

(19)



(11)

EP 3 784 004 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:

24.02.2021 Bulletin 2021/08

(51) Int Cl.:

H05B 6/80 (2006.01)

(21) Application number: **19192286.3**

(22) Date of filing: **19.08.2019**

(84) Designated Contracting States:

**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO
PL PT RO RS SE SI SK SM TR**

Designated Extension States:

BA ME

Designated Validation States:

KH MA MD TN

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(54) **MICROWAVE APPLICATOR CONTROL**

(57) System and method for applying a microwave treatment to a product. Features capturing image data indicative of a temperature distribution of a product and controlling, by means of a controller and based on the image data, an amount of applied microwave power to a product.

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Description

TECHNICAL FIELD

5 **[0001]** The present invention is in the field of microwave applicators, and in particular in the field of methods and devices for controlling microwave applicators.

BACKGROUND

10 **[0002]** Microwave systems are used for a variety of purposes including heating, drying, and assisting chemical reactions. In this regard, the following prior art is made of record:

EP0000957 describes a humidity controlled microwave oven and a method of cooking.

15 EP517433 describes a heating apparatus such as microwave ovens that includes a gas sensor sensitive to the density of water vapor and the like emanating from the food.

20 EP3462818 describes an electromagnetic cooking device that includes an enclosed cavity configured to receive a food load, a plurality of high power amplifiers and RF feeds for introducing electromagnetic radiation into the cavity, and a controller for controlling the frequency, phase and amplitude of the electromagnetic radiation fed into the cavity by the RF feeds.

25 EP0268329 describes a microwave oven comprising a generator for radiating energy, fan means for producing an air flow in the oven cavity, humidity sensor means for sensing the humidity in the oven cavity and control means for controlling the supply of energy in dependence on the sensed humidity

30 US4841111 describes a microwave oven comprising a generator for radiating energy, fan means for producing an air flow in the oven cavity, humidity sensor means for sensing the humidity in the oven cavity and control means for controlling the supply of energy in dependence on the sensed humidity.

US20160283822 describes a heating cooker that includes a heating chamber that houses food.

US20100115785 describes a method of drying an object comprising, providing an object into an RF cavity.

35 US20140103031 describes a furnace system for thermal processing of products and materials.

US20190098709 describes an electromagnetic cooking device includes an enclosed cavity configured to receive a food load.

40 WO2004054324 describes an industrial microwave oven for the thermal treatment of products and a method applied thereby, in particular for killing insects in wood.

WO2008000048 describes a device and method for heating multiple prepared meals.

45 US20090079101 describes microwave sintering methods and a related apparatus, in particular related to microwave sintering of ceramic materials.

WO2007107367 describes an improved method and apparatus for drying coatings.

50 WO2007039284 describes a method of tempering comprising the use of microwaves and non-polar and a non-ionic cooling composition.

55 **[0003]** Methods for manufacturing glass by means of a microwave applicator are disclosed in ZHOU, Y., et al. Microwave processing CaO-Al₂O₃-SiO₂ glass using sol-gel technique. In: Materials Research Society Symposium-Proceedings. 1996. p. 131-137.

SUMMARY

[0004] There remains a need to further improve microwave systems. There particularly remains a need to further increase methods for their control.

[0005] The present methods and systems address at least these needs.

[0006] In particular, provided herein is a method for applying a microwave treatment to a product, the method comprising the steps: a) providing a microwave system comprising a microwave applicator, an imaging device, a controller, and a microwave generator; b) placing the product in the microwave applicator; c) generating microwaves by means of the microwave generator at a pre-determined generated microwave power; d) directing the microwaves to the product in the microwave applicator; e) subjecting the product to the microwaves at a pre-determined applied microwave power; f) capturing, by means of the imaging device, image data indicative of a temperature distribution of the product; g) controlling, by means of the controller and based on the image data, the applied microwave power to the product.

[0007] In some embodiments, the imaging device comprises an infrared camera.

[0008] In some embodiments, step b) comprises the following sub-steps: b1) providing one or more positioning blocks in the microwave applicator; and, b2) placing the product on the one or more positioning blocks.

[0009] In some embodiments, step g) comprises the steps: g1) determining, by the controller and based on the image data captured by the image device, an amount of excess generated microwave power; and, g2) directing, by means of a circulator, the excess generated microwave power to a dummy load.

[0010] In some embodiments, step g) is followed by step h) which comprises the following steps: h1) measuring an amount of incident power by means of a power meter; h2) measuring an amount of reflected power by means of a power meter; h3) determining an amount of absorbed microwave power by subtracting the amount of incident power and the amount of reflected power; h4) either using the amount of absorbed microwave power as an approximation of the amount of microwave power that was absorbed by the product; or, calculating an amount of cavity losses, and calculating the amount of microwave power that was absorbed by the product by subtracting the amount of cavity losses from the amount of absorbed microwave power.

[0011] In some embodiments, the product is a liquid product, and wherein the method further comprises the step of stirring the product.

[0012] In some embodiments, step f) further comprises the step of determining a temperature distribution in the product based on the image data, and wherein in step g), the applied microwave power to the product is further controlled based on a maximum, average, or minimum value of the temperature distribution in the product.

[0013] In some embodiments, in step g), the applied microwave power is further controlled by means of a power limiter that limits the maximum applied microwave power.

[0014] Further provided herein is a microwave system for subjecting a product to a microwave treatment, the system comprising a microwave applicator, an imaging device, a controller, and a microwave generator; wherein the controller is operationally coupled with the microwave applicator, the imaging device, and the microwave generator; wherein the microwave generator is arranged to generate microwaves at a pre-determined power; wherein the system is arranged to subject the product to the microwaves; wherein the imaging device is arranged to capture image data indicative of a temperature distribution in the product; and, wherein the controller is arranged to adapt the power at which the microwaves are applied to the product based on the captured image data.

[0015] In some embodiments, the imaging device comprises an infrared camera.

[0016] In some embodiments, the system further comprises one or more positioning blocks for supporting the product.

[0017] In some embodiments, the system further comprises a circulator and a dummy load, wherein the controller is further configured to determine an amount of excess generated microwave power based on the image data captured by the image device; and wherein the circulator is configured for directing the excess generated microwave power to a dummy load.

[0018] In some embodiments, the system further comprises a power meter for measuring an amount of incident power and a power meter for measuring an amount of reflected power, wherein the controller is configured to determine an amount of absorbed microwave power by subtracting the amount of incident power and the amount of reflected power. Optionally, the controller is further configured for calculating an amount of cavity losses, and calculating the amount of microwave power that was absorbed by the product by subtracting the amount of cavity losses from the amount of absorbed microwave power.

[0019] In some embodiments, the system further comprises a stirrer and/or a power limiter.

[0020] Further provided herein is the use of a system according as described herein for drying a product; assisting a chemical reaction; and/or sterilizing a volume.

DESCRIPTION OF THE FIGURES

[0021] The following description of the figures of specific embodiments of the invention is only given by way of example

and is not intended to limit the present explanation, its application or use. In the drawings, identical reference numerals refer to the same or similar parts and features.

Fig. 1 shows a microwave system (100).

Fig. 2 shows a microwave pattern in a microwave applicator (200).

Fig. 3 shows input power, reflective power, and absorbed power as a function of time for an experiment at constant power (panel a) and an experiment at variable power (panel b).

Fig. 4 shows a photograph of a microwave applicator (200) and its associated components.

Fig. 5 shows the inside of a microwave applicator (200).

Fig. 6 shows a product discharge and collection device (290).

Fig. 7 shows selected power profile segments.

[0022] The following reference numerals are used in the description and figures:

100 - microwave system; 200 - microwave applicator (also called cavity); 201 to 207 - openings in the cavity (200); 2071 - PTFE sheet; 210 - microwave applicator door; 220 - infrared camera; 230 - vacuum suction line; 240 - pressure gauge; 250 - vacuum sensor; 260 - pressure feed; 270 - vacuum bleed line; 280 - vacuum pump; 285 - integrated water pump and chiller; 290 - product discharge and collection device; 291 - upper valve; 292 - lower valve; 300 - controller; 400 - microwave generator; 450 - wave guide; 500 - circulator; 520 - wave guide; 540 - coupler; 550 - power meter; 560 - sub-tuner module; 600 - dummy load; 700 - multi-purpose module; 800 - weighing scale; 1000 ultrasound aid.

DESCRIPTION OF THE INVENTION

[0023] As used below in this text, the singular forms "a", "an", "the" include both the singular and the plural, unless the context clearly indicates otherwise.

[0024] The terms "comprise", "comprises" as used below are synonymous with "including", "include" or "contain", "contains" and are inclusive or open and do not exclude additional unmentioned parts, elements or method steps. Where this description refers to a product or process which "comprises" specific features, parts or steps, this refers to the possibility that other features, parts or steps may also be present, but may also refer to embodiments which only contain the listed features, parts or steps.

[0025] The enumeration of numeric values by means of ranges of figures comprises all values and fractions in these ranges, as well as the cited end points.

[0026] The term "approximately" as used when referring to a measurable value, such as a parameter, an amount, a time period, and the like, is intended to include variations of $\pm 10\%$ or less, preferably $\pm 5\%$ or less, more preferably $\pm 1\%$ or less, and still more preferably $\pm 0.1\%$ or less, of and from the specified value, in so far as the variations apply to the invention disclosed herein. It should be understood that the value to which the term "approximately" refers per se has also been disclosed.

[0027] All references cited in this description are hereby deemed to be incorporated in their entirety by way of reference.

[0028] Unless defined otherwise, all terms disclosed in the invention, including technical and scientific terms, have the meaning which a person skilled in the art usually gives them. For further guidance, definitions are included to further explain terms which are used in the description of the invention.

[0029] Provided herein is a method for applying a microwave treatment to a product. The method comprising a) the step of providing a microwave system comprising a microwave applicator, an imaging device, a controller, and a microwave generator. In a further step b), product is placed in the microwave applicator, which is also called a cavity. In a further step c), microwaves are generated by means of the microwave generator at a pre-determined generated microwave power. In a further step d), microwaves are directed to the product in the microwave applicator. In a further step e), the product is subjected to the microwaves at a pre-determined applied microwave power. In a further step f), an imaging device captures image data indicative of a temperature distribution of the product. In a further step g), the controller controls the applied microwave power to the product based on the image data.

[0030] In some embodiments, the method further employs one or more wave guides, a circulator, a coupler, a power meter, a sub-tuner module, a multi-purpose module, and/or a weighing scale.

[0031] In some embodiments, the method further employs one or more of the following ancillary components: a microwave applicator door, an infrared camera, a vacuum suction line, a pressure gauge, a vacuum sensor, a pressure

feed, a vacuum bleed line, a vacuum pump, an integrated water pump and chiller, and/or a product discharge and collection device.

[0032] In some embodiments, the microwave applicator door can be closed by means of a plurality of butterfly nuts.

[0033] Preferably, the method employs a discharge and collection device as described herein.

[0034] In some embodiments, the microwave system is further equipped with one or more pressure regulating devices, preferably one or more pressure regulating device selected from the list comprising a vacuum suction line, pressure gauge, vacuum sensor, pressure feed, vacuum bleed line, and a vacuum pump.

[0035] In some embodiments, the system is used in a method for drying an object.

[0036] In some embodiments, the door is closable by means of a plurality of bolts, for example between 5 and 15 bolts. In some embodiments, the bolts are made of aluminium.

[0037] In some embodiments, the method is performed in a well-ventilated place.

[0038] In some embodiments, the method is applied in an atmosphere having a temperature below 30°C.

[0039] Preferably, the method involves the step of closing and securing the cavity door during operation of the microwave system.

[0040] Preferably, the method comprises the step of providing cooling water. Preferably, the cooling water is used in a dummy load or isolator to absorb mismatched (i.e. reflected) microwaves, thereby preventing them from bouncing back to the magnetron. Additionally or alternatively, the cooling water is used for cooling the magnetron. Using cooling water both in the isolator and for cooling the magnetron significantly improves the operation of the microwave applicator and the life expectancy of the electronics inside. The microwave (MW) unit is preferably not operated without a supply of cooling water at the correct temperature of, for example, between 10°C and 30°C. This can be enforced by requiring, for example, that the magnetron will not start if the water flow is too low or if the cooling water is too hot.

[0041] Preferably, the cooling water is circulated by a water pump that is integrated with a chiller. Thus the water pump and chiller are comprised in an integrated water pump and chiller. In some embodiments, the total cooling water volume of the microwave system is between 5 and 15 liters, for example 10 liters. The level of the water is preferably between the maximum and minimum lines in the level meter of the cooling unit. The water used is preferably solids-free and preferably does not contain any organic contaminants, such as, oils. Distilled water or potable water is suitable for this purpose.

[0042] In some embodiments, the method is used for drying products and the method comprises the step of checking whether or not the product is sufficiently dry by performing the following steps: a) ascertain the weight of the collector tank with its vacuum seal (tare); b) ascertain the initial moisture and weight of the product (measured by, e.g., IR scale); c) calculate the theoretical weight loss based on the initial moisture content and the desired end moisture content; and d) check the dryness of the material by weighing.

[0043] In some embodiments, the method is used for tempering or softening frozen foodstuffs, which comprises cooling the surface of the frozen foodstuffs with non-polar non-ionic cooling media during microwave radiation. The temperature at the surface may be as low as -40 °C to prevent surface thawing. The coolant may be carbon dioxide, nitrogen or argon.

[0044] In some embodiments, the method comprises applying microwave power to an object according to a power profile. A power profile provides a prescribed amount of power to be applied to the object as a function of time.

[0045] Preferably, the power profile is constructed from a plurality of segment types and types of power changes. Preferably, the segment types and types of power changes are selected from the list comprising: Rate, Dwell, Step, Time, GoBack, Wait, Call and End.

[0046] In order to control the rate of change of applied power, a ramp segment can be used. A ramp segment provides a controlled change of setpoint from an original to a target setpoint. The duration of the ramp is determined by the rate of change specified. The segment is specified by the target setpoint and the desired ramp rate.

[0047] In order to control the power at a constant level for a specified period, a dwell segment can be used. In a dwell segment, the setpoint remains constant for a specified period at the specified target. The operating setpoint of a dwell is inherited from the previous segment.

[0048] For a step segment, the setpoint changes instantaneously from its current value to a new value at the beginning of a segment. Preferably, a step segment has a minimum duration of 1 second.

[0049] Preferably, a time feature defines the duration of the segment. In this case the target setpoint is defined and the time taken to reach this value. A dwell period is set by making the target setpoint the same value as the previous setpoint.

[0050] Preferably, a GoBack feature is provided which allows segments to be repeated a number of times.

[0051] Preferably, a wait feature is provided which specifies a criterion according to which a segment cannot proceed to the next segment. Any segment can be defined as 'Wait'.

[0052] Preferably, the imaging device comprises an infrared camera. The camera allows capturing image data indicative of a temperature distribution in a product which is treated in the microwave applicator. The camera then provides real-time input data which can be used by the controller to adapt the power at which the microwaves are applied to the product based on the captured image data.

[0053] The imaging device is sensitive to electromagnetic radiation, preferably sensitive to UV, visible, and/or IR light. In some embodiments, the imaging device is a spectral imaging device. A suitable device is a hyperspectral camera. Preferably, and infrared (IR) camera is used. Alternatively, multiple cameras sensitive to different parts of the electromagnetic spectrum might be used.

[0054] In some embodiments, the microwave system comprises one, two or more imaging devices. Where there are two or more imaging devices, at least two may be positioned to capture image data of the product at different directions. At least 2 imaging devices may be sensitive to the same parts of the electromagnetic spectrum.

[0055] In some embodiments, step b) comprises the following sub-steps: b1) providing one or more positioning blocks in the microwave applicator; and, b2) placing the product on the one or more positioning blocks.

[0056] The positioning blocks allow controlling the position of the product in the microwave applicator before the microwave treatment is started.

[0057] In some embodiments, step g) comprises the steps: g1) determining, by the controller and based on the image data captured by the image device, an amount of excess generated microwave power; and, g2) directing, by means of a circulator, the excess generated microwave power to a dummy load.

[0058] The dummy load allows absorbing excess power, thereby enhancing the system's control mechanism and protecting the system against excess microwave power.

[0059] In some embodiments, step g) is followed by step h) which comprises the following steps: h1) measuring an amount of incident power by means of a power meter; h2) measuring an amount of reflected power by means of a power meter; h3) determining an amount of absorbed microwave power by subtracting the amount of incident power and the amount of reflected power; h4) either using the amount of absorbed microwave power as an approximation of the amount of microwave power that was absorbed by the product; or, calculating an amount of cavity losses, and calculating the amount of microwave power that was absorbed by the product by subtracting the amount of cavity losses from the amount of absorbed microwave power.

[0060] In some embodiments, the product is a liquid product, and the method further comprises the step of stirring the product.

[0061] In some embodiments, the product is moved during microwave treatment by means of a turntable. A turntable is a possible alternative for a stirrer, especially for solid objects.

[0062] In some embodiments, the product is subjected to ultrasound during microwave treatment.

[0063] In some embodiments, the product is moved during microwave treatment by means of an ultrasound aid. A suitable example of an ultrasound aid is a vibrating bar. The vibrating bar can, for example, protrude through one of the openings in the cavity. Preferably, the bar comprises a non-metallic material. This helps maintaining an optimum energy distribution. A vibrating table with positioning blocs is a valuable alternative to a vibrating bar.

[0064] Optionally, a turntable, an ultrasound bar and/or a stirrer may be used together.

[0065] When a liquid product is treated, a PTFE container is preferably used.

[0066] In some embodiments, step f) further comprises the step of determining a temperature distribution in the product based on the image data, and in step g), the applied microwave power to the product is further controlled based on a maximum, average, or minimum value of the temperature distribution in the product.

[0067] In some embodiments, in step g), the applied microwave power is further controlled by means of a power limiter that limits the maximum applied microwave power.

[0068] Preferably, the method employs a microwave system as described herein.

[0069] Further provided herein is a microwave system for subjecting a product to a microwave treatment. Preferably, the system is configured for executing a method as provided herein.

[0070] The system comprises a microwave applicator, an imaging device, a controller, and a microwave generator. The controller is operationally coupled with the microwave applicator, the imaging device, and the microwave generator. The microwave generator is arranged to generate microwaves at a pre-determined power. The system is arranged to subject the product to the microwaves. The imaging device is arranged to capture image data indicative of a temperature distribution in the product. The controller is arranged to adapt the power at which the microwaves are applied to the product based on the captured image data.

[0071] In some embodiments, the microwave generator has a power between 250 W and 2000 W, or between 500 W and 1750 W, or between 750 W and 1500 W, or between 1000 W and 1250 W.

[0072] In some embodiments, the system further comprises one or more wave guides, a circulator, a coupler, a power meter, a sub-tuner module, a multi-purpose module, and/or a weighing scale.

[0073] In some embodiments, the system further comprises one or more of the following ancillary components: a microwave applicator door, an infrared camera, a vacuum suction line, a pressure gauge, a vacuum sensor, a pressure feed, a vacuum bleed line, a vacuum pump, an integrated water pump and chiller, and/or a product discharge and collection device.

[0074] In some embodiments, the microwave applicator comprises a plurality of openings for ancillary components.

[0075] Preferably, the microwave applicator comprises an opening that allows for operational coupling with the micro-

wave generator. Preferably, the opening is sealed in an airtight manner, for example with a sheet that is transparent to microwaves, for example a plastic sheet, for example with a PTFE (polytetrafluoroethylene) sheet.

[0076] Preferably, the system comprises a discharge and collection device as described herein.

[0077] In some embodiments, the microwave system has a width between 2.0 and 3.0 m.

[0078] In some embodiments, the microwave system has a height between 1.0 and 1.4 m.

[0079] In some embodiments, the microwave applicator has a volume between 67 dm³ and 77 dm³.

[0080] In some embodiments, the magnetron has a power between 1.0 and 3.0 kW.

[0081] In some embodiments, the microwave applicator is equipped with means for providing a vacuum and/or over-pressure. In some embodiments, the maximum over-pressure is limited to at most 2.0 bar.

[0082] In some embodiments, the system comprises a stirrer. This is useful for homogenizing liquid objects which are treated.

[0083] In some embodiments, the system comprises a turn table. This is useful for applying uniform power to a solid object.

[0084] Preferably, the system comprises a power limiter for limiting the power applied to the object according to a pre-determined power profile.

[0085] In some embodiments, the microwave applicator is a multi-mode applicator.

[0086] In some embodiments, the microwave applicator is configured to treat an amount of material in the range of at least 10.0 gram to at most 3.0 kg.

[0087] In some embodiments, the microwave applicator is made of stainless steel, e.g. AISI304.

[0088] In some embodiments, the microwave applicator is mounted on a steel base plate with wheels.

[0089] In some embodiments, the cavity has a door which is equipped with one or more of, preferably all of, the following types of sealing: Copper alloy spring contactor for the protection for MW radiation; Teflon seal for the protection against irradiated heat; and/or Rubber seal for the air-tightness of the cavity.

[0090] The cavity comprises an opening for temperature monitoring by means of an imaging device, e.g. an infrared or hyperspectral camera. In some embodiments, this opening also allows access for a vacuum suction line.

[0091] In some embodiments, the microwave applicator comprises: an opening for discharge of dried product; one or more openings for various purposes. Preferably, these openings can be sealed when not in use, e.g. by means of a steel plate; one or more pressure sensors, one or more vacuum sensors, and an opening for the pressure and vacuum sensors; a pressure feed and an opening for a pressure feed; and/or a waveguide and vacuum seal plate. The vacuum seal plate is preferably made of a plastic which is transparent to microwaves such as polytetrafluoroethylene (PTFE).

[0092] The present systems employ a camera for temperature control.

[0093] Examples of suitable imaging devices for use with the present systems and methods are infrared cameras and hyperspectral cameras. In some embodiments, the imaging device is a spectral imaging device.

[0094] In some embodiments, the imaging device is positioned outside the cavity. In this case, the connection between imaging device and cavity is preferably sealed with a "window" in order to enhance the vacuum in the chamber. The window is made from a material which is transparent to the wavelengths employed by the imaging device for imaging. For example, when an infrared camera is used, the window is transparent to infrared light. If there is a "window" between the camera and the object of measurement, the transmissivity of the window is preferably known.

[0095] In some embodiments, the microwave system is equipped with an emergency stop button, which is positioned, for example, in the door panel of an associated electrical cabinet. Preferably, the entire system, including any installed vacuum pump, water pump, and/or chiller, is configured to shut down when the emergency stop button is pressed.

[0096] In some embodiments, the door frame of the cavity is equipped with one or more, for example two, pressure sensors for detecting whether or not the door is closed. Preferably, the magnetron cannot be started if the cavity door is open, or if at least one of the sensors has failed.

[0097] As mentioned before, the system comprises a vacuum suction line. The vacuum suction line allows drying under vacuum.

[0098] Preferably, the microwave system comprises a vacuum pump which is preferably connected to its dedicated power point. Optionally, it is operated manually by turning the power on or off.

[0099] In some embodiment, the vacuum suction line is disposed with an intermediate reservoir. This extends the lifetime of the vacuum pump when corrosive fumes are released during microwave treatment of the object in the microwave applicator.

[0100] In some embodiments, a vacuum bleed valve is provided in fluid connection with the cavity, preferably via an opening. When creating the vacuum, this valve is closed and when removing the vacuum, the bleed valve is opened. Optionally, the valve can be also used for controlling (lowering) the vacuum level.

[0101] In some embodiments, the vacuum level in the cavity is measured by a pressure meter on the top of the cavity. Preferably, a valve beneath the vacuum sensor is opened when the vacuum level is measured, and the valve is closed when no vacuum level is being measured. This reduces the chance of vacuum leaks.

[0102] In some embodiments, the cavity is equipped with a pressure gauge and a vacuum sensor. Preferably, they

are operationally connected to the cavity via an opening. Preferably, when vacuum is applied, a valve below the over-pressure meter closes and vice versa.

[0103] Preferably, the cavity is further equipped with a pressure feed line and a vacuum bleed line. The pressure feed line and the vacuum bleed line are operationally connected with a bleed valve which serves to control the vacuum level and for removing the vacuum (i.e. to bring the cavity to atmospheric pressure).

[0104] Preferably, the cavity is subjected to a pressure of no more than 2 bar.

[0105] In some embodiments, the system operates at 2.45 GHz.

[0106] In some embodiments, the system comprises a turn table for moving the object during microwave treatment.

[0107] In some embodiments, the system further comprises one or more additional sensors selected from the list comprising weight sensors, volatile organic compound sensors, pressure sensors, and temperature sensors.

[0108] In some embodiments, the imaging device comprises an infrared camera.

[0109] In some embodiments, the imaging device comprises a spectral imaging device.

[0110] In some embodiments, the system further comprises one or more positioning blocks for supporting the product.

[0111] In some embodiments, the system further comprises a circulator and a dummy load, wherein the controller is further configured to determine an amount of excess generated microwave power based on the image data captured by the image device; and wherein the circulator is configured for directing the excess generated microwave power to a dummy load.

[0112] In some embodiments, the system further comprises a power meter for measuring an amount of incident power and a power meter for measuring an amount of reflected power, wherein the controller is configured to determine an amount of absorbed microwave power by subtracting the amount of incident power and the amount of reflected power, optionally wherein the controller is further configured for calculating an amount of cavity losses, and calculating the amount of microwave power that was absorbed by the product by subtracting the amount of cavity losses from the amount of absorbed microwave power.

[0113] In some embodiments, the system further comprises a stirrer. In some embodiments, the stirrer comprises a glass stirring rod.

[0114] In some embodiments, the system further comprises a power limiter. This improves the control of the present system. Compared to ordinary PID controllers (proportional-integral-derivative controller), the operation of the methods may be improved because of rapid microwave response times. Therefore, a power limiter can be used to limit the maximum applied power to the object. Alternatively, the power limiter may set a maximum absorbed power.

[0115] In some embodiments, the power limiter is controlled according to a power profile that provides a maximum applied or absorbed power as a function of time. Accordingly, the maximum power can be adapted depending on the stage of the process.

[0116] Further provided herein is the use of a system as described herein for drying a product; assisting a chemical reaction; and/or sterilizing a volume.

[0117] The present systems and methods are especially suitable for drying porous products, wood, and clay.

[0118] When the system is used for assisting a chemical reaction, glycerol may be used as a reaction solvent.

[0119] Further provided herein is the use of a system as described herein for tempering or softening frozen foodstuffs.

[0120] Further provided herein is a discharge and collection device. It comprises an upper valve and a lower valve for product transfer.

[0121] The discharge and collection device can be operationally coupled with a microwave applicator. Such a device is useful, for example, when absorption of moisture in the air by a dried product is to be avoided. The product discharge and collection device comprises an upper valve and a lower valve. During the drying process both valves of the system are closed. When the drying is finished (magnetron is off, but the cavity is still under vacuum), the upper valve is opened first and, then, the lower valve. The locking mechanism of these valves requires that the handle is pulled before turning it. When the upper valve is opened, the bottom of the drying vessel opens and the product falls to the collector chute. Furthermore, the product is transferred to the collection tank by opening the lower valve. After the discharge, the collection tank is kept under vacuum by closing the lower valve. After the vacuum is removed from the cavity and the collector chute, the collector tank with the dry product under vacuum can be detached from the unit. Notice, that if the product discharge and collection device is not in use, the connection is preferably sealed with a steel plate.

[0122] Further provided herein is a method for operating a discharge and collection device. The discharge and collection device comprises an upper valve and a lower valve for product transfer. The method comprises the following steps:

- operationally coupling the discharge and collection device with a microwave applicator;
- maintaining both upper and lower valve closed while the product is treated in the microwave applicator;
- opening the upper valve when the product treatment has finished, thereby allowing the treated product to fall in a collector chute;

- after the upper valve has opened, opening the lower valve, thereby transferring the treated product in a collection tank.;
- closing the lower valve, thereby closing off the collection tank and maintaining a vacuum therein;
- 5 - removing the vacuum from the microwave applicator and the collector chute;
- detaching the collection tank containing the treated product from the microwave applicator.

EXAMPLES

10 **[0123]** The present invention is further illustrated by means of the following non-limiting examples.

Example 1

15 **[0124]** In a first example, reference is made to Figures 1, 2, 4, 5, and 6. Fig. 1 shows a microwave system (100) it comprises a microwave applicator (200), which is also called a cavity; an infrared camera (220), a controller (300), a microwave generator (400), also called magnetron; a wave guide (450), a circulator (500), another waveguide (520), a coupler (540), a power meter (550), a sub-tuner module (600), a multi-purpose module (700), a weighing scale (800), and an ultrasound aid (1000).

20 **[0125]** Fig. 2 shows a microwave intensity pattern in a microwave applicator (200). The microwave intensity is not constant throughout the microwave applicator (200).

[0126] Fig. 4 shows a various ancillary components of the microwave applicator (200). In particular, the microwave applicator comprises, or is associated with, the following components: a microwave applicator door (210), an infrared camera (220), a vacuum suction line (230), a pressure gauge (240), a vacuum sensor (250), a pressure feed (260),
25 a vacuum bleed line (270), a vacuum pump (280), an integrated water pump and chiller (285), and a product discharge and collection device (290).

[0127] Fig. 5 shows the inside of the microwave applicator (200), and particularly highlights a plurality of openings (201, 202, 203, 204, 205, 206, 207) for ancillary components. One opening (207) allows operational coupling with the microwave generator (400). This opening (207) is provided with a PTFE sheet (2071) which is transparent to microwaves.

30 **[0128]** Fig. 6 shows a product discharge and collection device (290) which employs an upper valve (291) and a lower valve (292) for product transfer.

[0129] The following features of the microwave system (100) are highlighted:

- A possible total width and height of the unit are e.g. 2125 mm and 1200 mm, respectively;
- 35 - The volume of the cavity (200) may be e.g. 72 dm³ (300x600x400 mm);
- The microwave unit/ generator has one water-cooled magnetron (400), with a power of e.g. 2 kW ;
- 40 - The microwave system (100) is equipped with continuous temperature monitoring and control system;
- Both vacuum and over-pressure can be applied. The maximum allowed over-pressure is limited, e.g. at 2 bar;
- There are several built-in safety features and controls.

45 **[0130]** When the system is used for processing liquid objects, a stirrer is provided for homogenizing the mixture. Additionally or alternatively, the system comprises a turn table.

[0131] Preferably, the system comprises a power limiter for limiting the power applied to the object according to a pre-determined power profile.

50 **[0132]** Various components of the present microwave system (100) are presented in Figures 1, 2, 4, 5, and 6.

[0133] The controller (300) is a general purpose controller which controls the various components of the microwave system (100)

[0134] The microwave applicator (200) is a multi-mode applicator that uses microwave energy to treat material from tens of grams to three kg at a time. It is designed for experimental use or for batch production in small scale. The cavity (i.e. the hollow space inside the microwave applicator 200) and its framework are made of stainless steel (AISI304) and are mounted on a steel base plate with wheels.

55 **[0135]** The microwave applicator (200) is suitable for use as a drying unit. It should be placed in a well-ventilated place, where the ambient temperature does not exceed 30°C. The microwave-proof door is closed and secured during

the operation of the device.

[0136] Any object (reservoirs, beakers, etc.) that is put in the cavity should be clean and made of material that does not couple with microwaves. Because microwaves are applied, there should not be any metal objects lying around the device.

[0137] The object is positioned in a desired position by means of one or more positioning blocks.

[0138] The microwave applicator (200) and its door (210) are certified for vacuum and over-pressure up to 2 bar and it is closed with ten bolts (M18). When closing the door, associated butterfly nuts are tightened firmly and evenly. In other words, equal force should be applied with each bolt. Too high load affects the life-time of the bolts, but first of all, it may damage the "saw-toothed" copper alloy lining (spring contactor) around the cavity opening that is used for an additional protection against MW radiation. Furthermore, an uneven load may cause MW leakages.

[0139] The cavity door has three types of sealing:

- Copper alloy spring contactor for the protection for MW radiation.

- Teflon seal for the protection against irradiated heat.

- Rubber seal for the air-tightness of the cavity.

[0140] The cavity (200) has seven through holes/openings (201-207) at different locations, that can be used for various purposes and set-ups. The inside of the cavity (200) is shown in Figure 5.

[0141] In particular, the cavity (200) comprises the following openings:

- an opening (201) for temperature monitoring by means of an infrared (IR) camera (220) and the vacuum suction line (230);

- an opening (202) for discharge of dried product;

- an opening (203) for various purposes (can be sealed by means of a steel plate when not in use)

- a further opening (204) for various purposes (can be sealed by means of a steel plate when not in use)

- an opening (205) for pressure and vacuum sensors;

- an opening (206) for a pressure feed;

- a waveguide and vacuum seal plate (2071). The vacuum seal plate is made of polytetrafluoroethylene (PTFE), which is transparent to microwaves.

[0142] Notice, that an opening (203,204) is used for temperature control by a camera (not shown in the figures). Examples of suitable cameras are infrared cameras and hyperspectral cameras (spectral imaging devices). The camera positioned outside the cavity (200). In this case, the connection is preferably sealed with a "window" (in order to enhance the vacuum in the chamber) that is specially made for this purpose (special IR transparent material). If there is a "window" between the camera and the object of measurement, the transmissivity of the window is preferably known.

[0143] Optionally, the microwave system comprises one, two or more imaging devices. Where there are two or more imaging devices, at least two may be positioned to capture image data of the product at different directions. At least 2 imaging devices may be sensitive to the same parts of the electromagnetic spectrum.

[0144] In the system according to the present example, temperature monitoring is performed by an infrared (IR) camera. This non-contact method measures the radiation of heat (IR radiation) from an object. The intensity of the emitted radiation depends on the material and for many substances this material-dependent constant, emissivity, is known, $\epsilon = 0-1$. If the emissivity of the material is unknown, it can be determined experimentally. For the determination of ϵ , a parallel method (not IR based - e.g. thermocouple) may be used, for example by means of the following procedure: the temperature of a specific material is measured both by the IR sensor and the comparative method. By decreasing or increasing the emissivity value the temperature reading of the IR sensor is adjusted to correspond the measured temperature by the comparative method. The factory setting of the emissivity is 0,95.

[0145] The camera allows capturing image data indicative of a temperature distribution in a product which is treated in the microwave applicator. The controller (300) of the microwave system (100) then adapts the power at which the microwaves are applied to the product based on the captured image data.

[0146] The system comprises a circulator and a dummy load. A controller in the system determines an amount of

excess generated microwave power based on the image data captured by the image device. Then, the circulator directs excess generated microwave to the dummy load, where it is absorbed.

[0147] The system further comprises a power meter for measuring an amount of incident power and a power meter for measuring an amount of reflected power. Also, the system comprises a controller which is configured to determine an amount of absorbed microwave power by subtracting the amount of incident power and the amount of reflected power. The can also take into account cavity losses. In this case, the controller is further configured for calculating an amount of cavity losses, and calculating the amount of microwave power that was absorbed by the product by subtracting the amount of cavity losses from the amount of absorbed microwave power.

[0148] As a particular safety feature, the microwave system (100) is equipped with an emergency stop button in the door panel of an associated electrical cabinet. After pressing it, the whole microwave system (100) shuts down, including the vacuum pump (280), and the integrated water pump and chiller (285). The alarm indicator light will be on until the emergency stop button is released and the system is reset by pushing a reset button. The emergency stop button is released by pulling the knob of the button back.

[0149] As a further safety feature, the door frame of the cavity (200) has two pressure sensors for detecting if the door is closed or not. The magnetron (400) is controlled by these sensors. In other words, the magnetron (400) cannot be started if the cavity door is open (one or both sensors fail).

[0150] In the context of the present devices and methods, cooling water is useful for two distinct purposes: 1) Feeding water to the isolator that prevents the mis-matched (reflected) microwaves to bounce back to the magnetron; and 2) cooling the magnetron.

[0151] The water circuit significantly improves the operation of the microwave oven and the life expectancy of the electronics inside. The microwave (MW) unit is preferably not operated without a supply of cooling water at the correct temperature. This can be enforced by requiring, for example, that the magnetron will not start if the water flow is too low or if the cooling water is too hot.

[0152] The water is circulated by a pump that is integrated with a chiller. The water pump and chiller are comprised in an integrated water pump and chiller (285). The total water volume of the system is 10 liters. The level of the water is preferably between the maximum and minimum lines in the level meter of the cooling unit. The water used is preferably solids-free and does not contain any organic contaminants, such as, oils. Distilled water or potable water are suitable for this purpose.

[0153] The microwave system (100) is further equipped with pressure regulating devices including a vacuum suction line (230), pressure gauge (240), vacuum sensor (250), pressure feed (260), vacuum bleed line (270), and a vacuum pump (280).

[0154] The vacuum suction line (230) allows drying under vacuum. The purpose of drying under vacuum is to lower the boiling point of the liquid (water). When the evaporation takes place at lower temperature, the product heats less and, therefore, the drying process is more gentle to the product. In addition, less energy is required for heating.

[0155] The vacuum pump (280) is connected to its dedicated power point and operated manually by turning the power on or off.

[0156] In case highly corrosive fumes are released during sample treatment in the microwave applicator (200), the use of an intermediate reservoir in the vacuum line is advised, which extends the life-time of the vacuum pump in such a case.

[0157] A vacuum bleed valve is provided in fluid connection with the cavity (200) via an opening (206). When creating the vacuum, this valve is closed and when removing the vacuum, the bleed valve is opened. Optionally, the valve can be also used for controlling (lowering) the vacuum level.

[0158] The vacuum level in the cavity is measured by a pressure meter on the top of the cavity (opening 205). When measuring vacuum, a valve beneath the vacuum sensor is opened.

[0159] The cavity (200) is equipped with a pressure gauge (240) and a vacuum sensor (250). They are operationally connected to the cavity via an opening (205). When vacuum is applied, a valve below the over-pressure meter closes and vice versa.

[0160] The cavity (200) is further equipped with a pressure feed line (260) and a vacuum bleed line (270). The pressure feed line (260) and the vacuum bleed line (270) are operationally connected with a bleed valve which serves to control the vacuum level and for removing the vacuum (i.e. to bring the cavity (200) to atmospheric pressure).

[0161] Preferably, the cavity (200) is subjected to a pressure of no more than 2 bar.

[0162] The cavity (200) is further equipped with a product discharge and collection device (290) for collecting dried product. This device (290) is particularly useful for preventing any absorption of the moisture in the air by treated products. By means of the product discharge and collection device (290) the dry product is transferred from the cavity to the collection tank under vacuum. The discharge and the collection device (290) of the dried product is shown in Figure 6.

[0163] The product discharge and collection device (290) comprises an upper valve (291) and a lower valve (292). During the drying process both valves of the system are closed. When the drying is finished (magnetron is off, but the cavity is still under vacuum), the upper valve (291) is opened first and, then, the lower valve (292). The locking mechanism

of these valves requires that the handle is pulled before turning it.

[0164] When the upper valve (291) is opened, the bottom of the drying vessel opens and the product falls to the collector chute. Furthermore, the product is transferred to the collection tank by opening the lower valve (292). After the discharge, the collection tank is kept under vacuum by closing the lower valve (292).

[0165] After the vacuum is removed from the cavity (200) and the collector chute, the collector tank with the dry product under vacuum can be detached from the unit. Notice, that if the product discharge and collection device (290) is not in use, the connection is preferably sealed with a steel plate.

[0166] The microwave applicator (200) is equipped with an ultrasound aid (1000) that can be used for applying to a product under microwave treatment.

Example 2

[0167] In a second example, reference is made to a series of microwave heating scaling-up experiments that were carried out by means of the microwave system (100) described in example 1. The applicator (200) that was used was a multimode microwave reactor with an internal cavity volume of 72 liters and was used at a power of 1.2 kW.

[0168] Microwave heating scaling-up constitutes a growing demand for industry due to the great success obtained in chemical reactions at laboratory scale and so, a great opportunity to enhance industrial processes. There are two known ways for this purpose: continuous flow method and batch mode. The microwave penetration for most of solvents is around a few centimeters for the most commonly used microwave frequency, 2.45 GHz. Because of this heating up bulk samples with microwave irradiation has several limitations. In this context, controlling the stirring rate in order to maintain a homogeneous solution and avoid thermal gradients, is preferably taken into account. As observed in literature, most of the reactions accomplished under microwave irradiation are performed at high temperatures in sealed vessels. Various approaches and processing techniques can be used for scaling-up a wide range of reactions. One technology of interest are open reaction vessels in batch methodologies which offer operational advantages to address scale-up needs. The small cavity of a monomode microwave apparatus is preferably replaced by a larger multimode unit when requiring high volumes. To perform our study, reduction of nitrobenzene to aniline was selected again; since it was already optimized in small scale-up to 15 mL volume, working on 1 mmol scale. Up to 45 mL (3 mmol) it was possible to translate the original conditions set up, but when moving to a higher quantity, a little reoptimization was required.

[0169] The used set up is a multipurpose test device for various microwave applications. The design has entries on the sides of the cavity allowing multiple connections for sensors and entrances/exits for gas or products. In this case, the opening on the right side was used to measure the temperature of the sample by means of an infrared (IR) camera, while the opening on top was used to insert the glass stirring rod. Different matter properties were studied.

[0170] The emissivity of matter can be defined as the effectiveness in emitting energy as thermal irradiation and varies from 0 to 1. Whereas matter transmissivity refers to the proportion of the radiation that hits a body and ends up being transmitted through it without being absorbed or reflected. Both were measured in our reaction solvent, glycerol. The emissivity of glycerol was calculated by comparing the solution temperature with a thermometer and with a microwave IR camera, and the factor was 0.95. While the emissivity value is intrinsic and only depends on the solution nature, the transmissivity value depends also on the vessel form and material. In our case the value of transmissivity results in 0.48. Preferably, the IR camera is always positioned in the same point in order to maintain constant parameter values. Once those parameters were set up, different experiments were performed.

[0171] As was observed in laboratory scale, nitrobenzene's conversion is higher when imposing a constant power in the microwave system. This phenomenon was also observed in larger scale. The reaction was carried out at 130 °C in a big round-bottom flask of 250 mL and a glass stick was used for stirring the solution. The histogram-density of temperature from the cavity was registered at any time thanks to an IR camera. This was aided by a commercially available software package (Optris PI Connect). The input power and the reflective one were measured in order to know the value of the power that is really absorbed by the reaction solution. As depicted in Figure 3, one experiment was done by maintaining a constant power (25-30 W) (Figure 3 panel a) and the other one by varying it (from 40 W to 0W) (Figure 3 panel b), keeping the reaction temperature (130 °C) constant.

[0172] The results are summarized in the table below. A 50 % yield of aniline in 20 min of microwave irradiation was obtained when working with constant power; however, the conversion was reduced to 35 % in the case of variable power. Based on our previous results on laboratory scale, a preceding ultrasound dispersion significantly enhances the reaction rate.

Table showing Nitrobenzene reduction optimization. Scale-up in an industrial multimode microwave.

Entry	Method	Scale (mmol)	Catalyst (mol%)	T(°C)	t (min)	Yield (%) ¹
1	MW-Cte.P	6	10	130	20	50
2	MW-UnCte.P	6	10	130	20	35

(continued)

Entry	Method	Scale (mmol)	Catalyst (mol%)	T(°C)	t (min)	Yield (%) ¹
3	US-MW-Cte.P ²	6	10	130	20	66
4	US-MW-Cte.P ²	6	5	130	20	60
5	US-MW-Cte.P ²	6	5	150	20	78
6	US-MW-Cte.P ²	6	5	150	45	>99
7	US-MW-Cte.P ²	18	5	150	45	93
8	US-MW-Cte.P ²	18	5	150	60	>99
9	US-MW-Cte.P ²	36	5	150	60	90

Reaction conditions: nitrobenzene (1 eq), glycerol (200 eq), KOH (2 eq). 1 Determinated by GC-MS. 2 Copper nanoparticles were added into the glycerol and sonicated for 10 min, forming a perfectly dispersed black solution.

[0173] Therefore, a new experiment was carried out after a total catalyst dispersion. In this case, 66% of reduced product was achieved (entry 3 in the table above). Catalyst loading was reduced from 10% to 5% thanks to the homogeneous suspension and the increase in the catalyst surface after the ultrasound irradiation. We found that conducting the reaction at 150 °C (20 °C higher than the optimized conditions in small quantity), made it possible to produce 78% yield of amino compound in 20 min. As shown, full conversion of nitrobenzene to aniline was obtained when increasing the reaction time to 45 min (entry 6). When the reaction was performed on a larger scale (18 mmol nitrocompound), the time was increased to 1h in order to complete the reduction. In addition, performing the reaction in a 1L flask (36 mmol) and sonicating the initial solution, we heated the reaction mixture for a total time of 1 hour and a 90 % yield was achieved.

[0174] In conclusion, process intensification means a great promise for sustainable synthesis. Effects of microwave and ultrasound irradiation have been studied for the synthesis of aniline by the chemoselective reduction of nitrobenzene with copper nanoparticles in glycerol as green reducing agent and solvent. Metal catalyzed reactions are known to be one of the favorite fields of ultrasound assisted reactions. As observed, previous ultrasound treatment shows to have a beneficial effect since it provides a homogeneous distribution of metal particles in the solution media and so, a higher catalytic surface. Additionally, the reduction reaction was accomplished using different microwave devices, mono- and multimode. In all cases, the selection of a constant power method showed to have a positive effect in the reaction outcome. Generation of active species in the reaction media and superheating when working at high microwave power could accelerate the reaction.

[0175] Microwave assisted scaling up has been explored up to 500 mL reaction solution. Results show that laboratory conditions can be translated to larger volumes. Once again, the ultrasound and microwave power effect observed in small amounts were confirmed on industrial scale.

Example 3

[0176] By way of a further example, reference is made to an exemplary method for operating the present microwave system (100). The system comprises a microwave applicator (200), an imaging device (220), a controller (300), and a microwave generator (400).

[0177] Specific reference is made to a method for microwave-assisted drying.

[0178] The following procedure should be followed during start-up of a drying process by means of the microwave system (100):

- i. Check that the valves in the product discharge and collection system are closed.
- ii. Fill a PTFE reservoir in the cavity with the product to be processed. The PTFE reservoir is supported by means of one or more positioning blocks.
- iii. Close the cavity door according to the following: The cavity door is closed with ten bolts. When closing the door, the butterfly nuts are tightened firmly and evenly. In other words, equal force should be applied with each bolt. Too high load affects the life-time of the bolts, but above all, it may damage the "saw-toothed" copper alloy lining (spring contactor) around the cavity opening that is used for an additional protection against MW radiation. Furthermore, an uneven load may cause MW leakages.
- iv. Turn on the main power from the MAIN POWER switch. The indicator lights and the switches are activated automatically.

v. Start the water circulation by switching on the chiller.

vi. Reset the PLC program by pushing the RESET button in the front panel (when the indicator light is turned on).

5 vii. Turn on the power of the unit by pushing the POWER SUPPLY ON button.

viii. Check that the vacuum bleed valve is closed and turn on the vacuum pump (manual switch in the pump). Wait till full vacuum achieved. In the case of leakage, check the system and fix the leakage.

10 ix. Set the process parameters (applied power and temperature control/limits).

x. Start the magnetron by turning its power on. The magnetron will start only after the pre-heating step that lasts for 1 minute.

15 **[0179]** During the executing method, image data indicative of a temperature distribution of the product are captured by means of an infrared camera. Based on these image data, the applied microwave power to the product is controlled.

[0180] Also, an amount of excess generated microwave power is determined by the controller based on the image data captured by the image device. The excess power is then directed to a dummy load (600) by means of a circulator (500).

20 **[0181]** In addition, the power delivered to the product to be processed is controlled by measuring an amount of incident power and an amount of reflected power by means of one or more power meters. Then, an amount of absorbed microwave power is determined by subtracting the amount of incident power and the amount of reflected power. The amount of absorbed microwave power is either used as an approximation of the amount of microwave power that was absorbed by the product, or an amount of cavity losses is calculated and the amount of microwave power that was absorbed by the product is then calculated by subtracting the amount of cavity losses from the amount of absorbed microwave power.

25 **[0182]** The applied microwave power to the product is further controlled by 1) determining a temperature distribution in the product based on the image data, and 2) a maximum, average, or minimum value of the temperature distribution in the product.

[0183] Also, the applied microwave power is further controlled by means of a power limiter that limits the maximum applied microwave power.

30 **[0184]** The following procedure should be followed when stopping a drying process by means of the microwave system (100):

i. switch off the magnetron (5).

35 ii. The dry product is transferred to a collection tank comprised in the product discharge and collection device (290) according to the following: When the drying is finished (magnetron is off, but the cavity is still under vacuum), the upper valve (291) is opened first and, then, the lower valve (292). The locking mechanism of these valves requires that the handle is pulled before turning it. When the upper valve (291) is opened, the bottom of the drying vessel opens and the product falls to the collector chute. Furthermore, the product is transferred to the collection tank by opening the lower valve (292). After the discharge, the collection tank is kept under vacuum by closing the lower valve (292).

iii. Stop the vacuum pump and remove the vacuum from the cavity and the collector chute via the vacuum bleed valve.

45 iv. Detach the collector tank with the dry product under vacuum from the unit.

v. Open the cavity door.

50 vi. Clean the PTFE drying reservoir and the collector chute from the residues of the processed material. Close the upper valve in the product discharge and collection system.

vii. Check the inside of the cavity.

55 viii. After the empty and clean collector tank is attached back in place and the lower valve in the product discharge and collection system is closed, the MW unit is ready for its next batch.

[0185] In order to determine whether or not the product that was treated is dry, the following procedure can be followed: a) ascertain the weight of the collector tank with its vacuum seal (tare); b) ascertain the initial moisture and weight of

the product (measured by, e.g., IR scale); c) calculate the theoretical weight loss based on the initial moisture content and the desired end moisture content; and d) check the dryness of the material by weighing.

[0186] The following procedure should be followed when shutting down the microwave system (100):

- i. Stop the water circulation by switching off the chiller.
- ii. Turn off the MAIN POWER switch.
- iii. Check and clean the inside of the cavity.
- iv. Clean the PTFE drying reservoir and the collector chute from the residues of the processed material.

[0187] During operation, the infrared camera is used for temperature control.

Example 4

[0188] The microwave system (100) provided herein allows to apply a power profile to a sample. The present example illustrates how a power profile can be constructed from a series of segments. The segments describe the evolution of the power during a pre-determined time period. There are several segment types and types of power changes, including Rate, Dwell, Step, Time, GoBack, Wait, Call and End. Various segment types are illustrated in Figure 7.

[0189] In order to control the rate of change of applied power, a ramp segment (Fig. 7 panel a)) can be used. A Ramp segment provides a controlled change of setpoint from an original to a target setpoint. The duration of the ramp is determined by the rate of change specified. The segment is specified by the target setpoint and the desired ramp rate. The ramp rate parameter is presented in engineering units (°C, °F) per real time units (Seconds, Minutes or Hours). In order to control the power at a constant level for a specified period, a dwell segment (Fig. 7 panel b)) can be used. In a dwell segment (Fig. 7 panel b), the setpoint (i.e. the applied power) remains constant for a specified period at the specified target. The operating setpoint of a dwell is inherited from the previous segment

[0190] For a step segment (Fig. 7 panel c)), the setpoint changes instantaneously from its current value to a new value at the beginning of a segment. A step segment has a minimum duration of 1 second.

[0191] A time feature defines the duration of a segment. In this case the target setpoint is defined and the time taken to reach this value. A dwell period is set by making the target setpoint the same value as the previous setpoint.

[0192] A GoBack feature is provided which allows segments to be repeated a number of times.

[0193] A wait feature is provided which specifies a criterion according to which a segment cannot proceed to the next segment. Any segment can be defined as 'Wait'.

Claims

1. A method for applying a microwave treatment to a product, the method comprising the steps:

- a) providing a microwave system comprising a microwave applicator (200), an imaging device (220), a controller (300), and a microwave generator (400);
- b) placing the product in the microwave applicator (200);
- c) generating microwaves by means of the microwave generator (400) at a pre-determined generated microwave power;
- d) directing the microwaves to the product in the microwave applicator (200);
- e) subjecting the product to the microwaves at a pre-determined applied microwave power;
- f) capturing, by means of the imaging device (220), image data indicative of a temperature distribution of the product;
- g) controlling, by means of the controller (300) and based on the image data, the applied microwave power to the product.

2. The method according to claim 1 wherein the imaging device comprises an infrared camera (220).

3. The method according to claim 1 or 2 wherein step b) comprises the following sub-steps:

- b1) providing one or more positioning blocks in the microwave applicator (200); and,
- b2) placing the product on the one or more positioning blocks.

4. The method according to any one of claims 1 to 3, wherein step g) comprises the steps:

- g1) determining, by the controller and based on the image data captured by the image device, an amount of excess generated microwave power; and,
- g2) directing, by means of a circulator (500), the excess generated microwave power to a dummy load (600).

5. The method according to any one of claims 1 to 4 wherein step g) is followed by step h) which comprises the following steps:

- h1) measuring an amount of incident power by means of a power meter;
- h2) measuring an amount of reflected power by means of a power meter;
- h3) determining an amount of absorbed microwave power by subtracting the amount of incident power and the amount of reflected power;
- h4) either
 - using the amount of absorbed microwave power as an approximation of the amount of microwave power that was absorbed by the product; or,
 - calculating an amount of cavity losses, and calculating the amount of microwave power that was absorbed by the product by subtracting the amount of cavity losses from the amount of absorbed microwave power.

6. The method according to any one of claims 1 to 5 wherein the product is a liquid product, and wherein the method further comprises the step of stirring the product.

7. The method according to any one of claims 1 to 6 wherein step f) further comprises the step of determining a temperature distribution in the product based on the image data, and wherein in step g), the applied microwave power to the product is further controlled based on a maximum, average, or minimum value of the temperature distribution in the product.

8. The method according to any one of claims 1 to 7 wherein in step g), the applied microwave power is further controlled by means of a power limiter that limits the maximum applied microwave power.

9. A microwave system (100) for subjecting a product to a microwave treatment, the system comprising a microwave applicator (200), an imaging device (220), a controller (300), and a microwave generator (400); wherein the controller is operationally coupled with the microwave applicator (200), the imaging device (220), and the microwave generator (400); wherein the microwave generator (400) is arranged to generate microwaves at a pre-determined power; wherein the system (100) is arranged to subject the product to the microwaves; wherein the imaging device (220) is arranged to capture image data indicative of a temperature distribution in the product; and, wherein the controller (300) is arranged to adapt the power at which the microwaves are applied to the product based on the captured image data.

10. The system according to claim 9 wherein the imaging device comprises an infrared camera.

11. The system according to claim 9 or 10 further comprising one or more positioning blocks for supporting the product.

12. The system according to any one of claims 9 to 11 further comprising a circulator (500) and a dummy load (600), wherein the controller (300) is further configured to determine an amount of excess generated microwave power based on the image data captured by the image device; and wherein the circulator (500) is configured for directing the excess generated microwave power to a dummy load (600).

13. The system according to any one of claims 9 to 12 further comprising a power meter for measuring an amount of incident power and a power meter for measuring an amount of reflected power, wherein the controller is configured to determine an amount of absorbed microwave power by subtracting the amount of incident power and the amount of reflected power, optionally wherein the controller is further configured for calculating an amount of cavity losses, and calculating the amount of microwave power that was absorbed by the product by subtracting the amount of cavity losses from the amount of absorbed microwave power.

14. The system according to any one of claims 9 to 13 further comprising an ultrasound aid, a stirrer, and/or a power limiter.

15. Use of a system according to any one of claims 9 to 14 for

- 5 - drying a product;
 - assisting a chemical reaction; and/or
 - sterilizing a volume.

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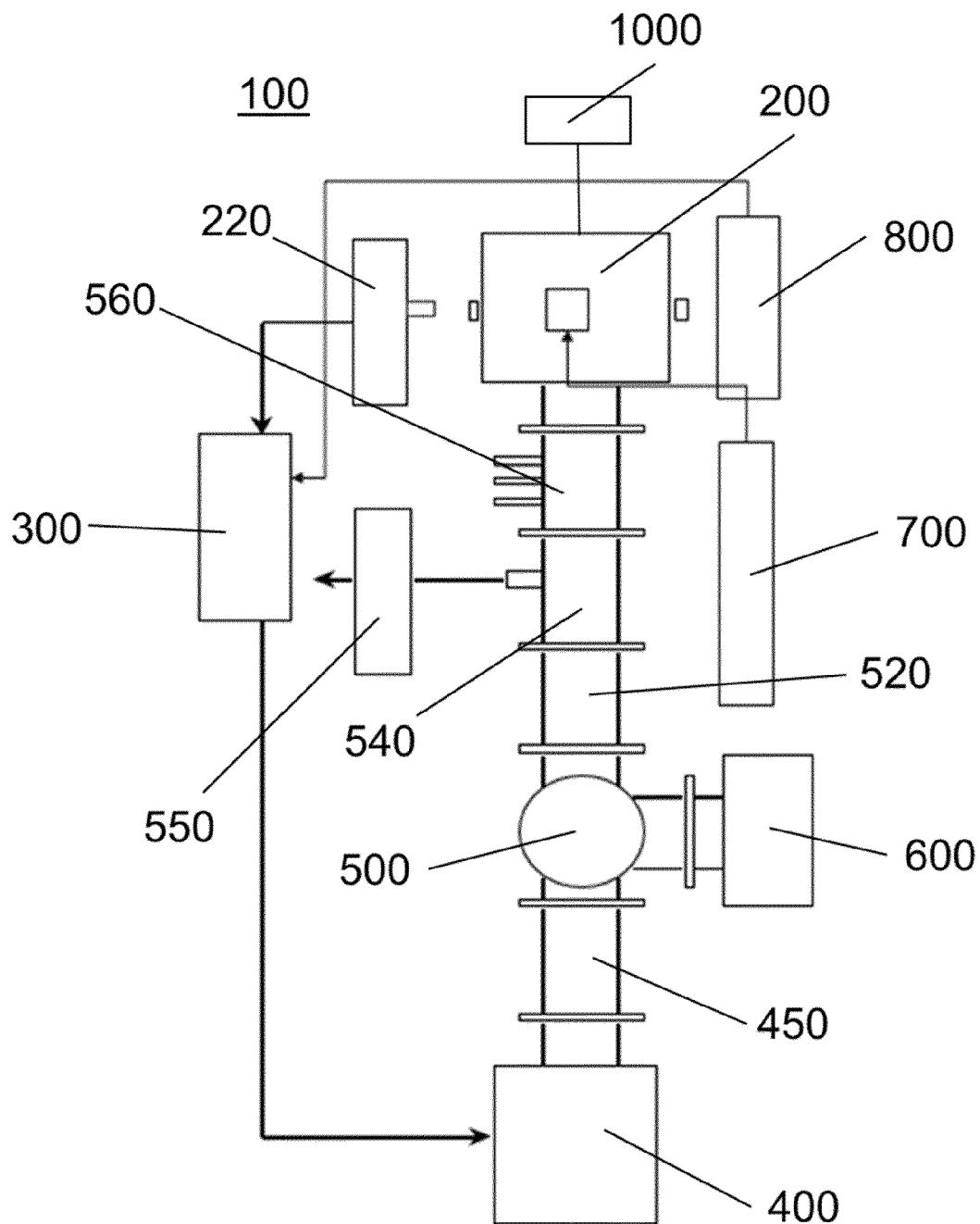


Fig. 1

200

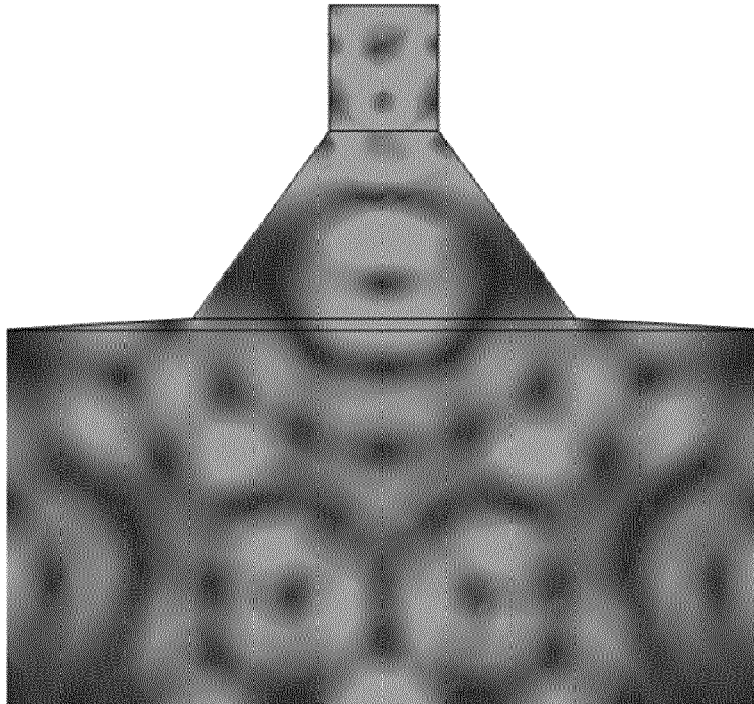


Fig. 2

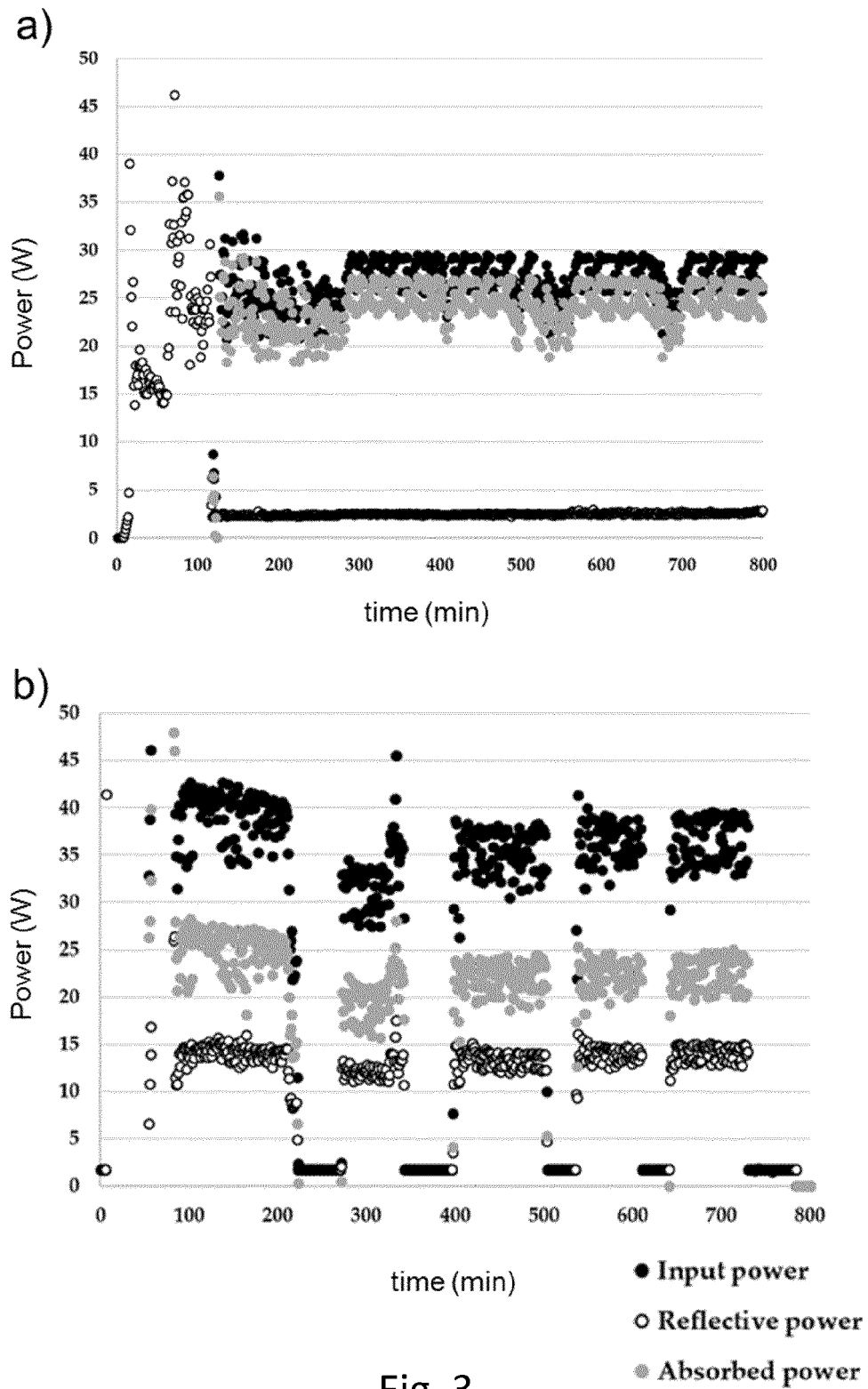


Fig. 3

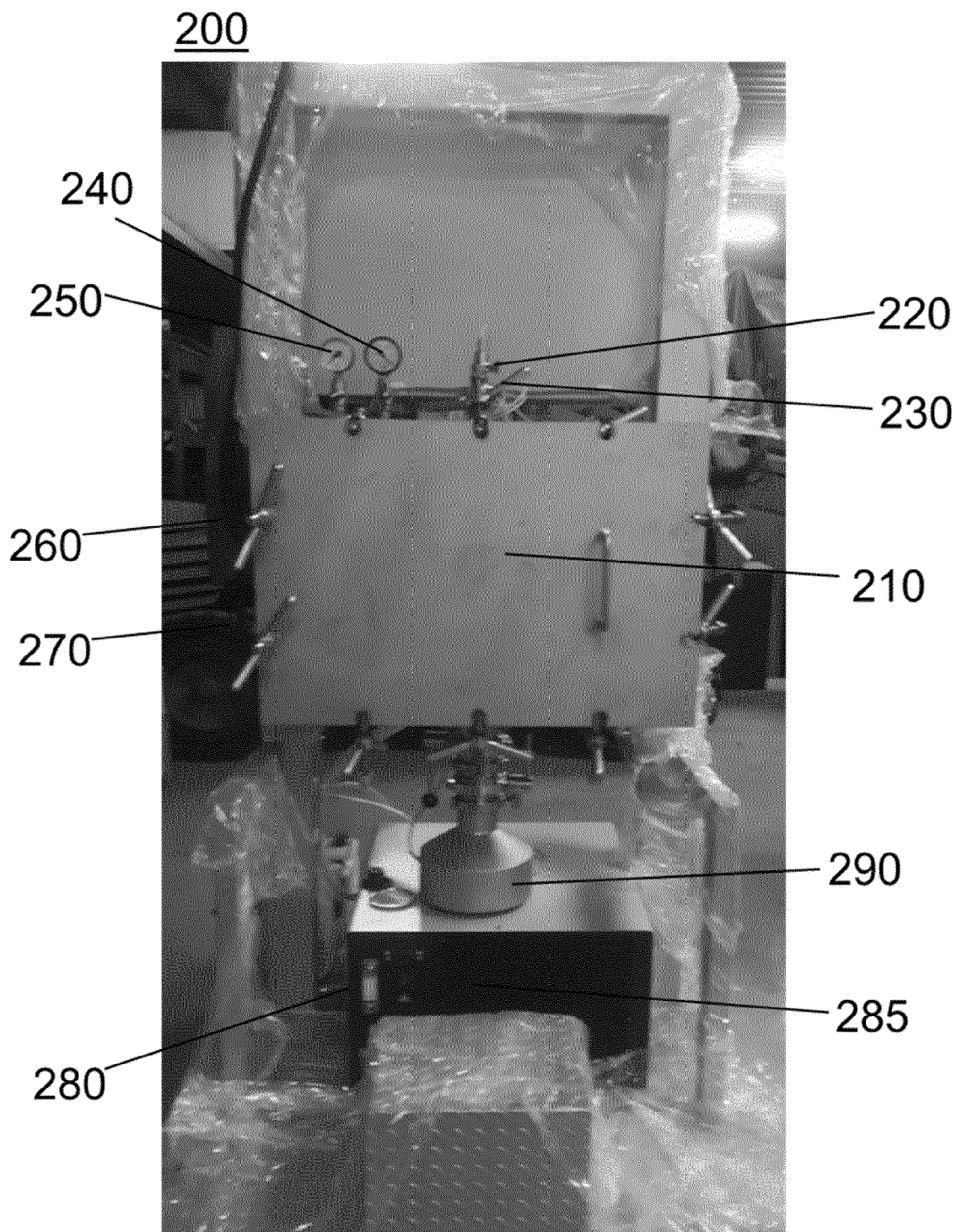


Fig. 4

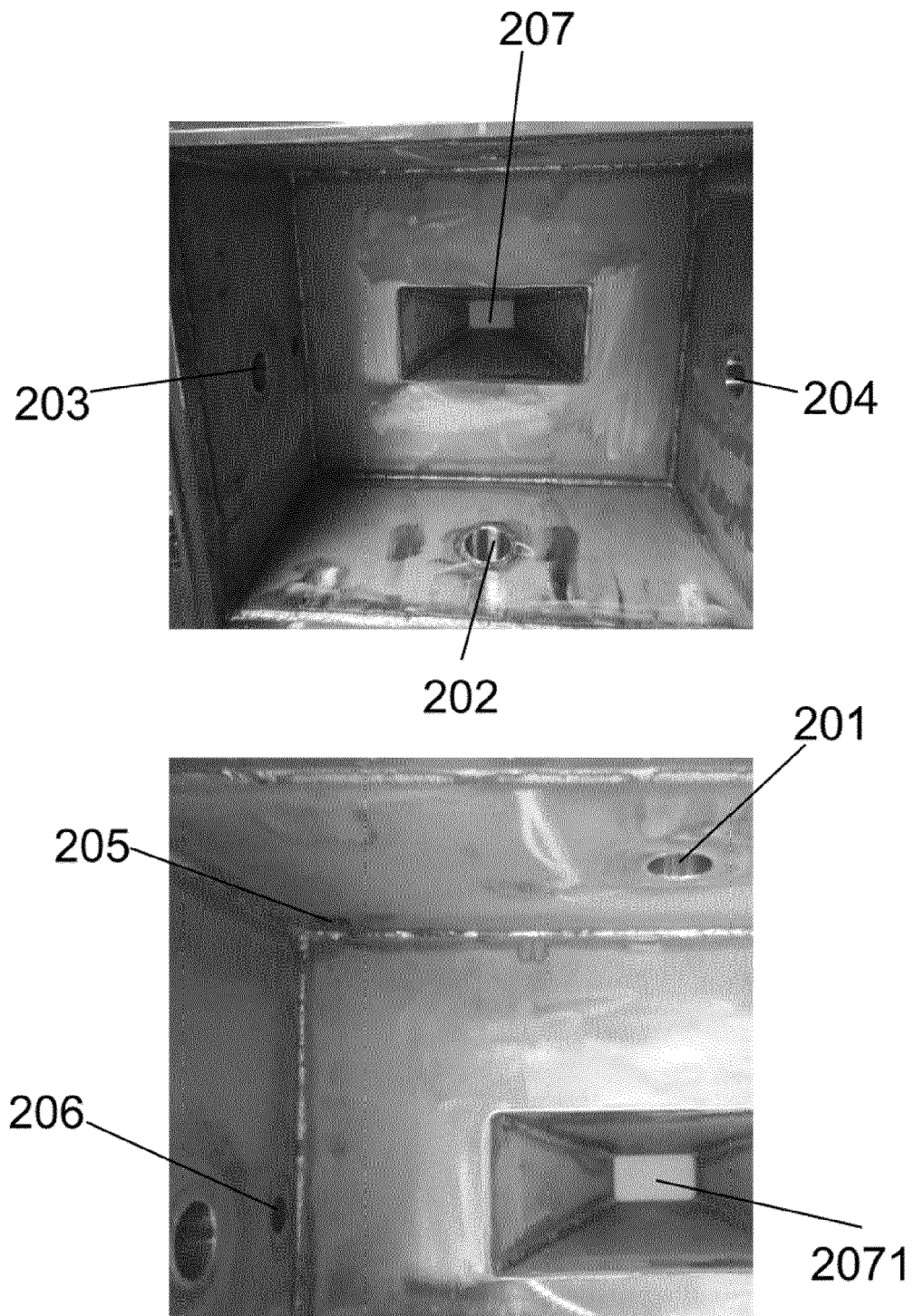


Fig. 5

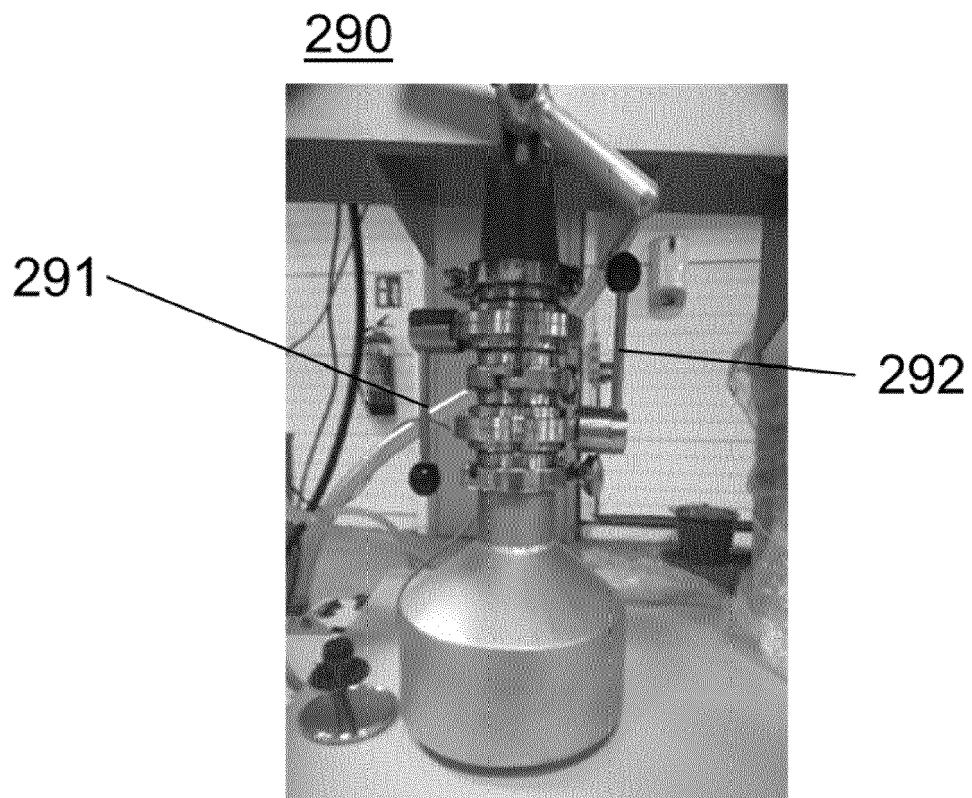


Fig. 6

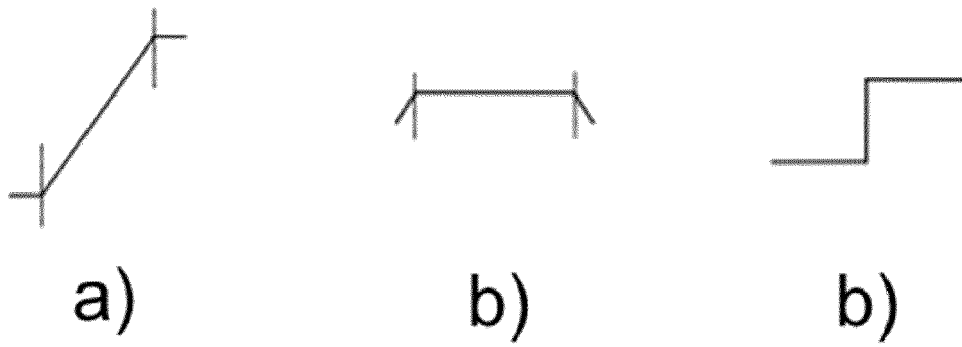


Fig. 7



EUROPEAN SEARCH REPORT

 Application Number
 EP 19 19 2286

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2011/002677 A1 (COCHRAN DON W [US] ET AL) 6 January 2011 (2011-01-06) * abstract; claims 1,10-15,23,28,29,30,55; figures 1-16 * * paragraph [0102] * -----	1-15	INV. H05B6/80
X	EP 2 618 634 A1 (WHIRLPOOL CO [US]) 24 July 2013 (2013-07-24) * abstract; claims 1-7; figures 1-4 * -----	1,9,15	
X	US 2015/289324 A1 (ROBER MARK BRAXTON [US] ET AL) 8 October 2015 (2015-10-08) * abstract; claim 1; figures 1-8 * -----	1,9,15	
X	US 2011/094654 A1 (GEARHART STEPHEN V [US]) 28 April 2011 (2011-04-28) * abstract; claim 1; figures 1-8 * * paragraph [0010] * -----	1,9,15	
			TECHNICAL FIELDS SEARCHED (IPC)
			H05B
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 11 February 2020	Examiner Garcia, Jesus
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

 1
 EPO FORM 1503 03.02 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 19 19 2286

5

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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11-02-2020

10

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2011002677 A1	06-01-2011	NONE	
EP 2618634 A1	24-07-2013	BR 102013001641 A2 EP 2618634 A1 US 2013186887 A1 US 2019208587 A1	12-05-2015 24-07-2013 25-07-2013 04-07-2019
US 2015289324 A1	08-10-2015	US 2015289324 A1 WO 2015157229 A1	08-10-2015 15-10-2015
US 2011094654 A1	28-04-2011	US 2011094654 A1 US 2011293767 A1	28-04-2011 01-12-2011

15

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EPO FORM P0459

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- EP 0000957 A [0002]
- EP 517433 A [0002]
- EP 3462818 A [0002]
- EP 0268329 A [0002]
- US 4841111 A [0002]
- US 20160283822 A [0002]
- US 20100115785 A [0002]
- US 20140103031 A [0002]
- US 20190098709 A [0002]
- WO 2004054324 A [0002]
- WO 2008000048 A [0002]
- US 20090079101 A [0002]
- WO 2007107367 A [0002]
- WO 2007039284 A [0002]

Non-patent literature cited in the description

- **ZHOU, Y. et al.** Microwave processing CaO-Al₂O₃-SiO₂ glass using sol-gel technique. *Materials Research Society Symposium-Proceedings*, 1996, 131-137 [0003]