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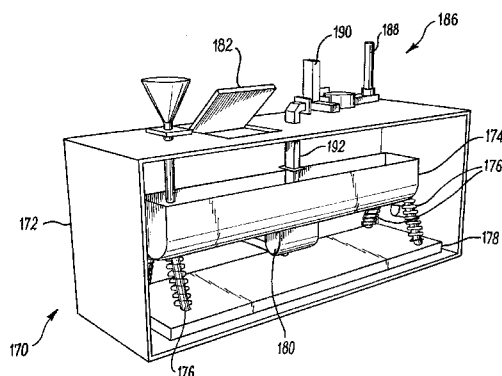
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(54) Title: APPARATUS FOR AND METHOD OF HEATING A FEEDSTOCK USING MICROWAVE ENERGY

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(57) Abstract: An apparatus for heating a feedstock using microwave energy, the apparatus has a feedstock receptacle, a vibrator which vibrates the receptacle so as to cause the feedstock to move relative to the receptacle, and a source of microwave energy arranged to direct microwave energy towards the receptacle. The vibrator vibrates the receptacle so as to cause a feedstock to describe a substantially helical path relative to the receptacle which results in substantially uniform heating of the feedstock by the microwave energy, regardless of a depth of a bed formed by the feedstock in the receptacle.

Apparatus for and Method of Heating a Feedstock using Microwave Energy

Field of the Invention

This invention relates to apparatus for heating a feedstock using microwave energy,
5 and to a method of heating a feedstock using such apparatus.

Background to the Invention

US Patent No. 4,045,638 shows apparatus for heating a feedstock using microwave energy, the apparatus comprising a trough for the feedstock, a vibrator operable to
10 vibrate the trough so as to cause the feedstock to move along the trough, and a source of microwave energy arranged to direct microwave energy into the trough.

In use of this known apparatus a rate at which the feedstock is introduced into the trough is controlled so that the feedstock forms a relatively shallow bed in the trough.

15 This is necessary to ensure reasonably uniform heating of the feedstock by the microwave energy.

The known apparatus is therefore less efficient than it might otherwise be, because in use of the apparatus only a relatively small portion of a volume of the trough is filled
20 by the feedstock.

Summary of the Invention

According to a first aspect of the invention there is provided apparatus for heating a feedstock using microwave energy, the apparatus comprising a receptacle with an
25 opening for receiving a feedstock, a vibrator operable to vibrate the receptacle so as to cause a feedstock in the receptacle to move relative to the receptacle, and a source of microwave energy arranged to direct microwave energy towards the receptacle, wherein the vibrator is operable to vibrate the receptacle so as to cause a feedstock in the receptacle to describe a substantially helical path relative to the receptacle.

30 The substantially helical path described by the feedstock results in substantially uniform heating of the feedstock by the microwave energy, regardless of a depth of a bed formed by the feedstock in the receptacle. This is because although at any given

moment a portion of the bed nearer to the source of microwave energy absorbs more of the microwave energy than a portion of the bed further from the source, the bed rotates relative to the source of microwave energy, so that as the feedstock moves relative to the receptacle, each part of the feedstock at some stage forms part of the portion of the bed nearer to the source of microwave energy. The term “substantially helical path” is used to convey the concept that the feedstock moves towards and away from the source of microwave energy in a curved path whilst at the same time travelling along the receptacle in a predetermined direction. The combined curved and linear movement of the feedstock describes a substantially helical curve although it will be appreciated that this description is not intended to be limited to curves which satisfy the mathematical definition of a helix.

The invention can provide apparatus that is more efficient than the known apparatus, because in use a relatively large portion of a volume of the receptacle can be filled by the feedstock.

In this specification the expression “microwave energy” means electromagnetic radiation with a frequency of 300 MHz or greater.

The receptacle may advantageously be substantially transparent to the microwave energy. In that case the source need not be arranged to direct the microwave energy into the opening of the receptacle but can direct the microwave energy at any part, even several parts, of the receptacle, the microwave energy passing through a wall of the receptacle to be absorbed by the feedstock.

Alternatively the receptacle may advantageously be substantially absorptive of microwave energy. This may be useful where the feedstock is incapable of absorbing the microwave energy, or is capable of absorbing the microwave energy only at an elevated temperature, because the receptacle can be heated by absorption of the microwave energy and the feedstock heated by contact with the receptacle. Although it is not essential for the source to be arranged to direct the microwave energy into the opening of the receptacle, this is desirable where the feedstock is capable of absorbing the microwave energy only at an elevated temperature, because the microwave energy

can then be absorbed by the feedstock when the feedstock has been heated by contact with the receptacle.

Of course, where the receptacle is substantially transparent to the microwave energy, or substantially opaque to the microwave energy and the source is not arranged to direct the microwave energy into the opening of the receptacle, the receptacle must be enclosed by a shield to protect the surroundings of the receptacle from the microwave energy.

Preferably, however, the receptacle is substantially reflective to the microwave energy.

In that case, although the source must be arranged to direct the microwave energy into the opening of the receptacle, or into a further opening for receiving the microwave energy, the use of the microwave energy is more efficient, as it is retained in the receptacle until it is absorbed by the feedstock, instead of being absorbed by the receptacle or a shield enclosing the receptacle. Where the receptacle is substantially reflective to the microwave energy it is unnecessary for the receptacle to be enclosed by a shield.

Where the receptacle has only the opening for receiving a feedstock, the apparatus must be operated in a batch mode, whereby the feedstock is introduced into the receptacle through the opening, the feedstock is heated and the feedstock must be discharged through the opening before more of the feedstock can be heated in the receptacle.

Preferably, therefore, the receptacle also has an opening for discharging a feedstock, and the vibrator is operable to vibrate the receptacle so as to cause a feedstock in the receptacle to move from the opening for receiving the feedstock to the opening for discharging the feedstock. The apparatus can then be operated in a continuous mode.

The receptacle may advantageously be provided with a portion capable of absorbing the microwave energy. This may be useful for heating a feedstock that is incapable of

absorbing the microwave energy, or that is capable of absorbing the microwave energy only at an elevated temperature, by contact with the feedstock.

5 The or each opening of the receptacle may advantageously be formed as a microwave choke adapted to permit the feedstock to be introduced or discharged through the opening, but to prevent the microwave energy from passing through the opening.

By way of example, the or each opening may comprise a plurality of substantially vertical slots, the width of each slot being no more than one quarter of the wavelength
10 of the microwave energy.

The receptacle may advantageously be provided with at least one further opening to allow gases released by the feedstock to escape from the receptacle.

15 Preferably the largest dimension of the at least one opening is no more than one quarter of a wavelength of the microwave energy.

In this way the at least one opening can allow gases released by the feedstock to escape from the receptacle whilst retaining the microwave energy in the receptacle.
20

Typical feedstocks to be heated using the apparatus are particulate solids.

It is envisaged, however, that feedstocks comprising a gas and a solid additive or a liquid and a solid additive might be heated using the apparatus.
25

For example, a feedstock comprising a hydrocarbon vapour and balls formed from a ceramic material capable of absorbing the microwave energy would be heated using the apparatus, to cause the hydrocarbon vapour to be "cracked" by the heated balls. The movement of the balls relative to the receptacle would cause the balls to collide
30 with one another, thereby cleaning the surfaces of the balls.

The receptacle is preferably provided with a lining formed from a ceramic material, to protect the receptacle from abrasive or corrosive feedstocks. The ceramic material is likely to be able to withstand higher temperatures than the material of the receptacle.

- 5 The lining may advantageously be provided with heating elements either inside the lining or between the lining and the material of the receptacle.

The heating elements can be used to heat the lining of the receptacle and to heat the feedstock by contact with the lining.

10

This is useful in the case of a feedstock the ability of which to absorb the microwave energy is dependent upon the temperature of the feedstock. With such a feedstock the feedstock can be heated by contact with the lining of the receptacle to a temperature at which it is capable of absorbing the microwave energy.

15

The lining is preferably constituted by a plurality of tiles formed from the ceramic material.

- 20 Whilst ceramic materials can be very hard wearing and resistant to corrosive chemicals, they can also be brittle. The plurality of tiles are therefore preferably fastened to the receptacle so as to allow sufficient relative movement between them to accommodate thermal expansion of the tiles and mechanical shock imparted by the feedstock.

- 25 The tiles may advantageously be fastened to the receptacle so as to define a plurality of substantially parallel grooves along which the feedstock moves as it describes the substantially helical path relative to the receptacle.

- 30 The substantially parallel grooves may be defined by the edges of the tiles, or the surfaces of the tiles against which the feedstock bears may be formed with grooves, which, when aligned, form "rifling" in the receptacle.

It has been found that the presence of the substantially parallel grooves helps to prevent fouling of the receptacle by the feedstock, as parts of the feedstock that adhere to the tiles are quickly scoured from the tiles by the movement of other parts of the feedstock through the grooves.

5

Where the receptacle is provided with an opening for receiving the feedstock and an opening for discharging the feedstock, the apparatus may advantageously further comprise a separator operable to separate an additive from the feedstock.

- 10 In the example of the feedstock comprising a hydrocarbon vapour and balls formed from a ceramic material, the balls would be such an additive.

The separator enables additives to be mixed with the feedstock at the opening for receiving the feedstock, the additives to pass with the feedstock to the opening for discharging the feedstock, and the additives to be separated from the feedstock at the opening for discharging the feedstock and returned to the opening for receiving the feedstock.

By way of example, where the feedstock is incapable of absorbing the microwave energy, the additive may be a substance, such as silicon carbide or magnetite, that is capable of absorbing the microwave energy, so that the feedstock can be heated by contact with the additive as the feedstock moves from the opening for receiving the feedstock to the opening for discharging the feedstock.

25 Alternatively, where the feedstock is capable of absorbing the microwave energy, the additive may be a substance, such as quartz, that is substantially transparent to the microwave energy, so that the feedstock is effectively provided with "windows" that assist the passage of the microwave energy into the centre of the feedstock.

30 Alternatively or additionally, the additive may be a catalyst to assist the treatment of the feedstock by the microwave energy, and or an abrasive to grind the feedstock as it moves from the opening for receiving the feedstock to the opening for discharging the feedstock.

In a first embodiment of the invention the receptacle comprises a helical chute, an axis of the helix being disposed substantially vertically in use of the apparatus.

- 5 The helical chute of the first embodiment may advantageously be constituted by a work bowl, separation flap and separation screen of a circular vibrator, the feedstock being introduced in use of the apparatus into the work bowl and being raised by the separation flap on to the separation screen as a result of the vibration of the work bowl. An example of a suitable circular vibrator is that sold under the name "CB" by
10 Walther Trowal GmbH & Co. KG of German. Other circular vibrators may be used such as that supplied by Rosler Hurley.

Where the helical chute is so constituted, the work bowl may advantageously be provided with a lid formed from a material reflective to the microwave energy so as to
15 retain microwave energy introduced into the work bowl in the work bowl until it is absorbed by the feedstock.

The lid may advantageously be formed with an opening for introducing microwave energy into the work bowl.

20

The opening preferably has the form of at least a portion of an annulus.

The apparatus may advantageously further comprise a waveguide arranged to transmit the microwave energy from the source of microwave energy to the opening of the lid.

25

Where the opening has the form of at least a portion of an annulus the waveguide preferably has the form of at least a portion of an annulus and is provided with a slot to transmit the microwave energy from the waveguide to the opening of the lid.

- 30 In this way the microwave energy can be directed continuously at the feedstock as it passes from the opening for receiving the feedstock to the opening for discharging the feedstock.

The ends of the helical chute are preferably each provided with a screen adapted to permit passage of the feedstock but to prevent passage of the microwave energy.

The screens may, for example, comprise a plurality of slots having a width of not
5 more than one quarter of a wavelength of the microwave energy.

In a second embodiment of the invention the receptacle comprises first and second cylindrical tubes, axes of the cylinders being disposed substantially horizontally in use of the apparatus with the first tube above the second tube and the first and second
10 tubes connected at one end by a third tube perpendicular to the first and second tubes.

The first, second and third tubes are preferably adapted to form a waveguide so that microwave energy introduced into the first tube is transmitted by the third tube into the second tube.

15 The vibrator is preferably arranged to vibrate the first and second tubes such that a feedstock introduced into a first end of the first tube passed along the first tube to the second end, falls through the third tube into the second end of the second tube, and passes along the second tube to the first end of the second tube.

20 The second embodiment of the invention gives a relatively long path length of the feedstock in the receptacle, and hence relatively lengthy exposure to the microwave energy, for a relatively small footprint of the apparatus.

25 Preferably at least one of the tubes is provided with an opening through which microwave energy can be introduced into the tube by the source of microwave energy.

It will be appreciated that sources of microwave energy are typically likely to be damaged if subjected to the vibrations necessary to move the feedstock relative to the
30 receptacle.

Moreover, vibration of a source of microwave energy can cause variation of the frequency of the microwave energy produced by the source of microwave energy.

Some sources of microwave energy are relatively insensitive to vibration in first and second orthogonal Cartesian planes but relatively sensitive to vibration in a third orthogonal Cartesian plane.

5

The vibration of the receptacle necessary to cause the feedstock to describe the substantially helical path relative to the receptacle is substantially restricted to first and second orthogonal Cartesian planes.

10 Where the source of microwave energy is relatively sensitive to vibration in the third Cartesian plane, therefore, the apparatus may advantageously further comprise a waveguide connecting the source of microwave energy and the receptacle, the waveguide being arranged to connect the source of microwave energy and the receptacle with their third Cartesian planes parallel to one another.

15

This reduces the transmission to the source from the receptacle of the vibrations that would be most harmful to the source.

The waveguide may advantageously further comprise a flexible portion to further
20 reduce the transmission of the vibrations that would be most harmful to the source.

Although the vibration of the receptacle necessary to cause the feedstock to describe the substantially helical path relative to the receptacle is substantially restricted to the first and second orthogonal Cartesian planes, in some circumstances the vibration in
25 the first plane is much larger than the vibration in the second plane.

In these circumstances the apparatus may advantageously further comprise a waveguide connecting the source of microwave energy and the receptacle, the waveguide comprising first and second portions, a first end of the first portion being
30 connected to the source, a second end of the second portion being connected to the receptacle, and a second end of the first portion forming a sliding fit in or over a first end of the second portion.

Such a waveguide can considerably reduce the vibrations in the first plane transmitted from the receptacle to the source of microwave energy.

At least one of the first and second portions of the waveguide may advantageously
5 include a flexible portion to reduce the transmission of vibrations of the receptacle in the second and third planes to the source.

Preferably, however, the apparatus further comprises a waveguide connecting the source of microwave energy and the receptacle, the waveguide comprising first and
10 second portions and a resonant cavity, a first end of the first portion being connected to the source, a second end of the second portion being connected to the receptacle, a second end of the first portion projecting into the resonant cavity through a first opening, a first end of the second portions being aligned with one another so as to permit the microwave energy to be transmitted from the second end of the first
15 portion to the first end of the second portion, but separated from one another by a distance sufficient to ensure that vibration transmitted to the second portion from the receptacle is not transmitted to the first portion.

The second end of the first portion and the first end of the second portion may
20 advantageously be provided with microwave horns.

The microwave horns increase the cross-sectional area of the first and second portions and reduce the effect on the transmission of the microwave energy of misalignment of the portions as a result of the vibration transmitted to the second portion by the
25 receptacle.

The source of microwave energy preferably comprises a travelling wave tube.

Travelling wave tubes are able to tolerate much greater vibrations than the more
30 common magnetron.

In a third embodiment of the invention the receptacle comprises a linear trough with a lid.

The linear trough of the third embodiment may advantageously be constituted by a trough of a trough vibrator, suitable examples of which are those sold under the name “TFM” and “TMV” by Walther Trowal GmbH & Co. KG of Germany.

5

The lid may advantageously be provided with at least one aperture for venting gases released from the feedstock from the receptacle.

10

The at least one aperture preferably has a maximum dimension of no more than one quarter of a wavelength of the microwave energy.

Such an aperture can vent gases from the receptacle whilst retaining the microwave energy in the receptacle.

15

It is envisaged that the receptacle may be divided into upper and lower compartments divided by a screen adapted to prevent passage of a solid feedstock between the compartments but to permit passage of the microwave energy and a gas between the compartments.

20

In use of such a receptacle the feedstock would be introduced into the upper compartment and a solvent would be introduced into the lower compartment, the solvent being evaporated either by absorption of the microwave energy or by contact with a portion of the receptacle capable of, and heated by, absorption of the microwave energy, and the evaporated solvent passing through the screen and the solid feedstock in the upper compartment.

25

For example, the solvent may be water, the apparatus then being suitable for hydrodistillation of the feedstock.

30

Preferably, the microwave energy is directed towards the feedstock from a position above the feedstock, in use.

Optionally, the microwave energy is directed towards the feedstock from a position to the side of the feedstock, in use.

- 5 According to a second aspect of the invention there is provided a method of heating a feedstock using microwave energy, the method comprising the steps of introducing a feedstock into a receptacle of apparatus according to the first aspect of the invention, vibrating the receptacle to move the feedstock relative to the receptacle, and directing microwave energy towards the receptacle, wherein the step of vibrating the receptacle
10 to move the feedstock relative to the receptacle comprises vibrating the receptacle to cause the feedstock to describe a substantially helical path relative to the receptacle.

The feedstock can be a solid, a liquid mixed with a solid, or a gas mixed with a solid.

- 15 The method may advantageously further comprise the step of introducing at least one body formed at least in part from a substance capable of absorbing the microwave energy into the receptacle.

Such substances include silicon carbide, graphite, magnetite and ferrite.

- 20 Introducing the at least one body formed from the substance capable of absorbing the microwave energy into the receptacle enables a feedstock that is incapable of absorbing the microwave energy to be heated by the microwave energy, by contact with the at least one body as the feedstock describes the substantially helical path
25 relative to the receptacle.

Preferably the method further comprises the step of introducing a plurality of bodies formed from the substance capable of absorbing the microwave energy into the receptacle.

- 30 The method preferably comprises the steps of introducing the feedstock into an opening of the receptacle for receiving the feedstock, vibrating the receptacle to move the feedstock relative to the receptacle from the opening for receiving the feedstock to

an opening for discharging the feedstock, and discharging the feedstock from the opening for discharging the feedstock.

Where the method comprises the steps of discharging the feedstock from the opening
5 for discharging the feedstock and introducing the plurality of bodies formed from the substance capable of absorbing the microwave energy into the receptacle, the method may advantageously further comprise separating the plurality of bodies from the feedstock at the opening for discharging the feedstock and returning them to the opening for receiving the feedstock.

10

This prevents the thermal energy of the plurality of bodies from being wasted.

The method may advantageously further comprise the step of introducing at least one body formed at least in part from a catalyst into the receptacle.

15

The method may advantageously further comprise the step of introducing at least one abrasive body into the receptacle.

The method may advantageously further comprise the step of introducing at least one
20 body formed at least in part from a material that is substantially transparent to the microwave energy into the receptacle.

The at least one body formed at least in part from a material that is substantially transparent to the microwave energy can provide a "window" in a bed formed by the
25 feedstock to allow the microwave energy to pass into a middle portion of the bed.

Brief Description of the Drawing Figures

The invention will now be described in greater detail with reference to the attached drawing figures, in which:

30

Figure 1 is a partially cut away perspective view of a first embodiment of apparatus in accordance with the first aspect of the invention;

Figure 2 is a partially cut away perspective view of a second embodiment of apparatus in accordance with the first aspect of the invention;

Figure 3 is a partial perspective view and detail from one end of a third embodiment
5 of apparatus in accordance with the first aspect of the invention;

Figure 4 is a partial perspective view and detail from one end and one side of the third embodiment;

10 Figure 5 is a perspective view of one of the tiles of Figures 3 and 4;

Figure 6a is a perspective view and figure 6b a side view of a circular waveguide with a T-junction;

15 Figure 7 is a perspective view of a first waveguide;

Figure 8 is a perspective view of a second waveguide;

Figures 9a and 9b are side and plan views respectively of another embodiment of the
20 present invention;

Figures 10a and 10b show a partial plan view and a side view of an embodiment of the present invention;

25 Figure 11 is a partial perspective view of another embodiment of the present invention; and

Figure 12 is a perspective view of yet another embodiment of the present invention.

30

Detailed Description of Embodiments

The first embodiment 10 of apparatus for heating a feedstock using microwave energy comprises a receptacle 12 in the form of a work bowl of a Walther Trowal "CB" circular vibrator, a vibrator (not shown) comprising an electric motor with an adjustable eccentric flyweight at each end of the shaft of the motor, the vibrator being
5 enclosed in a central housing 13 in the centre of the work bowl 12, a lid 14 closing the top of the work bowl, and a waveguide 16 connected to a magnetron (not shown) for transmitting microwave energy from the magnetron into the work bowl through the lid 14.

10 The vibrator and magnetron are not shown in Figure 1 because these components are conventional in their construction and their function is well understood.

The work bowl 12 is shown partially cut away in order to show more clearly an opening 18 for receiving a feedstock. The opening 18 is provided with a funnel 20 for
15 receiving the feedstock and a microwave choke 22 in the form of a steel sheet with a plurality of vertical slots is located in front of the opening 18. The slots have a width of no more than one quarter of the wavelength of the microwave energy.

The work bowl 12 also has an opening 24 for discharging the feedstock and a
20 microwave choke 26 of similar construction to microwave choke 22 is located in front of the opening 24.

In use of the apparatus the vibrator causes the work bowl to vibrate such that a particulate solid feedstock placed in the funnel 20 passes through the choke 22 and the
25 opening 18 into the work bowl 12 and moves around the work bowl away from the opening 18, describing a substantially helical path relative to the work bowl, the axis of the helix being substantially horizontal.

The circular vibrator also comprises a separator in the form of a separation flap 28 in
30 an upper portion of the work bowl 12 and a separation screen 30. The separation flap 28 projects into a lower portion of the work bowl 12 such that the feedstock moving around the work bowl passes from the lower portion of the work bowl over the

separation flap into the upper portion of the work bowl, over the separation screen 30 and through the opening 24 and choke 26 out of the work bowl.

It will be apparent that in moving from the opening 18 to the opening 24 the feedstock
5 describes a substantially helical path around the vibrator housing 13, an axis of the helix being substantially vertical. It is important to appreciate that this is not the substantially helical path of the invention, the substantially helical path of the invention being described by the feedstock about an axis that corresponds to the substantially helical path around the vibrator housing 13.

10

The separation screen 30 overlies a portion of the work bowl adjacent to the opening 18. This enables a solid additive to be introduced into the opening 18 with the feedstock, the additive moving with the feedstock from the opening 18 to the separation screen 30, then passing through the screen 30 to return to the portion of the
15 work bowl adjacent to the opening 18 while the feedstock passes over the screen 30 to the opening 24, from which it is discharged from the work bowl.

The additive might be pellets of a material, such as silicon carbide, capable of absorbing the microwave energy. Such an additive might be used where the feedstock
20 is incapable of absorbing the microwave energy, so as to heat the feedstock by contact with the feedstock as the feedstock and additive move through the work bowl.

Alternatively the additive might be serrated steel balls, to grind the feedstock as it moves through the work bowl.

25

The Walther Trowal "CB" circular vibrator is normally supplied with a polyurethane lining in the work bowl, which is formed from steel. The polyurethane lining is not present in the first embodiment 10 because it has a relatively low melting point and would be melted by contact with the feedstock, because of the temperature reached by
30 the feedstock.

As described in more detail below, the work bowl is preferably provided with a lining of tiles formed from a ceramic material (not shown), this being harder wearing and more resistant to corrosive feedstocks than the steel of the work bowl.

- 5 The waveguide 16 is connected by a further waveguide (not shown) to the magnetron in order to reduce the vibrations transmitted by the work bowl to the magnetron. Suitable further waveguides are shown in Figures 6 and 7.

10 The lid 14 has a slot (not shown) in the shape of the greater part of an annulus. The slot overlies the path followed by the feedstock as it moves through the work bowl. The waveguide 16 overlies the slot and is provided with a slot corresponding to that of the lid, so as to enable microwave energy introduced into the waveguide from the magnetron to be transmitted into the work bowl. The further waveguide is connected to an enlarged portion 32 at one end of the waveguide 16.

15 Turning to Figure 2, the second embodiment 40 of apparatus for heating a feedstock using microwave energy comprises a receptacle 42 in the form of first, second and third steel tubes 44, 46 and 48, respectively mounted in a support with the first and second tubes 44 and 46 horizontal and the first tube 44 above the second tube 46. The third tube 48 joins the first and second tubes 44 and 46. The second embodiment also comprises a vibrator in the form of an electric motor 52 with first and second eccentric flyweights 54a, 54b mounted on a shaft 56 driven by the motor 52, a travelling wave tube 58 connected by a section of flexible waveguide 60 to a waveguide 62 mounted on top of the first tube 44.

25 A first end of the first tube 44 is provided with an opening 64 for receiving a feedstock and a first end of the second tube 46 is provided with an opening 66 for discharging the feedstock. In use of the apparatus the motor 52 and eccentric flyweights 54a, 54b cause the support 50 and first and second tubes 44 and 46 to vibrate so as to cause a feedstock introduced into the opening 64 of the first tube 44 to move from the first end to the second end of the first tube 44, describing a substantially helical path, an axis of the helix being parallel to an axis of the first tube 44. The third tube 48 joins the second ends of the first and second tubes 44 and 46.

Upon reaching the second end of the first tube 44, the feedstock falls through the third tube 48 into the second end of the second tube 46. The vibration of the second tube causes the feedstock to move from the second end to the first end of the second tube 46, describing a substantially helical path, until the feedstock reaches the opening 66,
5 from which it is discharged from the second tube 46.

The first tube 44 is provided with a linear slot (not shown) in its upper surface, the slot extending for almost the entire length of the tube. The waveguide 62 is J-shaped, having a long limb that is attached to the top of the first tube 44 over the linear slot,
10 and a short limb parallel to the long limb, to which the section of flexible waveguide 60 is connected. The long limb of the waveguide 62 is formed with a linear slot corresponding to that of the first tube 44, so as to enable microwave energy in the waveguide 62 to be transmitted into the first tube 44. The first, second and third tubes 44, 46 and 48 form a resonant cavity, such that microwave energy introduced into the
15 first tube 44 that is not absorbed by the feedstock can be transmitted by the third tube 48 into the second tube 46 to heat the feedstock in the second tube 46.

It will be appreciated that the travelling wave tube 58, which is obtained from Albacom Limited of Scotland, is very much less sensitive to vibration than the more
20 conventional magnetron, so that the vibration isolation provided by the section of flexible waveguide 60 suffices to protect the travelling wave tube from damage.

Figure 3 shows a portion of a third embodiment 70 of apparatus for heating a feedstock using microwave energy, the apparatus comprising a receptacle in the form
25 of a trough 72 of a Walther Trowal "TFM" trough vibrator, a vibrator (not shown) operable to vibrate the trough 72 so as to cause a feedstock in the trough to move from a first end to a second end of the trough, describing a substantially helical path. The trough is formed from steel and the polyurethane lining normally provided by Walther Trowal is omitted. Instead the trough 72 is lined with a plurality of tiles formed from
30 sintered alumina. Three such tiles are shown in the detail of Figure 3, one of the tiles being denoted by reference numeral 74. The tile 74 is shown more clearly in Figure 5 and consists of a generally rectangular base portion 76 and a ridged upper portion 78.

The base portion 76 has two long sides and two short sides. A tongue 80 extends along one of the short sides and a corresponding groove extends along the other short side. Four wire holes 82a, 82b, 82c and 82d are formed through the base portion 76 between the long sides. The ridged upper portion 78 comprises a ridge with a
5 semicircular cross section, the ridge running parallel to the short sides of the base portion 76. A wire hole runs through an upper part of the ridge. The wire holes enable electric wires to be passed through the tiles when installed in the trough to heat the tiles and hence the feedstock by contact with the tiles. This is useful where the feedstock is capable of absorbing the microwave energy only at an elevated
10 temperature, as the tiles can be used to heat the feedstock to the elevated temperature at which the feedstock is capable of absorbing the microwave energy.

Returning to Figure 3, the tiles have been fastened into the trough with their short edges extending in the direction of travel of the feedstock. A more preferable
15 arrangement is shown in Figure 4, where the tiles have been fastened into the trough with their short edges extending perpendicular to the direction of travel of the feedstock. The ridges of the tiles define a series of grooves in the lining of the trough. One of these grooves is denoted by reference numeral 86 in Figure 4. It has been found that when the tiles are arranged as shown in Figure 4, that is with the grooves
20 running perpendicular to the direction of travel of the feedstock through the trough, the substantially helical path described by the feedstock causes the feedstock to run along the grooves, which tends to remove any of the feedstock that may have adhered to the tiles.

25 Although not shown in Figures 3 and 4, the trough 72 is provided with a lid made from steel, which prevents the microwave energy from escaping from the top of the trough. The lid is provided with a linear slot and a waveguide with a corresponding linear slot is fastened to the lid over the slot, to transmit microwave energy from the waveguide into the trough. The waveguide is connected to a magnetron.

30 Various features and considerations in respect of the microwave system design for the apparatus of the present invention are described below. Embodiments of the present invention may require the design of microwave applicators at 896 MHz (or possibly 2450 MHz). The apparatus will be used to treat loads including water, grain and ash

within a vibrating chamber which may contain ceramic chips (e.g. alumina) that assist with grinding and heating. Typically, a microwave applicator is designed for a single well designed and well characterised load. However, in the case of the present invention, the apparatus is required to function with a minimal amount of
5 modification for a range of treatments and a number of possible types of load have been identified.

The individual elements of the load are all much smaller than the wavelength, so it is possible to treat them as a homogeneous material having an effective permittivity. In
10 making this approximation, a uniform distribution of chips is assumed, which is consistent with the isotropic nature of the movement of the load that has been observed when vibrations are applied in the present invention.

In one example, similar to that shown in figure 1, the constraints adopted for
15 calculating the microwave applicator design were as follows.

1. Linear trough of circular or horseshoe cross section
2. Approximate diameter 320mm, length 500 – 1800 mm.
3. Uncoated inner metal surface. May later have grooved ceramic heaters
- 20 4. Preferred operating frequency 896 MHz
5. Preferred heating distribution is tapered to avoid thermal shock
6. Water inlet/outlet ca. 20mm diameter pipe (double as choke)
7. Grain inlet/outlet ca. 100mm diameter pipe (double as choke)
8. Grain inlet/outlet protected by sliding shutter
- 25 9. Ceramic window to be protected from strike by alumina chips
10. Vibration isolation - to be considered separately from this report.

On the basis of the above and other designs of the apparatus of the present invention described herein, two main design approaches have been adopted. The first uses a
30 slotted waveguide to deliver power along the length of the trough, the second involves directly illuminating one or more apertures spaced along the trough, treating it either as a resonant cavity or a travelling wave applicator.

Unloaded cavities demonstrated high quality factors (Q), in excess of 200,000 while loaded cavities had Qs closer to 500. Where the source is located at the top, any design relying on such narrow bandwidths will be expensive to machine to tolerance. A single source illuminating the end of a short section of rectangular waveguide that
5 then excited a circular waveguide (the trough) produced useful results. With a range of lossless loads the short trough simulated was resonant but between 30 – 96 % of the power was absorbed in the load depending on the relative permittivity of the load. The trough stops being resonant if the load is sufficiently absorbing that it prevents power reaching the far end wall and this is desirable. With a water load, 57 % of the
10 power is absorbed. In a second variation of this design, a 90° bend is used to put the source aperture above the load and out of the way of the ceramic chips. In this case, 52 % power was absorbed in the load, without any further matching being performed.

Figures 6a and 6b show an apparatus 81 connected to a microwave source 83 and to a
15 cavity 85 via a circular-waveguide T-junction 87. This arrangement gave strong heating under the junction and less heating towards the ends. The unoptimised performance of this system, under a variety of lossless loads was superior to the slotted waveguide with 22 – 25% of the power being absorbed into the load. The first water load performed even better, achieving similar power absorbed in the load to that
20 of the single ended design (51%). Most of the heating occurred immediately under the aperture, but with the second water load and grain load, the heating occurs at greater depths into the trough because these loads do not absorb as strongly.

Due to the impedance mismatch caused by the load in the cavity, an E-H tuner was
25 included to improve the performance improved. The E-H tuner comprises two waveguide stubs of tuneable length. The length of each stub is set by a plunger. The plunger settings were coarsely optimised for the first water load according to a well known scheme using a parametric analysis feature. This improved the performance significantly, with ca. 99% power absorbed in the load. Results for a simulated
30 second water load and grain load showed 95% and 87% power absorbed in the load, although these were with coarsely optimised E-H tuner settings.

A simulation of 20 mm diameter inlet and outlet pipes for the water-load application was conducted and even in the worst case where the chokes are full of workload, the power transfer out of these pipes was below -150Db.

5 An embodiment 100 of a further waveguide is shown in Figure 6. The further waveguide comprises a first section of waveguide 102 connected to a first microwave horn 104, a second section of waveguide 106 connected to a second microwave horn 108, and a cylindrical shield 110 enclosing the microwave horns 104 and 108. The shield 110 is provided with first and second apertures in diametrically opposed portions of its cylindrical surface. The first aperture 112 is larger than the cross
10 section of the first section of waveguide 102, which passes through the first aperture 112. The second aperture is the same size as the cross section of the second section of waveguide 106, which passes through the second aperture. The microwave horns 104 and 108 face one another inside the shield 110 and are separated by an airgap.

15 The second section of waveguide 106 would be connected to the waveguide of the apparatus for heating a feedstock. The first section of waveguide 102 would be connected to the magnetron. In use of the apparatus the second section of waveguide 106, second microwave horn 108 and shield 110 will vibrate because they are coupled to the receptacle of the apparatus. The airgap between the microwave horns 104 and
20 108 and the clearance between the first section of waveguide 102 and the shield 110, as determined by the size of aperture 112, is chosen to be sufficient to prevent the microwave horns 104 and 108 and the first section of waveguide 102 and the shield 110 from coming into contact. The magnetron is therefore isolated from the vibration of the receptacle but able to transmit the microwave energy to the waveguide of the
25 apparatus.

A second embodiment 120 of a further waveguide is shown in Figure 7. The waveguide comprises a magnetron 122 connected to a first section 124 of waveguide, a section of flexible waveguide 126 connected to the first section 124, a section 128 of
30 relatively large diameter waveguide connected to the section of flexible waveguide 126, a window 130 that is transparent to the microwave energy, a compliant seal 132 connecting the window 130 to a second section 134 of waveguide, a section of flexible waveguide 136 connected to the second section 134 of waveguide, and a

section 138 of relatively small diameter waveguide connected to the section of flexible waveguide 136. The section 138 of relatively small diameter waveguide is located inside the section 128 of relatively large diameter waveguide, in which it forms a sliding fit.

5

In use of the apparatus the window 130 would be connected over an aperture in a waveguide of the apparatus, to enable the microwave energy to pass through the window into the waveguide of the apparatus. The second embodiment 120 of further waveguide is suited to use where the magnitude of the vibration of the receptacle is much greater in the vertical direction than the horizontal direction, the further waveguide being used as shown in Figure 7, with the magnetron above the window. The sliding fit between the sections 128 and 138 can accommodate vibrations of large amplitude in the vertical direction. The flexible sections 126 and 136 can accommodate vibrations of smaller amplitude in horizontal directions.

15

Figures 9a and 9b are side and plan views respectively of another embodiment of the present invention. This embodiment is based on a similar trough to that shown in the embodiment of figure 1 and the same reference numerals are used to denote similar features.

20

The apparatus for heating a feedstock using microwave energy comprises a receptacle 12 in the form of a work bowl of a Walther Trowal "CB" circular vibrator, a vibrator (not shown) comprising an electric motor with an adjustable eccentric flyweight at each end of the shaft of the motor. In this embodiment, the waveguide 16 of figure 1 is replaced by six individual microwave horns positioned to provide microwave energy to a feedstock at different parts of the pathway 142. The microwave horns may each have separate sources or could transmit microwave radiation to the feedstock from a single source. The microwave output from each source may be separately controllable to further improve the homogeneity in the heating of the feedstock. Temperature sensors may also be included to provide to provide data on the heating effect of the microwave horns and regulate the microwave output.

30

Figures 10a and 10b show a partial plan view and a side view of an embodiment of the present invention 150 where the apparatus comprises an enclosed area such as a room 151 within which a trough 152 is enclosed. The room operates as a Faraday Cage to shield the area outside the room from microwaves. A door 154 and a window 156 are also shown along with a set of controls 158. The side view of figure 10b shows a microwave generator 160 connected to a horn 164 via a waveguide 162. The trough 152 is positioned beyond internal window 171 which separates the horn 164 from the trough 164 and is supported by resiliently mounted legs 166 which are mounted on a concrete base 168. The legs 166 allow vibration of the trough by a vibrator (not shown) and a damping medium. A rubber pad 170 dampens the vibrations and assists in providing mechanical isolation between the microwave generator and the vibrating trough so as to minimise the effect of vibrations on the microwave source.

Figure 11 is a partial perspective view of another embodiment of the present invention. The apparatus 170 comprises a casing 172 which encloses a vibrating trough 174 mounted at both ends upon legs 176 which couple the trough 174 to a vibration isolation floor 178 which mechanically decouples the vibrating trough from the magnetron 188. A vibrator 180 is mounted to the underside of the trough. The housing 172 is provided with an access lid 182 a feedstock inlet 184 and a microwave source 186 which comprises a magnetron 188 a circulator and an E-H tuner 190 which are connected to a waveguide 192 which feeds the microwaves into a slotted waveguide (not shown) situated inside the housing above the trough 174.

In another embodiment of the invention, the slotted waveguide is replaced by a plurality of horns spaced along the length of the trough.

Figure 12 is a perspective view of another embodiment of the present invention. In this embodiment, the apparatus 190 comprises a sealed cylindrical trough 192 with a microwave source 194 comprising a magnetron 196 and waveguide 198 mounted on the top of the cylinder 192. The waveguide 198 is connected to a slotted waveguide 200 inside the cylindrical trough where it runs along the length thereof. Damping means 202 provide vibration isolation to the magnetron to minimise the potential

damage to the magnetron that might be caused by vibrations. Fluid inlet 204 and fluid outlet 206 are provided to allow a liquid or gaseous feedstock to be continuously fed through the apparatus 190. Vibrator 208 provides a suitable vibration to the cylinder 192 which is mounted on vibration damping legs 210 and a platform 212.

5

The above centre-fed cylindrical troughs of figures 11 and 12 use an E-H tuner to achieve a good match with up to 99% of the power delivered to the feed waveguide being absorbed in the load. This trough could be extended in length and additional apertures added and could be to match different loads.

10

The apparatus of the invention is suitable for heating the following feedstocks amongst others.

Wood sawdust, olive waste, vineyard pulp (pomace) or waste products of hydrodistillation, where the microwave energy evaporates water from the feedstock, then additives capable of absorbing the microwave energy are added to heat the feedstock, which when dry is no longer capable of absorbing the microwave energy, to heat the feedstock to 230°C to torrefy it. This turns the feedstock into a solid fuel that can be pelletised and does not absorb moisture from the atmosphere during storage.

20

Egg shells with steel balls and additives capable of absorbing the microwave energy, where the microwave energy evaporates water from any residue in the egg shells, the additives heat the residue to render it sterile and the steel balls reduce the egg shells and residue to a calcium-rich powder that can be used as a chicken feed supplement or as a source of calcium in industrial processes.

25

Fly ash from power stations with serrated steel balls and an oxidising agent. It would be useful to be able to use fly ash in cement manufacture but this is not feasible at present because the fly ash contains carbon, which would be burnt when manufacturing the cement, incurring a penalty for the manufacturer. The serrated steel balls powder the fly ash and the carbon is heated by the microwave energy, the oxidising agent ensuring that ignition of the carbon occurs. The resulting powder can

30

then be used in cement manufacturing without incurring any penalty for the manufacturer.

5 Oily cuttings, where the microwave energy evaporates any water present in the cuttings, then evaporates the oil from the cuttings to produce hydrocarbon vapour, which can be used as a fuel, possibly to run a generator to drive the apparatus. The resulting dry, clean cuttings can be disposed of without causing pollution.

Barley, for which the second embodiment of the apparatus is particularly suitable.
10 The barley is mixed with grinding balls and introduced into the first tube of the apparatus. The microwave energy evaporates some of the water from the barley and the grinding balls break up the grains of the barley. The steam released from the barley can be used to heat water with which the barley is mixed to form a mash and liquor in a brewing process.

15 When the barley is finished with it can be introduced into the lower tube with an additive of silicon carbide, which absorbs the microwave energy and heats the barley to evaporate the water and sterilise the barley, and grinds the barley to micron size particles. In the form of micron size particles the barley is an animal feed containing
20 around 80 percent protein, or a protein supplement suitable for consumption by human beings.

A large number of applications of the present invention are envisaged, these include but are not limited to:

- 25 Recovery or removal of oil from oil industry drill cuttings;
Destruction of harvest waste and waste from food processing;
Destruction of animal carcasses and meat bone meal;
Breakdown of toxic chemicals found in industrial waste;
Recovery of production waste in fibreglass production;
30 Breakup of redundant fibreglass products;
Clean up of steel industry mill sludge;
Clean up of oil industry refinery sludge;
Land remediation particularly oil contaminated land;

- Oil contaminated shore sands;
- Clean up of harbour silts particularly those containing PCBs;
- Production of activated carbons in particular those with a wide range of wastes from the agriculture and food industries, e.g. nut shells;
- 5 Regeneration of carbon used in sugar refining;
- Production of charcoals from virgin wood and used wood and waste products;
- Pretreatment of foods such as coffee beans and cocoa, drying and elimination of alpha toxins;
- Controlled temperature cooking in food production;
- 10 Treatment of soft woods for extended anti-rot capabilities;
- Medical waste;
- The treatment of mineral ore; and
- The destruction of used tyres.
- 15 Improvements and modifications may be incorporated herein without deviating from the scope of the invention.

CLAIMS

- 5 1. Apparatus for heating a feedstock using microwave energy, the apparatus comprising a receptacle with an opening for receiving a feedstock, a vibrator operable to vibrate the receptacle so as to cause a feedstock in the receptacle to move relative to the receptacle, and a source of microwave energy arranged to direct microwave energy towards the receptacle, wherein the vibrator is operable to vibrate the
10 receptacle so as to cause a feedstock in the receptacle to describe a substantially helical path relative to the receptacle.
2. An apparatus as claimed in claim 1 wherein the receptacle is substantially transparent to the microwave energy.
- 15 3. An apparatus as claimed in claim 1 wherein the receptacle is substantially absorptive of the microwave energy.
4. An apparatus as claimed in any preceding claim wherein the source of
20 microwave energy is arranged to direct the microwave energy into the opening of the receptacle.
5. An apparatus as claimed in claim 1 wherein, the receptacle is substantially reflective to the microwave energy.
- 25 6. An apparatus as claimed in any preceding claim wherein, the receptacle has an opening for discharging a feedstock, and the vibrator is operable to vibrate the receptacle so as to cause a feedstock in the receptacle to move from the opening for receiving the feedstock to the opening for discharging the feedstock.
- 30 7. An apparatus as claimed in claim 1 wherein the receptacle is provided with a portion capable of absorbing the microwave energy for heating a feedstock.

8. An apparatus as claimed in any preceding claim wherein the or each opening of the receptacle is formed as a microwave choke adapted to permit the feedstock to be introduced or discharged through the opening, but to prevent the microwave energy from passing through the opening.

5

9. An apparatus as claimed in any preceding claim wherein the receptacle is provided with at least one further opening to allow gases released by the feedstock to escape from the receptacle.

10. An apparatus as claimed in any preceding claim wherein the largest dimension of the at least one opening is no more than one quarter of a wavelength of the microwave energy.

11. An apparatus as claimed in any preceding claim wherein the receptacle is preferably provided with a lining formed from a ceramic material, to protect the receptacle from abrasive or corrosive feedstock.

12. An apparatus as claimed in claim 11 wherein the lining is provided with heating elements either inside the lining or between the lining and the material of the receptacle.

13. An apparatus as claimed in claim 12 wherein the heating elements can be used to heat the lining of the receptacle and to heat the feedstock by contact with the lining.

14. An apparatus as claimed in any of claims 11 to 13 wherein the lining is preferably constituted by a plurality of tiles formed from the ceramic material.

15. An apparatus as claimed in claim 14 wherein, the plurality of tiles are fastened to the receptacle so as to allow sufficient relative movement between them to accommodate thermal expansion of the tiles and mechanical shock imparted by the feedstock.

16. An apparatus as claimed in claim 14 wherein, the tiles are fastened to the receptacle so as to define a plurality of substantially parallel grooves along which the feedstock moves as it describes the substantially helical path relative to the receptacle.

5 17. An apparatus as claimed in any preceding claim wherein the apparatus further comprises a separator operable to separate an additive from the feedstock.

18. An apparatus as claimed in claim 17 wherein the additive comprises a substance, such as silicon carbide or magnetite that is capable of absorbing the
10 microwave energy, so that the feedstock can be heated by contact with the additive as the feedstock moves from the opening for receiving the feedstock to the opening for discharging the feedstock.

19. An apparatus as claimed in claim 17 or claim 18 wherein the additive
15 comprises a substance, such as quartz, that is substantially transparent to the microwave energy, that assist the passage of the microwave energy into the centre of the feedstock.

20. An apparatus as claimed in claims 17 to 19 wherein, the additive comprises a
20 catalyst to assist the treatment of the feedstock by the microwave energy.

21. An apparatus as claimed in any of claims 17 to 20 wherein, the additive
comprises an abrasive to grind the feedstock as it moves from the opening for receiving the feedstock to the opening for discharging the feedstock.

25

22. As apparatus as claimed in any preceding claim wherein the receptacle
comprises a helical chute, an axis of the helix being disposed substantially vertically in use of the apparatus.

30 23. An apparatus as claimed in claim 22 wherein the helical chute is constituted by a work bowl, separation flap and separation screen of a circular vibrator, the feedstock being introduced in use of the apparatus into the work bowl and being raised by the

separation flap on to the separation screen as a result of the vibration of the work bowl.

24. An apparatus as claimed in claim 22 or claim 23 wherein, the work bowl is
5 provided with a lid formed from a material reflective to the microwave energy so as to retain microwave energy introduced into the work bowl in the work bowl until it is absorbed by the feedstock.

25. An apparatus as claimed in claim 24 wherein the lid is formed with an opening
10 for introducing microwave energy into the work bowl.

26. An apparatus as claimed in claims 1 to 21 wherein the receptacle comprises first and second cylindrical tubes, axes of the cylinders being disposed substantially horizontally in use of the apparatus with the first tube above the second tube and the
15 first and second tubes connected at one end by a third tube perpendicular to the first and second tubes.

27. An apparatus as claimed in claim 26 wherein first, second and third tubes are adapted to form a waveguide so that microwave energy introduced into the first tube
20 is transmitted by the third tube into the second tube.

28. An apparatus as claimed in claim 26 or claim 27 wherein the vibrator is arranged to vibrate the first and second tubes such that a feedstock introduced into a first end of the first tube passed along the first tube to the second end, falls through
25 the third tube into the second end of the second tube, and passes along the second tube to the first end of the second tube.

29. An apparatus as claimed in claims 26 to 28 wherein at least one of the tubes is provided with an opening through which microwave energy can be introduced into the
30 tube by the source of microwave energy.

30. An apparatus as claimed in claims 1 to 21 wherein the receptacle comprises a channel or trough mounted for vibration on a vibration damping platform, the channel

being at least partially enclosed in a housing which provides a feedstock inlet and microwave transmission means.

31. An apparatus as claimed in claim 30 wherein the channel or trough is enclosed in a Faraday Cage.

32. An apparatus as claimed in any preceding claim wherein the apparatus further comprises a waveguide arranged to transmit the microwave energy from the source of microwave energy to the receptacle.

33. An apparatus as claimed in claim 31 wherein the waveguide is provided with a slot to transmit the microwave energy from the waveguide to the receptacle.

34. An apparatus as claimed in any preceding claim wherein the apparatus further comprises a plurality of microwave sources arranged to directly transmit the microwave energy from the source of microwave energy to the receptacle.

35. An apparatus as claimed in any preceding claim wherein the microwave source is mechanically decoupled from the vibrator in order to minimise the transmission of vibrations to the microwave source.

36. An apparatus as claimed in any preceding claim wherein the microwave energy source is tuneable.

37. An apparatus as claimed in claim 32 wherein the waveguide further comprises a flexible portion to further reduce the transmission of the vibrations to the microwave energy source.

38. An apparatus as claimed in claim 1 wherein, the apparatus further comprises a waveguide connecting the source of microwave energy and the receptacle, the waveguide comprising first and second portions and a resonant cavity, a first end of the first portion being connected to the source, a second end of the second portion being connected to the receptacle, a second end of the first portion projecting into the

resonant cavity through a first opening, a first end of the second portions being aligned with one another so as to permit the microwave energy to be transmitted from the second end of the first portion to the first end of the second portion, but separated from one another by a distance sufficient to ensure that vibration transmitted to the second portion from the receptacle is not transmitted to the first portion.

39. An apparatus as claimed in claim 38 wherein the second end of the first portion and the first end of the second portion may advantageously be provided with microwave horns.

40. An apparatus as claimed in claim 39 wherein the microwave horns increase the cross-sectional area of the first and second portions and reduce the effect on the transmission of the microwave energy of misalignment of the portions as a result of the vibration transmitted to the second portion by the receptacle.

41. An apparatus as claimed in any preceding claim wherein the receptacle is divided into upper and lower compartments divided by a screen adapted to prevent passage of a solid feedstock between the compartments but to permit passage of the microwave energy and a gas between the compartments.

42. An apparatus as claimed in any preceding claim wherein the microwave energy is directed towards the feedstock from a position above the feedstock, in use.

43. An apparatus as claimed in any preceding claim wherein the microwave energy is directed towards the feedstock from a position to the side of the feedstock, in use.

44. An apparatus as claimed in any preceding claim wherein the vibrator comprises an eccentric flyweight.

45. An apparatus as claimed in claim 44 wherein the flyweight is adjustable to alter the magnitude and/or type of vibration.

46. A method of heating a feedstock using microwave energy, the method comprising the steps of introducing a feedstock into a receptacle of apparatus according to claims 1 to 41, vibrating the receptacle to move the feedstock relative to the receptacle, and directing microwave energy towards the receptacle, wherein the step of vibrating the receptacle to move the feedstock relative to the receptacle comprises vibrating the receptacle to cause the feedstock to describe a substantially helical path relative to the receptacle.

47. A method as claimed in claim 46 wherein the feedstock can be a solid, a liquid mixed with a solid, or a gas mixed with a solid.

48. A method as claimed in claim 46 or 47 further comprising the step of introducing at least one body formed at least in part from a substance capable of absorbing the microwave energy into the receptacle.

49. A method as claimed in claim 48 wherein the substances include silicon carbide, graphite, magnetite and ferrite.

50. A method as claimed in claims 46 to 49 further comprising the step of introducing a plurality of bodies formed from the substance capable of absorbing the microwave energy into the receptacle.

51. A method as claimed in any of claims 46 to 50 comprising the steps of introducing the feedstock into an opening of the receptacle for receiving the feedstock, vibrating the receptacle to move the feedstock relative to the receptacle from the opening for receiving the feedstock to an opening for discharging the feedstock, and discharging the feedstock from the opening for discharging the feedstock.

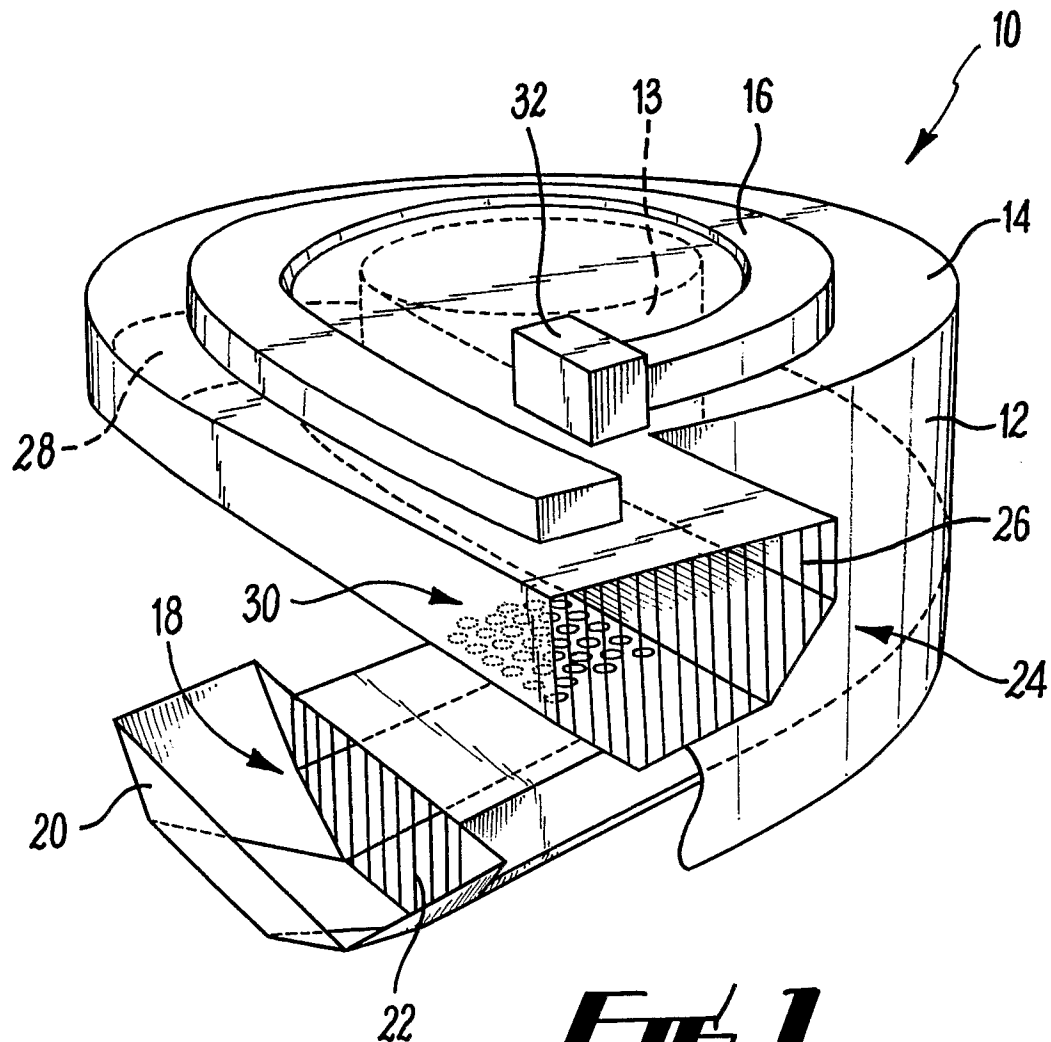
52. A method as claimed in any of claims 46 to 50 comprising the step of introducing at least one body formed at least in part from a catalyst into the receptacle.

53. A method as claimed in any of claims 46 to 52 further comprising the step of introducing at least one abrasive body into the receptacle.

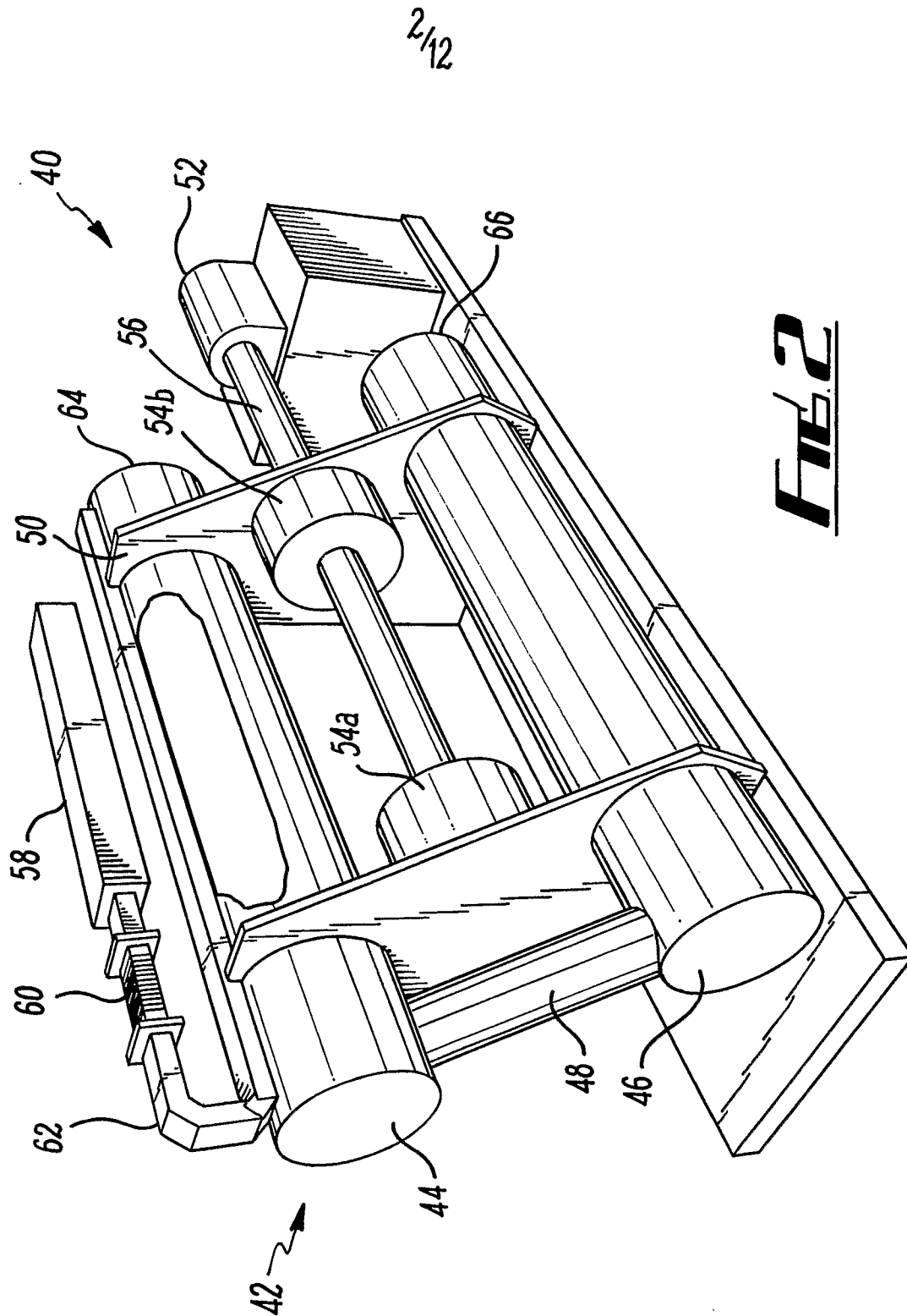
54. A method as claimed in any of claims 46 to 53 further comprising the step of introducing at least one body formed at least in part from a material that is substantially transparent to the microwave energy into the receptacle.

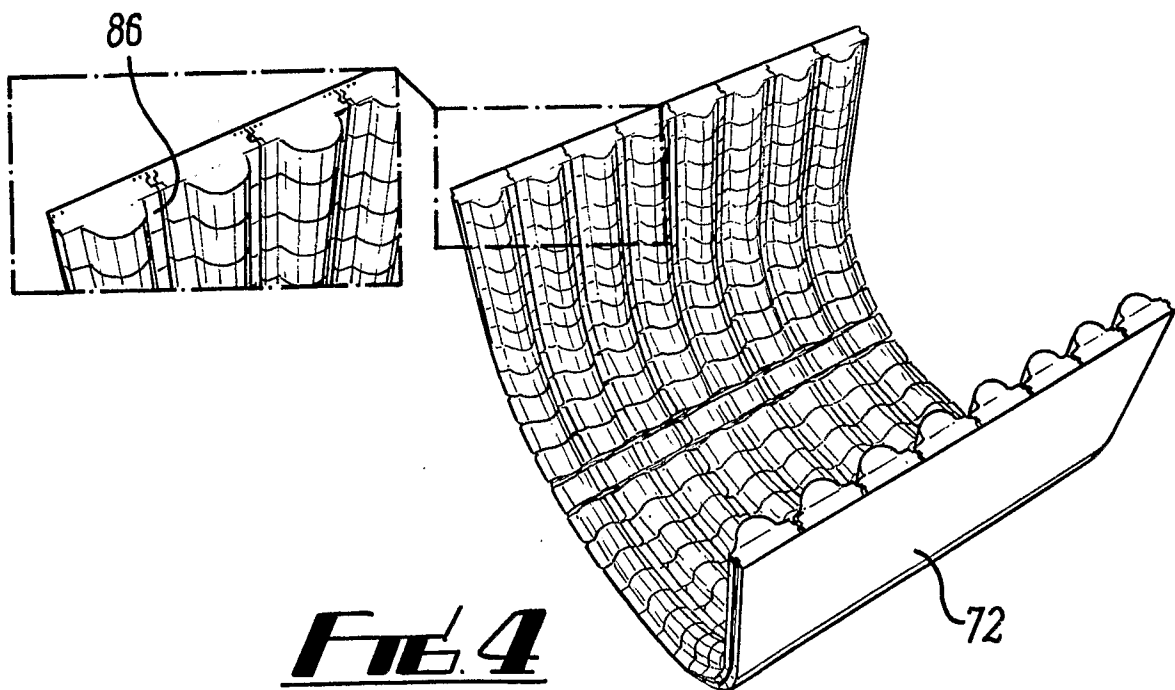
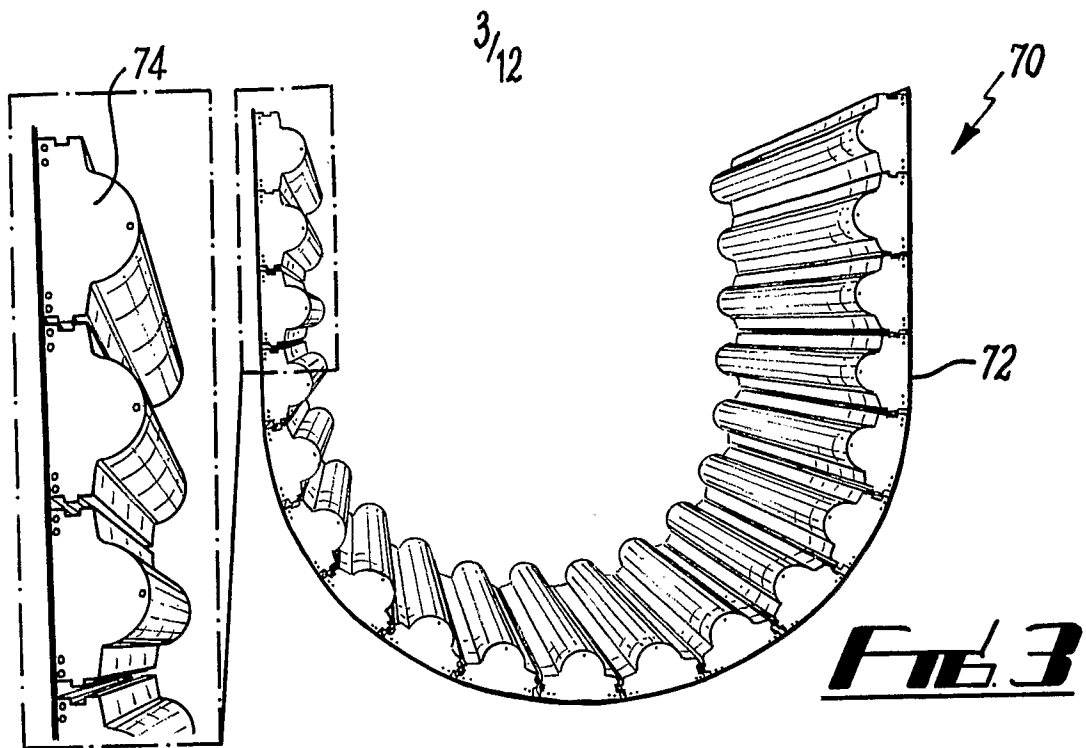
55. A method as claimed in any of claims 46 to 54 further comprising the step of introducing the microwave energy from a position above the feedstock, in use.

56. A method as claimed in any of claims 46 to 53 further comprising the step of introducing the microwave energy from a position to the side of the feedstock, in use.

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Frñe. 1





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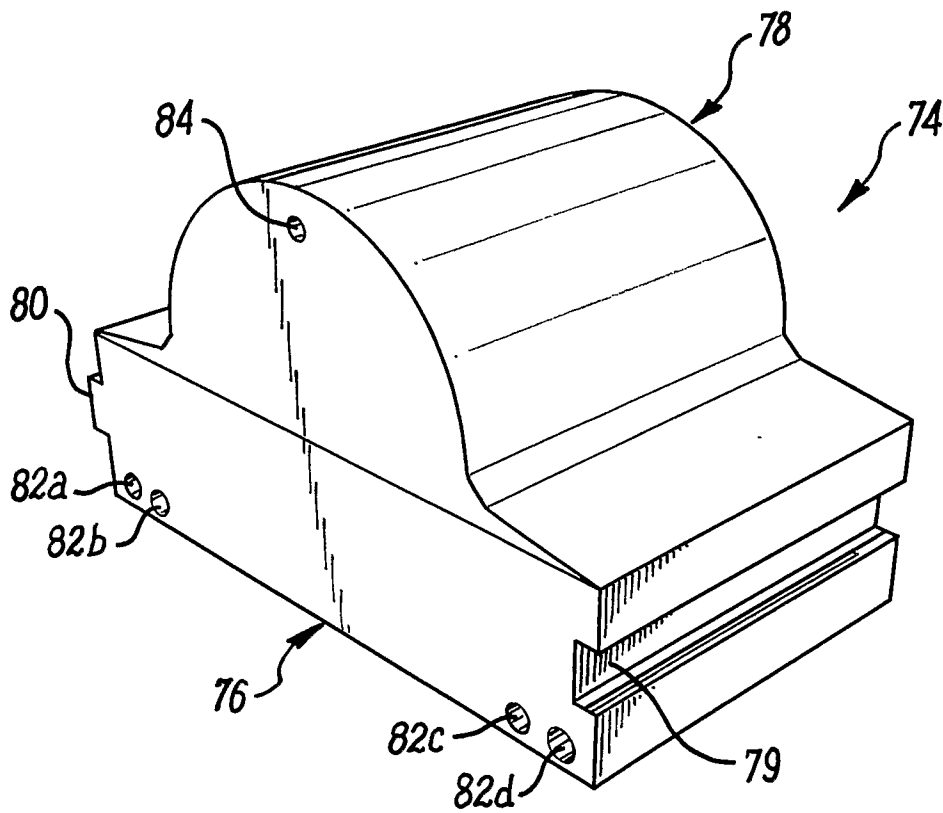
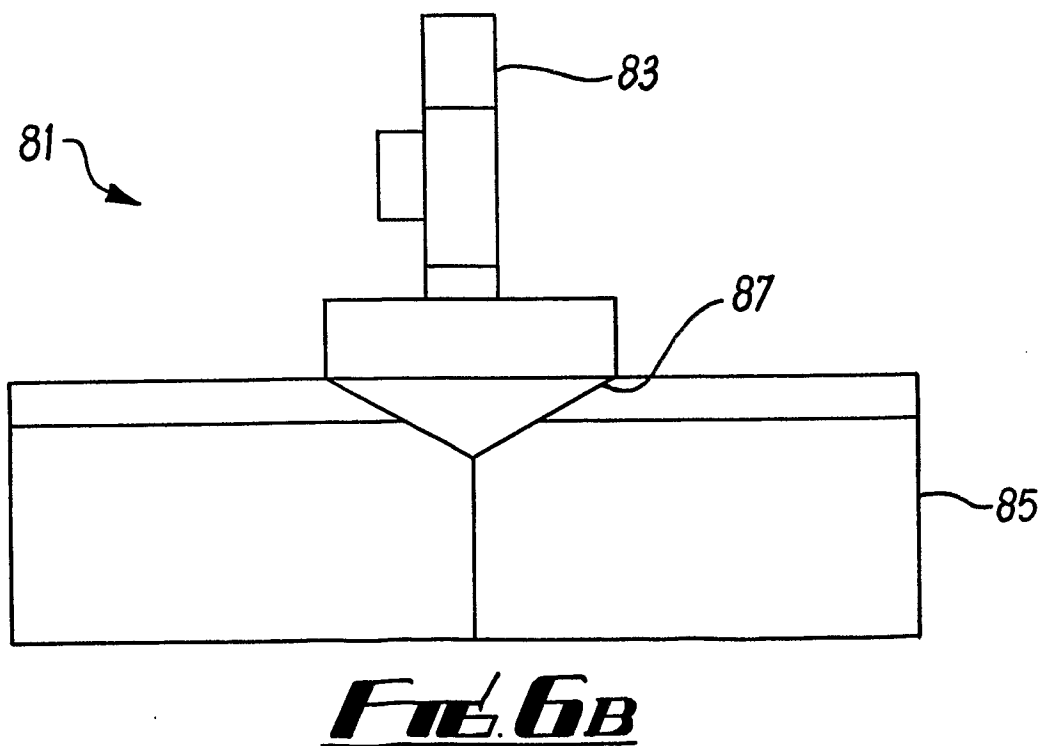
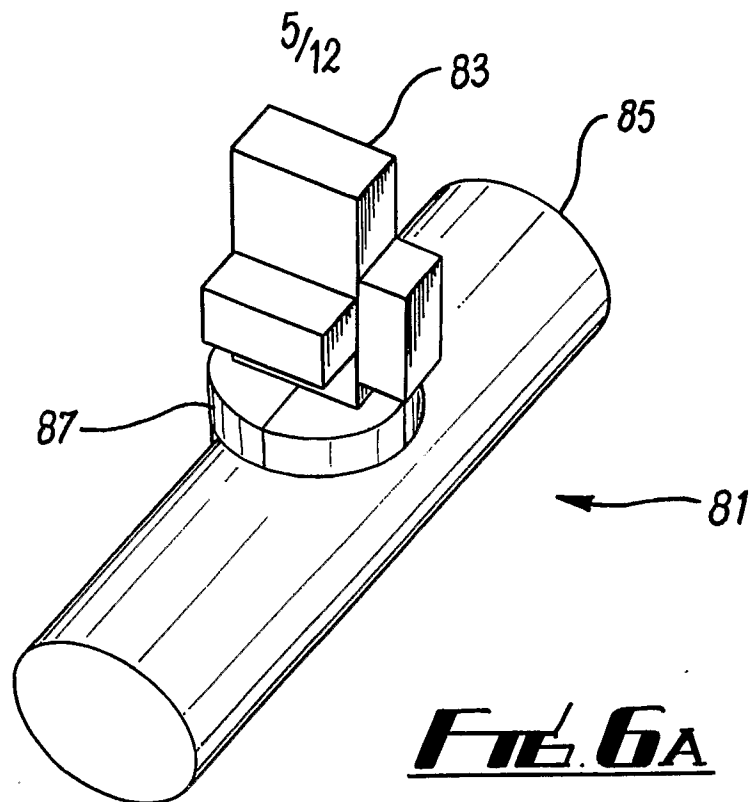


FIG. 5



6/12

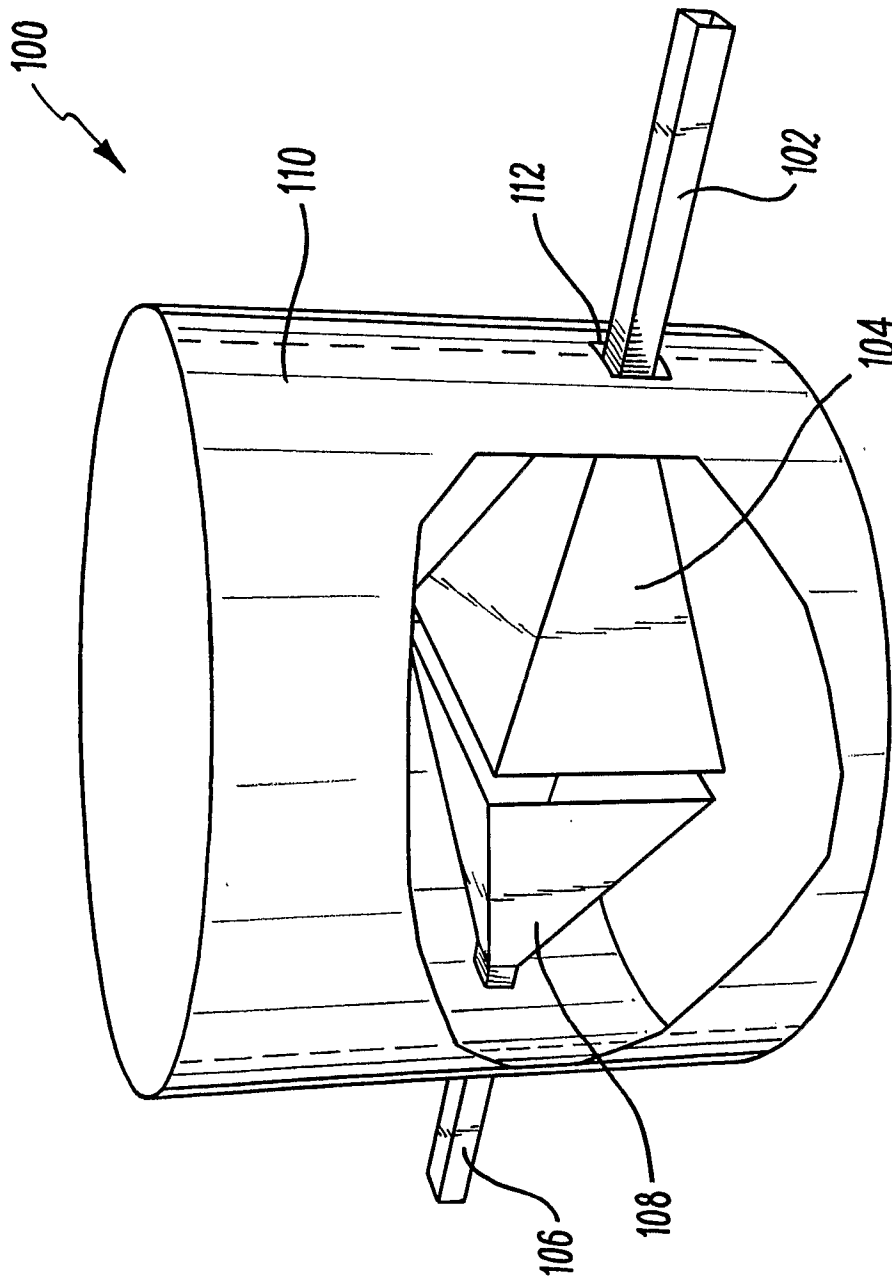
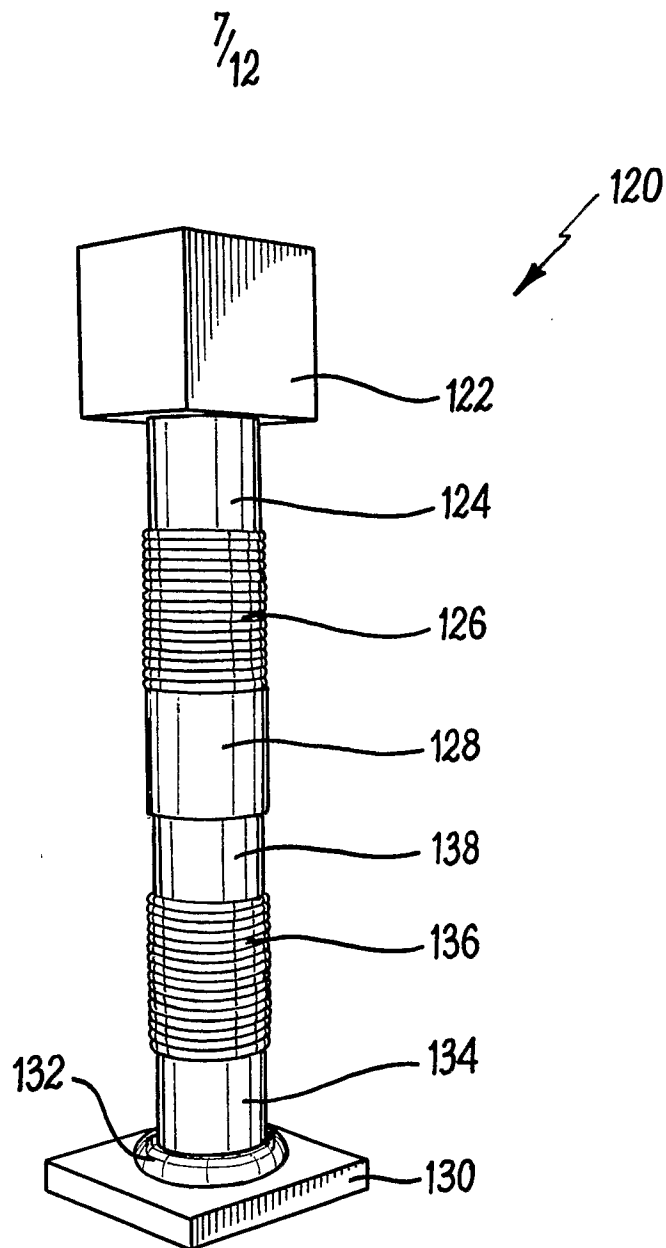
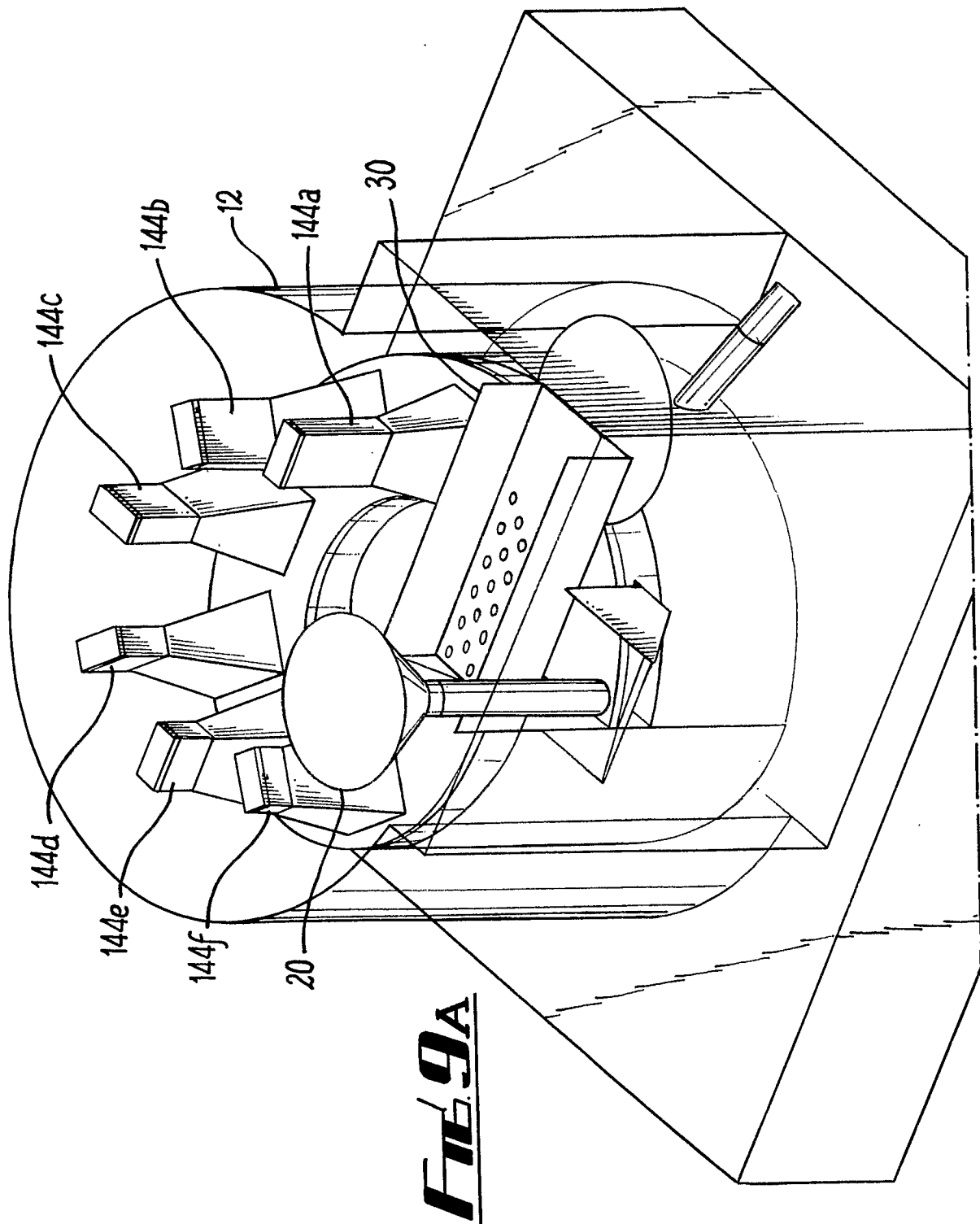


FIG. 7



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9/12

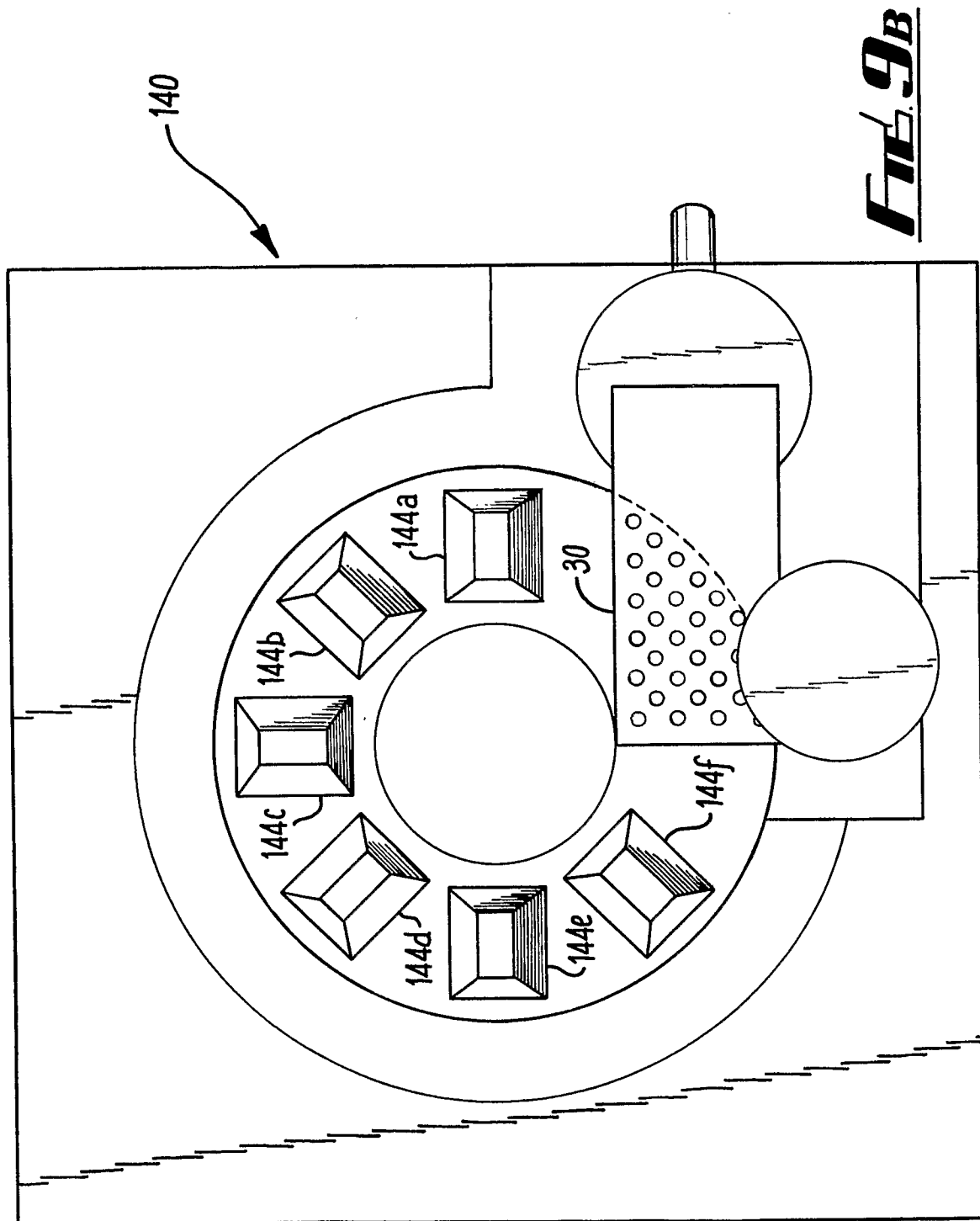
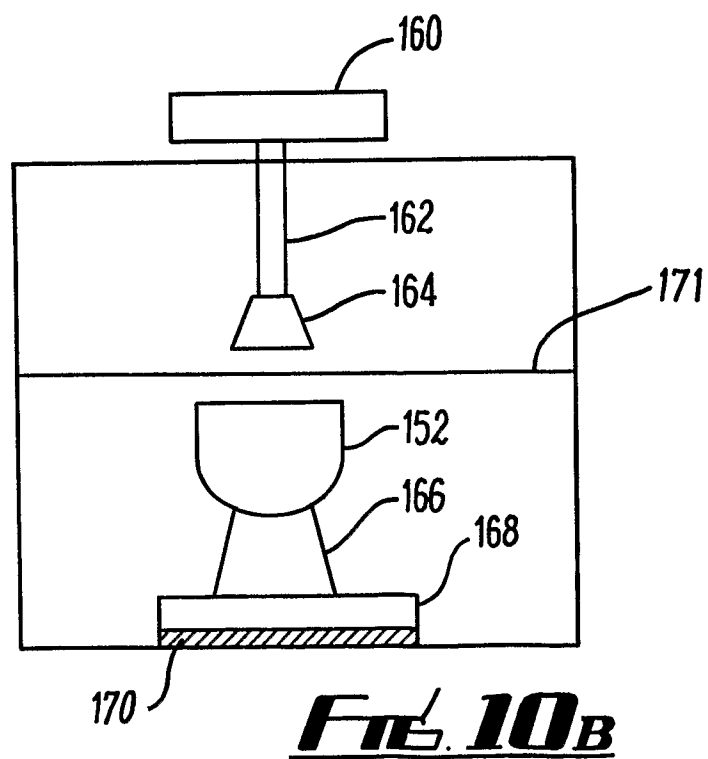
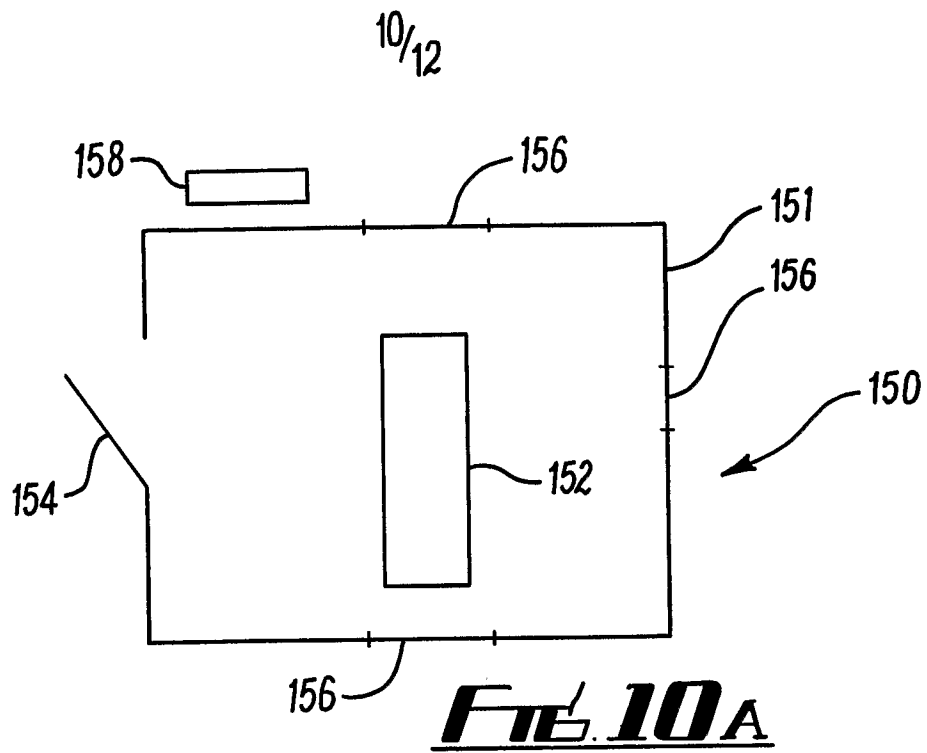
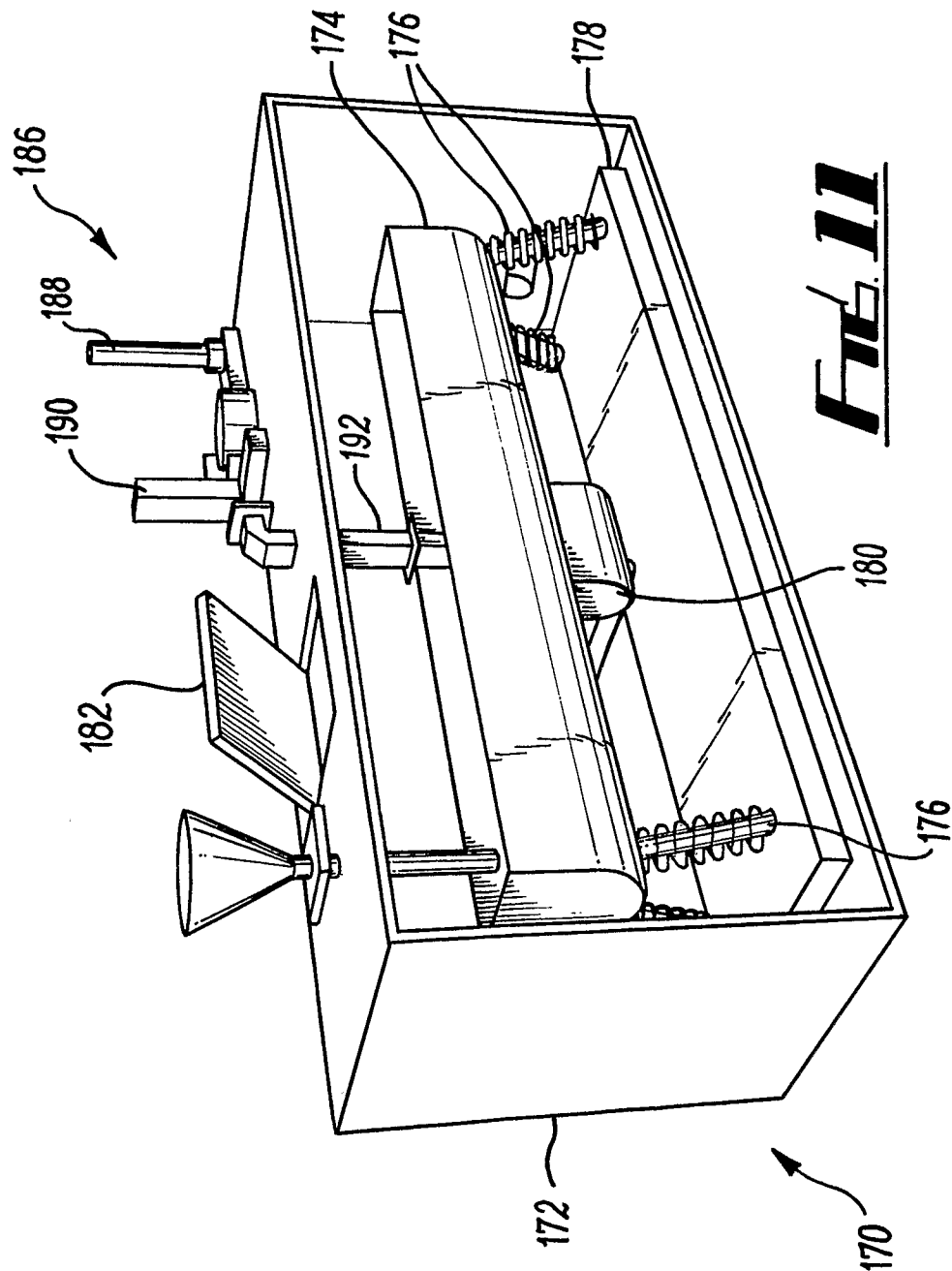


FIG. 9B



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FILE 11

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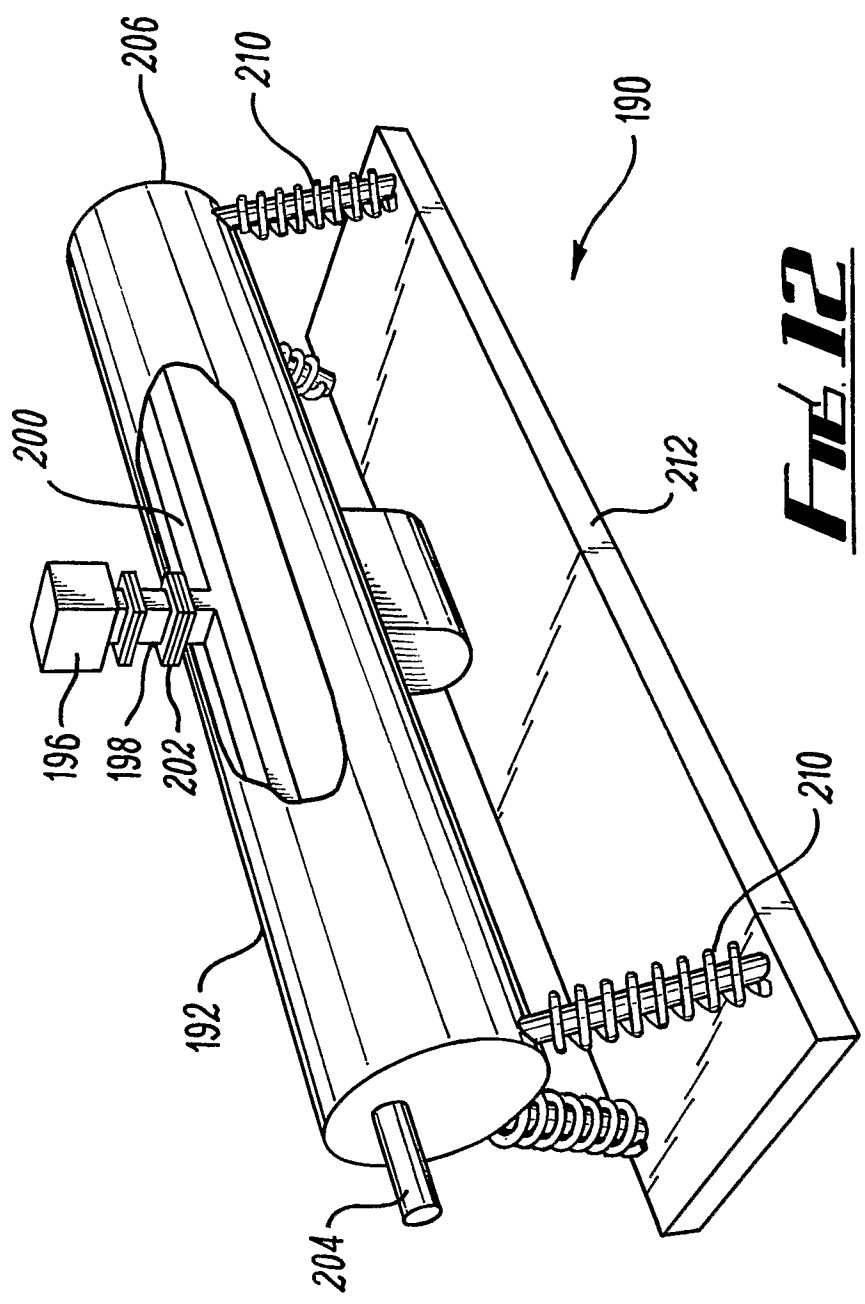


Fig. 12