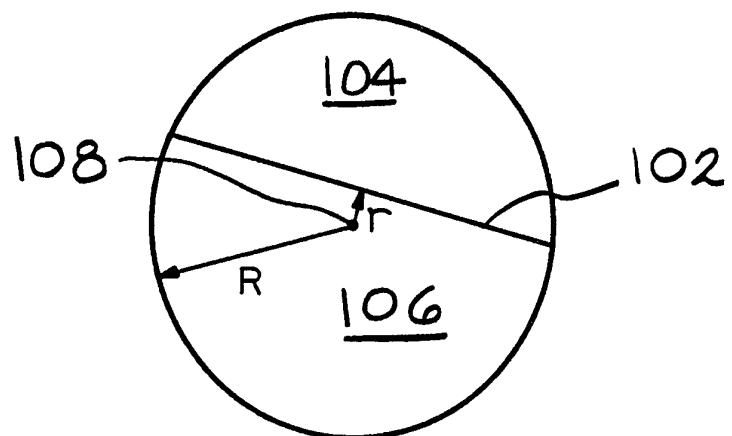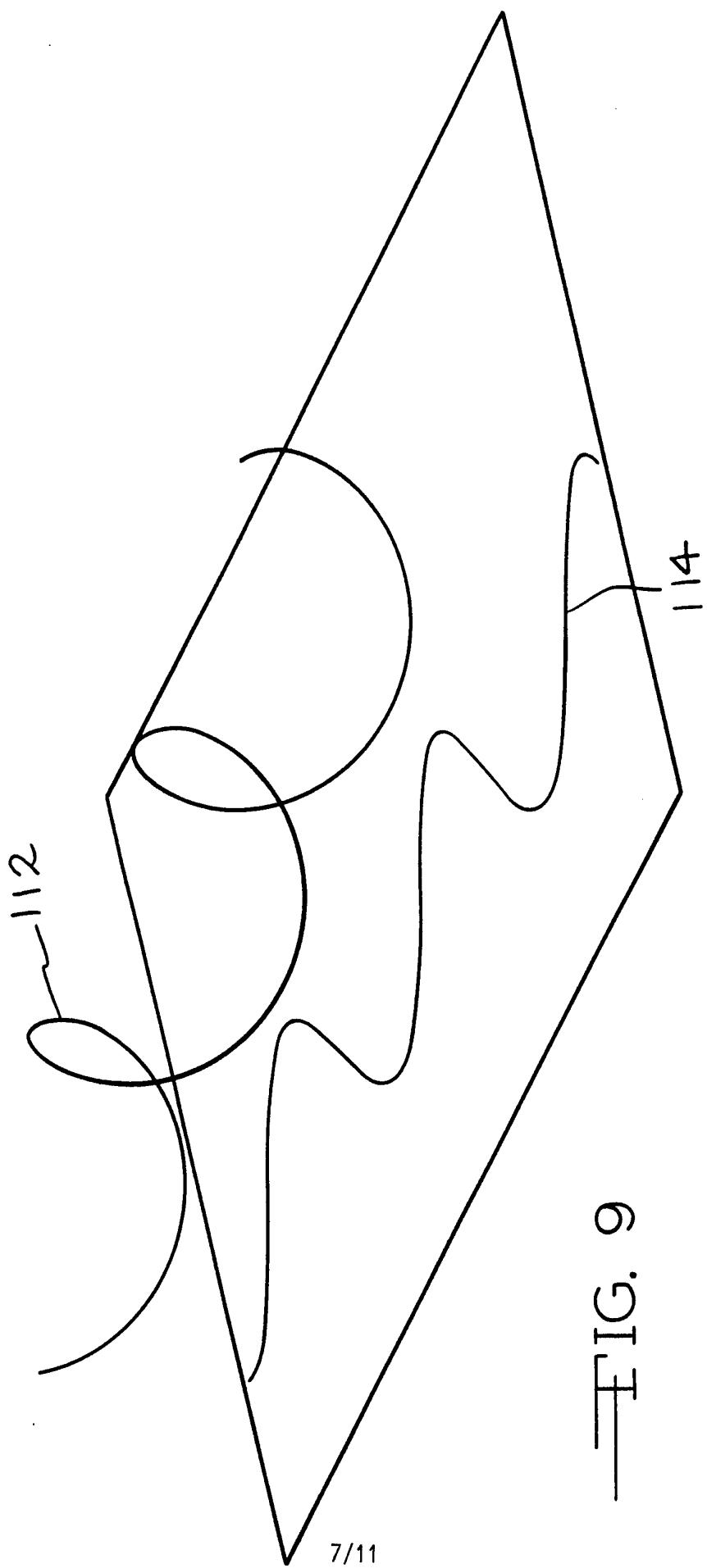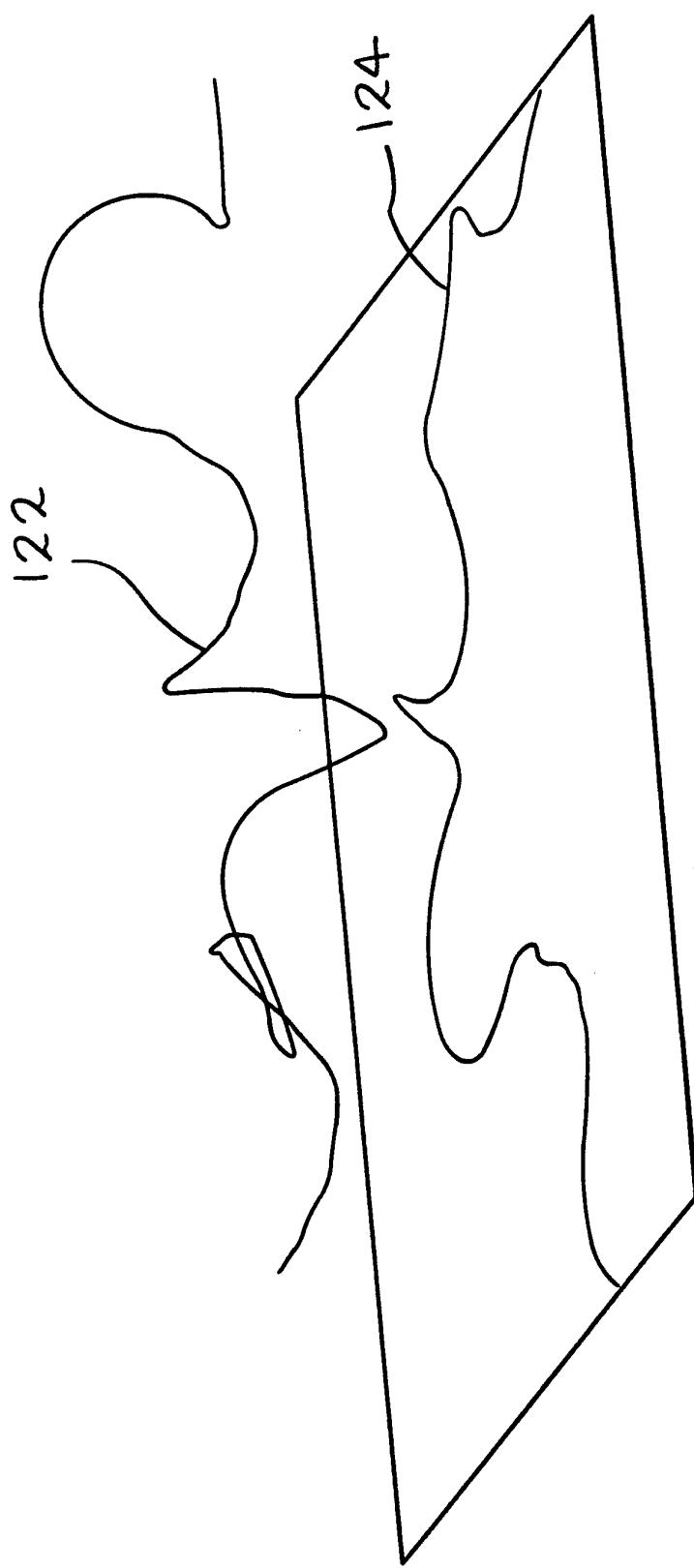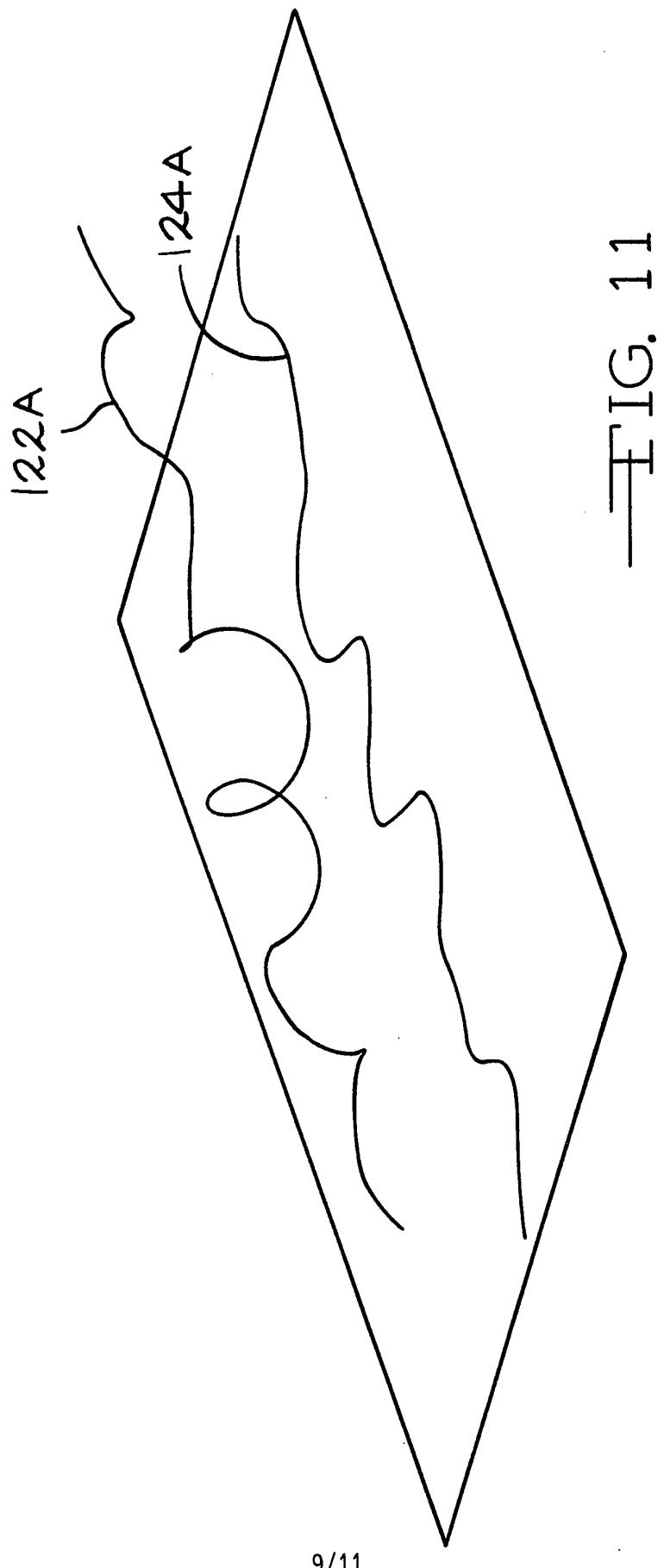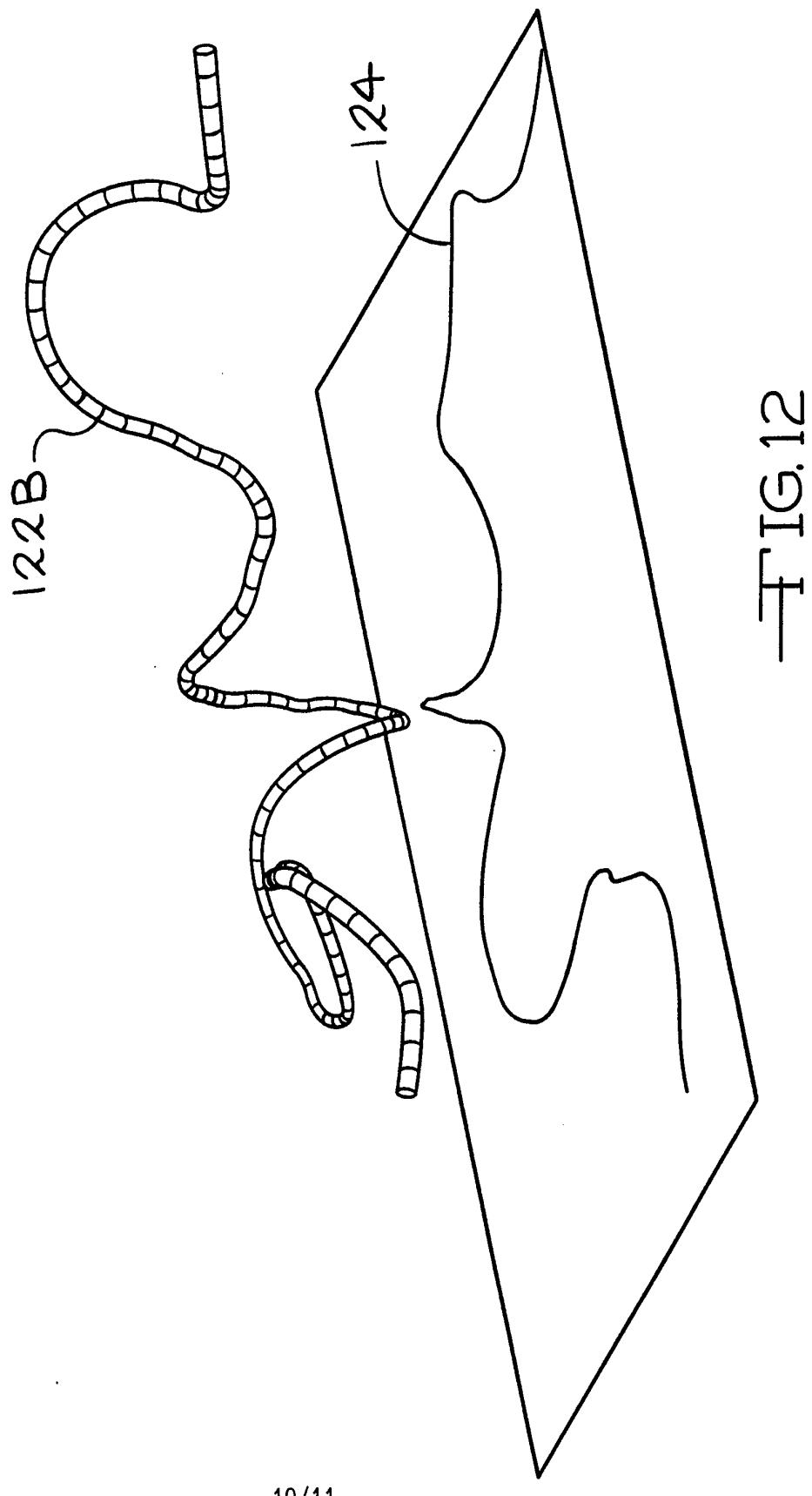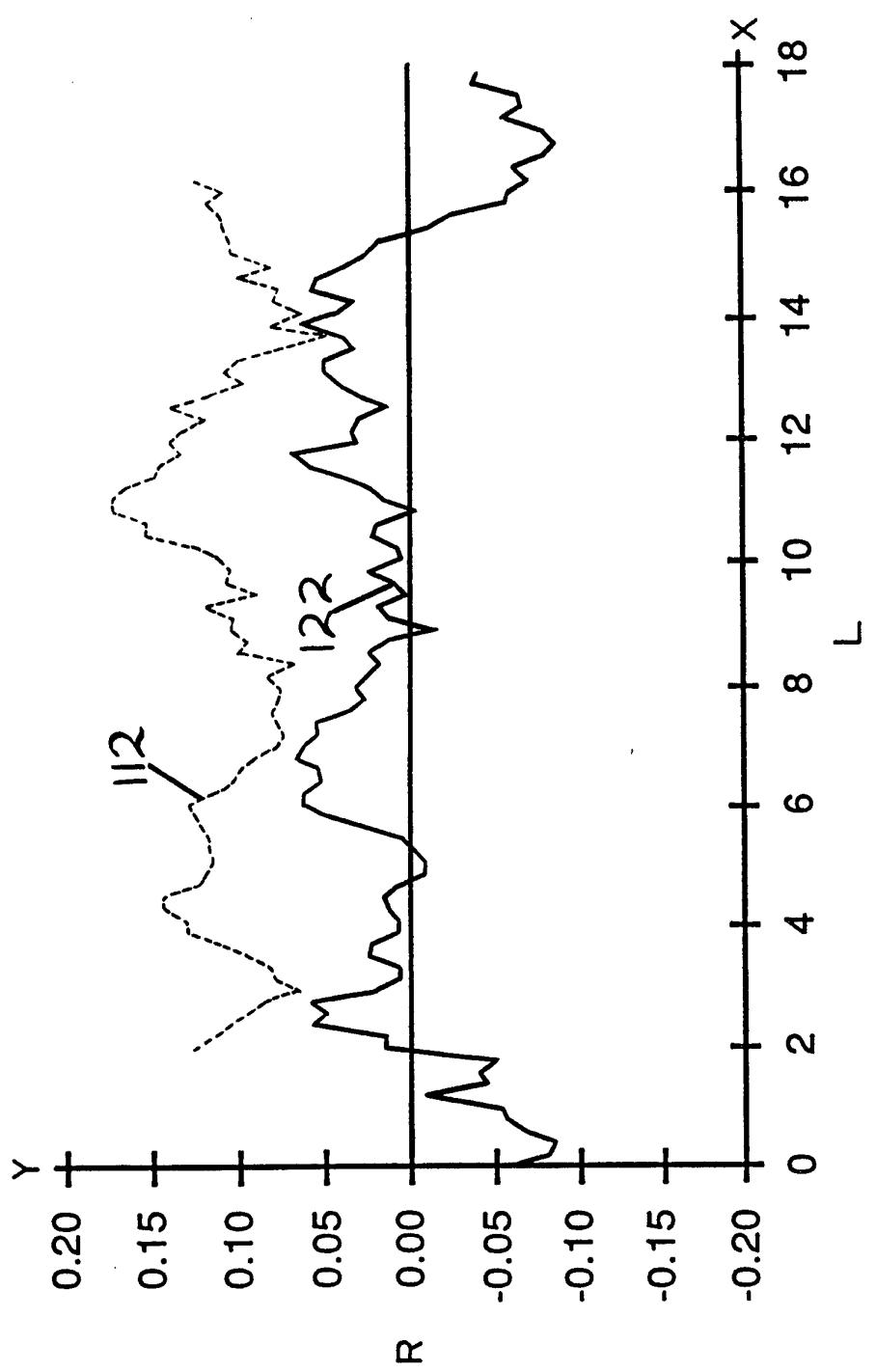
FIG. 13

INTERNATIONAL SEARCH REPORT

Intern. .onal Application No

PCT/US 94/12403

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6   C03B37/04   D02G1/18   D04H3/08

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 6   C03B   D02G   D04H

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.
A	US,A,2 927 621 (SLAYTER) 8 March 1960 see the whole document ---	1-20
A	US,A,3 073 005 (TIEDE) 15 January 1963 see the whole document -----	1-20

☐ Further documents are listed in the continuation of box C.   ☒ Patent family members are listed in annex.

* Special categories of cited documents :

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'L' document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

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

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'&' document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 February 1995	10. 02. 95

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Van den Bossche, W

Form PCT/ISA/210 (second sheet) (July 1992)

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US-A-2927621	08-03-60	NONE		
US-A-3073005	15-01-63	DE-B-	1217562	
		FR-A-	1217973	
		GB-A-	874808	