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(54) METHOD AND DEVICE FOR PRODUCING SIMPLE AND COMPOUND MICROMETRE-SIZED EMULSIONS

(57) The invention relates to a method for producing simple and compound emulsions having micrometre-sized, controllable diameters and coatings, using a device formed by elements having characteristic dimensions of the order of a millimetre. The emulsions are produced using the suction produced by the flow of a viscous liquid through the section of a millimetre-sized capillary tube. According to a parametric analysis, the liquid or the pair of liquids to be emulsified form a simple or compound steady capillary jet of micrometre diameter, by the action of the co-flow of the emulsifying liquid and the favourable pressure gradient produced. The jet breaks because of capillary instability, forming simple or compound monodisperse micro-drops. The invention disclosed in this description can be used in industrial sectors where the production of simple and compound, monodisperse, homogeneous emulsions having micrometric-sized, controllable diameters and coatings is an essential part of the process.

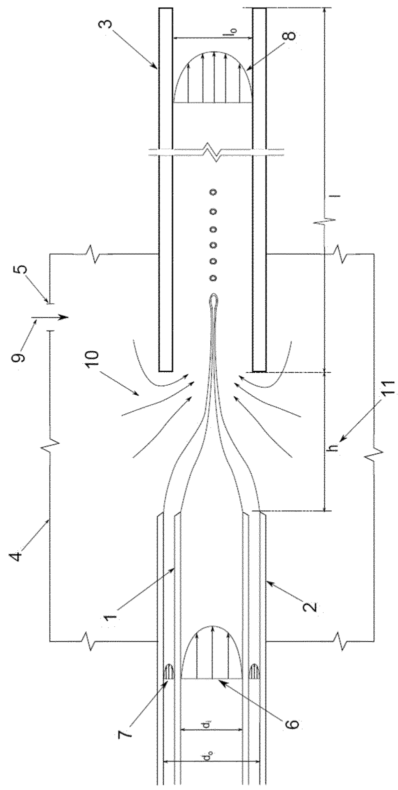

Figure 2

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Description

Object of the invention

[0001] The invention described in this specification pertains to the Scientific and Technical Area of Microfluidics. The study of microfluids is a multi-disciplinary field that includes elements from Physics, Chemistry, Engineering and Biotechnology. It conducts research on the behaviour of micro-scale fluids, wherein the motion regime is laminar, the gravity and the inertia are negligible, and the viscosity and the surface tension are dominant. This scientific and technical area comprises designing systems - devices and processes - for the controlled production of simple and compound steady jets that break up due to capillary forces, to produce simple and compound droplets which, in turn, are used for the production of micrometre- and submicrometre-sized fibres, tubes and capsules.

[0002] It is well-known that various sectors of activity in different industries are interested in the generation of simple and compound emulsions formed by micrometre-size droplets with or without a coating. For example, the food industry (encapsulation of additives), the phytosanitary industry, the cosmetics industry, the pharmaceutical industry (selective transport of active principles), the chemical industry (manufacturing of detergents), and the materials industry (manufacturing of optical devices by means of liquid crystals), amongst others. In general, the process and the device for generating emulsions of the invention described in this specification have applications in those industrial sectors wherein the production of simple and compound monodisperse, homogeneous emulsions having micrometre-sized, controllable diameters and coatings is an essential part of the process.

Prior art

[0003] In recent years, numerous studies, inventions and applications related to the microscopic monitoring of fluid streams have arisen, and particularly noteworthy amongst these studies and inventions are those that involve *free surfaces* or interfaces between two immiscible fluids in order to obtain microscopic structures (micro-droplets, micro-bubbles, micro-capsules, etc.) in a reproducible, robust manner. It is worth mentioning two peculiar phenomena/inventions which are representative of the generation of micro-jets: (i) *electrospraying*, or the production of liquid micro-jets by means of electrostatic forces, which has been known for centuries, and (ii) capillary flow focusing, which uses pressure forces (purely mechanical) and a "focusing" orifice to generate the jet. Depending on the geometry, both methods present a genuine axial symmetry (axially symmetric) in the area of the interface wherein the jet is produced, although there exist embodiments of flow-focusing devices with geometries that are practically two-dimensional (Anna et al., Appl. Phys. Lett. (2003), 82, 364-366, Gordillo et al., Phys. Fluids (2004), 16, 2828-2834).

[0004] In the case of *electrospraying*, the main disadvantages originate from (i) the inherent, inevitable dependency of the phenomenon on the electrical properties of the liquid, which greatly limits the physical-chemical parametric freedom of the method (even though some highly relevant applications have appeared in biochemistry - mass spectrometry for biological molecules -), (ii) the low productivity of the method (very low mass flow rate) and the difficulty in "scaling" or "multiplexing" it, and (iii) the mediocre robustness of the method due to its great dependency on the surface conditions and the sizes of the liquid feeding tubes.

[0005] Although the disadvantages associated with the dependency on the electrical properties of the fluid are eliminated in axially symmetric flow focusing, there are still problems related to the alignment of the feeding tubes with respect to the focusing orifices. In implementations of the 2D flow focusing type, the main problem originates from the wetting of the surfaces that confine the fluid to be dispersed.

[0006] The reason why the controlled production of micro- and submicrometric particles is one of the most active lines of research within the field of Fluid Mechanics is the large number of scientific and technological applications arising therefrom. For example, as noted in the article "Micro- and nanoparticles via capillary flows", Barrero and Loscertales, Annual Review of Fluid Mechanics (2007), 39, 89-106, the efficient absorption of new drugs by tissues and organs requires that the active product be confined in droplets with sizes substantially smaller than 10 microns. Emulsions formed by micrometre-sized droplets also have applications in many other fields, such as the food industry and materials science (manufacturing of optical devices by means of liquid crystals), amongst others. Currently, there is a significant number of processes that make it possible to obtain this type of micro-emulsions, with characteristic droplet sizes of about ten microns. However, there is only one technique that is able to efficiently reduce the size below this limit: that of simple and compound electrosprays (Loscertales, Barrero et al., Science (2002), 295, 5560). Here we present a technique that dispenses with the use of electric fields or surfactants, and which has such a simple geometry that it eliminates the focusing problems associated with devices of the three-dimensional flow focusing type, Gañán-Calvo and Gordillo, Phys. Rev. Lett. (2001), 87, 274501, or the problems associated with the wetting of the adjacent surfaces, as in the case of those techniques that use flow-focusing devices created by means of soft-lithography methods (Anna et al., Appl. Phys. Lett. (2003), 82, 364-366). In addition to having a more complex geometry, due to the fact that the stream to be dispersed must be focused through an orifice or a channel with a smaller size than that of the injection needle, these methods are not capable of systematically obtaining droplet sizes smaller than 5 microns.

[0007] In recent years, there has been increasing interest in the food, pharmaceutical and chemical industries in generating capsules that contain an active principle in the interior and which are externally coated with a flexible or rigid housing. Numerous patents have registered processes for the production of capsules or emulsions. In the case of capsules for food industry applications, some examples are patents AU754712 and EP1263451. In regards to applications in the chemical industry (primarily companies devoted to the manufacturing of detergents), EP1288287 and WO03002160. Pharmaceutical industry applications are the most widespread and have numerous registrations, amongst them WO03004003, WO0041740, US6514526, and EP1151746. In most of these examples, the capsules are generated by means of chemical substance deposition on the surface of a droplet containing an active compound or principle. The purpose of the external cover, which is usually elastic or rigid, is to protect the active principle contained inside. There are processes, initially patented at the University of Seville, which follow a different method for encapsulating liquids or generating emulsions. Both are based on causing two immiscible fluid streams to flow in a coaxial manner. It is well-known that cylindrical jets break up into droplets due to the growth of capillary instability, also known as Rayleigh instability. When this break-up takes place simultaneously in the inner and outer jets, droplets are generated which contain other smaller-sized droplets inside. If the external cover is made solid by means of any process (for example, by using a photopolymer that increases its viscosity or becomes rigid with ultraviolet light as the outer fluid), solid capsules may be generated. Emulsions may be generated in these devices by simply injecting a liquid, using any of the aforementioned processes, into a bath containing a liquid that is immiscible with the injected fluid. The first process belongs to the family of devices known as flow focusing, which is protected by patents US 6174469, US 6187214 and US 6450189. In this case, similarly to what occurs with atomisers of the flow focusing type, the two concentric fluid streams are accelerated due to the favourable pressure gradient that exists between a gas-pressurised chamber and the exterior. The diameters of the inner and outer jets decrease and, finally, thanks to a primarily capillary mechanism, the compound droplets are generated. These compound droplets may have diameters of the order of 100 microns. On the other hand, using the technology known as Y-Flow, the concentric inner and outer jets are accelerated using an electric field. The capsules generated may have nanometric sizes (the capsules produced using this process are the smallest ever generated) and are protected by patents P200100231, PCT ES02/00047 and PCT US 02/02787. However, this process has a disadvantage as compared to flow focusing devices; namely, that electric fields are necessary and the liquid flow rates are of the order of 1000 to 100 times lower than those that may be used in flow focusing technology.

Description of the figures

[0008] In order to supplement the description of the invention, and to contribute to a better understanding of its characteristics, the present descriptive specification includes, as an integral part thereof, two diagrams which show, for illustrative, non-limiting purposes, two prototype models for generating simple and compound emulsions (Fig. 1 and Fig. 2, respectively), as well as two sets of images that show the actual production of emulsions, both simple and compound (Fig. 3 and Fig. 4), with prototypes of both classes.

[0009] *Figure 1:* The figure consists of a diagram of a prototype device for generating simple emulsions.

[0010] The device is composed of the injection tube (1), designed to inject the liquid to be emulsified, which has an inner diameter d_i and is coaxially aligned with, and separated by a distance h from, the extraction tube (3), which has a length l and a square cross-section with an inner side l_o, and an outlet to the exterior, contained inside a discharge chamber (4) equipped with an orifice (5) designed for the inlet of the emulsifying liquid.

[0011] Moreover, in order to illustrate the generation of simple emulsions in the device by means of the process of the invention, the figure shows the velocity profile (6) of the liquid to be emulsified flowing inside the injection tube, and the streamlines (10) and the velocity profile (8) of the emulsifying liquid flowing in the surroundings of the inlet section of the extraction tube and downstream in the interior thereof, respectively.

[0012] *Figure 2:* The figure is a diagram of a prototype device for generating compound emulsions.

[0013] The different parts that make it up are a composite injection tube formed by an inner capillary tube (1), which has a diameter d_i, is designed to inject the inner liquid and is coaxially centered inside a second outer capillary tube (2), with a diameter d_o, through which the intermediate liquid is injected, and which is coaxially aligned with, and separated by a distance h from, the extraction tube (3), which has a length l and a square cross-section with an inner side l_o, and an outlet to the exterior, contained inside a discharge chamber (4) equipped with an orifice (5) designed for the inlet of the emulsifying liquid.

[0014] In addition, in order to illustrate the generation of compound emulsions in the device by means of the process of the invention, the figure shows the velocity profile of the inner liquid (6) flowing inside the inner injection tube, the velocity profile of the intermediate liquid (7) flowing inside the outer injection tube, and the streamlines (10) and the velocity profile (8) of the emulsifying liquid flowing in the surroundings of the inlet section of the extraction tube and downstream in the interior thereof, respectively.

[0015] *Figure 3:* The set of images in the figure shows the actual production of simple emulsions by means of the process of the invention in a prototype device of the invention with different geometrical configurations of the components thereof.

[0016] The outer liquid is silicone oil with a viscosity of 100 cSt and the inner liquid is distilled water (viscosity of 1 cSt). The flow rate of the outer liquid is 900 ml/h and the flow rate of the inner liquid is 0.5 ml/h, in all four cases.

[0017] The geometrical configuration of the devices in each of the images in the series is as follows: 3.1.- l_o = 1 mm, d_i = 450 μm and h = 0.5l_o; 3.2.- d_i = 450 μm and h = 1.0 l_o; 3.3.- d_i = l_o and h = 1.0 l_o; 3.4.- d_i = l_o and h = 1.5 l_o. The inner dimensions of the discharge chamber in the four prototypes are 3 cm x 3 cm x 3 cm.

[0018] *Figure 4:* The set of images in the figure shows the production of compound emulsions by means of the process of the invention in a prototype device of the invention, with the following geometrical configuration of the elements that compose it: d_i = 700 μm, d_o = 1.0 mm, l_o = 1.0 mm and h = 1.70 mm. The inner dimensions of the discharge chamber are 3 cm x 3 cm x 3 cm.

[0019] The outer liquid is silicone oil with a viscosity of 1000 cSt, the intermediate liquid is a mixture of glycerol and distilled water, with a viscosity of 400 cSt at 25°C, and the inner liquid is silicone oil with a viscosity of 10 cSt.

[0020] The flow rate of the outer liquid is 200 ml/h and the flow rate of the intermediate liquid is 2.00 ml/h. The flow rate of the inner liquid q_i in each of the images in the series is as follows: 4.1.- q_i = 0.10 ml/h; 4.2.- q_i = 0.30 ml/h; 4.3.- q_i = 0.50 ml/h; 4.4.- q_i = 0.70 ml/h.

Description of the invention

[0021] The object of the present invention is a process for generating simple and compound emulsions, from the formation of a simple or compound, as applicable, capillary micro-jet when a liquid or two immiscible or barely miscible liquids that flow coaxially are suctioned by means of a viscous outer liquid, which is immiscible or barely miscible with the simple or compound liquid to be emulsified, and which flows at the suitable velocity, as well as the device wherein and with which to perform said process.

[0022] According to one parametric determination, the specifications whereof are the essence of the process of the invention, in the case of the generation of simple emulsions, the suctioned liquid forms a steady capillary jet with a micrometre-sized, controllable diameter, due to the action of the co-flowing outer liquid and the favourable pressure gradient that it produces. This simple jet breaks up due to capillary instability, to produce droplets of a micro- and submicrometric size, with a limited size distribution.

[0023] In the case of the generation of compound emulsions, the suction causes a compound capillary jet, due to the action of the co-flowing outer liquid and the favourable pressure gradient produced on the intermediate liquid and, similarly, of the latter on the inner liquid. The interior of this compound jet breaks up into droplets due to capillary instability, which induces break-up of the intermediate liquid, to produce the coating of the inner liquid droplets and, consequently, the formation of compound micrometre-sized droplets.

[0024] The parametric determination in the generation of compound emulsions allows for control of both the size of the inner liquid droplets and the thickness of the coating with the intermediate liquid.

[0025] The process of the invention may be applied to all those technological demands that require the generation of simple monodisperse, micrometre-sized emulsions of the phase to be dispersed, as well as to those technological demands that require the generation of compound homogeneous emulsions, the dispersed phase whereof requires micrometre-sized, controllable droplet diameters and coating thicknesses.

[0026] The object of the present invention is a process and a device for generating simple and compound micrometre-sized emulsions.

[0027] The device that generates the emulsions is formed by the following elements: a discharge chamber with dimensions of the order of one centimetre, the interior whereof contains two coaxially aligned tubes, an extraction tube, with a diameter or inner side l_o of the order of one millimetre and a length l, and a simple capillary injection tube, with an inner diameter d_i of the order of one millimetre, or a compound capillary injection tube, formed by two concentric capillary tubes, the exterior whereof have an inner size d_o of the order of one millimetre. The outlet section of the simple or compound capillary tube is separated from the inlet section of the extraction tube by a distance h of the order of one millimetre. The geometrical dimensions d_i, d_o, l_o and h of the elements of the device constitute its geometrical configuration.

[0028] The circulation of a viscous outer liquid l_e, from the discharge chamber to the exterior through the extraction tube, produces the suction of the simple liquid l_i, injected into the chamber through the capillary tube where it flows, in the surroundings of the inlet section, to form a steady capillary jet, which narrows down downstream, to reach a constant micrometre-sized diameter. This jet is formed due to the action of the co-flowing outer fluid and the favourable pressure gradient that the outer fluid exerts on the simple capillary jet. This simple jet breaks up, due to capillary instability, into droplets of the same order of magnitude as that of the jet that originates them, to produce a simple monodisperse micrometre-sized emulsion.

[0029] If a composite capillary injection tube is used, the suction produces a capillary jet composed of the intermediate liquid, which forms the outermost layer of the jet, and the inner liquid, which is at the centre of the compound jet. The compound jet is formed due to the action of the co-flowing outer fluid and the favourable pressure gradient that the outer fluid exerts on the intermediate fluid. Likewise, the action of the outer co-flow and the favourable outer pressure gradient, jointly with the capillary pressure gradients exerted by the intermediate flow, lead to the formation of an inner liquid capillary jet which, due to capillary instability, breaks up into droplets that induce break-up of the intermediate liquid, thereby originating the coating thereof and, consequently, the formation of compound droplets, to produce a compound monodisperse emulsion having controllable, micrometre-sized inner and outer diameters and coating thickness.

[0030] The viscosities of the inner, intermediate and outer liquids, and the surface tensions between the inner and outer liquids, in the case of the generation of simple emulsions, and between the outer and intermediate liquids, and the intermediate and inner liquids, in the case of the generation of compound emulsions, are essential physical properties for the production of the emulsions described in this invention and constitute what we will call the dimensional configuration thereof.

[0031] The flow rates of the inner, intermediate and outer liquids, q_i, q_m and q_e, respectively, or, alternatively, the flow rates of the inner and intermediate liquids, q_i and q_m, respectively, and the manometric discharge pressure of the outer fluid Δp_e, which is related to the outer flow rate q_e according to the formula $\Delta p_e = Kq_e$, K being a constant that depends solely on the geometry of the device, are the operating control variables or parameters in the generation of emulsions produced by means of this technology and constitute what we will call the operational configuration thereof.

[0032] The process of the present invention involves the adequate selection of the aforementioned geometrical, dimensional and operating parameters or variables, i.e. the specification of the geometrical, dimensional and operational configurations.

[0033] The specification of the geometrical, dimensional and operational configurations define a parametric determination or a mode of production.

[0034] The following formulations express the physics of the phenomenon whereon the technology described above is grounded:

(i).- the characteristic Reynolds number of the outer and inner streams is lower than 1 and lower than 10, respectively; $\rho_o U_o D/\mu_o < 1$ and $\rho_i Q_i/(D\mu_o) < 10$, where U_o is the velocity of the outer fluid at the centre of the extraction tube;

(ii).- the capillary number is greater than 0.75; $\mu_o U_o/\sigma > 0.75$;

(iii).- the flow rate of the inner liquid and the velocity of the outer liquid are such that $[4Q_i/(\pi\, Uo)]^{1/2} < 1$ mm.

[0035] If the selected parametric determination or mode of production meets all of the aforementioned numerical ratios, the generation of simple emulsions by means of this device and this process is feasible. In this case, the scaling law that predicts the diameter of the droplets that form the emulsion is the following: $0.25[4Q_i/(\pi U_o)]^{1/2} < d < 4[4Q_i/(\pi U_o)]^{1/2}$.

[0036] The invention described in this specification has applications in those industrial sectors wherein the production of simple and compound monodisperse, homogeneous emulsions with controllable, micrometre-sized diameters and coatings is an essential part of the process.

Embodiment of the invention

Embodiment of the invention for generating simple emulsions.

[0037] Image 3.2 of Figure 3 of the present descriptive specification shows the actual production of simple emulsions by means of this invention. Moreover, Figure 1 presents a diagram of the device used.

[0038] The prototype is composed of a discharge chamber (4) with inner dimensions of 3 cm x 3 cm x 3 cm, which contains, in the interior thereof, a glass extraction tube (3) that has a square cross-section, with an inner side l_o = 1 mm and a length l = 4 cm, and a stainless steel simple capillary injection tube (1), which has an inner diameter d_i = 450 μm. The spacing between both tubes is h = 1 mm.

[0039] The discharge chamber contains two pairs of windows, in order to allow for real-time control of the production of simple emulsions.

[0040] The outer and inner liquids used in this embodiment of the invention for generating simple emulsions are 100-cSt silicone oil and distilled water (with a viscosity of 1 cSt), respectively, with a surface tension between them of 40 mN/m.

[0041] The flow rates of the outer and inner liquids, q_e and q_i, were varied between 450 ml/h and 1400 ml/h, and 0.1 ml/h and 10 ml/h, respectively, to produce emulsions with droplets sizes ranging between 10 μm and 100 μm, and a production frequency ranging between 1000 Hz and 10000 Hz.

[0042] Image 3.2 of Figure 3 illustrates the actual simple emulsion produced according to the aforementioned specifications by injecting flow rates q_e = 1150 ml/h and q_i = 0.5 ml/h. The rest of the images in the series, i.e. images 3.1, 3.3 and 3.4 of Figure 3, show the actual simple emulsions according to different geometrical configurations, without varying the rest of the specifications of the mode of production described above.

[0043] In order to evaluate the versatility of both the process and the device for generating simple emulsions, as well as the range of the parametric determination, emulsions were produced by modifying:

(i) the different variables that characterise the geometrical configuration of the elements thereof (d_o, h, l_o and l);

(ii) the viscosity of the outer and inner liquids in the ranges between 100 cSt and 1000 cSt, and between 1 cSt and 1 cSt, respectively, and the surface tension between them in the ranges between 1 mN/m and

40 mN/m, replacing some liquids with others having different properties;

(iii) and the concrete, specific values of the operating control parameters for the production of simple emulsions, i.e. of the outer and inner liquid flow rates, in the ranges between 100 ml/h and 4000 ml/h, and 0.01 ml/h and 100 ml/h, respectively.

[0044] In all cases, a parameter window was found wherein the production of the emulsions is effective, continuous, uniform and stable.

Embodiment of the invention for generating compound emulsions.

[0045] Image 4.2 of Figure 4 of the present descriptive specification shows the actual production of compound emulsions by means of this invention. Moreover, Figure 2 shows a diagram of the device used.

[0046] The prototype is composed of a discharge chamber with inner dimensions of 3 cm x 3 cm x 3 cm, which contains, in the interior thereof, a glass extraction tube (4) that has a square cross-section, with an inner side l_o = 1 mm and a length l = 4 cm, and a composite injection tube, formed by a capillary tube (1) through which the inner liquid ciruclates, with a diameter d_i = 450 μm, contained and coaxially centered inside a second capillary tube (3), which has an inner diameter d_o = 1.20 mm and through which the intermediate liquid flows. The spacing between both tubes is h = 1 mm.

[0047] The discharge chamber contains two pairs of windows, in order to allow for real-time control of the production of simple emulsions.

[0048] The outer, intermediate and inner liquids used in this embodiment of the invention for generating compound emulsions are 1000-cSt silicone oil, a mixture of glycerin and distilled water, with a viscosity of 400 cSt at 25°C, and silicone oil with a viscosity of 10 cSt, respectively, with a surface tension between both pairs of liquids (outer and intermediate liquids, and intermediate and inner liquids) of 50 mN/m.

[0049] The flow rates of the outer, intermediate and inner liquids, q_e, q_m and q_i, were varied between 100 ml/h and 200 ml/h, 0.1 ml/h and 10.0 ml/h, and 0.1 ml/h and 10 ml/h, respectively, to produce compound emulsions with droplets having inner diameters ranging between 10 μm and 100 μm, and coatings ranging between 10 μm and 40 μm, with a production frequency ranging between 100 Hz and 2000 Hz.

[0050] Image 4.2 of Figure 4 shows the production of a compound emulsion according to the aforementioned specifications, in the case of q_e = 200 ml/h, q_m = 2 ml/h and q_i = 0.5 ml/h. The rest of the images in the series, i.e. images 4.1, 4.3 and 4.4 of Figure 4, show the actual production of compound emulsions with different inner liquid flow rates, ranging between 0.1 ml/h and 0.7 ml/h, without varying the rest of the specifications of the mode of production described above.

[0051] In order to evaluate the versatility of both the process and the device for generating compound emulsions, as well as the range of the parametric determination, emulsions were produced by modifying:

(i) the different variables that characterise the geometrical configuration of the elements thereof (d_o, h, l_o and l);

(ii) the viscosity of the outer liquid, in the range between 100 cSt and 1000 cSt, the viscosity of the intermediate liquid between 50 cSt and 1000 cSt, the viscosity of the inner liquid between 1 cSt and 20 cSt, and the surface tension between both liquids ranging between 20 mN/m and 50 mN/m, replacing some liquids with others having different properties;

(iii) and the concrete, specific values of the operating control parameters for the production of the compound emulsions, i.e. the outer, intermediate and inner liquid flow rates, in the ranges between 100 ml/h and 4000 ml/h, 0.01 ml/h and 10 ml/h, and 0.01 ml/h and 100 ml/h, respectively.

[0052] In all cases, a parameter window was found wherein the production of the emulsions is effective, continuous, uniform and stable.

[0053] There are numerous materials with which the different elements that compose the generator of both simple and compound emulsions may be manufactured (metal, plastic, ceramics, glass), based primarily on the specific application of the device.

[0054] Any continuous feeding methods for the outer, intermediate and inner liquids may be used (pressure reservoirs, syringe pumps, etc.).

[0055] The aforementioned embodiments of the invention describe the process and the device, or individual cell, for generating simple or compound emulsions with the production limitations involved. If an increase in production is required, the device may be multiplexed. In this case, the flow rate of the inner liquid, or the intermediate and inner liquids, as applicable, should be as homogeneous as possible across the different cells, which may require discharge through multiple capillary needles, porous media, or any other medium capable of distributing a homogeneous flow rate across different feeding points.

Claims

1. Device for generating simple emulsions, hereinafter DGSE, composed of an injection tube (1), which has an inner diameter d_i, is coaxially aligned with, and separated by a distance h from, an extraction tube (3), which has a length l and a circular or square cross-section with a diameter or inner side l_o, and

an outlet to the exterior, contained inside a discharge chamber (4), **characterised in that**

1 a.- d_i ranges between 0.05 mm and 4 mm;
1 b.- l_o and l range between 0.05 mm and 4 mm, and 10 mm and 100 mm, respectively; and
1 c.- h ranges between 0 mm and 4 mm.

2. DGSE according to claim 1, **characterised in that**

2a.- d_i ranges between 0.40 mm and 1.40 mm;
2b.- l_o and l range between 0.70 mm and 1.20 mm, and 20 mm and 50 mm, respectively; and
2c.- h ranges between 0.50 mm and 1.50 mm.

3. Device for generating compound emulsions, hereinafter DGCE, composed of a composite injection tube formed by an inner capillary tube (1), which has an inner diameter d_i, is coaxially centered inside a second outer capillary tube (2), which has an inner diameter d_o, is coaxially aligned with, and separated by a distance h from, an extraction tube (3), which has a length l and a circular or square cross-section with a diameter or inner side l_o, and an outlet to the exterior, contained inside a discharge chamber (4), **characterised in that**

3a.- d_i ranges between 0.10 mm and 1.40 mm;
3b.- d_o ranges between 0.40 mm and 4 mm;
3c.- l_o and l range between 0.05 mm and 4 mm, and 10 mm and 100 mm, respectively; and
3d.- h ranges between 0 mm and 4 mm.

4. DGCE according to claim 3, **characterised in that**

4a.- d_i ranges between 0.30 mm and 0.70 mm;
4b.- d_o ranges between 0.70 mm and 1.40 mm;
4c.- l_o and l range between 0.70 mm and 1.20 mm, and 20 mm and 50 mm, respectively; and
4d.- h ranges between 0.50 mm and 1.50 mm.

5. Device for generating simple or compound emulsions, hereinafter DGE, according to claims 1 to 4, **characterised in that** the different parts that compose it are manufactured with various materials, such as metal, plastic, ceramic, glass or others.

6. DGE according to claims 1 to 5, **characterised in that** the discharge chamber is equipped with windows that allow for real-time control of the production of emulsions, as well as for studying the physical phenomenon whereon it is grounded.

7. Multiplexed device for generating emulsions, **characterised in that** each of the individual cells that compose it has the technical characteristics described in claims 1 to 6.

8. Simple emulsions of any two immiscible or barely miscible fluids, **obtained** by means of a device for generating emulsions having the technical characteristics described in claims 1, 2, 5, 6 and 7.

9. Compound emulsions of any two immiscible or barely miscible fluids, emulsified by means of any fluid that is immiscible or barely miscible with the exterior of those mentioned above, **obtained** by means of a device for generating emulsions having the technical characteristics described in claims 3, 4, 5, 6 and 7.

10. Process for generating simple micrometre-sized emulsions, hereinafter PGSE, by means of the effect of a co-flowing emulsifying liquid with a viscosity greater than that of the liquid to be emulsified, on the interface that they form, both being immiscible or barely miscible liquids, **characterised in that**

10a.- the viscosity of the liquid to be emulsified ranges between 1 cSt and 1000 cSt, and the viscosity of the emulsifying liquid ranges between 1 cSt and 10000 cSt;
10b.- the flow rate of the liquid to be emulsified ranges between 0.01 ml/h and 100 ml/h, and the flow rate of the emulsifying liquid ranges between 1 ml/h and 4000 ml/h;
10c.- the process is implemented using a device for generating simple emulsions which has the technical characteristics described in claims 1, 2, 5 and 6;
10d.- the process is implemented using a DGSE which has the technical characteristics described in claim 7, the flow rates described in claim 10b being those corresponding to an individual cell of the multiplexed device.

11. PGSE according to claim 10, **characterised in that**

11 a.- the viscosity of the liquid to be emulsified ranges between 1 cSt and 50 cSt, and the viscosity of the emulsifying liquid ranges between 50 cSt and 1000 cSt;
11 b.- the flow rate of the liquid to be emulsified ranges between 0.1 ml/h and 10 ml/h, and the flow rate of the emulsifying liquid ranges between 50 ml/h and 1000 ml/h.

12. Process for generating compound emulsions with micrometre-sized diameters and coatings, hereinafter PGCE, using two co-flowing immiscible or barely miscible liquids, by means of the effect, on the interface that they form, of a third co-flowing liquid which has greater viscosity than that of the exterior of those mentioned above, both liquids being immiscible or barely miscible, **characterised in that**

12a.- the viscosity of the inner liquid (l_i) of the compound jet to be emulsified ranges between 1 cSt and 1000 cSt, the viscosity of the outer liquid of the compound jet (l_m) to be emulsified ranges between 1 cSt and 1000 cSt, and the viscosity of the emulsifying liquid (l_e) ranges between 1 cSt and 1000 cSt;

12b.- the flow rate of the inner liquid of the compound jet to be emulsified ranges between 0.01 ml/h and 100 ml/h, the flow rate of the outer liquid of the compound jet to be emulsified ranges between 0.001 ml/h and 1000 ml/h, and the flow rate of the emulsifying liquid ranges between 1 ml/h and 4000 ml/h;

12c.- the process is implemented using a device for generating compound emulsions which has the technical characteristics described in claims 3, 4, 5 and 6;

12d.- the process is implemented using a DGCE which has the technical characteristics described in claim 7, the flow rates described in claim 12b being those corresponding to an individual cell of the multiplexed device.

13. PGCE according to claim 12, **characterised in that**

13a.- the viscosity of the liquid l_i ranges between 1 cSt and 10 cSt, the viscosity of the liquid l_m ranges between 10 cSt and 100 cSt, and the viscosity of the liquid l_e ranges between 100 cSt and 1000 cSt;

13b.- the flow rate of the liquid l_i ranges between 0.1 ml/h and 10 ml/h, the flow rate of the liquid l_m ranges between 0.01 ml/h and 100 ml/h, and the flow rate of the liquid l_e ranges between 50 ml/h and 1000 ml/h.

14. PGCE according to claim 12, **characterised in that**

14a.- the viscosity of the liquid l_i ranges between 1 cSt and 10 cSt, the viscosity of the liquid l_m ranges between 100 cSt and 400 cSt, and the viscosity of the liquid l_e ranges between 400 cSt and 1000 cSt;

14b.- the flow rate of the liquid l_i ranges between 0.1 ml/h and 10 ml/h, the flow rate of the liquid l_m ranges between 0.01 ml/h and 100 ml/h, and the flow rate of the liquid l_e ranges between 50 ml/h and 1000 ml/h.

15. PGCE according to claim 12, **characterised in that**

15a.- the viscosity of the liquid l_i ranges between 1 cSt and 10 cSt, the viscosity of the liquid l_m ranges between 400 cSt and 700 cSt, and the viscosity of the liquid l_e ranges between 700 cSt and 1000 cSt;

15b.- the flow rate of the liquid l_i ranges between 0.1 ml/h and 10 ml/h, the flow rate of the liquid l_m ranges between 0.01 ml/h and 100 ml/h, and the flow rate of the liquid l_e ranges between 50 ml/h and 1000 ml/h.

16. Simple emulsions of any two immiscible or barely miscible fluids, **obtained** by means of a process for generating emulsions which has the technical characteristics described in claims 10 and 11.

17. Compound emulsions of any two immiscible or barely miscible fluids, emulsified by means of any fluid that is immiscible or barely miscible with the exterior of those mentioned above, **obtained** by means of a process for generating emulsions which has the technical characteristics described in claims 12, 13, 14 and 15.

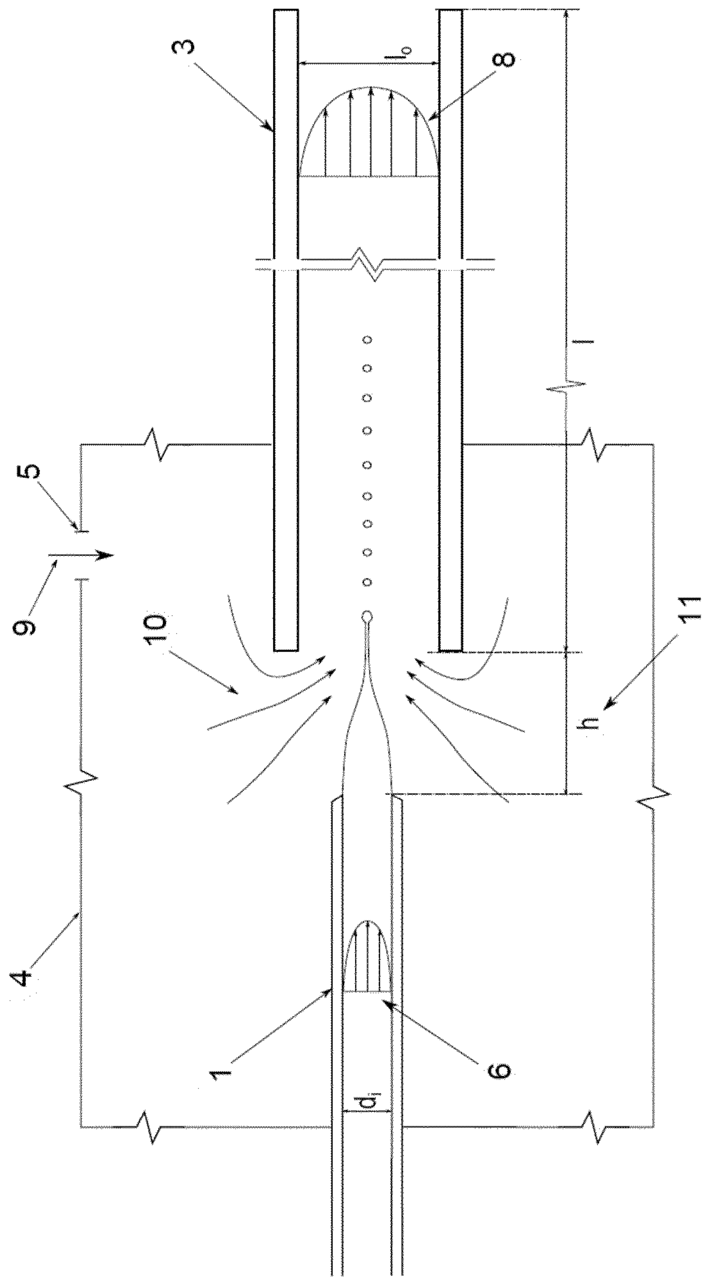

Figure 1

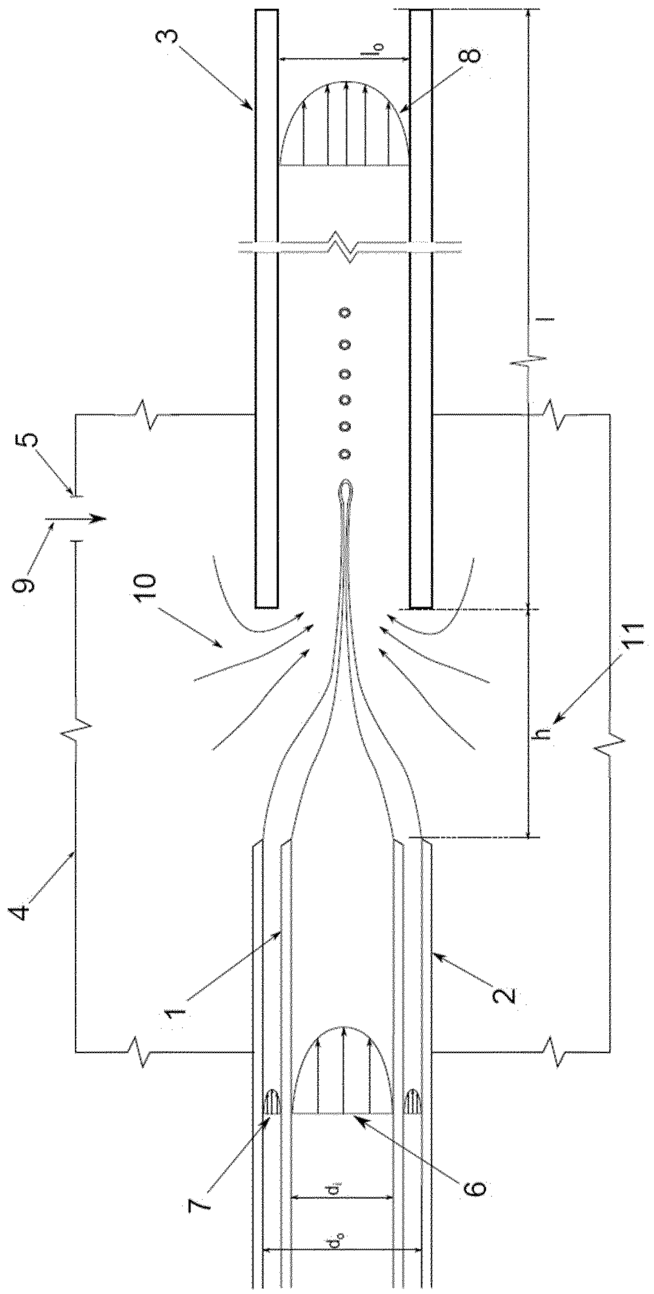

Figure 2

INTERNATIONAL SEARCH REPORT

International application No.
PCT/ES2015/000113

A. CLASSIFICATION OF SUBJECT MATTER

B01F3/08 (2006.01)

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)
B01F

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)

EPODOC, INVENES, WPI,TXTE, XPESP

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	VLADISAVLJEVIC et al. Industrial lab-on -a chip: Design,applications and scale-up for drug discovery and delivery. Advanced Drug Delivery Reviews, 2013, Vol.65, pages 1626 a 1663, figures 3.2.1 and 3.2.2	1-17
A	US 2009131543 A1 (WEITZ ET AL.) 21.05.2009, paragraphs[46 - 62]; figures 1, 17	1-17
A	SHAH et al. Designer emulsions using microfluidics.Materialstoday, 2008, April, Vol.11, N,4, pages 18 a 27	1-17
A	WO 2013006661 A2 (PRESIDENT AND FELLOWS OF HARVARD COLLEGE) 10.01.2013, page 9, line 14 - page 13, line 23; figures 2 - 6A	1-17

☐ 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 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	Date of mailing of the international search report
20/01/2016	**(21/01/2016)**
Name and mailing address of the ISA/ OFICINA ESPAÑOLA DE PATENTES Y MARCAS Paseo de la Castellana, 75 - 28071 Madrid (España) Facsimile No.: 91 349 53 04	Authorized officer A. Rua Aguete Telephone No. 91 3498518

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.
PCT/ES2015/000113

Patent document cited in the search report	Publication date	Patent family member(s)	Publication date
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		EP2248578 A1	10.11.2010
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		US2014220350 A1	07.08.2014
		CN103764265 A	30.04.2014
		EP2729238 A2	14.05.2014

Form PCT/ISA/210 (patent family annex) (January 2015)

REFERENCES CITED IN THE DESCRIPTION

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- **LOSCERTALES, BARRERO et al.** *Science,* 2002, vol. 295, 5560 **[0006]**
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