Therefore, there exists a need for an improved method and apparatus for spray drying a high-viscosity fluid, which at least partly meets the problem mentioned above.

Accordingly, ~~according to an aspect of the invention, there is provided~~ embodiments of the present invention provide a method of spray-drying a high-viscosity fluid that e.g. comprises a food product, the method comprising: - providing a nozzle plate wherein at least one nozzle is provided, said nozzle plate having an inner main surface and an outer main surface, the least one nozzle extending through the nozzle plate from the inner main surface to the outer main surface; - providing the high-viscosity fluid in a reservoir that is in fluidum connection with at least one nozzle; - pressurizing the high-viscosity fluid in the reservoir, wherein the fluid flows, as a result of said pressurizing, towards the nozzle plate, thus creating a pressure difference over the at least one nozzle so that the fluid flows out of the at least one nozzle, thereby passing the outer main surface after passing the inner main surface; and at least partially drying the droplets in a drying medium, such as air, to become particles; wherein a cross-sectional area of the at least one nozzle in the inner main surface exceeds a cross-sectional area of the at least one nozzle in the outer main surface.

A technical effect of having the cross-sectional area of the at least one nozzle in the inner main surface larger that the cross-sectional area of the at least one nozzle in the outer main surface, may be that a pressure differential over the at least one nozzle can be relatively low. Hence, a desired flow rate through the at least one nozzle, and hence a desired production rate, may be reached at a relatively low pressure difference over the at least one nozzle. Consequently, the nozzle plate can be designed relatively thin and/or a number of nozzles in the nozzle plate can be relatively high. Hence, said production rate may be relatively high.

The inventors thus realized an inventive thought that adapting a shape of the at least one nozzle can be used for decreasing a pressure difference over the at least one nozzle needed for spraying the high-viscosity fluid and/or increasing a production rate of the at least one nozzle, with only a limited impact on

strength of the nozzle plate and on a volume of a produced droplet. Further advantages and/or technical effects may include a stronger nozzle, a drop in necessary pressure, and/or the possibility for spray drying relatively higher viscosity fluids.

The high-viscosity fluid, or, in other words, viscous fluid, may have a shear viscosity larger than 0.1 pascal·second, preferably larger than 0.2 pascal·second, more preferably larger than 1 pascal·second. Said viscosity may be determined at a shear rate of 1 s^{-1} and a temperature of 20 degrees Celsius, using a cone-plate rheometer.

Preferably, during pressurizing, the pressure difference over the at least one nozzle is kept at at most 15 bar, preferably at at most 12 bar. Conversely, WO2008/069639 relates to a method of spray drying of a high-viscosity fluid. According to WO2008/069639, a pressure drop over a nozzle in order to force the fluid out of the nozzle is larger than 15 bar. Then, a substantially mono-disperse stream of droplets may be generated from the fluid that flows out of the nozzle. By means of the at least one nozzle, a substantially mono-disperse stream of droplets may be generated from the fluid that flows out of the nozzle, even when the pressure difference over the at least one nozzle is kept at pressures below 15 bar, or even below 12 bar. It is to be appreciated, that a required pressure difference is lowered compared to the known spray drying method of WO2008/069639 through the currently disclosed nozzle design. Alternatively, higher viscosity fluids may be spray-dried using the same pressure, e.g. also at 15 bar or higher.

Preferably, the method comprises drying the fluid after it has passed the outer main surface. Preferably, the method comprises collecting the dried food product, thus obtaining the food product in the form of a powder.

~~According to a further aspect~~Embodiments of the invention~~, there is provided~~ also provide an apparatus for spray-drying of a high-viscosity fluid that e.g. comprises a food product, the apparatus comprising: - a reservoir for containing the high-viscosity fluid; and - a nozzle plate that is in fluidum connection with the reservoir, has an inner main surface and an outer main surface, and is

provided with at least one nozzle extending through the nozzle plate from the inner main surface to the outer main surface; and drying means for causing and/or allowing the droplets to dry to become particles; the apparatus being arranged for pressurizing the fluid in the reservoir so that, in use, the fluid flows towards the nozzle plate, thus creating a pressure difference over the at least one nozzle so that the fluid flows out of the at least one nozzle, thereby passing the outer main surface after passing the inner main surface, wherein a cross-sectional area of the at least one nozzle in the inner main surface exceeds a cross-sectional area of the at least one nozzle in the outer main surface.

Preferably, the apparatus comprises pressurizing means for pressurizing the fluid in the reservoir so that the fluid flows towards and/or is pressurized against the nozzle plate and out of the at least one nozzle, thereby passing the outer main surface after passing the inner main surface. Preferably, the pressurizing means are arranged for keeping a pressure difference over the at least one nozzle at at most 15 bar, preferably at at most 12 bar. Additionally, a lower pressure difference over the at least one nozzle, e.g. at most 15 bar or at most 12 bar, may result in a lower strain on the fluid and on relatively vulnerable parts of the apparatus.

Preferably, the apparatus is arranged for carrying out a method according to the invention.

In view of the above, according to a first aspect of the present invention, there is provided a method of spray-drying a high-viscosity fluid using a praying device, the method comprising: providing a nozzle plate wherein at least one nozzle is provided, said nozzle plate having an inner main surface and an outer main surface, the at least one nozzle extending through the nozzle plate from the inner main surface to the outer main surface; providing the high-viscosity fluid in a reservoir that is in fluidum connection with the at least one nozzle; pressurizing the high-viscosity fluid in the reservoir, wherein the fluid flows, as a result of said pressurizing, towards the nozzle plate, thus creating a pressure difference over the at least one nozzle so that the fluid flows out of the at least one nozzle, thereby passing the outer main surface after passing the inner main surface; wherein the fluid flowing out of the

nozzle forms a jet that breaks up into droplets; and at least partially drying the droplets in a drying medium, such as air, to become particles; wherein a cross-sectional area (A_1) of the at least one nozzle in the inner main surface exceeds a cross-sectional area (A_2) of the at least one nozzle in the outer main surface thereby decreasing a pressure difference over the at least one nozzle needed for spraying the high-viscosity fluid.

According to a further aspect of the present invention, there is provided Apparatus for spray-drying of a high-viscosity fluid, the apparatus comprising a reservoir for containing the high-viscosity fluid; a nozzle plate that is in fluidum connection with the reservoir, has an inner main surface and an outer main surface, and is provided with at least one nozzle extending through the nozzle plate from the inner main surface to the outer main surface; and drying means; the apparatus being arranged for pressurizing the fluid in the reservoir so that, in use, the fluid flows towards the nozzle plate, thus creating a pressure difference over the at least one nozzle so that the fluid flows out of the at least one nozzle, thereby passing the outer main surface after passing the inner main surface; wherein the fluid flowing out of the nozzle forms a jet that breaks up into droplets; wherein the drying means is arranged for causing and/or allowing the droplets to dry to become particles wherein a cross-sectional area (A_1) of the at least one nozzle in the inner main surface exceeds a cross-sectional area (A_2) of the at least one nozzle in the outer main surface thereby decreasing a pressure difference over the at least one nozzle needed for spraying the high-viscosity fluid.

In said first aspect and said further aspect, preferably, an area ratio, being equal to the cross-sectional area of the at least one nozzle in the inner main surface divided by the cross-sectional area of the at least one nozzle in the outer main surface, is at least five and/or is at most fifty.

In said first aspect and said further aspect, preferably, the at least one nozzle comprises a substantially non-widening, e.g. cylindrical, part that extends from the outer main surface, and comprises a substantially widening, e.g. tapered, optionally frustoconical, part that extends from the substantially non-

widening part to the inner main surface. Optionally, the at least one nozzle is substantially trumpet-shaped.

In said first aspect and said further aspect, preferably, in use a pressure difference ratio, being equal to a pressure difference over the substantially widening part divided by a pressure difference over the substantially non-widening part, is at most 1, preferably at most 0.5, more preferably at most 0.3, e.g. at most 0.2.

In said first aspect and said further aspect, preferably, a length of the substantially non-widening part of the at least one nozzle, measured along an outflow direction of the high-viscosity fluid through said non-widening part, is at least equal to a diameter of the at least one nozzle, preferably at least three times a diameter of the at least one nozzle in the outer main surface. As a result, a relatively stable jet and/or droplet formation may be obtained by the fluid flowing out of the at least one nozzle 14. E.g. in an embodiment, the length of the substantially non-widening part is at least 60 micrometer, preferably 180 micrometer and/or at most 250 micrometer.

In said first aspect and said further aspect, preferably, the at least one nozzle widens gradually from the outer main surface to the inner main surface.

In said first aspect and said further aspect, preferably, a width, a length, and a thickness of the nozzle plate, a composition of the nozzle plate, as well as a size, a number, and a distribution of nozzles in the nozzle plate, are arranged for withstanding a pressure difference over the at least one nozzle of at least 12 bar, preferably at least 15 bar.

The invention also provides a food product that is produced by means of a method according to invention and/or an apparatus according to the invention.

Embodiments of the invention will now be described with reference to the accompanying drawings, in which corresponding reference symbols indicate corresponding parts, and in which:

Figure 1 shows a schematic cross-section of an apparatus for spray-drying of a high-viscosity fluid, in a first embodiment according to the invention;

CLAIMS

1. Method of spray-drying a high-viscosity fluid (4) using a spraying device, the method comprising:

– providing a nozzle plate (8) wherein at least one nozzle (14) is provided, said nozzle plate (8) having an inner main surface (10) and an outer main surface (12), the at least one nozzle (14) extending through the nozzle plate (8) from the inner main surface to the outer main surface;

– providing the high-viscosity fluid (4) in a reservoir (6) that is in fluidum connection with the at least one nozzle (14);

– pressurizing the high-viscosity fluid (4) in the reservoir (6), wherein the fluid (4) flows, as a result of said pressurizing, towards the nozzle plate (8), thus creating a pressure difference over the at least one nozzle (14) so that the fluid (4) flows out of the at least one nozzle (14), thereby passing the outer main surface (12) after passing the inner main surface (10); wherein the fluid flowing out of the nozzle (14) forms a jet that breaks up into droplets (18); and

– at least partially drying the droplets (18) in a drying medium, such as air, to become particles;

– wherein a cross-sectional area (A_1) of the at least one nozzle (14) in the inner main surface (10) exceeds a cross-sectional area (A_2) of the at least one nozzle (14) in the outer main surface (12) thereby decreasing a pressure difference over the at least one nozzle needed for spraying the high-viscosity fluid.

2. Method according to claim 1, wherein an area ratio, being equal to the cross-sectional area of the at least one nozzle in the inner main surface divided by the cross-sectional area of the at least one nozzle in the outer main surface, is at least five and/or is at most fifty.

3. Method according to claim 1 or 2, wherein the at least one nozzle comprises a substantially non-widening, e.g. cylindrical, part that extends from the outer main surface, and comprises a substantially widening, e.g. frustoconical, part that extends from the substantially non-widening part to the inner main surface.

4. Method according to claim 3, wherein a pressure difference ratio, being equal to a pressure difference over the substantially widening part divided by a pressure difference over the substantially non-widening part, is at most 1, preferably at most 0.5, more preferably at most 0.3, e.g. at most 0.2.

5. Method according to one of claims 1-4, wherein, during pressurizing, the pressure difference over the at least one nozzle is kept at at most 15 bar, preferably at at most 12 bar.

6. Method according to one of claims 1-5, further comprising the step of generating dynamic pressure variations in the fluid ~~(4)~~ near the nozzle ~~(14)~~ that propagate through the nozzle ~~(14)~~ and cause a controlled breakup of the fluid jet flowing out of the nozzle ~~(14)~~, the broken up fluid jet forming substantially mono-disperse droplets ~~(18)~~.

7. Apparatus for spray-drying of a high-viscosity fluid ~~(4)~~, the apparatus comprising:

- a reservoir ~~(6)~~ for containing the high-viscosity fluid ~~(4)~~;
- a nozzle plate ~~(8)~~ that is in fluidum connection with the reservoir ~~(6)~~, has an inner main surface ~~(10)~~ and an outer main surface ~~(12)~~, and is provided with at least one nozzle ~~(14)~~ extending through the nozzle plate ~~(8)~~ from the inner main surface ~~(10)~~ to the outer main surface ~~(12)~~; and
- drying means;
- the apparatus being arranged for pressurizing the fluid ~~(4)~~ in the reservoir ~~(6)~~ so that, in use, the fluid ~~(4)~~ flows towards the nozzle plate ~~(8)~~,

thus creating a pressure difference over the at least one nozzle ~~(14)~~ so that the fluid ~~(4)~~ flows out of the at least one nozzle ~~(14)~~, thereby passing the outer main surface ~~(12)~~ after passing the inner main surface ~~(10)~~; wherein the fluid flowing out of the nozzle ~~(14)~~ forms a jet that breaks up into droplets ~~(18)~~; wherein the drying means is arranged for causing and/or allowing the droplets ~~(18)~~ to dry to become particles

– wherein a cross-sectional area ~~(A_1)~~ of the at least one nozzle ~~(14)~~ in the inner main surface ~~(10)~~ exceeds a cross-sectional area ~~(A_2)~~ of the at least one nozzle ~~(14)~~ in the outer main surface ~~(12)~~ thereby decreasing a pressure difference over the at least one nozzle needed for spraying the high-viscosity fluid.

8. Apparatus according to claim 7, wherein an area ratio, being equal to the cross-sectional area of the at least one nozzle in the inner main surface divided by the cross-sectional area of the at least one nozzle in the outer main surface, is at least five and/or is at most fifty.

9. Apparatus according to claim 8, wherein the at least one nozzle comprises a substantially non-widening, e.g. cylindrical, part that extends from the outer main surface, and comprises a substantially widening, e.g. frustoconical, part that extends from the substantially non-widening part to the inner main surface.

10. Apparatus according to claim 8 or 9, wherein a length of the substantially non-widening part of the at least one nozzle, measured along an outflow direction of the high-viscosity fluid through said non-widening part, is at least equal to three times a diameter of the at least one nozzle in the outer main surface ~~(12)~~.

11. Apparatus according to one of claims 7-10, comprising pressurizing means for pressurizing the fluid in the reservoir so that the fluid flows towards

the nozzle plate and out of the at least one nozzle, thereby passing the outer main surface after passing the inner main surface.

12. Apparatus according to claim 11, wherein the pressurizing means are arranged for keeping a pressure difference over the at least one nozzle at at most 15 bar, preferably at at most 12 bar.

13. Apparatus according to one of claims 7-12, further comprising a pressure varying means ~~(50)~~ in the fluid ~~(4)~~ near the nozzle, the pressure varying means arranged for generating dynamic pressure variations in the fluid ~~(4)~~ near the nozzle ~~(14)~~ that propagate through the nozzle ~~(14)~~ and cause a controlled breakup of the fluid jet flowing out of the nozzle ~~(14)~~, the broken up fluid jet forming substantially mono-disperse droplets ~~(18)~~.

14. Apparatus according to one of claims 7-13, wherein the pressure varying means ~~(50)~~ comprises a pressure focusing member arranged such that an end of the pressure focusing member facing the nozzle ~~(14)~~ is placed at a distance of 2-1000 µm from the outflow opening and wherein the pressure focussing member and/or the nozzle plate are arranged for vibrating with respect to each other for varying the pressure adjacent the outflow opening.