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(54) **EJECTORS**

(57) An ejector (200) has: a motive flow inlet (40); a secondary flow inlet (42); an outlet (44); and a motive nozzle (200). The motive nozzle has an exit (110). A motive flow flowpath proceeds through the motive nozzle and joins a secondary flow flowpath extending from the secondary flow inlet to form a combined flowpath to the outlet. From upstream to downstream along the motive flow flowpath, the motive nozzle has: a convergent sec-

tion (206); a throat (208); a first divergent section (210) commencing within 10% of a throat-to-exit length (200) and diverging over a first length (L_{D1}) of at least 10% of the throat-to-exit length (L_{TE}); a second divergent section (212), the second divergent section diverging over a second length (L_{D2}) of at least 10% of the throat-to-exit length at a shallower angle than the first divergent section over said first length.

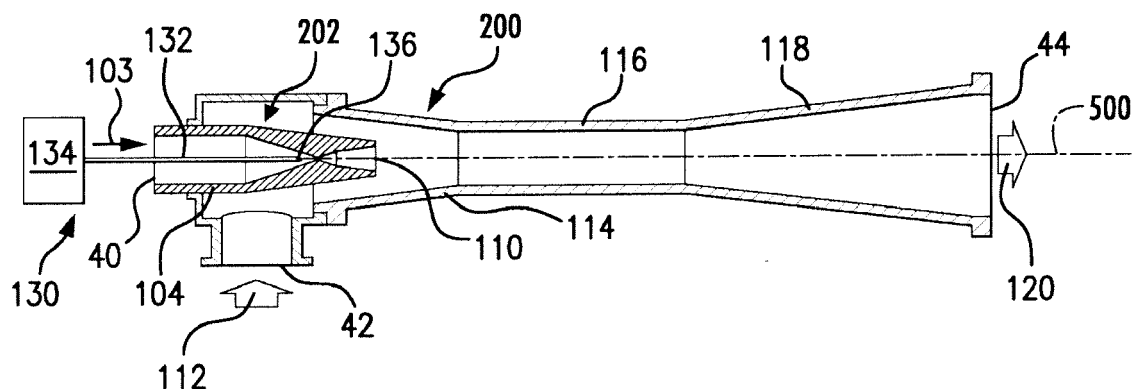


FIG. 3

Description

CROSS-REFERENCE TO RELATED APPLICATION

[0001] Benefit is claimed of U.S. Patent Application No. 62/162,618, filed May 15, 2015, and entitled "Ejectors", the disclosure of which is incorporated by reference herein in its entirety as if set forth at length.

BACKGROUND

[0002] The present disclosure relates to refrigeration. More particularly, it relates to ejector refrigeration systems.

[0003] Earlier proposals for ejector refrigeration systems are found in US1836318 and US3277660. FIG. 1 shows one basic example of an ejector refrigeration system 20. The system includes a compressor 22 having an inlet (suction port) 24 and an outlet (discharge port) 26. The compressor and other system components are positioned along a refrigerant circuit or flowpath 27 and connected via various conduits (lines). A discharge line 28 extends from the outlet 26 to the inlet 32 of a heat exchanger (a heat rejection heat exchanger in a normal mode of system operation (e.g., a condenser or gas cooler)) 30. A line 36 extends from the outlet 34 of the heat rejection heat exchanger 30 to a primary inlet (liquid or supercritical or two-phase inlet) 40 of an ejector 38. The ejector 38 also has a secondary inlet (saturated or superheated vapor or two-phase inlet) 42 and an outlet 44. A line 46 extends from the ejector outlet 44 to an inlet 50 of a separator 48. The separator has a liquid outlet 52 and a gas or vapor outlet 54. A suction line 56 extends from the gas outlet 54 to the compressor suction port 24. The lines 28, 36, 46, 56, and components therebetween define a primary loop 60 of the refrigerant circuit 27. A secondary loop 62 of the refrigerant circuit 27 includes a heat exchanger 64 (in a normal operational mode being a heat absorption heat exchanger (e.g., evaporator)). The evaporator 64 includes an inlet 66 and an outlet 68 along the secondary loop 62. An expansion device 70 is positioned in a line 72 which extends between the separator liquid outlet 52 and the evaporator inlet 66. An ejector secondary inlet line 74 extends from the evaporator outlet 68 to the ejector secondary inlet 42.

[0004] In the normal mode of operation, gaseous refrigerant is drawn by the compressor 22 through the suction line 56 and inlet 24 and compressed and discharged from the discharge port 26 into the discharge line 28. In the heat rejection heat exchanger, the refrigerant loses/rejects heat to a heat transfer fluid (e.g., fan-forced air or water or other fluid). Cooled refrigerant exits the heat rejection heat exchanger via the outlet 34 and enters the ejector primary inlet 40 via the line 36.

[0005] The exemplary ejector 38 (FIG. 2) is formed as the combination of a motive (primary) nozzle 100 nested within an outer member 102. The primary inlet 40 is the inlet to the motive nozzle 100. The outlet 44 is the outlet

of the outer member 102. The primary refrigerant flow (motive flow) 103 enters the inlet 40 and then passes into a convergent section 104 of the motive nozzle 100. It then passes through a throat section 106 and an expansion (divergent) section 108 through an outlet (exit) 110 of the motive nozzle 100. The motive nozzle 100 accelerates the flow 103 and decreases the pressure of the flow. The secondary inlet 42 forms an inlet of the outer member 102. The pressure reduction caused to the primary flow by the motive nozzle helps draw the secondary flow 112 into the outer member. The outer member includes a mixer having a convergent section 114 and an elongate throat or mixing section 116. The outer member also has a divergent section or diffuser 118 downstream of the elongate throat or mixing section 116. The motive nozzle outlet 110 is positioned within the convergent section 114. As the flow 103 exits the outlet 110, it begins to mix with the flow 112 with further mixing occurring through the mixing section 116 which provides a mixing zone. Thus, respective primary and secondary flowpaths extend from the primary inlet and secondary inlet to the outlet, merging at the exit. In operation, the primary flow 103 may typically be supercritical upon entering the ejector and subcritical upon exiting the motive nozzle. The secondary flow 112 is gaseous (or a mixture of gas with a smaller amount of liquid) upon entering the secondary inlet port 42. The resulting combined flow 120 is a liquid/vapor mixture and decelerates and recovers pressure in the diffuser 118 while remaining a mixture. Upon entering the separator, the flow 120 is separated back into the flows 103 and 112. The flow 103 passes as a gas through the compressor suction line as discussed above. The flow 112 passes as a liquid to the expansion valve 70. The flow 112 may be expanded by the valve 70 (e.g., to a low quality (two-phase with small amount of vapor)) and passed to the evaporator 64. Within the evaporator 64, the refrigerant absorbs heat from a heat transfer fluid (e.g., from a fan-forced air flow or water or other liquid) and is discharged from the outlet 68 to the line 74 as the aforementioned gas.

[0006] Use of an ejector serves to recover pressure/work. Work recovered from the expansion process is used to compress the gaseous refrigerant prior to entering the compressor. Accordingly, the pressure ratio of the compressor (and thus the power consumption) may be reduced for a given desired evaporator pressure. The quality of refrigerant entering the evaporator may also be reduced. Thus, the refrigeration effect per unit mass flow may be increased (relative to the non-ejector system). The distribution of fluid entering the evaporator is improved (thereby improving evaporator performance). Because the evaporator does not directly feed the compressor, the evaporator is not required to produce superheated refrigerant outflow. The use of an ejector cycle may thus allow reduction or elimination of the superheated zone of the evaporator. This may allow the evaporator to operate in a two-phase state which provides a higher heat transfer performance (e.g., facilitating reduction in

the evaporator size for a given capability).

[0007] The exemplary ejector may be a fixed geometry ejector or may be a controllable ejector. FIG. 2 shows controllability provided by a needle valve 130 having a needle 132 and an actuator 134. The actuator 134 shifts a tip portion 136 of the needle into and out of the throat section 106 of the motive nozzle 100 to modulate flow through the motive nozzle and, in turn, the ejector overall. Exemplary actuators 134 are electric (e.g., solenoid or the like). The actuator 134 may be coupled to and controlled by a controller 140 which may receive user inputs from an input device 142 (e.g., switches, keyboard, or the like) and sensors (not shown). The controller 140 may be coupled to the actuator and other controllable system components (e.g., valves, the compressor motor, and the like) via control lines 144 (e.g., hardwired or wireless communication paths). The controller may include one or more: processors; memory (e.g., for storing program information for execution by the processor to perform the operational methods and for storing data used or generated by the program(s)); and hardware interface devices (e.g., ports) for interfacing with input/output devices and controllable system components.

[0008] A further variation is shown in Ogata et al. US8523091, September 3, 2013. Ogata et al. shows an ejector with a motive nozzle having a convergent section leading to at least three distinct divergent sections. An intermediate section of the three has a shallower taper than the other two sections.

SUMMARY

[0009] One aspect of the disclosure involves an ejector comprising: a motive flow inlet; a secondary flow inlet; an outlet; and a motive nozzle. The motive nozzle has an exit. A motive flow flowpath proceeds through the motive nozzle and joins a secondary flow flowpath extending from the secondary flow inlet to form a combined flowpath to the outlet. From upstream to downstream along the motive flow flowpath, the motive nozzle has: a convergent section; a throat; a first divergent section commencing within 10% of a throat-to-exit length and diverging over a first length of at least 10% of the throat-to-exit length (L_{TE}); a second divergent section, the second divergent section diverging over a second length (L_{D2}) of at least 10% of the throat-to-exit length at a shallower angle than the first divergent section over said first length.

[0010] In one or more embodiments of the other embodiments, along the motive flow flowpath: the first divergent section extends at a single first half-angle (θ_{D1}) directly from the throat; and the second divergent section extends at a single second half-angle (θ_{D2}) directly from the first divergent section.

[0011] In one or more embodiments of the other embodiments, the first half-angle is 1.0° to 4.0° ; and the second half-angle is 0.7° to 3.0° .

[0012] In one or more embodiments of the other embodiments, the first half-angle is 1.5° to 2.5° ; and the

second half-angle is 0.8° to 1.5° .

[0013] In one or more embodiments of the other embodiments, the second half-angle is 30% to 80% of the first angle.

5 **[0014]** In one or more embodiments of the other embodiments, the second half-angle is 40% to 60% of the first angle.

[0015] In one or more embodiments of the other embodiments, the first length is at least 50% of the throat-to-exit length; and the second length is at least 15% of the throat-to-exit length

10 **[0016]** In one or more embodiments of the other embodiments, the second divergent section ends within 5% of the throat-to-exit length from the exit.

15 **[0017]** In one or more embodiments of the other embodiments, a convergent section length (L_c) is greater than the throat-to-exit length.

[0018] In one or more embodiments of the other embodiments, the convergent section length is at least 20 110% of the throat-to-exit length.

[0019] In one or more embodiments of the other embodiments, the motive nozzle is metallic.

25 **[0020]** In one or more embodiments of the other embodiments: there is only a single said motive flow inlet; there is only a single said secondary flow inlet; and there is only a single said outlet.

30 **[0021]** Another aspect of the disclosure involves a method for using the ejector. The method comprises: passing a motive flow through the motive flow inlet; passing a secondary flow through the secondary flow inlet; merging the motive flow and the secondary flow to form a merged flow; and passing the merged flow through the outlet. The motive flow reaches a first Mach number of 0.9 to 1.2 at a downstream end of the first divergent section. The motive flow accelerates to a second Mach number of at least 0.05 greater than the first Mach number in the second divergent section.

35 **[0022]** In one or more embodiments of the other embodiments, the second Mach number is at least 0.2 greater than the first Mach number.

40 **[0023]** In one or more embodiments of the other embodiments, a vapor compression system comprises the ejector.

45 **[0024]** In one or more embodiments of the other embodiments, the vapor compression system further comprises: a compressor; a first heat exchanger; a second heat exchanger; and a separator having: an inlet; a liquid outlet; and a vapor outlet; an expansion device.

50 **[0025]** In one or more embodiments of the other embodiments, the vapor compression system further comprises: a plurality of conduits positioned to define a first flowpath sequentially through: the compressor; the first heat exchanger; the ejector from the motive flow inlet through the ejector outlet; and the separator, and then branching into: a first branch returning to the compressor; and a second branch passing through the expansion device and second heat exchanger to the secondary inlet.

[0026] Another aspect of the disclosure involves an

ejector comprising: a motive flow inlet; a secondary flow inlet; an outlet; and a motive nozzle. The motive nozzle has an exit. A motive flow flowpath proceeds through the motive nozzle and joins a secondary flow flowpath extending from the secondary flow inlet to form a combined flowpath to the outlet. From upstream to downstream along the motive flow flowpath, the motive nozzle has: a convergent section; a throat; and means for providing a second acceleration upstream of the exit lower than a first acceleration downstream of the throat.

[0027] In one or more embodiments of the other embodiments, the means comprises a first divergent section and a second divergent section at a shallower angle than the first divergent section.

[0028] The details of one or more embodiments are set forth in the accompanying drawings and the description below. Other features, objects, and advantages will be apparent from the description and drawings, and from the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029]

FIG. 1 is a schematic view of a prior art ejector refrigeration system.

FIG. 2 is an axial sectional view of a prior art ejector.

FIG. 3 is an axial sectional view of a second ejector.

FIG. 4 is an axial sectional view of a motive nozzle of the second ejector.

[0030] Like reference numbers and designations in the various drawings indicate like elements.

DETAILED DESCRIPTION

[0031] FIG. 3 shows a modified ejector 200 that may replace the ejector of FIG. 2 in the system of FIG. 1. However, the modification as described below may apply to other ejectors used in other vapor compression systems. The ejector 200 may represent a modification of a baseline ejector differing in terms of the interior of the motive nozzle 202. Various features that may be shared with the baseline FIG. 2 ejector are referenced with corresponding numerals and are not necessarily separately discussed.

[0032] As with the baseline ejector, the nozzle 200 and its passageway comprise a convergent section 206 leading to a throat 208. The exemplary throat is a single longitudinal location (zero length). Alternative throats may be represented by a cylindrical cross-section (e.g., a right circular cylinder) of non-zero length. Downstream of the throat (e.g., immediately/directly downstream) is a first divergent section 210. An exemplary first divergent section extends over a length L_{D1} . An exemplary first divergent section has a single angle of diversion (shown as a half-angle θ_{D1}).

[0033] A second divergent section 212 is downstream

of the first divergent section 210. The second divergent section is less divergent (smaller magnitude of an angle between the surface and the centerline or axis of the passageway) than the first divergent section. The second divergent section may have a single constant divergence angle (shown as half-angle θ_{D2}) over a length L_{D2} . The second divergent section can extend directly from the first divergent section to the exit so that the two lengths equal the throat-to-exit length L_{TE} . For throats of non-zero length, L_{TE} may be measured from the downstream end of the throat. With the addition of variations such as bevels and chamfers, the length of the two may sum to greater than or equal to 90% of L_{TE} , for example at least 95% or at least 98%.

[0034] In some embodiments, the angle θ_{D1} is from 0.5° to 5.0°, or 1.0 to 4.0°, or 1.5° to 2.5°, or 2.0°. The angle θ_{D1} may be selected to provide a rapid expansion/vaporization of the motive flow.

[0035] In some embodiments, the angle θ_{D2} is from 0.3° to 4.0°, or 0.7° to 3.0°, or 0.8° to 1.5°, or 1.0° to 1.3°. This may be selected to tailor the exit flow for improved mixing with the secondary flow. In some embodiments, the angle θ_{D2} is from 40% to 60% of θ_{D1} , or 40% to 70% of θ_{D1} , or 30% to 80% of θ_{D1} .

[0036] In some embodiments, the angle L_{D1} is 5% to 80% of L_{TE} , or 10% to 60%, or 20% to 40%. This may be selected to limit the Mach number of material flowing through the first divergent section 210 (e.g., the downstream end thereof forming a junction with the second divergent section 212) to a range of 0.9 to 1.2. The Mach number in the second divergent section 212 will be higher (e.g., 1.0 to 2.0 at the exit 110 and at least 0.050 higher than in the first divergent section (e.g., at the downstream end of the first divergent section), or at least 0.10 higher, or at least 0.20 higher).

[0037] In some embodiments, the angle L_{D2} is 20% to 95% of L_{TE} , or 40% to 90%, or 60% to 80%. This may be selected to avoid flow separation and avoid a shock inside the nozzle.

[0038] In operation, high pressure (e.g., transcritical or liquid state), low velocity (e.g., Mach number of 0.01 to 0.1), flow enters the motive nozzle. It then undergoes acceleration to a Mach number of 0.8 to 1.0 near the throat (minimum cross-section) location or region. Thereafter, the flow further accelerates in the first divergent section to a Mach number of 0.9 to 1.2 at the end of the first divergent section. The flow further accelerates in the second divergent section to a Mach number of 1.0 to 2.0 at the exit of the second divergent section. The Mach number of the flow in the second divergent section (e.g., at the end of the second divergent section) is at least 0.05 higher than that in the first divergent section (e.g., at the end of the first divergent section). In various implementations, this may offer an advantageous combination of smooth flow acceleration and cost reduction (minimizing divergent angles and optimal choice of angle relationships) because faster acceleration is first targeted in the first divergent section using a larger angle (than

the second divergent section) and slower acceleration (with the highest Mach number) is targeted in the second divergent section with a smaller angle (than the first divergent section).

[0039] Relative to a baseline nozzle with a single angle of divergence, one or more advantages may be present in some particular implementations. For example, the first divergent section may quickly expand and vaporize the motive flow; whereas the second divergent section controls the fluid exiting angle and velocity which can improve the mixing process in the mixer.

[0040] Relative to more complex configurations such as the third figure of Ogata et al. there may also be one or more of several advantages in some particular implementations. One notable advantage is that an implementation with just two divergent angles may be easier to align the sections when manufacturing (e.g., allow for easier centering of the axes of the throat, the first divergent section, and/or the second divergent section relative to any one of the preceding when machining). Second, reduced overall length may correspondingly reduce material cost and/or reduce costs of the needle and its actuator if present.

[0041] A further potential advantage in some particular implementations relative to the Ogata et al. configuration involves the relationship of the convergent section length L_C to the total divergent section length or throat-to-exit length L_{TE} . Whereas Ogata et al. shows an extremely short convergent length, the present exemplary L_C may be larger than L_{D1} and L_{D2} individually and combined. For example, exemplary L_C may be at least 80% of L_{TE} , at least, 100% of L_{TE} , or at least 105% of L_{TE} . This relatively long convergent section can provide benefits of smoothed flow transition in some particular implementations. For example, flow through the convergent section may have a Mach number of 0.1 to 1.0 (e.g., entering the convergent section having a Mach number of 0.10 and exiting the convergent section having a Mach number of 0.9 to 1.0), this relatively longer transition can provide smother flow acceleration and thus reduced flow separation and hence reduced frictional or shear losses. The losses can be more significant at higher Mach numbers (e.g., at Mach numbers of 0.5 to 1.0). A shorter convergent section may have a similar change in Mach number over a shorter length, thus suffering greater flow separation frictional and/or shear losses. A relatively longer convergent section can be particularly beneficial for embodiments having needles extending into the convergent section. The presence of the needle can cause additional flow disturbances in the convergent section as the flow is accelerated.

[0042] In other variations, additional features such as those of other baseline nozzles may be present. For example, a non-zero length throat is noted above. Furthermore, the use of various needles and their actuators are within the scope of the present disclosure and their use without does not depart from the spirit of the present disclosure.

[0043] Materials and manufacturing techniques commonly used for ejectors and vapor compression systems may be used. Motive nozzles can include metal (e.g., steel, aluminum, copper, titanium, or a combination including at least one of the foregoing), plastic, or a combination comprising at least one of the foregoing. Manufacturing techniques can include machining (e.g., lathe turning of exterior surface portions of the motive nozzle and drilling or electro-discharge machining (EDM) of the central passageway from motive nozzle inlet to motive nozzle exit). Such techniques can yield a passageway (e.g., throat, convergent section and/or divergent section) centered on the nozzle axis (e.g., of circular cross-section). Exemplary forming of the passageway comprises end-to end drilling. This may define the throat diameter. Then the divergent section may be formed by EDM (e.g., wire EDM). An exemplary EDM of the convergent section involves using a conical tool (electrode) shaped to the profile of the convergent section. Similarly, one or more electrodes may be used to EDM the divergent sections (e.g., two conical electrodes corresponding to the respective divergent sections). In an embodiment, the ejector can be formed in an additive manufacturing process such as, but not limited to, powdered metal sintering, direct deposition, and the like.

[0044] The use of "first", "second", and the like in the description and following claims is for differentiation within the claim only and does not necessarily indicate relative or absolute importance or temporal order. Similarly, the identification in a claim of one element as "first" (or the like) does not preclude such "first" element from identifying an element that is referred to as "second" (or the like) in another claim or in the description.

[0045] One or more embodiments have been described. Nevertheless, it will be understood that various modifications may be made. For example, when applied to an existing basic system, details of such configuration or its associated use may influence details of particular implementations. Accordingly, other embodiments are within the scope of the following claims.

Claims

1. An ejector (200) comprising:

a motive flow inlet (40);
a secondary flow inlet (42);
an outlet (44);
a motive nozzle (200) having an exit (110); and
a motive flow flowpath proceeding through the motive nozzle and joining a secondary flow flowpath extending from the secondary flow inlet to form a combined flowpath to the outlet,

wherein from upstream to downstream along the motive flow flowpath, the motive nozzle has:

- a convergent section (206);
a throat (208);
a first divergent section (210) commencing within 10% of a throat-to-exit length (200) and diverging over a first length (LD1) of at least 10% of the throat-to-exit length (LTE); and
a second divergent section (212), the second divergent section diverging over a second length (LD2) of at least 10% of the throat-to-exit length at a shallower angle than the first divergent section over said first length.
2. The ejector of claim 1 wherein, along the motive flow flowpath:
the first divergent section extends at a single first half angle ($\theta D1$) directly from the throat; and
the second divergent section extends at a single second half angle ($\theta D2$) directly from the first divergent section.
3. The ejector of claim 2 wherein:
the first half angle is 1.0° to 4.0°, particularly 1.5° to 2.5°; and
the second half angle is 0.7° to 3.0°, particularly 0.8° to 1.5°; and/or
the second half angle is 30% to 80%, particularly 40% to 60% of the first angle.
4. The ejector of any previous claim wherein:
the first length is at least 50% of the throat-to-exit length; and
the second length is at least 15% of the throat-to-exit length.
5. The ejector of any previous claim wherein:
the second divergent section ends within 5% of the throat-to-exit length from the exit.
6. The ejector of any previous claim wherein:
the motive nozzle is metallic.
7. The ejector of any previous claim wherein:
a convergent section length (LC) is greater than the throat to exit length, and/or
the convergent section length is at least 110% of the throat to exit length.
8. The ejector of any previous claim wherein:
there is only a single said motive flow inlet;
there is only a single said secondary flow inlet;
and
- there is only a single said outlet.
9. A vapor compression system (20) comprising the ejector of any previous claim.
10. The vapor compression system of claim 9 further comprising:
a compressor (22);
a first heat exchanger (30);
a second heat exchanger (64); and
a separator (48) having:
an inlet (42);
a liquid outlet (52); and
a vapor outlet (54);
an expansion device (70).
11. The vapor compression system of claim 10 further comprising:
a plurality of conduits positioned to define a first flowpath sequentially through:
the compressor;
the first heat exchanger;
the ejector from the motive flow inlet through the ejector outlet; and
the separator, and then branching into:
a first branch returning to the compressor; and
a second branch passing through the expansion device and second heat exchanger to the secondary inlet.
12. A method for using the ejector or vapor compression system of any previous claim comprising:
passing a motive flow through the motive flow inlet;
passing a secondary flow through the secondary flow inlet;
merging the motive flow and the secondary flow to form a merged flow; and
passing the merged flow through the outlet,
wherein:
the motive flow reaches a first Mach number of 0.9 to 1.2 at a downstream end of the first divergent section; and
the motive flow accelerates to a second Mach number of at least 0.05 greater than the first Mach number in the second divergent section.
13. The method of claim 12 wherein:

the second Mach number is at least 0.2 greater than the first Mach number.

14. An ejector (200) comprising:

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a motive flow inlet (40);

a secondary flow inlet (42);

an outlet (44);

a motive nozzle (200) having an exit (110); and

a motive flow flowpath proceeding through the motive nozzle and joining a secondary flow flowpath extending from the secondary flow inlet to form a combined flowpath to the outlet,

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wherein from upstream to downstream along the motive flow flowpath, the motive nozzle has:

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a convergent section (206);

a throat (208); and

means (210; 212) for providing an a second acceleration upstream of the motive nozzle exit exit that is lower than a first acceleration downstream of the throat.

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15. The ejector of claim 14 wherein the means comprises;

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a first divergent section (210); and

a second divergent section (212), the second divergent section diverging at a shallower angle than the first divergent section.

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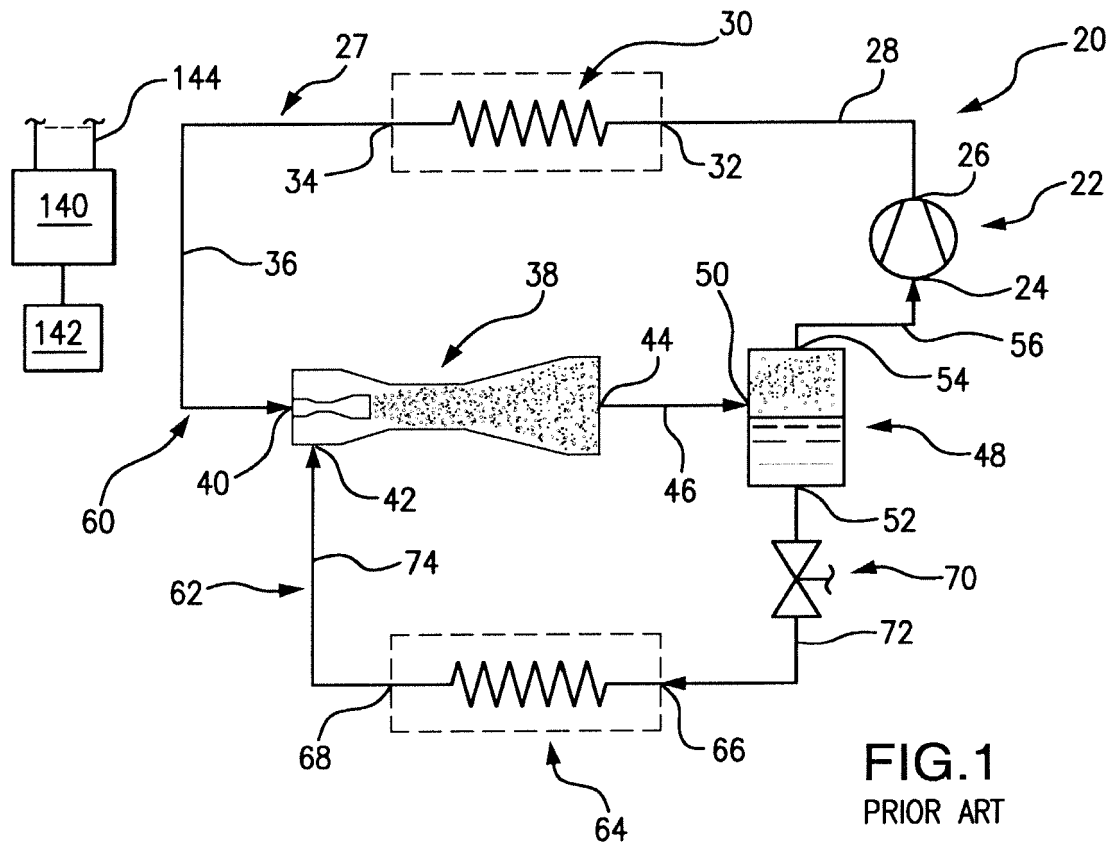


FIG. 1
PRIOR ART

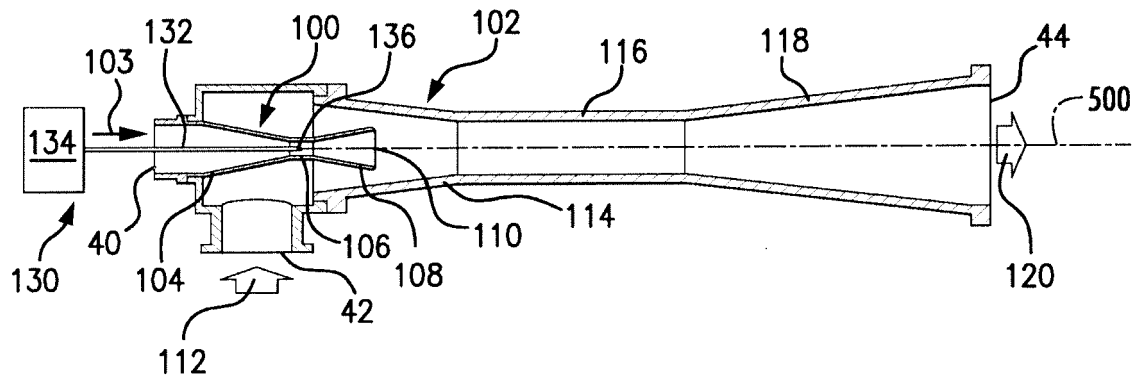


FIG. 2
PRIOR ART

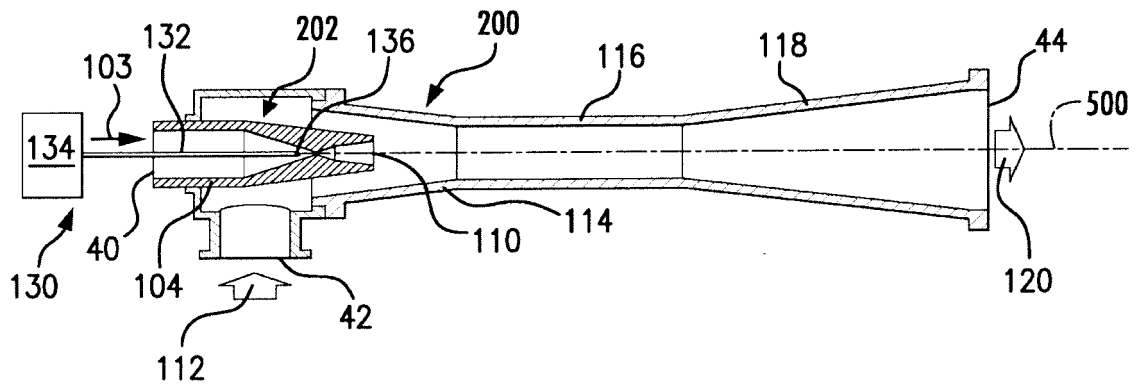


FIG. 3

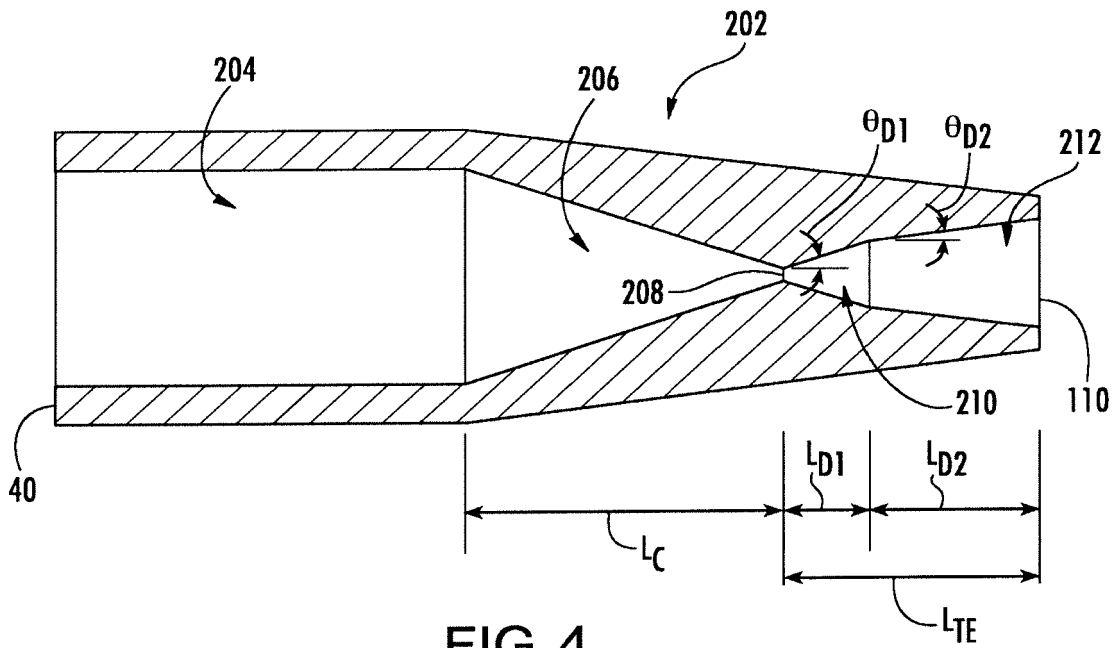


FIG. 4



EUROPEAN SEARCH REPORT

 Application Number
 EP 16 16 9423

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DOCUMENTS CONSIDERED TO BE RELEVANT			
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Place of search Munich		Date of completion of the search 14 September 2016	Examiner Ritter, Christoph
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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**ANNEX TO THE EUROPEAN SEARCH REPORT
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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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