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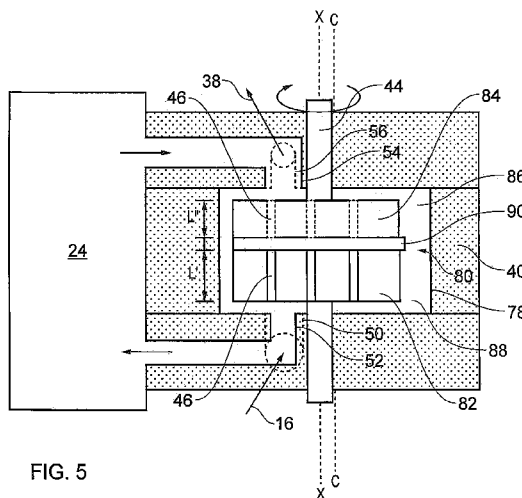


FIG. 5

(57) Abstract: Liquid ring pumps are used to pump a variety of fluid types. The present invention provides a two stage liquid ring pump through which an exhaust gas comprising compounds to be destroyed is passed. The exhaust gas passes through the first stage to a gas abatement device, following which it is passed back to the second stage of the liquid ring pump for removal of the compounds formed in said abatement device. The stages of the liquid ring pump may be adjustable.

WO 2017/013382 A1

## ABATEMENT SYSTEM

The present invention relates to a liquid ring pump for treating an effluent gas stream from a processing chamber. In particular an effluent gas stream which is reactive  
5 with or soluble in a service liquid of the pump.

Liquid ring pumps are used to pump a variety of gases, however their typical materials of construction (e.g. stainless steel, cast iron, brass, etc.) precludes their use with strongly corrosive or reactive gases (i.e. acidic, basic, oxidising or reducing gases).  
10 Known liquid ring pumps have been made from exotic materials such titanium, ceramics and polymers, however, not only can these materials be costly but it is difficult to manufacture pumps with these materials with the required close dimensional tolerances between certain components, for example the rotor and the stator.

15 In some pumping applications an effluent gas stream is chemically reactive with, or soluble in, the service liquid in the liquid ring pump, which is typically water, generating corrosion products. Such corrosion products can cause additional corrosion and wear issues.

20 The present invention seeks at least to mitigate one or more of the problems associated with the prior art.

The present invention provides an abatement system for treating an effluent gas stream, the system comprising: a two-stage liquid ring pump, the stages comprising  
25 respective gas inlets and gas outlets; and at least one abatement apparatus, wherein the gas inlet of the first stage of the liquid ring pump is arranged to receive said effluent gas stream for treatment in the first stage and the gas outlet of the first stage is arranged to exhaust gas to the abatement apparatus, and the gas inlet of the second stage of the liquid ring pump is arranged to receive gas treated by the abatement apparatus for treatment by  
30 the second stage and the gas outlet of the second stage is arranged to exhaust gas so that the effluent gas stream can be treated in series by the first stage of the liquid ring pump, the abatement apparatus and the second stage of the liquid ring pump.

Other preferred and/or optional aspects of the invention are defined in the accompanying claims.

In order that the present invention may be well understood, several embodiments thereof, which is given by way of example only, will now be described with reference to  
5 the accompanying drawings, in which:

Figure 1 illustrates schematically an abatement system including a two stage liquid ring pump;

10 Figure 2 illustrates a radial cross-section through a first pump;  
Figure 3 shows an axial cross-section through a second pump;  
Figure 4 shows an axial cross-section through a third pump;  
Figure 5 shows an axial cross-section through a fourth pump; and  
Figure 6 shows a radial cross-section through a prior art pump.

15

With reference first to Figure 1, an abatement system 10 is shown for treating an effluent gas stream for example an effluent gas stream 12 exhausted from a processing tool or chamber 14 for processing semiconductors, flat panel displays, and solar panels. A dry pumping arrangement 16 evacuates gas from the chamber which may be at vacuum  
20 in the region of 1 mbar to  $1 \times 10^{-6}$  mbar for example. The dry pumping arrangement may comprise a high vacuum pump such as a turbo molecular pump and a lower vacuum pump such as a blower.

The abatement system 10 comprises a two-stage liquid ring pump 20, comprising  
25 two pumping stages 26, 28, and an abatement apparatus 22. The first stage 26 of the liquid ring pump 20 serves as a pre-scrubber and the second stage 28 as a post scrubber for the effluent gas flow which flows to and from the abatement device. The abatement apparatus 22 may be, for example, a reaction chamber, catalytic, plasma or combustor 24 for abating a component of the effluent gas flow.

30

The first pumping stage 26 comprises a gas inlet 30 and a gas outlet 32. The second pumping stage 28 comprises a gas inlet 34 and a gas outlet 36. The gas inlet 30 of

- 3 -

the first stage 26 is arranged with suitable pipework to receive the effluent gas stream 12 from the dry pumping arrangement 16 for pre scrubbing treatment in the first stage 26. The gas outlet 32 of the first stage is arranged with suitable pipework to exhaust gas to the abatement apparatus 22. A liquid gas separator may be provided between the first stage 26 of the liquid ring pump 20 and the abatement apparatus 22 to separate gas from water exhausted from the first stage 26. However, as indicated in more detail below, a separator may not be preferred in certain abatement applications.

The abatement apparatus 22 treats gas exhausted from the first stage 26 of the liquid ring pump 20 for example by plasma reaction or combustion.

The gas inlet 34 of the second stage 28 of the liquid ring pump 20 is arranged with suitable pipework to receive gas treated by the abatement apparatus 22 for treatment by the second stage 28. The gas outlet 36 of the second stage is arranged with suitable pipework to exhaust gas to a facility 38 after the effluent gas stream has been treated by the second stage of the liquid ring pump.

In this way, the effluent gas stream can be treated in series by the first stage 26 of the liquid ring pump 20, the abatement apparatus 22 and the second stage 28 of the liquid ring pump.

The two-stage pumping arrangement of the liquid ring pump 20 may take a number of suitable forms. Figure 2 shows a radial cross-section taken through a pumping chamber and rotor of one suitable arrangement of the liquid ring pump 20. The section is taken generally perpendicularly to the axis X of the pump.

Liquid ring pumps are well known in the art and the pumping mechanism of a typical pump is shown in Figure 6. A liquid ring 100 is formed around an outer periphery of a generally cylindrical pumping chamber 102 on rotation of a rotor 104 mounted for rotation about an axis X which is eccentric to the central axis C of the pumping chamber. The rotor has blades 106 that extend radially outwardly from a hub 108 and are equally spaced around the rotor. With rotation of the rotor, the blades engage the liquid conveyed

to the chamber from a source of liquid 110 forming an annular ring inside the pumping chamber.

This means that gas entering through an inlet 112 that enters compression regions 5 114 located between adjacent rotor blades 106 is moving radially outward, away from the rotor hub, while on the outlet side of the pump the gas is moving radially inward toward the rotor hub prior to exhaust through outlet 116. This results in a piston-type pumping action on the gas passing through the pump. That is, the compression regions increase and decrease in volume through rotation of the rotor. The compression regions are 10 defined by adjacent rotor blades, the liquid ring and an outer surface 118 of the hub. Accordingly, gas is pumped through a single stage for each rotation of the rotor.

The Figure 2 arrangement provides a pumping chamber which is non-circular in cross-section such that gas can be pumped from the gas inlets to the gas outlets of the first 15 and second stages for each half rotation of the rotor. That is, the pump is configured so that a rotor is received for forming a liquid ring in the pumping chamber and pumping gas from the gas inlet to the gas outlet of the first stage and from the gas inlet to the gas outlet of the second stage of the pump. As described in more detail below, the liquid ring is not cylindrical in Figure 2 as would be the case in a typical liquid ring pump, and instead may 20 be elliptical or generally elliptical.

Referring to Figure 2, a pumping chamber 38 is formed by a stator 40. The pumping chamber has a generally elliptical cross-section having a major axis in the Y direction and a minor axis in the Z direction. The elliptical shape is one way in which 25 two-stage pumping can be provided in a single pumping chamber. A rotor 42 is mounted to a drive shaft 44 for rotation in the chamber as indicated by the arrow showing in Figure 2 counter-clockwise movement. The rotor rotates about a rotor axis X which is generally coincident with the central axis of the pumping chamber, at the intersection of the Y and Z axes. The rotor comprises a plurality of rotor blades 46 extending radially outwardly 30 from a central hub 48.

- 5 -

In the first stage of pumping, gas is pumped in a first direction relative to the major axis Y of the ellipse from inlet 30 to outlet 32 and in the second stage, gas is pumped in a second, generally opposing direction relative to the major axis Y from an inlet 34 to an outlet 36. The pumping chamber comprises for the first stage inlet port 50 and outlet port 52 in a first pumping chamber portion 58 and for the second stage inlet port 54 and outlet port 56 in a second pumping chamber portion 60. The inlet port 50 and outlet port 52 are in gas communication with respective inlet 30 and outlet 32 of the first stage. The inlet port 54 and outlet port 56 are in gas communication with respective inlet 34 and outlet 36 of the second stage.

10

In the first stage of pumping, the pumping chamber portion 58 is shaped so that gas conveyed into the inlet port 50 enters a compression region between rotor blades 46 and undergoes piston-like pumping action over rotation of the rotor through approximately  $180^\circ$  prior to exhaust through outlet port 52. In the second stage of pumping, the pumping chamber portion 60 is shaped so that gas conveyed into the inlet port 54 enters a compression region between rotor blades 46 and undergoes piston-like pumping action over rotation of the rotor through approximately  $180^\circ$  pumping chamber portions prior to exhaust through outlet port 56.

20

As shown, the pumping chamber 38 is generally elliptical and therefore the shape of each pumping chamber portion 58, 60 causes the compression region to increase and decrease in volume over rotation of the rotor through approximately  $180^\circ$ . It will be appreciated that an elliptical shape is not the only possible shape in which the compression regions can be caused to increase and decrease in volume a plurality of times over one full rotation of the rotor. In this regard, the profile of the first stage pumping chamber sections may be such that its radius increases from a gas inlet at between  $0^\circ$  and  $30^\circ$  to its maximum between  $0^\circ$  and  $180^\circ$  and preferably at about  $90^\circ$ . Subsequently, the radius decreases from the maximum to its minimum radius at the pump outlet at between about  $150^\circ$  and  $180^\circ$ . Similarly, the profile of the second stage pumping chamber section may be such that its radius increases from a gas inlet at between  $180^\circ$  and  $210^\circ$  to its maximum between  $180^\circ$  and  $360^\circ$  and preferably at about  $270^\circ$ . Subsequently, the radius

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- 6 -

decreases from a maximum to a minimum radius at the pump outlet at between about 330° and 360°. Preferably, the profile of both pumping chamber portions are curved.

In Figure 2, the first pumping chamber portion 58 is symmetrical with the second  
5 pumping chamber portion 60, such that similar pumping characteristics are achieved in  
the first and the second stage. Alternatively, the pumping chamber portions may be  
asymmetric such that the first stage and the second stage have dissimilar pumping  
characteristics. A volume of a pumping chamber portion 58 of the first stage 26 is greater  
10 than a volume of a pumping chamber portion 60 of a second stage 28 such that greater  
compression can be provided when pumping gas through the first stage compared to the  
second stage. For example, the pumping chamber has a semi-major axis defining the first  
stage which is longer than the semi-major axis defining the second stage so that  
compression ratio is higher in the first stage. Such dissimilar characteristics may be  
15 desirable in the present arrangement as the first stage of the liquid ring pump 20 prior to  
treatment by the abatement apparatus 24, may be required to provide a relatively high  
compression, for example for reducing a power requirement of the upstream dry pump  
16. The second stage of the liquid ring pump, downstream of the abatement apparatus,  
may be required to provide relatively low compression, for example to pump gas to  
provide scrubbing but not to compress gas to any significant degree.

20

In a second arrangement shown in Figure 3, the liquid ring pump 20 comprises  
first and second pumping chambers 62, 64 in which respective rotors 66, 68 are received  
for forming liquid rings in the pumping chambers and pumping gas in the first stage from  
the gas inlet 30 to the gas outlet 32 of the first pumping chamber 62 and in the second  
25 stage from the gas inlet 34 to the gas outlet 36 of the second pumping chamber 64. This  
arrangement is similar to a typical liquid ring pump except that two pumping stages are  
provided and the rotors are rotated by a common drive shaft 44 for pumping gas trapped  
in compression regions 47 between rotor blades and the liquid ring. In this regard, rotors  
66, 68 are mounted eccentrically for rotation about axis X relative to a central axis C of  
30 the generally cylindrical pumping chambers 62, 64. The stator 40 comprises a partition  
wall 70 between the pumping chambers having an opening 72 through which the drive  
shaft 44 extends.

- 7 -

As shown in Figure 3, the first and second pumping stage having pumping chambers 62, 64 and rotors 66, 68 are generally the same and therefore have similar pumping characteristics. In one alternative shown in Figure 4, the pumping characteristics of the first and second stages are designed to be dissimilar. Figure 4 will be described herein only in the aspects which differ from Figure 3.

In Figure 4, the pumping chamber 62 and rotor 68 of the first stage has a greater axial extent, or depth, than the pumping chamber 74 and rotor 76 of the second stage. Therefore, the volume trapped in the compression regions 47 of the first stage is greater than the volume trapped in the compression regions 47 of the second stage. Accordingly, the first stage is configured for a different (larger) volumetric pumping capacity than the second stage and is therefore suitable for the arrangement shown in Figure 1. In a further alternative, the radius of the rotor hub 48 may be different in the first and second stages of the pump to achieve dissimilar pumping characteristics. Other aspects of the rotor could be different from one stage to the next stage to achieve such dissimilar pumping characteristics, such as the circumferential spacing between rotor blades.

A further arrangement of a liquid ring pump is shown in Figure 5. In this arrangement, the liquid ring pump comprises a pumping chamber 78 in which a rotor 80 is received having two arrays 82, 84 of impeller blades 46 on axial sides thereof projecting into respective chamber portions 86, 88 of the pumping chamber for forming respective liquid ring portions in the chamber portions and pumping gas in the first stage from the gas inlet port 50 to the gas outlet port 52 of the first chamber portion 86 and in the second stage from the gas inlet port 54 to the gas outlet 56 of the second chamber portion 88.

The rotor 80 has a central generally circular disc, or back plate, 90 from which the blades of arrays 82, 84 extend. The rotor may be formed as a single piece or more than one piece and then joined together. When driven by drive shaft 44, the rotor portions 82, 84 engage with liquid in the pumping chamber 78 to form a liquid ring comprising two liquid ring portions. One portion of the ring is formed by the blades of the array 82 and the other portion of the ring is formed by the blades of the array 84. The first stage is

- 8 -

formed by the rotor portion 82 in pumping chamber portion 88 and the second stage is formed by the rotor portion 84 in pumping chamber portion 86.

The axial length of the rotor array 82 is  $L'$  and the axial length of the rotor array 84 is  $L''$ .  $L'$  is longer than  $L''$  so that the first stage of pumping has a greater volumetric pumping capacity/pumping speed ( $\text{m}^3\text{h}^{-1}$ ) than the second stage of pumping.

It is also possible that impeller (rotor) comprises a back plate 90 which is moveable relative to, whilst sealing against, the rotor blades 46 and rotor shaft 44 to change  $L'$  and  $L''$  and thus the volume in the first and second pumping stages.

The volume of each stage is sized to suit the incoming gas stream flow rates. For example if additional gas is required in the abatement device then the volume of the pump can be configured such that the volume of the second pumping stage is larger than that of the first pumping stage. Similarly, if the abatement device reduces the total gas flow the pump can be configured such that the volume of the second pumping stage is smaller than that of the first pumping stage.

Waste streams containing one or more target gases to be destroyed may often contain additional materials, solids, condensable vapours or permanent gases which are hydrolysable particulate forming materials (e.g.  $\text{SiF}_4$ ,  $\text{BCl}_3$ ,  $\text{AlCl}_3$ ) which are best removed prior to entry into a gas abatement system, e.g. a plasma reactor or a burner (such as, but not limited to, a fired radiant combustors).

In addition, the reaction of target species, especially perfluorinated compounds such as  $\text{CF}_4$ ,  $\text{C}_2\text{F}_6$ ,  $\text{NF}_3$  is improved if there is a controlled proportion of water vapour in the gas stream containing the species, especially if the abatement is to be performed in a plasma reactor.

Furthermore, the by-products of the plasma reactor will include HF which requires to be dissolved in water in a wet scrubber.

- 9 -

Very often the abatement apparatus, for example a plasma abatement device, treats the gas stream most efficiently when the gas stream has a ratio of water vapour to gas is within a specific range of ratios  $R$ , thus it is advantageous if the liquid ring pump is configured to exhaust from the first stage of the liquid ring pump a gas stream which has  
5 a ratio of water vapour to gas within said range of ratios  $R$ . This can be achieved by varying the water temperature for a given first stage pumping capacity.

CLAIMS

1. An abatement system for treating an effluent gas stream, the system comprising:  
a two-stage liquid ring pump, the stages comprising respective gas inlets and gas  
5 outlets; and  
at least one abatement apparatus,  
wherein the gas inlet of the first stage of the liquid ring pump is arranged to  
receive said effluent gas stream for treatment in the first stage and the gas outlet of the  
first stage is arranged to exhaust gas to the abatement apparatus, and  
10 the gas inlet of the second stage of the liquid ring pump is arranged to receive gas  
treated by the abatement apparatus for treatment by the second stage and the gas outlet of  
the second stage is arranged to exhaust gas so that the effluent gas stream can be treated  
in series by the first stage of the liquid ring pump, the abatement apparatus and the second  
stage of the liquid ring pump.  
15
2. An abatement system as claimed in claim 1, wherein the liquid ring pump  
comprises a pumping chamber in which a rotor is received for forming a liquid  
ring in the pumping chamber and pumping gas from the gas inlet to the gas outlet  
of the first stage and from the gas inlet to the gas outlet of the second stage of the  
20 pump.
3. An abatement system as claimed in claim 2, wherein the pumping chamber is non-  
circular in cross-section such that gas can be pumped from the gas inlets to the gas  
outlets of the first and second stages for each half rotation of the rotor.  
25
4. An abatement system as claimed in claim 3, wherein the pumping chamber is  
generally elliptical in cross-section and in the first stage gas is pumped in a first  
direction relative to the minor axis of the ellipse and in the second stage gas is  
pumped in a second, generally opposing direction relative to the minor axis.  
30
5. An abatement system as claimed in claim 1 or 2, wherein the liquid ring pump  
comprises a pumping chamber in which a rotor is received having two arrays of

impeller blades on axial sides thereof projecting into respective chamber portions of the pumping chamber for forming a liquid ring and pumping gas in the first stage from the gas inlet to the gas outlet of the first chamber portion and in the second stage from the gas inlet to the gas outlet of the second chamber portion.

5

6. An abatement system as claimed in claim 1, wherein the liquid ring pump comprises first and second pumping chambers in which respective rotors are received for forming liquid rings in the pumping chambers and pumping gas in the first stage from the gas inlet to the gas outlet of the first pumping chamber and in the second stage from the gas inlet to the gas outlet of the second pumping chamber, the rotors being supported rotation by a single drive shaft.

10

7. An abatement system as claimed in claim 1, wherein the liquid ring pumping stages are configured so that the volume of the first stage is different to the volume of the second stage so that the gas pumping speed of each stage is different.

15

8. An abatement system as claimed in claim 7, wherein the liquid ring pumping stages are configured so that the volume of the first stage is smaller than the swept volume of the second stage so that the gas pumping speed of the the second stage is greater than the pumping speed of the first stage.

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9. An abatement system as claimed in claim 7, wherein the liquid ring pumping stages are configured so that the volume of the first stage is greater than the swept volume of the second stage so that the gas pumping speed of the the second stage is smaller than the pumping speed of the first stage.

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10. An abatement system as claimed in any one of claims 7 to 9, wherein the rotor comprises a back plate which is axially moveable relative to the rotor vanes and rotor shaft axis to change the volume in the first and second pumping stages.

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- 12 -

11. An abatement system as claimed in claim 3 or 4, wherein the pumping chamber is asymmetric such that that dissimilar pumping characteristics can be provided in the first stage and the second stage.
- 5 12. An abatement system as claimed in claim 11, wherein a volume of a pumping chamber portion of the first stage is different to the volume of a pumping chamber portion of a second stage such that different gas volumes can be accommodated in each stage when pumping gas through the first stage compared to the second stage.
- 10 13. An abatement system as claimed in claim 11 or 12, when dependent on claim 5, wherein the rotor arrays are asymmetric such that dissimilar pumping characteristics are provided in the first stage and the second stage.
- 15 14. An abatement apparatus as claimed in any preceding claim, wherein the abatement apparatus comprises a reaction chamber, plasma, catalyst or a burner device for treating gas passing therethrough after pre-scrubbing by the first stage of the liquid ring pump and before post-scrubbing by the second stage of the liquid ring pump.
- 20 15. An abatement system as claimed in any of claims 2 to 14, wherein the or each rotor is driven by a single drive mechanism comprising a motor and a drive shaft.
- 25 16. An abatement system as claimed in any preceding claim wherein, the abatement apparatus treats the gas stream most efficiently when the gas stream entering said abatement device has a ratio of water vapour to gas within a range of ratios R and the liquid ring pump is configured to exhaust from the first stage of the liquid ring pump, a gas stream which has a ratio of water vapour to gas within said range of ratios R.
- 30

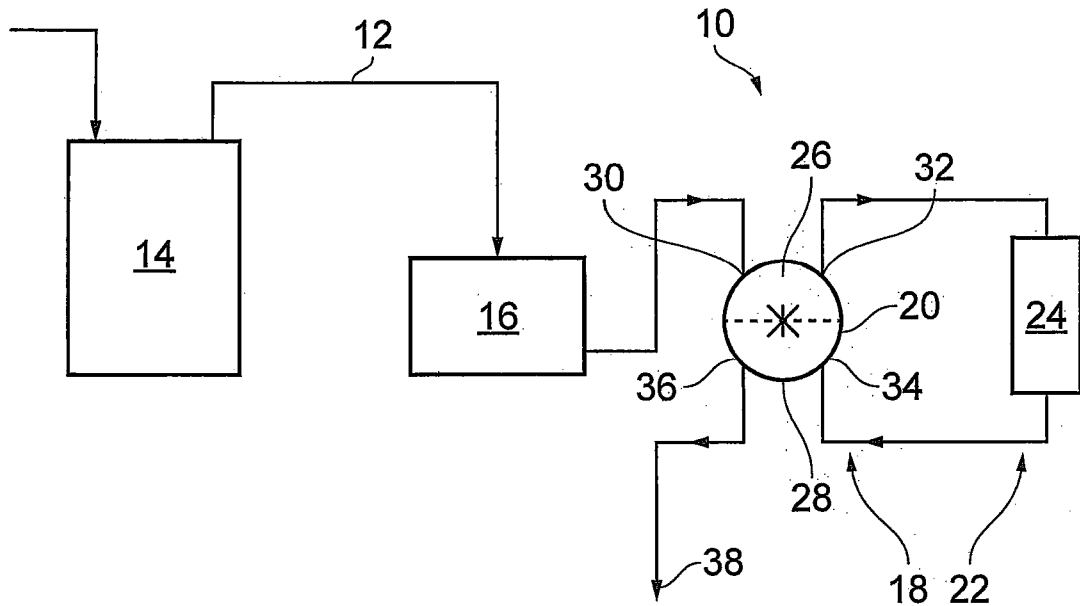


FIG. 1

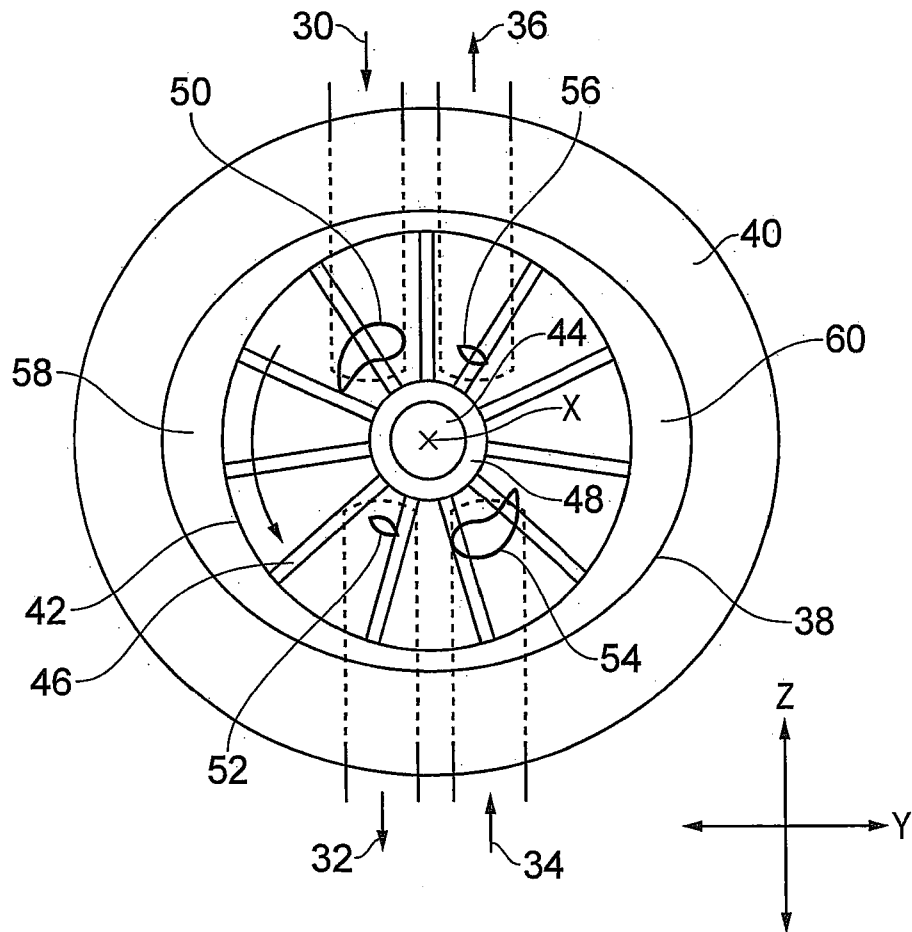


FIG. 2

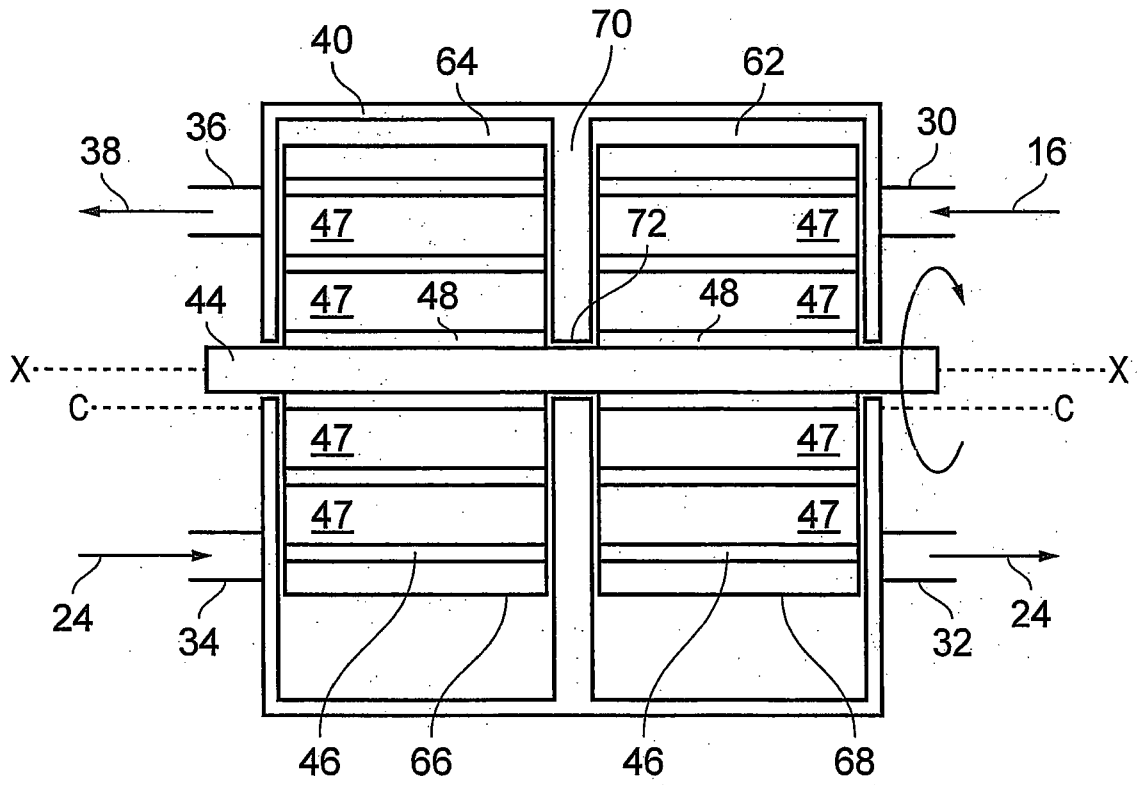


FIG. 3

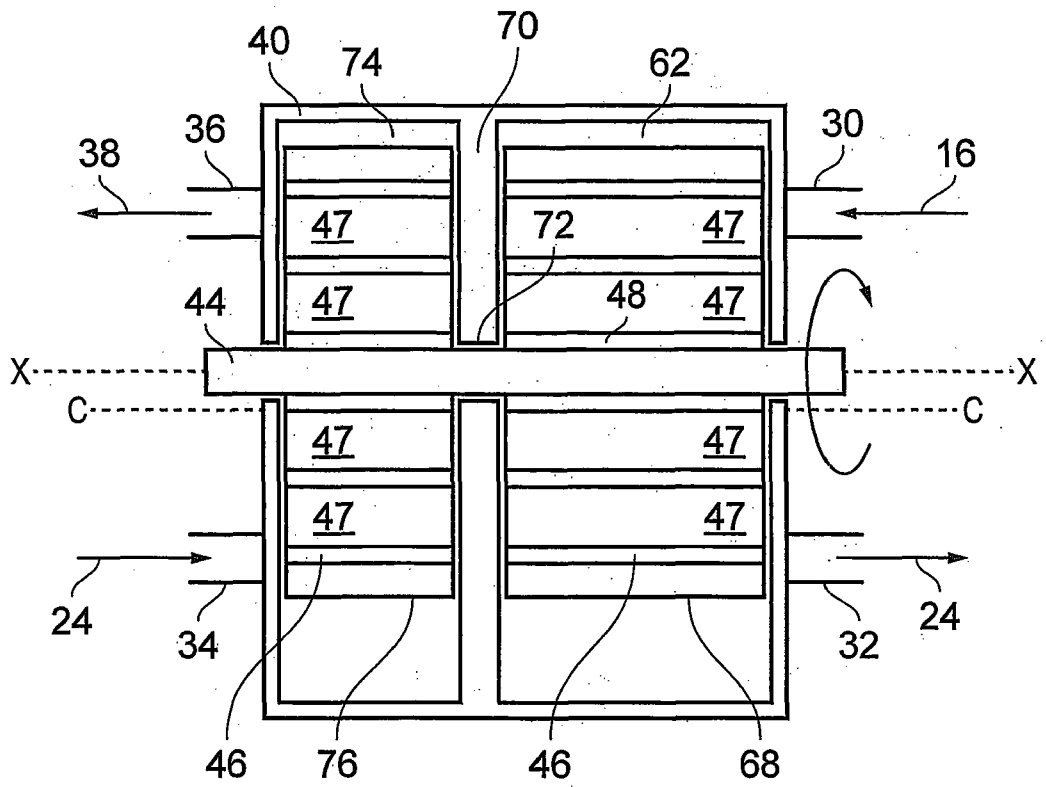


FIG. 4

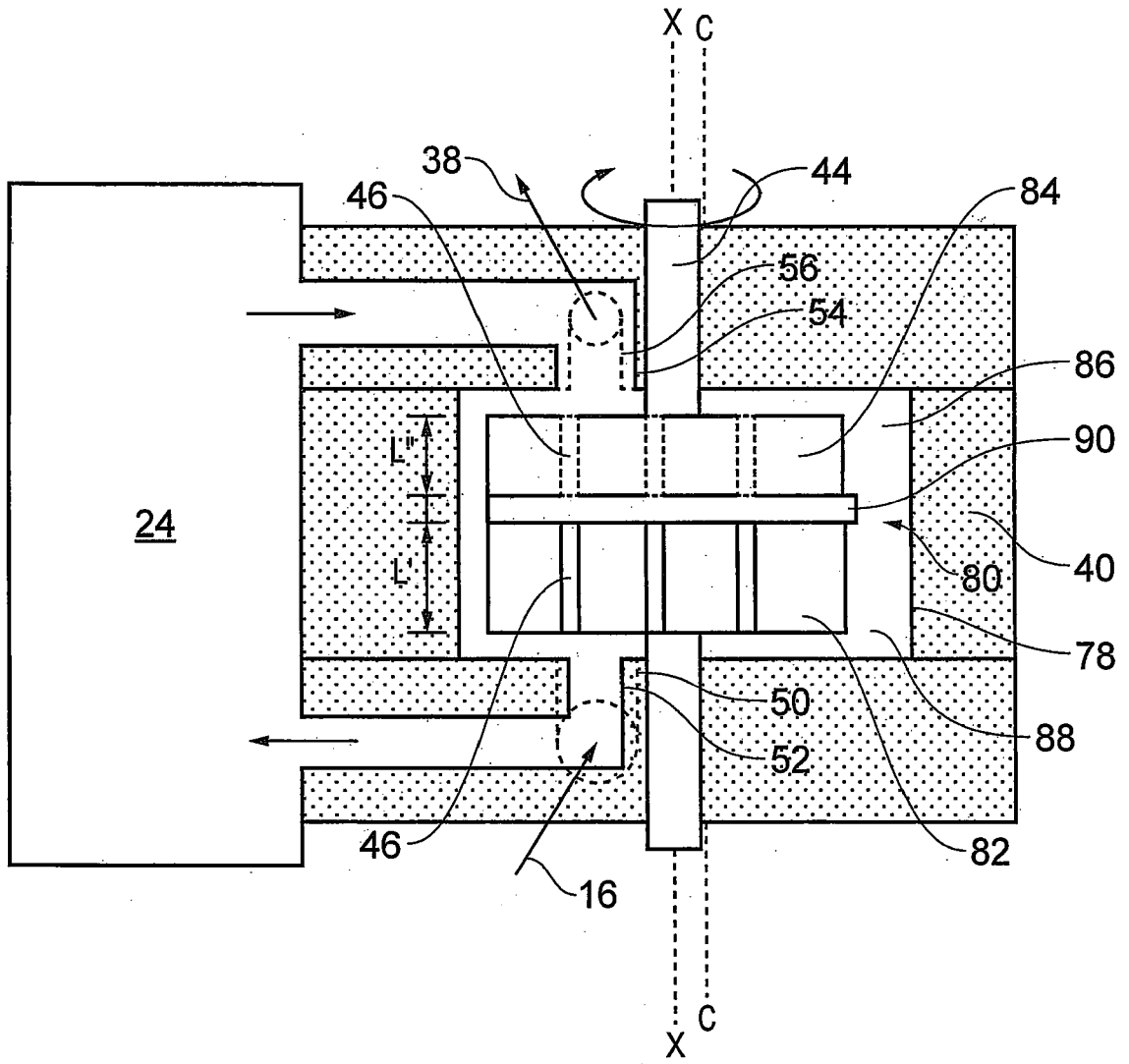


FIG. 5



INTERNATIONAL SEARCH REPORT

International application No  
PCT/GB2016/051763

A. CLASSIFICATION OF SUBJECT MATTER  
INV. F04C19/00  
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)  
F04C

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, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2010/019079 A1 (METSU POWER AB [SE]; LUNDAHL ROBERT [SE]; BLOMSTROEM SOFIA [SE]) 18 February 2010 (2010-02-18)	1,2
Y	page 6, line 29 - page 8, line 30; figure 3	3-13,15
A		16
Y	EP 2 587 065 A1 (NSB GAS PROC AG [CH]) 1 May 2013 (2013-05-01) paragraph [0013] - paragraph [0014]; figure 2	3,4,11,13
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Y	US 3 068 801 A (WILLIAM MURRAY) 18 December 1962 (1962-12-18) column 1, line 20 - line 41; figure 1 claim 1	10

Further documents are listed in the continuation of Box C.

See patent family annex.

\* Special categories of cited documents :

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Date of the actual completion of the international search

22 August 2016

Date of mailing of the international search report

30/08/2016

Name and mailing address of the ISA/

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# INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/GB2016/051763

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