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(54) METHODS AND APPARATUS FOR THE MICROWAVE HEATING
 OF FOODS

- (71) We, UNILEVER LIMITED, a company organised under the laws of Great Britain, of Unilever House, Blackfriars, London, E.C.4, England, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—
- This invention relates to processes and apparatus for the microwave heating of foods, for example for use in the preparation for consumption of frozen pre-packed meals. Institutionalised catering, for example factory canteens or hospital meal services, desirably requires as little preparation time as can be managed, combined with a reasonable quality of product, a fair choice of alternatives, and economy.
- With these aims in mind, the use of prepared frozen packs of food in conjunction with micro-wave heating has been considered; however re-heating takes generally of the order of ten minutes or so and this usually constitutes an unacceptable delay; and also a wide ranging free choice is impractical. Consequently, in factory canteens, it is still the practice to have pre-heated quantities of food available from which to serve means of restricted choice, range and quality.
- In a factory canteen, each member of a queue of people should desirably be able in turn to select a meal, pay for it and take it away on a tray; and in a smooth running system this should be possible in two to three minutes.
- If therefore the re-heating time in a microwave oven can be reduced from ten minutes to less than three minutes, the meal becomes capable of being re-heated while the individual customer goes through the process of selecting and paying for it. Then there is no longer a requirement for pre-heated quantities of food to be available, and improved quality and greater selection become possible.
- To achieve this rapid heating would be difficult in a conventional multi-mode microwave oven, because merely increasing the power accentuates the so-called thermal runaway problem. Thermal runaway is an effect which occurs when microwave energy is applied to a frozen food, in which, as soon as a part of the frozen food thaws and changes from ice to liquid, this part assumes a greater dielectric loss factor than the remaining ice and selectively takes more of the power from the system, so distorting the microwave energy field and resulting in uneven heating.
- The present invention provides a method of heating a pack of frozen food for consumption, which pack is of substantially uniform width, comprising effecting relative movement of the pack in its length direction past an outlet fed by a source of microwave energy, so that said outlet supplies microwave energy to the pack with the direction of propagation of the microwave energy through the outlet, and the direction of the electric field vector of the microwave energy at the outlet, both substantially at right angles to each other and to the direction of movement of the pack past the outlet, and so that substantially uniform heating occurs across the pack width, and the dimensions of the outlet and the pack length are such that heating is concentrated in a band which is shorter than the pack length, and which is through the relative movement between the pack and said microwave outlet traverses the pack length.
- The invention also provides apparatus for heating frozen food packs for consumption, comprising a microwave energy source, energy feeding means for feeding microwave energy from the source to an outlet, and conveying means for conveying a pack containing frozen food past the outlet substantially at right angles to the direction of propagation of microwave energy through the outlet, and also substantially at right angles to the direction of the electric field vector of the microwave energy at the outlet,

said directions also being at right angles to each other.

Concentration of the length direction heating into a restricted band coupled with relative movement between pack and energy source enables a high heat input into the pack to be achieved without encountering significant thermal runaway problems.

This is because the energy source (the microwave outlet) is continuously being moved away from zones where thermal runaway would otherwise occur. Thus any distortion of the field consequent on frozen material thawing is kept at a minimum, and the only such effect is a slight dragging of the heating zone in the direction of pack movement, that is to say that greatest heating will be at a zone slightly in advance of the centre of the microwave outlet; and this dragging effect will be evened out as the heating zone traverses the whole of the pack length, and each zone of the food pack will then have received in total substantially the same amount of heating.

It will be recognised that the dragging effect described above will tend to cause uneven heating at the front and rear ends of the food pack. This can be overcome conveniently by either having dummy loads preceding and succeeding the pack as it progresses past the microwave outlet; or a very large number of packs juxtaposed without any gap between the front of the first and the rear of the next (effectively equivalent to an infinitely long pack) would also solve the problem of the end effect.

However we have found that the simplest way of avoiding overheating of the ends is by switching the microwave energy on and off in timed relationship with the pack movement. In particular the energy should be switched on as the leading edge of the pack has moved about halfway across the microwave outlet and should be switched off as the trailing edge is halfway across the microwave outlet. In practice, owing to slight field distortion, (e.g. due to the variation of permittivity of the feed pack with temperature), switch-on should be just after the halfway point and switch off just before the relevant edge reaches halfway.

As an alternative to choosing the correct time of switching on and off, which will be effected when a unidirectional single movement of the pack takes place past the outlet, the pack can be moved back and forth across the microwave outlet and overheating of the ends can be avoided by moving the pack back and forth, i.e. in reciprocating motion, over a restricted pathway, i.e. by reversing the movement of the pack past the outlet at or just after the times when a trailing edge of the food pack passes the centre of the outlet.

In order to ensure that the total quan-

tity of heat received at different points along the length of the pack is adequately uniform, as well as to take sufficiently into account the end effect problems referred to above, it is desirable for two other criteria to be substantially satisfied. The first of these is that the movement past the microwave outlet should be at a predetermined rate, and the second is that the food to be heated should be suitably distributed within the pack in relation to its energy absorbing properties.

Speed of movement and distribution of food within the pack are, of course, related functions, and while in practice constant speed and even distribution are the most convenient ways of achieving even heating, other correlated values of these two functions are theoretically also possible (for example if a portion of food near the centre of the pack needs more heat, the speed of movement could be slowed down at that stage).

The manner in which the food is arranged within the pack to ensure even heating is generally based on trial and error and experience. For example dense high water content foods, e.g. spinach puree, absorb more energy than lower water content particulate foods, e.g. peas; and non-uniform geometric shapes such as lamb cutlets create similar problems. It then becomes a matter of arranging such materials within the pack in such a way that the effective absorption properties are as uniform as possible.

As previously stated heating in the pack length direction is concentrated in a band which is shorter than the pack length. Generally the intensity of heating in this direction will increase to and then recede from a peak of intensity sinusoidally within a distance which may be a third to a half of the pack length, when a pack of usually encountered dimensions is used (see example to be described later).

However in the pack width direction heating should be substantially uniform. This is preferably achieved by radiation of microwave energy from a rectangular-section waveguide in single mode with the electric field polarised in the direction of the pack width from an outlet of substantially the same width as that of the pack. While this is the preferred method, other methods of achieving equal heating across the pack width are also possible, for example by use of the equipment described in U.S. Patent Specification No. 3 110 794.

With the single mode arrangement where the electric field is polarised in the direction of the pack width, the intensity of the effective electric field will theoretically be substantially constant across the transverse width of the pack; while intensity will increase sinusoidally to a peak and then

similarly subside in the direction of movement.

In regard to the width direction, a single rectangular waveguide outlet using the most commonly used frequency, i.e. 2450 MHz, would only encompass a particularly narrow pack width i.e. about 5 cm. Therefore to achieve adequate heating across a pack width which is commercially more acceptable, we have found it desirable substantially to double the waveguide outlet width by using an outlet or applicator in the form of a Y type power divider supplied from a single power source. The same effect could be achieved by using two waveguide outlets next to each other, combined with other known power dividers, and greater multiples are also possible.

As a further measure to improve the uniformity of heating across the width of the food pack we have found that when heating certain particularly dense, high water content, food steps need to be taken in prevent overheating at the side edges of such a pack. By guiding the microwave energy via a pair of slots one at each side of the applicator and corresponding to the edges of the pack, greater uniformity can be achieved provided these slots are spaced half a wavelength apart. This provides, in effect, two in phase sources spaced half a wavelength apart.

The result then is that in the region of each slot there will be a degree of out-of-phase cancellation of microwave intensity due to the out-of-phase relation between the radiations from the two slots reducing the power intensity, while midway between the two slots, the radiations from the two slots are in-phase and will therefore reinforce one another so that the power available in this region is greater. These slots can for example be achieved by use of a thin conductive baffle plate parallel to and spaced from the pack base and closing the central zone of the outlet of the Y-type power divider.

Alternatively it is possible to use a dielectric insert disposed in the waveguide outlet adjacent and generally parallel to the food pack path, and of low loss factor and of a greater relative permittivity than air, which can vary the impedance matching to the food pack and thereby be utilised to improve the uniformity of heating across the pack width. The shape and disposition of such a low-loss baffle can then be chosen to tailor the intensity of heating as desired.

From the foregoing, it will be apparent that in the preferred arrangements a substantially rectangular parallelepiped shaped pack will be used of which the width dimension is selected in relation to the waveguide outlet width, while pack length—though not critical—should be taken into

account in arranging for a switching sequence or reciprocating movement to overcome leading and lagging edge end effects.

The third dimension of the pack, i.e. height, needs to be restricted to take into account the energy transmission capability of the microwave source. If height is too great the top of the pack would not receive adequate energy, but there is no minimum requirement.

An additional factor limiting pack height comes in when considering the method of conveying the pack and of screening the system to prevent radiation outwards from the equipment to provide adequate safety. Conveniently the radiating outlet for the microwave source opens into a screened rectangular cross-section tunnel along which the pack is caused to move. This arrangement will generally be T-shaped.

In order to inhibit propagation of radiation, when this polarised with its field horizontal, from travelling along the upper horizontal limbs of the T (the pack pathway), these limbs should be less than half a wavelength in height. This then puts a similar limitation on the height of the pack—i.e. since the pack has to pass along within these upper limbs it must also be less than half a wavelength high.

An embodiment of the invention, for operation at a microwave frequency of 2450 MHz in the particular example described, will now be described by way of example with reference to the accompanying diagrammatic drawings, in which:—

Figure 1 is a perspective view part cut away of a pack heating device;

Figure 2 is a side view showing the form of the electric field;

Figure 3 shown the field disposition pictorially;

Figure 4 shows the sequential heating effect on a pack;

Figure 5 shows an end view of the waveguide outlet with one form of field compensating device;

Figures 6 and 7 show similar views to Figure 5 with different forms of field compensating device; and

Figure 8 shows an overall view of the microwave system layout.

Referring to Figure 1, food pack heating apparatus is shown, the apparatus including a conveyor system (shown only in part and schematically) having a horizontal metal screening guide channel 1 for guiding a food pack 2 while it is conveyed past a microwave outlet or applicator and vertically disposed waveguide 3 which feeds the outlet. Other dispositions than horizontal and vertical are of course also feasible, but are less convenient.

The microwave outlet or applicator and waveguide is located so that the electric

field component of the microwave energy (E) is at right angles to the longitudinal conveying direction L and is as uniform as possible across a horizontal plane in the E direction shown. In the direction of movement of the food pack 2 however the intensity rises to a peak and then falls again as shown by graph G (Figure 2). The height of the guide channel 1 is less than half a wavelength, so as to inhibit transmission of horizontally polarised radiation along the guide channel.

The microwave outlet or applicator and wavelength 3 consist essentially of a rectangular waveguide 4 of standard internal dimensions (86 mm $\times$ 43 mm) feeding into a flared outlet section 5 and fed from a supply circuit including a magnetron. The microwave transmission is single mode with electric field polarised in a plane transverse to the direction of pack motion or longitudinal baffle. Within the outlet section 5 is a conductive divider plate 6 (shown dotted in Figure 1) attached at each end to the side walls within the outlet section 5. The dimensions and arrangement within the flared outlet section 5 thus form a Y type divider, giving rise to a widened zone of constant electric field in the direction transverse to the direction of movement of the food pack 2 (in fact two outputs are supplied in phase, and they consequently behave in effect as one), which corresponds to the pack width (see Figure 3). An effect of the divider or baffle is to pressure single mode propagation conditions in the flared waveguide outlet section.

Conveniently the outlet width may be about 115 mm, instead of the 43 mm of the standard rectangular waveguide 4, and a pack of 110 mm width may then be accommodated. The equipment can be fabricated from thin conductive sheeting, for example aluminium sheeting about 1 mm thick. The depth of the channel 1 and the height of the food pack should be less than half a wavelength, e.g. about 55 mm and 35 mm respectively.

While, theoretically, a Y type power divider gives a field of constant intensity in the transverse direction, in use and practice some edge over-heating would tend to occur with certain dense, high water content foods, e.g. spinach puree, at edge zones 7 (see Figure 5).

Referring to Figure 5, one method of overcoming this problem is by provision of a baffle plate 8 attached to the top of the divider plate 6 and to the opposing parallel walls of the flared outlet section 5 (for which see Figure 1). Plate 8 is spaced from the path of the pack base, so as to leave a slot 9 at each end, corresponding to the edge zones 7 of the food pack which would otherwise be overheated.

The centres of the two slots 9 are spaced apart by a distance equal to approximately a half wavelength of the generated microwave energy. In use, this results in a degree of phase cancellation of the microwave intensity at each of the edges, which thus reduces the heating at zones 7, while the two slot sources will augment one another in a central zone.

Figure 6 shows an alternative version where in the place of divider plate 6 and transverse plate 8 there is a wedge 22, performing a basically similar function in the same manner.

Figure 7 shows another version where the plate 8 is replaced by a block 23 of polypropylene 2 cm deep which equalises the transverse field in a different manner. This has provided the most uniform and efficient transfer of power so far achieved in the width direction.

Since the polypropylene is a low loss material having low loss factor and a higher relative permittivity than the equivalent volume of air (about 2.2 times), it affects the matching of power into the pack. Thus by selecting its depth, shape and location the power into the pack can be tailored to provide the required uniformity. Moreover power can be transferred to the pack more effectively with less reflection back down the waveguide. This method of matching is also to be preferred over the previously discussed horizontal baffle system, since it can also be used with a higher multiplicity of flared outlet branches than the doubling of the outlet by means of a single branching previously described.

In practice food packs containing 176 gm of frozen food and measuring 110 mm $\times$ 140 mm $\times$ 35 mm can be fed past the outlet or applicator 5 and heated from the deep frozen state (about -20°C) to a temperature for consumption in less than three minutes. A substantially uniform heating with either no or very little thermal runaway has been observed. The system can be coupled to a supply circuit including a magnetron, giving a nominal 2 kilowatts output power, via a conventional matching device, which produces an effective power transfer of about $1\frac{1}{2}$ kW into the foodpack.

The overall set up of the microwave system is shown schematically in Figure 8. The outlet or applicator is connected to a wave guide section containing an adjustable stub 14 for matching. The next section is a circulator 15 (with three ports); one port is connected to the supply apparatus including the magnetron; the second port goes to the flared outlet applicator and the third port is connected to a water load 17, incorporating a probe 18 connected to a crystal detector 19 and a microammeter 20. The circulator directs all the power from the mag-

netron forward to the applicator, and also diverts any power reflected from the applicator into the dummy load 17, thereby protecting the magnetron. The crystal detector monitors the reflected power which is minimised by adjustment of the matching stub. An oscillatory feeding mechanism 21 is provided.

Setting up the matching is a compromise. There is a big difference between the impedance of the food material in the frozen and thawed conditions, but the fully frozen condition lasts such a short time that it is preferred to set up the matching for the unfrozen condition. In the unfrozen condition the match varies somewhat with the type of food and, to a small extent, with its temperature. We have found by experience that a satisfactory compromise is to adjust the matching stub to give minimum reflected power (indicated by crystal current) when 200 ml of water in a carton of the size referred to above is stationary and centrally over the flare. Under this condition the effective microwave power can be measured by recording the temperature rise of the water in 20 seconds. (At perfect match—zero crystal current—1.6 to 1.7 kW has been obtained from the microwave power pack in use.)

Overheating of the end edges of the pack can occur due to the field lagging as the pack enters the heating zone. This can be compensated for, when the food packs are moved past the outlet in back-and-forth reciprocating, fashion, by restricting the length of reciprocating travel across the waveguide outlet.

The desirable amplitude of the reciprocating travel was investigated by observing the heating pattern as the amplitude, that is to say, the length of backward and forward stroke, was altered. When the length of stroke was too short, the leading and trailing edges of the food pack remained too cold, and when the length of stroke was too long, the edges were overheated. The optimum stroke length was found to be $3\frac{1}{2}$ cm either side of the central position, i.e. a total travel of 7 cm, of a pack of which the base was 11 cm long. The points to which the ends of the pack move and then change direction to move back are indicated by the lines 12 and 13 of Figure 1. Thus, viewing Figure 1, a reciprocatingly-moved pack is moved to the left until its right hand edge is at line 13, and is then moved back to the right, until its left hand edge is at line 12, and it is subsequently moved reciprocatingly between these positions.

A number of different methods of operating the flared outlet or applicator section 5 is possible. Using a single flared outlet the best method has been found to be to move the food pack back and forth across the flare

mouth about twelve times at a speed of 150 cm per minute. The amplitude of the reciprocating motion of the food pack past the waveguide outlet is preferably restricted to avoid end edge overheating as previously discussed. Satisfactory heated packs have been achieved by this method in about one minute.

Where food packs are moved continuously in one direction past the waveguide outlet is preferable to use several spaced flared outlet sections arranged sequentially in the path of the foodpacks, with corresponding switching arrangements to ensure against end edge overheating, as described above. Using two flared waveguide outlet sections, a food pack speed of 10 cm per minute has been found to give a heating time of one minute from each flared outlet section, and this achieved the desired temperature. With this manner of operation, the points reached by the food pack at the times of switching the microwave energy on and off corresponded to lines 12 and 13 of Figure 1: switch-on was made to occur when the leading edge of a food pack reached the line 12, and switch-off was made to occur when the trailing edge of the pack reached the line 13. Switch-on and switch-off can be triggered and effected in any convenient manner, such as for example by micro-switches or light beams: the details of such control mechanism, as with the details of the conveyor mechanism, can be of conventional kinds, and in themselves form no part of this invention.

When a single flared waveguide outlet section was used together with a slower speed (5 cm per minute approximately) of motion of the food packs past the outlet, it was often possible for the food packs to reach the desired temperature in two minutes, but with some packed products this mode of operation introduced a degree of unevenness of heating.

This description has been written in terms of an example of operation using a transmission frequency of 2450 MHz (about 12 wavelength) which at the present time is the part of the electromagnetic frequency/wavelength spectrum normally allocated to microwave heating. However it will be understood that other microwave heating frequencies be used as well, where this is permitted by law, provided the waveguide and pack geometry are adjusted in accordance with the principles previously discussed.

WHAT WE CLAIM IS:—

1. A method of heating a pack of frozen food for consumption, which pack is of substantially uniform width, comprising effecting relative movement of the pack in its length direction past an outlet fed by

a source of microwave energy, so that said outlet supplies microwave energy to the pack with the direction of propagation of the microwave energy through the outlet, and the direction of the electric field vector of the microwave energy at the outlet, both substantially at right angles to each other and to the direction of movement of the pack past the outlet, and so that substantially uniform heating occurs across the pack width, and the dimensions of the outlet and the pack length are such that heating is concentrated in a band which is shorter than the pack length, and which through the relative movement between the pack and said microwave outlet, traverses the pack length.

2. A method according to claim 1 in which the pack is caused to perform a reciprocating movement back and forth across the microwave outlet, in which the movement of the pack is reversed at or just after the times when trailing edge of the pack passes the centre of the outlet, so that relative overheating of the pack at its leading and trailing edges is reduced.

3. A method according to claim 1 in which the pack is caused to perform a continuous movement past the microwave outlet, and the microwave source is switched on when the leading edge of the pack is substantially opposite the centre of the outlet, and is switched off when the trailing edge of the pack is substantially opposite the centre of the outlet, to ensure substantially even generation of heat at the beginning, intermediate zones and end of the pack length.

4. A method according to any one of the preceding claims in which a rectangular waveguide outlet is used which is flared to provide a width of energy field approximately equal to the width of the pack, and greater than a standard waveguide width.

5. A method according to claim 4 in which at least one longitudinal baffle is used within the flared waveguide outlet to preserve single mode propagation conditions.

6. A method according to claim 4 in which the flared outlet used is in the form of a Y type divider to ensure single mode propagation of the energy.

7. A method according to claim 6 in which the Y type divider has a baffle located parallel to the plane of the waveguide outlet and defining at its edges a pair of slots spaced half a wavelength apart so that energy emerging from said slots is subject to cancellation in the region of the slots and to reinforcement halfway therebetween, thereby to reduce the overheating at the edges of the pack width which would otherwise occur.

8. A method according to any one of claims 1-5 in which an impedance-matching

dielectric insert having a relative permittivity greater than air and a low loss factor is disposed within the outlet.

9. A method according to any one of the preceding claims in which the pack is caused to move within a metal tunnel less than half a wavelength high and parallel to the plane of the microwave outlet.

10. Apparatus for heating frozen food packs for consumption, comprising a microwave energy source, energy feeding means for feeding microwave energy from the source to an outlet, and conveying means for conveying a pack containing frozen food past the outlet substantially at right angles to the direction of propagation of microwave energy through the outlet and also substantially at right angles to the direction of the electric field vector of the microwave energy at the outlet, said directions also being at right angles to each other.

11. Apparatus according to claim 10 including switching means for switching the microwave energy on and off at pre-determined times in the travel path of a pack when conveyed past the outlet, namely for switching on when the leading edge of the pack is substantially opposite the centre of the outlet, and for switching off when the trailing edge of the pack is substantially opposite the centre of the outlet.

12. Apparatus according to claim 10 in which the conveying means is arranged to feed the pack in a reciprocating movement across the microwave energy outlet.

13. Apparatus according to claim 10 in which the energy feeding means is a rectangular waveguide outlet which is flared to provide a width of energy field of greater width than a standard waveguide width.

14. Apparatus according to claim 13 comprising at least one longitudinal baffle located within the flared waveguide outlet to preserve single mode propagation conditions.

15. Apparatus according to claim 14 in which the outlet is a Y type power divider.

16. Apparatus according to claim 14 or claim 15 in which the outlet comprises a baffle located parallel to the plane of the waveguide outlet and defining at its edges a pair of slots spaced half a wavelength apart so that energy emerging from said slots is subject to cancellation in the region of the slots and to reinforcement halfway therebetween.

17. Apparatus according to any of claims 10 to 15 comprising an impedance-matching dielectric insert having a relative permittivity greater than air and a low loss factor disposed within the outlet.

18. Apparatus according to any of claims 10 to 17 also having a metal tunnel for surrounding food packs during their conveyance to and from the outlet, which tunnel

is less than half a wavelength high and is parallel to the plane of the microwave energy outlet.

19. Apparatus substantially as herein described with reference to Figures 1—4 and 8 of the accompanying diagrammatic drawings, or with reference to Figures 1—4 and 8 and modified as described with reference to Figure 5, Figure 6 or Figure 7 of the accompanying drawings.

20. A method of heating frozen foods by microwave energy substantially as herein described with reference to Figures 1—4

and 8 of the accompanying drawings or with reference to Figures 1—4 and 8 and modified as described with reference to Figure 5, Figure 6 or Figure 7 of the accompanying drawings. 15

21. A pack of food which has been heated from the frozen state by a method or apparatus as claimed in any preceding claim. 20

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COMPLETE SPECIFICATION

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Sheet 1

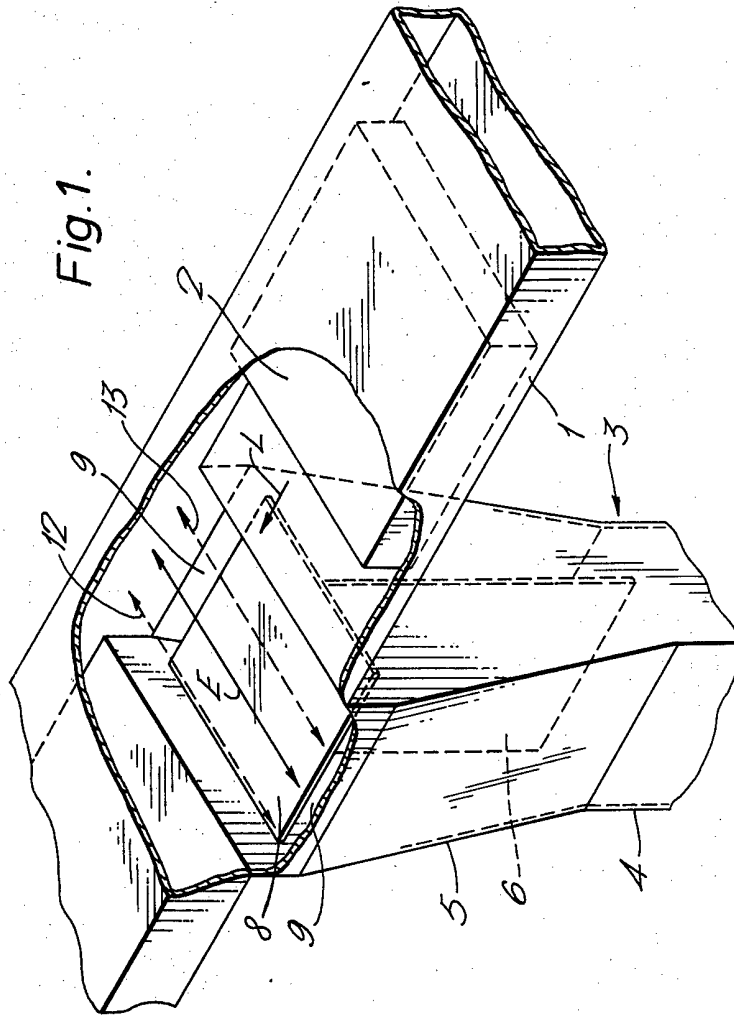


Fig. 2.

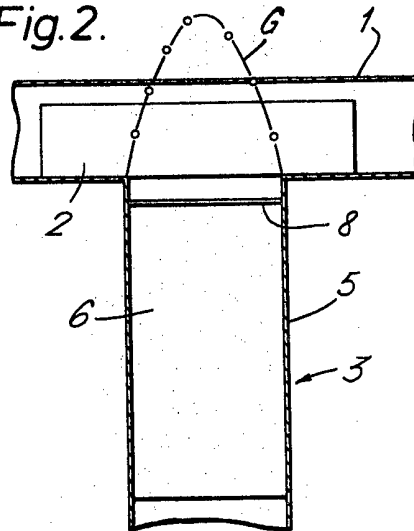


Fig. 3.

