

NEBULISER OUTLET

5 CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority from and the benefit of United Kingdom patent application No. 2310637.0 filed on 11 July 2023, the entire contents of which is incorporated herein by reference.

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FIELD

The present invention relates to a nebuliser outlet and, in particular, to a nebuliser outlet for an ion source that can support a capillary therein for supplying a liquid to be

15 nebulised by a gas supplied through the nebuliser outlet.

BACKGROUND

A nebuliser may be utilised in ionisation techniques, such as Electrospray Ionisation (ESI), to generate a spray of droplets from which ions can be obtained.

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Such nebulisers typically comprise a removable liquid capillary arranged coaxially within a surrounding gas conduit. In this arrangement, liquid supplied through and out of the liquid capillary is nebulised by a flow of gas supplied via the gas conduit.

The positioning of the liquid capillary and the resulting geometry of the nebuliser outlet can significantly affect the properties of the nebulised spray of droplets, which can correspondingly affect the ion signal detected for ions obtained from the spray of droplets. To control this, the position of the liquid capillary within the nebuliser outlet can be optimised during an experiment by detecting ions using an analytical instrument and adjusting the position of the liquid capillary until a desired ion signal is achieved.

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To reduce the possible variation in the radial positioning of the capillary, a nebuliser outlet may be provided with a conduit for supporting the liquid capillary and separate gas channels for providing the nebulising gas. However, providing the required structure to separate the channels from the liquid capillary conduit can affect the gas flow properties in a manner that negatively impacts the spray characteristics of the nebuliser.

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SUMMARY

According to a first aspect of the present invention, a nebuliser outlet is provided, comprising:

- 5 an outer wall;
- a liquid capillary support conduit arranged radially inward of the outer wall for radially confining a liquid capillary therein;
- a radial support structure that radially connects the liquid capillary support conduit to the outer wall in a manner such that one or more gas channels are provided radially
- 10 between the outer wall and the liquid capillary support conduit;
- a first annular channel surrounding the liquid capillary support conduit at a first position that is axially upstream of the radial support structure, and a second annular channel surrounding the liquid capillary support conduit at a second position that is axially downstream of the radial support structure, wherein the one or more gas channels connect
- 15 the first and second annular channels.

The liquid capillary support conduit can control the radial position occupied by a liquid capillary within the nebuliser outlet, when the liquid capillary is inserted into the liquid capillary support conduit. The first and second annular channels, and the one or more gas channels that interconnect them, allow nebulising gas to be passed downstream through

20 the nebuliser outlet, radially outward of the liquid capillary support conduit. The nebulising gas can therefore be passed from the upstream end of the nebuliser outlet to the downstream end for nebulising a liquid that is supplied through a liquid capillary within the support conduit.

Each of the first and second annular channels fully surrounds the circumference of

25 the liquid capillary support conduit. This allows a nebulising gas to be distributed around the full circumference of the liquid capillary support conduit at the location where the nebulising gas enters the one or more gas channels and at the location where the nebulising gas leaves the one or more gas channels. This provides relatively consistent and efficient nebulisation by allowing for high uniformity of the gas flow around the capillary

30 and reducing or negating turbulence within the gas flow. Furthermore, by providing the first and second annular channels axially either side of the radial support structure, the nebuliser outlet can require less material to construct compared to if the radial support structure extended the full distance along the liquid capillary support conduit.

As the first and second annular channels are annular, there is 360-degree free

35 space surrounding the liquid capillary support conduit at these regions (i.e. there is no radial connection between the outer wall and the liquid capillary support conduit in these regions). However, as the one or more gas channels are provided by the radial support

structure, a radial connection between the liquid capillary support conduit and the outer wall is present in the region where the radial support structure is located.

The radial support structure may comprise one or more radial supports, wherein each radial support extends in a radial direction (perpendicular to the longitudinal axis of the nebuliser outlet), so as to radially connect the liquid capillary support conduit to the outer wall.

The radial support structure may comprise a plurality of radial supports connecting the liquid capillary support conduit to the outer wall, and the plurality of radial supports may be spaced apart in a circumferential direction around the liquid capillary support conduit so as to define said gas channels therebetween.

Accordingly, the radial support structure may comprise radial supports that are spaced circumferentially (azimuthally) around the longitudinal axis of the nebuliser outlet.

The gas channels may each be located between pairs of the radial supports. For example, there may be three radial supports circumferentially separated from one another to provide three gas channels. Other numbers of radial supports and gas channels may be provided. For example, there may be from 2 to 10 gas channels and/or radial supports. However, it has been recognised that ideally a single gas channel would be provided that fully surrounds the liquid capillary support conduit. Therefore, a low number of gas channels is generally desired, where the gas channels may have a relatively large cross-sectional area in the direction perpendicular to the longitudinal axis of the nebuliser outlet.

The one or more gas channels may extend in straight path(s) from the first annular channel to the second annular channel, and may extend substantially parallel to the longitudinal axis of the nebuliser outlet.

Each gas channel may have an arcuate cross-sectional shape in the plane orthogonal to the longitudinal axis of the nebuliser outlet.

The gas channels may be equally sized and may each have the same cross-sectional shape. The gas channels (and radial supports) may be spaced around the liquid capillary support conduit equidistantly.

The second annular channel may extend in the downstream direction from the radial support structure to a downstream end of the liquid capillary support conduit.

Providing an annular channel at the downstream end of the liquid capillary support conduit can allow a gas flow that is substantially uniform around a liquid capillary that is supported by the liquid capillary support conduit. In other words, this annular channel allows the circumferentially segmented gas flow from the gas channels through the radial support structure to be redistributed and re-mix before reaching the end of the liquid capillary.

The liquid capillary support conduit can support a liquid capillary that extends from an inlet aperture to the outlet aperture of the nebuliser outlet. In other words, the downstream end of the liquid capillary may be located at or downstream of the outlet aperture of the nebuliser outlet. Alternatively, the downstream end of a liquid capillary supported by the liquid capillary support conduit may be retained upstream of the outlet aperture of the nebuliser outlet such that liquid supplied out of the liquid capillary meets with the gas inside the nebuliser outlet and a resulting nebulised spray is emitted from the outlet aperture.

The first and second annular channels may have larger outer circumferences than the circumference of the outlet aperture, so that the nebuliser outlet can accommodate the liquid capillary support conduit within the first and second annular channels. However, the second annular channel may taper radially inwards towards the outlet aperture, to allow a smooth transition in diameter towards the outlet aperture and provide relatively little turbulence in the gas flow.

The downstream end of the liquid capillary support conduit may be located upstream from the outlet aperture of the nebuliser outlet, to allow the gas to flow more closely to the capillary at the downstream end. An outer circumference of the liquid capillary support conduit may taper radially inward in the downstream direction proximate the downstream end of the liquid capillary support conduit. This may avoid abrupt changes in a direction of the gas flow at the downstream end of the liquid capillary support conduit to avoid turbulence. For example, the second annular channel may taper radially inwards towards the outlet aperture whilst maintaining a substantially constant separation between the liquid capillary support conduit and the outer wall.

A region that is within the outer wall of the nebuliser outlet and proximate to the outlet aperture may taper radially outward in the downstream direction towards the outlet aperture, so as to provide an outwardly flared outlet, e.g. in the shape of a frustum of a cone. The region that tapers radially outwards towards the outlet aperture is preferably immediately adjacent to the outlet aperture and is provided between the outlet aperture and the second annular channel. An outlet that tapers (flares) radially outward has been found to be beneficial for nebulisation compared to an outlet of constant cross-sectional shape, in that an outwardly tapered (e.g. conical) shaped outlet may provide more consistency in the nebulised spray properties between uses (when the capillary may be removed and re-inserted) and/or from one nebuliser outlet to another than is intended to be manufactured to the same specification.

The outer diameter of the outer wall may be reduced at an upstream portion of the nebuliser outlet to allow the upstream portion of the nebuliser outlet to be inserted into a tube for supplying the gas into the nebuliser outlet. A downstream portion of the nebuliser

outlet therefore has a larger diameter, and the downstream end of the tube may abut against the portion having the larger diameter when the nebuliser outlet is inserted into the tube. The upstream portion of the nebuliser outlet may then be secured to the tube, e.g. by welding.

- 5 The second annular channel may extend within the upstream portion of the nebuliser outlet where the outer diameter of the outer wall is reduced, such that an outer diameter of the outer wall around the first annular channel is smaller than an outer diameter of the outer wall around the second annular channel.

 In use, the nebulising gas may be provided through the inlet aperture of the
10 nebuliser outlet (that the capillary may also be inserted through).

 The first annular channel may have a length along a longitudinal axis of the nebuliser outlet of at least 5 mm.

 The second annular channel may have a length along a longitudinal axis of the nebuliser outlet of at least 5 mm.

- 15 The first annular channel may have a length along a longitudinal axis of the nebuliser outlet between 0.2 mm and 50 mm and/or the second annular channel may have a length along a longitudinal axis of the nebuliser outlet between 0.2 mm and 50 mm.

 For example, the first and/or second annular channel may have a length along a longitudinal axis of the nebuliser outlet of at least 0.2 mm, of at least 1 mm, of at least
20 5 mm, of at least 10 mm, of at least 15 mm, of at least 20 mm, or of at least 25 mm.

 The nebuliser outlet may comprise a funnel portion having a tapered wall for guiding a liquid capillary, when inserted through an inlet aperture of the nebuliser outlet, into the liquid capillary support conduit.

- The funnel portion can allow the inlet aperture at the upstream end of the nebuliser
25 outlet to have a larger diameter than the liquid capillary supporting conduit so that the liquid capillary can be more easily inserted through the (larger) inlet aperture but guided by the funnel portion into the liquid capillary support conduit. The funnel portion may taper inwards in the downstream direction (for example at a substantially constant rate) so as to provide a smooth surface for guiding the liquid capillary and avoiding the capillary being
30 snagged during insertion. For example, the funnel portion may enclose a region in the shape of the frustum of a cone or dome. The funnel portion may be joined to the outer wall at the upstream end of the funnel portion. The funnel portion may be joined to the liquid capillary support conduit at a downstream end of the funnel portion (e.g. such that the liquid capillary support conduit is joined to the outer wall via the funnel portion).

- 35 The funnel portion may comprise one or more gas flow apertures through its tapered wall for supplying a gas passing through the funnel portion into the first annular channel.

The funnel portion also has an aperture for the liquid capillary to pass through and into the liquid capillary support conduit, and said aperture is preferably on the central axis of the funnel portion.

5 The one or more gas flow apertures are sized such that the liquid capillary cannot pass into them. The one or more gas flow apertures preferably each have a width or diameter less than that of the liquid capillary to avoid the capillary passing through the gas flow aperture. A plurality of separate gas flow apertures (e.g. slots) may extend through the wall of the funnel portion and may be spaced circumferentially (azimuthally) around the longitudinal axis. The one or more gas flow apertures may be equally spaced around the
10 longitudinal axis and may be positioned in a manner that provides rotational symmetry around the longitudinal axis.

The first annular channel may extend between the one or more gas flow apertures in the funnel portion and the one or more gas channels provided by the radial support structure. For example, the first annular channel may be bounded by the wall of the funnel
15 portion, the upstream end of the radial support structure, the outer wall and an outer surface of the capillary support conduit.

A different number of gas flow apertures in the funnel portion to the number of one or more gas channels provided by the radial support structure may be provided, for example there may be a greater number of gas flow apertures than gas channels.

20 Providing the first annular channel between the one or more gas flow apertures and the one or more gas channels allows the circumferentially segmented gas flow through the gas flow apertures in the funnel portion to be redistributed such that it can more efficiently enter the one or more gas channel in the radial support structure. This can also avoid the need to align the gas flow apertures with the gas channels, so as to give more design
25 freedom to the nebuliser outlet.

The Applicant believes that this arrangement of the funnel portion and first annular channel is novel and inventive in its own right.

Thus, according to a second aspect of the present invention, a nebuliser outlet is provided, comprising:

- 30 an outer wall;
a liquid capillary support conduit within the outer wall for radially confining a liquid capillary therein;
a radial support structure that radially connects the liquid capillary support conduit to the outer wall in a manner such that one or more gas channels are provided radially
35 between the outer wall and the liquid capillary support conduit;
a first annular channel surrounding the liquid capillary support conduit at a position that is upstream of the radial support structure; and

a funnel portion at a position that is upstream of the first annular channel and having a tapered wall for guiding a liquid capillary into the liquid capillary support conduit, the funnel portion comprising one or more gas flow apertures in its wall for supplying a gas passing therethrough into the first annular channel region.

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The nebuliser outlet of the second aspect of the present invention may comprise any other features of a nebuliser outlet described herein.

For example, the nebuliser outlet may have any of the features described in relation to the first aspect of the present invention except that it may or may not have the second
10 annular channel.

The radial support structure may comprise a plurality of radial supports connecting the liquid capillary support conduit to the outer wall; and the one or more gas channels may be plural gas channels that are each provided between radial supports.

There may be a different number of gas channels to the number of gas flow
15 apertures; and/or

at least some of the gas flow apertures in the funnel portion may be circumferentially located such that they are not axially aligned with any of the gas channels.

The first annular channel may have a length along a longitudinal axis of the nebuliser outlet of at least 5 mm.

20 The first annular channel may have a length along a longitudinal axis of the nebuliser outlet between 0.2 mm and 50 mm.

For example, the first annular channel may have a length along a longitudinal axis of the nebuliser outlet of at least 0.2 mm, of at least 1mm, of at least 5 mm, of at least 10 mm, of at least 15 mm, of at least 20 mm, or of at least 25 mm.

25 The liquid capillary support conduit may be connected to the outer wall via the funnel portion.

Connecting the liquid capillary support conduit to the outer wall via the funnel portion can provide additional support to the liquid capillary support conduit to maintain its position in conjunction with the radial support structure.

30 Furthermore, the Applicant has found that the funnel portion can provide sufficient radial support to avoid radial support(s) being required towards the downstream end of the liquid capillary support conduit in order to maintain the position of the liquid capillary. This can allow a high uniformity of gas flow around the downstream end of the liquid capillary support conduit and the Applicant believes a nebuliser outlet having this geometry is novel
35 and inventive in its own right.

Thus, according to a third aspect of the present invention, a nebuliser outlet is provided, comprising:

an outer wall;

a liquid capillary support conduit within the outer wall for radially confining a liquid capillary therein;

5 a funnel portion for guiding a liquid capillary into the liquid capillary support conduit, wherein the liquid capillary support conduit is joined to the outer wall via the funnel portion; and

an annular channel between the liquid capillary support conduit and outer wall, the annular channel extending upstream from the downstream end of the liquid capillary support conduit for at least a distance of 5 mm.

10 The nebuliser outlet of the third aspect of the present invention may comprise any other features of a nebuliser outlet described herein.

For example, the annular channel surrounds the full circumference of the liquid capillary support conduit, i.e. the annular channel is a 360-degree free space surrounding the liquid capillary support conduit.

15 The annular channel may extend upstream from the downstream end of the liquid capillary support conduit for at least 5 mm, for at least 10 mm, for at least 15 mm, for at least 20 mm, or for at least 25 mm.

The annular channel may extend upstream from the downstream end of the liquid capillary support conduit for at least a third of the axial length of the liquid capillary support conduit, for at least half of the axial length of the liquid capillary support conduit, or for at least two thirds of the axial length of the liquid capillary support conduit.

20 The nebuliser outlet may have any of the features described in relation to the first or second aspect of the present invention except that it may or may not have a radial support structure and/or said first annular channel region upstream of a radial support structure. If the radial support structure is provided it may be provided upstream from the annular channel (of the third aspect of the invention) and at a distance greater than 5 mm from the downstream end of the liquid capillary support conduit. However, it is preferred that such a radial support structure is not provided and that the liquid capillary support conduit may be joined to the outer wall solely by the funnel portion with no other radial support provided.

30 Thus, the annular channel may extend downstream from the funnel portion to the downstream end of the liquid capillary support conduit; and/or

the liquid capillary support conduit may be joined to the outer wall solely by the funnel portion.

35 Features described herein in relation to the first and/or second annular channel may also apply to the annular channel in the third aspect of the present invention, as appropriate.

For example, the funnel portion may comprise one or more gas flow apertures through its wall for supplying a gas passing through the funnel portion into the annular channel.

5 The annular channel may have a larger outer circumference than the circumference of the outlet aperture of the nebuliser outlet, so that the nebuliser outlet can accommodate the liquid capillary support conduit within the annular channel. However, the annular channel may taper radially inwards as a function of position towards the outlet aperture, to allow a smooth transition in outer diameter towards the outlet aperture and provide relatively little turbulence in the gas flow.

10 An outer circumference of the outer wall around an upstream portion of the annular channel may be smaller than an outer circumference of the outer wall around a downstream portion of the annular channel. An outer circumference of the upstream portion of the annular channel may be less than an outer circumference of the downstream portion of the annular channel, so as to accommodate a decrease in outer circumference of the outer wall. An outer circumference of the liquid capillary support conduit may be 15 smaller in the upstream portion of the annular channel than the downstream portion of the annular channel, e.g. so as to provide a substantially constant separation between the liquid capillary support conduit and the outer wall in the first and second annular channels.

20 In any of the aspects of the present invention, the liquid capillary support conduit may comprise an elongate structure in the shape of a tube, e.g. a cylinder, having an annular cross-section.

The liquid capillary support conduit may have a length along the axial direction of the nebuliser outlet of at least 5 mm, such as of at least 10 mm, of at least 15 mm, of at least 20 mm, or of at least 25 mm.

25 The inner diameter of the liquid capillary support conduit may decrease in the downstream direction.

For example, the inner diameter of the liquid capillary support conduit may decrease in a stepped manner in the downstream direction (e.g. at a position downstream of the funnel portion). In this regard, the inner diameter of the liquid capillary support 30 conduit is preferably about the same as the outer diameter of the liquid capillary. However, any manufacturing defects in the nebuliser outlet that unintentionally restrict the cross-sectional size of the inner diameter of the liquid capillary support conduit may prevent the liquid capillary from passing therethrough. For example, if the nebuliser outlet is made using additive manufacturing (as discussed below) a nodule of material may accidentally 35 be formed inside the conduit. To address this, the smallest inner diameter of the liquid capillary support conduit may be reserved for only the downstream end portion of the conduit to reduce the chance of any such defect being problematic to the insertion of the

liquid capillary. The conduit may have a substantially constant inner diameter over an upstream portion of its length and may transition to a smaller substantially constant inner diameter over a downstream portion of its length.

5 The liquid capillary support conduit may have a straight channel therethrough that is co-axial with the inlet aperture and outlet aperture of the nebuliser outlet. This can provide a straight path to guide a liquid capillary to the radial centre of the outlet aperture.

However, alternatively, the liquid capillary support conduit may have a curved channel therethrough.

10 The curved channel has a central axis that extends along the length of the channel and is curved. The curved channel is configured such that when a liquid capillary is inserted therethrough, the liquid capillary is supported by the wall of the curved channel at contact points located on opposing sides of the liquid capillary so as to radially confine the liquid capillary.

15 The Applicant has recognised that a liquid capillary support conduit having a channel with a degree of curvature along its length may still allow a liquid capillary to pass through the conduit, but the curvature can cause opposing sides of the capillary to be in contact with the conduit wall so as to fix the radial position of the capillary. This technique has been found to provide a precise radial positioning of a liquid capillary within the nebuliser outlet, and can be even more precise than that obtained by attempting to locate a
20 straight liquid capillary support conduit at the desired radial position. For example, a straight channel may require sufficient cross-sectional size for a liquid capillary to reliably pass therethrough (and may be made larger than the diameter of the liquid capillary in order to account for manufacturing tolerances). In contrast, a liquid capillary may have less radial freedom in a conduit having a curved channel where the curved internal walls of the
25 conduit contact opposing sides of the liquid capillary.

The Applicant believes that providing a conduit having a curved channel to radially confine the position of a liquid capillary in the manner disclosed herein is novel and inventive in its own right.

30 Thus, according to a fourth aspect of the present invention, a nebuliser outlet is provided, comprising

a liquid capillary support conduit having a channel therethrough with a curved central axis.

35 The channel of the liquid capillary support conduit is configured to radially confine a liquid capillary therein by supporting the liquid capillary at contact points on opposing sides of the liquid capillary.

The nebuliser outlet of the fourth aspect of the present invention may comprise any other features of a nebuliser outlet described herein.

For example, the nebuliser outlet comprises an outer wall and the liquid capillary support conduit may be arranged radially within the outer wall such that one or more gas channels are provided radially between the outer wall and the liquid capillary support conduit.

5 The nebuliser outlet may comprise a radial support structure that radially connects the liquid capillary support conduit to the outer wall. The one or more gas channels may pass between radial supports of the radial support structure. The nebuliser outlet may comprise one or more annular channels surrounding the liquid capillary support conduit at positions along its length.

10 The curved channel may provide two, three, or more points of contact between a liquid capillary and the liquid capillary support conduit, when the liquid capillary is inserted into the curved channel. The channel may have one or more turning points in its curvature. For example, there may be a single turning point after which the channel curves back on itself (e.g. and there may be three contact points with the liquid capillary), or there may be
15 plural turning points such that the channel curves in one direction and then another direction.

The channel may curve along its entire length or only a portion of the channel may be curved. For example, the channel may be configured to have a curved portion arranged between straight portions. The straight portions may be at the ends of the liquid capillary support conduit and may be coaxial with the inlet and outlet apertures of the nebuliser outlet.
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The channel may have a substantially constant diameter along its entire length or at least a portion of the channel may have a substantially constant diameter. The channel may curve whilst maintaining a substantially constant diameter such that the channel
25 comprises at least a curved portion that has a substantially constant diameter.

The nebuliser outlet may comprise an inlet aperture and an outlet aperture that the liquid capillary support conduit extends between. The channel may be curved in a manner such that the liquid capillary can extend from the inlet aperture to the outlet aperture, through the curved channel, without the liquid capillary bending. As such, a straight liquid
30 capillary may be maintained substantially straight and radially confined by the curved channel. Alternatively, the degree of curvature of the channel may be such that there is no straight path extending through the curved channel from the inlet aperture to the outlet aperture. In this regard, a (initially straight) capillary may bend when inserted along the curved channel .

35 The central axis through the outlet aperture may be co-axial with the inlet aperture.

Alternatively, the central axis through the outlet aperture may be radially offset from the central axis through inlet aperture, and/or at an angle thereto. For example, in

embodiments in which the curved channel bends the liquid capillary, the central axis through the outlet aperture may be angled relative to the central axis through the inlet aperture such that the longitudinal axis of the downstream end portion of the bent capillary remains coaxial with the central axis of the outlet aperture.

5 This can allow a uniform gas flow around the capillary at the exit aperture.

The entirety of a nebuliser outlet as described herein may be a single integral component.

As such, in this case the outer wall and the liquid capillary support conduit are integrally connected to one another.

10 The Applicant has found that an additive manufacturing process may also be applicable to other nebuliser outlet geometries that can radially confine a capillary therein and that are believed to be novel and inventive in their own right, such as by utilising radial fins to confine the position of a liquid capillary.

In accordance with a fifth aspect of the present invention, a nebuliser outlet is
15 provided, comprising:

an outer wall having an inlet aperture and an outlet aperture spaced apart from one another in an axial direction; and

a plurality of fins extending radially inwards from the outer wall for confining a liquid capillary provided through the inlet aperture at a position concentric to the outlet aperture;

20 wherein the plurality of fins provide gas channel regions therebetween spaced apart in a circumferential direction around the inside of the outer wall;

and wherein the entirety of the nebuliser outlet is a single integral component.

Providing a nebuliser outlet as described herein as a single integral (monolithic) component (instead of being an assembly of separately manufactured components) can
25 avoid manufacturing tolerances allowing for movement between relative portions of the nebuliser outlet, and allow for consistency of the geometry throughout the lifetime of the nebuliser outlet. In particular, having the liquid capillary support conduit integral with the outer wall can provide a consistent radial positioning of a liquid capillary within the support conduit relative to an outlet aperture through the outer wall, so as to provide consistent
30 spray characteristics for a liquid output from the conduit and nebulised by a gas flow.

Due to manufacturing considerations, a nebuliser outlet provided as a single component may typically have a uniform geometry along substantially all of its length, where channels may be manufacturing with a drilling technique, for example. However, the Applicant has recognised that additive manufacturing techniques are suitable for providing
35 the nebuliser outlet as a single integral component with an internal geometry that varies along the length. Varying the geometry along the length of the nebuliser outlet can provide features described herein such as a curved channel, non-annular channels between

annular channels, and portions of the nebuliser outlet that taper inward or outward, for example.

An alternative manner of providing a nebuliser outlet with a geometry that varies along the length may be to provide a separately manufactured distal tapered portion at the tip of the nebuliser outlet that can fill a larger aperture in the nebuliser outlet used to provide tooling access during manufacture. However, this may introduce manufacturing/assembly tolerances referred to above that affect the consistency of positioning of the capillary relative to the outlet aperture. Furthermore, providing the nebuliser outlet as a single component allows any seal/weld to be provided further upstream between the nebuliser outlet and the upstream assembly, compared to if this is provided to connect a tapered portion at the tip of the nebuliser outlet, where a weld close to the tip may cause an unwanted discharge when a high voltage is provided in this region for electrospraying.

Accordingly, the present invention also provides a method of manufacturing a nebuliser outlet comprising using an additive manufacturing process to provide a nebuliser outlet as described herein.

For example, the additive manufacturing process may comprise a Selective Laser Melting (SLM) process, a stereolithography (SLA) process or an or electron-beam additive manufacturing process.

The method may comprise manufacturing the nebuliser outlet solely by an additive manufacturing process or one or more other processes may be used, e.g. following the additive manufacturing process. For example, the method may further comprise inserting a tool through the liquid capillary support conduit to dislodge undesired material protruding radially inward into the channel, such as nodules of material accidentally provided during the additive manufacturing process.

The additive manufacturing process may comprise laying down powdered material and applying energy to that material so as to solidify it. This may be repeated until the nebuliser outlet has been built up to its final form. Features of the nebuliser outlet described herein may assist with removing excess powdered material that was not solidified during the additive manufacturing process. For example, forming the annular (optionally tapered) channels around parts of the geometry allows for the excess material to be efficiently removed from inside the nebuliser outlet.

Accordingly, the method of manufacturing may comprise providing a gas flow through the nebuliser outlet so as to remove powdered material used to form the nebuliser outlet.

The present invention also provides a nebuliser system comprising a nebuliser outlet as described herein and a liquid capillary for providing a liquid to be nebulised.

The capillary may be made of, for example, a ceramic, glass (e.g. the capillary may be a pulled glass capillary), or a metal (e.g. steel).

The capillary may be configured to be insertable and removable from the liquid capillary support conduit.

5 The present invention also provides an ion source comprising a nebuliser system as described herein.

The ion source may comprise an Electrospray Ionisation (ESI) ion source, a Desorption Electrospray Ionisation (DESI) ion source, a Desorption Electro-Flow Focusing Ionisation (DEFFI) ion source, an impactor ion source, or an Atmospheric Pressure
10 Chemical Ionisation (APCI) ion source.

The present invention also provides a method of nebulising a liquid, comprising:
providing a nebuliser system as described herein;
providing the liquid capillary within the nebuliser outlet;
supplying a liquid out of the downstream end of the liquid capillary; and
15 supplying a gas through the nebuliser outlet to nebulise the liquid to thereby provide a nebulised spray.

The capillary may be provided within the liquid capillary support conduit such that the liquid capillary is radially confined therein.

The capillary may be inserted into liquid capillary support conduit via an inlet
20 aperture or outlet aperture of the nebuliser outlet.

In use, the downstream end of the liquid capillary may protrude outward downstream from the outlet aperture or be within the nebuliser outlet upstream from the outlet aperture.

25 BRIEF DESCRIPTION OF THE DRAWINGS

Various embodiments will now be described, by way of example only, and with reference to the accompanying drawings in which:

Figure 1 shows schematically a perspective view of a nebuliser system in
30 accordance with an embodiment of the present invention;

Figure 2 shows schematically a perspective view of a nebuliser outlet in accordance with an embodiment of the present invention;

Figures 3A-B show schematically cross-sectional views of a nebuliser outlet in accordance with an embodiment wherein the nebuliser outlet has first and second annular
35 channels located axially upstream and downstream from a radial support structure supporting a liquid capillary support conduit;

Figures 4A-C show schematically cross-sectional views of a nebuliser outlet in

accordance with another embodiment wherein one continuous axial channel surrounds a liquid capillary support conduit within the nebuliser outlet;

Figures 5A-B show schematically cross-sectional views of a nebuliser outlet in accordance with an embodiment wherein a liquid capillary support conduit of the nebuliser outlet has a curved channel therein;

Figures 6A-C show schematically cross-sectional views of a nebuliser outlet in accordance with another embodiment wherein radial support fins are provided to radially confine a liquid capillary;

Figure 7A shows schematically a front (outlet end) view of the nebuliser outlet of Figures 6A-C with a capillary inserted therein;

Figure 7B shows schematically a back (inlet end) view of the nebuliser outlet of Figures 6A-C.

DETAILED DESCRIPTION

Figure 1 shows a nebuliser system 100 in accordance with an embodiment of the present invention. The nebuliser system 100 is for an ion source, such as an Electrospray Ionisation (ESI) ion source. The nebuliser system 100 comprises a housing assembly 102 for attachment to an analytical instrument, such as a mass and/or ion mobility spectrometer. The nebuliser system 100 further comprises a probe assembly 104 that is shown inserted into the housing assembly 102 in Figure 1.

The probe assembly 104 comprises a capillary 106 for transmitting a liquid (e.g. analyte sample) to be nebulised, an attachment fitting 108 configured for attaching the probe assembly 104 to the housing assembly 102, and a fluid line 110 that, in use, supplies the liquid to the capillary 106. The capillary 106 may be formed from an electrically conductive material, such as a metal (e.g. steel). Alternatively, the capillary may be formed from an electrically insulating material, such as glass, and may optionally have an electrically conductive coating. A voltage may be supplied to the capillary 106 (e.g. via a component of the housing assembly 102) to electrify a liquid such that the nebuliser system 100 emits a spray of charged droplets. The probe assembly 104 may be in accordance with a probe assembly as described in GB 2520389 A (Micromass UK Limited), the entire content of which is incorporated herein by reference.

The housing assembly 102 comprises a conduit 112 that surrounds the capillary 106 when the probe assembly 104 is inserted into the housing assembly 102. The nebuliser outlet 114 may be provided as a device that is attachable to the conduit 112 that forms part of the housing assembly 102. For example, the nebuliser outlet 114 may be welded (e.g. laser welded) to the conduit 114 of the housing assembly 102. However,

alternatively, the nebuliser outlet 114 may otherwise be attachable to, and/or form part of, the probe assembly 104. The nebuliser outlet 114 can receive the liquid capillary 106 therein and a supply of a gas from the conduit 112. The nebuliser outlet 114 is configured to, in use, output a nebulising gas flow to nebulise liquid that is output from an outlet end of the capillary 106 to thereby form droplets. The outlet end of the capillary 106 may be located within the nebuliser outlet 114 or the capillary may extend through the nebuliser outlet 114 and protrude from the nebuliser outlet 114 such that the outlet end of the capillary 106 is located outside of the nebuliser outlet 114. The probe assembly 104 may control the length of the capillary 106 extending into the housing assembly 102 to control the position of the outlet end of the capillary 106 relative to the nebuliser outlet 114 (to control the distance that the outlet end of the capillary 106 protrudes from, or is recessed within, the nebuliser outlet 114).

To nebulise a liquid using the nebuliser system 100, the probe assembly 104 is inserted into the housing assembly 102 such that the capillary 106 is received within the nebuliser outlet 114 and is surrounded by the conduit 112. A liquid is supplied to an inlet end of the capillary 106 from the fluid line 110 and is output from an outlet end of the capillary 106. A gas is supplied to the nebuliser outlet 114 via the conduit 112 and is output from the nebuliser outlet 114 as a nebulising gas flow to nebulise the liquid that is output from the outlet end of the capillary 106 and thereby form droplets.

Figure 2 shows the nebuliser outlet 114 in accordance with an embodiment of the present invention. The nebuliser outlet 114 may be a single integral component, such that the nebuliser outlet 114 is one continuous component that does not comprise separately manufactured components that are later assembled together. The nebuliser outlet 114 can be formed using an additive manufacturing process, such as Selective Laser Melting (SLM), stereolithography (SLA), or electron-beam additive manufacturing.

The nebuliser outlet 114 comprises a shank 202 for insertion into the conduit 112 of the nebuliser system 100. The shank 202 may comprise one or more attachment structures for locating the nebuliser outlet at a particular position within the conduit 112 and/or attaching the nebuliser outlet 114 to the conduit 112 (releasably or non-releasably). The outer surface of the shank 202 may comprise a plurality of notches 204 as attachment structures. The notches 104 can engage corresponding protrusions on an inner surface of the conduit 112 and/or can provide a recess for an adhesive or a weld to be provided. Alternatively, the shank 202 may be provided with no attachment structures or may be provided with additional or alternative attachment structures such as one or more protrusions or a screw thread. The notches 104 or other markings on the outside of the nebuliser outlet 114 may optionally be used as a visual indication of the internal geometry

of the nebuliser outlet 114, where for example different nebuliser outlets are available with different internal geometries.

Figure 3A shows a cross-sectional view of an embodiment of the nebuliser outlet 114. The cross-section shown in Figure 3A is along plane A shown in Figure 3B. In Figure 3A, the nebuliser outlet 114 is shown connected to conduit 112 and having the capillary 106 inserted therein. The nebuliser outlet 114 comprises an outer wall 304 having an inlet aperture 306 and an outlet aperture 308 therein. The nebuliser outlet 114 has a downstream axial direction 310 from the inlet aperture 106 towards the outlet aperture 308 and an upstream axial direction 312 from the outlet aperture 308 towards the inlet aperture 306. The nebuliser outlet 114 comprises a liquid capillary support conduit 314 within the outer wall 304. The liquid capillary support conduit 314 can radially confine a capillary that extends therein along the upstream and downstream axial directions. The liquid capillary support conduit 314 comprises an elongate structure with an annular cross-section, and the nebuliser outlet 114 comprises a funnel portion 316 upstream of the liquid capillary support conduit 314 arranged such that, when the capillary 106 is inserted through the inlet aperture 306, the funnel portion 316 can guide the capillary 106 into the liquid capillary support conduit 314. The funnel portion 316 has a sidewall that tapers radially inwards from the inlet aperture 306 in the downstream direction 310 to the liquid capillary support conduit 314. The funnel portion 316 may enclose a region in the shape of the frustum of a cone (as shown in Figure 3A) or may have any other suitable tapered geometry, such as with a curved sidewall enclosing a region in the shape of the frustum of a curved dome. The upstream end of the funnel portion 316 is located at and contiguous with the outer wall 304, and the downstream end of the funnel portion 316 is located at and contiguous with the elongate portion 314 of the liquid capillary support conduit 314, such that the liquid capillary support conduit 314 is radially supported within the outer wall 304 via the funnel portion 316, and such that a continuous channel is provided through the funnel portion 316 into the liquid capillary support conduit (e.g. with a common central axis through the funnel portion 316 and the liquid capillary support conduit 314).

The liquid capillary support conduit 314 has an internal diameter substantially the same as (but slightly larger than) the diameter of the capillary 106. At least a portion of the liquid capillary support conduit 314 may have an internal diameter intended to be as small as possible while still allowing the capillary 106 to pass therethrough. However, the greater the proportion of the length of the liquid capillary support conduit 314 that has the smallest diameter the greater likelihood of a manufacturing defect accidentally reducing the diameter at some point along the length (e.g. by an nodule of material extending into the channel of the liquid capillary support conduit) to prevent the capillary 106 passing therethrough. As shown in Figure 3A, the internal diameter of the liquid capillary support

conduit 314 may therefore be reduced (e.g. stepped down) at a position 317 along its length to reduce the proportion having the smallest diameter (e.g. to a portion at the downstream end of the support conduit 314).

5 The nebuliser outlet 114 comprises a radial support structure 318 having a plurality of radial supports 318a-c (best shown in Fig. 3B) that each extend in a radial direction perpendicular to the longitudinal axis of the liquid capillary support conduit 314 and radially connect the elongate portion 314a of the liquid capillary support conduit 314 to the outer wall 304.

10 As shown in Figure 3B, the radial support structure 318 comprises three radial supports 318a-c that are circumferentially spaced around the longitudinal axis so as to define three arcuate gas channels 320 between the radial supports 318a-c, and that are radially between the liquid capillary support conduit 314 and the outer wall 304. However, any other suitable number of one or more radial supports 318a-c and arcuate gas channels 320 may be provided. For example, there may be a single radial support and a single
15 arcuate gas channel 320 with ends on either side of the radial support, or any number of plural radial supports and arcuate gas channels 320 may be provided, such as between 2 and 10 radial supports and/or arcuate gas channels 320.

The liquid capillary support conduit 314 extends beyond the radial supports 318a-c in the upstream 312 and downstream 310 directions, and the nebuliser outlet 114 further
20 comprises a first annular channel 322 and a second annular channel 324. The first annular channel 322 surrounds the liquid capillary support conduit 314 at a first position that is upstream of the radial supports 318a-c, and the second annular channel 324 surrounds the liquid capillary support conduit 314 at a second position that is downstream of the radial supports 318a-c. The first annular channel 322 extends in the downstream direction from
25 the funnel portion 316 to the (upstream end of the) arcuate channels 320. The second annular channel extends in the downstream direction from the (downstream end of the) arcuate channels 320 to the downstream end of the liquid capillary support conduit 314a. By being annular, the first and second annular channels 322, 324 fully surround (360 degrees around) the liquid capillary support conduit 314.

30 Providing annular channels 322, 344 upstream and downstream of the radial support structure 318 allows a nebulising gas to be distributed around the full circumference of the liquid capillary support conduit 314 at the location where the nebulising gas enters the one or more gas channels 320 and at the location where the nebulising gas leaves the one or more gas channels 320. This provides relatively
35 consistent and efficient nebulisation by allowing for high uniformity of the gas flow around the capillary 106 and reducing or negating turbulence within the gas flow before it converges with and nebulises a liquid supplied out of the capillary 106. Furthermore, by

providing the first and second annular channels 322, 344 axially either side of the radial support structure 318, the nebuliser outlet 114 can require less material to construct compared to if the radial support structure 318 extended the full distance along the liquid capillary support conduit 314, and can more fully utilise available space within the nebuliser outlet 114 for the gas flow.

The funnel portion 316 comprises gas flow apertures 326 through the sidewall of the funnel portion 316. Any number of one or more gas flow apertures 326 may be provided, and there may be a different number of gas flow apertures 326 to the number of arcuate gas channels 320. For instance, there may be more gas flow apertures 326 than arcuate gas channels 320 (e.g. double the number or more). The gas flow apertures 326 allow for a gas received via the inlet aperture from the conduit 112 to be supplied into the first annular channel 322 and distributed into the gas channels 320. The gas flow apertures 326 may be in the form of elongated slots. The slots are preferably arranged with their longitudinal axis extending substantially in the downstream direction 310 but may extend radially outward from the liquid capillary support conduit 314 (as shown in Figure 4C). Alternatively, or additionally, the slots may have a width that is smaller than the outer diameter of the capillary 106 (and smaller than an internal diameter of the liquid capillary support conduit 314). These features enable gas to flow through the wall of the funnel portion 316 and into the first annular channel 322 relatively freely, whilst still facilitating the funnel portion 316 to smoothly guide the capillary 106 into the liquid capillary support conduit 314.

In use, a gas is supplied via the conduit 112 into the funnel portion 316 via the inlet aperture 306. The gas passes through the gas flow apertures 326 into the first annular channel 322 and from the first annular channel 322 to the second annular channel via the arcuate channels 320. From the second annular channel 324, the gas is supplied to the outlet aperture 308 to nebulise a liquid supplied out of a downstream end 106a of the capillary 106. The capillary 106 is shown protruding out of the outlet aperture 308 in Figure 3A. However, the downstream end 106a of the capillary 106 may instead be located within the nebuliser outlet 114 at a point downstream of the liquid capillary support conduit 314 such that the gas mixes with the liquid within the nebuliser outlet 114 between the outlet aperture 308 and the downstream end 106a of the capillary 106.

The second annular channel 324 tapers radially inwards in the downstream direction 310 towards the outlet aperture 308. An outer circumference of the liquid capillary support conduit 314 may also taper radially inward in the downstream direction 310 proximate a downstream end 3144 of the liquid capillary support conduit 314 so as to provide a smooth transition in the direction of the gas flow towards the outlet aperture 308 (to avoid turbulence in the gas flow).

If the nebuliser outlet is manufactured using additive manufacturing (e.g. a Selective Laser Melting (SLM) process), having the downstream end of the second annular channel 324 taper radially inwards can also allow for excess material (e.g. powder that is not melted to form the nebuliser outlet 114) to more easily flow out of the nebuliser outlet 114 in the downstream 310 direction. The first and second annular channels 322, 324 may also provide for efficient removal of excess material between the liquid capillary support conduit 314 and the outer wall 304.

A distal end portion 328 of the nebuliser outlet 114 adjacent to the outlet aperture 308 may taper radially outward in the downstream direction 310 towards the outlet aperture 308 to provide an outlet in the shape of a frustum of a cone. Compared to an outlet of constant cross-sectional shape, an outwardly tapered (e.g. conical) shaped outlet may provide more consistency in the nebulised spray properties between uses (when the capillary 106 may be removed and re-inserted) and/or from one nebuliser outlet to another than is intended to be manufactured to the same specification.

The first annular channel 322 extends within the shank 202 of the nebuliser outlet where the outer wall 304 has a reduced outer diameter relative to a downstream axial position where the outer wall 304 has a larger outer diameter around the second annular channel 324. An outer diameter of the liquid capillary support conduit 314 is also reduced in the shank 202 to provide substantially the same separation between the liquid capillary support conduit 314 and the outer wall 304 in the first and second annular channels 322, 324, and allows for smooth transitions in the flow path therebetween.

Figures 4A-C show cross-sectional views of the nebuliser outlet 114 in accordance with another embodiment of the present invention in which the liquid capillary support conduit 314 is only supported at its upstream end.

Figure 4B shows a cross-sectional view along plane B shown in Figure 4A, wherein in Figure 4B the downstream direction is directed into the page.

Figure 4C shows a cross-section view along plane C shown in Figure 4A, wherein in Figure 4C the upstream direction is directed into the page.

This embodiment of the nebuliser outlet 114 may have any features described above in relation to Figures 3A-B apart from that in this embodiment the radial support structure is omitted. The same reference numerals used in Figures 4A-C represent the same components as described above.

The liquid capillary support conduit 314 is supported within the outer wall 304 solely by the funnel portion 314b with an annular channel 425 extending from the funnel portion 314b to the downstream end of the liquid capillary support conduit 314c. Having the annular channel 425 extend uninhibited from the funnel portion 316 to the downstream end 314a of the liquid capillary support conduit allows for a uniform gas flow in the axial

direction with substantially no change in direction required such that turbulence may be reduced or negated before the gas flows further downstream to the outlet aperture 308.

Figures 5A-B show cross-sectional views of the nebuliser outlet 114 in accordance with another embodiment of the present invention.

5 Figure 5A shows the full length of the nebuliser outlet 114 and includes a capillary 106 inserted through the nebuliser outlet 114. Figure 5B shows the geometry at the downstream end of the nebuliser outlet 114.

10 The nebuliser outlet 114 may have any of the features described above in relation to the other embodiments of the nebuliser outlet 114 and the same reference numerals represent the same components.

15 However, the nebuliser outlet 114 differs from the embodiments shown in Figures 3A-B and 4A-C in that the central longitudinal axis 502 of the channel of the liquid capillary support conduit 314 is curved such that the capillary 106 is supported within the liquid capillary support conduit 314 by contact points 404 between the capillary 106 and the liquid capillary support conduit 314 on opposing sides of the capillary 106. One or more turning points 403 in the curvature of the channel within the liquid capillary support conduit 314 may be provided part way along its length, and two or more contact points 404 may be present between the capillary 106 and the liquid capillary support conduit 314.

20 Although in Figure 5A the capillary 106 is shown bending as it extends through the liquid capillary support conduit, in other embodiments the bend in the channel may be less pronounced such that the capillary 106 is able to remain substantially straight as it extends through the curved channel, whilst still being supported at the contact points 404.

25 Figure 5B shows that the distal end portion 328 of the nebuliser outlet 114 may be angled relative to the longitudinal axis of the nebuliser outlet to provide a capillary 106 bent away from the longitudinal axial direction with a substantially constant separation between the outer wall 304 and the capillary 106 in the distal end portion 328. For example, the capillary may extend through the distal end portion 328 in a manner that provides full circular symmetry to thereby provide a uniform flow of gas around the capillary for nebulising a liquid supplied out of the downstream end 106a of the capillary 106.

30 The nebuliser outlet 114 in accordance with any of the embodiments shown in Figures 3A-B, 4A-C and 5A-B is preferably a single integral component. As such, (at least) the outer wall and the liquid capillary support conduit are preferably integrally connected to one another. The nebuliser outlet 114 may be manufactured as a single integral component using an additive manufacturing technique. Traditional manufacturing techniques such as milling, turning and joining techniques may require a multipart assembly. However, an unwanted effect of multiple part assemblies is the cumulative tolerances from the manufacturing and assembly processes. Whereas, an additive

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manufacturing process such as SLM can allow creation of sub millimetre sized components formed as a single part which eliminates the multi part tolerance build up.

Figures 6A-C show cross-sectional views of the nebuliser outlet 114 in accordance with another embodiment of the present invention. The nebuliser outlet 114 in

5 Figures 6A-C is a single integral component. As best seen in Figure 6A, the nebuliser outlet 114 comprises an outer wall and a plurality of fins 606 extending radially inwards from the outer wall 604. Figure 6A shows three fins 606 but any number of fins spaced circumferentially around the inside of the outer wall 604 may be provided. The fins 606 provide gas channel regions 608 therebetween spaced apart in a circumferential direction
10 around the inside of the outer wall 604. The fins 606 can guide a liquid capillary along an inner channel region 610 extending along the axial direction surrounded by the fins 606 and the gas channel regions 608.

Figure 6B shows a cross-section along plane A shown in Figure 6A. Figure 6B shows a cross-section along plane B shown in Figure 6A when the nebuliser outlet 114 is
15 inserted into the conduit 112 and the capillary 106 is inserted into the nebuliser outlet 114.

As shown in Figures 6A and 6B, the nebuliser outlet comprises an inlet aperture 612 and an outlet aperture 614 in the outer wall 604 axially spaced apart from one another.

The fins 606 are arranged within the outer wall 604 for confining a liquid capillary provided through the inlet aperture 612 at a position concentric to (radially central to) the
20 outlet aperture 614.

The nebuliser outlet 114 comprises a funnel portion 616 for guiding a liquid capillary into the radial confinement of the fins 606. An intermediate aperture 618 is provided at the downstream end of the funnel portion 616. A nebulising gas can be provided through the funnel portion 616 to the gas channel regions 608. The gas channel regions 608 may
25 extend radially outward from the downstream end of the funnel portion 616. The gas channel regions 608 may taper radially inwards towards the outlet aperture 614. The fins 606 may extend into a tapered region of the nebuliser outlet 114 in which one or more of the gas channel regions 608 tapers radially inwards towards the outlet aperture 614.

Figure 7A shows the nebuliser outlet 114 from the front (outlet) end with the
30 capillary 106 inserted therein. Figure 7B shows the nebuliser outlet 114 from the back (inlet) end.

As shown in Figures 7A-B, the inlet aperture 612 and the outlet aperture 614 are co-axial with the position of a liquid capillary 106 radially confined by the fins 606. The fins 606 extend radially inwards beyond the radial bounds of the outlet aperture 614 and
35 intermediate aperture 618 to radially confine the capillary 106 co-axially to the inlet aperture 614.

The nebuliser outlet 114 in accordance with any of the embodiments described herein may form part of an ion source, such as an Electrospray Ionisation (ESI) ion source. It would also be possible for the nebuliser outlet 114 to form part of another type of ion source that utilises a nebuliser, such as for example a Desorption Electrospray Ionisation (DESI) ion source, a Desorption Electro-Flow Focusing Ionisation (DEFFI), an impactor ion source, or an Atmospheric Pressure Chemical Ionisation (APCI) ion source.

The ion source may form part of, connectable and or used in conjunction with an analytical instrument, such as a mass and/or ion mobility spectrometer. Ions generated by the ion source may be analysed by the analytical instrument, e.g. so as to determine properties of the ions, such as one or more of their mass, mass to charge ratio, ion mobility, etc.

As described herein, in use, the nebuliser outlet 114 can emit a spray of nebulised droplets by nebulising a flow of liquid emitted out of the liquid capillary 106 to produce the spray of droplets. By radially confining the position liquid capillary 106 within the nebuliser outlet 114 and providing a relatively consistent and uniform nebulising gas flow around the liquid capillary 106, the properties of the spray of droplets may be more reliably controlled, which in turn can provide reliable and consistent ion signals for ions obtained from the droplets.

Although the present invention has been described with reference to preferred embodiments, it will be understood by those skilled in the art that various changes in form and detail may be made without departing from the scope of the invention as defined by the accompanying claims.

Claims

- 5 1. A nebuliser outlet, comprising:
 an outer wall;
 a liquid capillary support conduit arranged radially inward of the outer wall for
 radially confining a liquid capillary therein;
 a radial support structure that radially connects the liquid capillary support conduit
10 to the outer wall in a manner such that one or more gas channels are provided radially
 between the outer wall and the liquid capillary support conduit;
 a first annular channel surrounding the liquid capillary support conduit at a first
 position that is axially upstream of the radial support structure, and a second annular
 channel surrounding the liquid capillary support conduit at a second position that is axially
15 downstream of the radial support structure, wherein the one or more gas channels connect
 the first and second annular channels.
2. The nebuliser outlet of claim 1, wherein the radial support structure
 comprises a plurality of radial supports connecting the liquid capillary support conduit to the
20 outer wall, and wherein the plurality of radial supports are spaced apart in a circumferential
 direction around the liquid capillary support conduit so as to define said gas channels
 therebetween.
3. The nebuliser outlet of claim 1 or 2, wherein the second annular channel
25 extends in the downstream direction from the radial support structure to a downstream end
 of the liquid capillary support conduit.
4. The nebuliser outlet of any preceding claim, wherein the first annular
 channel has a length along a longitudinal axis of the nebuliser outlet of at least 5 mm.
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5. The nebuliser outlet of any preceding claim, wherein the second annular
 channel has a length along a longitudinal axis of the nebuliser outlet of at least 5 mm.
6. The nebuliser outlet of any preceding claim, comprising a funnel portion
35 having a tapered wall for guiding a liquid capillary, when inserted through an inlet aperture
 of the nebuliser outlet, into the liquid capillary support conduit.

7. The nebuliser outlet of claim 6, wherein the funnel portion comprises one or more gas flow apertures through its tapered wall for supplying a gas passing through the funnel portion into the first annular channel.

5 8. A nebuliser outlet, comprising:
an outer wall;
a liquid capillary support conduit within the outer wall for radially confining a liquid capillary therein;
a radial support structure that radially connects the liquid capillary support conduit
10 to the outer wall in a manner such that one or more gas channels are provided radially between the outer wall and the liquid capillary support conduit;
a first annular channel surrounding the liquid capillary support conduit at a position that is upstream of the radial support structure; and
a funnel portion at a position that is upstream of the first annular channel and
15 having a tapered wall for guiding a liquid capillary into the liquid capillary support conduit, the funnel portion comprising one or more gas flow apertures in its wall for supplying a gas passing therethrough into the first annular channel region.

9. The nebuliser outlet of claim 8, wherein the radial support structure
20 comprises a plurality of radial supports connecting the liquid capillary support conduit to the outer wall; and wherein the one or more gas channels are plural gas channels that are each provided between radial supports.

10. The nebuliser outlet of claim 7, 8 or 9, wherein there are a different number
25 of gas channels to the number of gas flow apertures; and/or
wherein at least some of the gas flow apertures in the funnel portion are circumferentially located such that they are not axially aligned with any of the gas channels.

11. The nebuliser outlet of claim 8, 9 or 10, wherein the first annular channel
30 has a length along a longitudinal axis of the nebuliser outlet of at least 5 mm.

12. The nebuliser outlet of any one of claims 6-11, wherein the liquid capillary support conduit is connected to the outer wall via the funnel portion.

35 13. A nebuliser outlet, comprising:
an outer wall;

a liquid capillary support conduit within the outer wall for radially confining a liquid capillary therein;

a funnel portion for guiding a liquid capillary into the liquid capillary support conduit, wherein the liquid capillary support conduit is joined to the outer wall via the funnel portion;

5 and

an annular channel between the liquid capillary support conduit and outer wall, the annular channel extending upstream from the downstream end of the liquid capillary support conduit for at least a distance of 5 mm.

10 14. The nebuliser outlet of claim 13, wherein the annular channel extends downstream from the funnel portion to the downstream end of the liquid capillary support conduit; and/or

wherein the liquid capillary support conduit is joined to the outer wall solely by the funnel portion.

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15. The nebuliser outlet of claim 13 or 14, wherein the funnel portion comprises one or more gas flow apertures through its wall for supplying a gas passing through the funnel portion into the annular channel.

20 16. The nebuliser outlet of any preceding claim, wherein the inner diameter of the liquid capillary support conduit decreases in the downstream direction.

17. A nebuliser outlet as claimed in any preceding claim, wherein the liquid capillary support conduit has a curved channel therethrough.

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18. A nebuliser outlet comprising
a liquid capillary support conduit having a channel therethrough with a curved central axis.

30 19. The nebuliser outlet of any preceding claim, wherein the entirety of the nebuliser outlet is a single integral component.

20. A nebuliser outlet, comprising:

35 an outer wall having an inlet aperture and an outlet aperture spaced apart from one another in an axial direction; and

a plurality of fins extending radially inwards from the outer wall for confining a liquid capillary provided through the inlet aperture at a position concentric to the outlet aperture;

wherein the plurality of fins provide gas channel regions therebetween spaced apart in a circumferential direction around the inside of the outer wall;

and wherein the entirety of the nebuliser outlet is a single integral component.

5 21. A method of manufacturing a nebuliser outlet, comprising using an additive manufacturing process to provide the nebuliser outlet of any preceding claim.

 22. A nebuliser system comprising the nebuliser outlet of any one of claims 1-20 and a liquid capillary for providing a liquid to be nebulised.

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 23. An ion source comprising the nebuliser system of claim 22.

 24. A method of nebulising a liquid, comprising:
 providing a nebuliser system as claimed in claim 22;
15 providing the liquid capillary within the nebuliser outlet;
 supplying a liquid out of the downstream end of the liquid capillary; and
 supplying a gas through the nebuliser outlet to nebulise the liquid to thereby provide
a nebulised spray.