EUROPEAN PATENT SPECIFICATION

Rotary dielectric drying of ceramic honeycomb ware
Rotierende dielektrische Trocknung von keramischen Wabenkörpern
Séchage rotatif diélectrique d'articles céramiques en nid d'abeilles

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References cited:
EP-A-0 023 940
FR-A-2 299 443
US-A-4 439 929

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Description

[0001] The invention relates to a method and an apparatus for drying a wet honeycomb structure having cells extending longitudinally therethrough parallel to a longitudinal axis of said honeycomb structure.

[0002] Thin-walled honeycomb structures have utility as a catalyst substrate or as a diesel particulate filter. Such substrates may be formed from extrudable material such as particulate ceramic and/or metal batches which may be sintered, and similar materials which have the property of being able to flow or plastically deform during extrusion, while being able to become sufficiently rigid immediately thereafter so as to maintain their structural integrity, in the manner set forth in U.S. Patent Nos. 3,790,654 and 4,758,272. Alternatively, the honeycomb structure may be made of pleated thin porous sheets of filter material whose layers are interleaved with corrugated or crimped spacers with parallel corrugations or crimps thereof extending substantially perpendicular to the folds or the pleated sheets, as disclosed in U.S. Patent Nos. 2,884,091, 2,952,333 and 3,242,649.

[0003] The invention more particularly relates to improved method and apparatus for drying wet honeycomb structures, formed of such particulate material or sheets, of virtually any desired size and shape or transverse cross-section. Honeycomb ware is typically manufactured by extruding or fabricating ceramic material into logs, followed by the drying, cutting and firing of such ceramic logs. The drying of such honeycomb logs must be done very carefully in order to not induce stresses in the honeycomb ware pieces, produced by non-uniform drying and shrinkage, which can create distortion, warping or cracking. Conventional convection or oven drying cannot be used, particularly with the relatively large logs required for diesel particulate filters, since by its nature, convection drying dries the ware from the outside inwardly, and the early outside drying results in the shrinking of the outer layers, thereby invariably leading to cracking or distortion, rendering the product unusable.

[0004] Some forms of dielectric drying through the use of dielectric heating have been utilized in the past. However, due to non-uniform radio frequency fields between the dielectric electrodes and the orientation of such electrodes relative to the honeycomb ware, the results obtained with such prior art devices and methods were not entirely satisfactory. Typically, the larger green ceramic honeycomb structures were initially subjected to dielectric drying for about 25 minutes followed by hot air convection drying for about 72 hours. Not only was the required total drying time excessive, but also the available radio frequency fields produced by the dielectric heating are not uniform, thus resulting in a variable drying pattern within the honeycomb structure.

[0005] EP-A-273707 discloses a method of drying a wet honeycomb structure having cells defined by cell walls, said cells extending longitudinally therethrough parallel to a longitudinal axis of said honeycomb structure. Said pre-known method comprises placing said honeycomb structure between a pair of dielectric electrodes, applying RF energy to said dielectric electrodes to produce uniform electric heating in drying of said structure and blowing heated air through the cells of said honeycomb structure to remove water vapors therefrom and facilitate the rapid drying of said honeycomb structure. Disclosed is also an apparatus comprising a pair of parallel spaced-apart dielectric electrodes, means for applying RF energy to said dielectric electrodes for producing uniform dielectric heating and drying of said structure and means for flowing heated air through the cells of said honeycomb structure to remove water vapor therefrom and facilitate the rapid drying of said honeycomb structure with means for heating said air.

[0006] However, drying results are not sufficiently uniform and efficient.


[0008] It is an object of the present invention to provide an improved method and apparatus for efficiently and uniformly drying green ceramic honeycomb structures without distorting, warping, or cracking the structure and thus minimizing the development of harmful stresses within the structure.

[0009] According to the invention, this object is attained by the method of claim 1 and an apparatus of claim 7. Further advantageous embodiments of the method and the apparatus are subject matter of dependent claims, respectively.

Detailed Description of the Drawings

[0010] Fig. 1 is a schematic block diagram of representative apparatus for carrying out the present invention.

Fig. 2 is a somewhat schematic representation of essential operating portions of the drying apparatus embodying the present invention.

Fig. 3 is a graph illustrating the range of temperature within a honeycomb structure during a drying cycle, relative to the orientation of the dielectric electrodes.

Fig. 4 is a graph illustrating various drying rates which are obtainable with different air velocity and air temperature settings.

Detailed Description of the Invention

[0011] In order to accomplish the desired rapid, uniform and complete drying of green ceramic or wet honeycomb structures, the present invention incorporates
the utilization of dielectric heating, a unique orientation of dielectric electrodes relative to the position of the honeycomb structure, the rotation of the honeycomb structure about its longitudinal axis, and the flowing of heated air through the longitudinally extending cells of the honeycomb structure to, in effect, produce a synergistic result. The drying of the green honeycomb structure is accomplished through the use of dielectric heating, which is radio frequency (RF) heating, in which energy is released in a non-conducting medium through dielectric hysteresis. The advantage of dielectric drying over standard convection or oven drying is the fact that in RF drying, the energy passes through the entire honeycomb structure and is absorbed wherever there is water or other RF absorbing materials, and as a result the heating takes place throughout the honeycomb structure and the subsequent drying and shrinking are relatively uniform.

However, as currently practiced, the available RF fields are not uniform, and such fields are further modified by the presence of the wet honeycomb structure, resulting in a variable drying pattern. Although RF drying is preferable to convection drying, a non-uniformity still exists which can result in the driest parts of a structure becoming overheated and damaged when attempting to dry the wettest parts of the honeycomb. We have discovered, however, that by positioning or orienting the dielectric electrodes parallel to the longitudinal axis of the honeycomb structure extending longitudinally through its cells, and by rotating the honeycomb structure about its longitudinal axis, the non-uniformity problem is overcome. That is, the rotation of the ware within the RF field cancels out most of the effect of the RF field variations, by positioning each portion of the ware in a variety of locations in the RF field, and resulting in a smoothed, average energy transfer.

Preferably, after the temperature of the honeycomb ware has been raised and partially dried with RF energy, and while such ware is still being heated by the RF field, hot air is passed longitudinally through the cells of the honeycomb structure. The hot air serves to remove evaporated moisture which otherwise must diffuse out of the honeycomb channels or cells. As a result, the partial pressure of water vapor in the cells is greatly reduced and the evaporation rate increases. This combination of a smoothed out RF energy, through rotation of the ware, together with parallel electrode orientation to uniformly supply the heat of evaporation throughout the honeycomb ware, and the hot air flow to quickly remove the resulting water vapor, provides an unusually fast and uniform drying process.

Referring now to the drawings, and particularly Fig. 1, a schematic illustration of apparatus which may be used to carry out the present invention is shown. The apparatus includes a drying oven 10, an RF power unit and control cabinet 12, and a control cabinet 14 for controlling the velocity and temperature of the air supplied to the honeycomb structure, and the rate of rotation of the turntable upon which the honeycomb structure is positioned. The drying oven 10 is provided with an access door 16 and a suitable heater 18 for heating the air to be supplied to the ware, and a fan 20 for controlling the velocity of the air supplied to the honeycomb structure.

Referring now to Fig. 2, the interior working structure of the drying oven 10 is schematically disclosed. A turntable 22 is rotatably mounted upon a lower support structure 24. An air inlet duct 26 communicates with the turntable 22 and is operably connected with the heater 18 and fan 20 positioned in the lower portion of the drying oven 10, which are controlled through control cabinet 14.

The turntable 22 is mounted for rotation upon an upper surface of the lower support structure 24. Preferably, the turntable is made of a material which is transparent to RF energy, such as most ceramics and plastics. A hollow carrier 28, having a cylindrical upper portion 30 and a lower disk portion 32, is positioned upon the upper open end of turntable 22, such that the disc portion 32 engages the open end of the turntable. Preferably, the carrier 28 is made of a material, such as fiberglass/epoxy, and fired ceramic material (preferably, fired ceramic honeycomb), which is transparent to RF energy, and accordingly is not heated by such energy. A perforated support disc 34 which is transparent to RF energy, operatively fits within the upper open end of the carrier 28 and functions as an open free-flowing support for a green ceramic or wet honeycomb ware structure W positionable thereon.

Heated air from the heater 18 is forced at a desired velocity by fan 20 through the air inlet duct 26 into the hollow turntable 22. The turntable may be provided with a plurality of air diverters in order to effect the distribution of the air flow upwardly through the hollow carrier 28, the open honeycomb support disc 34 and through the longitudinal cells of the ware W. The turntable 22, carrier 28 and disk support 34 are all aligned so that the longitudinal axis A of the honeycomb ware structure W is coincident with the axis of rotation of the turntable 22. Thus, the turntable 22 rotates the honeycomb ware W about its longitudinal axis A, which extends parallel with the longitudinally extending cells of the honeycomb structure. In addition, the flow of heated air, supplied to the honeycomb structure W, also flows parallel with the longitudinal axis A and thus flows through the cells of the ware.

A pair of support plates 38 are positioned within the drying oven 10 and support dielectric electrodes 40 by means of insulated standoffs 42. The electrodes 40 are preferably planar and extend parallel with the longitudinal axis A of the honeycomb ware W, but could be contoured to complement the curvature of the ware in a batch process, if desired. The support plates 38 may be secured to the lower support structure 24 and the shell or inner wall 11 of the drying oven 10, as shown, or they may be adjustably positioned on support
leads 41 to the electrodes 40 to produce an RF field controlled by control cabinet 12 to supply RF energy via a preferred range being between about 1 and 6 rpm. 14, may vary from about 1/4 rpm to about 10 rpm, with parallel with the longitudinal axis A of the ware W. The evenly between the electrodes 40, which are oriented about its longitudinal axis A on the support disk 34 energized by control cabinet 14 to rotate the ware W of rotation of the turntable 22. The turntable 22 is then its longitudinal axis A is virtually coincident with the axis of rotation of the turntable 22. A green ceramic or wet addition, the electrodes are evenly spaced from the axis operative attached to the oven structure.

As previously mentioned, it may be desirable, from an operational standpoint, to be able to vary the distance between the electrodes 40, and thereby vary the RF field between such electrodes. In such a case, the support plates 38 would not be secured to supporting structure of the oven 10, but rather could be attached to motorized screw adjustment means 44, such as shown at the top of the support plates 38. If desired, such motorized screw adjustment means could be secured to suitable support rods secured to the frame of the oven 10. The dielectric electrodes 40 are of course operatively connected to the RF power unit 12 by suitable leads 41.

The basis of the present apparatus may be utilized either for batch operations or for continuous drying processes. For example, again referring to Fig. 2, in a continuous drying operation, the oven 10 would extend longitudinally into the page of the figure, and the upper surface 36 of the lower support structure 24 would be in the form of a conveyor or a series of trolleys for moving a plurality of turntables 22 longitudinally there along into the page of Fig. 2, while incorporating suitable gearing for rotating each table and its associated carrier and ware, such that the ware is rotated about its longitudinal axis as it moves parallel with and between the electrodes 40, also extending into the page of the figure. Needless to say, the air duct 26 would extend along underneath the trolleys or conveying mechanism 36.

In operation, the electrodes 40 are positioned parallel to one another at a desired spacing relative to the wet honeycomb ware structure to be dried. In addition, the electrodes are evenly spaced from the axis A of rotation of the turntable 22. A green ceramic or wet honeycomb ware structure W to be dried is positioned upon the open or honeycomb support disk 34, such that its longitudinal axis A is virtually coincident with the axis of rotation of the turntable 22. The turntable 22 is then energized by control cabinet 14 to rotate the ware W about its longitudinal axis A on the support disk 34 evenly between the electrodes 40, which are oriented parallel with the longitudinal axis A of the ware W. The rotation of the turntable 22, controlled by control cabinet 14, may vary from about 1/4 rpm to about 10 rpm, with a preferred range being between about 1 and 6 rpm.

An RF generator is positioned within and controlled by control cabinet 12 to supply RF energy via leads 41 to the electrodes 40 to produce an RF field therebetween. The amount of voltage applied to the electrodes 40 will of course vary depending upon the size of the RF generator being utilized, the size of the ware item being dried, and the moisture content within such ware. However, with a 10-KW RF generator, voltages of about 10 to 20 KV have been successfully applied.

With the ware item W rotating about its longitudinal axis A between the RF energized electrodes 40, extending parallel to said longitudinal axis, it is preferred to delay the application of forced heated air through inlet duct 26 until evaporation of water from the cell walls is substantially uniform throughout the length of the ware. The length of the delay or the point at which this uniform evaporation is attained for a given ware is determined by experimentation. In general, the appropriate delay will depend on process variables such as the RF energy level, air flow rate, air temperature, the size and shape of the ware, ware composition etc. One indicator of the point at which forced heated air can be applied without stress cracking (i.e., when uniform water evaporation is attained), is ware temperature. For example, for the large ceramic bodies used for experimentation, we observed that uniform water evaporation was attained at ware temperatures of 80 to 90 °C. At these ware temperatures, forced air flow did not produce stress cracking in the ceramic ware.

Accordingly, after a predetermined delay wherein only RF energy is applied to the rotating ware W so as to uniformly heat and evaporate water from the ware, heated forced air is applied through inlet air duct 26 by means of heater 18 and fan 20, as controlled by control cabinet 14. The heated air flow from inlet duct 26 passes through the turntable 22, the hollow carrier 28, through the openings of the honeycomb disk support 34, and upwardly longitudinally through the longitudinally extending cells of the honeycomb structure W. The temperature and velocity of the air supplied to the honeycomb ware W to be dried, is controlled by the control cabinet 14 which operates the heater 18 and the fan 20. Although air temperatures between about 80°C and 150°C have been successfully utilized, it is preferred to utilize an air flow at a temperature of about 100°C + or - 20°C. Further, air velocities between about 2 meters per second and 5 meters per second have been successfully utilized. Also, the velocity of the air supplied to the ware W may be varied during the drying process, if desired, such that a reduced initial velocity may be supplied and then a greater velocity may be provided to hasten the final drying.

Due to the fact that the green ceramic or wet honeycomb ware W is placed with its longitudinal channels or cells parallel to the electrodes 40, and rotated about its longitudinal axis A in the RF field, all parts of the ware are exposed to the same RF field, thus producing a uniform energy transfer by leveling the non-uniformities and variations of the RF field to produce a virtually stress-free drying of the ware.

Referring now to Fig. 3, the benefits of orienting the electrodes 40 so as to be parallel with the lon-
The temperature of the ware within a given area can be seen to have a significant effect on the drying process. As an example, a green ceramic honeycomb extrusion approximately 13.5 inches in diameter and 17 inches in length, weighing about 60 lbs., was positioned on the honeycomb support disk 34, with the longitudinal axis thereof being virtually coincident with the axis of turntable 22 and parallel with the dielectric electrodes 40 which were spaced apart with an electrode gap of 15.5 inches. RF energy was applied to the electrodes 40 by means of control cabinet 14 at about 18 KV while the ware was rotated about its longitudinal axis at 6 rpm. After a period of 6 minutes, air at 100°C was introduced through inlet duct 26 at a velocity of about 2 meters per second for flow longitudinally through the longitudinal cells of the ware W. After a period of 24 minutes from the beginning of the drying operation, the RF energy was turned off, and the drying was finished with an additional 5 minutes of the hot air flow alone. Many variations of this drying cycle may be utilized, and are within the scope of the invention, including different air temperatures and flow rates, different rotation rates, different applied voltages, and any changes in any and all of these variables during the drying cycle itself.

Further, it has been observed that rotation rates of the turntable 22 between about 1/4 rpm and 6 rpm had no significant affect on the drying of the ware.

As a specific example, but by no means limiting in nature, a green ceramic honeycomb extrusion approximately 13.5 inches in diameter and 17 inches in length, weighing about 60 lbs., was positioned on the honeycomb support disk 34, with the longitudinal axis thereof being virtually coincident with the axis of turntable 22 and parallel with the dielectric electrodes 40 which were spaced apart with an electrode gap of 15.5 inches. RF energy was applied to the electrodes 40 by means of control cabinet 14 at about 18 KV while the ware was rotated about its longitudinal axis at 6 rpm. After a period of 6 minutes, air at 100°C was introduced through inlet duct 26 at a velocity of about 2 meters per second for flow longitudinally through the longitudinal cells of the ware W. After a period of 24 minutes from the beginning of the drying operation, the RF energy was turned off, and the drying was finished with an additional 5 minutes of the hot air flow alone. Many variations of this drying cycle may be utilized, and are within the scope of the invention, including different air temperatures and flow rates, different rotation rates, different applied voltages, and any changes in any and all of these variables during the drying cycle itself.

Although the present invention may be applied to wet honeycomb structures of virtually any size and transverse cross-sectional shape, it will be apparent that the drying uniformity obtained through the rotation of the structure about its longitudinal axis makes the invention especially useful for those honeycomb structures having circular, oval or regular polygonal transverse external cross-sections, and particularly those exhibiting relatively large cross-sectional diameters of at least about 8 inches.

Claims

1. A method of drying a wet honeycomb structure having cells defined by cell walls, said cells extending longitudinally therethrough parallel to a longitudinal axis of said honeycomb structure which comprises:

   - rotating said honeycomb structure about its longitudinal axis between a pair of dielectric electrodes, and applying RF energy to said dielectric electrodes for a desired period of time at which water evaporation from the cell walls is substantially uniform throughout the surface of the structure while said honeycomb structure is rotated about its longitudinal axis therebetweent to produce uniform dielectric heating and drying of said structure and then,
   - flowing heated air longitudinally through the cells of said rotating honeycomb structure after the temperature thereof has been raised and it

   - air temperature will significantly affect drying rate.

   Further, it has been observed that rotation rates of the turntable 22 between about 1/4 rpm and 6 rpm had no significant affect on the drying of the ware.

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   - flowing heated air longitudinally through the cells of said rotating honeycomb structure after the temperature thereof has been raised and it

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1. A method of drying a wet honeycomb structure having cells defined by cell walls, said cells extending longitudinally therethrough parallel to a longitudinal axis of said honeycomb structure which comprises:

   - rotating said honeycomb structure about its longitudinal axis between a pair of dielectric electrodes, and applying RF energy to said dielectric electrodes for a desired period of time at which water evaporation from the cell walls is substantially uniform throughout the surface of the structure while said honeycomb structure is rotated about its longitudinal axis therebetweent to produce uniform dielectric heating and drying of said structure and then,
has been partially dried with RF energy to remove water vapors therefrom and to facilitate the rapid drying of said honeycomb structure.

2. A method as defined in claim 1 including the step of orienting said pair of dielectric electrodes so as to be parallel with said longitudinal axis of said honeycomb structure.

3. A method as defined in claim 1 including the step of applying heated air to said rotating honeycomb structure at a temperature of between about 80°C and 120°C, or applying heated air to said honeycomb structure after said dielectric heating has heated the honeycomb structure to a temperature of 80 - 90°C.

4. A method as defined in any one of claims 1 - 3 including the step of varying the velocity of the heated air flowing longitudinally through the cells of said rotating honeycomb structure during the drying cycle, or of initially flowing said heated air longitudinally through the cells of said rotating honeycomb structure at one velocity, and thereafter increasing the velocity of flow through said longitudinal cells.

5. A method as defined in claim 1 including the step of rotating said honeycomb structure about its longitudinal axis at a speed of rotation between about 1 and 6 rpm and/or the step of flowing said heated air longitudinally through the cells of said rotating honeycomb structure at a velocity of between about 2 and 5 meters per second.

6. A method as defined in claim 1 including the step of interrupting the application of said RF energy to said dielectric electrodes and completing the drying of said honeycomb structure with the continued application of heated air to said rotating structure.

7. Apparatus for drying a wet honeycomb (W) having cells extending longitudinally therethrough parallel to a longitudinal axis (A) of said honeycomb structure which comprises:

   a pair of parallel spaced-apart dielectric electrodes (40), means (22) for rotating said honeycomb structure (W) about its longitudinal axis (A) between said pair of dielectric electrodes (40), means (12) for applying RF energy to said dielectric electrodes (40) simultaneously with the rotation of said honeycomb structure (W) theretbetween and for producing uniform dielectric heating and drying of said structure, and means (20) for flowing heated air longitudinally through the cells of said honeycomb structure (W) simultaneously with the rotation thereof to remove water vapor therefrom and facilitate the rapid drying of said honeycomb structure, and a control means (14) for delaying the flowing of heated air longitudinally through the cells of said honeycomb structure (W) until a time when the application of said RF energy has resulted in the substantially uniform evaporation of water from the cell walls throughout the surface of the structure.

8. Apparatus as defined in claim 7 wherein said pair of spaced-apart dielectric electrodes (40) are oriented parallel to, and equally spaced-apart from, said longitudinal axis (A) of said honeycomb structure (W).

9. Apparatus according to claim 7 or 8 further comprising means (36) for moving the structure (W) parallel with and between said electrodes (40).

10. Apparatus according to claims 7 or 8, further comprising means (44) for adjusting the distance between said electrodes (40).

11. Apparatus as defined in one of claims 7 - 10 including means (14) for controlling the temperature of the air flowing through the longitudinal cells of said honeycomb structure (W) and/or means (14) for controlling or varying the velocity of the heated air flowing longitudinally through the cells of said honeycomb structure (W) and/or means (12) for interrupting the application of RF energy to said dielectric electrodes (40) during the drying of said wet honeycomb structure and during the flowing of heated air longitudinally through the cells of said honeycomb structure (W).

Patentansprüche

1. Verfahren zur Trocknung einer nassen Wabenstruktur, die Zellen aufweist, die durch Zellwände definiert sind, wobei die Zellen longitudinal dadurch parallel zu einer longitudinalen Achse der Wabenstruktur verlaufen, welches umfaßt:

   Drehen der Wabenstruktur um ihre longitudinalen Achse zwischen einem Paar von dielektrischen Elektroden, und Anlegen von RF-Energie an die dielektrischen Elektroden für eine gewünschte Zeitdauer, bei welcher eine Wasserverdampfung von den Zellwänden im wesentlichen gleichförmig über der Fläche der Struktur ist, während die Wabenstruktur um ihre longitudinalen Achse dazwischen gedreht wird, um eine gleichförmige dielektrische Heizung und eine Trocknung der Struktur zu erzeugen, und dann

   Strömen erwärmter Luft longitudinal durch die
Zellen der sich drehenden Wabenstruktur, nachdem die Temperatur davon erhöht worden ist und sie teilweise mit RF-Energie getrocknet worden ist, um Wasserdämpfe davon zu entfernen und die rasche Trocknung der Wabenstruktur zu erleichtern.

2. Verfahren nach Anspruch 1, einschließlich den Schritt eines Orientierens des Paars von dielektrischen Elektroden so, daß sie parallel zu der longitudinalen Achse der Wabenstruktur liegen.

3. Verfahren nach Anspruch 1, einschließlich den Schritt eines Anlegens erwärmter Luft an die sich drehende Wabenstruktur bei einer Temperatur von zwischen ungefähr 80°C und 120°C, oder eines Anlegens erwärmter Luft an die Wabenstruktur, nachdem die dielektrische Heizung die Wabenstruktur auf eine Temperatur von 80-90°C erwärmt hat.

4. Verfahren nach einem der Ansprüche 1-3, einschließlich den Schritt eines Varierens der Geschwindigkeit der erwärmten Luft, die longitudinal durch die Zellen der sich drehenden Wabenstruktur während des Trocknungszyklus strömt, oder des anfänglichen Strömens der erwärmten Luft longitudinal durch die Zellen der sich drehenden Wabenstruktur bei einer Geschwindigkeit, und danach ein Erhöhen der Strömungsgeschwindigkeit durch die longitudinalen Zellen.

5. Verfahren nach Anspruch 1, einschließlich den Schritt des Drehens der Wabenstruktur um ihre longitudinale Achse zwischen ungefähr 1 und 6 UpM und/oder den Schritt des Unterbrechens des Anlegens der RF-Energie an die dielektrischen Elektroden gleichzeitig mit der Drehung der Wabenstruktur (W) dazwischen und zum Erzeugen einer gleichförmigen dielektrischen Heizung und einer Trocknung der Struktur, und

8. Vorrichtung nach Anspruch 7, dadurch gekennzeichnet, daß das Paar von beabstandeten dielektrischen Elektroden (40) parallel zu und gleich beabstandet von der longitudinalen Achse (A) der Wabenstruktur (W) orientiert ist.

9. Vorrichtung nach Anspruch 7 oder 8, weiter umfassend eine Einrichtung (36) zum Bewegen der Struktur (W) parallel zu und zwischen den Elektroden (40).

10. Vorrichtung nach Ansprüchen 7 oder 8, weiter umfassend eine Einrichtung (44) zum Einstellen der Entfernung zwischen den Elektroden (40).

11. Vorrichtung nach einem der Ansprüche 7-10, einschließlich eine Einrichtung (14) zum Steuern der Temperatur der Luft, die durch die longitudinalen Zellen der Wabenstruktur (W) strömt, und/oder eine Einrichtung (12) zum Unterbrechen des Anlegens von RF-Energie an die dielektrischen Elektroden (40) während der Trocknung der nassen Wabenstruktur und während des Strömens von erwärmter Luft longitudinal durch die Zellen der Wabenstruktur (W).

**Revendications**

1. Procédé de séchage d'une structure en nid d'abeilles humide ayant des cellules définies par...
Procédé selon la revendication 1, comprenant
5.

4.

Procédé selon l'une quelconque des revendications
2.

Procédé selon la revendication 1, comprenant
3.

la rotation de ladite structure en nid d'abeilles autour de son axe longitudinal entre une paire d'électrodes diélectriques et l'application d'énergie RF auxdites électrodes diélectriques pendant une période de temps souhaitée pendant laquelle l'évaporation d'eau de parois cellulaires est sensiblement uniforme sur toute la surface de la structure, tandis que ladite structure en nid d'abeilles est soumise à une rotation autour de son axe longitudinal entre elles pour produire un chauffage et un séchage diélectriques uniformes de ladite structure et, ensuite, l'écoulement d'air chauffé longitudinal à travers les cellules de ladite structure en nid d'abeilles en rotation, après élévation de sa température et son séchage partiel par l'énergie RF, pour en éliminer la vapeur d'eau et faciliter le séchage rapide de ladite structure en nid d'abeilles.

2.

Procédé selon la revendication 1, comprenant l'étape d'orientation de ladite paire d'électrodes diélectriques de manière qu'elle soit parallèle àudit axe longitudinal de ladite structure en nid d'abeilles.

3.

Procédé selon la revendication 1, comprenant l'étape d'application d'air chauffé à ladite structure en nid d'abeilles en rotation à une température environ 80 et 120°C ou d'application d'air chauffé à ladite structure en nid d'abeilles après que le chauffage diélectrique aura chauffé la structure en nid d'abeilles à une température de 80 à 90°C.

4.

Procédé selon l'une quelconque des revendications 1 à 3, comprenant l'étape de variation de la vitesse de l'air chauffé s'écoulant longitudinal à travers les cellules de ladite structure en nid d'abeilles en rotation au cours du cycle de séchage, ou d'écoulement initial dudit air chauffé longitudinal à travers les cellules de ladite structure en nid d'abeilles en rotation à une vitesse en augmentant ensuite la vitesse d'écoulement à travers lesdites cellules cellulaires longitudinales.

5.

Procédé selon la revendication 1, comprenant l'étape de mise en rotation de ladite structure en nid d'abeilles autour de son axe longitudinal à une vitesse de rotation environ 1 et 6 tr/mn et/ou l'étape d'écoulement dudit air chauffé longitudinal à travers les cellules de ladite structure en nid d'abeilles en rotation à une vitesse entre environ 2 et 5 mètres/seconde.

6. Procédé selon la revendication 1, comprenant l'étape d'interruption de l'application de ladite énergie RF auxdites électrodes diélectriques et d'achèvement du séchage de ladite structure en nid d'abeilles par application continue d'air chauffé à ladite structure en rotation.

7. Appareil de séchage d'une structure en nid d'abeilles humide (W) ayant des cellules s'étendant longitudinal à travers ladite structure en nid d'abeilles, ledit appareil comprenant :

une paire d'électrodes diélectriques parallèles (40) espacées l'une de l'autre, un moyen (22) pour faire tourner ladite structure en nid d'abeilles (W) autour de son axe longitudinal (A) entre ladite paire d'électrodes diélectriques (40), un moyen (12) pour appliquer de l'énergie RF auxdites électrodes diélectriques (40) simultanément avec la rotation de ladite structure en nid d'abeilles (W) entre elles et produire un chauffage et un séchage diélectriques uniformes de ladite structure, et un moyen (20) pour faire couler de l'air chauffé longitudinal à travers les cellules de ladite structure en nid d'abeilles (W) simultanément avec sa rotation pour en éliminer la vapeur d'eau et faciliter le séchage rapide de ladite structure en nid d'abeilles, et un moyen de commande (14) pour retarder l'écoulement d'air chauffé longitudinal à travers les cellules de ladite structure en nid d'abeilles (W) jusqu'à un moment où l'application de ladite énergie à RF entraîne l'évaporation sensiblement uniforme de l'eau des parois cellulaires sur toute la surface de la structure.

8. Appareil selon la revendication 7, dans lequel lesdites deux électrodes diélectriques (40) espacées l'une de l'autre sont orientées parallèlement à et égale distance dudit axe longitudinal (A) de ladite structure en nid d'abeilles (W).

9. Appareil selon la revendication 7 ou 8, comprenant en outre un moyen (36) pour déplacer la structure (W) parallèlement auxdites électrodes (40) et entre elles.

10. Appareil selon la revendication 7 ou 8, comprenant en outre un moyen (44) pour ajuster la distance entre lesdites électrodes (40).

11. Appareil selon l'une quelconque des revendications 7 à 10, comprenant un moyen (14) pour comman-
der la température de l'air s'écoulant à travers les cellules longitudinales de ladite structure en nid d'abeilles (W) et/ou un moyen (14) pour commander ou faire varier la vitesse de l'air chauffé qui s'écoule longitudinalement à travers les cellules de ladite structure en nid d'abeilles (W) et/ou un moyen (12) pour interrompre l'application d'énergie RF auxdites électrodes diélectriques (40) au cours du séchage de ladite structure en nid d'abeilles humide et au cours de l'écoulement d'air chauffé longitudinalement à travers les cellules de ladite structure en nid d'abeilles (W).
Fig. 3

PIECE TEMPERATURE RANGE
Vs. ORIENTATION OF THE ELECTRODES

TEMP. (°C)

TIME (sec)

160 140 120 100 80 60 40 20 0

0 100 200 300 400

a b c
Fig. 4

DRIYING RATES vs. AIR VELOCITY & TEMP.

NORMALIZED WEIGHT

0 4 8 12 16 20 24 28 32

TIME (MINUTES)