



An algae drier and a system for drying algae paste and/or liquid algae biomass

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- (54) **Title: AN ALGAE DRIER AND A SYSTEM FOR DRYING ALGAE PASTE AND/OR LIQUID ALGAE BIOMASS**

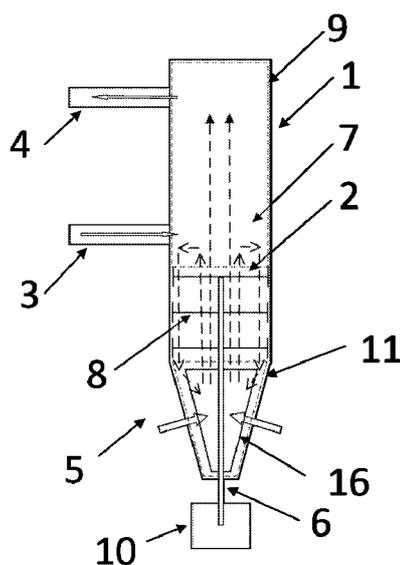


Fig. 1

(57) **Abstract:** The present invention relates to a drier such as for drying micro algae paste and/or liquid algae biomass, the drier comprising a drying chamber comprising an elongate tubular member forming an internal elongate void. The elongate tubular member is, during use (when used for drying material such as algae paste and/or liquid algae biomass), arranged with its longitudinal direction being vertical.



AN ALGAE DRIER AND A SYSTEM FOR DRYING ALGAE PASTE AND/OR LIQUID ALGAE BIOMASS

5 FIELD OF THE INVENTION

The present invention relates to a drier such as for drying micro algae paste and/or liquid algae biomass, the drier comprising a drying chamber comprising an elongate tubular member forming an internal elongate void. The elongate tubular member is, during use (when used for drying material such as algae paste and/or
10 liquid algae biomass), arranged with its longitudinal direction being vertical.

The algae drier comprising a rotatable fluidizer having a number of fluidizing paddles radially extending. The rotatable fluidizer has a longitudinal extension being less the length of the internal elongate void and being arranged inside the
15 internal elongate void in position providing a head space above the rotatable fluidizer inside said internal elongate void.

BACKGROUND OF THE INVENTION

Microalgae are a diverse group of phototrophic microorganism; generally possess
20 chlorophyll, and ranging in size from a few micrometers (μm) to a few hundred micrometers. The term microalgae often includes cyanobacteria (blue green algae), diatoms and green algae. Microalgal biomass cultivation is receiving a great deal of attention as a potential source of bioactive compounds. Microalgae can be cultivated on low price growth media such as waste water and produce
25 high amounts of protein, lipids, pigments and many other valuable compounds. Carbon dioxide (e.g. from combustion) can be used as a source of carbon for algal growth (1 kg of dry algal biomass requiring about 1.8 kg of CO_2). It is believed that both productivity and growth rate of microalgae are much higher compared to terrestrial crops. Microalgae can produce high amounts of protein (up to 70%),
30 lipids (up to 70%) and carotenoids (e.g. 20 mg/g dry weight). So microalgae biomass is a sustainable and environmental-friendly product which can be used in different applications.

Large scale cultivation of microalgae is being done in raceway open ponds or
35 photo bio reactors which include flat panel airlift reactors, and tubular reactors.

Concentration of biomass on harvest time depends on the growth conditions, culture age and species and ranges from 100-600 mg/L. This low amount of dry matter as well as tough cell walls, high viscosity and heat sensitive bioactive compounds are main challenges in processing of microalgae.

5

Microalgae downstream processing includes a combination of two or more steps such as harvest, up concentration and drying, depending on the application of the biomass. Aiming at utilization of microalgae biomass as a food/feed ingredient; the resulting biomass should be dried in an economic manner while reasonably
10 preserving valuable ingredients such as omega-3 polyunsaturated fatty acids, pigments and proteins. The main harvesting procedures, which are currently used, include sedimentation in gravity field, centrifugation, flotation and filtration. Centrifugation is the main method for up concentration, and several types of continuous centrifuges are used in industrial processes. Spray drying is the most
15 important industrial method which is being use for drying of microalgae biomass, but this method negatively affects some sensitive compounds such as carotenoids. The downstream processing of microalgal biomass is known as a major and costly component of production.

20 There is no single globally accepted downstream processing method for microalgae. Most commercial producers of microalgae biomass use one step harvest-up concentration followed by direct spray drying of the resulting slurry (10-20 g/L DM). This process results in higher energy consumption as well as more deterioration of valuable compounds such as carotenoids.

25

Hence, an improved device for drying algae paste and/or liquid algae biomass would be advantageous, and in particular a more efficient and/or reliable device for drying algae paste and/or liquid algae biomass would be advantageous.

30 OBJECTS OF THE INVENTION

An object of the present invention is to provide an alternative to the prior art.

In particular, it may be seen as a further object of the present invention to provide an algae drier that solves the above mentioned problems of the prior art.

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SUMMARY OF THE INVENTION

Thus, the above described object and several other objects are intended to be obtained in a first aspect of the invention by providing

A drier for drying material, such as algae paste and/or liquid algae biomass, the
5 drier comprising

- a drying chamber comprising an elongate tubular member forming an internal elongate void and being made from a fluid non-penetrable material, the elongate tubular member being, during use, arranged with its longitudinal direction being vertical;
- 10 - a rotatable fluidizer comprising a rotational shaft and a number of fluidizing paddles radially extending from the rotational shaft, said rotatable fluidizer has a longitudinal extension being less the length of the internal elongate void and being arranged inside the internal elongate void in position providing a head space above said rotatable fluidizer inside said internal
15 elongate void;
- a motor for rotating said rotation shaft;
- an outlet from said head space for outletting dried material, such as dried algae, said outlet being arranged at an upper end of the head space;
- an inlet into said head space for inletting material, such as algae paste
20 and/or liquid algae biomass, to be dried, said inlet being arranged below said outlet;
- an inlet arranged at a lower end of or below said rotatable fluidizer for inletting heated gas, such as air into the tubular elongate member.

25 The invention is found useful for drying wet biological materials such as algae paste and/or liquid algae biomass, but it is envisaged that other materials could be dried by the drier according to the invention. Thus, it is noted that although the disclosure of the drier herein has been focussed on drying algae paste and/or liquid algae biomass, the invention should not be limited to such purpose since the
30 drier is found to be useful for drying other materials.

The Inventors have designed, optimized and tested an algae drier and system as presented herein. Specially engineered fluidizing paddles (rotating swirling paddles) designed to handle high viscosity, sticky microalgae paste and prevent
35 the accumulation of feed on the interior walls which can result in burning are

presented herein. The fluidizing paddles may also provide a spiral air movement which increases the drying efficiency due to higher contact rate between drying medium and particles. The drying temperature can be lower than what is used in conventional spray drying, so the heat damages on both micro and macro nutrients is believed to be lower. Drying by use of the present invention may also use less energy, which will be more feasible.

The present invention is found to represent a set of well studied processing steps for economical production of microalgae biomass with less heat-induced negative effects on bioactive compounds. Lower degradation and higher stability of bioactive compounds are suggested as value propositions for future use of the technology. In addition, the technology presented herein is suggested to be more energy efficient than other technologies such as spray drying.

In the present context terms are used in a manner being ordinary to a skilled person; some of these terms are elucidated below:

Head space is typically used to reference a void above the rotatable fluidizer;

Blade-shaped is used to reference an element having a thickness being smaller than a chord length

Algae paste is preferably used to reference a slurry of algae cells, such as a dense suspension of microalgae cells in water (microalgae paste), the slurry preferably contains water. Without being limiting for the present invention, a concentration of algae may be more than 15 %

Liquid algae biomass is preferably used to reference an algae biomass being thinner/more liquid than algae paste. Without being limiting for the present invention, a concentration of algae may be about 10-15 % or even lower than 10 %.

Further embodiments and aspects are presented in the following as well as in the claims.

BRIEF DESCRIPTION OF THE FIGURES

The present invention and in particular preferred embodiments thereof will now be described in more details with reference to the accompanying figures. The figures show ways of implementing the present invention and are not to be construed as
5 being limiting to other possible embodiments falling within the scope of the attached claim set.

Figure 1 is a schematically illustration of a preferred embodiment of an algae drier according to first preferred embodiment;

10

Figure 2 is illustration of further preferred embodiment of an algae drier according to a further preferred embodiment, the algae drier is illustrated with indications as to dimensions used in a pilot plant;

15 Figure 3 is an illustration of the rotatable fluidizer used in the embodiment of figure 2, the fluidizer is illustrated while it is located in the lower section of the elongate tubular member and the view is as seen from above and into the lower section of the elongate tubular member of figure 2;

20 Figure 4 is a photograph illustrating an embodiment of a rotational fluidizer according to the invention;

Figure 5 is a photograph illustrating the rotational fluidizer of fig. 4 arranged inside the elongate tubular member;

25

Figure 6 is a schematically illustration of system for drying algae, and

Figure 7 is a schematically illustration of an air inlet according to a preferred embodiment of the present invention,

30

Figure 8 is an illustration of a further embodiment of a rotatable fluidizer usable in the embodiment of figure 2, the fluidizer is illustrated while it is located in the lower section of the elongate tubular member and the view is as seen from above and into the lower section of the elongate member of figure 2;

35

Figure 9 is an illustration of the fluidizer illustrated in figure 8 in a side-view.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

5 Before detailing the embodiments presented in figures 1-7 the following comments are presented.

On Downstream processing steps: Harvest/ Dewatering

Before drying, a harvest of micro algae biomass can, if desired, be done by an
10 optimized microfiltration unit based on silicon carbide (SiC) technology (Liqtech A/S). The ceramic membranes made by Liqtech A/S are being used for filtration and/or clarification of liquids. The membrane substrates as well as the coatings are made from 100% silicon carbide. The feed stream is introduced under a gentle pressure (such as less than 3 bar) at one end of the element and flows through
15 the channels during processing. The portion of the liquid passing through the membrane, the permeate, flows into the porous structure of the element. The combined volume of permeate from all channels flow toward the outer shell of the monolith support and is removed continuously. This in turn gives the membranes some unique advantages compared to traditional ceramic and polymeric
20 membranes. The dry matter will be around 10-20 g/L. If desired, a further upconcentration e.g. by centrifugation can be applied. The thereby harvested suspension is still a slurry, which may be more suitable for drying.

On Heat Treatment

25 If used, a heat treatment may be designed to deactivate the enzymes like e.g. chlorophyllase and endogenous lipase which can affect the quality and shelf life of the final product (dried algae), reduction of probable microbial population and increase the bio availability of macronutrients in the microalgae biomass. It also improves the separation of oil phase in the fractionated product. Heat treatment
30 may be initial when the resulting paste is intended to be used directly or dried by freeze drying. Selected procedure (temperature & time) has been tested on several microalgae species with minimum degradation of un-saturated fatty acids and pigments. This procedure(70°C & 15 sec.) also extends the shelf life of final dried product.

On Drying

Most popular drying methods which have been used for microalgae include spray drying, drum drying, freeze-drying and sun drying. Spray drying is the method of choice for industrial scale, but it can cause significant deterioration of some algal components such as pigments. The cost of drying can be a significant impediment to producing microalgal biomass powder for use in food and feeds. Freeze-drying, or lyophilization, has been widely used for drying microalgae in research laboratories; however, freeze-drying is too expensive for use in large-scale commercial production of microalgal products. It has already been shown in several studies that endogenous enzymes remains active in a freeze dried microalgae biomass and as a result, can reduce the shelf life stability lipid parts in the course of storage.

On Drying process according to preferred embodiments of the invention

Microalgae paste was introduced to the algae drier by a peristaltic pump, (a positive displacement pump such as a gear pump, a mono pump or the like is considered to be useful in particular in larger scales plants), at a low flow rate (5 ml/min) and directed to the first scraping paddle; maximum inlet air temperature is 120°C. Drying time depends on the species, and biomass composition and particular conditions such as the proportion of free water to bound water and normally is less than 5 seconds. Incoming airflow provides the heat requirements. Scrappers on the fluidizing paddles prevent the material to adhere to the walls, distribute the incoming feed to smaller particles and provide the fluidising spiral flow which moves the particles to the outlet. Particles move upward via a spiral pattern close to the walls. Bigger particles move back to the scraping section.

Due to the physical status of the feed as a non-Newtonian pseudo plastic fluid, an inlet 3 (feeding unit) see fig.s 1 and 5 introduces the feed to the drying chamber typically in a direction being tangential to the wall of the drying chamber and horizontal or slightly inclined downwardly, which feed immediately is scraped and distributed by the scraping paddles (see fig. 4), which moves close to the drying chamber walls (2mm or even less than 2mm) and fluidised in the stream of the air. After drying, which occurs in seconds, the density of smaller particles reduces so that they can be moved with the stream of air to the outlet. Bigger particles

return continuously to the scrapping area and can move to the outlet and are being distributed to smaller sizes. The air inlet, located at the conically shaped bottom of drying chamber, so the air stream flows spirally to the drying chamber, prevents the feed from sticking on the walls.

5

On embodiments presented inter alia in the figures

Reference is made to fig. 1 schematically illustrating a preferred embodiment of an algae drier according to first preferred embodiment. Please note, that the illustration of fig. 1 may be seen as a cross sectional view although the commonly
10 used cross hatching of surfaces is not applied.

As illustrated, an algae drier for drying algae paste and/or liquid algae biomass comprising a drying chamber comprising an elongate tubular member forming an internal elongate void 7. The elongate tubular member is made from a fluid non-
15 penetrable material (that is a material fluid can not pass through), such as metal (e.g. stainless steel) or other suitable material being able to provide non-permeability and withstanding the mechanical and thermal conditions prevailing during use. The elongate tubular member 1 is preferably made with as a cylinder providing a cylindrical shaped void (except from the lower part as illustrated in
20 fig. 1).

The elongate tubular member 1 being, during use, arranged with its longitudinal direction being vertical. "During use" refer to the situation where algae paste and/or liquid algae biomass is fed into the algae drier and being dried in the algae
25 drier.

The algae drier also comprising a rotatable fluidizer 2, which serves inter alia the purpose of at least contributing to a fluidization of the matter (alga) inside the drier. As will be disclosed below, gas (typically being air, such as atmospheric air)
30 is fed into the void of the elongate tubular member 1 from below which infeed of gas may also at least contribute to a fluidization of the matter in the void of the elongate tubular member 1.

The rotatable fluidizer 2 comprises a rotational shaft 6 and a number of fluidizing
35 paddles 8 radially extending from the rotational shaft 6. The elements are labelled

"paddles" since during rotation they perform a paddling (stirring or agitation) motion in the matter contained in the void of the elongate tubular member 1.

As illustrated in fig. 1, the rotatable fluidizer 2 has a longitudinal extension being less the length of the internal elongate void 7 and being arranged inside the internal elongate void 7 in position providing a headspace 9 above said rotatable fluidizer 2 inside said internal elongate void 7. The head space 9 in the embodiment of fig. 1 is a region above the rotatable fluidizer 2 being free of obstacles. However, the head space may in general contain obstacles such as fluid guiding elements, process elements and/or sensors for e.g. sensing the temperature in the head space 7.

The algae drier of fig. 1 also comprising a motor 10 arranged to rotate the rotation shaft 6; thereby by rotating the rotation shaft 6, the rotation of the fluidizing paddles 8 is effectuated. As indicated in fig. 1, the rotational axis of the rotation shaft 6 is parallel with the longitudinal axis of the elongate tubular member, in a further preferred embodiment, where the elongate tubular member is in the form of a cylinder (except from the bottom) the rotational axis of the rotation shaft 6 coincides with the centre of the cylinder.

20

An outlet 4 from said head space 9 is provided in the algae drier for outletting dried algae and such an outlet is arranged at an upper end of the head space 9.

An inlet 3 to said head space 9 is provided for inletting algae paste and/or liquid algae biomass to be dried and such an inlet is arranged below said outlet 4.

Further, an inlet 5 is arranged at a lower end of or below said rotatable fluidizer 2 for inletting heated gas, such as air into the tubular elongate member 1, preferably at a position below the rotatable fluidizer 2.

As illustrated in fig. 1, the positioning of the outlet 4, the inlets 3 and 5 together with the rotation of the rotatable fluidizer provides a flow pattern inside the void where matter goes upwardly in a centre region (in the vicinity of the rotation shaft 6) and downwardly in an outer region (in the vicinity of the inner wall of the elongate tubular member). As illustrated, this provides a region where the matter circulates in a general torus shaped flow pattern. The paddling motion of the

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paddles 8 - or in general the rotation of the fluidizing paddles 8 -provides a vertical and/or spiral velocity component to the matter resulting in that the flow in the void becomes spiralling.

- 5 As mentioned above, the elongate tubular member 1 is preferably cylindrical and the rotation shaft 6 is arranged with its rotational axis in the geometrical centre of the cylindrical shaped elongate tubular member 1.

Reference is made inter alia to fig. 4 illustrating that the radial extending paddles
10 8 each are blade shaped having a chord to thickness ratio (c/t) being larger than 1. The chord is defined as the distance from a leading edge to a trailing edge of the blade, and the thickness is the maximum thickness measured along a chord (using the notation ordinary within for instance aerodynamic blades).

- 15 As illustrated perhaps most clearly in fig. 3, the chord length of each blade is decreasing in radial direction of the blade. In fig. 3, the blades are between their outermost extremity. Here, radial direction of the blade may also be seen as the longitudinal direction of the blade.

20 Fig. 3 also illustrates an air duct 22 and how it approach the bottom part of drying chamber. As also illustrated in fig. 3, the scrapper edge is in this particular embodiment arranged in a distance of 1mm from the wall. Further, the length of the scrapper is indicated as being 30mm and the thickness of the scrapper is indicated to be 3mm.

25

Reference is made to fig. 1 and 4 in which it is illustrated that a number of fluidizing paddles 8 are arranged in horizontal, neighbouring sections, where two neighbouring horizontal sections are vertically distanced from each other with a horizontal section not comprising fluidizing paddles 8. In the embodiment shown
30 in fig. 4, four horizontal sections containing fluidizing paddles 8 with three horizontal section not comprising fluidizing paddles 8 are illustrated. It is noted that the scrappers 13 (will be disclosed in greater details below) are not taken into account in the statement "not comprising fluidizing paddles".

The fluidizing paddles 8 in each horizontal section are typically arranged symmetrically. This includes that the two or more fluidizing paddles 8 being arranged in each horizontal section are arranged equiangular with reference to the angle between to neighbouring paddles 8 within one horizontal section. In the 5 embodiment shown in the figures, two paddles 8 are arranged in each horizontal section with 180 degrees in-between. If three paddles 8 are arranged in horizontal section they are preferably arranged with 120 degrees in between and so forth.

As perhaps most clear from fig. 4, the fluidizing paddles 8 in two horizontal, 10 neighbouring sections are staggered relatively to each other; in fig. 4 they are staggered 90 degrees relatively to vertically neighbouring paddles 8.

The chord of each blade of the paddles 8 may be inclined relative to the horizontal. Such an inclination may have the potential to increase the pressure 15 difference between the upper and lower side of the blade which can be used to emphasize a given desired flow pattern inside the elongate tubular member 1.

As illustrated in the figures (see in particular fig. 4 and 5) each fluidizing paddle 8 has at a position being distal to the rotation shaft, preferably at the outer most 20 end of the fluidizing paddles 8, a scrapper 13 arranged to scrape an inner surface of the elongate tubular element 1 when rotatable fluidizer 2 is rotated.

In fig. 5, the contour of the scrappers 13 is outlined by a black line and as illustrated in fig. 4, the scrappers 13 are blade-shaped with a scraper edge 14 25 extending in the longitudinal direction of the elongate tubular member 1. It is noted that the contour of the scrappers 13 may be modified compared to what is illustrated in fig. 5. The scrapper edges 14 are arranged in close proximity to the inner surface of the elongate tubular member 1, such as with distance between the scraper edge 14 and the inner surface of the elongate tubular element 1 being 30 between 0.5 and 5 mm, such as between 1 and 3 mm, preferably between 1.5 and 2 mm such as less than 1 mm, preferably less than 0.75 mm, such as less than 0.5 mm, such as less than 0.25 mm. It may generally be preferred to prevent contact between scrapper edge 14 and the inner surface of the elongate element, and the distance between scrapper edge 14 and the inner wall is 35 therefore preferred to be larger than zero. The scrapper edges 14 defines typically

the leading edge (as seen from the rotational direction of the scrappers 13) of the scrappers 13.

Fig. 4 also disclose that a stirrer 16 may be arranged below the fluidizing paddles 5 8 which stirrer is preferably arranged on the rotation shaft 6 of the rotatable fluidizer. If considered advantageously, the stirrer 16 may also be arranged in closed proximity to the inner surface of the elongate member 1 so as to perform a scrapping action during rotation. This stirrer 16 may also be given a different shape and form thereby deviating from the embodiment shown in fig. 4.

10

The lower part of the elongate tubular member 1 may preferably have a conical shaped bottom section with its smallest cross section at the bottom of the elongate tubular member 1 as illustrated in fig. 1, e.g.

15 The inlet 3 to the head space 9 is configured for inletting the algae to be dried in a direction being substantial tangential to the inner wall of the elongate member and preferably also in horizontal direction. This is illustrated in fig. 5 with the tube pointing in the tangential direction of the inner wall and being substantial horizontal. It is noted that deviances from horizontal in the infeed direction may
20 be used. Fig. 5 also illustrates that the inlet 3 is arranged to deliver algae paste and/or liquid algae biomass onto the wall of the elongate tubular member 1. This is in the embodiment of shown in fig. 4 by the inlet is formed by a tube with its opening (inside the elongate member) arranged so that an outflow of algae paste and/or liquid algae biomass from the opening deposits on the wall in the head
25 space.

As illustrated in fig. 2, the elongate tubular member 1 may be formed by two separate sections, a lower section 1A in which the rotational fluidizer 2 and the inlet 3 to said head space 9 are arranged and an upper section I B in which the
30 outlet 4 from said head space 9) is arranged.

Fig. 2 also illustrates a stirrer 16 which has been found to improve the spiral flow and/or prevent settling of heavy particles of microalgae during the drying process. The stirrer 16 may be embodied as a set of arms extending radially and upwardly from a rotational shaft as shown in fig. 2.

35

Fig. 6 illustrates schematically a system layout for a system for drying algae paste and/or liquid algae biomass, the system comprising an algae drier 19 as defined herein. The system also comprises a heater 17 arranged for heating the gas, such as air, being inlet through the inlet 5 arranged at a lower end of or below said rotatable fluidizer (2). Such a heater may be an electrical heater and other heater suited for heating the air in a controlled manner to avoid heating to temperatures (over heating) which could destroy or reduce the quality of the produced dried algae.

10 The system also comprising an air pump 18 arranged to pump said gas through the heater 17 and into the tubular elongate member 1. In the embodiment illustrated, the air pump 18 is arranged upstream of the heater, but the air pump may be positioned differently.

15 An algae pump 20, such as a positive displacement pump is also arranged to pump the algae paste and/or liquid algae biomass to and through the inlet 3 for inletting algae paste and/or liquid algae biomass.

The system may also comprise a separator 15, such as a cyclone separator a bag filter or a combination thereof, arranged to receive a stream of dried algae and gas from the outlet 4 and to separate out the received algae from the gas.

Reference is made to fig. 7 schematically illustrating an air inlet according to a preferred embodiment of the invention. The air inlet is lateral to provide the spiral flow through the system. The air inlet forms the conical shaped bottom section with its smallest cross section at the bottom of the elongate tubular member 1. The air flows in a spiralling motion downwardly towards an opening 23 into an internally arranged tubular structure 24 being closed at its bottom, thereby forcing the air upwardly inside the tubular structure 24 in a spiralling motion toward the rotatable fluidizer 2.

Reference is made to fig. 8 illustrating a further embodiment of a rotatable fluidizer 2 usable in the embodiment of figure 2, the fluidizer is illustrated while it is located in the lower section of the elongate tubular member 1A and the view is as seen from above and into the lower section of the elongate member 1 of figure 2.

The fluidizing paddles 8 are connected to the rotation shaft 6 and comprising at their ends distal thereto scrappers 13. To avoid friction while still allowing the scrapper 13 to come in close contact, such as close as e.g. 0.5 mm between the edge of the scrappers 13 and the interior wall of the elongate member 1A, the
5 scrappers 13 each comprising two element 13A and 13B; the element 13A is a holder for the other element 13B which is an element made from ceramics. As illustrated in the figure in the lower right corner of fig. 8, the element 13B is arranged with its scrapper edge 14 arranged in close proximity to the wall of the elongate element 1 and the element 13A is arranged in a position retracted
10 relatively thereto. The element 13B extends partly behind the element 13A. It is noted, that although fig. 8 illustrates the scrapper 13 as comprised by two elements, the scrapper 13 may be made solely from ceramics which is then attached to the distal end of a fluidizing paddle 8.

15 It is further noted that while the drawing of fig. 8 illustrates schematically the scrappers 13, the photograph shown in the lower right corner of fig. 8 illustrates an implementation of the scrapper 13.

As disclosed herein, the algae slurry may be distributed to the internal wall,
20 through the inlet 3 (see e.g. fig.s 1 and 5) close to the first set of fluidizing paddles 8. By first set of fluidizing paddles is typically meant the upper most fluidizing paddles 8 which often is arranged in sets (see e.g. 1 where three sets of fluidizing paddles 8 are arranged in three vertically distanced sets).

25 Once the algae slurry is introduced, the slurry thickens, typically almost immediately, and the thickened layer of slurry on the wall is whipped out by the scrappers 13 which moves close to the wall. The whipped particles (of algae slurry) (still wet) moves into the interior of the drying chamber and is dried (typically considered to be immediately dried) in the stream of hot air in the
30 drying chamber.

As illustrated in fig. 8, with the cross sectional view labelled A-A, the fluidizing paddles 8 has a tapered leading edge 21; in the embodiment of fig. 8 the tapering is a wedge shape with an angle of 15°, where the angle is measured from
35 horizontal and downward as illustrated. As also illustrated in fig. 8, the tapering

extends from mid-chord of the paddles and forward (illustrated by the meandering line extending in longitudinal direction of the paddles) whereas the section behind the mid-chord is rectangular shaped. Forward refers to the rotational direction of the fluidizer 2.

5

Figure 9 is an illustration of the fluidizer illustrated in figure 8 in a side-view. As illustrated by horizontal dotted lines the scrappers 13 are arranged so that all of the surface in between an upper boundary of the upper most scrapper 13 and a lower boundary of the lower most scrapper 13 is scrapped. Thus, the scrappers 13
10 in two neighbouring sections are arranged so that a lower end of scrappers 13 in an upper section is at the same or lower horizontal level than an upper edge of scrappers 13 in lower, neighbouring section.

The embodiments shown in fig. 8 and 9 have been suggested to be particular
15 useful (but not limited to) for drying less viscous and or thinner biomass, such as liquid algae biomass compared to the embodiments of fig.s 3 and 4 which have been suggested to be particular useful (but not limited to) for drying algae paste.

As presented herein, the system for drying algae paste and/or liquid algae
20 biomass comprising a heater 17. This heater 17 is configured to provide a temperature inside the drier being less than 85°C, such as less than 75°C. preferably less than 65°C. This is typically provided by a temperature sensor (not shown) arranged downstream of the heater 17 for measuring the temperature of the heated air. If the temperature sensor determines a temperature above the
25 desired temperature, the heating effect provided by the heater is reduced and if the temperature is below a desired temperature the heating effect is increased. Downstream of the heater may also refer to the inside of the drier.

List of reference symbols used:

- 30 1 elongate tubular member
1A Lower section of the elongate tubular member 1
1B Upper section of the elongate tubular member 1
2 Rotatable fluidizer
3 Inlet for algae to be dried
35 4 Outlet for dried algae

- 5 Inlet for heated gas, such as air
- 6 Rotation shaft of rotatable fluidizer
- 7 Internal elongate void
- 8 Fluidizing paddles
- 5 9 Head space
- 10 Motor
- 11 Foot space
- 12 Support structure
- 13 Scrapper
- 10 14 Scrapper edge
- 15 Separator (cyclone separator)
- 16 Stirrer
- 17 Heater
- 18 Air Pump
- 15 19 Algae drier
- 20 Algae pump
- 21 Leading edge of fluidising paddles
- 22 Air duct
- 23 Opening
- 20 24 Internally arranged tubular structure

Although the present invention has been described in connection with the specified embodiments, it should not be construed as being in any way limited to 25 the presented examples. The scope of the present invention is set out by the accompanying claim set. In the context of the claims, the terms "comprising" or "comprises" do not exclude other possible elements or steps. Also, the mentioning of references such as "a" or "an" etc. should not be construed as excluding a plurality. The use of reference signs in the claims with respect to elements 30 indicated in the figures shall also not be construed as limiting the scope of the invention. Furthermore, individual features mentioned in different claims, may possibly be advantageously combined, and the mentioning of these features in different claims does not exclude that a combination of features is not possible and advantageous.

CLAIMS

1. A drier for drying material, such as algae paste and/or liquid algae biomass, the drier comprising
- a drying chamber comprising an elongate tubular member (1) forming an internal elongate void (7) and being made from a fluid non-penetrable material, the elongate tubular member (1) being, during use, arranged with its longitudinal direction being vertical;
 - a rotatable fluidizer (2) comprising a rotational shaft (6) and a number of fluidizing paddles (8) radially extending from the rotational shaft (6), said rotatable fluidizer (2) has a longitudinal extension being less the length of the internal elongate void (7) and being arranged inside the internal elongate void (7) in position providing a head space (9) above said rotatable fluidizer (2) inside said internal elongate void (7);
 - a motor (10) for rotating said rotation shaft (6);
 - an outlet (4) from said head space (9) for outletting dried material, such as dried algae, said outlet being arranged at an upper end of the head space (9);
 - an inlet (3) into said head space (9) for inletting material, such as algae paste and/or liquid algae biomass, to be dried, said inlet being arranged below said outlet (4);
 - an inlet (5) arranged at a lower end of or below said rotatable fluidizer (2) for inletting heated gas, such as air into the tubular elongate member (1).
2. A drier according to claim 1, wherein the elongate tubular member (1) is cylindrical and the rotation shaft (6) is arranged with its rotational axis in the geometrical centre of the cylindrical shaped elongate tubular member (1).
3. A drier according to any of the preceding claims, wherein the radial extending paddles (8) each are blade shaped having a chord to thickness ratio (c/t) of at least 3, such as at least 5, such as at least 10.
4. A drier according to claim 3, wherein the chord length of each blade is decreasing in radial (longitudinal) direction of the blade, e.g. as by the blade is tapered towards their outermost extremity.

5. A drier according to claim 3 or 4, wherein a number of fluidizing paddles (8) are arranged in horizontal, neighbouring sections, where two neighbouring horizontal sections are vertically distanced from each other with a horizontal section not comprising fluidizing paddles (8).

5

6. A drier according to claim 5, wherein the two or more fluidizing paddles (8) are arranged in each horizontal section, the said two or more fluidizing paddles (8) are arranged equiangular with reference to the angle between to neighbouring paddles (8) within one horizontal section.

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7. A drier according to claim 5 or 6, wherein fluidizing paddles (8) in two horizontal, neighbouring sections are staggered relatively to each other.

8. A drier according to any of the preceding claims 3-7, wherein the chord of each
15 blade is inclined relative to the horizontal.

9. A drier according to any of the preceding claims, wherein each fluidizing paddle (8) comprising at a position being distal to the rotation shaft (6), preferably at the outer most end of the fluidizing paddles (8), a scrapper (13) arranged to scrape
20 an inner surface of the elongate tubular element (1) when said rotatable fluidizer (2) is rotated.

10. A drier according to claim 9, wherein the scrappers (13) are blade-shaped with a scraper edge (14) extending in the longitudinal direction of the elongate
25 tubular member (1) and being arranged in close proximity to the inner surface of the elongate tubular member (1), such as with distance between the scraper edge (14) and the inner surface of the elongate tubular element (1) being between 0.5 and 5 mm, such as between 1 and 3 mm, preferably between 1.5 and 2 mm, such as less than 1 mm, preferably less than 0.75 mm, such as less than 0.5 mm, such
30 as less than 0.25 mm.

11. A drier according to claim 9 or 10, wherein at least a part (13B) of each of the scrappers (13) is made from a ceramic material.

12. A drier according to claim 11, wherein the each of the scrapers (13) comprising a holder (13A) configured for holding the ceramic part (13B).
13. A drier according to any of the claims 9-12, wherein scrapers (13) in two
5 neighbouring horizontal sections are arranged so that a lower end of scrapers (13) in an upper section is at the same or lower horizontal level than an upper edge of scrapers (13) in lower horizontal neighbouring section.
14. A drier according to any of the preceding claims, further comprising a stirrer
10 (16) arranged below the fluidizing paddles (8), the stirrer being preferably arranged on the rotation shaft (6) of the rotatable fluidizer.
15. A drier according to any of the preceding claims, wherein the elongate tubular
15 member (1) comprises a conical shaped bottom section with its smallest cross section at the bottom of the elongate tubular member (1).
16. A drier according to any of the preceding claims, wherein said inlet (3) to said
head space (9) is configured for inletting the material, such as algae paste and/or
liquid algae biomass, to be dried in a direction being substantial tangential to the
20 inner wall of the elongate member and preferably also in horizontal direction or preferably inclined by up to 10°, such as inclined up to 5° downwardly relatively to horizontal.
17. A drier according to any of the preceding claims, wherein said inlet (3) to said
25 head space (9) comprising a tube having an opening arranged so that outflow from said opening deposits onto the inside wall of the tubular elongate member in said head space (9).
18. A drier according to any of the preceding claims, wherein the elongate tubular
30 member (1) has two separate sections, a lower section (1A) in which the rotational fluidizer (2) and the inlet (3) to said head space (9) are arranged and an upper section (1B) in which the outlet (4) from said head space (9) is arranged.

19. A drier according to any of the preceding claims, wherein each fluidizing paddles (8) has a tapered leading edge (21).

20. A system for drying material, such as algae paste and/or liquid algae biomass the system comprising a drier (19) according to any of the preceding claims, the system further comprising

- a heater (17) arranged for heating the gas, such as air, being inlet through the inlet (5) arranged at a lower end of or below said rotatable fluidizer (2), and an air pump (18) arranged to pump said gas through the heater (17) and into the tubular elongate member (1);
- an pump (20), such as a positive displacement pump, arranged to pump the material, such as algae paste and/or liquid algae biomass to and through the inlet (3) for inletting material.

21. A system for drying material, such as algae paste and/or liquid algae biomass, according to claim 20, wherein the system further comprising a separator (15), such as a cyclone separator a bag filter or a combination thereof, arranged to receive a stream of dried material, such as dried algae and gas from the outlet (4) and to separate out the received material from the gas.

20

22. A system according to any of claims 20 or 21, wherein the heater (17) is configured to provide a temperature inside the drier being less than 85°C, such as less than 75°C. preferably less than 65°C.

23. A method of drying algae paste and/or liquid algae biomass, the method utilises a system according to any of the preceding claims 20-22 and comprising, feeding algae paste and/or liquid algae biomass into the drier and operating the system to produce dried algae.

25

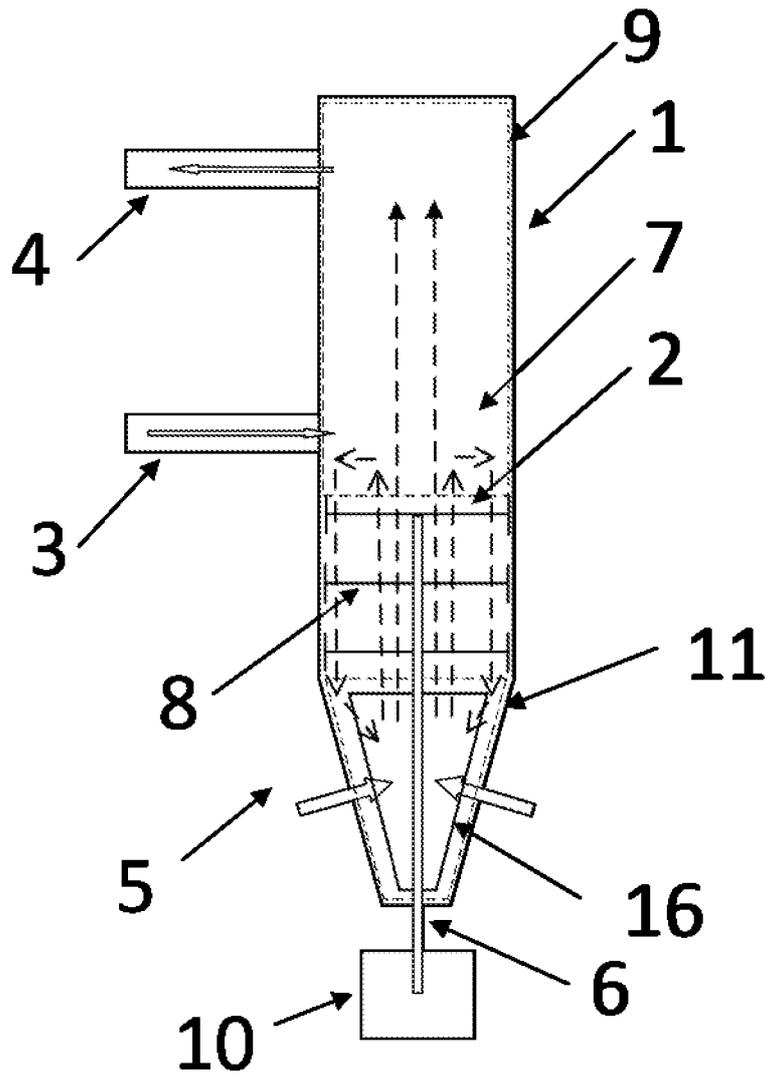


Fig. 1

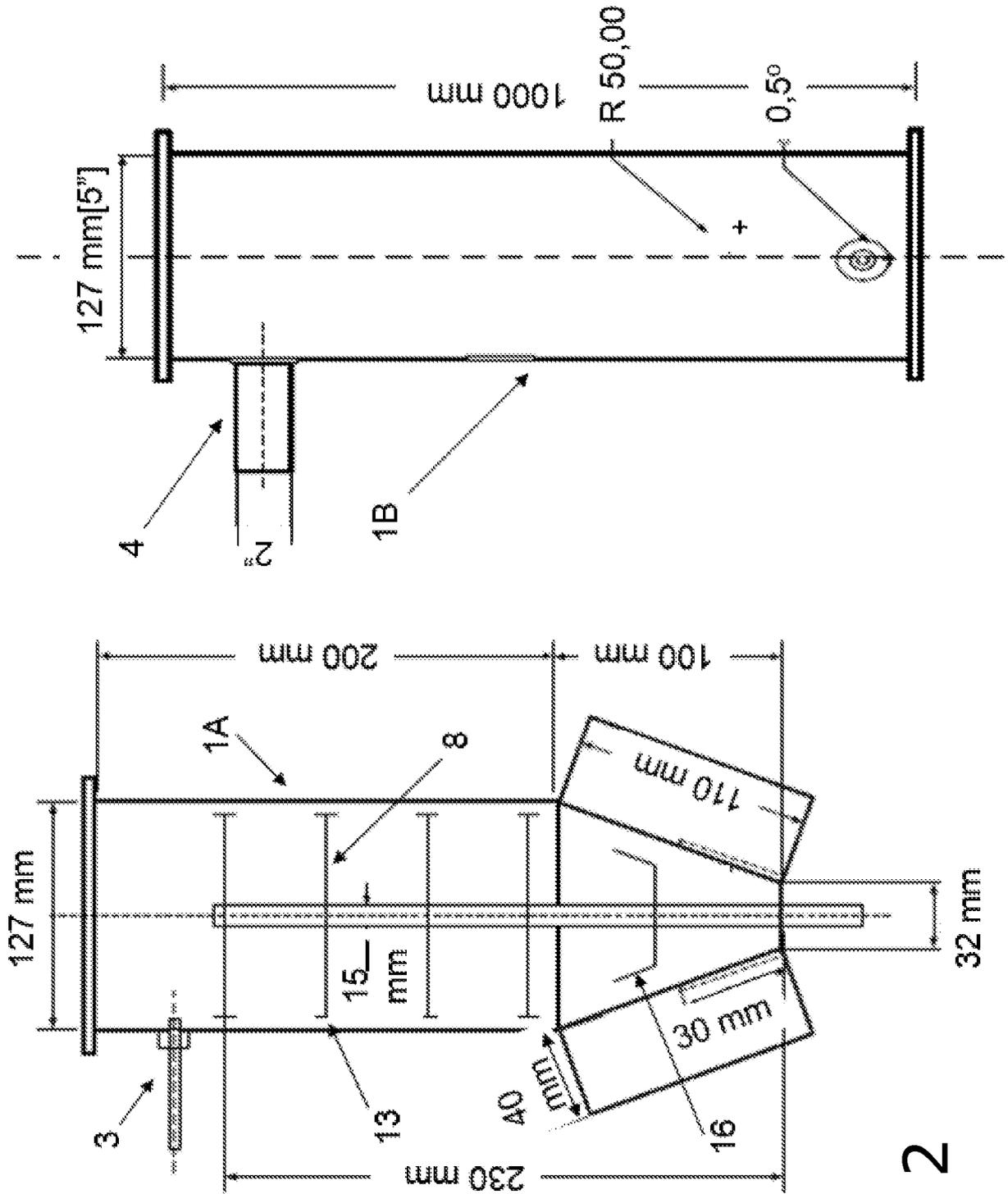


Fig. 2

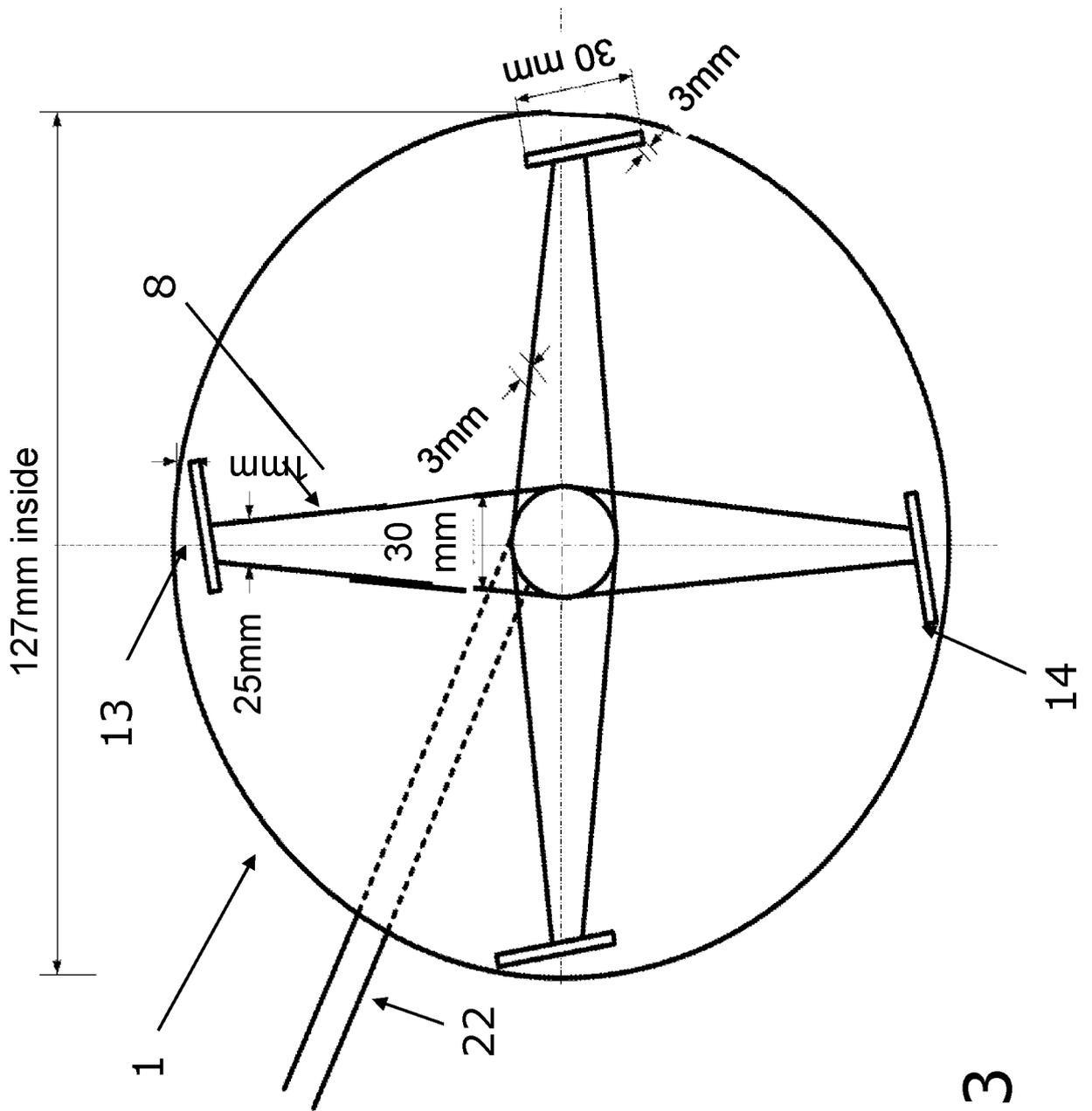


Fig. 3

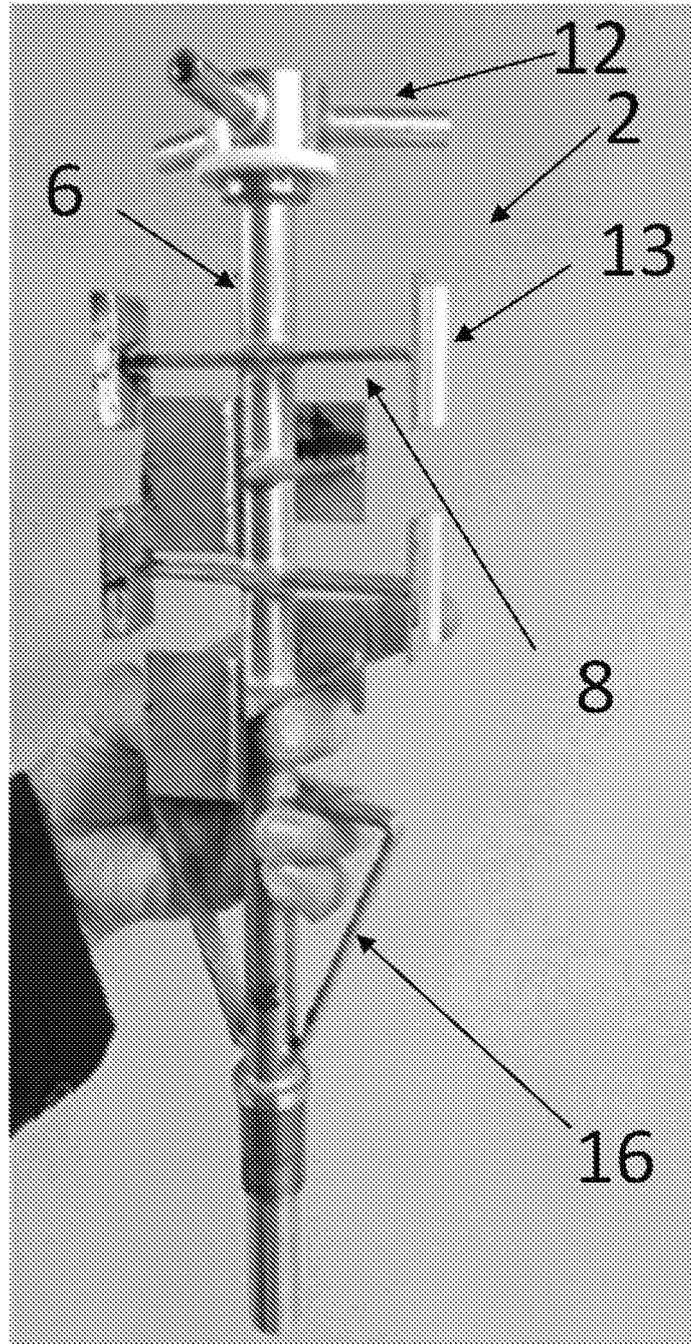


Fig. 4

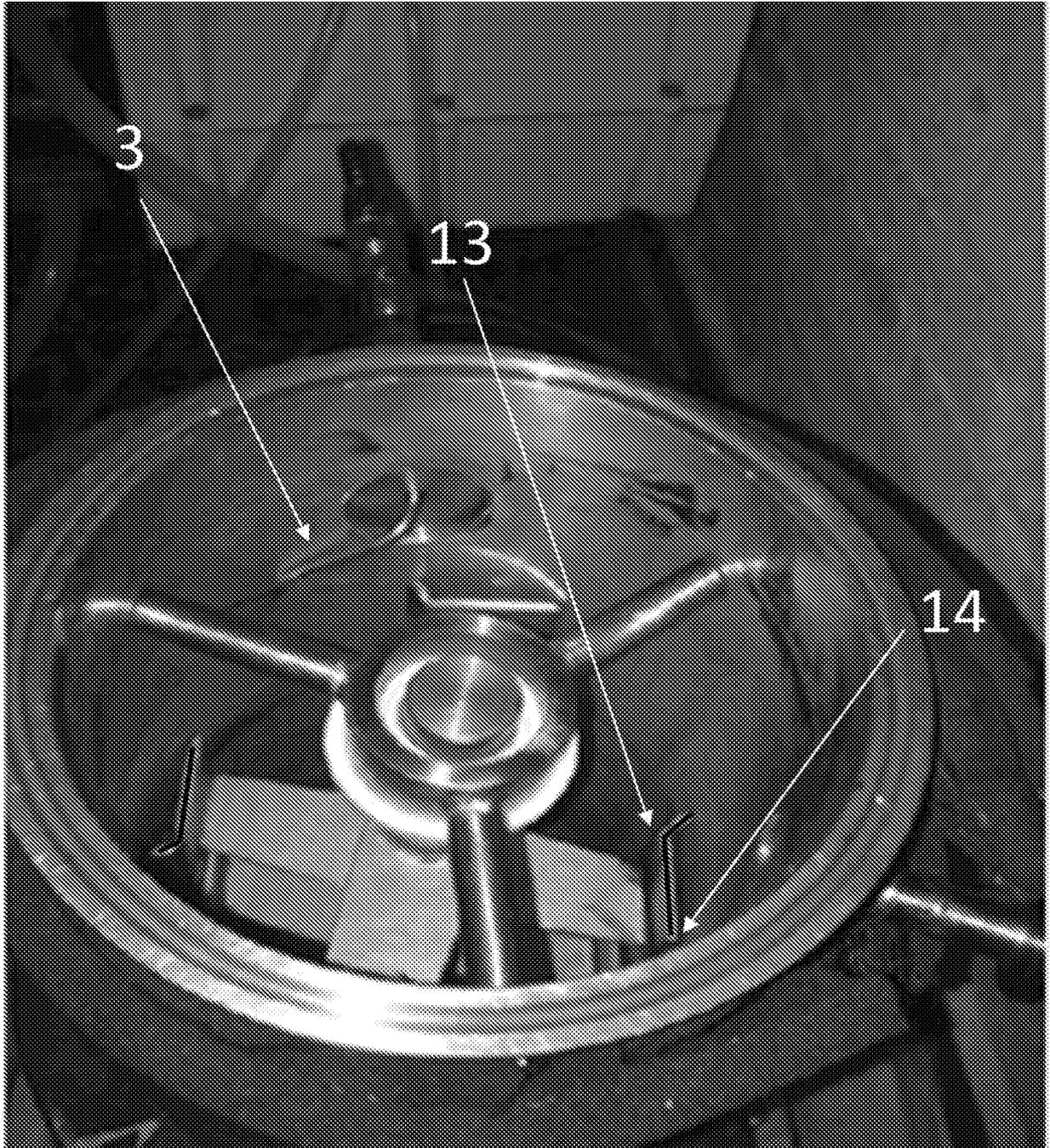
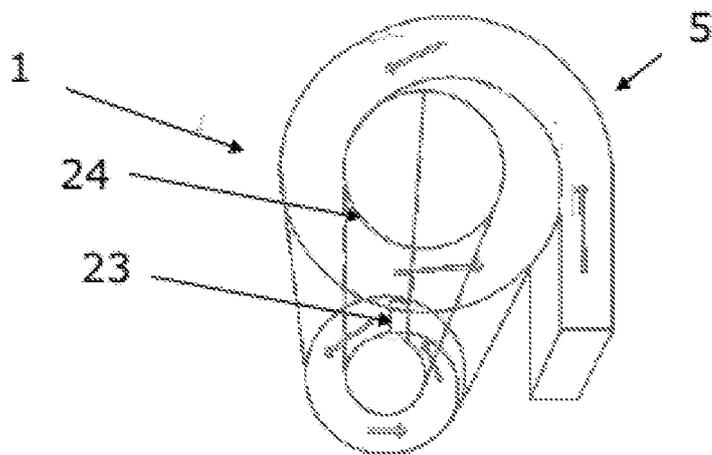
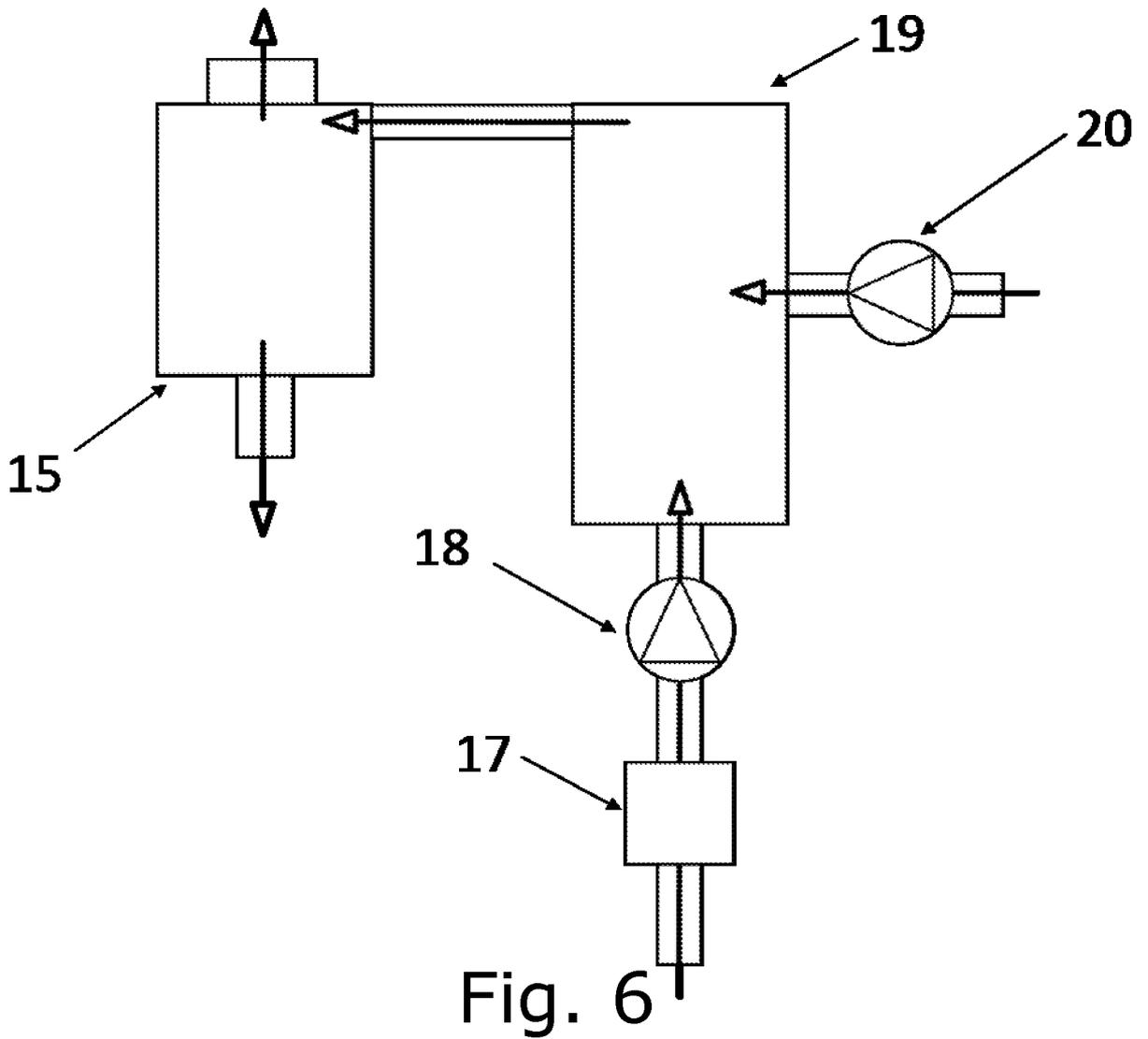


Fig. 5



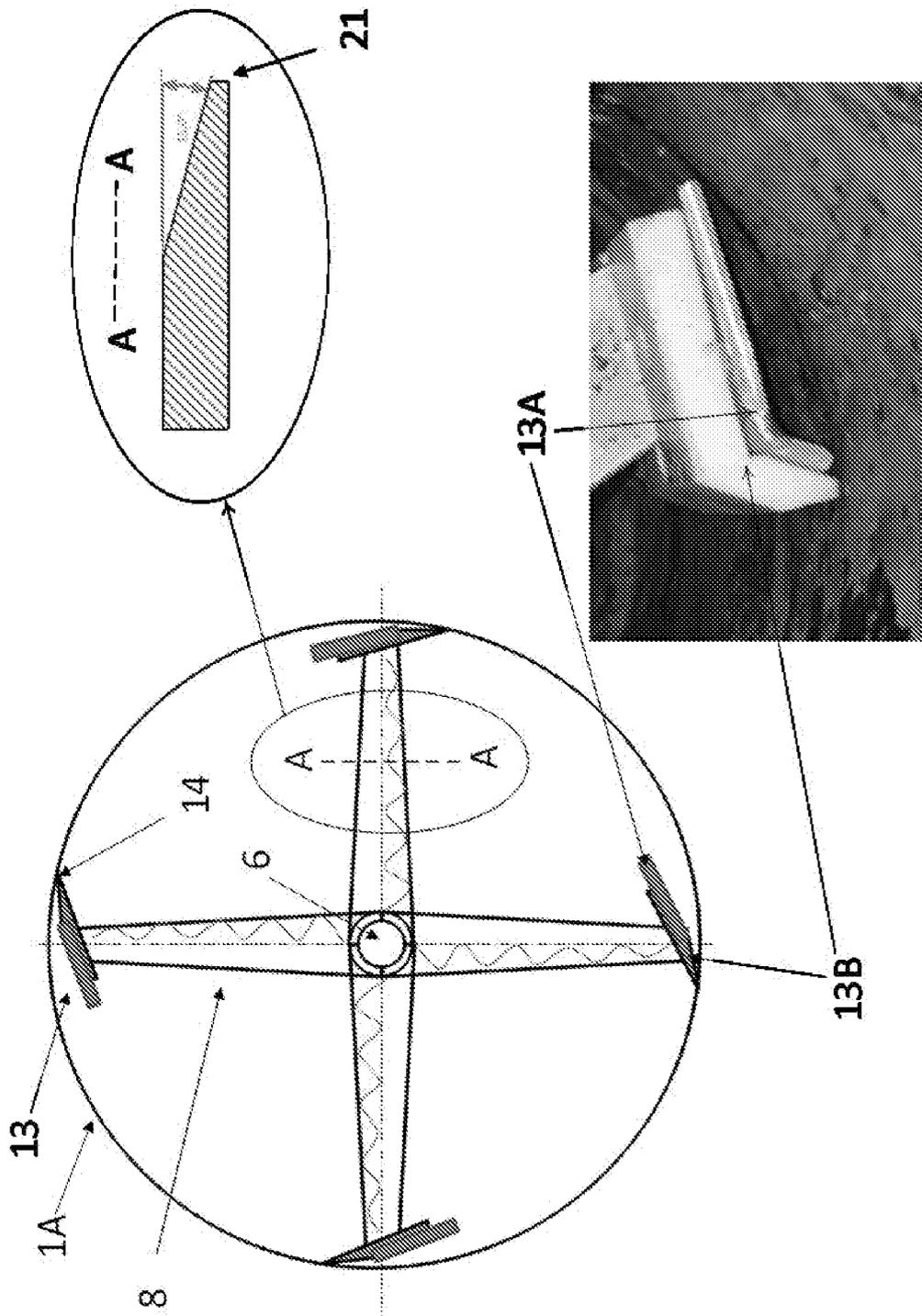


Fig. 8

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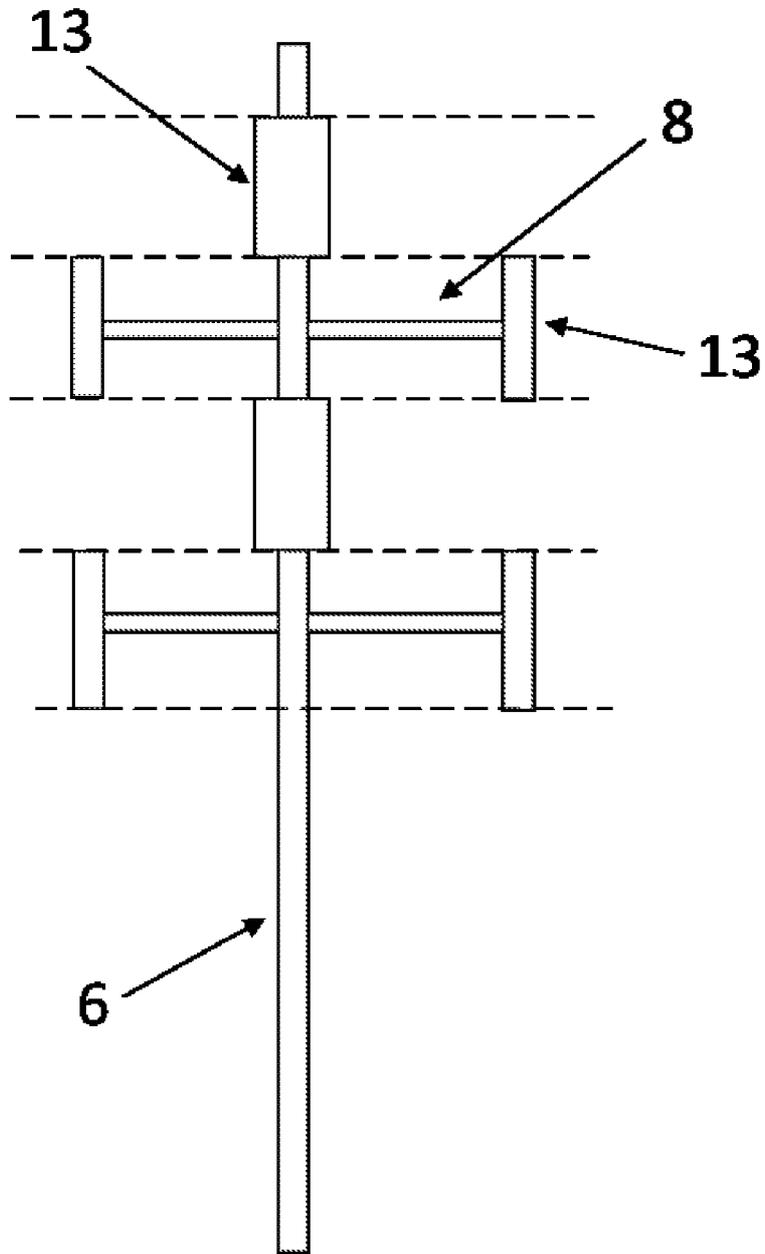


Fig. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/DK2017/050403

A. CLASSIFICATION OF SUBJECT MATTER
INV. C12M1/00 F26B3/092
ADD.
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED
Minimum documentation searched (classification system followed by classification symbols)
C12M F26B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal , WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	wo 2015/136070 AI (SPX FLOW TECHNOLOGY DANMARK AS [DK]) 17 September 2015 (2015-09-17)	1-8, 14-23
Y	claim 1; figure 1	9-13
X	EP 0 141 403 A2 (ANHYDR0 AS [DK]) 15 May 1985 (1985-05-15)	1-8, 14-23
Y	figure 1	9-13
X	wo 92/12796 AI (TECHDANIA I S [DK]) 6 August 1992 (1992-08-06)	1-8, 14-23
Y	claims 1, 11	9-13
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Further documents are listed in the continuation of Box C.

See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

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

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 8 February 2018	Date of mailing of the international search report 15/02/2018
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Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Authorized officer Jones , Laura
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INTERNATIONAL SEARCH REPORT

International application No
PCT/DK2017/050403

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	US 5 659 977 A (JENSEN GLENN [US] ET AL) 26 August 1997 (1997-08-26) figure 1 -----	21

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International application No PCT/DK2017/050403
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