

(19) **DANMARK**



Patent- og
Varemærkestyrelsen

(10) **DK/EP 4073002 T3**

(12) **Oversættelse af
europæisk patentskrift**

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- (51) Int.Cl.: **C 02 F 1/46 (2023.01)** **C 02 F 1/48 (2023.01)** **H 05 H 1/48 (2006.01)**
- (45) Oversættelsen bekendtgjort den: **2025-03-03**
- (80) Dato for Den Europæiske Patentmyndigheds bekendtgørelse om meddelelse af patentet: **2024-11-27**
- (86) Europæisk ansøgning nr.: **20898503.6**
- (86) Europæisk indleveringsdag: **2020-12-07**
- (87) Den europæiske ansøgnings publiceringsdag: **2022-10-19**
- (86) International ansøgning nr.: **CZ2020000054**
- (87) Internationalt publikationsnr.: **WO2021115498**
- (30) Prioritet: **2019-12-13 CZ 201900772 U**
- (84) Designerede stater: **AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR**
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- (54) Benævnelse: **ANORDNING TIL BEHANDLING AF VÆSKER OG FREMGANGSMÅDE TIL BEHANDLING AF VÆSKER VED ANVENDELSE AF DENNE ANORDNING**
- (56) Fremdragne publikationer:
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KEN-ICHI KUDO ET AL: "Oxidative DNA damage caused by pulsed discharge with cavitation on the bactericidal function", JOURNAL OF PHYSICS D: APPLIED PHYSICS, INSTITUTE OF PHYSICS PUBLISHING, BRISTOL, GB, vol. 48, no. 36, 12 August 2015 (2015-08-12), pages 365401, XP020289214, ISSN: 0022-3727, [retrieved on

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MARÁ Ñ• LEK B. ET AL.: "Removal of through the Combined Effect of Plasma Discharge and Hydrodynamic Cavitation", WATER, vol. 12, no. 1, 18 December 2019 (2019-12-18), pages 8, XP055834692, DOI: <https://doi.org/10.3390/w12010008>

DESCRIPTION

Description

Art Domain

[0001] The invention falls into the area of water modification, especially for purpose of liquidation of microorganisms and concerns design for treatment of liquids and the method of treatment of liquids with use of this device.

Present Prior Art

[0002] The problematic of liquidation of microorganisms by use of cavitation with a specially shaped nozzle and an entry body which increases efficiency of cavitation is solved in the file CZ303197, where, however, is not considered influence of low temperature plasma. In device, which is here described, comes to cavitation due to decrease of pressure behind narrowed cross section with consequent generation of super cavitation followed with not so extensive area of water vapor.

[0003] Higher efficiency in liquidation of microorganisms is reached with use of plasma technologies. The principle is that in the area of super cavitation are inserted electrodes with high voltage. By all so far known designs are electrodes placed in the way that the electromagnetic field has perpendicular direction to direction of flowing liquid.

[0004] There is known the whole range of technologies which are used for plasma treatment of liquids, possibly powder materials which are dispersed in liquid. These are mainly discharges working in atmospheric pressure. We can divide discharges into two groups either where the plasma is in direct contact with the liquid or not. As an example of discharges with direct contact of the liquid with the plasma is possible to mention for example jet discharges burning with regard to surface of the liquid or under its surface as is it described in the file CZ 307098, various surface discharges on the surface of liquid mentioned in the documents BRUGGEMAN, P.J., KUSHNER, M.J., LOCKE, B.R., et al., Plasma-liquid interactions: and review and roadmap, Plasma Sources Science and Technology, IOP Publishing, 2016, 25(5), 053002 and LUKESŠ, P., DOLEŽALOVÁ, E., SISROVA, I. and ČLUPEK, M., Aqueous-phase chemistry and bactericidal effects from an air discharge plasma in contact with water: evidence for the formation of peroxyne through a pseudo-second-order post-discharge reaction of H₂O₂ and HNO₂, Plasma Sources Science and Technology, IOP Publishing, 2014, 13(1), 015019, possibly diaphragm discharges which are described in the publication STARÁ, Z., KRCMA, F.,

NEJEZCHLEB, M. and SKALNÝ, J.D., Organic dye decomposition by DC diaphragm discharge in water: Effect of solution properties on dye removal, *Desalination*, 2009, 239(1-3), 283-294, furthermore discharges in bubbles generated by gas flow described in the document PAW

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AT, J., HENSEL, K. and IHARA, S., Generation of oxidants and removal of indigo blue by pulsed power in bubbling and foaming systems, *Czechoslovak Journal of Physics*, 2006, 56(Supplement 2), B1174-B1178, or by heat by electric current excited discharges described in the article LOCKE, B.R., LUKES, P. and BRISSET, J.-L., Elementary Chemical and Physical Phenomena in Electrical Discharge Plasma in Gas-Liquid Environments and in Liquids, *Plasma Chemistry and Catalysis in Gases and Liquids*, Wiley-VCH Verlag GmbH & Co., 2012, 185-241. Into the second category, thus the group of discharges without direct contact with the liquid we can list discharges above the surface of the liquid possibly discharges in multiphase systems of liquids where the liquid is dispersed into aerosol or vapor and the discharge burns in this aerosol as it is described for example in the section MACHALA, Z., TARABOVA, B., SERSENOVA, D., JANDA, M. a HENSEL, K., Chemical and antibacterial effects of plasma activated water: correlation with gaseous and aqueous reactive oxygen and nitrogen species, plasma sources and air flow conditions, *Journal of Physics D: Applied Physics*, 2018, 52(3), 034002. One from disadvantages is then for example impossibility of treatment of the liquids which do not withstand higher temperatures.

[0005] Use of above mentioned induced discharges is quite significantly limited also by a small interactive area of plasma in comparison with capacity of by plasma treated liquid. Moreover some discharges, especially jet discharges need for their operation expensive gases as are for example argon or helium and it is in reality possible only in technologies where is necessary to treat small amount of liquids with high added value of plasma treatment therefore these types of discharges are not usable by applications where are main criteria costs.

[0006] Problem of ignition of discharge in liquids is necessity of an exceptionally high intensity of electric field, more than 1 MV/cm for excitation of avalanche ionization which leads to electric breakdown. Practically is therefore used trick with generation of gaseous micro bubbles in the area of discharge whereby critical value of electric field breakdown decreases under 10kV/cm. When used ohmic heating the amount of energy used only for evaporation of the liquid and formation of bubble makeup up to 95% of total input. Possible solution of this shortage is artificial pumping of gases in the form of micro bubbles into the liquid, namely either through a high voltage electrode or into the area of discharge space. Complication for ignition of the discharge this way is often high electric conductivity of the liquid which enables to reach break down intensity of the electric field only in capacity of only few bubbles. Consequently the resulting plasma is highly non-homogenous, filamentary and space restricted. This is solved through excitation of plasma in the form of HV pulse charging where the energy in pulse is enormous and thus is possible to create discharge in the bubbles. However pulse discharge has quite high costs connected with high purchase price of charging high-voltage pulse sources and also next significant costs especially for modification of this technology for higher capacities.

[0007] Generation of plasma in liquids is followed with sonoluminescence which appears during implosion of bubbles of vapors in liquids where are these bubbles generated by high-frequency waves without external application of electric field which leads to production of plasma bubbles in size in order 1 μ m and lifecycle around 100ps.

[0008] Analogic type of bubbles is possible to generate also with a fast flow of liquid through a suitably shaped contraction when appears so called hydrodynamic cavitation. In the articles IHARA, S., HIROHATA, T., KOMINATO, Y., YAMABE, C., IKE, H., HAKIAI, K., HIRABAYASHI, K. and TAMAGAWA, M., Water Treatment Using Discharge Generated in Cavitation Field with Micro Bubble Cloud, Electrical Engineering in Japan, Wiley Periodicals, 2014, 186(4), 1-10 and IHARA, S., SAKAI, T., YOSHIDA, Y. and NISHIYAMA, H., Fundamental characteristics of discharge plasma generated in a water cavitation field, Journal of Electrostatics, Elsevier, 2018, 93, 110-117 is described layout where the couple of HV electrodes is placed outside of shaped contraction whose electromagnetic field is perpendicular to direction of liquid flow in tube and in this way formed cavitation cloud they ignite intensive but space restricted plasma and herewith only comes to poor treatment of the liquid. The device which is described in the file US 2009/0071910 is always based on two electrodes (powered and grounding) which are present in the area of cavitation and furthermore it does not enable any inlet of gasses or solid powder into the area of plasma discharge. In the publication OKA, Y., OHNISHI, K., ASAMI, K., et al, Dispersion of carbon nanotubes into water without dispersant using cavitation bubble plasma, Vacuum, Elsevier, 2017, 136, 209-213 [9] is mentioned design where was for formation of cavitation cloud used rotating cylinder with revolutions 7200rev/min., also here were both powered electrodes placed directly in the cavitation cloud and resulting plasma was also strongly non-homogenous.

[0009] An example of treatment of fluids by the use of plasma discharge combined with cavitation occurring in a waist of the fluid flow is disclosed in: \$

[0010] KEN-ICHI KUDO ET AL: "Oxidative DNA damage caused by pulsed discharge with cavitation on the bactericidal function", JOURNAL OF PHYSICS D: APPLIED PHYSICS, INSTITUTE OF PHYSICS PUBLISHING, BRISTOL, GB, vol. 48, no. 36, 12 August 2015 (2015-08-12), page 365401.

[0011] An extreme example of formation of bubbles in liquids is then formation of foam which is a thermodynamically unstable colloid structure with high concentration of dispersed gas. This is therefore a two-phase system where the water is present in the form of a thin membrane which is separated by gas bubbles. The foam can be generated by whipping, gas pumping, shaking or vacuuming. All depends on characteristic of the liquid, temperature, pressure, presence of various surfactants and so on. In such foamy environment is possible to simply ignite the discharge and treatment of the liquid is highly effective up to 10x better than in above mentioned discharges. Disadvantage is then the necessity to supply big amount of gas, energy demandingness of foam production especially when characteristic of the liquid prevent generation of foam and furthermore not big suitability of usage in higher quantities.

[0012] The aim of the invention is to eliminate above described disadvantages of known designs and create such method of plasma treatment of liquids and a device for generation of low-temperature plasma in liquids which would be universally suitable for industrial plasma treatment of various types of liquids with wide variety of characteristic and conductivity including liquids with dispersed powders which would not need for right function high volume of working gas, would be energetically, spatially and investment modest, would generate plasma in the whole cross section of supplied liquid and would enable simple dimensioning and scaling up for various flows.

Essence of the invention

[0013] in a first aspect, the invention discloses a device for treatment of liquids according to claim 1.

[0014] In a second aspect the invention discloses a method for treatment of liquids according to claim 8.

[0015] Advantageous embodiments are disclosed in the dependent claims.

[0016] With presented invention is reached higher efficiency because when is used a full powered electrode the discharge is electrically excited in diluted vapors of the liquid without access of air which is advantageous for flammable liquids and dispersions. Also the plasma burns in super-cavitation from the powered electrode to capacity of the liquid and for different conductivities of the liquid is not necessary to optimize distance of the electrodes. Conductivity of the liquid has influence only on length of the zone with powered plasma namely at keeping of constant performance thus it is not necessary to optimize distance of the electrodes for given medium with various parameters. In case of use of a hollow powered electrode is possible to suck into the flowing liquid gas, reaction liquid or particles in form of powder which are then dispersed into the working liquid and consequently treated by formed plasma in super-cavitation. In case of use of even hollow grounding electrode is possible to treat also solid non-conductive materials in form of fibers or rods.

Clarification of drawings

[0017] Particular examples of invention design are schematically illustrated in enclosed drawings where:

Fig. 1 is a schematic drawing of the device in cavitation mode,

Fig. 2 is a schematic drawing of the device in super-cavitation mode,

Fig. 3 is a schematic drawing of the device with alternative design of grounding electrode,

Fig. 4 is a schematic drawing of the device with added ejector and

Fig. 5 is a schematic drawing of the device with an ultrasound generator connected to the grounding electrode.

[0018] The drawings which illustrate presented invention and consequently described examples of particular design do not in any case anyhow limit the extent of the protection which is defined by the claims.

Examples of realisation:

[0019] The device for pursuit of the method of treatment of liquids consists, in basic design which is illustrated in fig. 1, of mutually in series connected a pressure regulator 1 and a cavitation tube 2 which is formed by in series on each other connected a cylindrical inlet chamber 21, confusor 22, cylindrical working chamber 23, diffusor 24 and a cylindrical discharge chamber 25. In the inlet chamber 21 is perpendicularly to the lengthwise axis of the cavitation tube 2 placed an electrode support 31 to which is fixed an oblong powered electrode 3 placed on the lengthwise axis of the inlet chamber 21 and reaches with its free end into the working chamber 23, whereas the powered electrode 3 is electrically conductive connected with the electrode support 31 yet both elements 3 and 31 are from the body of the cavitation tube 2 electrically insulated. To the electrode support 31 is connected a high voltage source 4 by which is via the electrode support 31 powered the powered electrode 3. In the discharge chamber 25 is placed the grounding electrode 5 by the help of which is grounded also the liquid flowing in the cavitation tube 2. The circular shape of cross section of the cavitation tube 2 is not only possible design, as the cross section of the cavitation tube 2 can have arbitrary shape.

[0020] Alternatively are the electrode support 31 and the powered electrode 3 made hollow with formed common non-illustrated transit cavity which is open on one side out from the cavitation tube 2 and on the other side on free end of the powered electrode 3 reaches into the working chamber 23 as it is illustrated in figs. 3 to 5.

[0021] Another alternative is design of the grounding electrode 5 as a part of the shell of the cylindrical discharge chamber 25 as it is illustrated in fig.3.

[0022] Another alternative which is illustrated in fig. 4 is placement of an ejector 6 behind the discharge chamber 25. The ejector 6 is formed by a supply chamber 61 which is connected to the discharge chamber 25 and a throat 62. From the supply chamber 61 is sideways taken out a suction pipeline 63 which opens into the throat 62. The ejector 6 can be alternatively substituted by a non-illustrated pump.

[0023] Alternatively is the grounding electrode 5 designed as an oscillating ultrasound powered tip which is connected to an ultrasound generator 8 as it is illustrated in fig.5.

[0024] During pursuit of the method of treatment of the liquids according to the fig.1 is by the pressure regulator 1 kept such pressure value of the liquid which flows through the inlet chamber 21 into the cavitation tube 2 to enable, at the place of contraction, generation of cavitation or super-cavitation. The liquid is from the inlet chamber 21 taken to the confusor 22 where comes to significant increase of its speed and at the same time to decrease of the pressure, namely under pressure of saturated vapors. In this moment in the confusor 22 start to appear first bubbles which at high speed advance through the working chamber 23 where starts to generate cavitation. In the diffusor 24 comes, thanks to separation of a boundary layer, to next decrease of the pressure and significant extension of the cavitation zone which fills practically the whole space of the diffusor 24 and advances even into the discharge chamber 25 where comes to generation of cavitation cloud 71. Possibly comes to generation of super-cavitation 72 when the liquid flows only through the central part of the discharge chamber 25 and around it is the space completely filled with super-cavitation medium as it is illustrated in fig. 2. By the high voltage source 4 whose frequency ranges between 0 to 20MHz is powered the powered electrode 3 through whose potential toward the grounding electrode 5 is generated electromagnetic field whose direction is parallel with the direction of liquid flow. Through this electromagnetic field are then powered the discharges of the plasma which burns in the whole area of the cavitation 71 or super-cavitation 72.

[0025] In an alternative design when the electrode support 31 and the electrode 3 are made hollow, can be through the cavity, which is formed inside of them, supplied into the space of generation of the cavitation 71 or super-cavitation 72 gas or solid particles.

Industrial usability

[0026] The invention is usable for generation of low-temperature plasma in liquids which serves for plasma treatment of liquids or suspensions of liquids which contain biological and chemical contaminants or liquids which contain dispersed powders but also for treatment of non-conductive materials in the form of rods and threads in liquids without access of air in hygiene industry, chemical industry, building industry, industry, food industry and so on. The invention is usable for decontamination of water not only waste water but also for sterilization of potable and service water and furthermore for treatment of liquids based on hydrocarbons as are for example oils, paints and so on.

REFERENCES CITED IN THE DESCRIPTION

Cited references

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- [CZ307098 \[0004\]](#)
- [US20090071910A \[0008\]](#)

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- Elementary Chemical and Physical Phenomena in Electrical Discharge Plasma in Gas-Liquid Environments and in Liquids **LOCKE, B. R. LUKES, P. BRISSET, J.-L.** Plasma Chemistry and Catalysis in Gases and Liquids Wiley-VCH Verlag GmbH & Co 2012 0000 185-241 [\[0004\]](#)
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- Water Treatment Using Discharge Generated in Cavitation Field with Micro Bubble Cloud **IHARA, S. HIROHATA, T. KOMINATO, Y. YAMABE, C. CIKE, H. HAKIAI, K. HIRABAYASHI, K. TAMAGAWA, M.** Electrical Engineering in Japan Wiley Periodicals 2014 0000 vol. 186, 1-10 [\[0008\]](#)
- Fundamental characteristics of discharge plasma generated in a water cavitation field **IHARA, S. SAKAI, T. YOSHIDA, Y. NISHIYAMA, H.** Journal of Electrostatics, Elsevier 2018 0000 vol. 93, 110-117 [\[0008\]](#)
- Dispersion of carbon nanotubes into water without dispersant using cavitation bubble

plasmaOKA, YOHNISHI, KASAMI, K. et al.VacuumElsevier20170000vol. 136, 209-213 [0008]

- Oxidative DNA damage caused by pulsed discharge with cavitation on the bactericidal functionKEN-ICHI KUDO et al.JOURNAL OF PHYSICS D: APPLIED PHYSICSINSTITUTE OF PHYSICS PUBLISHING20150812vol. 48, 365401- [0010]

P A T E N T K R A V

1. Anordning til behandling af væsker ved hjælp af dannelse af en elektrisk drevet udladning af lavtemperatursplasma i et væskemiljø, hvor det, når væsken flyder, er muligt at opnå dannelse af kavitation eller superkavitation, hvor nævnte anordning omfatter en trykregulator (1) og et kavitationsrør (2), som er indbyrdes forbundet i serie, hvor kavitationsrøret (2) er dannet ved et indløbskammer (21), en konfuser (22), et arbejdskammer (23), en diffusor (24) og et udledningskammer (25), som er indbyrdes forbundet to og to, hvor anordningen yderligere omfatter en strømledende elektrode (3) placeret i indløbskammeret (21) i dets længdeakse i retning af væskestrømmen, hvor den strømledende elektrode (3) med sin frie ende når ind i arbejdskammeret (23), og en højspændingskilde (4), til hvilken den strømledende elektrode (3) er elektrisk ledende forbundet, hvor den strømledende elektrode (3) er elektrisk isoleret fra kavitationsrøret (2), hvor anordningen yderligere omfatter en jordet elektrode (5), der er placeret i udledningskammeret (25) og i elektrisk kontakt med væsken.

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2. Anordning ifølge krav 1, hvor den strømledende elektrode (3) er fastgjort på en elektrodestøtte (31), som er placeret inde i indløbskammeret (21) vinkelret på kavitationsrørets (2) længdeaksen, hvorfra den er elektrisk isoleret, mens den strømledende elektrode (3) er elektrisk forbundet med elektrodestøtten (31) og gennem elektrodestøtten (31) er forbundet med højspændingskilden (4).

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3. Anordning ifølge krav 2, hvor elektrodestøtten (31) og den strømledende elektrode (3) er gjort hule med et formet fælles gennemløbshulrum, som er åben på dets ene side ud fra kavitationsrøret (2) og på den anden side af den frie ende af den strømledende elektrode (3), som når ind i arbejdskammeret (23).

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4. Anordning ifølge et hvilket som helst af kravene 1 til 3, hvor den jordet elektrode (5) er gjort som en del af skallen på udledningskammeret (25).

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5. Anordning ifølge et hvilket som helst af kravene 1 til 3, hvor den jordet elektrode (5) er gjort som en oscillerende ultralydsdrevet spids, der er forbundet til en ultralydsge-

erator (8).

6. Anordning ifølge et hvilket som helst af kravene 1 til 5, hvor der bag udledningskammeret (25) er placeret en ejektor (6) dannet af et forsyningskammer (61), som er forbundet til udledningskammeret (25) og en hals (62) hvorfra der fra forsyningskammeret (61) går en sugerørsledning (63), som ledes ind i halsen (62).

7. Anordning ifølge et hvilket som helst af kravene 1 til 6, der yderligere omfatter en pumpe, der er placeret bag udledningskammeret (25) og forbundet med kavitationsrøret (2).

8. Fremgangsmåde til behandling af væsker ved hjælp af anordningen ifølge kravene 1 til 7, hvor lavtemperatursplasma er dannet på det sted, hvor kavitation eller superkavitation dannes, eller i umiddelbar nærhed af dens dannelse mod væskestrømmen, i dens retning ved hjælp af den strømledende elektrode (3), som er placeret på linje med væskestrømmen, hvor frekvensen af højspændingsudledningen varierer i værdier fra 0 til 20 MHz.

9. Fremgangsmåde ifølge krav 8, hvor plasmaet er ultralydsstimuleret.

10. Fremgangsmåde ifølge kravene 8 eller 9, hvor der tilføres gas til det sted, hvor der dannes kavitation eller superkavitation.

11. Fremgangsmåde ifølge kravene 8 eller 9, hvor der tilføres fast stof i pulverform til stedet for dannelse af kavitation eller superkavitation.

12. Fremgangsmåde ifølge krav 11, hvor det faste stof i pulverform er fotoreaktivt.

13. Fremgangsmåde ifølge et hvilket som helst af kravene 8 til 12, hvor væsken suges fra området bag det sted, hvor kavitationen forsvinder.

DRAWINGS

Drawing

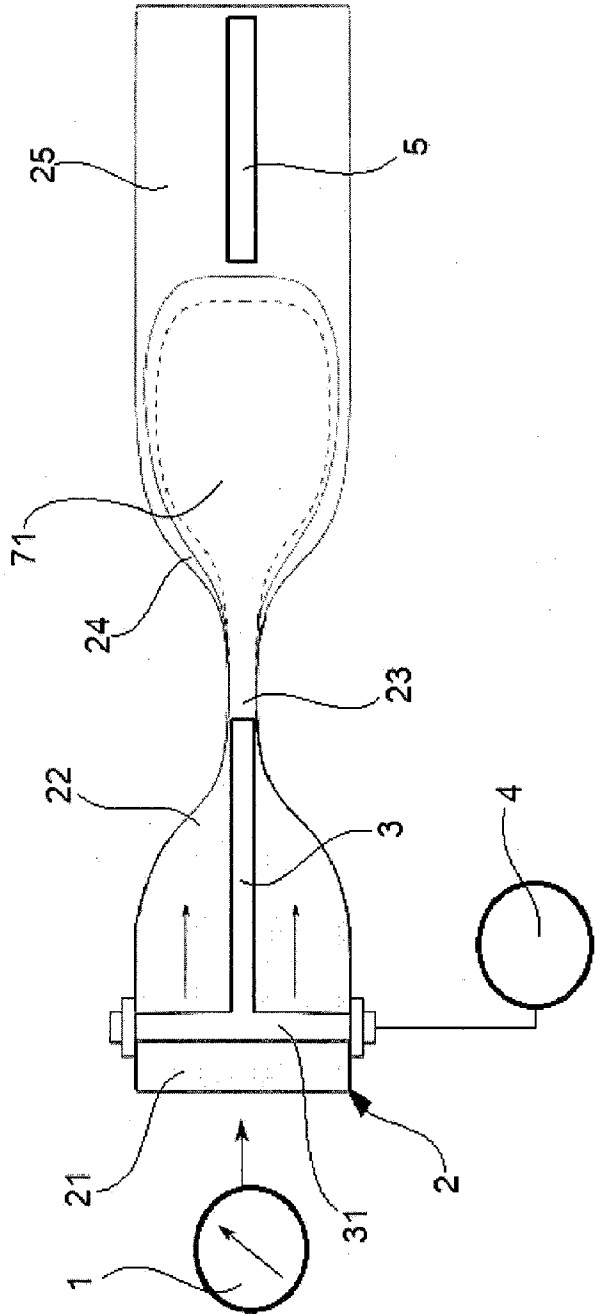


FIG. 1

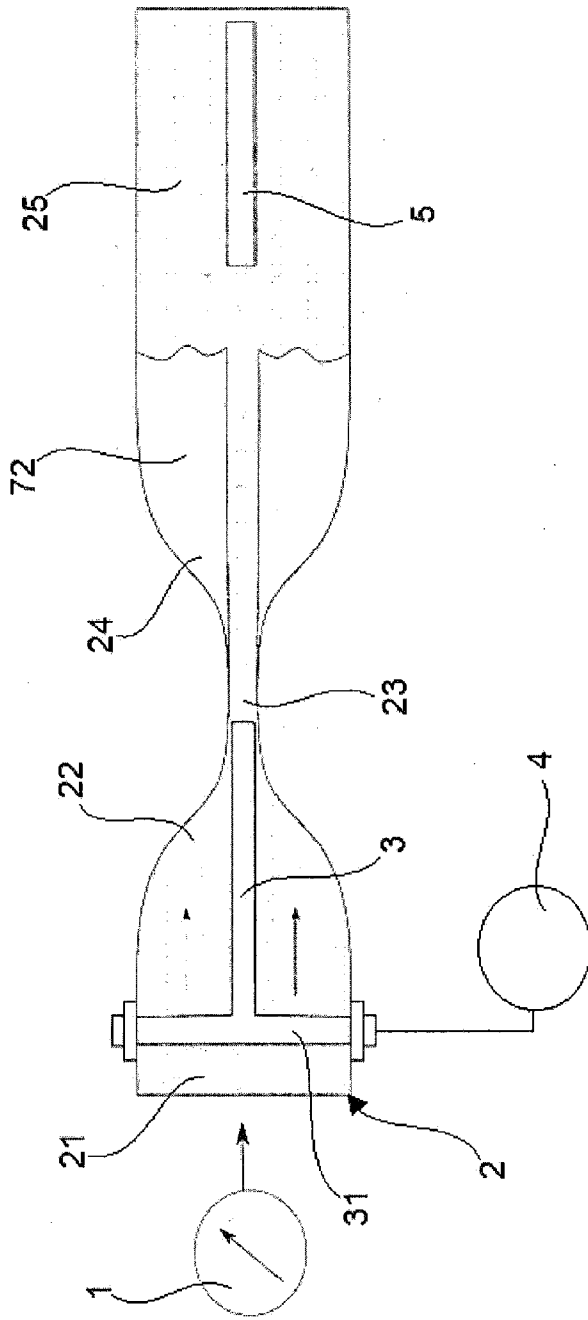


FIG. 2

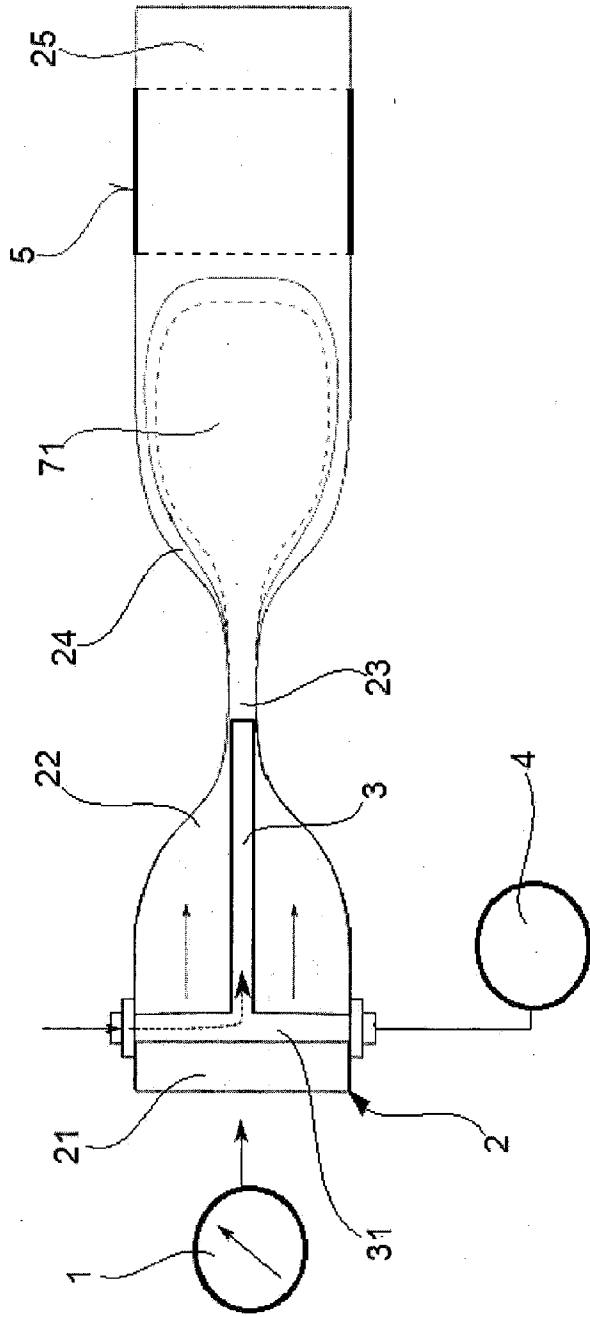


FIG. 3

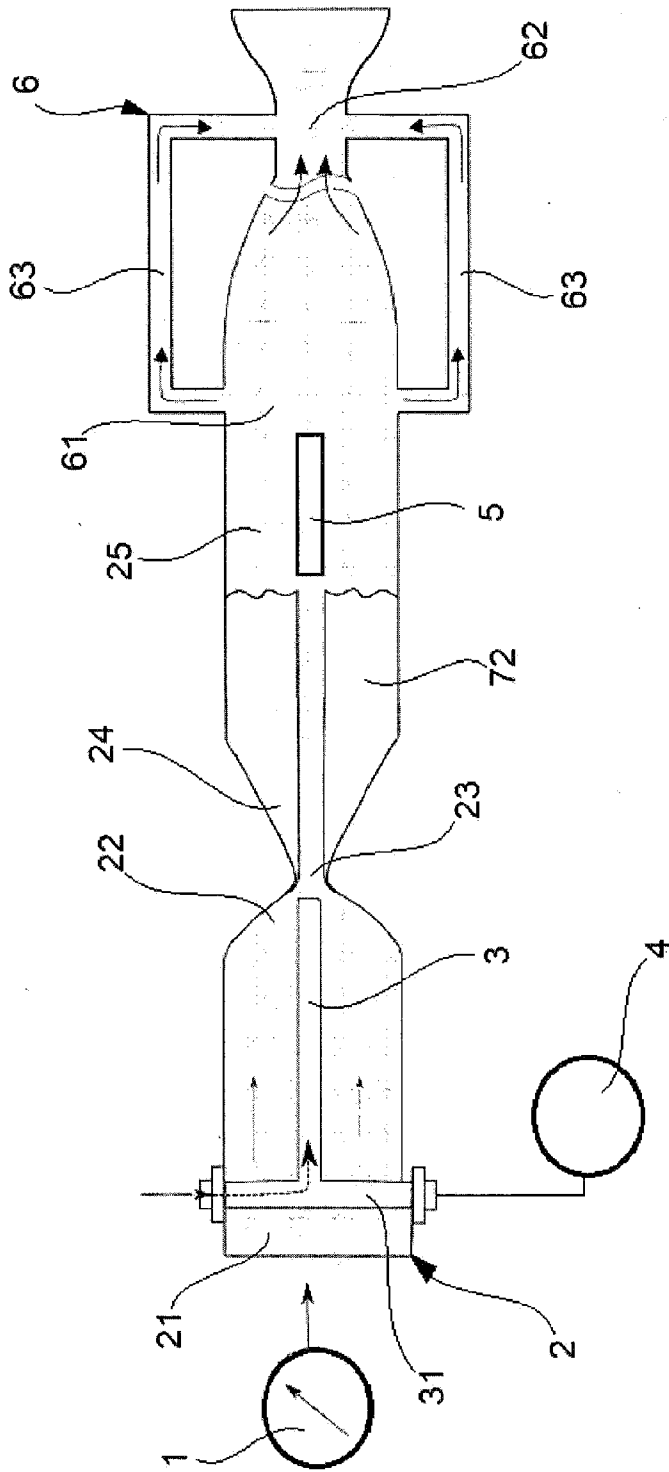


FIG. 4

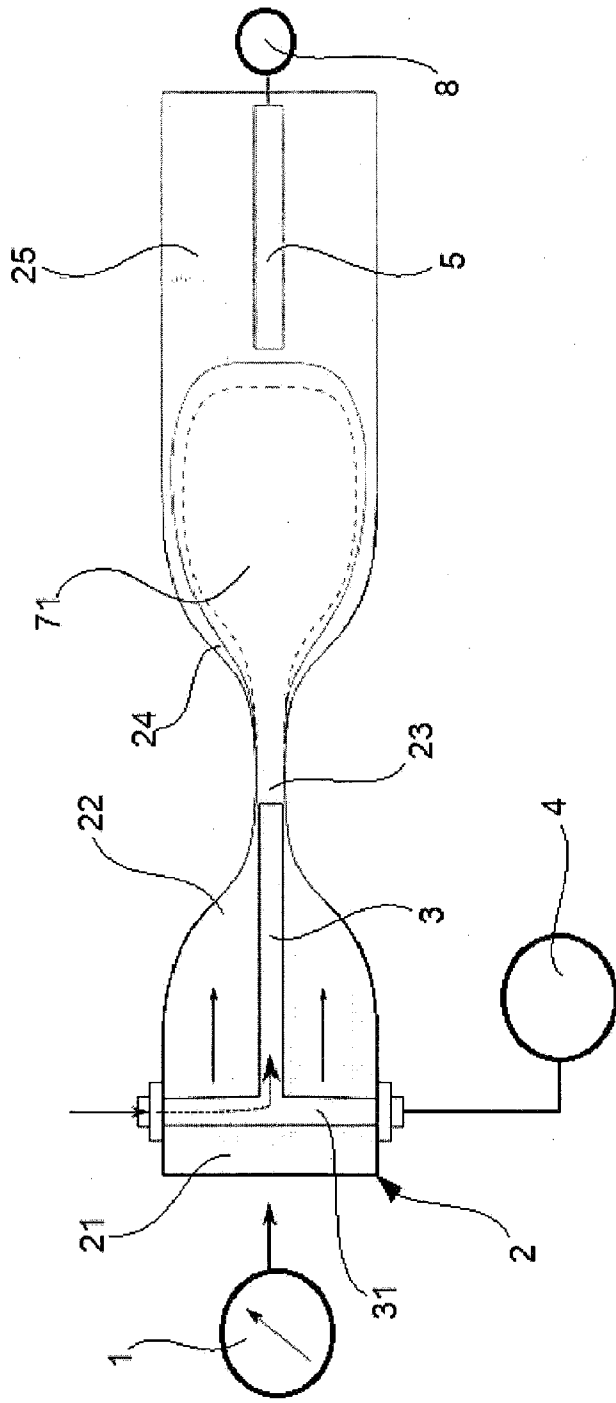


FIG. 5

FIGURE FOR ANNOTATION

