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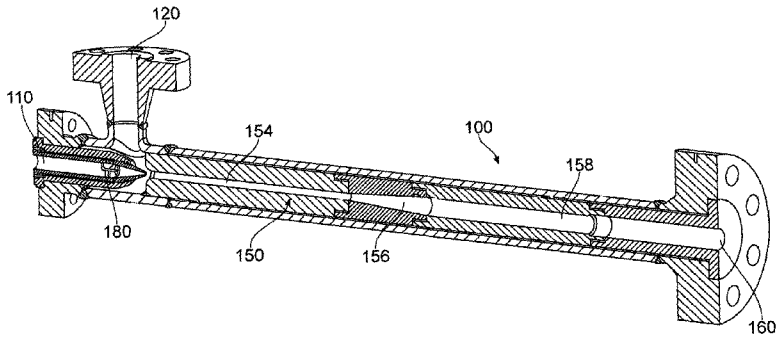


FIG. 2

(57) Abstract: An ejector device (100) for compressing and pumping a fluid, especially a gas, comprises: an injector portion (110), and a diffuser portion (150), the injector portion (110) being arranged for injecting a motive fluid from a motive fluid inlet into the diffuser portion (150) thereby to draw a suction fluid into the diffuser portion (150) from a suction fluid inlet (120), and the diffuser portion (150) including a Venturi portion comprising a converging inlet section (152), a throat section (154) and a diverging outlet section (156), wherein the throat section (154), which is preferably smooth-walled with a uniform diameter along its length, has a length Lt defined by the following equation (I): $L_t > x\ D_t$ (I), where D_t is the diameter of the said throat section (154) and x is a number (especially an integer) greater than 6, preferably greater than 7, especially a number in the range of from about 10 up to about 50. In embodiments the injector portion (110) of the ejector device (100) additionally comprises a rotational deflector element (180), constructed and arranged to rotate motive fluid as its passes from the motive fluid inlet into the diffuser portion (150), comprising a plurality of helical deflector vanes (182a, 182b, 182c) arranged for imparting helical rotation to the motive fluid as its passes the said vanes (182a, 182b, 182c), each said deflector vane (182a, 182b, 182c) having: a longitudinal length being approximately equal to or less than a diameter of the injector portion (110); and a radial twist angle of greater than approximately 30°, preferably a twist angle in the range of from about 35 or 40 ° up to about 80 or 90 °.

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EJECTOR DEVICE AND METHOD

TECHNICAL FIELD

This invention relates to an ejector device. More particularly, though not exclusively, the invention relates to an ejector device for the pumping of a fluid.

BACKGROUND

Ejector devices are well known for the pumping of fluids, e.g. liquids or gases. Known ejector devices typically employ a relatively high pressure fluid (the "motive" fluid) to compress a relatively low pressure fluid (the "entrained" or "suction" fluid) to an intermediate pressure. The fluid at intermediate pressure is then ejected from the ejector device as a "discharge" fluid. Examples of such ejector devices which employ a motive liquid to pressurise a gas may often be termed a "liquid jet compressor" or a "Venturi pump". Ejector devices have an advantage over many conventional mechanical pumps in that they may have substantially no moving parts, so may therefore enjoy a substantially longer service life in many practical applications.

FIG. 1 of the accompanying drawings shows an example of one such known form of ejector device. The ejector device 1 has a motive inlet 10 through which a motive fluid may enter the ejector device 1. The motive fluid may for example be pumped by a pump (not shown) into and through the motive inlet 10. The velocity of the motive fluid increases as it passes through a conical nozzle portion 40 of the ejector device 1 before being injected through an outlet aperture 44 of the nozzle portion 40 at an apex thereof into an inlet aperture 52 of a diffuser portion 50. The diffuser portion 50 provides a fluid conduit in the form of a Venturi tube. That is, a diameter of the conduit initially decreases along a first length of the diffuser portion 50 to a diameter less than that of the inlet aperture 52, and then along a second length of the diffuser portion 50 the diameter of the conduit increases towards an outlet aperture 60 of the diffuser portion 50.

The outlet aperture 44 of the nozzle portion 40 and the inlet aperture 52 of the diffuser portion 50 are in fluid communication with a suction fluid inlet 20 of the ejector device 1. Thus a flow of motive fluid out from the outlet aperture 44 of the nozzle portion 40 and into the diffuser portion 50 mixes the motive and suction fluids. This is accompanied by a transfer of momentum and thus kinetic energy from the motive fluid to the suction fluid, thereby increasing the pressure of the suction fluid phase. It is to be

understood that this is a reverse process to that occurring in the nozzle portion 40 where an increase in motive fluid velocity occurs, thereby reducing a pressure of the motive fluid as it exits the nozzle portion 40 through its outlet aperture 44.

In practical applications of ejectors of the type shown in FIG. 1, the motive fluid may be a liquid or a gas or any other suitable fluid, and the suction fluid may independently also be a liquid or a gas or any other suitable fluid. However, in many particularly useful applications such ejector devices may be used to pressurise and thus pump gaseous fluids, in which case the motive fluid may typically be a liquid phase and the suction fluid may be the gaseous phase to be pumped.

A problem often found with many known designs of ejector device is that they can achieve only limited compression of the "entrained" or "suction" fluid, especially when it is a gas. This places practical limits on such devices' usefulness for pumping gases and other fluids at relatively high pressures. This limited compression of the suction fluid phase has been recognised as resulting from limited transfer of momentum and thus kinetic energy from the motive fluid to the suction fluid as its passes through the ejector device.

Hitherto there have been various attempts at ameliorating this problem of limited momentum and thus kinetic energy transfer from the motive fluid to the suction fluid, in particular by means of imparting a degree of rotational motion to the body of motive fluid as it comes into contact with the suction fluid upon entering the diffuser portion of the ejector device. Examples of prior proposals of this type include the use of twisted deflector fins in the motive fluid inlet (for example as disclosed in US Patent no. US857920) or the provision of helical slots or channels in the element that defines the motive fluid inlet conduit (for example as disclosed in US Patents Nos. US2804341, US3680793 and US5322222). However, such known attempts at generating higher levels of compression in the suction fluid represent only moderate improvements at best, and they still cannot achieve levels of compression that are often desirable in many practical applications, especially those in which relatively high pressure pumping of gases is desirable.

SUMMARY OF THE INVENTION

It is a primary object of the present invention to provide an ejector device which is able to achieve higher levels of compression of a suction fluid by a given motive fluid than has

hitherto been possible using prior art ejector devices.

Aspects of the present invention relate to an ejector device, a pumping apparatus comprising the ejector device, and a method of pumping a fluid using the ejector device or an apparatus comprising the ejector device.

In a first aspect of the invention there is provided an ejector device comprising:

an injector portion, and

a diffuser portion,

the injector portion being arranged for injecting a motive fluid from a motive fluid inlet into the diffuser portion thereby to draw a suction fluid into the diffuser portion from a suction fluid inlet, and the diffuser portion including a Venturi portion comprising a converging inlet section, a throat section and a diverging outlet section,

wherein the throat section of the Venturi portion has a length L_t defined by the following equation (I):

$$L_t > x\, D_t \qquad (I),$$

where D_t is the diameter of the said throat section and x is a number greater than 6.

In some embodiments of the ejector device of the invention the throat section of the Venturi portion may have a substantially uniform diameter along its length. In other words the inner walls of the throat section may be substantially parallel.

In other embodiments, however, the throat section of the Venturi portion may have a non-uniform diameter along its length, e.g. the throat section may include a taper or a non-constant diameter along its length.

In some embodiments of the ejector device of the invention, in the above equation (I) x may be an integer greater than 6.

In some embodiments of the ejector device of the invention, in the above equation (I) x may be a number (e.g. an integer) greater than 7.

In some embodiments of the ejector device of the invention, in the above equation (I) x may be a number (e.g. an integer) in the range of from greater than 6 or 7 up to about 50.

In some embodiments of the ejector device of the invention, in the above equation (I) x

may be a number (e.g. an integer) in the range of from about 10 up to about 50, optionally up to about 40.

In some embodiments of the ejector device of the invention, in the above equation (I) *x* may be a number (e.g. an integer) in the range of from about 20 up to about 30.

It is to be understood that in accordance with many embodiments of the ejector device of the invention the defined length of the throat section of the Venturi portion of the diffuser portion may represent an unusually extended length thereof in comparison with the lengths of corresponding Venturi throat sections of prior art ejector devices. The latter typically have throat sections of relatively short or limited lengths, in order - in accordance with established theory - to minimise frictional energy losses associated with the inner walls of the throat section. However we have now found that it is possible to employ to particularly good effect longer Venturi throat sections, especially longer and often maybe substantially parallel- and smooth-walled Venturi throat sections, and in some embodiments significantly longer such throat sections, than conventional theory suggests would be possible or advantageous. The result is that, owing to the longer Venturi throat section lengths in accordance with many embodiments of the invention, it is possible to effect a greater degree or level of transfer of momentum, and thus kinetic energy, from the motive fluid to the suction fluid, thereby enabling a greater level of compression of the suction fluid as its mixture with the motive fluid passes into and through the diffuser portion of the ejector device.

In embodiments where the ejector device is a liquid jet compressor, i.e. the motive fluid is a liquid phase and the suction fluid to be compressed and/or pumped is a gaseous phase, such an enhanced degree or level of transfer of momentum, and thus kinetic energy, may typically manifest itself as an enhanced degree or level of transfer of momentum, and thus kinetic energy, from particles or droplets of the motive fluid being injected into the diffuser portion of the device and into the suction gaseous phase itself.

In order to enhance the efficacy of the extended length throat sections as defined above in accordance with some embodiments of the invention, the one or more inner walls of at least the throat section of the Venturi portion may be substantially smooth. As mentioned above, the inner walls of the throat section may in some (though not necessarily in all) embodiments preferably be substantially parallel. Such smooth and parallel inner walls of the Venturi throat section may in practice be provided by modern manufacturing, moulding, casing, machining and/or polishing techniques used to form

the ejector device.

In certain embodiments of the ejector device of the invention, one or more further component features may be included for imparting a rotational or helical motion to motive fluid as it passes from the motive fluid inlet into the diffuser portion. It is to be understood that this may be useful for enhancing, increasing or optimising break-up of the motive fluid, especially break-up of particles or droplets thereof when it is a liquid phase, as it passes from the motive fluid inlet into the diffuser portion. The effect of this is to further enhance or increase the degree or level of transfer of momentum, and thus kinetic energy, from the motive fluid to the suction fluid, thereby further increasing a level of compression of the suction fluid as its mixture with the motive fluid passes into and through the diffuser portion of the ejector device.

Accordingly, in some embodiments of the invention the injector portion of the ejector device may additionally comprise a rotational deflector element constructed and arranged to rotate motive fluid as its passes from the motive fluid inlet into the diffuser portion. In other words, the rotational deflector element may be constructed and arranged to force the motive fluid into a helical path as it moves from the motive fluid inlet into the diffuser portion.

In some embodiment forms the rotational deflector element may comprise a plurality of helical deflector vanes arranged for imparting rotation to the motive fluid as its passes the said vanes, each said deflector vane having:

a longitudinal length being approximately equal to or less than a diameter of the injector portion; and

a radial twist angle of greater than approximately 30°.

As used herein the term “radial twist angle” means the angle, measured in a plane perpendicular to a longitudinal axis of the deflector element, through which the respective deflector vane twists in space as it extends along its length in a direction parallel to the said longitudinal direction of the deflector element.

In some embodiments the radial twist angle of each deflector vane may be in the range of from greater than about 30° up to about 90°.

In some embodiments the radial twist angle of each deflector vane may be in the range of from about 35 or 40° up to about 80 or 90°. In some embodiments the radial twist

angle of each deflector vane may be in the range of from about 40° up to about 60 or 70°.

In some embodiments the rotational deflector element may comprise two or more helical deflector vanes.

In some embodiments the rotational deflector element may comprise three, or optionally even 4 (or possibly even more than 4), helical deflector vanes.

In some embodiments the deflector vanes - or deflector blades, as they may alternatively be termed - may each have a substantially flat (or bluff) profile or face on both their leading and trailing edges. This serves to enhance levels of turbulence and mixing of sections of motive fluid present in the respective chambers defined between respective pairs of the deflector vanes as the motive liquid passes thereover. Alternatively, the leading and/or trailing edges may be tapered in order to reduce turbulence.

In some embodiments the rotational or helical motion imparted to the motive fluid by the rotational deflector element may be in the form of a spline line rotation.

In accordance with some embodiment forms of the rotational deflector element, each deflector vane or blade may have a longitudinal length which is approximately equal to or less than substantially a single diameter of the injector portion of the ejector device at the location of the injector portion at which the deflector element is provided. This dimensioning may thus lead to a rotational deflector element that appears substantially square in side-on and/or top (or bottom) profile. This feature may serve to ensure that an optimum, or sufficiently large, rotational force - and thus a resulting turbulence-inducing rotational or helical motion - is imparted to the motive fluid within the shortest longitudinal distance possible, and consequently with as small as possible a potential pressure drop over that longitudinal distance.

For example, by way of comparative explanation, if the rotational configuration of the deflector vanes of the deflector element were instead to extend over a longitudinal length significantly greater than substantially a single diameter of the injector portion of the ejector device, then the efficiency improvements (in terms of minimised potential pressure drop over that longitudinal distance) would be reduced, owing to a longer length of the frictional surfaces of the respective deflector vanes over which the motive fluid must pass.

In some embodiments the rotational deflector element may additionally comprise a longitudinal extension element, e.g. in the form of a spike, protruding longitudinally within the injector portion from a junction between the respective deflector vanes. Such a spike or other extension element may act to disrupt or substantially prevent recirculation of motive fluid passing over the deflector vanes of the deflector element as it exits the deflector element, thereby reducing pressure (and thus energy) losses as the motive fluid passes over the deflector vanes. It may additionally serve to promote pressure equalisation between the respective chambers of the deflector element defined by respective pairs of deflector vanes.

As an alternative to the aforementioned spike as a longitudinal extension element for preventing recirculation of motive fluid passing over the deflector vanes of the deflector element as it exits the deflector element, the rotational deflector element may alternatively additionally comprise a longitudinal aperture, channel or conduit extending through the deflector element at or adjacent a junction between the respective deflector vanes. Such a longitudinally extending channel or conduit may serve to guide a minor proportion of motive fluid through the deflector element in addition to the major proportion thereof passing over the deflector vanes, thereby again stabilising and/or smoothing out the overall passage of motive fluid past the deflector element, helping to reduce pressure (and thus energy) losses as the motive fluid passes over the deflector vanes, and/or serving to promote pressure equalisation between the respective chambers of the deflector element defined by respective pairs of deflector vanes.

Owing to the above-mentioned effect of the above-defined deflector element in further enhancing or increasing the degree or level of transfer of momentum, and thus kinetic energy, from the motive fluid to the suction fluid, and thereby further increasing a level of compression of the suction fluid as its mixture with the motive fluid passes into and through the diffuser portion of the ejector device, it is envisaged in the context of the present invention that in some forms of the ejector device such a rotational deflector element as defined in any of the preceding paragraphs may possibly even be an alternative to, or replace, the above-defined extension of the length of the throat section of the Venturi portion of the diffuser portion of the device as defined as the first aspect of the invention.

Accordingly, in an alternative or auxiliary first aspect of the present invention there is provided an ejector device comprising:

an injector portion, and

a diffuser portion,

the injector portion being arranged for injecting a motive fluid from a motive fluid inlet into the diffuser portion thereby to draw a suction fluid into the diffuser portion from a suction fluid inlet, and the diffuser portion including a Venturi portion comprising a converging inlet section, a throat section and a diverging outlet section,

wherein the injector portion comprises a rotational deflector element constructed and arranged to rotate motive fluid as its passes from the motive fluid inlet into the diffuser portion, the rotational deflector element comprising a plurality of helical deflector vanes arranged for imparting rotation to the motive fluid as its passes the said vanes, each said deflector vane having:

a longitudinal length being approximately equal to or less than a diameter of the injector portion; and

a radial twist angle of greater than approximately 30°.

Optional or preferred features of the rotational deflector element in embodiment ejector devices of this alternative or auxiliary first aspect of the invention may correspond to any of the optional or preferred features of any of the rotational deflector elements defined hereinabove in the context of the main first aspect of the invention.

In some embodiments of the ejector device according to the first aspect of the invention, the ejector device may further comprise a flow stabilisation portion downstream of the diffuser portion thereof, especially immediately downstream of the Venturi portion thereof.

In some embodiments the flow stabilisation portion may be constructed and arranged to stabilise a flow of motive fluid and suction fluid therethrough before the flow of the fluids through the ejector device exits the diffuser portion thereof. It is to be understood that the stabilisation portion may be useful for permitting or promoting the settling and/or dissipation of any recirculation currents or eddies in the combined fluid phases exiting the diffuser portion of the ejector device and prior to the discharged flow exiting the device is passed to a subsequent system or ancillary device utilising the thus compressed and/or pumped suction fluid phase.

In some forms the flow stabilisation portion may comprise a flow stabilisation conduit of substantially uniform diameter and a length substantially equal to at least the diameter thereof. The flow stabilisation conduit may for example be integrally formed with the

Venturi portion of the diffuser portion of the ejector device, for example by casting, moulding or machining from a single piece of material.

In some arrangements in which laminar flow conditions are assumed downstream of the Venturi portion, the flow of the combined fluid phases may be able to assume laminar flow conditions a shorter distance than would otherwise be possible downstream of the Venturi portion owing to the presence of the flow stabilisation portion.

In some embodiments the flow stabilisation conduit may advantageously have substantially the same diameter as a downstream end of the Venturi portion. Alternatively in other embodiments the flow stabilisation conduit may be of a different diameter from the downstream end of the Venturi portion.

In some embodiments the flow stabilisation portion may preferably have a length L_s defined by the following equation (II):

$$L_s > y\, D_t \qquad \text{(II)},$$

where D_t is the diameter of the throat section and *y* is a number, e.g. an integer, of 1 or more, preferably at least equal to 2, 3, 4 or 5. In some embodiments the flow stabilisation portion may usefully have a length such that *y* is a number, e.g. an integer, in the range of from about 5 up to about 20 (or optionally even up to about 30), for example in the range of from about 7 or 8 up to about 15.

In a second aspect of the invention there is provided a fluid pump apparatus comprising an ejector according to the first aspect of the invention or any embodiment thereof.

According to embodiments of this second aspect of the invention there may thus be provided a fluid pump apparatus comprising an ejector device, the apparatus comprising:

a motive fluid inlet arranged to supply motive fluid to the apparatus,

a suction fluid inlet arranged to supply suction fluid to the apparatus, and

a common discharge outlet from which motive fluid and suction fluid that have passed through the ejector may be expelled from the apparatus,

wherein the ejector device comprises:

an injector portion, and

a diffuser portion,

the injector portion being arranged for injecting motive fluid from the motive fluid inlet into the diffuser portion thereby to draw suction fluid into the diffuser portion from the suction fluid inlet, the diffuser portion including a Venturi portion comprising a converging

section, a throat section and a diverging section,

wherein the throat section of the Venturi portion has a length L_t defined by the following equation (I):

$$L_t > x\, D_t \qquad (I),$$

where D_t is the diameter of the said throat section and x is a number (e.g. an integer) greater than 6, preferably greater than 7, optionally in the range of from about 10 to about 50, e.g. from about 20 to about 30.

Preferred and/or optional features of the above-defined ejector device in embodiments of fluid pumping apparatus according to this second aspect may be the same as or correspond to any of the preferred and/or optional features thereof as defined hereinabove in the context of the first aspect of the invention.

In a third aspect of the invention there is provided a method of pumping a fluid, comprising passing it through an ejector device according to the first aspect of the invention or any embodiment thereof, or passing it through a fluid pump apparatus according to the second aspect of the invention or any embodiment thereof, wherein the said fluid to be pumped is the said suction fluid.

According to embodiments of this third aspect of the invention there may thus be provided a method of pumping a suction fluid from a supply of said suction fluid through an ejector device, the ejector device comprising:

an injector portion, and

a diffuser portion including a Venturi portion including a converging section, a throat section and a diverging section, wherein the throat section of the Venturi portion has a length L_t defined by the following equation (I):

$$L_t > x\, D_t \qquad (I),$$

where D_t is the diameter of the said throat section and x is a number greater than 6;

wherein the method comprises:

providing a supply of motive fluid, and

injecting motive fluid from a motive fluid inlet into the diffuser portion of the ejector device via the injector portion thereby to draw the suction fluid into the diffuser portion via a suction fluid inlet and to be mixed with the injected motive fluid,

passing the mixed motive fluid and suction fluid through the Venturi portion of the diffuser portion and expelling the mixed motive fluid and suction fluid from the ejector device via a common discharge outlet thereof.

Preferred and/or optional features of the above-defined ejector device in embodiments of the method according to this third aspect may be the same as or correspond to any of the preferred and/or optional features thereof as defined hereinabove in the context of the first and second aspects of the invention.

Embodiments of the present invention in its various aspects may be applied in a wide variety of practical applications involving the pumping of a wide variety of "suction" fluids, e.g. gaseous phases, by a wide variety of "motive" fluids, e.g. liquid phases. By way of non-limiting examples, some practical applications in which ejector devices according to various or particular embodiments of the invention may be usefully employed may include any of the following:

(i) Water treatment applications:

- entraining ozone, chlorine or other disinfectant gas for disinfection of water used for e.g. swimming pools, cooling towers, bottling plants, etc;
- entraining atmospheric air for transferring oxygen to remove irons and manganese from borehole water;
- entraining atmospheric air for filtering backwashing and/or scouring of filter media.

(ii) Oil and gas industry applications:

- entraining vent gas;
- de-aeration of seawater;
- entraining header gas for oil/water separation;
- flare gas recovery.

(iii) Effluent treatment applications:

- entraining atmospheric air for transferring oxygen for sewage treatment;
- entraining atmospheric air for transferring oxygen for chemical oxidising purposes;
- entraining atmospheric air for aerating and mixing balance tanks;
- entraining pressurised air for producing "white water" on DAF (dissolved air flotation) plants.

(iv) Process applications:

- entraining CO_2 for carbonating soft drinks;
- simultaneous scrubbing and pumping of corrosive gases;
- scrubbing and neutralising of sour gas (e.g. using amines);
- recycling and mixing off-gas with motive liquor for increasing contact time and thus enhancing process reactions.

Thus, in some non-limiting practical examples of the use of ejector devices according to embodiments of the invention, any of the following combinations of liquid phase (as the "motive" fluid) and gaseous phase (as the "suction" fluid to be pumped) may be used:

(a) sea water – hydrocarbon(s) (gaseous; single or mixtures thereof);
(b) produced water – hydrocarbon(s) (gaseous; single or mixtures thereof);
(c) water – chlorine;
(d) water – ozone;
(e) water – air;
(f) corn syrup – CO_2;
(g) amine(s) – CO_2;
(h) amine(s) – hydrocarbon(s) (gaseous; single or mixtures thereof);
(i) amines(s) – sour gas;
(j) sewage – air;
and various other specific liquid – gas combinations.

Within the scope of this application it is expressly envisaged that the various aspects, embodiments, examples and alternatives, and in particular the individual features thereof, set out in the preceding paragraphs, in the claims and/or in the following description and drawings, may be taken independently or in any combination. For example features described in connection with one embodiment are applicable to all embodiments, unless such features are incompatible.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings, in which:

FIGURE 1 is a cross-sectional view of a typical prior art ejector device, and has already been described;

FIGURE 2 is a perspective cut-away view of an ejector device according to an embodiment of the invention;

FIGURE 3 is an enlarged cut-away side view of the region of the ejector device of Figure 2 comprising the injector portion, showing an embodiment of the rotational deflector element within the injector portion in greater detail; and

FIGURES 4(a), (b), (c) and (d) are, respectively perspective, top, side and rear- end views of the rotational deflector element of the embodiment shown in FIG. 3.

DETAILED DESCRIPTION OF EMBODIMENTS

Referring firstly to FIG. 2 (in which corresponding features to the ejector device of FIG. 1 are labelled with corresponding reference numerals but incremented by 100), the ejector device shown generally as 100 comprises a motive fluid inlet injector portion 110 for receiving a motive fluid, e.g. a liquid phase, and a suction fluid inlet 120 for receiving a suction fluid, e.g. a gaseous phase, which is the fluid to be compressed and pumped by the device 100. The motive fluid may for example be pumped into the motive fluid inlet injector portion 110 by any suitable conventional pump (not shown).

The body of the ejector device 100 comprises the injector portion 110, a central diffuser portion 150, and a terminal stabilising portion 158 downstream of the diffuser portion. The central diffuser portion 150 comprises a Venturi tube-type portion which comprises a converging, e.g. internally conical, inlet section 152, an intermediate throat section 154 and a diverging outlet section 156.

The throat section 154 of the Venturi portion is in this embodiment of substantially uniform diameter along its length, so that its inner walls are substantially parallel to each other, and also preferably substantially smooth. The forming of the smooth inner walls of the throat section 154 with such uniform and constant diameter along its length, e.g. by suitable manufacturing and/or post-manufacturing techniques, for example selected from any suitable known casting, moulding, machining and/or polishing techniques, is preferably as accurate as manufacturing tolerances will allow, in order to minimise frictional losses as fluid passes along the throat section 154.

The throat section 154 has a length that is extended substantially beyond conventional lengths of throat sections of corresponding Venturi tube portions of known liquid jet compressors or other ejectors, and indeed the throat section 154 has a length which is substantially longer than conventional theory would suggest is possible or tolerable without significant deleterious effects of frictional energy losses. Thus, in accordance with this embodiment of the invention the throat section 154 has a length which may be greater than about 6 times, perhaps even greater than about 7 times, its diameter. In some embodiment forms the throat section 154 may have a length which is anywhere

from about 10 up to about 40 or even 50 times its diameter. In a typical embodiment, as illustrated by way of example in FIG. 2, the throat section 154 has a length which is in the region of about 20 to 30 times its diameter.

The diverging outlet section 156 of the diffuser portion 150 may typically have a conical internal shape, and may suitably for example have a length which is anywhere from about 5 up to about 20 times the diameter of the throat section 154. In a typical practical embodiment, as illustrated by way of example in FIG. 2, the diverging outlet section 156 has a length which is in the region of about 10 to about 12 times the diameter of the throat section 154.

Mounted within the injector portion 110 of the ejector device 100 is a rotational deflector element 180, which acts to impart rotational or helical motion to motive fluid as it passes through the injector portion 100 from the motive fluid inlet into the diffuser portion 150. This motion serves to enhance the break-up of the motive fluid, especially into particles or droplets thereof when it is a liquid phase, as it passes through the injector portion 110, with the result that the degree or level of transfer of momentum, and thus kinetic energy, from the motive fluid to the suction fluid, as they are mixed in the inlet section 152 of the diffuser portion 150, is enhanced. This results in further increases in levels of compression of the suction fluid as its mixture with the motive fluid passes into and through the diffuser portion 150 of the ejector device 100. The region of the ejector device 100 containing the deflector element 180 is shown in greater detail in FIG. 3, and the physical shape and configuration of the deflector element 180 itself is shown enlarged in FIG. 4.

The deflector element 180 comprises a central spine 181, extending in generally radial directions outwardly from which are three deflector vanes or blades 182a, 182b, 182c. The deflector vanes or blades 182a, 182b, 182c are equi-angularly or symmetrically positioned around the central spine, so they form a trio of like-shaped longitudinally extending compartments or chambers which divide up the flow of motive fluid passing through and past the deflector element 180 during its passage through the injector portion 110.

Each deflector vane or blade 182a, 182b, 182c has a generally helical twisted shape or configuration, in order to impart the necessary twisting or rotational motion to the motive fluid as it passes thereover. The radial twist angle of each deflector vane or blade 182a, 182b, 182c is greater than approximately 30°, preferably in the range of from greater

than about 30° up to about 90°. In a typical embodiment, as illustrated by way of example in FIG. 4, the twist angle of the deflector vanes or blades 182a, 182b, 182c may be in the region of about 50°, although twist angles of greater than 50°, e.g. up to about 90°, may be possible, again preferably generally as long as frictional losses are not increased to unacceptable levels.

Both the forward (leading) and rear (trailing) edges or ends of each deflector vane or blade 182a, 182b, 182c have a flat or bluff face, in order to increase the level of turbulence caused by the helically rotating chambers of motive fluid as they meet and mix with the suction fluid in the inlet section 152 of the diffuser portion 150.

Although three such deflector vanes or blades 182a, 182b, 182c are shown in this illustrated embodiment, it is to be understood that any suitable number of deflector vanes or blades may be employed, e.g. most preferably 2, 3, 4 or possibly even more than 4. It may generally be preferable however that the number of deflector vanes or blades is not so high that collective frictional losses as the motive fluid passes over them become unacceptably high.

The deflector element 180 may be substantially fixed within the bore of the injector portion 110, e.g. welded to the inner wall(s) thereof or formed integrally therewith, so that motive fluid is caused to assume a helical motion as it passes through the deflector element 180 during its passage through the injector portion 110.

It will be noted, as more readily seen in FIG. 4, that the longitudinal length of the deflector element 180 is approximately equal to or less than a single diameter of the injector portion 110 in which the deflector element 180 is located. Thus, the side-on profile of the deflector element 180 takes the form of an approximate square, as seen by way of example in FIG. 4(c). This serves to ensure that the helical rotation and resulting turbulence are applied to the motive fluid within the shortest longitudinal distance possible, whilst at the same time minimising any pressure drop over that distance. For instance, if the rotational motion applied by the helical deflector vanes or blades 182a, 182b, 182c were to be generated over a length substantially longer than a single diameter of the injector portion 110, the efficiency improvements would be reduced owing to greater frictional losses against the surfaces of the (in that case) longer deflector vanes or blades.

Projecting from the forward end of the spine 181 of the deflector element, especially

substantially co-axially with respect to the deflector element 180, is a spike element 190 with a tapered or sharp forward tip section, which spike serves to not only prevent or disrupt recirculation of motive fluid at the forward end of the deflector element, but also to provide a degree of pressure equalisation between the three chambers of fluid defined by the three deflector vanes or blades 182a, 182b, 182c.

As an alternative to such a spike 190, it is envisaged that alternatively a longitudinal aperture, channel or conduit (not shown) may be provided extending through the deflector element 180, e.g. through the spine 181 thereof, and thus at or adjacent a junction between the respective deflector vanes 182a, 182b, 182c. Such a longitudinally extending channel or conduit may thus serve to guide a minor proportion of motive fluid through the deflector element 180 in addition to the major proportion thereof passing over the deflector vanes or blades, thereby acting in a similar or corresponding way to the spike 190 referred to above.

Located immediately downstream of the diverging outlet section 156 of the Venturi portion of the diffuser portion 150 of the ejector device 100 is a stabilisation portion 158. This stabilisation portion 158 serves to permit or promote the settling and/or dissipation of any recirculation currents or eddies in the combined fluid phases exiting the diffuser portion 150 prior to the discharged flow exiting the ejector device 100 via discharge outlet 160 for subsequent passage to a system or ancillary device utilising the thus compressed and/or pumped suction fluid phase.

The stabilisation portion 158 may typically be a flow stabilisation conduit of substantially uniform diameter, for example integrally formed with the Venturi portion of the diffuser portion 150, and may have a diameter which is substantially the same as that of the downstream end of the outlet section 156 of the Venturi portion. In one form the flow stabilisation portion 158 may have a length which is anywhere from about 1, 2, 3, 4 or 5 up to about 20 times the diameter of the throat section 154. In a typical embodiment, as illustrated by way of example in FIG. 2, the flow stabilisation portion 158 has a length which is in the region of about 10 to about 12 times the diameter of the throat section 154.

In use, in compressing and thus pumping suction fluid (which in many embodiments may be a gaseous phase) by means of the motive fluid (which in many embodiments may be a liquid phase) through the ejector device 100, the general principle which is used to a hitherto unattained advantage is one of enhancing the degree to which momentum and

thus kinetic energy of the motive fluid is able to be transferred to the gaseous phase of the suction fluid as the motive fluid meets and mixes with the suction fluid and the admixture of fluids passes along the Venturi portion of the diffuser portion of the device.

Thus, at the entry to the diffuser portion of the device the motive fluid is aspirated and the resulting particles or droplets thereof become mixed with the relatively low pressure suction fluid which meets it in that region of the device. The admixture of liquid particles/droplets and gas then enter the Venturi portion of the diffuser portion of the device, whereupon they pass firstly through the throat section, within which enhanced transfer of momentum and kinetic energy from the motive fluid particles/droplets to the gaseous phase takes place, and secondly they encounter a "diffusion zone" of expanded volume in the outlet section of the Venturi portion, where pressure rises at the expense of kinetic energy, i.e. the velocity of the admixture liquid is reduced. The combination of the mixing of the particles/droplets of motive fluid with the gas of the suction fluid in the throat section and the decrease in velocity in the "diffusion zone" thus converts the momentum and kinetic energy of the motive fluid into compression of the gaseous phase of the suction fluid.

Thus, the greater the level of energy that is transferrable, the greater the compression of the gaseous phase that results as it mixes with the motive fluid and thereafter into and through the Venturi portion of the diffuser portion of the device in accordance with established physical principles, as discussed hereinabove.

This improvement may be achievable, in accordance with various embodiments of the invention, and as exemplified by the embodiment described above, by the use principally of the extended length of the throat section 154 of the diffuser portion 150. Additionally it may be further enhanced by the action of the rotational deflector element 180 in the motive fluid injector portion 110, whereby a rotational or helical motion of the split-chambered flow of motive fluid as it meets and mixes with the suction fluid on entering the inlet section 152 of the diffuser portion 150 may further enhance the transfer of kinetic energy from the motive to the suction fluids. As a result, higher levels of compression of the suction fluid may be possible in comparison with prior art ejector devices, especially those based on shorter Venturi throat sections.

It is to be understood that the above description of embodiments and aspects of the invention has been by way of non-limiting examples only, and various modifications may be made from what has been specifically described and illustrated whilst remaining

within the scope of the invention as defined in the appended claims.

Throughout the description and claims of this specification, the words “comprise” and “contain” and variations of the words, for example “comprising” and “comprises”, mean “including but not limited to”, and are not intended to (and do not) exclude other moieties, additives, components, integers or steps.

Throughout the description and claims of this specification, the singular encompasses the plural unless the context otherwise requires. In particular, where the indefinite article is used, the specification is to be understood as contemplating plurality as well as singularity, unless the context requires otherwise.

Features, integers, characteristics, compounds, chemical moieties or groups described in conjunction with a particular aspect, embodiment or example of the invention are to be understood to be applicable to any other aspect, embodiment or example described herein unless incompatible therewith.

CLAIMS:

1. An ejector device comprising:

an injector portion, and

a diffuser portion,

the injector portion being arranged for injecting a motive fluid from a motive fluid inlet into the diffuser portion thereby to draw a suction fluid into the diffuser portion from a suction fluid inlet, and the diffuser portion including a Venturi portion comprising a converging inlet section, a throat section and a diverging outlet section,

wherein the throat section of the Venturi portion has a length L_t defined by the following equation (I):

$$L_t > x\, D_t \qquad (I),$$

where D_t is the diameter of the said throat section and x is a number greater than 6.

2. An ejector device according to Claim 1, wherein the injector portion of the ejector device additionally comprises a rotational deflector element constructed and arranged to rotate motive fluid as its passes from the motive fluid inlet into the diffuser portion.

3. An ejector device according to Claim 2, wherein the rotational deflector element is constructed and arranged to force the motive fluid into a helical path as it passes from the motive fluid inlet into the diffuser portion.

4. An ejector device according to Claim 2 or Claim 3, wherein the rotational deflector element comprises a plurality of helical deflector vanes arranged for imparting rotation to the motive fluid as its passes the said vanes, each said deflector vane having:

a longitudinal length being approximately equal to or less than a diameter of the injector portion; and

a radial twist angle of greater than approximately 30°.

5. An ejector device according to Claim 4, wherein the radial twist angle of each deflector vane is in the range of from greater than about 30° up to about 90°.

6. An ejector device according to Claim 4 or Claim 5, wherein the radial twist angle of each deflector vane is in the range of from about 35 or 40° up to about 80 or 90°.

7. An ejector device according to any one of Claims 4 to 5, wherein the radial twist angle of each deflector vane is in the range of from about 40° up to about 60 or 70°.

8. An ejector device according to any one of Claims 4 to 7, wherein the rotational deflector element comprises two or more helical deflector vanes.

9. An ejector device according to Claim 8, wherein the rotational deflector element comprises three, or optionally four, helical deflector vanes.

10. An ejector device according to any one of Claims 4 to 9, wherein each of the deflector vanes has a substantially flat profile or face on both their leading and trailing edges.

11. An ejector device according to any one of Claims 4 to 10, wherein the rotational deflector element additionally comprises a longitudinal extension element protruding longitudinally within the injector portion from a junction between the respective deflector vanes.

12. An ejector device according to any one of Claims 4 to 10, wherein the rotational deflector element additionally comprises a longitudinal aperture, channel or conduit extending through the deflector element at or adjacent a junction between the respective deflector vanes.

13. An ejector device according to any preceding Claim, further comprising a flow stabilisation portion downstream of the diffuser portion thereof.

14. An ejector device according to Claim 13, wherein the flow stabilisation portion is constructed and arranged to stabilise a flow of motive fluid and suction fluid therethrough before the flow of the fluids through the ejector device exits the diffuser portion thereof.

15. An ejector device according to Claim 12 or Claim 14, wherein the flow stabilisation portion comprises a flow stabilisation conduit of substantially uniform diameter and a length substantially equal to at least the diameter thereof.

16. An ejector device according to Claim 15, wherein the flow stabilisation conduit is integrally formed with the Venturi portion of the diffuser portion of the ejector device.

17. An ejector device according to Claim 15 or Claim 16, wherein the flow stabilisation conduit has substantially the same diameter as a downstream end of the

Venturi portion.

18. An ejector device according to Claim 15 or Claim 16, wherein the flow stabilisation conduit has a different diameter from the downstream end of the Venturi portion.

19. An ejector device according to any of Claims 15 to Claim 18, wherein the flow stabilisation portion has a length L_s defined by the following equation (II):

$$L_s > y\, D_t \qquad \text{(II)},$$

where D_t is the diameter of the throat section and *y* is a number, e.g. an integer, of 1 or more.

20. An ejector device according to Claim 19, wherein in equation (II) *y* is a number in the range of from about 5 up to about 20 (or optionally up to about 30).

21. An ejector device according to Claim 20, wherein in equation (II) *y* is a number in the range of from about 7 or 8 up to about 15.

22. An ejector device according to any preceding Claim, wherein the throat section of the Venturi portion has a substantially uniform diameter along its length, or the inner walls of the throat section are substantially parallel.

23. An ejector device according to any one of Claims 1 to 21, wherein the throat section of the Venturi portion has a non-uniform diameter along its length.

24. An ejector device according to any preceding Claim, wherein in equation (I) *x* is an integer greater than 6.

25. An ejector device according to any preceding Claim, wherein in equation (I) *x* is a number greater than 7.

26. An ejector device according to any preceding Claim, wherein in equation (I) *x* is a number in the range of from greater than 6 or 7 up to about 50.

27. An ejector device according to any preceding Claim, wherein in equation (I) *x* is a number in the range of from about 10 up to about 50.

28. An ejector device according to any preceding Claim, wherein in equation (I) *x* is a number in the range of from about 20 up to about 30.

29. An ejector device according to any preceding Claim, wherein the ejector device is a liquid jet compressor, the motive fluid being a liquid phase and a suction fluid to be compressed and/or pumped being a gaseous phase.

30. An ejector device according to any preceding Claim, wherein the inner wall(s) of at least the throat section of the Venturi portion is/are substantially smooth.

31. A fluid pump apparatus comprising an ejector according to any one of Claims 1 to 30.

32. A fluid pump apparatus comprising an ejector device, the apparatus comprising:

a motive fluid inlet arranged to supply motive fluid to the apparatus,

a suction fluid inlet arranged to supply suction fluid to the apparatus, and

a common discharge outlet from which motive fluid and suction fluid that have passed through the ejector may be expelled from the apparatus,

wherein the ejector device comprises:

an injector portion, and

a diffuser portion,

the injector portion being arranged for injecting motive fluid from the motive fluid inlet into the diffuser portion thereby to draw suction fluid into the diffuser portion from the suction fluid inlet, the diffuser portion including a Venturi portion comprising a converging section, a throat section and a diverging section,

wherein the throat section of the Venturi portion has a length L_t defined by the following equation (I):

$$L_t > x\, D_t \qquad (I),$$

where D_t is the diameter of the said throat section and *x* is a number (e.g. an integer) greater than 6, preferably greater than 7.

33. A method of pumping a fluid, comprising passing it through an ejector device according to any one of Claims 1 to 30 or a fluid pump apparatus according to Claim 31 or Claim 32, wherein the said fluid to be pumped is the said suction fluid.

34. A method of pumping a suction fluid from a supply of said suction fluid through an ejector device, the ejector device comprising:

an injector portion, and

a diffuser portion including a Venturi portion including a converging section, a throat section and a diverging section, wherein the throat section of the Venturi portion has a length L_t defined by the following equation (I):

$$L_t > x\, D_t \qquad (I),$$

where D_t is the diameter of the said throat section and x is a number greater than 6;

wherein the method comprises:

providing a supply of motive fluid, and

injecting motive fluid from a motive fluid inlet into the diffuser portion of the ejector device via the injector portion thereby to draw the suction fluid into the diffuser portion via a suction fluid inlet and to be mixed with the injected motive fluid,

passing the mixed motive fluid and suction fluid through the Venturi portion of the diffuser portion and expelling the mixed motive fluid and suction fluid from the ejector device via a common discharge outlet thereof.

35. An ejector device, or a fluid pump apparatus, or a method of pumping a fluid, or a method of pumping a suction fluid, substantially as herein described with reference to Figures 2 to 4 of the accompanying drawings.

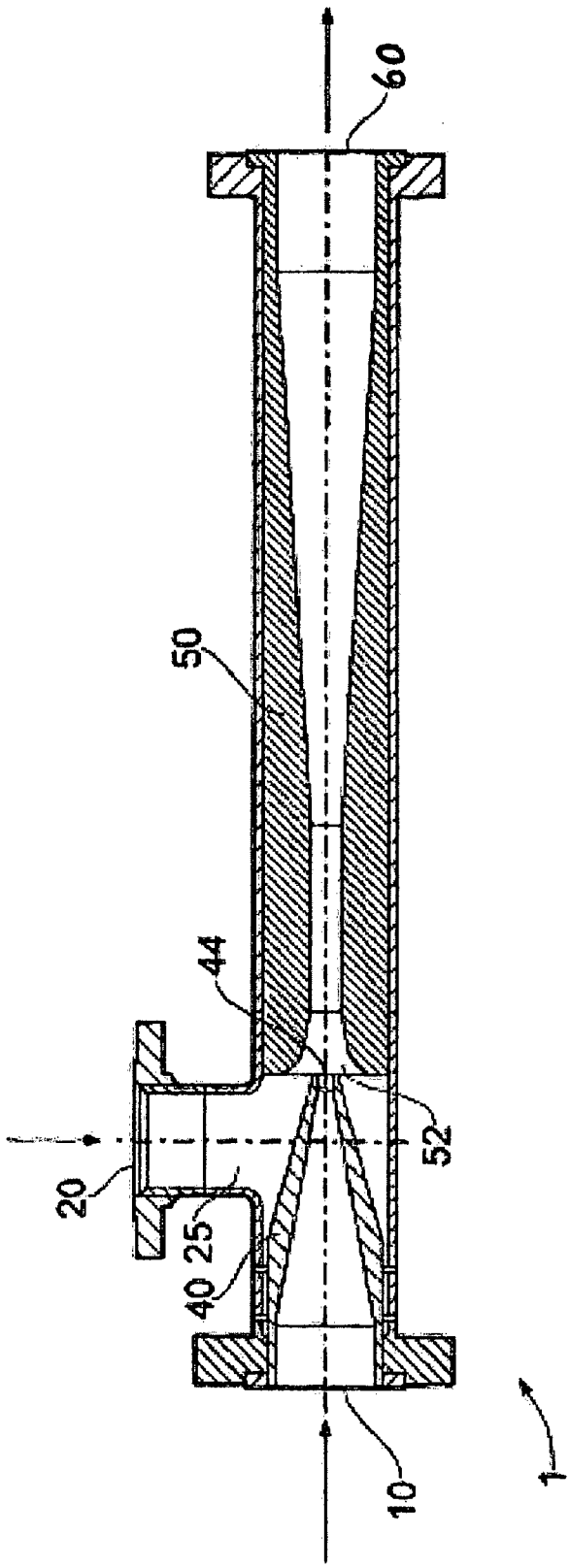


FIG. 1 (Prior Art)

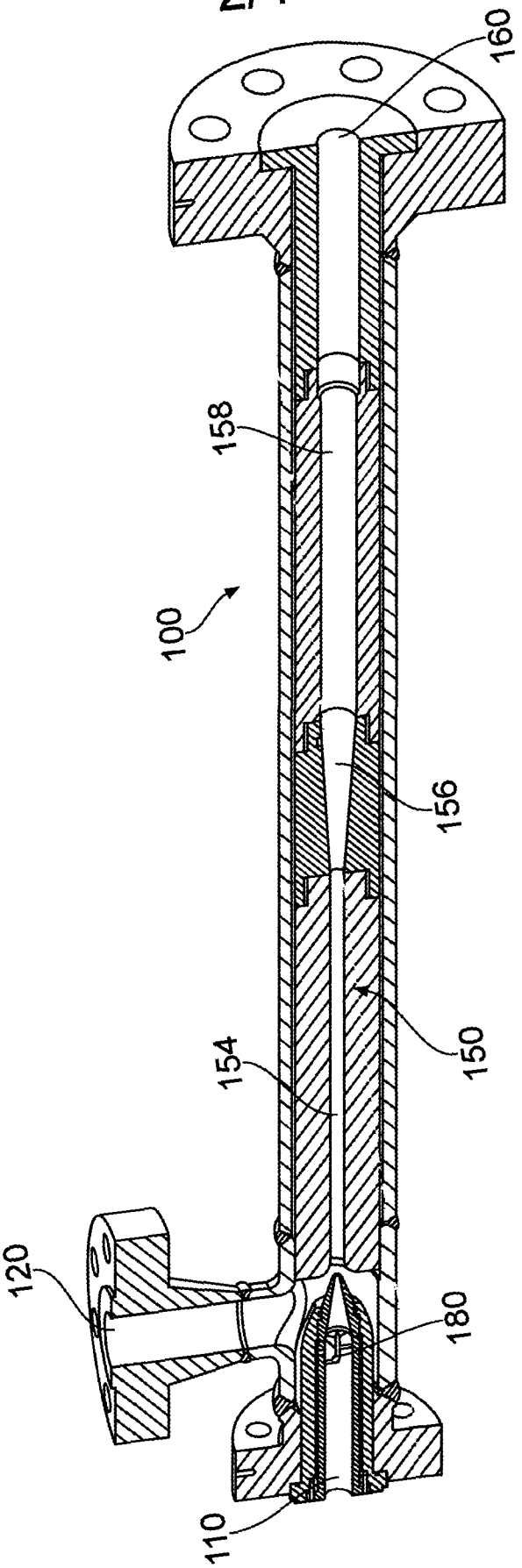


FIG. 2

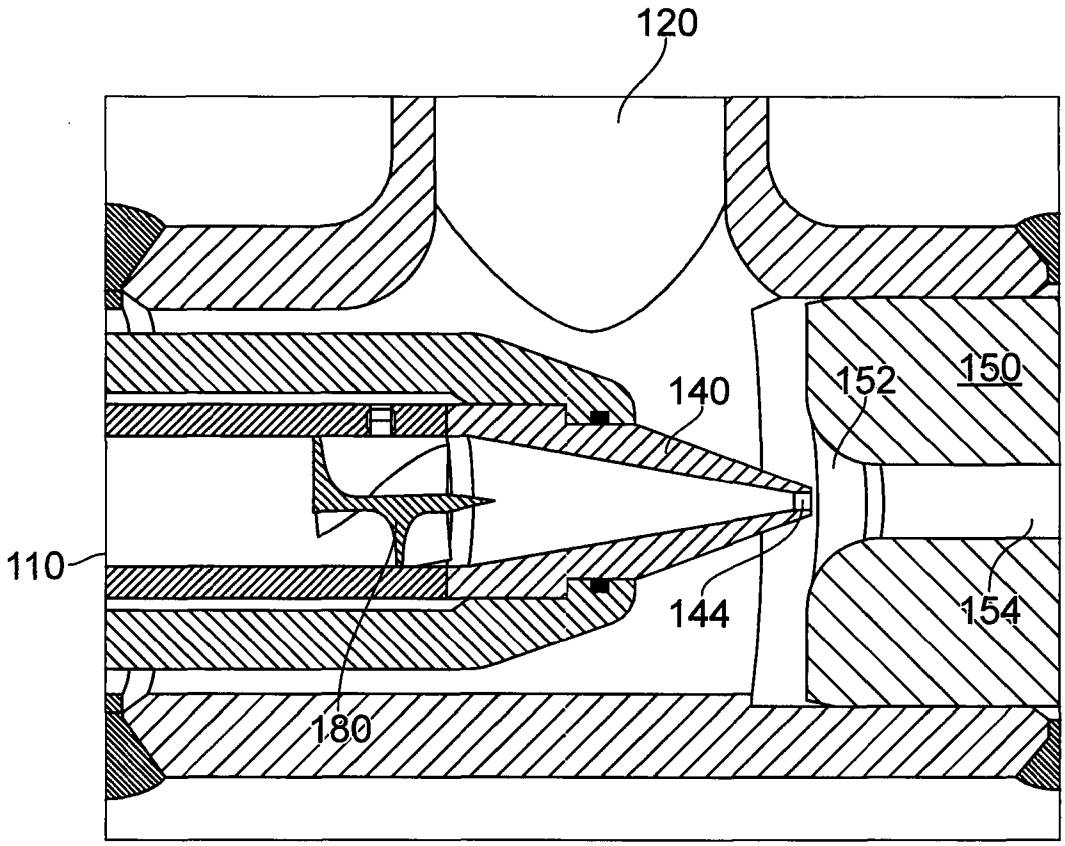


FIG. 3

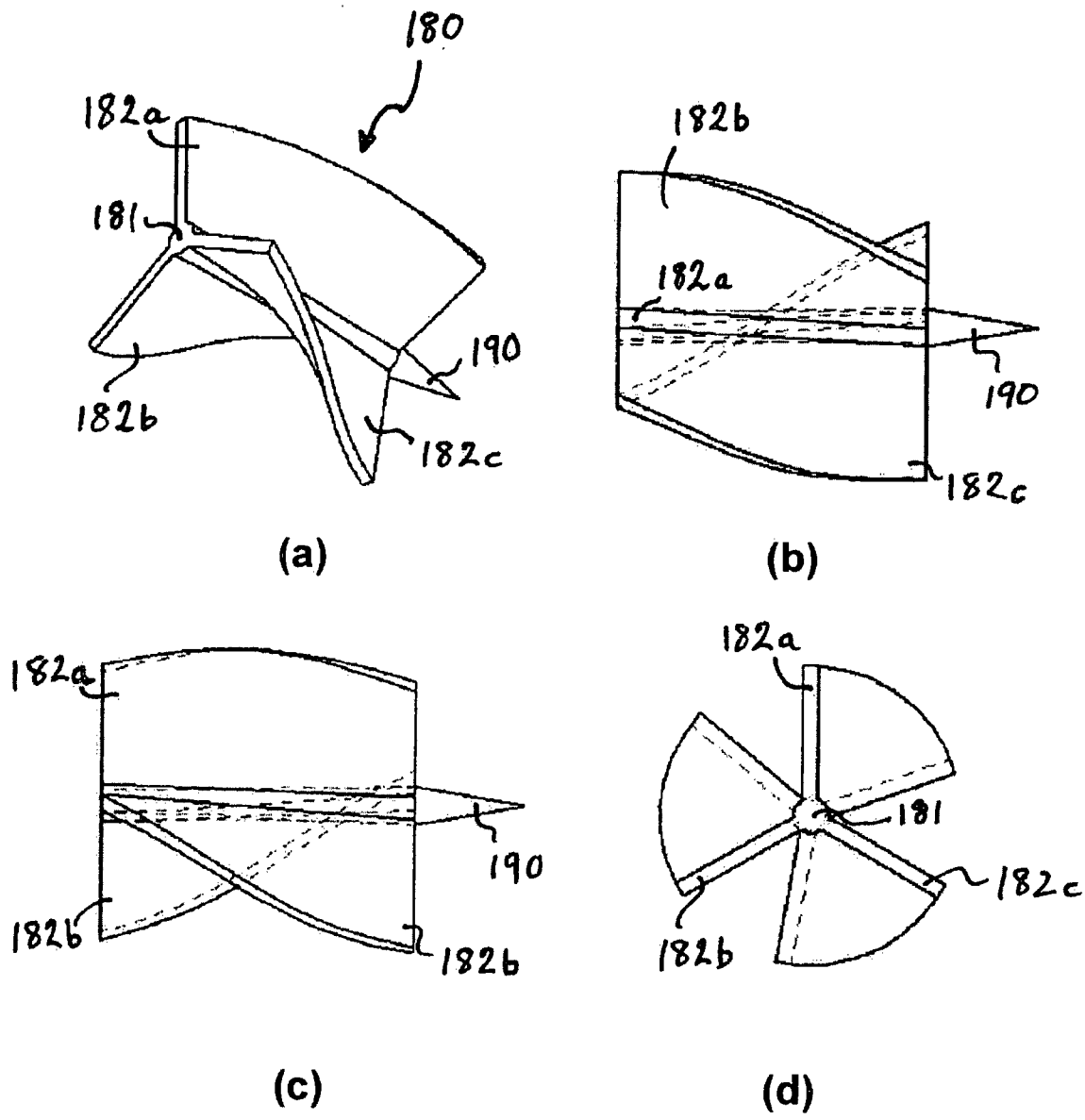

180
182a
181
190
182b
182c
(a)
182b
182a
190
182c
(b)
182a
190
182b
182b
(c)
182a
181
182c
182b
(d)

FIG. 4

INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2015/051727

A. CLASSIFICATION OF SUBJECT MATTER
INV. F04F5/46 F04F5/42
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F04F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 221 575 A (JOHN WILKINSON GREIG) 15 September 1924 (1924-09-15) page 2; claims; figures	1-10, 13-35
X Y	US 3 625 820 A (GLUNTZ DOUGLAS M ET AL) 7 December 1971 (1971-12-07) abstract; claims; figures	1,13-35 2-12
X Y	WO 2012/059773 A2 (TRANSVAC SYSTEMS LTD [GB]; SHORT GARY [GB]) 10 May 2012 (2012-05-10) abstract; claims; figures page 5, line 20 - page 10, line 1	1,13-35 2-12
X	US 4 810 170 A (IDE RUSSELL D [US]) 7 March 1989 (1989-03-07) abstract; claims; figures	1-10, 13-35

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[X] Further documents are listed in the continuation of Box C.

[X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
15 September 2015	24/09/2015

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INTERNATIONAL SEARCH REPORT

International application No
PCT/GB2015/051727

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2006/239831 A1 (GARRIS CHARLES A JR [US]) 26 October 2006 (2006-10-26) abstract; claims; figures	2-12
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1

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Information on patent family members

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