DEVICE AND METHOD FOR PRODUCING A FLUID MIXTURE

The invention generally relates to a device for producing a fluid mixture and to a corresponding method. A fluid mixture may be a mixture of two fluids (liquids), but, within the meaning of the present application, may in particular also be a dispersion. A dispersion is a heterogeneous mixture of at least two substances which do not dissolve in one another or dissolve only to a small extent. In this case, a dispersed phase is distributed in a dispersion medium. In the present case, the device and the method serve in particular for producing a suspension, in which a liquid serves as the dispersion medium and a solid serves as the dispersed phase, or an emulsion, in which both the dispersed phase and the dispersion medium are liquid.

The invention is concerned with combining or mixing at least three separate fluids with one another. Depending on the type of fluids used, particles may form during the process, which particles are distributed, for example, in a liquid, such that a suspension is produced overall. The particles may be regarded as a solid which forms the dispersed phase. In many applications, particles having a small diameter are desirable. Particles in the nanometer size range are also referred to as nanoparticles. These nanoparticles may be relevant in chemical, biochemical or pharmaceutical processes. The invention relates in particular to a device and a method for producing such nanoparticles or particles in the micrometer range.

One example of suspensions of pharmaceutical significance is liposomally formulated medicinal products. In this case, the particle or vesicle size and the polydispersity index constitute key physical parameters which influence the therapeutic index of liposomally formulated medicinal products. It is known that smaller liposomes exhibit slower blood clearance and thus increase the bioavailability of medicinal products. There is therefore a need to be able to produce particles in the pharmaceutically required size with high quality, that is to say with a low polydispersity index.

Devices which are referred to as microfluidic devices or microfluidic mixers are known for producing nanoparticles. Microfluidic mixers generally have very small microchannels which produce low Reynolds numbers and therefore generally a laminar flow without appreciable turbulence, which is disadvantageous for mixing fluids. In this case, the flow channels are relatively long in relation to the cross-sectional dimension. These channels are expensive to manufacture and may readily become clogged during operation. Moreover, use of these channels in mass production may be difficult or even impossible.

The object underlying the present invention is to provide a device and a method for producing a fluid mixture (with nanoparticles having a specific particle size and a defined size distribution) which are as little susceptible to malfunction as possible. In particular, the object is also to provide a device and a method which can be used both on a laboratory scale (i.e. a few nanolitres per minute) and in mass production (i.e. several liters per minute).

According to the invention, this object is achieved by a device having the features of claim 1. Configurations of the invention are specified in the dependent claims.

Accordingly, the device for producing a fluid mixture initially comprises a first mixing chamber having a first inlet opening, via which a first fluid can be introduced into the first mixing chamber along a first fluid flow direction, a second inlet opening, via which a second fluid can be introduced into the first mixing chamber along a second fluid flow direction, and an outlet opening, via which an intermediate fluid mixture comprising the first fluid and the second fluid can be discharged along a fluid mixture flow direction. An outlet channel is formed (immediately) upstream of the outlet opening, the cross-sectional area of which, defined transversely to the fluid mixture flow direction, decreases along the fluid mixture flow direction toward the outlet opening. The outlet channel forms a downstream end section of the first mixing chamber. The formation of so-called dead-water regions in the first mixing chamber can be avoided by means of the outlet channel.

The device further comprises a second mixing chamber having a first inlet opening, via which the intermediate fluid mixture can be introduced into the second mixing chamber along the fluid mixture flow direction, a second inlet opening, via which a third fluid can be introduced (stationarily) into the second mixing chamber along a third fluid flow direction, and an outlet opening, via which the fluid mixture comprising the first fluid, the second fluid and the third fluid can be discharged. The second mixing chamber is consequently arranged downstream of the first mixing chamber, wherein the first mixing chamber and the second mixing chamber are fluidically connected in such a manner that the intermediate fluid mixture exiting from the outlet opening of the first mixing chamber enters the second mixing chamber via the first inlet opening thereof.

Supply devices may be provided for introducing the fluids into the mixing chambers. Specifically, the device comprises a first supply device which is fluidically connected to the first mixing chamber via the first inlet opening and is configured to conduct the first fluid into the first mixing chamber along the first fluid flow direction (in a manner variable over time and in space).

In this case, the first supply device comprises a fluidic component having an outlet opening which is fluidically connected to the first inlet opening of the first mixing chamber. In particular, the outlet opening of the fluidic component may correspond to the first inlet opening of the first mixing chamber.

The fluidic component comprises at least one means for specifically changing the direction of the first fluid flowing through the fluidic component. Alternating vortices, for example produced by colliding fluid flows within the fluidic component, or an obstruction body within the fluidic component, may be used for specifically changing the direction. In the case of this type of means for producing the specific change in direction, sufficient space must be provided for producing and subsequently dissipating the vortex structures. In particular, this at least one means is provided and configured to form a spatial oscillation of the first fluid at the outlet opening. In one embodiment, the means for specifically changing the direction of the first fluid may be configured to cause an oscillation of the first fluid in an oscillation plane.

The first fluid is thus not conducted into the first mixing chamber as a (quasi-)stationary flow, but as an oscillating fluid flow which moves periodically in a manner variable over time. In addition to a longitudinal flow component along the first fluid flow direction, the first fluid also has a lateral flow component (transverse to the first fluid flow direction) which varies over time. Turbulence can thereby be produced in the first mixing chamber, such that a high mixing quality can be achieved in the first mixing chamber. Accordingly, the first fluid enters the first mixing chamber from the first supply device in an oscillating or dynamic manner. As a result, the first fluid acquires a continuously changing flow-velocity component transverse to its main flow direction (lateral flow component or first fluid flow direction).

The device further comprises a first interaction channel which is arranged between the first mixing chamber and the second mixing chamber. The first interaction channel connects the outlet opening of the first mixing chamber and the first inlet opening of the second mixing chamber to one another and has a cross-sectional area transverse to the fluid mixture flow direction which is constant at least over a section immediately downstream of the outlet opening of the first mixing chamber. Accordingly, the outlet opening of the first mixing chamber or the inlet opening of the first interaction channel represents the downstream end of the outlet channel. Since the cross-sectional area of the outlet channel decreases along the fluid mixture flow direction toward the outlet opening, the cross-sectional area of the outlet channel is smallest at the outlet opening of the first mixing chamber or at the inlet opening of the first interaction channel. This position is further distinguished in that it forms the upstream end of a section (of the first interaction channel) having a constant cross-sectional area.

For example, the first interaction channel may be tubular in said section. The first interaction channel may have a length which is at least three times as great as its width at the level of the outlet opening of the first mixing chamber. In this case, the length is the extent of the first interaction channel along the fluid mixture flow direction from the outlet opening of the first mixing chamber to the first inlet opening of the second mixing

chamber. In this case, the width is the extent of the first interaction channel in the oscillation plane transversely to the fluid mixture flow direction.

The first interaction channel may serve to continue the mixing process downstream of the outlet opening of the first mixing chamber; and, if particles are produced during the mixing process, these particles may grow in the first interaction channel (controlled by the length of the first interaction channel). The section of the first interaction channel having a constant cross-sectional area has the effect that the intermediate fluid mixture initially remains as undisturbed as possible, in order to realize a defined reaction time for the intermediate fluid mixture without flow-separation effects while simultaneously making the flow more uniform.

According to one embodiment, the first interaction channel extends, at least in sections, along a longitudinal axis which is in particular parallel to the fluid mixture flow direction. The first interaction channel may also (alternatively or additionally) have a meandering section. The curvature(s) resulting from the meandering shape may have the effect of preventing the formation of so-called dead-water regions.

In addition, the first interaction channel may have a section in which the cross-sectional area transverse to the fluid mixture flow direction increases downstream.

The transition between the first interaction channel and the second mixing chamber (that is to say the position of the outlet opening of the first interaction channel or of the first inlet opening of the second mixing chamber) may be characterised by an abrupt enlargement of the cross-sectional area (transverse to the fluid mixture flow direction). In this case, the second inlet opening of the second mixing chamber may be arranged in the region of the abrupt enlargement of the cross-sectional area.

The device further comprises a second supply device which is fluidically connected to the first mixing chamber via the second inlet opening and is configured to conduct the second fluid into the first mixing chamber along the second fluid flow direction, and a third supply device which is fluidically connected to the second mixing chamber via the

second inlet opening and is configured to conduct the third fluid into the second mixing chamber along the third fluid flow direction.

The third fluid flow direction, that is to say the fluid flow direction in which the third fluid enters the second mixing chamber, and the fluid mixture flow direction, that is to say the direction in which the intermediate fluid mixture of the first and second fluids enters the second mixing chamber, may enclose an angle of less than or equal to 90°. The shear rate of the fluids in the second mixing chamber is thereby limited. Particles present in the intermediate fluid mixture are thus subjected to the lowest possible mechanical loads when meeting the third fluid. Damage to the particles or agglomeration/aggregation of the particles by fusion or adhesion of the particles can therefore be avoided. This has a positive effect on the polydispersity index of the particles. In order to enhance this effect, it is advantageous to select the magnitudes of the velocities of the third fluid and of the intermediate fluid mixture to be very similar. This can be realized by selecting suitable process parameters. By means of the device according to the invention and the method described further below, the particles mentioned at the outset can be produced in the pharmaceutically required size with high quality, that is to say with a low polydispersity index.

The angle between the fluid mixture flow direction and the third fluid flow direction is preferably less than 45° and, in particular, lies between 5° and 40°. The smaller this angle, the lower the shear rate of the fluids.

According to one embodiment, the third supply device is provided and configured to conduct the third fluid into the second mixing chamber as a (quasi-)stationary flow. The shear rate of the fluids in the second mixing chamber is thereby likewise limited. The second supply device may also be provided and configured to conduct the second fluid into the first mixing chamber as a (quasi-)stationary flow.

The third supply device has a supply channel which extends along the third fluid flow direction and opens into the second inlet opening of the second mixing chamber. In particular, the supply channel has a straight shape. For the most part, the supply

channel or its shape predetermines the fluid flow direction of the third fluid upon entry into the second mixing chamber.

The means for specifically changing the direction of the first fluid is configured to cause an oscillation of the first fluid in an oscillation plane. The supply channel extends in a plane which is parallel to the oscillation plane or corresponds to the oscillation plane. The intermediate fluid mixture and the third fluid thereby move in a common plane.

As already mentioned, the fluidic component comprises at least one means for specifically changing the direction of the first fluid flowing through the fluidic component. This configuration of the first supply device brings about the specific change in direction of the first fluid, such that the first fluid moves in the first mixing chamber in a manner variable over time, wherein the first fluid has a movement component along the first fluid flow direction and a movement component transverse to the first fluid flow direction.

According to one embodiment, it is provided that the fluidic component comprises a flow chamber which, in addition to the outlet opening already mentioned, also has an inlet opening and through which the first fluid can flow, the first fluid entering the flow chamber through the inlet opening and exiting the flow chamber through the outlet opening. According to one embodiment, the inlet opening and the outlet opening of the fluidic component may have widths of different sizes. In particular, the flow chamber has a main flow channel which connects the inlet opening of the flow chamber (or of the fluidic component) and the outlet opening of the flow chamber (or of the fluidic component) to one another, and at least one secondary flow channel as a means for specifically changing the direction of the first fluid. Moving components for producing the oscillation can be dispensed with in the fluidic component, such that the costs and expenditure associated therewith do not arise. Furthermore, by dispensing with moving components, the development of vibration and noise is relatively low.

As a means for specifically changing the direction of the first fluid, the flow chamber may have the at least one secondary flow channel already mentioned. A part of the

first fluid, the secondary flow, can flow through the secondary flow channel. The part of the first fluid which does not enter the secondary flow channel but exits from the fluidic component is referred to as the main flow. The at least one secondary flow channel may have an inlet which is located in the vicinity of the outlet opening of the fluidic component, and an outlet which is located in the vicinity of the inlet opening of the fluidic component. Viewed along the first fluid flow direction (from the inlet opening to the outlet opening), the at least one secondary flow channel may be arranged beside (not behind or in front of) the main flow channel. In particular, two secondary flow channels may be provided which extend laterally beside the main flow channel (viewed along the first fluid flow direction), wherein the main flow channel is arranged between the two secondary flow channels. According to a preferred embodiment, the secondary flow channels and the main flow channel are arranged in a row transversely to the first fluid flow direction and each extend along the first fluid flow direction.

Preferably, the at least one secondary flow channel is separated from the main flow channel by a block. This block may have different shapes. Thus, viewed along the first fluid flow direction (from the inlet opening to the outlet opening), the cross-section of the block may taper. The block may also have rounded edges. Sharp edges may be provided on the block, in particular in the vicinity of the inlet opening and/or the outlet opening.

According to one embodiment, the at least one secondary flow channel may have a greater or smaller depth than the main flow channel. (The depth is the extent transverse to the oscillation plane of the first fluid.) The oscillation frequency of the first fluid exiting from the fluidic component can thereby be influenced. By reducing the component depth in the region of the at least one secondary flow channel (in comparison with the main flow channel), the oscillation frequency decreases if the remaining parameters remain substantially unchanged. Correspondingly, the oscillation frequency increases if the component depth in the region of the at least one secondary flow channel (in comparison with the main flow channel) is increased and the remaining parameters remain substantially unchanged.

A further possibility for influencing the oscillation frequency of the first fluid exiting from the fluidic component may be created by at least one separator which is preferably provided at the inlet of the at least one secondary flow channel. The separator assists separation of the secondary flow from the flow of the first fluid. A separator is understood here to mean an element which projects into the flow chamber at the inlet of the at least one secondary flow channel (transversely to the flow direction prevailing in the secondary flow channel). The separator may be provided as a deformation (in particular an indentation) of the secondary-flow-channel wall or as a projection configured in some other way. Thus, the separator may be (circular-)conical or pyramidal. In addition to influencing the oscillation frequency, the use of such a separator also makes it possible to vary the so-called oscillation angle. The oscillation angle is the angle swept by the oscillating fluid jet (between its two maximum deflections). If a plurality of secondary flow channels are provided, a separator may be provided for each of the secondary flow channels or only for some of the secondary flow channels.

The cross-sectional area of the inlet opening and outlet opening of the fluidic component (and also of the first mixing chamber and the second mixing chamber) may have any desired shape, for example square, rectangular, polygonal, round, oval, etc.

According to one embodiment, the first supply device and the first inlet opening of the first mixing chamber, on the one hand, and the second supply device and the second inlet opening of the first mixing chamber, on the other hand, are arranged relative to one another in such a manner that the first fluid flow direction and the second fluid flow direction enclose an angle of 45° to 90° in a plane parallel to the first fluid flow direction. An angle of substantially 45° is particularly preferred. The mixing quality and the mixing path length or mixing duration can thereby be positively influenced. For manufacturing reasons, the angle may also be substantially 90°.

If the means for specifically changing the direction of the first fluid is configured to cause an oscillation of the first fluid in an oscillation plane, the second supply device and the second inlet opening of the first mixing chamber may be arranged in such a

manner that the second fluid flow direction and the oscillation plane of the first fluid enclose, in a plane transverse to the first fluid flow direction, an angle of 30° to 150°. This angle is preferably substantially 90°.

With regard to the second supply device, it may be provided that the latter is provided and configured to conduct the second fluid into the first mixing chamber as a (quasi-)stationary flow. Thus, the second supply device may, for example, be configured as a tube, the longitudinal axis of which (or the downstream elongate end section of which) predetermines the second fluid flow direction of the second fluid. The second fluid may be conducted through the tube and the second inlet opening into the first mixing chamber by means of a pumping device.

Alternatively, the second supply device (like the first supply device already described) may likewise comprise a fluidic component. This fluidic component may operate according to the same principle as the fluidic component of the first supply device. Thus, it may have at least one means for specifically changing the direction of the second fluid flowing through the fluidic component, in particular for forming a spatial oscillation of this fluid at the outlet opening. The remaining features of the fluidic component of the first supply device are likewise transferable to the fluidic component of the second supply device. A first oscillating fluid and a second oscillating fluid thus meet one another in the first mixing chamber. The fluidic component of the second supply device may have a smaller oscillation angle than the fluidic component of the first supply device. Both oscillation angles may also be of the same size.

The first mixing chamber may have a longitudinal axis which is defined such that it extends along the first fluid flow direction or the fluid mixture flow direction. According to one embodiment, it is provided that the cross-sectional area of the first mixing chamber transverse to the longitudinal axis increases along the longitudinal axis in at least one section. For example, starting from the first inlet opening of the first mixing chamber, the cross-sectional area may increase in an upstream end section of the first mixing chamber with increasing distance from the first inlet opening. The upstream end section may thus form an inlet channel of the first mixing chamber (which widens

downstream). In this case, the outlet channel may directly adjoin the inlet channel. Alternatively, an intermediate section of the first mixing chamber may be provided between the inlet channel and the outlet channel, in which intermediate section the cross-sectional area of the first mixing chamber is substantially constant.

If the means for specifically changing the direction of the first fluid is configured to cause an oscillation of the first fluid in an oscillation plane, the extent of the first mixing chamber in the oscillation plane and transverse to the longitudinal axis, starting from the first inlet opening of the first mixing chamber, may increase in the inlet channel with increasing distance from the first inlet opening, or the extent of the first mixing chamber in the oscillation plane and transverse to the longitudinal axis may decrease in the outlet channel with increasing distance from the first inlet opening. In particular, this extent of the first mixing chamber may also increase in the inlet channel (immediately) downstream of the second inlet opening of the first mixing chamber. In the inlet channel, the boundary walls of the first mixing chamber (viewed in the oscillation plane) therefore enclose an angle which is preferably oriented toward the oscillation angle of the oscillating first fluid. This angle may be up to 10° smaller or up to 10° larger than the oscillation angle, or may assume a value between these two values. It is particularly preferred if this angle is up to 5° smaller or up to 5° larger than the oscillation angle, or assumes a value between these two values. It can thereby be avoided that the oscillation of the first fluid in the first mixing chamber is adversely affected. The oscillation angle of the first fluid may be at least 5°, preferably at least 25°, and particularly preferably at least 40°. For many applications, an oscillation angle between 25° and 50°, in particular between 30° and 45°, is suitable. A typical maximum value for the oscillation angle is 75°. In the outlet channel as well, the boundary walls of the first mixing chamber (viewed in the oscillation plane) enclose an angle which is preferably smaller than the angle between the boundary walls of the first mixing chamber in the inlet channel. It is particularly preferred for the angle of the outlet channel to be up to 15° smaller than the angle of the inlet channel. In addition, the extent of the first mixing chamber transverse to the oscillation plane may also increase in the inlet channel with increasing distance from the first inlet opening, or the extent

of the first mixing chamber transverse to the oscillation plane may decrease in the outlet channel with increasing distance from the first inlet opening.

The (relative) size of the inlet channel and outlet channel of the first mixing chamber may be configured depending on the application.

According to one embodiment, the second inlet opening of the first mixing chamber is offset downstream relative to the first inlet opening of the first mixing chamber along the longitudinal axis of the first mixing chamber. The second inlet opening is preferably formed within the inlet channel (that is to say in a boundary wall of the inlet channel). Viewed along the longitudinal axis, the distance between the first and second inlet openings may correspond to at least half the width of the first inlet opening of the first mixing chamber, wherein the width is defined parallel to the oscillation plane of the first fluid and transverse to the longitudinal axis of the first mixing chamber.

The first inlet opening and the outlet opening of the first mixing chamber may be formed on opposite sides of the first mixing chamber. Thus, the first inlet opening may form the upstream end of the first mixing chamber, and the outlet opening may form the downstream end. In particular, the first inlet opening and the outlet opening may lie on the longitudinal axis. The first inlet opening and the outlet opening may be defined where the cross-sectional area of the first mixing chamber transverse to its longitudinal axis, through which the entering first fluid or the exiting intermediate fluid mixture passes, is smallest in each case.

It is further conceivable that the first mixing chamber has a volume which is greater than the volume of the fluidic component or of the flow chamber of the fluidic component. In this case, in particular both the width (extent transverse to the longitudinal axis of the first mixing chamber and in the oscillation plane of the first fluid) and the length (extent along the longitudinal axis) of the first mixing chamber may be greater than the width (extent transverse to the first fluid flow direction and in the oscillation plane of the first fluid) or length (extent along the first fluid flow direction) of the flow chamber of the fluidic component. This volume ratio can prevent an

undesirably high pressure from building up in the first mixing chamber. Alternatively, the volume of the first mixing chamber may be smaller than the volume of the flow chamber of the fluidic component. In this case, the width and/or the length of the first mixing chamber may be smaller than the width or length of the flow chamber of the fluidic component.

Analogously to the first interaction channel, a second interaction channel may adjoin the outlet opening of the second mixing chamber downstream.

The second mixing chamber and/or the second interaction channel each extend along an axis which corresponds to the flow direction of the produced fluid mixture. This axis in each case encloses an angle with the third fluid flow direction and the fluid mixture flow direction (of the intermediate fluid mixture). According to one embodiment, the angle between the axis and the third fluid flow direction and the angle between the axis and the fluid mixture flow direction are of different sizes (in the oscillation plane). In particular, the angle between the axis and the third fluid flow direction may be greater than the angle between the axis and the fluid mixture flow direction. Both angles are preferably less than 180°. For example, the angle between the axis and the third fluid flow direction may be 170° to 179°. For example, the angle between the axis and the fluid mixture flow direction may be 160° to 169°. The angle between the axis and the third fluid flow direction, the angle between the axis and the fluid mixture flow direction, and a further angle between the fluid mixture flow direction and the third fluid flow direction add up to 360°.

When the device is used, for example in a method for producing a fluid mixture described further below, the volumetric flow rates of the first, second and third fluids may be selected in such a manner that the resultant velocity vector of the intermediate fluid mixture at the first inlet opening of the second mixing chamber and the resultant velocity vector of the third fluid at the second inlet opening of the second mixing chamber, when added together, are such that the resultant velocity vector of the fluid mixture is parallel to the axis of the second mixing chamber or of the second interaction channel. Thus, the angle between the velocity vector of the fluid mixture and the third

fluid flow direction (the velocity vector of the third fluid) may be 170° to 179°. Furthermore, the angle between the velocity vector of the fluid mixture and the fluid mixture flow direction (the velocity vector of the intermediate fluid mixture) may be 160° to 169°.

The first, second and third fluids may each be supplied to the first, second and third supply devices, respectively, with the aid of a pumping device. For example, the pumping devices may be configured as syringe pumps or circulation pumps. As alternatives to syringe pumps, HPLC pumps or diaphragm pumps may be used.

The device for producing a fluid mixture presented here has thus far been described with a first mixing chamber and a second mixing chamber. It is, however, conceivable for the device to comprise at least one further mixing chamber having a corresponding supply device. In this case, the at least one further mixing chamber may be arranged according to the described principle, such that the first inlet opening of the nth mixing chamber is fluidically connected to the outlet opening of the (n-1)th mixing chamber. This results in a cascade-like arrangement of the n mixing chambers.

The object explained at the beginning is likewise achieved by a device having the features of claim 9.

Accordingly, the device for producing a fluid mixture initially comprises a first mixing chamber having a first inlet opening, via which a first fluid can be introduced into the first mixing chamber along a first fluid flow direction, a second inlet opening, via which a second fluid can be introduced into the first mixing chamber along a second fluid flow direction, and an outlet opening, via which an intermediate fluid mixture comprising the first fluid and the second fluid can be discharged along a fluid mixture flow direction. The device further comprises a second mixing chamber having a first inlet opening, via which the intermediate fluid mixture can be introduced into the second mixing chamber along the fluid mixture flow direction, a second inlet opening, via which a third fluid can be introduced into the second mixing chamber along a third fluid flow direction, and an outlet opening, via which the fluid mixture comprising the first fluid, the second fluid

and the third fluid can be discharged. The second mixing chamber is consequently arranged downstream of the first mixing chamber, wherein the first mixing chamber and the second mixing chamber are fluidically connected in such a manner that the intermediate fluid mixture exiting from the outlet opening of the first mixing chamber enters (immediately) into the second mixing chamber via the first inlet opening thereof.

Supply devices may be provided for introducing the fluids into the mixing chambers. Specifically, this device too comprises a first supply device which is fluidically connected to the first mixing chamber via the first inlet opening and is configured to conduct the first fluid into the first mixing chamber along the first fluid flow direction.

Furthermore, a second supply device may be provided which is fluidically connected to the first mixing chamber via the second inlet opening and is configured to conduct the second fluid into the first mixing chamber along the second fluid flow direction, and a third supply device may be provided which is fluidically connected to the second mixing chamber via the second inlet opening and is configured to conduct the third fluid into the second mixing chamber along the third fluid flow direction.

The first supply device comprises a fluidic component. The fluidic component comprises an outlet opening which is fluidically connected to the first inlet opening of the first mixing chamber, and at least one means for specifically changing the direction of the first fluid flowing through the fluidic component, in particular for forming a spatial oscillation of the first fluid at the outlet opening.

The device is charcterized in that the first inlet opening of the second mixing chamber has a cross-sectional area transverse to the fluid mixture flow direction which is smaller than the cross-sectional area of the second inlet opening of the second mixing chamber. The cross-sectional area of the second inlet opening of the second mixing chamber is defined transversely to the third fluid flow direction. Alternatively or additionally, the device is charcterized in that the sum of the cross-sectional area of the first inlet opening of the second mixing chamber and the cross-sectional area of the second inlet opening of the second mixing chamber is approximately the same size

as (when the third fluid flow direction and the fluid mixture flow direction lie in one plane) or is greater than (when the third fluid flow direction and the fluid mixture flow direction do not lie in one plane) the cross-sectional area of the outlet opening of the second mixing chamber. Consequently, the mean velocity of the intermediate fluid mixture at the first inlet opening of the second mixing chamber is greater than the mean velocity of the third fluid at the second inlet opening of the second mixing chamber. This results in the fluid-mechanical effect that the momentum of the intermediate fluid mixture upon entering the second mixing chamber is greater than the momentum of the third fluid flow upon entering the second mixing chamber. This difference in momentum makes it possible for the fluid mixture flow direction at the first inlet opening of the second mixing chamber and the third fluid flow direction at the second inlet opening of the second mixing chamber to enclose a relatively large angle, for example 90°, without appreciable shearing of the intermediate fluid mixture occurring in the second mixing chamber. Owing to the possibility of selecting 90° for the angle mentioned, the second mixing chamber in the region of the second inlet opening and the third supply device can be configured in a structurally simple manner.

Possible configurations and embodiments of the fluidic component have already been described further above. Here too, the means for specifically changing the direction of the first fluid may therefore be configured to cause an oscillation of the first fluid in an oscillation plane.

According to one embodiment, the second mixing chamber has an extent parallel to the oscillation plane and transverse to the fluid mixture flow direction which is constant. This extent may be referred to as the width of the second mixing chamber. In this case, the width of the second mixing chamber may be constant over its entire length (extent along the fluid mixture flow direction).

It is also conceivable for the second mixing chamber to have an extent parallel to the oscillation plane and transverse to the fluid mixture flow direction which is the same size as the extent parallel to the oscillation plane and transverse to the fluid mixture flow direction of the outlet opening of the first mixing chamber and/or of the first inlet

opening of the second mixing chamber. Furthermore, the first inlet opening and the outlet opening of the second mixing chamber may have the same width, which may, for example, correspond to the width of the second mixing chamber. The structural configuration of the second mixing chamber can thereby likewise be simplified.

According to one embodiment, the second mixing chamber has an extent transverse to the oscillation plane which is greater than the extent of the first inlet opening of the second mixing chamber transverse to the oscillation plane. The extent transverse to the oscillation plane may be referred to as the depth. Accordingly, the depth of the second mixing chamber may be greater than the depth of the first inlet opening of the second mixing chamber. The depth of the second mixing chamber may be constant over its entire length (extent along the fluid mixture flow direction). In particular, the cross-sectional area (transverse to the fluid mixture flow direction) of the first inlet opening of the second mixing chamber may be smaller than the cross-sectional area (transverse to the fluid mixture flow direction) of the second mixing chamber. The change in cross-section may in particular be abrupt and may, for example, be realized by a stepped shape which abruptly changes the depth. Such a stepped shape may indeed lead to the formation of recirculation regions (also referred to as dead-water regions) in the second mixing chamber immediately downstream of the first inlet opening and may thereby impair the function of the second mixing chamber. However, the second inlet opening may be arranged immediately downstream of the first inlet opening, that is to say in a region of potential recirculation regions, such that the third fluid flows through the potential recirculation regions. Although the residence time of the third fluid in the second mixing chamber may thereby be indeterminate, the residence time of the intermediate fluid mixture is not, such that ultimately the function of the second mixing chamber is not impaired.

According to one embodiment, a first interaction channel is arranged between the first mixing chamber and the second mixing chamber and connects the outlet opening of the first mixing chamber and the first inlet opening of the second mixing chamber to one another. The first interaction channel has a cross-sectional area transverse to the fluid mixture flow direction which is constant at least in sections. In particular, the cross-

sectional area of the first interaction channel may be smaller than the cross-sectional area of the second mixing chamber. In this case, the depth (extent transverse to the oscillation plane) of the first interaction channel may be smaller than the depth of the second mixing chamber, while their widths (extent parallel to the oscillation plane and transverse to the fluid mixture flow direction) may be of the same size. In particular, the depth of the second mixing chamber may be (constant and) twice as great as the depth of the first interaction channel (in a section immediately upstream of the second mixing chamber). The ratio of the depths (first interaction channel/second mixing chamber) to one another may be based on the ratio of the volumetric flow rate of the intermediate fluid mixture to the sum of the volumetric flow rates within the second mixing chamber. Preferably, the ratio of the depths (first interaction channel/second mixing chamber) corresponds to the ratio of the volumetric flow rates (intermediate fluid mixture/(intermediate fluid mixture + third fluid)).

According to one embodiment, the depth (extent transverse to the oscillation plane) of the first interaction channel is smaller than the width (extent parallel to the oscillation plane and transverse to the fluid mixture flow direction) of the first interaction channel. The ratio of width to depth may lie in a range between 1.5 and 100, preferably between 2 and 10.

The first interaction channel may have a length which is at least three times as great as its width at the level of the outlet opening of the first mixing chamber. In this case, the length is the extent of the first interaction channel along the fluid mixture flow direction from the outlet opening of the first mixing chamber to the first inlet opening of the second mixing chamber. In this case, the width is the extent of the first interaction channel in the oscillation plane transverse to the fluid mixture flow direction.

The transition between the first interaction channel and the second mixing chamber (that is to say the position of the outlet opening of the first interaction channel or of the first inlet opening of the second mixing chamber) may be characterised by an abrupt change in the cross-sectional area (transverse to the fluid mixture flow direction). For example, the depth and/or width may change abruptly at the transition.

The transition between the first mixing chamber and the first interaction channel (that is to say the position of the outlet opening of the first mixing chamber or of the inlet opening of the first interaction channel) may be defined in that a section (outlet channel of the first mixing chamber) is arranged immediately upstream, the cross-sectional area of which decreases along the fluid mixture flow direction toward the outlet opening, wherein the cross-sectional area is smallest at the outlet opening of the first mixing chamber or at the inlet opening of the first interaction channel.

In order to make the construction as simple as possible, the first interaction channel may extend along a longitudinal axis which is in particular parallel to the first fluid flow direction or the fluid mixture flow direction. However, it is also conceivable for the first interaction channel to comprise a meandering section.

It is further conceivable for a second interaction channel to adjoin the outlet opening of the second mixing chamber.

Configurations of the first supply device, the second supply device and the first mixing chamber have already been described further above in connection with other embodiments and are also transferable to the embodiments in which the first inlet opening of the second mixing chamber has a smaller cross-sectional area than the second inlet opening of the second mixing chamber.

The device according to the invention may be manufactured with the aid of machining or material-removing manufacturing methods, replicative methods, for example by means of injection molding, or additive methods (3D printing). Methods using a defined cutting edge (for example milling) or material-removing methods (for example electrical-discharge machining) are likewise suitable for manufacture.

The device according to the invention may be manufactured from various materials. Plastics (PEEK, PVDF, COC), metals or alloys (stainless steel, aluminum), glass or ceramic may be considered as materials.

The invention further relates to a method for producing a fluid mixture. The method is carried out using the device according to the invention. To carry out the method, a device according to the invention in accordance with one of the embodiments described here, a first fluid, a second fluid and a third fluid are initially provided. The first fluid is introduced into the first mixing chamber at a first volumetric flow rate via the first supply device. At the same time, the second fluid is introduced into the first mixing chamber at a second volumetric flow rate via the second supply device, and the third fluid is introduced into the second mixing chamber at a third volumetric flow rate via the third supply device.

In the first mixing chamber, the first and second fluids are given an opportunity to mix and thereby form an intermediate fluid mixture (with particles). The formation of (nano)particles may be achieved by changing the solubility of substances dissolved in the second fluid by bringing the second fluid into contact with/diluting the second fluid with the first fluid. Nanoparticles are precipitated by nanoprecipitation. Owing to the configuration of the first supply device, which causes a spatial oscillation of the first fluid, the velocities or velocity differences between the first and second fluids in the first mixing chamber fluctuate strongly, such that so-called turbulent mixing takes place. The residence time of the two fluids in the first mixing chamber may vary depending on the application.

In the second mixing chamber, the intermediate fluid mixture produced in the first mixing chamber and the third fluid are brought together. Owing to the configuration of the second mixing chamber in the region of its first and second inlet openings, the shear rates in the second mixing chamber are low, such that, in particular, no turbulent mixing (but rather quasi-laminar mixing) takes place in the second mixing chamber. The mechanical loading of the particles can thereby be kept as low as possible. The mixing process in the second mixing chamber serves to stabilize particles of the intermediate fluid mixture.

The size and the size distribution of the particles may be influenced by the volumetric flow rates of the first and second fluids, the oscillation frequency of the first oscillating fluid, and the geometry of the first and second mixing chambers. In particular, the width (extent in the oscillation plane and transverse to the first fluid flow direction/fluid mixture flow direction) plays a role. The oscillation frequency of the oscillating first fluid may be at least 100 Hz, typically more than 2000 Hz.

The fluid mixture comprising the first fluid, the second fluid and the third fluid is subsequently discharged from the second mixing chamber via its outlet opening.

According to one embodiment, the volumetric flow rates are adjusted in such a manner that the first volumetric flow rate is greater than the second volumetric flow rate, or that the first volumetric flow rate and the second volumetric flow rate are of the same size. With regard to the second mixing chamber, the third volumetric flow rate may be adjusted in such a manner that the volumetric flow rate at which the intermediate fluid mixture enters the second mixing chamber is greater than the third volumetric flow rate or is of the same size as the third volumetric flow rate. Depending on the application, however, the third volumetric flow rate may also be greater than the volumetric flow rate at which the intermediate fluid mixture enters the second mixing chamber. The volumetric flow rate of the intermediate fluid mixture results from the volumetric flow rates of the first and second fluids. It is conceivable for the first volumetric flow rate, the second volumetric flow rate and the third volumetric flow rate each to be constant over the duration of the mixing process.

The volumetric flow rate of the first, second and third fluids may be controlled by pumping devices which pump the first, second and third fluids into the first or second mixing chamber via the first, second and third supply devices, respectively. Depending on the application, the pressure of the introduced fluids may lie in the range of a few millibars (mbar) up to several hundred bar (relative to ambient pressure). For applications in the mass production of (lipid) nanoparticles, the inlet pressure may lie between 1 and 50 bar, preferably between 1 and 25 bar, and particularly preferably between 1 and 10 bar. For the production of emulsions, the pressure may be several

hundred bar. A pressure range between 2 and 500 bar is preferred. A pressure range between 10 and 250 bar is particularly preferred.

For use of the method on an industrial scale, the introduction of the first fluid into the first mixing chamber, the introduction of the second fluid into the first mixing chamber and the introduction of the third fluid into the second mixing chamber may each take place continuously.

According to one embodiment, the method is carried out with a liquid or a suspension as the first fluid. The second fluid is likewise either a liquid or a suspension. In the case of suspensions, the two fluids may, for example, differ (exclusively) in terms of particle size. Owing to the turbulence prevailing in the first mixing chamber, in the case of identical suspensions (as the first and second fluids), for example, the size of the particles in the suspension may be varied. The size distribution of the particles may also be influenced in this case.

In general, the first fluid and the second fluid may be different or identical in terms of chemical composition and/or concentration of individual constituents. For example, the first fluid may comprise an aqueous buffer solution, and the second fluid may comprise a polymer, a pharmaceutical active ingredient, a polymer-active-ingredient conjugate or a lipid, in each case in a solvent. The aqueous buffer solution (first fluid) may, for example, be an acetate, citrate, phosphate or TRIS buffer. The buffer solution may contain one or more nucleic acids (DNA, RNA or mRNA). The buffer solution may have a pH value of 3 to 7, preferably 3 to 6. The aqueous solution (first fluid) may further contain surfactants such as, for example, poloxamers and polyvinyl alcohols. The solvent of the second fluid may be water-miscible (for example ethanol, acetonitrile, acetone) or water-insoluble (for example ethyl acetate, chloroform).

It is conceivable for the first fluid to be a suspension comprising a solvent and a nucleic acid. The second fluid may comprise a lipid mixture and may be suitable for enclosing the nucleic acid of the first fluid during the mixing process and for functioning, in the

intermediate fluid mixture thus obtained, as a carrier or vehicle for the nucleic acid. The nucleic acid may be DNA, RNA or mRNA.

The first fluid and the third fluid may be identical or different in terms of chemical composition and/or concentration of individual constituents.

Depending on the application, the third fluid may have a particular function. Thus, the third fluid may serve to adjust the pH value, a particle density or the solvent content in the intermediate fluid mixture and/or may comprise a surfactant.

In general, the chemical composition of the fluids used also determines the particle size of the particles in the produced fluid mixture. At the first inlet opening of the first mixing chamber, the oscillating first fluid has a Reynolds number Re of more than 500, preferably more than 1000, particularly preferably more than 2000. At the first inlet opening of the second mixing chamber, the intermediate fluid mixture has a Reynolds number Re of more than 50, preferably more than 100, particularly preferably more than 200. The Reynolds number Re is determined according to

$$Re = (u_i \times h_i)/v,$$

where u_i is the flow velocity at the respective inlet opening, h_i is the height or depth of the respective inlet opening, and v is the kinematic viscosity of the fluid (mixture).

The method may be used to produce lipid nanoparticles, polymer nanoparticles or liposomes.

The invention will be explained in greater detail below on the basis of exemplary embodiments in conjunction with the drawings.

The drawings show in:

Fig. 1 a cross-section through a device for producing a fluid mixture according to one embodiment;

Fig. 2 a cross-section through a detail of a device for producing a fluid mixture according to a further embodiment, wherein the detail shows in particular a first mixing chamber and a first supply device;

Figs. 3-5 sectional views of the device from Figure 2 along lines A′-A″, B′-B″ and C′-C″, respectively;

Fig. 6 a cross-section through a device for producing a fluid mixture according to a further embodiment;

Fig. 7 the deflection of the oscillating first fluid as a function of time upon entry into the first mixing chamber of the device for producing a fluid mixture;

Fig. 8 a cross-section through a device for producing a fluid mixture according to a further embodiment;

Fig. 9 a cross-section through a device for producing a fluid mixture according to a further embodiment;

Fig. 10 a cross-section through a device for producing a fluid mixture according to a further embodiment;

Fig. 11 a sectional view of the device from Figure 10 along line D′-D″;

Fig. 12 a schematic representation of a second mixing chamber according to a further embodiment; and

Fig. 13 a schematic representation of a method for producing a fluid mixture.

The devices shown in the figures and their components are not illustrated to scale. Combinations of the illustrated embodiment variants other than those shown in the following figures are also possible.

Figure 1 schematically illustrates a device 1 for producing a fluid mixture according to one embodiment of the invention.

The device 1 comprises a first mixing chamber 20, a first interaction channel 30, a second mixing chamber 40, a second interaction channel 50, a first supply device 60, a second supply device 50 and a third supply device 80. Figure 2 shows the first mixing chamber 20 and the first supply device 60 of a device according to a further embodiment. While the first mixing chamber 20 and the first supply device 60 of the device from Figure 2 differ in a few details from the embodiment in Figure 1, the remaining components (first interaction channel 30, second mixing chamber 40, second interaction channel 50, second supply device 50 and third supply device 80) may be identical to those in Figure 1. Figures 3 to 5 each show a sectional view of the device 1 from Figure 2 along lines A′-A″, B′-B″ and C′-C″, respectively. Owing to the many common features, the embodiments of Figures 1 and 2 are described together below. Differences are addressed at the appropriate point.

The first mixing chamber 20 has a first inlet opening 201, a second inlet opening 202 and an outlet opening 203. A first fluid F_1 can be introduced into the first mixing chamber 20 via the first inlet opening 201, and a second fluid F_2 can be introduced via the second inlet opening 202. In the first mixing chamber 20, the first and second fluids F_1, F_2 form an intermediate fluid mixture F_{12} which can be discharged via the outlet opening 203 of the first mixing chamber 20.

The first supply device 60 is connected (fluidically) to the first mixing chamber 20 via the first inlet opening 201 and serves to introduce the first fluid F_1 into the first mixing chamber 20. The second supply device 70 is connected (fluidically) to the first mixing

chamber 20 via the second inlet opening 202 and serves to introduce the second fluid F_2 into the first mixing chamber 20.

The first interaction channel 30 adjoins the outlet opening 203 downstream. It has an inlet opening 301 and an outlet opening 302. The inlet opening 301 of the first interaction channel 30 coincides with the outlet opening 203 of the first mixing chamber 20, such that the intermediate fluid mixture F_{12} can flow from the first mixing chamber 20 into the first interaction channel 30.

The second mixing chamber 40 has a first inlet opening 401, a second inlet opening 402 and an outlet opening 402. The first inlet opening 401 coincides with the outlet opening 302 of the first interaction channel 30. The intermediate fluid mixture F_{12} can be introduced into the second mixing chamber 40 via the first inlet opening 401, and a third fluid F_3 can be introduced via the second inlet opening 402. In the second mixing chamber 40, the intermediate fluid mixture F_{12} and the third fluid F_3 form the fluid mixture F_{123}, which can be discharged via the outlet opening 403 of the second mixing chamber 40.

The second interaction channel 50 adjoins the outlet opening 402 downstream. It has an inlet opening 501 and an outlet opening 502. The inlet opening 501 of the second interaction channel 50 coincides with the outlet opening 403 of the second mixing chamber 40. The produced fluid mixture F_{123} can be removed from the device 1 via the outlet opening 502. According to one embodiment, the device 1 has no second interaction channel, and the produced fluid mixture F_{123} can be removed from the device 1 via the outlet opening 403 of the second mixing chamber 40.

The first supply device 60 comprises a fluidic component 10 having two secondary flow channels (feedback channels) 104a, 104b as means for producing a first fluid F_1 which moves spatially and/or temporally, and in particular for forming a spatial oscillation of the first fluid F_1. The fluidic component 10 having the secondary flow channels 104a,

104b illustrated in Figure 1 is merely exemplary. In principle, other fluidic components may also be used, for example so-called feedback-free components.

The energy for producing the fluid jet which moves spatially and/or temporally results from the inlet pressure (at the inlet opening of the flow chamber 100) of the first fluid F_1 (also referred to as first phase A). The inlet pressure may assume values of up to 1000 bar. The inlet pressure is typically below 400 bar. The inlet pressure is preferably between 0.5 and 200 bar, particularly preferably between 1 and 25 bar. For applications for producing liquid nanoparticles, these pressures are generally below 10 bar. The use of the fluidic component 10 has the advantage that no additional energy source has to be used, thereby reducing the complexity and susceptibility to failure of the device. It can also thereby be ensured that no additional external energy is introduced into the fluids. The introduction of additional/external energy may destroy sensitive constituents of the fluids (for example long-chain molecules) and should therefore be avoided.

The fluidic component 10 comprises a flow chamber 100 through which a first fluid (flow) F_1 can flow. The fluidic component 10 has the function of causing an oscillation of the first fluid F_1, such that, when entering the first mixing chamber 20 through the first inlet opening 201 of the mixing chamber 20, the first fluid F_1 oscillates temporally and/or spatially. The temporal frequency of the oscillation is typically 1 Hz to 10 kHz, preferably 10 Hz to 10 kHz and particularly preferably 100 Hz to 5 kHz.

The flow chamber 100 comprises an inlet opening 101 having an inlet width b_{101}, via which the first fluid flow F_1 enters the flow chamber 100, and an outlet opening 102 having an outlet width b_{102}, via which the first fluid flow F_1 exits from the flow chamber 100. The inlet opening 101 and the outlet opening 102 are respectively defined where the cross-sectional area (transverse to the fluid flow direction) of the fluidic component 10 through which the fluid flow passes when entering the flow chamber 100 or exiting again from the flow chamber 100 is smallest in each case. The widths b_{101} and b_{102} of the inlet opening 101 and outlet opening 102, respectively, correspond to the extent of

the inlet opening 101 and outlet opening 102 transversely to the fluid flow direction and within the oscillation plane of the first fluid F_1 (explained later).

The outlet opening 102 of the flow chamber 100 of the fluidic component 10 corresponds here to the first inlet opening 201 of the first mixing chamber 20.

The inlet width b_{101} may assume a dimension of 0.15 µm to 5,000 µm. The minimum dimensions of the respective narrowest cross-sectional areas within the fluidic component 10 may be selected depending on the desired volumetric flow rate. The higher the volumetric flow rate at a constant inlet pressure (at the inlet opening 101 of the flow chamber 100), the greater the dimension, for example, of the inlet width b_{101} and/or of the inlet height h_{101} must be. Typical dimensions lie between 100 µm and 1,500 µm. Typical values for the width b_{101} are 100 µm, 150 µm, 300 µm, 600 µm and 1,200 µm.

The inlet opening 101 and the outlet opening 102 are arranged on two sides of the fluidic component 10 which are opposite one another in terms of flow. The flow chamber 100, more precisely a main flow channel 103 of the flow chamber 100, connects the inlet opening 101 and the outlet opening 102 to one another free of obstructions. In an embodiment which is not illustrated, the inlet opening 101 and the outlet opening 102 may be connected by means of a flow chamber which is not free of obstructions.

The first fluid flow F_1 moves in the flow chamber 100 substantially along a longitudinal axis A of the fluidic component 1 (which connects the inlet opening 101 and the outlet opening 102 to one another) from the inlet opening 101 to the outlet opening 102. The longitudinal axis A forms an axis of symmetry of the fluidic component 1. The longitudinal axis A lies in two planes of symmetry S1 and S2 which are perpendicular to one another and with respect to which the fluidic component 1 is mirror-symmetrical.

For specifically changing the direction of the fluid flow, the flow chamber 100 comprises, in addition to the main flow channel 103, two secondary flow channels 104a, 104b. The main flow channel 103 and the two secondary flow channels 104a, 104b extend substantially along the longitudinal axis A of the fluidic component 10, wherein the main flow channel 103 (viewed transversely to the longitudinal axis A) is arranged between the two secondary flow channels 104a, 104b. Immediately downstream of the inlet opening 101, the flow chamber 100 divides into the main flow channel 103 and the two secondary flow channels 104a, 104b, which reunite immediately upstream of the outlet opening 102. In the embodiment illustrated here, the two secondary flow channels 104a, 104b are arranged symmetrically with respect to the plane of symmetry S2 (Figure 4). These secondary flow channels may also be arranged outside the illustrated flow plane. These channels may be realized, for example, by tubes which are also located outside the plane of symmetry S1, or by channels which are at an angle to the flow plane (plane of symmetry S1).

The main flow channel 103 connects the inlet opening 101 and the outlet opening 102 to one another in a substantially straight line, such that the fluid flow F_1 flows substantially along the longitudinal axis A of the fluidic component 10.

Starting from the inlet opening 101, the secondary flow channels 104a, 104b initially each extend, in a first section, in opposite directions at an angle of substantially 90° to the longitudinal axis A. The secondary flow channels 104a, 104b then bend such that they each extend substantially parallel to the longitudinal axis A (in the direction toward the outlet opening 102) (second section). In order to reunite the secondary flow channels 104a, 104b and the main flow channel 103, the secondary flow channels 104a, 104b change their direction once more at the end of the second section, such that they are each directed substantially toward the longitudinal axis A (third section). In the embodiments of Figures 1 and 2, the direction of the secondary flow channels 104a, 104b changes by an angle of approximately 120° at the transition from the second section to the third section. However, an angle other than the angle mentioned here may also be selected for the change in direction between these two sections of

the secondary flow channels 104a, 104b, or the channels may even follow a completely different course.

The secondary flow channels 104a, 104b are a means for influencing the direction of the first fluid flow F_1 flowing through the flow chamber 100. For this purpose, the secondary flow channels 104a, 104b each have an inlet 104a1, 104b1 formed by the end of the secondary flow channels 104a, 104b facing the outlet opening 102, and each have an outlet 104a3, 104b3 formed by the end of the secondary flow channels 104a, 104b facing the inlet opening 101. A small part of the first fluid flow F_1, namely the secondary flows, flows through the inlets 104a1, 104b1 into the secondary flow channels 104a, 104b. The remaining part of the first fluid flow F_1 (the so-called main flow) exits from the fluidic component 10 via the outlet opening 102. The secondary flows exit from the secondary flow channels 104a, 104b at the outlets 104a3, 104b3, where they can exert a lateral momentum (transverse to the longitudinal axis A) on the first fluid flow F_1 entering through the inlet opening 101. The direction of the first fluid flow F_1 is thereby influenced in such a manner that the main flow exiting at the outlet opening 102 oscillates spatially, namely in a plane in which the main flow channel 103 and the secondary flow channels 104a, 104b are arranged. The plane in which the main flow oscillates is also referred to as the oscillation plane and corresponds substantially to the plane of symmetry S1 or is parallel to the plane of symmetry S1 (Figure 3).

In the embodiment illustrated here, the secondary flow channels 104a, 104b each have a cross-sectional area which is virtually constant over the entire length of the secondary flow channels 104a, 104b (from the inlet 104a1, 104b1 to the outlet 104a2, 104b2). By contrast, the size of the cross-sectional area of the main flow channel 103 increases substantially continuously in the flow direction of the main flow (that is to say in the direction from the inlet opening 101 to the outlet opening 102) (Figures 1 and 2). In both embodiments, the shape of the main flow channel 103 is, by way of example, mirror-symmetrical with respect to the planes of symmetry S1 and S2.

In principle, however, the cross-sectional area of the main flow channel 103 may also decrease downstream.

The main flow channel 103 is separated from each secondary flow channel 104a, 104b by a block 11a, 11b. In the embodiments of Figures 1 and 2, the two blocks 11a, 11b are arranged symmetrically with respect to the mirror plane S2. In principle, however, they may also be configured differently and may not be oriented symmetrically. In the case of a non-symmetrical orientation, the shape of the main flow channel 103 is likewise not symmetrical with respect to the mirror plane S2. A symmetrical embodiment of the two blocks 11a, 11b is preferred.

The shapes of the blocks 11a, 11b illustrated in Figures 1 and 2 are merely exemplary and may be varied. The blocks 11a, 11b have rounded edges. Sharp edges are also possible. The embodiment variant having rounded edges is preferred. The blocks 11a, 11b in Figures 1 and 2 differ in the shape of their side facing the main flow channel 103. While this side is virtually planar in Figure 1, it has a curvature in Figure 2.

A funnel-shaped extension 106 is arranged upstream of the inlet opening 101 of the flow chamber 100 and tapers in the direction toward the inlet opening 101 (downstream). In principle, an extension 106 having a substantially constant cross-section or an enlarged cross-sectional area in sections is also possible. This funnel-shaped extension may also be referred to as an inlet channel. The flow chamber 100 likewise tapers, specifically in the region of the outlet opening 102 downstream of the inner blocks 11a, 11b. The taper is formed by an outlet channel 107 and begins at the secondary-flow-channel inlet 104a1, 104b1. The extension 106 and the outlet channel 107 taper in such a manner that only their width, that is to say their extent in the plane of symmetry S1 perpendicular to the longitudinal axis A, decreases downstream in each case. In this embodiment, the taper does not affect the depth (that is to say the extent in the plane of symmetry S2 perpendicular to the longitudinal axis A) of the extension 106 and of the outlet channel 107 (Figure 3). Alternatively, the extension 106 and the outlet channel 107 may each taper both in width and in depth. Furthermore, only the extension 106 may taper in depth or in width, while the outlet channel 107

tapers both in width and in depth, and vice versa. The shapes of the extension 106 and of the outlet channel 107 are shown in Figures 1 and 2 only by way of example. Here, their widths each decrease linearly downstream, wherein the boundary walls of the extension 106 and of the outlet channel 107 (viewed in the oscillation plane in each case) enclose an angle ε and φ, respectively. Other forms of taper are possible. The length l_{106} of the inlet channel of the funnel-shaped extension 106 corresponds, for example, to at least 1.5 times the inlet width b_{101}, that is to say $l_{106} \geq 1.5 \times b_{101}$. According to a preferred embodiment, the length l_{106} of the funnel-shaped extension 106 is greater than 7.5 times the width b_{101}. For a given and fixed value of the width b_{101}: the smaller the angle ε, the longer the inlet channel 106 should be.

The inlet opening 101 and the outlet opening 102 each have an idealized rectangular cross-sectional area. They each have the same depth (extent in the plane of symmetry S2 perpendicular to the longitudinal axis A, Figure 3), but differ in their widths b_{101}, b_{102} (extent in the plane of symmetry S1 perpendicular to the longitudinal axis A, Figure 2). In principle, the corners of the cross-sectional areas may be rounded, and the opposite surfaces bounding the inlet opening 101 and outlet opening 102, respectively, need not extend parallel to one another.

In Figures 1 and 2, the outlet opening 102 of the flow chamber 100 of the fluidic component 10 corresponds to the first inlet opening 201 of the first mixing chamber 20. At the outlet opening 102 or the first inlet opening 201 (which are identical in shape and size), the tapering outlet channel 107 of the fluidic component 10 and the widening inlet channel 206 of the first mixing chamber 20, explained later, meet one another, such that an edge is formed in this transition region. This transition region may preferably be rounded. The rounding may have a radius 109 which is smaller than the minimum width of b_{101} (width of the inlet opening 101) and b_{11} (associated width of the smallest cross-sectional area A_{11} in the main flow channel 103 between the inner blocks 11a, 11b, Figure 2). An extreme value, by which a sharp-edged outlet 102 is produced, is a radius of zero. Owing to the greater mechanical stability, a radius 109 is preferred. The widths b_{101}, b_{11} and b_{102} are approximately of the same size. For

example, they may be approximately 0.3 mm. The radius 109 at the outlet opening 102 may then be approximately 0.025 mm.

An inlet channel 206 adjoins the first inlet opening 201 of the first mixing chamber 20 downstream. The inlet channel 206 has a cross-sectional area which increases downstream (transverse to the first fluid flow direction or to the longitudinal axis L of the first mixing chamber 20). In particular, the width (extent in the oscillation plane and transverse to the longitudinal axis L) of the inlet channel 206 increases downstream. The width increases linearly here. However, the increase in width may also follow a polynomial. Viewed in the oscillation plane, the walls bounding the inlet channel 206 enclose an angle δ. This angle δ may have different magnitudes. An angle δ selected as a function of the oscillation angle α is advantageous. A deviation from the oscillation angle α of +40° and -10° is possible, that is to say $\alpha - 10° < \delta < \alpha + 40°$. A particularly preferred value for the angle δ is $\alpha - 5° < \delta < \alpha + 20°$. The oscillation angle α here corresponds to the natural oscillation angle of the oscillating first fluid F_1 which would be established in the absence of the inlet channel 206 and the first mixing chamber 20. In the embodiments of Figures 1 and 2, the angle δ is different. The first inlet opening 201 is therefore defined in the inlet channel 206 where the latter has the smallest cross-sectional area (transverse to the first fluid flow direction R_1) or the smallest width (parallel to the oscillation plane and transverse to the first fluid flow direction R_1).

The width b_{20} of the first mixing chamber 20 is defined by two approximately parallel and planar surfaces which function as boundary walls in an intermediate section of the first mixing chamber 20. The intermediate section is formed along the first fluid flow direction R_1 between the inlet channel 206 and an outlet channel 207 of the first mixing chamber 20. In principle, the boundary walls may also be configured differently (other than planar and parallel).

The outlet channel 207 adjoins the downstream end of the intermediate section. Its cross-sectional area (transverse to the first fluid flow direction or to the longitudinal axis L of the mixing chamber 20) decreases downstream along the longitudinal axis L. In particular, the width (extent in the oscillation plane and transverse to the longitudinal

axis L) of the outlet channel 207 decreases downstream. The width decreases linearly here. However, the decrease in width may also follow a polynomial. Viewed in the oscillation plane, the walls bounding the outlet channel 207 enclose an angle ω. In the embodiments of Figures 1 and 2, the angle ω is of a different size.

The downstream end of the outlet channel 207 is formed by the outlet opening 203. The outlet opening 203 is therefore defined in the outlet channel 207 where the latter has the smallest cross-sectional area (transverse to the fluid mixture flow direction R_{12}) or the smallest width (parallel to the oscillation plane and transverse to the fluid mixture flow direction R_{12}). The intermediate fluid mixture F_{12} of the first and second fluids F_1, F_2 leaves the first mixing chamber 20 through the outlet opening 203 thereof.

If the first mixing chamber 20 merges into the first interaction channel 30 without a change in cross-section, the length l_{20} of the first mixing chamber 20 is defined as a function of twenty times the diameter D_{202} of the second inlet opening 202 of the first mixing chamber 20. Thus: $l_{20} \approx 20 \times D_{202}$.

The outlet opening 203 has a cross-sectional area A_{203} which is, for example, rectangular and therefore has a width b_{203} and a height h_{203}. In principle, a non-rectangular cross-sectional area of the outlet opening 203 is also possible. The cross-sectional area A_{203} is greater than the smallest cross-sectional area of the fluidic component 10 (A_{101}, A_{11} or A_{102}). The cross-sectional area A_{203} is of the same size as or greater than the sum of the cross-sectional area A_{202} of the second inlet opening 202 of the first mixing chamber 20 and the smallest cross-sectional area of the fluidic component 10 (A_{101}, A_{11} or A_{102}).

The outlet channel 207 has the fluid-mechanical effect that the vortices produced by the fluidic component 10 are contracted to a smaller cross-section. Since the circulation present in a vortex must be conserved according to Helmholtz's vortex theorems, the contraction of the vortices leads to an increase in vortex velocity and thus to an increase in the transverse velocities in the fluid. The higher velocities lead

to faster mixing of the fluids and also to faster decay of the vortices, which in turn leads to better mixing on the smaller scales. This vortex decay substantially determines the length l_{30} of the first interaction channel 30 adjoining the first mixing chamber 20. The outlet channel 207 of the first mixing chamber 20 thus makes a substantial contribution to rapid mixing of the fluids F_1, F_2. In order to utilize this effect, the ratio of the maximum cross-sectional area A_{20} of the first mixing chamber 20 (where $A_{20} = b_{20} \times h_{20}$, cf. Figures 2 and 3) to the cross-sectional area A_{203} of the outlet opening 203 (where $A_{203} = b_{203} \times h_{203}$, cf. Figures 2 and 3) must be selected such that $2 < A_{20}/A_{203} < 100$, preferably $2 < A_{20}/A_{203} < 50$ and particularly preferably $3 < A_{20}/A_{203} < 20$.

In an embodiment which is not illustrated, a plurality of outlet openings 203 may also be provided, which open into interaction channels 30 connected in parallel and subsequently into second mixing chambers connected in parallel. In this case, the sum of the cross-sectional areas A_{203} of the individual outlet openings 203 is greater than the smallest cross-sectional area of the fluidic component 10 (A_{101}, A_{11} or A_{102}).

The second inlet opening 202 is formed in the inlet channel 206. Alternatively, the second inlet opening 202 may be formed in the outlet channel 207. It is conceivable for more than one second inlet opening (for introducing the second fluid F_2 or other fluids) to be provided. In this case, at least one of the second inlet openings 202 is preferably located in the inlet channel 206.

In Figures 1 and 2, the second inlet opening 20 is circular, although a non-circular shape of the second inlet opening 202 is also possible. The cross-sectional area of the second inlet opening 202 is approximately the same size as the cross-sectional area of the first inlet opening 201.

The distance of the second inlet opening 202 from the first inlet opening 201 along the first fluid flow direction R_1 is shown as l_{202} in Figure 2. It is advantageous if the length l_{202} corresponds to at least the width b_{201} of the first inlet opening 201 (or outlet opening 102), that is to say $l_{202} \geq b_{201}$. It is particularly advantageous if the length l_{202}

corresponds to at least the sum of the width b_{201} and the width b_{202} of the first and second inlet openings 201, 202, or to at least twice the width b_{201}, that is to say $l_{202} \geq (b_{201} + b_{202})$ or $l_{202} \geq 2 \times b_{201}$.

Figure 3 shows a sectional view of the device 1 from Figure 2 along line A′-A″ (perpendicular to the sectional plane in Figure 2). Accordingly, in this embodiment, the fluidic component 10, the first mixing chamber 20 and at least the upstream end of the first interaction channel 30 have a constant height h. The height (also referred to as depth) is the extent transverse to the oscillation plane of the first fluid F_1. In an embodiment which is not illustrated, the height h need not be constant. In particular, in the region of the inlet channels 106 and 206 and of the outlet channels 107 and 207, the height h may differ from the height in the remainder of the device.

Figure 3 shows that the second supply device 70 opens into the second inlet opening 202 of the first mixing chamber 20. The second supply device 70, which is provided for introducing the second fluid F_2 into the first mixing chamber 20, comprises a supply channel 701 which extends along a longitudinal axis and predetermines the fluid flow direction R_2 for the second fluid F_2 (Figure 3). The supply channel 701 is connected to the first mixing chamber 20 via the second inlet opening 202 of the first mixing chamber 20. Viewed in the plane of symmetry S2, or in a plane which extends perpendicular to the oscillation plane and along the longitudinal axis L, the supply channel 701 is at an angle β to the oscillation plane of the fluidic component 10 or to the plane of symmetry S1. In this embodiment, the angle β = 90°. In principle, the angle may assume a different value. The mixing quality and/or the mixing path length or mixing time is influenced by the angle β.

Figure 4 shows a sectional view of the device 1 from Figure 2 along line B′-B″. In this sectional view, the cross-sectional area of the main flow channel 103 and of the secondary flow channels 104a, 104b of the fluidic component 10 can be seen. In this embodiment, the heights h_{103}, h_{104}a, h_{104}b of the channels 103, 104a, 104b are of the same size. In principle, however, they may also differ from one another. In Figure 4,

the cross-sectional areas of the main and secondary flow channels 103, 104a, 104b are shown in a simplified manner with sharp edges. However, the corners may be provided with radii, that is to say may be rounded.

Figure 5 shows a sectional view of the device 1 from Figure 2 along line C′-C″. In this sectional view, a cross-section through the inlet channel 206 of the first mixing chamber 20 can be seen. Once again, the corners are shown in a simplified manner without radii, although such radii may be present. The distance between the lateral boundary walls of the inlet channel 206 (parallel to the oscillation plane and transverse to the longitudinal axis L) is constant over the entire height h_{206}. This distance may, however, also change along the height h_{206}.

Figure 5 also shows that the second inlet opening 202 of the first mixing chamber 20 is formed in the inlet channel 206 thereof. Viewed in a plane transverse to the longitudinal axis L, the supply channel 701 encloses an angle η with the oscillation plane. In the illustrated embodiment, the angle η = 90°. In principle, the angle may assume another value, for example may lie between 30° and 150°. An angle η of 90° is preferred.

The mixing of the first and second fluids F_1, F_2 in the first mixing chamber 20 is characterised in that the fluidic component 10 produces strong velocity fluctuations transverse to the main flow direction of the first fluid flow direction R_1 (that is to say substantially in the Y direction (Figure 1)), which fluctuations lead to rapid mixing of the two fluid flows by chaotic advection.

Furthermore, the fluidic component 10 produces large-scale vortices which successively decay into smaller vortices through fluid-mechanical processes and are ultimately dissipated through viscous processes. In addition to dissipation of the vortices, this cascade of vortices leads to mixing of the fluids F_1, F_2 on increasingly smaller scales. This mixing takes place for the (greater) part in the first mixing chamber 20.

The first interaction channel 30 adjoins the outlet opening 203 of the first mixing chamber 20. Mixing is continued continuously in the first interaction channel 30 until, after a characteristic mixing time t_{mix}, a sufficiently homogeneous mixture of the two fluids F_1, F_2 is present. This mixing time t_{mix} may lie in the range from 0.1 ms to 1000 ms (0.1 ms to 1 ms, 1 ms to 1000 ms). The mixing time t_{mix} typically lies between 0.1 ms and 500 ms (1 ms to 500 ms), and in particular between 0.1 ms and 100 ms (1 ms to 100 ms). Mixing is intended to be completed in the first interaction channel 30. For this purpose, the length l_{20} of the first mixing chamber 20 and the length l_{30} of the first interaction channel 30 may be selected to be sufficiently great that a particle transported at the mean velocity can completely pass through the first mixing chamber 20 and the first interaction channel 30 within the mixing time t_{mix}.

In Figure 1, starting from its inlet opening 301, the first interaction channel 30 initially has a section having a constant cross-sectional area. A section in which the cross-sectional area increases downstream adjoins downstream. This section is symmetrical with respect to the fluid mixture flow direction R_{12}. This is followed downstream by a further section having a constant cross-sectional area, which in turn is followed by a section in which the cross-sectional area increases downstream. This section is asymmetrical with respect to the fluid mixture flow direction R_{12}.

The first interaction channel 30 may widen once or several times (increase in the cross-sectional area, in particular increase in the width transverse to the fluid mixture flow direction R_{12} and parallel to the oscillation plane). It is also possible for the first interaction channel 30 to narrow once or several times (decrease in the cross-sectional area, in particular decrease in the width transverse to the fluid mixture flow direction R_{12} and parallel to the oscillation plane). By means of such a change in the cross-sectional area A_{30} of the first interaction channel 30 along the fluid mixture flow direction R_{12}, improved mixing of pulsating flows can be achieved at low Reynolds numbers (<10), and, at substantially higher Reynolds numbers (<100), pulsations in the mixing which are produced by the fluidic component 10 can be reduced. The changes in cross-section are within a range such that no separations (so-called dead-

water regions) occur which may lead to indeterminate residence times of the intermediate fluid mixture in the first interaction channel 30. This is achieved in that an angle λ_{30} is less than 10°. This angle is defined between the center line of the interaction channel 30 and the bounding wall of the interaction channel 30 in a section which widens (viewed in the fluid mixture flow direction R_{12}). If the first interaction channel 30 widens several times (viewed in the fluid mixture flow direction R_{12}), there are a plurality of angles λ_{30}, for example in Figure 1 the upstream angles λ_{30}ia and λ_{30}ib and the downstream angle λ_{30}ii. The angle λ_{30} is preferably less than 8°. The angle λ_{30} advantageously lies between 2° and 6°. In the illustrated embodiment variant, an upstream symmetrical widening is realized in the interaction channel 30, in which the angles λ_{30}ia and λ_{30}ib are of the same size.

In Figure 1, the interaction channel 30 is straight (extending along the fluid mixture flow direction R_{12}). In principle, it may also be non-straight and may have, for example, at least one meandering section, as illustrated by way of example in Figure 6. Depending on the fluids F_1, F_2 to be mixed, such meanders may lengthen the residence time in the interaction channel 30 and thereby enable secondary mixing. This is advantageous for certain intermediate fluid mixtures F_{12} consisting of the fluids F_1, F_2 which require a certain maturation time and therefore have a longer mixing time t_{mix}.

In order to terminate growth of the particles after the mixing time t_{mix} and further stabilize the particles, the intermediate fluid mixture F_{12} (with the particles) is brought together with the third fluid F_3 in the second mixing chamber 40. For this purpose, the intermediate fluid mixture F_{12} enters the second mixing chamber 40 from the first interaction channel 30 via the first inlet opening 401, and the third fluid F_3 enters via the second inlet opening 402. The third fluid F_3 flows from a supply channel 801 of the third supply device 80. When the intermediate fluid mixture F_{12} and the third fluid F_3 are mixed in the second mixing chamber 40, the particles are subjected to the lowest possible mechanical stress in order to avoid damage to the particles and fusion and adhesion (agglomeration and aggregation) of particles. For this purpose, the

magnitude and direction of the intermediate fluid mixture F_{12} and of the third fluid F_3 are very similar.

The claimed method for producing a fluid mixture may require that the intermediate fluid mixture F_{12} have a mean velocity u_{302} at the outlet opening 302 of the first interaction channel 30, that the third fluid F_3 have a mean velocity u_{402} at the second inlet opening 402 of the second mixing chamber 40, and that the fluid mixture F_{123} have a mean velocity u_{403} at the outlet opening 403 of the second mixing chamber 40, wherein the following applies to the velocity ratios: $0.8 < u_{402}/u_{302} < 1.2$ and $0.8 < u_{403}/u_{302} < 1.2$. The desired velocity ratio may be adjusted by the size of the cross-sectional areas of the outlet openings 302, 403 and of the second inlet opening 402, taking into account the volumetric flow rates of the intermediate fluid mixture F_{12} and of the third fluid F_3. If the volumetric flow rate of the intermediate fluid mixture F_{12} is twice as great as the volumetric flow rate of the third fluid F_3, the cross-sectional area of the outlet opening 302 is to be selected to be twice as great as the cross-sectional area of the second inlet opening 402 ($A_{302} = 2A_{402}$), and the cross-sectional area of the outlet opening 403 is to be selected to be three times as great as the cross-sectional area of the second inlet opening 402 ($A_{403} = 3A_{402}$). With the outlet openings 302, 403 and the second inlet opening 402 having the same height, the ratio of the cross-sectional areas is transferred to the corresponding widths.

In summary, the cross-sectional area A_{403} of the outlet opening of the second mixing chamber 40 approximately corresponds to the sum of the cross-sectional area A_{302} of the outlet opening (of the first inlet opening A_{401}) and the cross-sectional area A_{402} of the second inlet opening. This is in particular the case when the direction R_3 of the third fluid F_3 and the direction R_{12} of the intermediate fluid mixture F_{12} are located within the oscillation plane or parallel to the oscillation plane.

The transition from the first interaction channel 30 to the second mixing chamber 40 (that is to say the position of the outlet opening 302 of the first interaction channel 30 and of the first inlet opening 401 of the second mixing chamber 40) is characterised by

an abrupt enlargement of the cross-sectional area (transverse to the fluid mixture flow direction R_{12}). In the region of this abrupt enlargement in cross-section, a supply channel 801 of the third supply device 80 opens into the second mixing chamber 40. The supply channel 801 extends (in a straight line) along the third fluid flow direction R_3. In this case, the third fluid flow direction R_3 and the fluid mixture flow direction R_{12} enclose an angle ζ which is less than or equal to 90°, preferably less than 45°, and particularly preferably lies between 5° and 40°.

The produced fluid mixture F_{123} flows from the outlet opening 403 of the second mixing chamber 40 into the second interaction channel 50 and leaves the device 1 through the outlet opening 502 of the second interaction channel 50.

Figure 6 shows a device 1 according to a further embodiment. It differs from the embodiments of Figures 1 to 5 in particular in the shape of the first interaction channel 30. Thus, the first interaction channel 30 has a meandering section having (here by way of example) one 180° bend 303 and two 90° bends 304. The meandering section lengthens the first interaction channel 30, such that the residence time of the intermediate fluid mixture F_{12} in the first interaction channel 30 is lengthened (in comparison with the embodiment of Figure 1).

In this embodiment variant, the interaction channel 30 has a constant channel width b_{300} in the bends 303, 304.

A straight section 305 adjoins the meandering section immediately downstream of the last bend 304. The straight section 305 has a length l_{305} which is at least three times as great as the channel width b_{300} ($l_{305} \geq 3 \times b_{300}$), preferably at least five times as great as the channel width b_{300} ($l_{305} \geq 5 \times b_{300}$). The straight section 305 serves to make the velocity profile of the intermediate fluid mixture F_{12} more uniform.

An asymmetrical section 307 adjoins the straight section 305 downstream. The asymmetrical section 307 takes account of the asymmetrical flow-velocity profile of the

intermediate fluid mixture F_{12}. The asymmetrical section 307 can prevent recirculation regions from forming. This widening is achieved by means of the angle λ_{30}.

A further straight section 308 is arranged immediately downstream of the asymmetrical section 307. The length l_{308} of this section is based on the desired mixing time t_{mix} of the fluids F_1, F_2 to be mixed in order to produce particles having the desired size and shape. Mixing times of around 10 ms are required for producing lipid nanoparticles.

In this embodiment variant, the cross-sectional area A_{201} of the first inlet opening 201 of the first mixing chamber 20 is approximately 25% greater than the cross-sectional area A_{202} of the second inlet opening 202 of the first mixing chamber 20.

An embodiment which differs from that of Figure 6 in that the first interaction channel 30 does not comprise the bends 303 and 304, but only the straight section 305 (which directly adjoins the first mixing chamber 20), a widening symmetrical section 307 and the straight section 308, is also conceivable.

The second interaction channel 50 extends (in general) along an axis which corresponds to the direction of the fluid mixture F_{123}. The direction of the fluid mixture F_{123} results from the velocity vector $\overrightarrow{v_{123}}$ of the fluid mixture F_{123}. The velocity vector $\overrightarrow{v_{123}}$ of the fluid mixture F_{123} corresponds to the sum of the velocity vector $\overrightarrow{v_{12}}$ of the intermediate fluid mixture F_{12} at the first inlet opening 401 and the velocity vector $\overrightarrow{v_3}$ of the third fluid F_3 at the second inlet opening 402. The axis of the second interaction channel 50 and the fluid mixture flow direction R_{12} enclose an angle ε which is less than 180° in the embodiment of Figure 6. The axis of the second interaction channel 50 and the third fluid flow direction R_3 enclose an angle κ which is less than 180° in the embodiment of Figure 6. The angles ε and κ are of different sizes here; in particular, the angle κ is greater than the angle ε. For example, the angle κ is between 170° and 179° (174°), and the angle ε is between 160° and 169° (166°). The angle ζ between the fluid mixture flow direction R_{12} and the third fluid flow direction R_3, and the angles ε and κ, add up to 360°.

Figure 7 schematically illustrates the deflection of the moving (oscillating) first fluid F_1 (at the outlet opening 102 of the fluidic component 10) over time. Accordingly, the first fluid F_1 oscillates periodically between two maximum deflections of, here by way of example, approximately +25° and -25°. The dashed line represents an idealized sinusoidal course. An additional intermediate oscillation is advantageous for increasing the mixing quality in the first mixing chamber 20. The course shown by a solid line comprises such an intermediate oscillation. For example, the intermediate oscillation is provided at approximately ±5°. Such a course over time, as illustrated by the solid line, may be produced, for example, using the fluidic components 10 according to Figure 1 or 2. The oscillation angle α may be selected depending on the desired mixing quality, the fluids to be mixed and their volumes. The oscillation angle α may be determined in various ways. For example, it may be determined from the ratio of the velocity components at the center of the cross-sectional area of the outlet opening 102 according to the relationship $\alpha = 2 \times \arctan(v/u)$, where u is the velocity component in the flow direction and v is the velocity component transverse to the flow direction, in the oscillation plane.

In the first mixing chamber 20, the first fluid F_1 preferably has a turbulence intensity Tu_{20} greater than 0.05; the turbulence intensity particularly preferably lies between 0.1 and 0.5. In general, the turbulence intensity indicates the variation of the velocity in relation to the mean velocity. Here, the turbulence intensity is specifically defined as the quotient of the maximum temporal fluctuation $\sigma_{u,max,20}$ of the local velocity of F_1 in the first mixing chamber 20 and the mean velocity u_{201} of the first fluid F_1 at the first inlet opening 201: $Tu_{20} = \sigma_{u,max,20}/u_{201}$. To determine the maximum temporal fluctuation, the temporal variance σ_u of the velocity is determined with the aid of a transient numerical simulation of the flow (CFD) of the first fluid F_1. The spatial maximum of σ_u in the mixing chamber 20 is identified.

In the second mixing chamber 40, the turbulence intensity Tu_{40} is defined according to $Tu_{40} = \sigma_{u,max,40}/u_{401}$, where $\sigma_{u,max,40}$ is the maximum variance of the velocity of F_{12} in

the mixing chamber 40 and u_{401} is the velocity of the intermediate fluid mixture F_{12} at the first inlet opening 401 of the second mixing chamber 40. The turbulence intensity Tu_{40} is preferably less than 0.1, particularly preferably less than 0.05, and especially preferably less than 0.025.

In the first mixing chamber 20 of the embodiments presented here, in particular by means of the respective fluidic component 10, a Kolmogorov scale Lk (length scale of the smallest vortices in the turbulent flow) of less than 20 µm can be achieved for rapid mixing of the first and second fluids F_1, F_2, preferably less than 10 µm and especially preferably less than 5 µm. The Kolmogorov scale Lk can be estimated from the results of turbulent CFD (Reynolds-averaged Navier-Stokes, abbreviated RANS). For this purpose, the turbulent dissipation rate ε, which is calculated as a transport variable of a so-called k-ε turbulence model, is related to the kinematic viscosity ν of the fluid mixture F_{12} as follows:

$Lk = \sqrt[4]{\nu^3/\varepsilon}$.

In contrast to mixing in the first mixing chamber 20, mixing in the second mixing chamber 40 is intended to take place with the lowest possible shear of the intermediate fluid mixture F_{12}. For this purpose, the relative differences between the velocities u_{401} at the first inlet opening 401 of the second mixing chamber 40 (or at the outlet opening 302 of the first interaction channel 30) and u_{402} at the second inlet opening 402 of the second mixing chamber 40 are as small as possible. In absolute terms, the turbulence in the second mixing chamber 40 is likewise intended to be smaller than in the first mixing chamber 20. For this purpose, the absolute velocities in the second mixing chamber 40 may be smaller than in the first mixing chamber 20. Preferably, $u_{401} < u_{201}$; particularly preferably, $u_{401} < u_{201}/2$, where u_{401} is the velocity of the intermediate fluid mixture F_{12} at the first inlet opening 401 of the second mixing chamber 40 and u_{201} is the velocity of the first fluid F_1 at the first inlet opening 201 of the first mixing chamber 20.

Figure 8 shows a further embodiment of the device 1. This embodiment differs from those of Figures 1 to 6 in particular in the configuration of the first supply device 60 and in the number of third supply devices 80a, 80b, 80c, 80d. Thus, the fluidic component 10 of the first supply device 60 has only one secondary flow channel 104. This secondary flow channel 104 is annular and is arranged upstream of the main flow channel 103. Four third supply channels 801a, 801b, 801c, 801d open into the second mixing chamber 40.

In Figure 8, the secondary flow channel 104 has a substantially constant cross-sectional area over its entire length (between points 104a1 and 104b1). An enlargement of the respective cross-sectional area is provided in the region of each secondary-flow-channel inlet or outlet (at points 104a1 and 104b1). In principle, the size of the cross-sectional area may also be the same here as over the entire length of the secondary flow channel 104.

At the transition between the secondary flow channel 104 and the main flow channel 103, the fluidic component 10 has a width b_{11} (extent parallel to the oscillation plane and transverse to the first fluid flow direction R_1). Preferably, the inlet width b_{101} is smaller than the width b_{11}. Starting from the transition region to the secondary flow channel 104, the width of the main flow channel 103 initially increases downstream and then decreases. In comparison with the fluidic components 10 of Figures 1 and 2, this fluidic component 10 produces a higher oscillation frequency at the same inlet pressure P_{10}IN. A higher oscillation frequency shortens the mixing time of the first fluid F_1 and of the second fluid F_2 in the first mixing chamber 20 and the adjoining first interaction channel 30.

In Figure 8, the length l_{20} (extent along the first fluid flow direction R_1) of the first mixing chamber 20 is smaller than the length l_{10} of the fluidic component 10. It should be taken into account that, in this embodiment variant which is simpler to manufacture, the length l_{10} includes the length l_{106}. In this case, the length l_{10} is defined from a point of the outer bounding wall of the secondary flow channel 104 which is at a maximum

distance from the outlet opening 102 along the axis X, to the outlet opening 102. The main flow channel 103 and the secondary flow channel 104 lie in one plane. According to an alternative, the secondary flow channel 104 may lie in a plane parallel to the plane of the main flow channel 103. In this case, the length l_{10} does not include the length l_{106}. In this case, the length l_{10} extends from the inlet opening 101 to the outlet opening 102. It is also conceivable for the length l_{20} to be greater than the length l_{10}.

The third fluid F_3 is conducted into the second mixing chamber 40 via a plurality of third supply channels 801a, 801b, 801c, 801d. By way of example, there are four third supply channels 801a, 801b, 801c, 801d in Figure 8. A different number is conceivable. The two third supply channels 801a, 801c arranged further upstream are arranged symmetrically relative to one another (with respect to the second mixing chamber 40), while the two third supply channels 801b, 801d arranged further downstream are not arranged symmetrically relative to one another (or are offset along the fluid mixture flow direction R_{12}). The supply channels 801a, 801b, 801c, 801d are each part of a third supply device 80a, 80b, 80c, 80d. However, the supply channels 801a, 801b, 801c, 801d may also be part of a common third supply device and may be fed by a common inlet which branches into the individual supply channels 801a, 801b, 801c, 801d.

The plurality of third supply channels 801a, 801b, 801c, 801d has the effect that the momentum exerted by the third fluid F_3 on the intermediate fluid mixture F_{12} is comparatively low (with respect to the embodiments of Figures 1 to 6), since the momentum is spatially distributed.

The cross-sections are designed such that the mean velocities at the inlet openings and outlet openings are as similar as possible. For example, the mean velocity u_{302} of the intermediate fluid mixture F_{12} at the outlet opening 302 of the first interaction channel 30 bears the following relationship to the mean velocities $u_{402}a$ and $u_{402}c$ of the third fluid F_3 at the second inlet openings 402a and 402c of the second mixing chamber 40: $0.8 < u_{402a}/u_{302} < 1.2$ and $0.8 < u_{402c}/u_{302} < 1.2$. The volumetric flow rates

through the second inlet openings 402a and 402c, and the volumetric flow rate of the intermediate fluid mixture F_{12} through the first inlet opening 401, determine the size of the cross-sectional areas at the openings mentioned. If the volumetric flow rates through the second inlet openings 402a and 402c are equal and each half as great as the volumetric flow rate through the first inlet opening 401, the cross-sectional areas of the second inlet openings 402a and 402c are correspondingly equal and each half as great as the cross-sectional area of the first inlet opening 401.

Figure 9 shows a further embodiment of the device 1. It differs from those of Figures 1 to 6 and 8 in particular in the configuration of the first supply device 60. Thus, the first supply device 60 in Figure 9 has two inlet openings 101a, 101b, but no secondary flow channel. An extension 106 is provided upstream of the inlet openings 101a, 101b and divides, viewed in the fluid flow direction, into two channels 106a and 106b. The channels 106a, 106b open into the inlet openings 101a, 101b. The channels 106a, 106b serve to condition the fluid flow of the first fluid F_1. The shape of the two channels 106a, 106b in Figure 9 is merely exemplary. The downstream end of the channels 106a and 106b, which faces the inlet openings 101a, 101b, is formed by a straight end section. The channels 106a, 106b are arranged mirror-symmetrically with respect to a longitudinal axis of the device 1, as are the inlet openings 101a, 101b. The inlet openings 101a, 101b form the transition between the channels 106a, 106b on the one hand and the main flow channel 103 on the other hand. The downstream straight end sections of the channels 106a and 160b enclose an angle σ. This angle σ assumes values between 95° and 175°. The vertex of the angle σ lies downstream of the inlet openings 101a, 101b. The angle σ is measured upstream of the vertex. The smaller the angle σ, the longer the fluidic component 10 becomes.

The embodiment from Figure 9 additionally differs from the other embodiments in the configuration of the first interaction channel 30 and of the supply channel 801 of the third supply device 80. Thus, the first interaction channel 30 has a section 307, the cross-section of which decreases downstream. The section 307 is located closer to the outlet opening 302 than to the inlet opening 301. The supply channel 801 likewise has a section 807, the cross-section of which decreases downstream. These changes in

cross-section have the effect that relative velocity fluctuations are reduced and the velocity distribution over the cross-section becomes more uniform. Moreover, the velocities of the intermediate fluid mixture F_{12} and of the third fluid F_3 can be controlled more effectively when they are brought together, and the conditions during mixing can thereby be defined more precisely. This makes it possible to define precisely and thereby limit the shear during mixing of the two fluid flows. In order to reduce the velocity fluctuations of the fluids and equalize the velocity distribution, the cross-sectional area of the outlet opening 302 may be reduced, in comparison with the maximum cross-sectional area of the first interaction channel 30, by a factor of 2 to 100, preferably by a factor of 2 to 20, and especially preferably by a factor of 2 to 10. Likewise, the cross-sectional area of the second inlet opening 402 may be reduced, in comparison with the maximum cross-sectional area of the supply channel 801 of the third supply device 80, by a factor of 2 to 100, preferably by a factor of 2 to 20, and especially preferably by a factor of 2 to 10.

The explanations relating to the angles ε and κ in connection with Figure 6 are likewise transferable to Figure 9.

The embodiment of the device 1 illustrated in Figure 10 differs from the embodiment of Figure 1 in particular in the configuration of the fluidic component 10, of the first interaction channel 30, and in the relative arrangement of the third supply device 80 with respect to the second mixing chamber 40. The relative arrangement is such that the intermediate fluid mixture F_{12} and the third fluid F_3 meet one another at an angle of substantially 90°, or such that the fluid mixture flow direction R_{12} and the third fluid flow direction R_3 enclose an angle of substantially 90°. In the devices 1 of the other embodiments, this angle is designated ζ and is less than 90°. In Figure 10, the direction R_3 of the third fluid F_3 does not extend in the oscillation plane or parallel to the oscillation plane.

The first interaction channel 30 is tubular with a constant cross-sectional area and constant width along its extent between the inlet opening 301 and the outlet opening 302. The second mixing chamber 40 is formed by an extension of the first interaction

channel 30, wherein the width does not change. However, the depth of the second mixing chamber 40 is greater than the depth of the first interaction channel 30. Specifically, in the embodiment of Figure 10 (see also Figure 11), the depth of the second mixing chamber 40 is twice as great as the depth of the first interaction channel 30. The first inlet opening 401 of the second mixing chamber 40 thus has a smaller cross-sectional area (depth) than the outlet opening 403 of the second mixing chamber 40. The ratio of the depth of the first inlet opening 401 to the depth of the outlet opening 403 is based on the ratio of the volumetric flow rates of the intermediate fluid mixture F_{12} and of the fluid mixture F_{123}. The ratio of the depths t_{403}/t_{401} is preferably greater than or equal to the ratio of the volumetric flow rate of F_{123} to the volumetric flow rate of F_{12}.

The second mixing chamber 40 has a length (extent along the fluid mixture flow direction R_{12}) and a width (extent transverse to the fluid mixture flow direction R_{12} and transverse to the third fluid flow direction R_3), each of which corresponds to the diameter of the second inlet opening 402 of the second mixing chamber 40. The width of the second mixing chamber 40 corresponds to the width of the first inlet opening 401. The ratio of the width of the second mixing chamber 40 to the diameter of the second inlet opening 402 may range from 1:1 to 2:1. Here, the second inlet opening 402 has, for example, a round cross-sectional area. Alternatively, it may be polygonal or oval.

As Figure 11 shows in conjunction with Figure 10, the depth t_{302} of the outlet opening 302 of the first interaction channel 30 is significantly smaller than the depth t_{403} of the outlet opening 403 of the second mixing chamber 40. The cross-sectional area A_{302} is formed by the width b_{302} at the outlet opening 302 and the depth t_{302}. The cross-sectional area A_{403} is formed by the width b_{403} at the outlet opening 403 and the depth t_{403}. In this embodiment variant, the cross-sectional area A_{402} of the second inlet opening 402 of the second mixing chamber 40 is formed by the diameter d_{801} at the outlet opening 402.

In this embodiment variant, the cross-sectional area of the second inlet opening 402 is significantly greater than that of the first inlet opening 401 (which corresponds to the outlet opening 302), whereby the mean velocity at the second inlet opening 402 is significantly lower than the mean velocity at the first inlet opening 401. This results in the fluid-mechanical effect that the momentum of the intermediate fluid mixture F_{12} (which enters the second mixing chamber 40 via the first inlet opening 401) upon entering the second mixing chamber 40 is significantly greater than the momentum of the third fluid F_3 (which enters the second mixing chamber 40 via the second inlet opening 402) upon entering the second mixing chamber 40. Although the intermediate fluid mixture F_{12} and the third fluid F_3 meet one another substantially at a right angle, only minimal shearing of the intermediate fluid mixture F_{12} occurs owing to the different momenta.

In summary, the cross-sectional area of the outlet opening A_{403} is smaller than the sum of the cross-sectional area A_{302} at the outlet opening 302 and the cross-sectional area A_{402} at the second inlet opening 402. This is the case when the direction R_3 of the third fluid F_3 is at an angle to the direction R_{12} of the intermediate fluid mixture F_{12} and does not lie within the oscillation plane. In the embodiment variant illustrated in Figures 10 and 11, the direction R_3 is orthogonal to the oscillation plane.

In contrast to the embodiment variant in which the direction R_3 lies within the oscillation plane, in the embodiment of Figures 10 and 11 the cross-sectional area A_{403} is intended to be greater than the cross-sectional area A_{401} ($A_{403} > A_{401}$). The following area relationship is preferred: $1.1\ A_{403} < A_{401} + A_{402} < 10\ A_{403}$. The following area relationship is particularly preferred: $1.9\ A_{403} < A_{401} + A_{402} < 7.9\ A_{403}$.

A further feature of the embodiment illustrated in Figures 10 and 11 is the abrupt enlargement of the cross-sectional area (transverse to the fluid mixture flow direction R_{12}) at the first inlet opening 401. According to the embodiment illustrated in section D′-D″ in Figure 11, the enlargement of the cross-sectional area is step-shaped. The step is formed in the direction of the supply channel 801. Viewed in the fluid mixture

flow direction R_{12} of the intermediate fluid mixture F_{12}, the inflow of the third fluid F_3 into the mixing chamber 40 takes place downstream of the step. According to fluid-mechanical knowledge, such steps should be avoided because they lead to the formation of recirculation regions (dead-water regions), which lead to indeterminate residence times of the fluid mixture F_{123} in the mixing chamber 40 and thereby impair its function. In the embodiment illustrated in Figure 10, however, the mixing chamber 40 or the ratio of the depth t_{403} at the outlet opening 403 to the depth t_{302} at the outlet opening 302 is configured such that only the third fluid F_3 flows through the potential recirculation region. As a result, only the third fluid F_3, for which the residence time in the mixing chamber 40 is irrelevant, is recirculated. The ratio of the depth t_{403} at the outlet opening 403 to the depth t_{302} at the outlet opening 302 depends on the velocity ratio of the fluid F_{12} and of the fluid F_3. In the embodiment variant illustrated in Figures 10 and 11, the depth t_{403} = 1.8 t_{302}, with a constant width b_{302} = b_{403}.

The embodiment of Figures 10 and 11 combines fluid-mechanical aspects for gentle mixing of the intermediate fluid mixture F_{12} and the third fluid F_3 with a minimalist construction.

Figure 12 shows a further embodiment. It differs from that of Figures 10 and 11 in particular in the configuration of the first interaction channel 30 and of the second mixing chamber 40.

The second mixing chamber 40 is tubular and has a bend. Specifically, the bend here is L-shaped, having two sections which are arranged at an angle of 90° to one another and each open into an open end. The end of the first section of the tubular mixing chamber 40 forms the second inlet opening 402, via which the third fluid F_3 enters the mixing chamber 40. The end of the second section of the tubular mixing chamber 40 forms the outlet opening 403, via which the fluid mixture F_{123} exits from the mixing chamber 40.

The first interaction channel 30 is likewise tubular and has a smaller diameter than the second mixing chamber 40. The tubular interaction channel 30 and the second section of the tubular mixing chamber 40 are arranged concentrically and extend along an axis on which the outlet opening 403 also lies. In the region of the bend, the first interaction channel 30 projects into the mixing chamber 40. For this purpose, an opening is provided in the wall of the mixing chamber 40 which corresponds in shape and size to the cross-sectional area of the interaction channel 30. The outlet opening 302 of the first interaction channel 30, which is simultaneously the first inlet opening 401 of the mixing chamber 40, is located upstream of the outlet opening 403. The intermediate fluid mixture F_{12} enters the mixing chamber 40 via the first inlet opening 401.

In the mixing chamber 40, the intermediate fluid mixture F_{12} flows in a round jet at the mean velocity u_{302}, and the third fluid F_3 flows through the concentric annular gap at the mean velocity u_{401} at the level of the first inlet opening 401. The following applies to the velocity ratio: $0.5 < u_{401}/u_{302} < 2$. The velocities are adjusted by means of the diameters/cross-sectional areas of the tubes (which form the first interaction channel 30 and the second mixing chamber 40) in such a manner that the desired velocity ratios are obtained at the volumetric flow rate required for the process. If, for example, the volumetric flow rates of the third fluid F_3 and of the intermediate fluid mixture F_{12} are to be mixed in a ratio of 3:1 and the cross-sectional areas of the tubes which form the first interaction channel 30 and the second mixing chamber 40 are circular, a ratio of the diameter of the outer tube to the inner tube of 2:1 is selected, such that an area ratio of 3:1 of the annular gap to the inner tube results.

Figure 13 schematically shows the sequence of a method for continuously mixing a plurality of (three or more) fluids for producing a fluid mixture according to one embodiment. Steps illustrated by dashed or dotted lines merely represent optional method steps.

The method is charcterized in that different mixing techniques are combined with one another at very short time intervals using a device 1 according to the invention. High

reproducibility is thereby achieved and the risk of errors is minimized, whereby consistent quality of the produced fluid mixture is ensured and costs can be reduced.

Rapid/turbulent mixing (turbulence intensity greater than 0.1) of the first and second fluids F_1, F_2 takes place in the first mixing chamber 20 in order to produce the intermediate fluid mixture F_{12}, which is subjected, in the second mixing chamber 40 together with the third fluid F_3 (and further fluids), to quasi-laminar mixing (turbulence intensity less than 0.1) at low shear rates.

The first method steps, which are designated P1.1, P2.1 and P3.1 in Figure 13, relate to the first fluid F_1 and take place in parallel with method steps P1.2, P2.2, which relate to the second fluid F_2, and with method steps P1.3 and P2.3, which relate to the third fluid F_3. Depending on the embodiment, these may also take place in parallel with the optional method steps P1.4 and P2.4, which relate to further fluids.

During the method steps mentioned, the first fluid F_1, the second fluid F_2, the third fluid F_3 (and the further fluids) are present in separate form.

Initially, in method steps P1.1, P1.2 and P1.3 (and optionally P1.4), the volumetric flow rate (flow rate) of the first fluid F_1, of the second fluid F_2 and of the third fluid F_3 (and of the further fluids) is adjusted. Their volumetric flow rates are adjusted depending on the mixing ratio of fluid F_1 and fluid F_2. If particles are produced during the mixing process, the particle size may also be influenced and adjusted by the ratio of the volumetric flow rates.

The ratio between the flow rate of the first fluid F_1 and the flow rate of the second fluid F_2 is greater than or equal to 1:1 (for example 1:1, 2:1, 3:1, 4:1, 5:1, 6:1, 7:1, 8:1, 9:1 or 10:1, and values therebetween). In other cases, the ratio between the flow rate of the second fluid F_2 and the flow rate of the first fluid F_1 is greater than 1:1 (for example 1:1, 2:1, 3:1, 4:1, 5:1, 6:1, 7:1, 8:1, 9:1 or 10:1, and values therebetween).

In the subsequent method steps P2.1, P2.2 and P2.3 (and optionally P2.4), the inlet pressure of the first fluid F_1 (at the inlet opening 101 of the fluidic component 10), the inlet pressure of the second fluid F_2 (at the second inlet opening 202 of the first mixing chamber 20), the inlet pressure of the third fluid F_3 (at the second inlet opening 402 of the second mixing chamber 40) (and optionally the inlet pressures of the further fluids) are adjusted by means of suitable pumping devices (depending on the quantity, for example syringe pumps, multi-piston pumps, diaphragm pumps, gear pumps, circulation pumps, peristaltic pumps or other positive-displacement pumps). The first, second and third fluids F_1, F_2, F_3 (and optionally further fluids) are conducted into the first, second and third supply devices 60, 70, 80, respectively (and optionally further supply devices).

After the first fluid F_1 has been introduced into the first supply device 60, the flow properties of the first fluid F_1 are adapted with the aid of the supply devices 60 in method steps P3.1. Thus, in P3.1, an oscillation of the first fluid F_1 is produced with the aid of the fluidic component 10. The oscillation frequency is generally higher than 100 Hz. An oscillation frequency of several thousand hertz, for example 2000 Hz, is advantageous. Since the oscillation frequency may change considerably depending on the size of the fluidic component 10, it is customary to specify the oscillation frequency in dimensionless form as the Strouhal number (St). For this purpose, the oscillation frequency f is divided by the mean velocity u_{102} at the outlet opening 102 of the fluidic component 10 and multiplied by the width b_{102} of the outlet opening 102 of the fluidic component 10: $St = f \times b_{102}/u_{102}$. The Strouhal number defined in this manner may lie in the range $0.001 < St < 1$, preferably $0.005 < St < 0.5$ and particularly preferably $0.01 < St < 0.05$. A passively oscillating first fluid F_1 is thus provided at the outlet opening 102 of the fluidic component 10. The oscillation angle α of the first fluid F_1 may be at least 5°, preferably at least 25°, and particularly preferably at least 40°. For many applications, an oscillation angle between 25° and 50°, in particular between 30° and 45°, is suitable. A typical maximum value for the oscillation angle is 75°.

In method step P4, the oscillating first fluid jet F_1 provided by the first supply device 60 and the (quasi-)stationary second fluid jet F_2 provided by the second supply device 70 are conducted into the first mixing chamber 20 via the first and second inlet openings 201, 202, respectively, and are combined there to form the intermediate fluid mixture F_{12}. The collision takes place at the angles β and η, which have already been explained in greater detail further above in connection with the device 1. When the method is used on an industrial production scale or in mass production, the first and second fluids F_1, F_2 are conducted into the first mixing chamber 20 at a continuous volumetric flow rate.

In method step P5, the fluid mixture F_{12} which exits from the first mixing chamber 20 via the outlet opening 203 thereof at the end of mixing process P4 is conducted into a downstream first interaction channel 30 having the length l_{30}, in which mixing is continued until, after a characteristic mixing time t_{mix}, a sufficiently homogeneous mixture of the two fluids F_1, F_2 is present. If particles (for example lipid nanoparticles, polymer nanoparticles, liposomes) or crystals have formed during mixing process P4, they have time to mature in the first interaction channel 30.

In method step P6.1, the intermediate fluid mixture F_{12} exiting from the first interaction channel 30 is conducted into the second mixing chamber 40 and combined with the third fluid F_3 (and optionally the further fluids successively). In this case, the third fluid F_3 and the further fluids may be different or identical.

In order to achieve gentle mixing, the third fluid F_3 and the intermediate fluid mixture F_{12} are brought together under specific fluid-mechanical criteria, which are shown below on the basis of various exemplary embodiments. In order to keep the shear rates in the second mixing chamber 40 as low as possible, the velocities of the third fluid F_3 and of the intermediate fluid mixture F_{12} must be as similar as possible in terms of magnitude and direction. If particles have formed during mixing process P4, process step P6.1 may serve to stabilize the particles. Gentle mixing at low shear rates

minimizes the mechanical stress on the particles, whereby better particle quality can be achieved.

In one embodiment variant, increased stability of the particles (for example lipid nanoparticles) is achieved by diluting the particle flow (intermediate fluid mixture F_{12}) with an aqueous solution, for example a buffer solution (third fluid F_3). In some method variants, the diluting fluid (third fluid F_3) is the same buffer solution as is also used in the first fluid F_1. In some method variants, the diluting fluid (third fluid F_3) differs from the buffer solution used in the first fluid F_1. In this case, the solvent proportion of the intermediate fluid mixture F_{12} is reduced, which leads to increased stability of the nanoparticles. For some nanoparticles, a solvent proportion of less than 50% leads to increased particle stability. In another embodiment variant, a solvent proportion of less than 25% leads to increased stability of the nanoparticles. In another embodiment variant, a solvent proportion of less than 10% leads to increased stability of the nanoparticles.

In one embodiment variant, the stability of the particles (for example lipid nanoparticles) is increased by increasing, decreasing or neutralizing the pH value of the particle flow (intermediate fluid mixture F_{12}) from mixing process P4 by dilution with a corresponding medium (third fluid F_3) (for example by means of an acidic or basic buffer solution).

In one embodiment variant, the stability of the particles (for example polymer nanoparticles) is increased by adding a diluting medium (third fluid F_3) containing a surfactant to the particle flow (intermediate fluid mixture F_{12}) from mixing process P4. The surfactant may, for example, be a poloxamer or a polyvinyl alcohol, but is not limited to these substances.

In one embodiment variant, the embodiment variants mentioned above may be combined, wherein a plurality of fluids (for example two, but not limited to two) are successively supplied to the particle flow (intermediate fluid mixture F_{12}) from mixing

process P4. Thus, for example, the third fluid F_3 is first supplied to the particle flow before a further fluid is supplied to the fluid mixture F_{123} resulting therefrom.

The ratio between the flow rate of the intermediate fluid mixture F_{12} and the flow rate of the third fluid F_3 is greater than or equal to 1:1 (for example 1:1, 2:1, 3:1, 4:1 or 5:1, and values therebetween). In other cases, the ratio between the flow rate of the third fluid F_3 and the flow rate of the intermediate fluid mixture F_{12} is greater than 1:1 (for example 2:1, 3:1, 4:1 or 5:1, and values therebetween).

In method step P7.1, the fluid mixture F_{123} which exits from the second mixing chamber 40 via the outlet opening 403 thereof at the end of mixing process P6.1 is conducted into a downstream second interaction channel 50 having the length l_{50}, in which the mixing from the second mixing chamber 40 is continued.

This second mixing process in the second mixing chamber 40 may be cascaded (optional method steps P6.2 and P7.2) by arranging a plurality of second mixing chambers 40 in succession (where appropriate, each combined with a second interaction channel 50). In P6.2 and P7.2, analogously to P6.1 and P7.1, one or more further fluids are combined with the fluid mixture generated from the preceding mixing process. The fluids added in the optional steps may be identical to the third fluid F_3 or may differ therefrom.

Method step P7.1 (optionally P7.2) is followed by method step P8, in which the produced fluid mixture is removed from the device 1. Method step P8 may be followed by thermal treatment (for example cooling) of the produced fluid mixture and/or separation of a component (for example a solvent) from the fluid mixture.

Process parameters must be specified for carrying out the method. These depend on the size of the device. The size of the device influences the fluid velocity, which results in limitations on the volumetric flow rates. The device from Figure 1 serves as a

reference, wherein the first inlet opening 201 of the first mixing chamber has a width b_{201} and a height h_{201}, where $h_{201} = b_{201}$.

b_{201}	**Volumetric flow rate V_1 of the first fluid F_1**
0.1 mm	1 ml/min < V_1 < 150 ml/min preferably 2 ml/min < V_1 < 75 ml/min particularly preferably 4 ml/min < V_1 < 38 ml/min
0.15 mm	1.5 ml/min < V_1 < 340 ml/min preferably 3 ml/min < V_1 < 170 ml/min particularly preferably 6 ml/min < V_1 < 85 ml/min
0.3 mm	6 ml/min < V_1 < 1360 ml/min preferably 12 ml/min < V_1 < 680 ml/min particularly preferably 24 ml/min < V_1 < 340 ml/min
0.6 mm	24 ml/min < V_1 < 5400 ml/min preferably 48 ml/min < V_1 < 2700 ml/min particularly preferably 96 ml/min < V_1 < 1350 ml/min
1.2 mm	95 ml/min < V_1 < 21600 ml/min preferably 190 ml/min < V_1 < 10800 ml/min particularly preferably 380 ml/min < V_1 < 5400 ml/min
1.5 mm	150 ml/min < V_1 < 34000 ml/min preferably 300 ml/min < V_1 < 17000 ml/min particularly preferably 600 ml/min < V_1 < 8500 ml/min

The volumetric flow rates of the further fluid flows then result from the respective ratios of the volumetric flow rates for particular embodiments of the process.

Various embodiments of the device 1 are illustrated in the figures, each corresponding to a specific combination of fluidic component 10, first mixing chamber 20, first interaction channel 30, second mixing chamber 40 and second interaction channel 50. Beyond the combinations specifically illustrated, the components mentioned of the individual embodiments may be combined with one another. It is also conceivable for the second interaction channel to be omitted.

Different types of fluidic components may be used. As means for specifically changing the direction, these may have secondary flow channels or other means.

In the description, the terms height h and depth t are used synonymously for the extent transverse to the oscillation plane of the first fluid.

REFERENCE SIGNS

F_1	first fluid
F_2	second fluid
F_3	third fluid
F_{12}	intermediate fluid mixture
F_{123}	fluid mixture
R_1	first fluid flow direction
R_2	second fluid flow direction
R_3	third fluid flow direction
R_{12}	fluid mixture flow direction
1	device for producing a fluid mixture
10	fluidic component
11a, 11b	inner blocks
100	flow chamber
101	inlet opening
102	outlet opening
103	main flow channel
104a, 104b	secondary flow channel
106	extension
107	outlet channel
20	first mixing chamber
201	first inlet opening
202	second inlet opening
203	outlet opening
206	inlet channel
207	outlet channel

30	first interaction channel
301	inlet opening
302	outlet opening
303	bend
304	bend
305, 307, 308	sections of the first interaction channel
40	second mixing chamber
401	first inlet opening
402	second inlet opening
403	outlet opening
50	second interaction channel
501	inlet opening
502	outlet opening
60	first supply device
70	second supply device
701	supply channel
80	third supply device
801	supply channel

Claims

1. A device (1) for producing a fluid mixture, comprising
   - a first mixing chamber (20) having a first inlet opening (201), via which a first fluid (F_1) can be introduced into the first mixing chamber (20) along a first fluid flow direction (R_1), a second inlet opening (202), via which a second fluid (F_2) can be introduced into the first mixing chamber (20) along a second fluid flow direction (R_2), and an outlet opening (203), via which an intermediate fluid mixture (F_{12}) comprising the first fluid (F_1) and the second fluid (F_2) can be discharged along a fluid mixture flow direction (R_{12}), wherein an outlet channel (207) is formed upstream of the outlet opening (203), the cross-sectional area of which, defined transversely to the fluid mixture flow direction (R_{12}), decreases along the fluid mixture flow direction (R_{12}) toward the outlet opening (203),
   - a second mixing chamber (40) having a first inlet opening (401), via which the intermediate fluid mixture (F_{12}) can be introduced into the second mixing chamber (40) along the fluid mixture flow direction (R_{12}), a second inlet opening (402), via which a third fluid (F_3) can be introduced into the second mixing chamber (40) along a third fluid flow direction (R_3), and an outlet opening (403), via which the fluid mixture (F_{123}) comprising the first fluid (F_1), the second fluid (F_2) and the third fluid (F_3) can be discharged, and
   - a first supply device (60) fluidically connected to the first mixing chamber (20) via the first inlet opening (201) and configured to conduct the first fluid (F_1) into the first mixing chamber (20) along the first fluid flow direction (R_1), wherein the first supply device (60) comprises a fluidic component (10) which has
     • an outlet opening (102) which is fluidically connected to the first inlet opening (201) of the first mixing chamber (20), and
     • at least one means (104a, 104b) for specifically changing the direction of the first fluid (F_1) flowing through the fluidic component (10), for forming a spatial oscillation of the first fluid (F_1) at the outlet opening (102), wherein the means (104a, 104b) for specifically changing the direction of the first fluid

(F_1) is configured to cause an oscillation of the first fluid (F_1) in an oscillation plane,

- a second supply device (70) fluidically connected to the first mixing chamber (20) via the second inlet opening (202) and configured to conduct the second fluid (F_2) into the mixing chamber (20) along the second fluid flow direction (R_2), and
- a third supply device (80) fluidically connected to the second mixing chamber (40) via the second inlet opening (402) and configured to conduct the third fluid (F_3) into the second mixing chamber (40) along the third fluid flow direction (R_3), wherein the third supply device (80) has a supply channel (801) which extends along the third fluid flow direction (R_3) and opens into the second inlet opening (402) of the second mixing chamber (40), wherein the supply channel (801) extends in a plane which is parallel to the oscillation plane,

wherein a first interaction channel (30) is arranged between the first mixing chamber (20) and the second mixing chamber (40), the first interaction channel (30) connecting the outlet opening (203) of the first mixing chamber (20) and the first inlet opening (401) of the second mixing chamber (40) to one another, and having a cross-sectional area transverse to the fluid mixture flow direction (R_{12}) which is constant at least over a section immediately downstream of the outlet opening (203) of the first mixing chamber (20).

2. The device (1) according to claim 1, characterised in that the first interaction channel (30) has a section in which the cross-sectional area transverse to the fluid mixture flow direction (R_{12}) increases downstream.

3. The device (1) according to claim 1 or 2, characterised in that the third supply device (80) is provided and configured to conduct the third fluid (F_3) into the second mixing chamber (40) as a (quasi-)stationary flow.

4. The device (1) according to any one of the preceding claims, characterised in that the supply channel (801) is straight.

5. The device (1) according to any one of the preceding claims, characterised in that the first supply device (60) is configured to cause the specific change in direction of the first fluid (F_1), such that the first fluid (F_1) moves within the first mixing chamber (20) in a manner variable over time, wherein the first fluid (F_1) has a movement component along the first fluid flow direction (R_1) and a movement component transverse to the first fluid flow direction (R_1), wherein the first fluid (F_1) moves within the first mixing chamber (20), in particular periodically, in a manner variable over time.

6. The device according to any one of the preceding claims, characterised in that the fluidic component (10) comprises a flow chamber (100) through which the first fluid (F_1) can flow and which has a main flow channel (103), which connects an inlet opening (101) of the fluidic component (10) and the outlet opening (102) thereof to one another, and at least one secondary flow channel (104a, 104b) as a means for specifically changing the direction of the first fluid (F_1).

7. The device (1) according to any one of the preceding claims, characterised in that the first mixing chamber (20) has a longitudinal axis (L) which extends along the first fluid flow direction (R_1), and in that the cross-sectional area of the mixing chamber (20), defined transversely to the longitudinal axis (L), increases, starting from the first inlet opening (201) of the first mixing chamber (20), in an upstream end section of the first mixing chamber (20) which forms an inlet channel (206), with increasing distance from the first inlet opening (201).

8. The device (1) according to any one of the preceding claims, characterised in that a second interaction channel (50) adjoins the outlet opening (403) of the second mixing chamber (40).

9. A device (1) for producing a fluid mixture, comprising
   - a first mixing chamber (20) having a first inlet opening (201), via which a first fluid (F_1) can be introduced into the first mixing chamber (20) along a first fluid flow

direction (R_1), a second inlet opening (202), via which a second fluid (F_2) can be introduced into the first mixing chamber (20) along a second fluid flow direction (R_2), and an outlet opening (203), via which an intermediate fluid mixture (F_{12}) comprising the first fluid (F_1) and the second fluid (F_2) can be discharged along a fluid mixture flow direction (R_{12}),

- a second mixing chamber (40) having a first inlet opening (401), via which the intermediate fluid mixture (F_{12}) can be introduced into the second mixing chamber (40) along the fluid mixture flow direction (R_{12}), a second inlet opening (402), via which a third fluid (F_3) can be introduced into the second mixing chamber (40) along a third fluid flow direction (R_3), and an outlet opening (403), via which the fluid mixture (F_{123}) comprising the first fluid (F_1), the second fluid (F_2) and the third fluid (F_3) can be discharged,
- a first supply device (60) fluidically connected to the first mixing chamber (20) via the first inlet opening (201) and configured to conduct the first fluid (F_1) into the first mixing chamber (20) along the first fluid flow direction (R_1), wherein the first supply device (60) comprises a fluidic component (10) which has
  - an outlet opening (102) which is fluidically connected to the first inlet opening (201) of the first mixing chamber (20), and
  - at least one means (104a, 104b) for specifically changing the direction of the first fluid (F_1) flowing through the fluidic component (10), in particular for forming a spatial oscillation of the first fluid (F_1) at the outlet opening (102),

wherein the first inlet opening (401) of the second mixing chamber (40) has a cross-sectional area transverse to the fluid mixture flow direction (R_{12}) which is smaller than the cross-sectional area of the second inlet opening (402) of the second mixing chamber (40), wherein the cross-sectional area of the second inlet opening (402) of the second mixing chamber (40) is defined transversely to the third fluid flow direction (R_3), and/or

wherein the sum of the cross-sectional area of the first inlet opening (401) of the second mixing chamber (40) and the cross-sectional area of the second inlet opening (402) of the second mixing chamber (40) is approximately the same size

as or greater than the cross-sectional area of the outlet opening (403) of the second mixing chamber (40).

10. The device (1) according to claim 9, characterised in that the means (104a, 104b) for specifically changing the direction of the first fluid (F_1) is configured to cause an oscillation of the first fluid (F_1) in an oscillation plane.

11. The device (1) according to claim 10, characterised in that the second mixing chamber (40) has an extent parallel to the oscillation plane and transverse to the fluid mixture flow direction (R_{12}) which is constant.

12. The device (1) according to claim 10 or 11, characterised in that the second mixing chamber (40) has an extent parallel to the oscillation plane and transverse to the fluid mixture flow direction (R_{12}) which is of the same size as the extent parallel to the oscillation plane and transverse to the fluid mixture flow direction (R_{12}) of the outlet opening (203) of the first mixing chamber (20) and/or of the first inlet opening (401) of the second mixing chamber (40).

13. The device (1) according to any one of claims 10 to 12, characterised in that the second mixing chamber (40) has an extent transverse to the oscillation plane which is greater than the extent of the first inlet opening (401) of the second mixing chamber (40) transverse to the oscillation plane.

14. The device (1) according to any one of the preceding claims, characterised in that the device (1) further comprises:
    - a second supply device (70) fluidically connected to the first mixing chamber (20) via the second inlet opening (202) and configured to conduct the second fluid (F_2) into the mixing chamber (20) along the second fluid flow direction (R_2), and
    - a third supply device (80) fluidically connected to the second mixing chamber (40) via the second inlet opening (402) and configured to conduct the third fluid

(F_3) into the second mixing chamber (40) along the third fluid flow direction (R_3).

15. The device (1) according to any one of claims 9 to 14, characterised in that the first supply device (60) is configured to cause the specific change in direction of the first fluid (F_1), such that the first fluid (F_1) moves within the first mixing chamber (20) in a manner variable over time, wherein the first fluid (F_1) has a movement component along the first fluid flow direction (R_1) and a movement component transverse to the first fluid flow direction (R_1), wherein the first fluid (F_1) moves within the first mixing chamber (20), in particular periodically, in a manner variable over time.

16. The device according to any one of claims 9 to 15, characterised in that the fluidic component (10) comprises a flow chamber (100) through which the first fluid (F_1) can flow and which has a main flow channel (103), which connects an inlet opening (101) of the fluidic component (10) and the outlet opening (102) thereof to one another, and at least one secondary flow channel (104a, 104b) as a means for specifically changing the direction of the first fluid (F_1).

17. The device (1) according to any one of claims 9 to 16, characterised in that the first mixing chamber (20) has a longitudinal axis (L) which extends along the first fluid flow direction (R_1), and in that the cross-sectional area of the first mixing chamber (20), defined transversely to the longitudinal axis (L), increases, starting from the first inlet opening (201) of the first mixing chamber (20), in an upstream end section of the first mixing chamber (20) which forms an inlet channel (206), with increasing distance from the first inlet opening (201), and/or in that the cross-sectional area decreases, in a downstream end section of the first mixing chamber (20) which forms an outlet channel (207), with increasing distance from the first inlet opening (201).

18. The device (1) according to claim 10 and claim 17, characterised in that the extent of the first mixing chamber (20) in the oscillation plane and transverse to the

longitudinal axis (L), starting from the first inlet opening (201) of the first mixing chamber (20), in particular downstream of the second inlet opening (202) of the first mixing chamber (20), increases in the inlet channel (206) with increasing distance from the first inlet opening (201), or in that the extent of the first mixing chamber (20) in the oscillation plane and transverse to the longitudinal axis (L) decreases in the outlet channel (207) with increasing distance from the first inlet opening (201).

19. The device (1) according to any one of claims 9 to 18, characterised in that a first interaction channel (30) is arranged between the first mixing chamber (20) and the second mixing chamber (40), the first interaction channel (30) connecting the outlet opening (203) of the first mixing chamber (20) and the first inlet opening (401) of the second mixing chamber (40) to one another, and in particular having a cross-sectional area transverse to the fluid mixture flow direction (R_{12}) which is constant at least in sections.

20. The device (1) according to claim 19, characterised in that the first interaction channel (30) has a smaller cross-sectional area transverse to the fluid mixture flow direction (R_{12}) than the second mixing chamber (40).

21. The device (1) according to claim 10 and according to one of claims 19 and 20, characterised in that the first interaction channel (30) has an extent transverse to the oscillation plane which is smaller than the corresponding extent of the second mixing chamber (40), wherein in particular the extent of the first interaction channel (30) parallel to the oscillation plane and transverse to the fluid mixture flow direction (R_{12}) and the corresponding extent of the second mixing chamber (40) are of the same size.

22. The device (1) according to claim 10 and according to any one of claims 19 to 21, characterised in that the first interaction channel (30) has an extent transverse to the oscillation plane which is smaller than the extent parallel to the oscillation plane and transverse to the fluid mixture flow direction (R_{12}).

23. A method for producing a fluid mixture, comprising the following steps:
    - providing a device (1) according to any one of claims 1 to 22, a first fluid (F_1), a second fluid (F_2) and a third fluid (F_3),
    - simultaneously introducing the first fluid (F_1), at a first volumetric flow rate, into the first mixing chamber (20) via the first supply device (60), the second fluid (F_2), at a second volumetric flow rate, into the first mixing chamber (20) via the second supply device (70), and the third fluid (F_3), at a third volumetric flow rate, into the second mixing chamber (40) via the third supply device (80), and
    - discharging the fluid mixture (F_{123}) comprising the first fluid (F_1), the second fluid (F_2) and the third fluid (F_3) from the second mixing chamber (40) via the outlet opening (403) thereof.

24. The method according to claim 23, characterised in that the first volumetric flow rate is greater than the second volumetric flow rate, or in that the first volumetric flow rate and the second volumetric flow rate are of the same size.

25. The method according to claim 23 or 24, characterised in that the intermediate fluid mixture (F_{12}) enters the second mixing chamber (40) at a volumetric flow rate which is greater than the third volumetric flow rate or is of the same size as the third volumetric flow rate.

26. The method according to any one of claims 23 to 25, characterised in that the introduction of the first fluid (F_1) into the first mixing chamber (20), the introduction of the second fluid (F_2) into the first mixing chamber (20), and the introduction of the third fluid (F_3) into the second mixing chamber (40) each take place continuously.

27. The method according to any one of claims 23 to 26, characterised in that the first fluid (F_1) and the third fluid (F_3) are identical or different.

28. The method according to any one of claims 23 to 27, characterised in that the third fluid (F_3) serves to adjust a pH value, a particle density or a solvent content in the intermediate fluid mixture (F_{12}) and/or comprises a surfactant.

29. The method according to any one of claims 23 to 28, characterised in that the first fluid (F_1) and the second fluid (F_2) differ in terms of chemical composition and/or concentration of individual constituents.

30. The method according to any one of claims 23 to 29, characterised in that the first fluid (F_1) comprises an aqueous buffer solution, in particular in combination with one or more nucleic acids, and in that the second fluid (F_2) comprises a polymer, a pharmaceutical active ingredient or a polymer-active-ingredient conjugate, or a lipid, in each case in a solvent.