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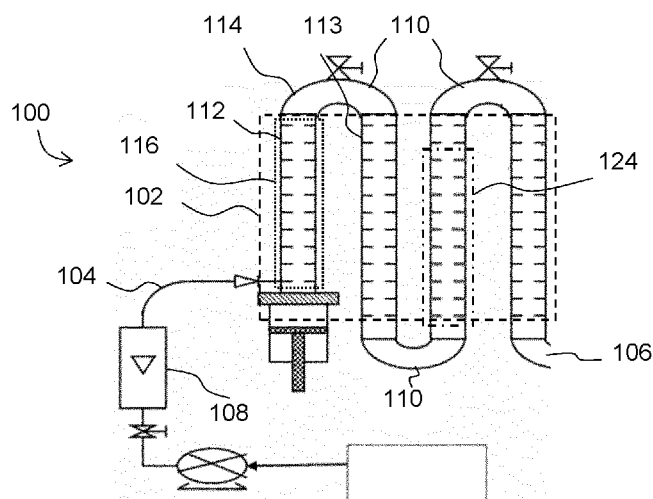


Fig. 3

(57) Abstract: Herein is presented an apparatus comprising a vessel adapted to receive and discharge fluids, the vessel comprising a series of tubular members, each tubular member defining a discrete process zone, the series of tubular members being arranged and operatively connected in a flow system to form at least one continuous fluid flow path having an inlet and an outlet, wherein at least one baffle is provided within at least one tubular member of the series of tubular members and at least one light source is provided on one or more of the at least one baffle such that the at least one light source is configured to emit light into the fluid flow path during use.



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Photo Reactor

Field of the Invention

The present disclosure relates to apparatus and methods for chemical reactions, more specifically to apparatus and methods for photo-initiated chemical reactions.

Background of the Invention

Many of the commodities and consumables that are central to modern life are made using chemical synthesis processes. Such chemical processes are typically initiated by raising the temperature of the reactants by the application of heat, or by increasing the pressure to which the reactants are subjected.

Both the application of heat and increased pressure are energy intensive and as a result increase the carbon footprint of those processes. Accordingly, there is increased interest in chemical synthesis pathways that can be carried out at lower temperatures and pressures, if not at ambient conditions (i.e. room temperature and pressure). However, such chemical pathways often require the use of a catalyst to lower the enthalpy of the reaction to bring it into the ambient range. Such catalysts are typically expensive and can be difficult to dispose of after the process is completed, or if the catalyst becomes poisoned.

Therefore, there is a need for improved chemical synthesis pathways and apparatus for carrying out such improved chemical synthesis pathways that does not require the use of catalysts or elevated temperatures and pressures.

One alternative approach that has been proposed is the use of photo-initiated reactions that use a photo-sensitiser additive that convert the energy absorbed from light into energy that can be used to initiate the chemical reaction. Accordingly, in such processes it is necessary to arrange one or more light sources around the reaction chamber, or to arrange such light sources within the reaction chamber itself. For chemical reactions that are carried out in a laboratory setting, the volumes being processed are typically small, and it is relatively straightforward to arrange light sources in positions around the chemical reactor or reaction flow path to ensure that a substantially consistent intensity of light is present across the reaction volume. However, as a chemical process is scaled up from processing microliters as may be used in the laboratory, to tens or hundreds of liters as may be processed in industry, it is difficult to ensure that the distribution of light within the reaction volume is consistent. As a result, there are inevitable dark and bright areas within the reaction volume, poor control of light distribution

as well as heat distribution, and light sources such as light bars provided within a reactor volume presents practical challenges of stability and durability.

These issues result in lower reaction conversion, increased side reactions, and also limits the scale up of the process to industrial scale production.

Therefore, there remains a need for improved photo-initiated reactors.

Accordingly, it is at least one object of the present disclosure to address at least one of these problems.

Summary of the Invention

According to a first aspect there is provided an apparatus comprising a vessel adapted to receive and discharge fluids. The vessel typically comprises a series of tubular members, each tubular member defining a discrete process zone. The series of tubular members may be arranged and operatively connected in a flow system to form at least one continuous fluid flow path having an inlet and an outlet. At least one baffle may be provided within at least one tubular member of the series of tubular members. At least one light source may be provided on one or more of the at least one baffle such that the at least one light source is configured to emit light into the fluid flow path during use.

Alternatively, one or more of the at least one baffle may comprise at least one light source. For example, the one or more of the at least one baffle may be a light source.

Typically, the apparatus is used to carry out chemical processes, such as chemical reactions and to synthesise a chemical product.

Traditionally, large scale chemical reactions are carried out in batch processes. Such processes normally involve the use of a stirred tank reactor (see Figure 1A and 1B, for example) that define a reaction volume, in which the reactants are mixed by means of one or more impellers in fixed positions.

If such traditional stirred tank reactors are used in photo-initiated reactions, light sources are required to be installed within the tank itself, in which case the support for the light source occupies reaction volume and light emitted by the light source is unable to provide consistent and even light intensity for the entire reaction volume.

Alternatively, light sources may be installed outside the tank reactor for safety reasons, but requires light emitted by the light sources to be transmitted through the walls of the tank reactor thereby reducing effective light intensity within the reaction volume for a given light source intensity, and, dependent on the material used for the tank reactor walls, the wavelength of light that can be transmitted into the reaction volume is limited, limiting the reactions that can be carried out in a given tank reactor.

As the tank reactor is scaled up to significantly increase the reaction volume that can be processed, the light intensity that is provided within the reactor as well as the heat so generated becomes increasingly inhomogeneous leading to potential side reactions and reductions in yield.

An improved apparatus is provided in WO 2007/060412 to NiTech Solutions Ltd (incorporated herein by reference). An apparatus is presented therein shown in Figure 2 comprising a vessel adapted to receive and discharge fluids having a series of cylindrical tubes the cylindrical tubes being configured to follow a succession of return paths in one plane and being arranged and operatively connected in a flow system to form at least one continuous fluid flow path having an inlet and an outlet, wherein a plurality of baffles (for example, orificed plates) that extend radially inwards towards the centre of the cylindrical tubes is provided within the flow path.

The inventors have surprisingly found that apparatus comprising at least one tubular member having at least one baffle provided within the interior of the at least one tubular member to provide passive mixing of a fluid or reaction mixture flowing therethrough can be adapted for photo-initiated reactions by mounting at least one light source on the at least one baffle. Accordingly, the at least one light source is provided within the tubular member to thereby allow light to be emitted directly into the fluid flowing through the apparatus without taking up significant volume of the reaction vessel as the support (i.e. the baffle) for the light source is already present in the vessel.

Furthermore, the apparatus of the present aspect comprises a series of tubular members that form a continuous fluid flow path. Accordingly, reactant flows through the apparatus continuously through the tubular members and as a result, the reaction volume adjacent to a given light source is relatively small, and therefore, the light intensity emitted by the at least one light source across the tubular member is substantially uniform, whilst allowing the volume

of reactant to be processed to be dependent on the fluid flow rate of reactant through the apparatus.

5 The at least one baffle may comprise a plurality of light sources. The light sources of the plurality of light sources may be arranged regularly around a surface of the baffle. The light sources of the plurality of light sources may be arranged irregularly around a surface of the baffle. The light sources of the plurality of light sources may be arranged on one side of the baffle. Accordingly, the plurality of light sources may be configured to emit light upstream of the baffle. The plurality of light sources may be configured to emit light downstream of the baffle. 10 The light sources of the plurality of light sources may be arranged on both sides of the baffle. Accordingly, the plurality of light sources may be configured to emit light upstream of the baffle and downstream of the baffle.

15 The at least one light source may comprise a light emitting diode (LED) or LED array.

The at least one light source may be configured to emit light downstream into the fluid flow path.

20 The at least one light source may be configured to emit light upstream into the fluid flow path.

In some embodiments, each baffle within the apparatus may comprise at least one light source. Typically, the apparatus comprises at least one portion that comprises baffles that do not comprise at least one light source.

25 The apparatus may comprise a plurality of reaction zones. The apparatus may comprise at least a first reaction zone and a second reaction zone. The apparatus may comprise a first plurality of light sources in the first reaction zone. The apparatus may comprise a second plurality of light sources in the second reaction zone. At least one baffle in the first reaction zone may comprise a first plurality of light sources and at least one baffle in the second reaction zone may comprise a second plurality of light sources. The first plurality of light 30 sources may emit light at a first wavelength. The second plurality of light sources may emit light at a second wavelength. The first wavelength may be the same as the second wavelength. The first wavelength may be different to the second wavelength. For example, the first wavelength may be shorter than the second wavelength or the first wavelength may be longer than the second wavelength. 35

The first plurality of light sources may emit light at a first intensity. The second plurality of light sources may emit light at a second intensity. The first intensity may be the same as the second intensity. The first intensity may be different to the second intensity. For example, the first intensity may be greater than the second intensity or the first intensity may be less than the second intensity.

The first reaction zone may be configured to initiate a first photo-initiated chemical reaction. The second reaction zone may be configured to initiate a second photo-initiated chemical reaction.

Alternatively, the first reaction zone may be configured to initiate a first photo-initiated chemical reaction, and the second reaction zone may be configured to allow a second, non-photo-initiated chemical reaction, for example.

The at least one baffle may extend inwardly from an interior surface of the tubular members.

Each baffle within the at least one baffle may comprise a plate that extends radially inwards towards the centre of the tubular member. Typically, the at least one baffle defines an aperture extending from the centre of the baffle to the centre of the tubular member.

The at least one baffle may be mounted on rails attached to the inner surfaces of the tubular members. Accordingly, the position of the at least one baffle within the tubular member may be adjusted. The at least one baffle within a tubular member may be removed from the tubular member. Alternatively, the at least one baffle within a tubular member may be a uniform part of the tubular member that cannot be readily removed from the tubular member.

The at least one baffle is preferably an orifice baffle.

In some embodiments, the tubular members may be cylindrical tubes. Accordingly, the fluid comprising the reaction mixture flows through the cylindrical tubes through the at least one baffle to be exposed to the at least one light source.

The reactants may be combined to form a reaction mixture. The reaction mixture may further comprise a solvent. A first reactant may act as a photo-initiator and therefore, it may not be necessary to add a photo-initiator to the reactants within the reaction mixture. Alternatively, a photo-initiator may be added to the reaction mixture.

The apparatus may comprise one or more auxiliary inputs. The one or more auxiliary inputs may be located between the input and the output of the apparatus. Accordingly, one or more species may be added to the reaction mixture at a specific point in the fluid flow.

- 5 In embodiments where the apparatus comprises at least a first reaction zone and a second reaction zone, the one or more auxiliary input may be located between the first reaction zone and the second reaction zone. Accordingly, a species may be added to the reaction mixture after the first reaction zone such that it is present in the reaction mixture when the reaction mixture has flowed into the second reaction zone.

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The species added to the reaction mixture may be a photo-initiator. In embodiments where the reaction mixture comprises a first photo-initiator, the species may be a second photo-initiator. The absorption band of the first photo-initiator may be different to the absorption band of the second photo-initiator. For example, the first photo-initiator may be different to
15 the second photo-initiator. The absorption band of the first photo-initiator may be the same as the second photo-initiator. For example, the first photo-initiator may be the same as the second photo-initiator. The absorption band refers to the range of wavelengths of light that the photo-initiator can absorb to create reactive species that then initiate the desired chemical reaction in the reaction mixture.

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Example photo-initiators that may be used with the apparatus of the present aspect may include organic dyes, aromatic hydrocarbons, transition metal complexes, immobilized photosensitizers, azobisisobutyronitrile (AIBN), benzoyl peroxide, 2,2-dimethoxy-2-phenylacetophenone (DMPA), camphorquinone, or hydrogen peroxide. Further photo-
25 initiators suitable for use with the apparatus of the invention can be readily determined by the person skilled in the art.

Typically, the at least one light source emits light that corresponds to the absorption band of the specific photo-initiator to be used.

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In embodiments where the at least one light source comprises an LED light source, the wavelength of light emitted by the LED may be adjusted between uses of the apparatus such that the wavelength of light emitted by the LED falls within the absorption band of the photo-initiator of the reaction mixture for a specific reaction.

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Photo-initiated reactions may be used to synthesise species such as biomolecules, pharmaceutical agents or other species. The species may include ketones, esters, alkenes,

alkynes, allenes, cyclobutanes, aromatic compounds, or lactones, for example. The biomolecules may include species such as unsaturated lipids, proteins and nucleic acids. The species may include essential oils, creams or fragrances. The essential oils may include lemon-grass oil, pennyroyal oil, lavender oil, anise oil, nutmeg oil, clove oil, cinnamon oil, or spearmint oil, for example.

In a second aspect there is presented a baffle assembly comprising at least one baffle mounted on at least one support, one or more of the at least one baffle comprising at least one light source on a surface of the baffle. The baffle assembly may be configured to be installed in an apparatus comprising a vessel adapted to receive and discharge fluids. The vessel typically comprises a series of tubular members, each tubular member defining a discrete process zone, and the at least one baffle is configured to be installed in a tubular member. The series of tubular members may be arranged and operatively connected in a flow system to form at least one continuous fluid flow path having an inlet and an outlet. The at least one baffle comprises at least one light source that is configured to emit light into the fluid flow path of the apparatus during use when the at least one baffle is installed within the apparatus.

The at least one baffle may be a light source.

The at least one baffle may comprise a plurality of light sources. The light sources of the plurality of light sources may be arranged regularly around a surface of the baffle. The light sources of the plurality of light sources may be arranged on one side of the baffle. Accordingly, the plurality of light sources may be configured to emit light upstream of the baffle. The plurality of light sources may be configured to emit light downstream of the baffle. The light sources of the plurality of light sources may be arranged on both sides of the baffle. Accordingly, the plurality of light sources may be configured to emit light upstream of the baffle and downstream of the baffle.

Accordingly, the baffle assembly of the present aspect may be configured to be used in a tubular member of an apparatus of the first aspect.

The baffle assembly may further comprise a power source. Power from the power source may be transmitted to the at least one light source via the at least one support.

The at least one support may comprise a plurality of rods. For example, the plurality of rods may comprise two, three or four rods. The plurality of rods may connect each baffle of the at

least one baffle. Each baffle of the at least one baffle may be connected such that they are spaced apart from one another. Each baffle of the at least one baffle may be connected to one another such that the at least one baffle has a common axis. The plurality of rods may connect a power source to one or more of the at least one baffle. The plurality of rods may connect the power source to each light source of each of the at least one baffle. At least one rod in the plurality of rods may comprise an electrically conductive element. The electrically conductive element may extend from a power source to at least one baffle to thereby connect at least one light source of the at least one baffle to a power source. The electrically conductive element may extend from a power relay point to at least one baffle to thereby connect at least one light source of the at least one baffle to a power source via the power relay point. The electrically conductive element may include one or more wires. The electrically conductive element may be retained within the at least one rod. Accordingly, the electrically conductive element may be protected within the at least one rod from liquids such as a chemical solvent, for example.

The baffle assembly may comprise a controller. The controller may be configured to control or adjust the intensity of light emitted by the at least one light source. The controller may be configured to control or adjust the wavelength of light emitted by the at least one light source.

The baffle assembly may comprise a receiver adapted to receive a signal from an external or central controller that is configured to control or adjust the intensity of light emitted by the at least one light source and/or adjust the wavelength of light emitted by the at least one light source.

Brief Description of the Figures

Embodiments of the present invention will now be described, by way of non-limiting example, with reference to the accompanying drawings.

Figure 1: Photo-initiated reactors known in the art (A) stirred batch reactor with light sources provided within reactor volume, (B) stirred batch reactor with light sources provided outside the reactor vessel, and (C) microfluidic reactor with light sources provided outside the channel;

Figure 2: A flow reactor known in the art;

Figure 3: Apparatus according to an embodiment;

Figure 4: Baffle comprising light sources installed in an apparatus according to an embodiment;

Figure 5: A pair of baffles comprising light sources installed in an apparatus according to an embodiment, where the light sources of a first baffle in the pair are offset from the light sources of a second baffle in the pair;

Figure 6: A series of baffles comprising light sources according to an embodiment;

5 **Figure 7:** Apparatus according to an embodiment;

Figure 8: Apparatus according to an embodiment; and

Figure 9: A side view of a baffle *in situ* according to an embodiment.

Detailed Description

10 While the making and using of various embodiments of the present invention are discussed in detail below, it should be appreciated that the present invention provides many applicable inventive concepts that can be embodied in a wide variety of specific contexts. The specific embodiments discussed herein are merely illustrative of specific ways to make and use the invention and do not delimit the scope of the invention.

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To facilitate the understanding of this invention, a number of terms are defined below. Terms defined herein have meanings as commonly understood by a person of ordinary skill in the areas relevant to the present invention. Terms such as "a", "an" and "the" are not intended to refer to only a singular entity, but include the general class of which a specific example may
20 be used for illustration. The terminology herein is used to describe specific embodiments of the invention, but their usage does not delimit the invention, except as outlined in the claims.

Apparatus for photo-initiated chemical reactions are typically carried out in stirred batch reactors 1, such as those shown in Figure 1 A and B. In these stirred batch reactors 1, the
25 light sources 2 are required to be mounted on supports 4 that are provided within the reaction volume 6 defined by the reactor vessel 8 (Figure 1A), or are provided outside the reactor vessel 8 (Figure 1B). The reactor comprises a stirrer 10 and often beads 12 that comprise photo-initiators are added to the reaction volume 6 so that the reaction can be photo-initiated. Once the reaction is completed the beads 12 may be removed from the reaction mixture.

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In small scale reactions, microfluidic channels 14, such as that shown in Figure 1C can include beads 16 embedded or fixed within the flow channel 18 such that as reaction mixture flows past the beads 16 light emitted by light sources 20 outside the microfluidic channel 14 is absorbed by photo-initiator in the beads 16 and initiates the reaction within the reaction
35 mixture. However, if this type of reactor is scaled up to increase the volume of product to be produced, the homogeneity of light intensity across the channel 14 is reduced and the

transmission of light through the wall 22 of the reaction path becomes more problematic and restrictive.

A recent development in reaction apparatus is shown in Figure 2. The apparatus 30 comprises a series of cylindrical tubes 32, each cylindrical tube is connected to one another by a curved tubular portion 36 and the series of cylindrical tubes 32 forms a serpentine flow path from an input 38 to an output 40. The apparatus 30 comprises species inputs (for example 42) that may be used to introduce species into the flow path defined by the series of cylindrical tubes.

Each cylindrical tube 32 comprises baffles (for example 44). The baffles are orifice baffles and form an annulus around the interior surface of the cylindrical tube 32 and define an aperture 46 through which a reaction mixture may flow. The provision of the baffles 44 on the interior of the cylindrical tubes induces turbulence in the fluid flowing within the cylindrical tube 34 and so promotes thorough mixing of the fluid as it flows along the flow path.

Example 1

With reference to Figure 3, there is provided an apparatus 100 comprising a plurality of linear cylindrical tubes 102, an input 104, an output 106, a flow pump 108 and a plurality of curved cylindrical tubes 110. Each linear cylindrical tube (for example 112, 113) within the plurality of linear cylindrical tubes 102 is connected to one another by a curved tube (for example 114) within the plurality of curved cylindrical tubes 110. Accordingly, the plurality of linear cylindrical tubes 102 and the plurality of curved cylindrical tubes 110 form a flow path extending from the input 104 to the output 106.

Each linear cylindrical tube (for example 112, 113) within the plurality of linear cylindrical tubes 102 comprises a plurality of baffles 116 arranged regularly along the length of the interior of the linear cylindrical tube 112. With reference to Figure 5, each baffle 118 within the plurality of baffles 116 comprises a plate 120 that extends from the interior surface 121 of the linear cylindrical tube 123 and forms an annulus around the interior surface of the linear cylindrical tube within which the baffle 118 is installed and defines an aperture 122 through which fluid may flow through during use.

The apparatus 100 further comprises a photo-initiating zone 124. Each baffle 118 within the photo-initiating zone 124 comprise an array of LEDs 126 on a first side of the plate 120 arranged around the baffle 118 (see Figure 5, for example). Each LED within the array of LEDs 126 is configured to emit light into fluid that flows through the aperture 122 defined by the baffle 118.

Alternatively, with reference to Figure 10, each baffle 600 within the photo-initiating zone 124 comprises an array of LEDs 602 on a first side 604 of the plate 120 and an array of LEDs 606 on a second side 608 of the plate 120.

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During use, a first reactant and a second reactant are provided and mixed into a common solvent to form a reaction mixture. The first reactant and the second reactant do not react to any significant extent under ambient conditions (for example, 25°C and 100kPa). A photo-initiator is added to the reactant mixture to produce a photo-sensitised reactant mixture. The photo-sensitised reactant mixture is then urged or pumped by the fluid pump into the input of the apparatus such that the photo-sensitised reactant mixture flows from the input to the output.

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As the photo-sensitised reactant mixture passes through the photo-initiating zone 124 light from the LEDs on the baffles 116 is absorbed by the photo-initiator and thereby initiates the reaction between the first reactant and the second reactant. The reaction proceeds as the reaction mixture flows from the photo-initiating zone 124. The length of the flow path from the photo-initiating zone 124 and the rate of flow of the reaction mixture are configured such that the reaction between the first reactant and the second reactant is substantially complete when the reactant mixture reaches the output 106.

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An example reaction that can be carried out using the apparatus is the oxidation of α -terpinene to form ascaridole where α -terpinene in chloroform with the photo-initiator polyamide-2-aminobenzothiazole (PA-ABT) provided on 2,1,3-benzothiadiazole (BTZ)-based vinyl cross-linker containing beads is illuminated with light from LEDs at a wavelength of 420 nm. PA-ABT absorbs light and promotes molecular oxygen in the air from the ground state to the singlet state, which then reacts with the α -terpinene to produce ascaridole.

25

Example 2

With reference to Figure 5 in a further alternative example the arrangement of LEDs of each array of LEDs 126 for subsequent baffles in the plurality of baffles 116 in the photo-initiating zone 124 are offset from one another. As a result, the homogeneity of the intensity of light across the extent of the cylindrical tube is improved to ensure that the reaction conditions in substantially all of the reaction volume through the photo-initiating zone is the same to thereby maximize reaction efficiency and minimize side reactions etc.

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Whilst Figure 6 shows each LED array to comprise 4 LEDs, it will be appreciated that the number of LEDs of the LED arrays may be greater or less than this number. For example, the number of LEDs in the LED array may be 2, 3, 4, 5, 6, 7, 8 or more, depending on the requirements of a given diameter of cylindrical tube and a given reaction.

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Example 3

With reference to Figure 6, a baffle array 300 comprises three baffles 302, 304, 306 connected with and separated by a pair of rails 308. Each baffle 302, 304, 306 comprises six LEDs 310 arranged regularly around the aperture defined within the plate of the baffle.

10

The pair of rails comprise electrical connectors to allow electrical power to be provided to the LEDs of each baffle 302, 304, 306.

The baffle array is configured to be inserted into a tubular shell to form a cylindrical tube of a photo-initiating zone of an apparatus of Example 1 or Example 2.

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Example 4

With reference to Figure 7, an apparatus 400 comprises a plurality of linear cylindrical tubes 402, an input 404, an output 406, a flow pump 408 and a plurality of curved cylindrical tubes 410. Each linear cylindrical tube (for example 412, 413) within the plurality of linear cylindrical tubes 402 is connected to one another by a curved tube (for example 414) within the plurality of curved cylindrical tubes 410. Accordingly, the plurality of linear cylindrical tubes 402 and the plurality of curved cylindrical tubes 410 form a flow path extending from the input 404 to the output 406.

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Each linear cylindrical tube 412 within the plurality of linear cylindrical tubes 402 comprises a plurality of baffles 416 arranged regularly along the length of the interior of the linear cylindrical tube 412. Each baffle 418 within the plurality of baffles 416 comprises a plate 420 that extends from the interior surface of the linear cylindrical tube and forms an annulus around the interior surface of the linear cylindrical tube within which the baffle 418 is installed and defines an aperture 422 through which fluid may flow through during use.

25

The apparatus 400 further comprises a first photo-initiating zone 430. Each baffle within the first photo-initiating zone comprise a first array of LEDs on a first side of the plate arranged around the baffle (see Figure 5, for example). Each LED within the first array of LEDs is configured to emit light of a first wavelength into fluid that flows through the baffle.

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The apparatus 400 further comprises a second photo-initiating zone 440. Each baffle within the second photo-initiating zone comprise a second array of LEDs on a first side of the plate arranged around the baffle (see Figure 5, for example). Each LED within the second array of LEDs is configured to emit light of a second wavelength into fluid that flows through the baffle.

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The apparatus 400 further comprises a third photo-initiating zone 450. Each baffle within the third photo-initiating zone comprise a third array of LEDs on a first side of the plate arranged around the baffle (see Figure 5, for example). Each LED within the array of LEDs is configured to emit light into fluid that flows through the baffle.

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Accordingly, the apparatus may be used to photo-initiate up to three reactions using up to three photo-initiators that absorb light at three different wavelengths.

The apparatus 400 further comprises species inputs 460. The species inputs are arranged between the first photo-initiating zone 430 and the second photo-initiating zone 440, between the second photo-initiating zone 440 and the third photo-initiating zone 450, such that additional reactants, photo-initiators, additives and/or solvents may be added to the flow path after the first reaction and before the second reaction, or after the second reaction and before the third reaction.

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Example 5

With reference to Figure 8, the device of Example 1 can be adapted to comprise a first stage 502, and second stage 504 and a third stage 506. The first stage 502 comprises an input 508, a series of cylindrical tubes 510 comprising baffles 512 connected to one another by a series of curved tubes 514 and an output 516 that feeds into a common manifold 518. The common manifold 518 acts as an input into the second stage 504 and the third stage 506 to divide the flow of fluid from the first stage 502 to the second stage 504 and third stage 506. The second stage 504 comprises a series of cylindrical tubes 520 connected to one another by a series of curved tubes (for example, 522), a first photo-initiating zone 524 and a first product output 530. The third stage 506 comprises a series of cylindrical tubes 532 connected to one another by a series of curved tubes 534, a second photo-initiating zone 536, and a second product output 542.

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The first photo-initiating zone 524 comprises baffles 544 comprising an array of LED lights (not shown) that emit light of a first wavelength of light and a first intensity into fluid that passes through the cylindrical tubes 520 of the second stage 504 in the first photo-initiating zone 524.

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The second photo-initiating zone 536 comprises baffles 546 comprising an array of LED lights (not shown) that emit light of a second wavelength of light and a second intensity into fluid that passes through the cylindrical tubes 532 of the third stage 506 in the second photo-initiating zone 536.

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During use, reactants, solvent and beads comprising a photo-initiator are entered into the input of the first stage. The reactants and solvent are mixed in the first stage due to the turbulence induced by the baffles in the cylindrical tubes of the first stage. The mixture is then divided by the common manifold such that equal amounts of the mixture pass into the second stage and the third stage.

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The pre-loaded beads within the second stage absorb light at the first wavelength and initiate a first reaction. The first reaction proceeds in the second stage to produce a first product that is then extracted from first product outlet.

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The pre-loaded beads within the third stage absorb light at the second wavelength and initiate a second reaction. The second reaction proceeds in the third stage to produce a second product that is then extracted from second product outlet.

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Accordingly, the apparatus can be used to produce two products from common reactants using two photo-initiated reactions.

For example, the apparatus could be used to separate two chiral isomers of a common product during synthesis by exposing the chiral reactant to different wavelengths of light.

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While there has been hereinbefore described approved embodiments of the present invention, it will be readily apparent that many and various changes and modifications in form, design, structure and arrangement of parts may be made for other embodiments without departing from the invention and it will be understood that all such changes and modifications are contemplated as embodiments as a part of the present invention as defined in the appended claims.

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Claims

1. An apparatus comprising a vessel adapted to receive and discharge fluids, the vessel comprising a series of tubular members, each tubular member defining a discrete process zone, the series of tubular members being arranged and operatively connected in a flow system to form at least one continuous fluid flow path having an inlet and an outlet, wherein at least one baffle is provided within at least one tubular member of the series of tubular members and at least one light source is provided on one or more of the at least one baffle such that the at least one light source is configured to emit light into the fluid flow path during use.
2. The apparatus of claim 1, wherein one or more of the at least one baffle comprises a plurality of light sources.
3. The apparatus of claim 2, wherein the light sources of the plurality of light sources are arranged regularly around a surface of the baffle.
4. The apparatus of claim 2, wherein the light sources of the plurality of light sources are arranged irregularly around a surface of the baffle.
5. The apparatus of claim 3 or claim 4, wherein the light sources of the plurality of light sources are arranged on both sides of the baffle.
6. The apparatus of any one preceding claim, wherein the at least one light source comprises a light emitting diode (LED) or LED array.
7. The apparatus of any preceding claim, wherein the apparatus comprises a plurality of reaction zones comprising at least a first reaction zone and a second reaction zone, wherein at least one baffle in the first reaction zone comprises a first plurality of light sources and at least one baffle in the second reaction zone comprises a second plurality of light sources.
8. The apparatus of claim 7, wherein the first plurality of light sources emit light at a first wavelength, and the second plurality of light sources emit light at a second wavelength.
9. The apparatus of claim 7 or claim 8, wherein the first wavelength is the same as the second wavelength or the first wavelength is different to the second wavelength.

10. The apparatus of any one of claim 7 to claim 9, wherein the first plurality of light sources emit light at a first intensity and the second plurality of light sources emit light at a second intensity.
- 5
11. The apparatus of any one preceding claim, wherein each baffle within the at least one baffle comprises a plate that extends radially inwards towards the centre of the tubular member and defines an aperture arranged in substantially the middle of the plate.
- 10
12. The apparatus of any one preceding claim, wherein the at least one baffle is mounted on rails attached to the inner surfaces of the tubular members.
13. The apparatus of any one preceding claim, wherein the at least one baffle is preferably an orifice baffle.
- 15
14. The apparatus of any preceding claim, wherein the tubular members are cylindrical tubes.
15. A baffle assembly comprising at least one baffle mounted on at least one support, one or more of the at least one baffle comprising at least one light source on a surface of the baffle.
- 20
16. The baffle assembly of claim 15, wherein the at least one baffle comprises a plurality of light sources arranged regularly around a surface of the baffle.
- 25
17. The baffle assembly of claim 15 or claim 16 further comprising a power source.
18. The baffle assembly according to any one of claims 15 to claim 17 further comprising a controller configured to control the intensity of light emitted by the at least one light source and/or to control the wavelength of light emitted by the at least one light source.
- 30

PRIOR ART

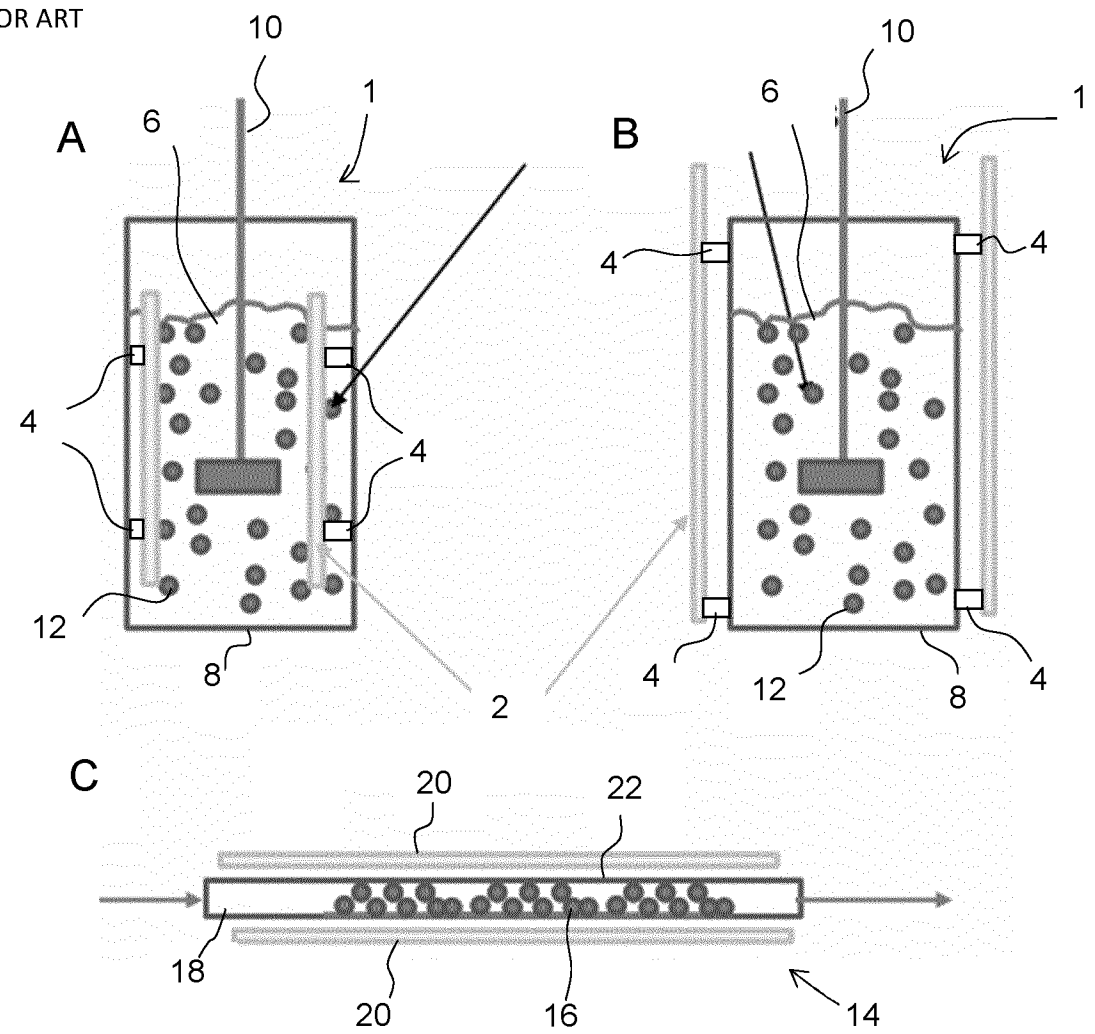


Fig. 1

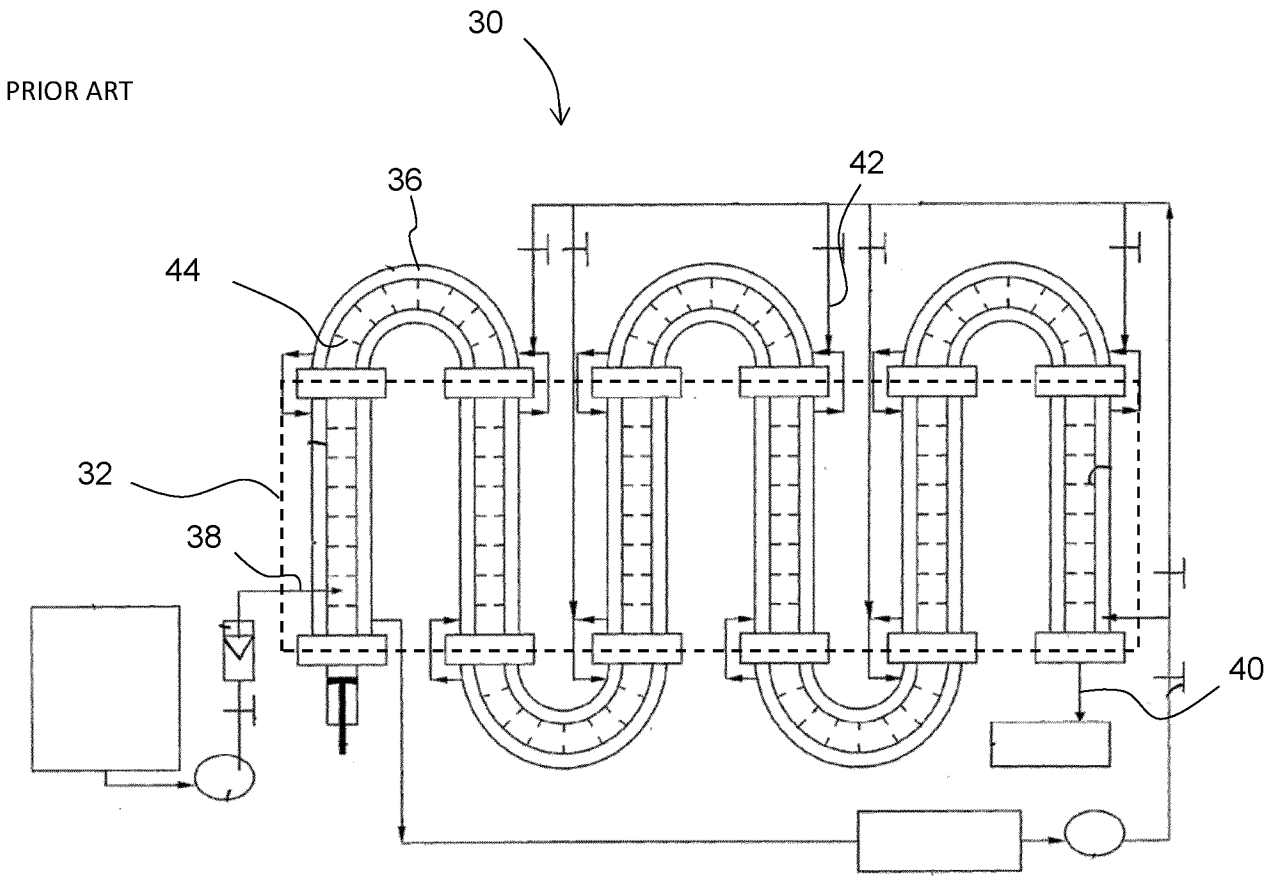


Fig. 2

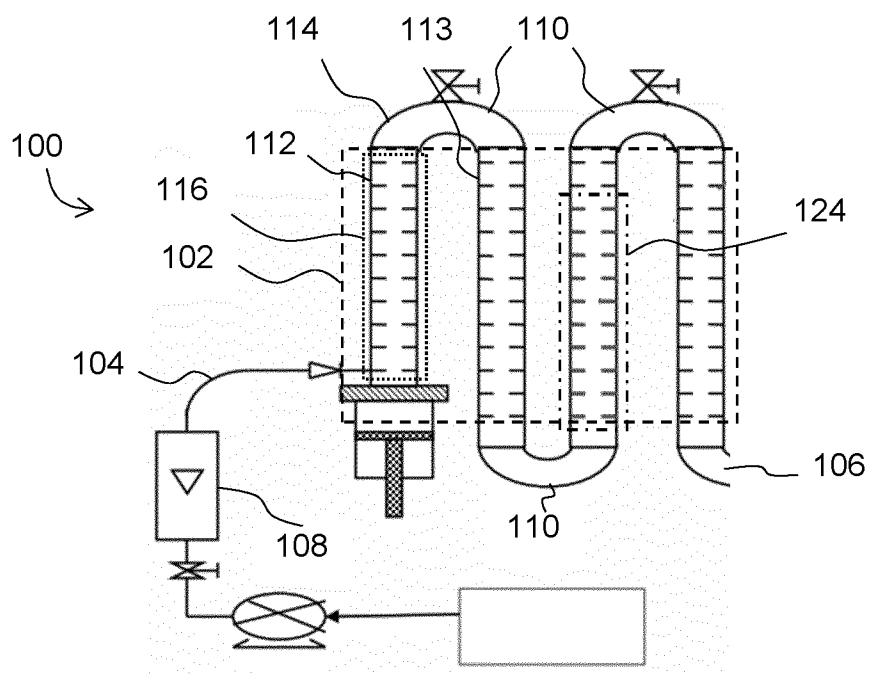


Fig. 3

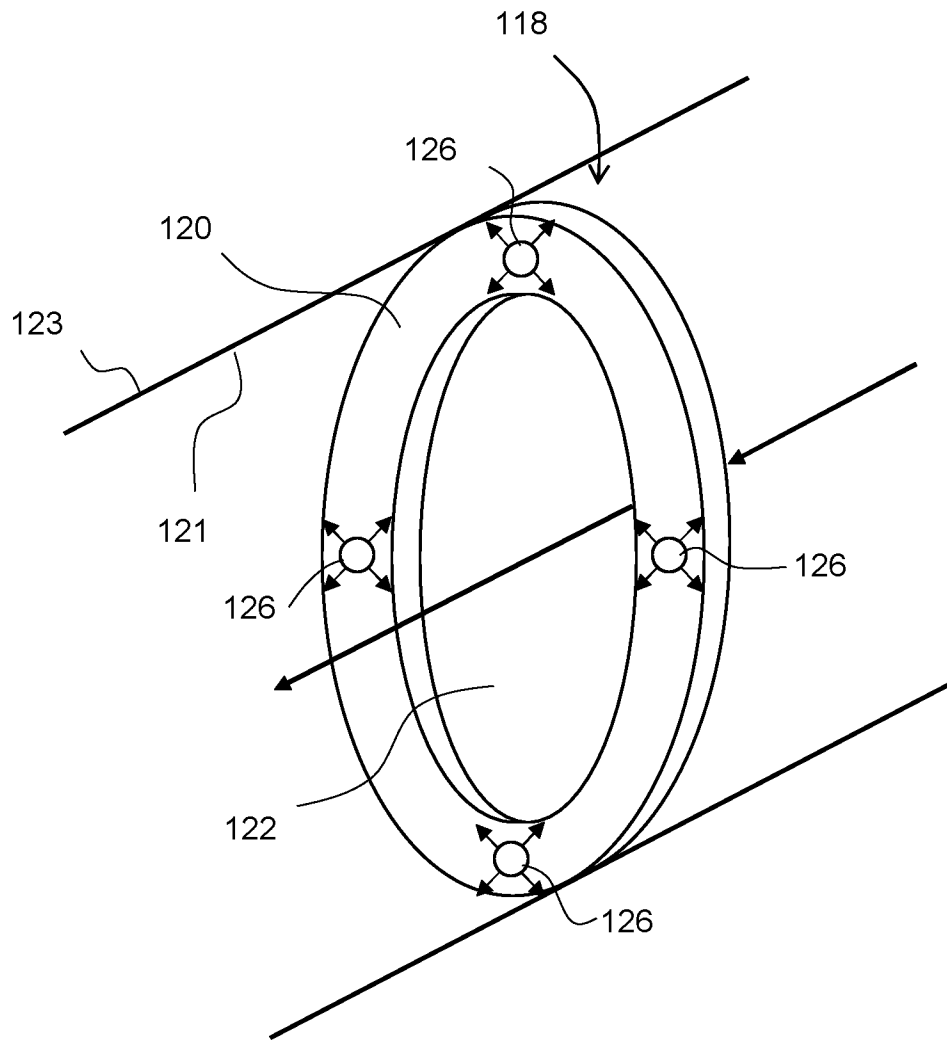


Fig. 4

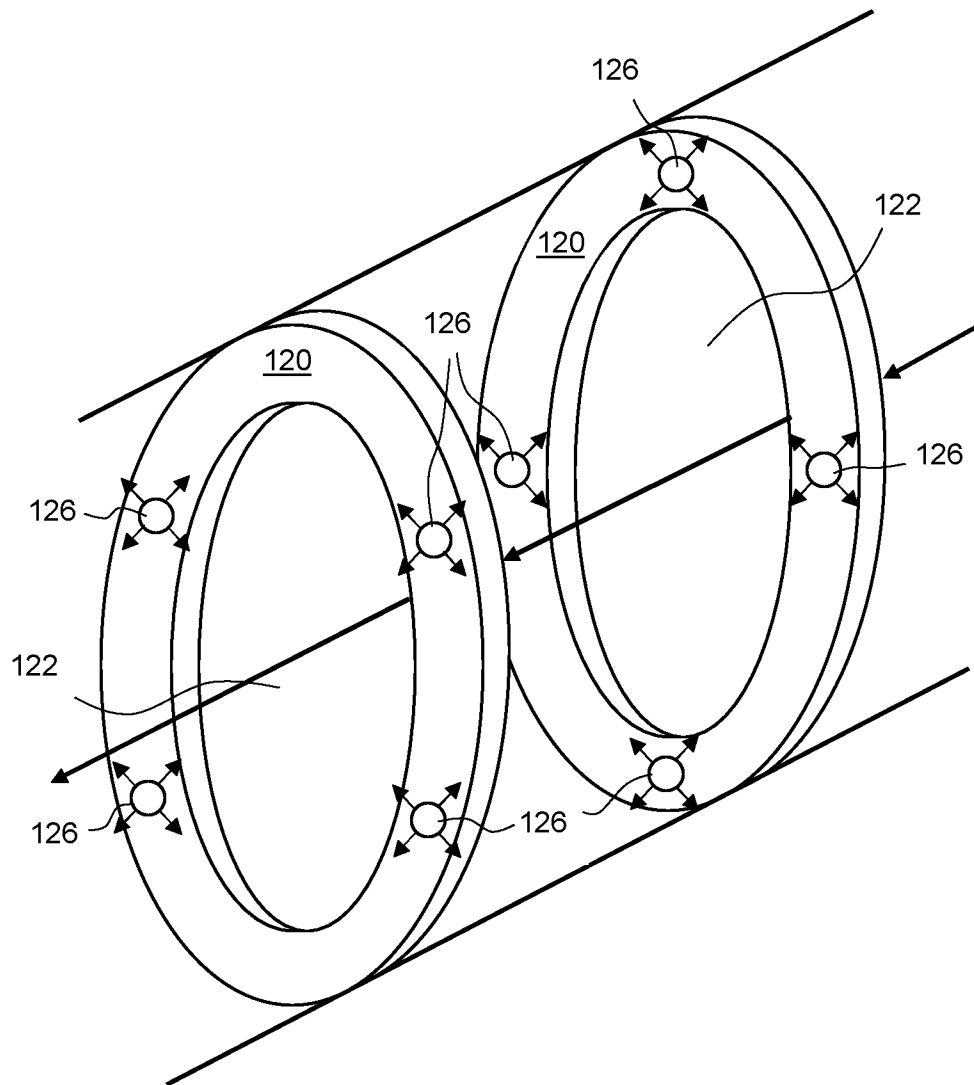


Fig. 5

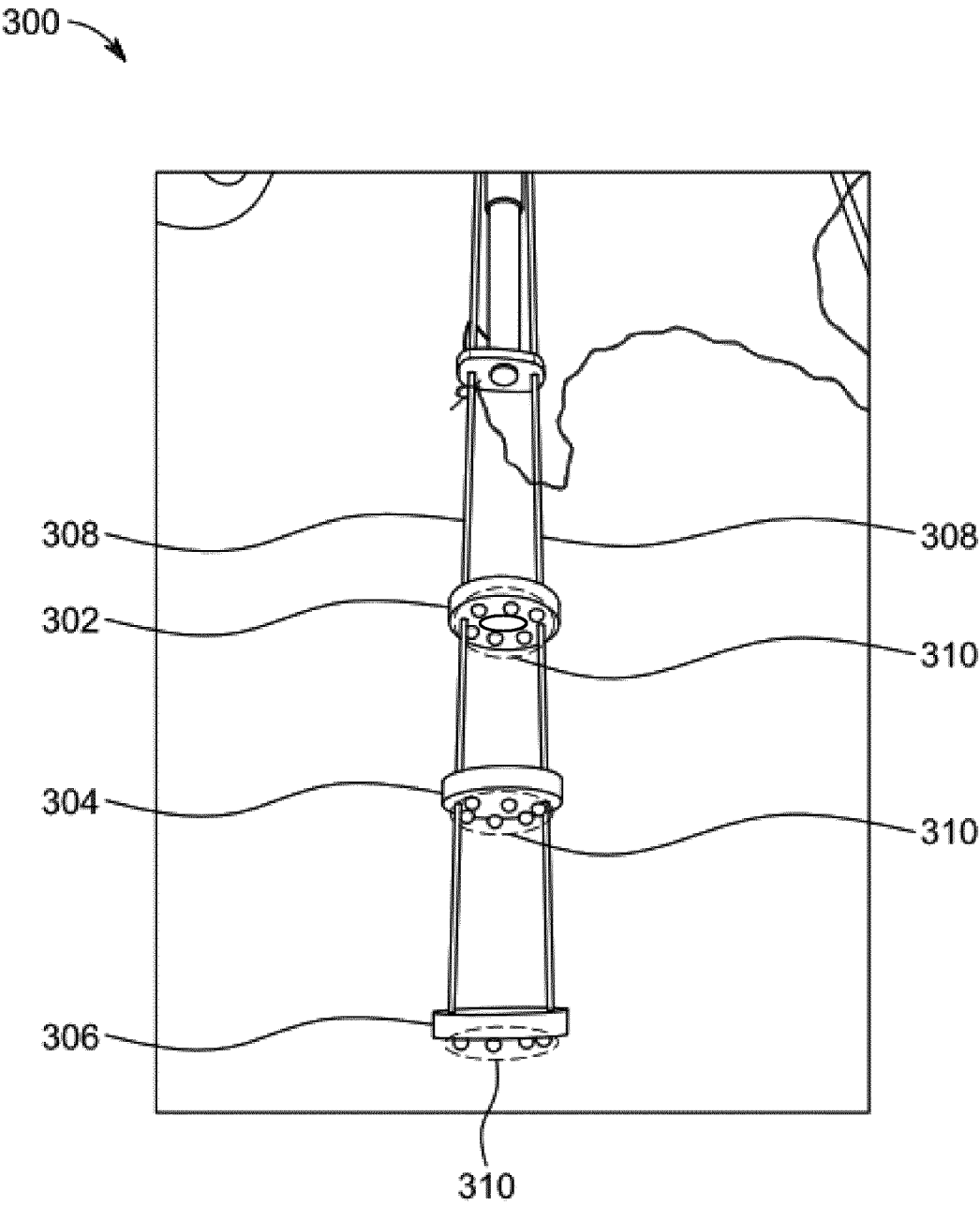


Fig. 6

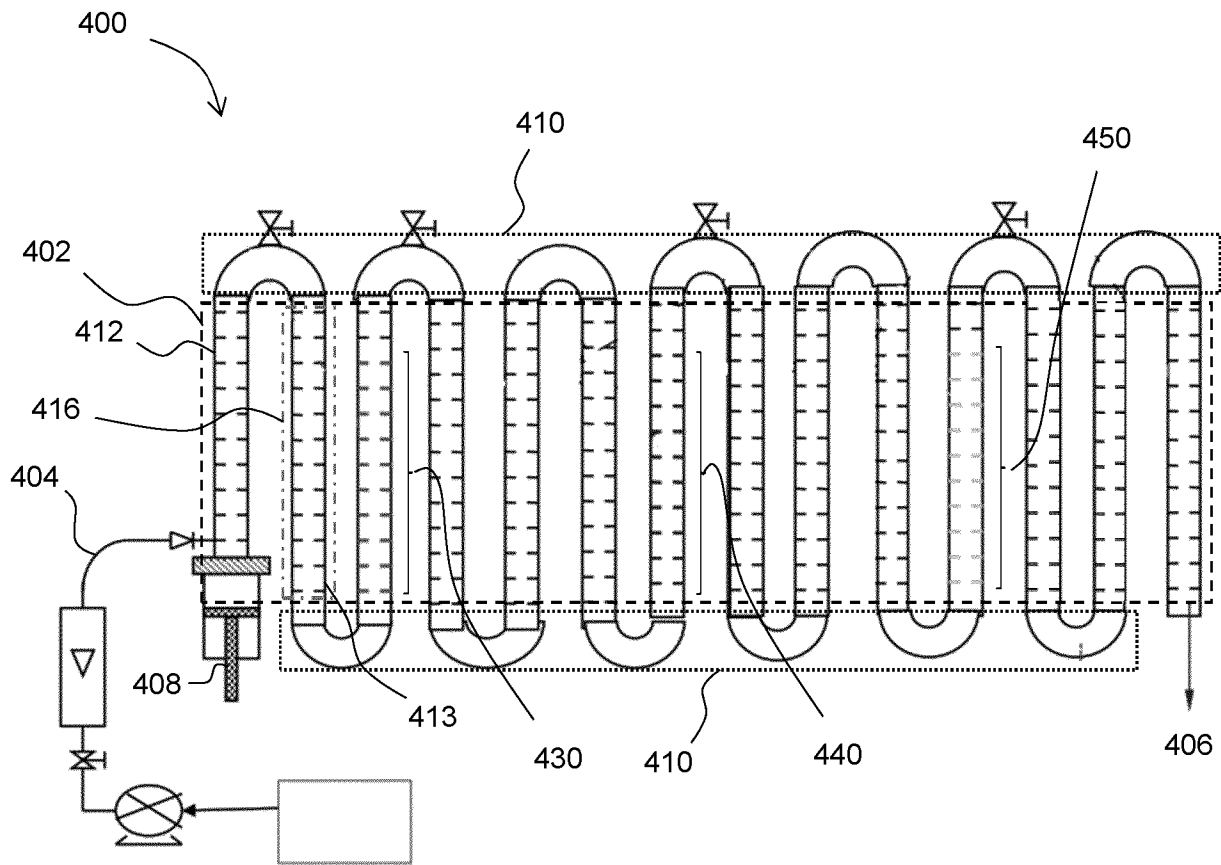


Fig. 7

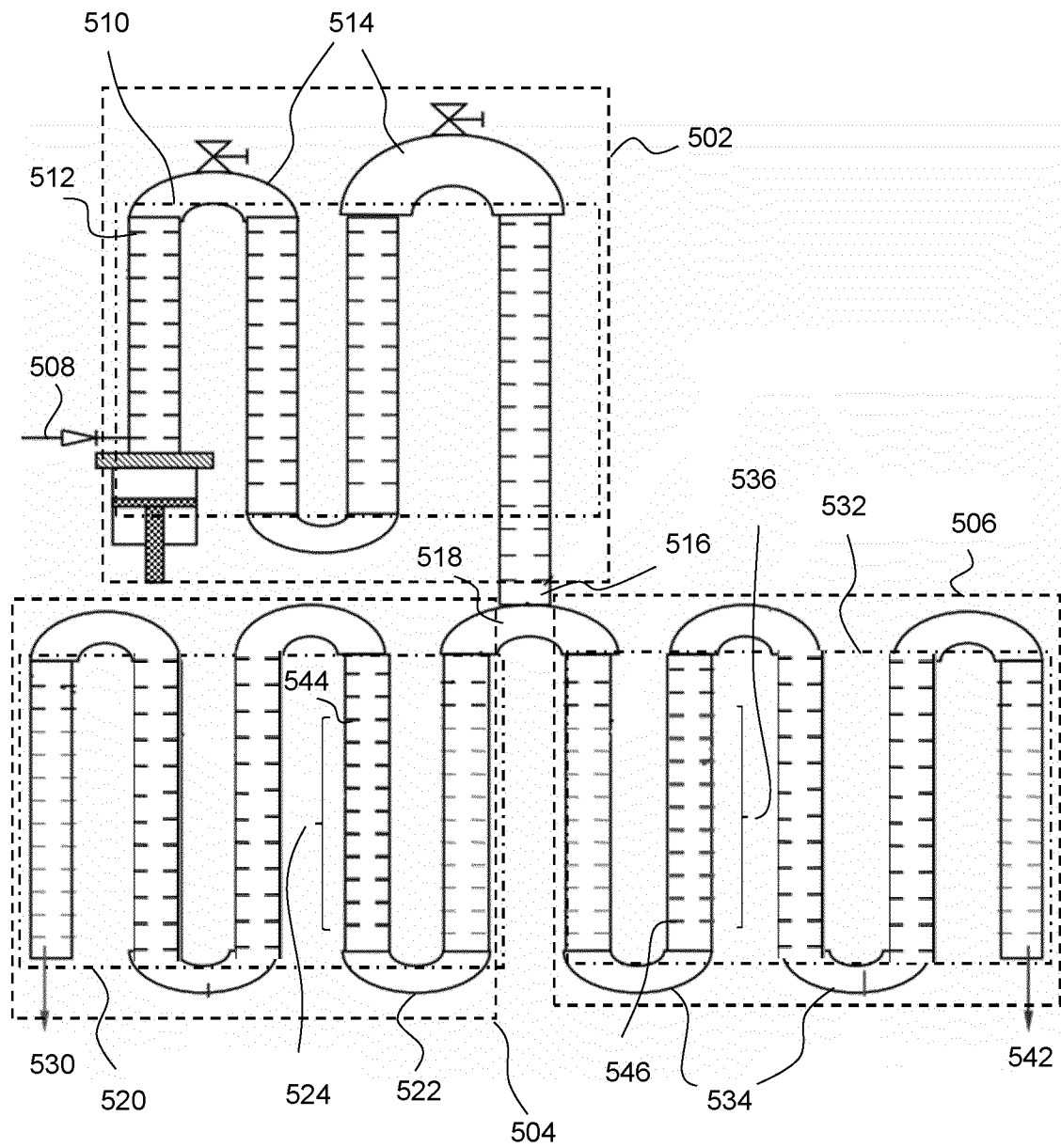


Fig. 8

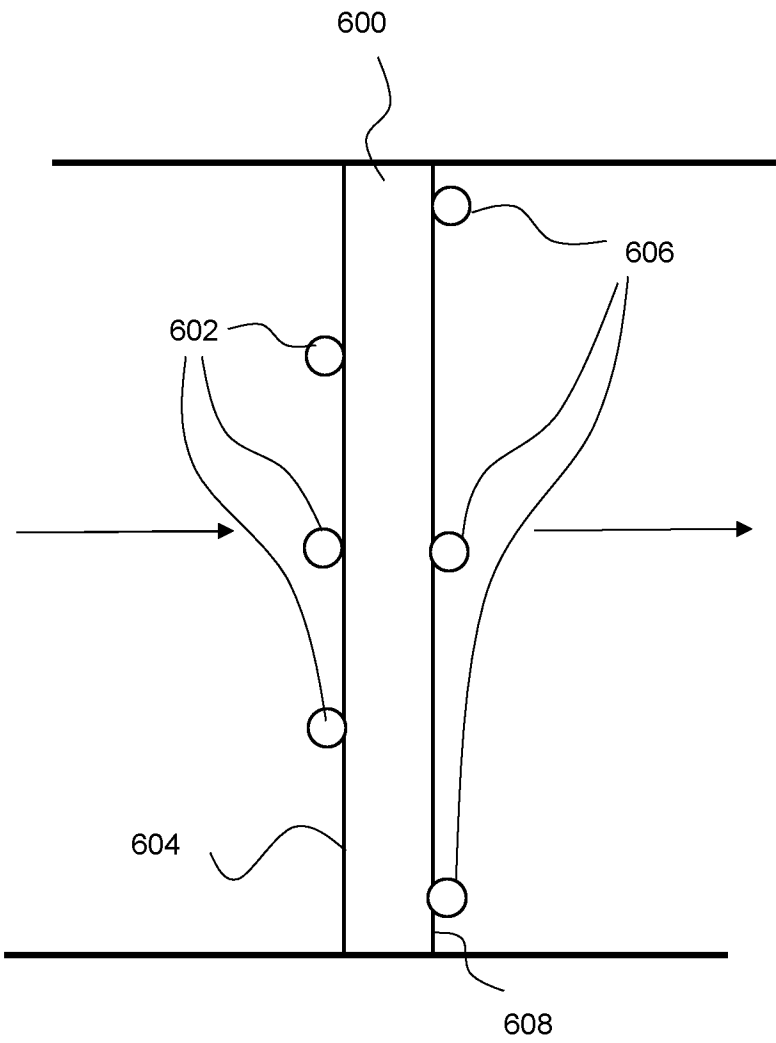


Fig. 9

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2021/069749

A. CLASSIFICATION OF SUBJECT MATTER
INV. B01J19/12 B01J19/24 B01J19/00
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)
B01J C02F

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	US 2017/355622 A1 (KIM JAE JO [KR]) 14 December 2017 (2017-12-14)	1-4,6,7, 11-17
Y	paragraphs [0026], [0027], [0040] - [0044]; figures 1-6	5,8-10, 18
X	US 2003/170151 A1 (HUNTER CHARLES ERIC [US] ET AL) 11 September 2003 (2003-09-11)	1-18
Y	paragraphs [0051], [0052] - [0063]; figures 3,4,6	5,8-10, 18
X	CN 205 838 772 U (SHAANXI SCI-TECH UNIV) 28 December 2016 (2016-12-28) figure 1	1,15
A	CN 206 951 170 U (FUJIAN HIGHSEA UNITED PHARMACEUTICAL CO LTD) 2 February 2018 (2018-02-02) figure 1	1-18



Further documents are listed in the continuation of Box C.



See patent family annex.

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Date of the actual completion of the international search

8 October 2021

Date of mailing of the international search report

20/10/2021

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/EP2021/069749

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