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(54) **Title:** APPARATUS FOR MONITORING PARTICLES

(57) **Abstract:** The invention relates to an apparatus for electrically monitoring particles in an aerosol in non-collective manner such that a sample aerosol flow is arranged to flow through the apparatus, the apparatus (1) comprising an outer housing (A) for forming an outer casing of the apparatus. The apparatus (1) of the present invention further comprises a sensor housing (B) arranged inside the outer housing (A) and electrically separated from the outer housing (A) for receiving a sample aerosol flow and electrically monitoring particles in the sample aerosol flow.



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Apparatus for monitoring particles

The present invention relates to an apparatus for monitoring particles and especially to an apparatus as defined in the preamble of independent claim 1.

Background of the invention

- 5 Fine particles are formed in many industrial processes and combustion processes. Furthermore, fine particles exist in breathing air flowing in ducts and ventilation systems and in room spaces. For various reasons these fine particles are measured. The fine particle measurements may be conducted because of their potential health effects and also for monitoring operation of
- 10 industrial processes and combustion processes. The fine particles are also measured in ventilation systems for monitoring air quality. Another reason for monitoring fine particles is the increasing use and production of nanosized particles in industrial processes. The above reasons generate a need for reliable fine particle measurement equipments and methods.
- 15 One prior art method and apparatus for measuring fine particles is described in document WO20091 09688 A1. In this prior art method clean, essentially particle free, gas is supplied into the apparatus and directed as a main flow via an inlet chamber to an ejector provided inside the apparatus. The clean gas is further ionized before and during supplying it into the inlet chamber. The ionized clean
- 20 gas may be preferably fed to the ejector at a sonic or close to sonic speed. The ionizing of the clean gas may be carried out for example using a corona charger. The inlet chamber is further provided with a sample inlet arranged in fluid communication with a channel or a space comprising aerosol having fine particles. The clean gas flow and the ejector together cause suction to the
- 25 sample inlet such that a sample aerosol flow is formed from the duct or the space to the inlet chamber. The sample aerosol flow is thus provided as a side flow to the ejector. The ionized clean gas charges the particles. The charged particles may be further conducted back to the duct or space containing the aerosol. The fine particles of the aerosol sample are thus monitored by
- 30 monitoring the electrical charge carried by the electrically charged particles. Free ions may removed further be removed using an ion trap. The application does not describe using a double-faraday cage construction in the device and does not say anything on the materials of the sensor chamber and the outer chamber. The figures of the application are principle drawings (page 7) and
- 35 cannot be interpreted in a wider context than what is written in the description. One important demand for the fine particle monitoring apparatuses is reliable operation and efficient operation. It has been discovered that one problem of

the prior art fine particle measurement apparatuses is a quick and consistent response to variations in measurement properties or in the monitored aerosol. In the prior art particle measurement apparatuses the time response is rather slow. Furthermore, in the prior art non-collective particle measurement apparatuses the time response is usually dependent on surrounding conditions, especially in cases where the measurements are conducted by measuring electrical current escaping from the apparatus. Thus the time response may vary in different applications and measurement conditions.

Brief description of the invention

10 The object of the present invention is to provide an apparatus so as to overcome or at least alleviate the prior art disadvantages. The objects of the present invention are achieved with an apparatus according to the characterizing portion of claim 1.

The preferred embodiments of the invention are disclosed in the dependent claims.

15 The present invention is based on the idea of providing an apparatus for electrically monitoring particles in an aerosol in non-collective manner. The apparatus according to the present invention comprises an outer housing and a sensor housing arranged inside the outer housing. The sensor housing and the outer housing are formed from electrically conductive material. The sensor housing is further electrically separated from the outer housing. The sensor housing is arranged to receive a sample aerosol flow from outside the outer housing and to electrically monitor particles in the sample aerosol flow. Accordingly the sensor housing and the outer housing are formed as faraday cages, and especially nested faraday cages. The apparatus may further comprise a first insulation arrangement for electrically insulating sensor housing from the outer housing. The apparatus may also comprise an intermediate space provided between the outer housing and the sensor housing for further separating the outer housing the sensor housing electrically from each other.

30 In the present invention the measurement space inside the sensor housing is separated from the surrounding environment and atmosphere with two inside each other arranged housings formed from electrically conductive material. These nested housings are thus formed as faraday cages such that the measurement space inside the sensor housing is separated from the environment and atmosphere with the two nested faraday cages. All the supplies into the inner sensor housing are lead from outer side of the outer housing and through the both faraday cages. The sensor housing is connected to virtual ground and the outer

housing is connected to real ground. The real ground means in this context the Earth, the system ground or the ground of the entire apparatus. The apparatus is thus arranged to measure current escaping from inside the sensor housing through the intermediate space between the sensor housing and the outer housing and out of the outer housing and apparatus.

The present invention has the advantage that the outer housing connected to real ground is used to provide fixed time response for the apparatus. The distance and flow conditions between the sensor housing and the outer housing is fixed which enables the time response to be also fixed or constant. Therefore, the present invention removes or at least alleviates variations in the time response. Furthermore, the outer housing may also be arranged such that time response of the apparatus is minimized. The present invention enables to provide minimized and constant time response.

Brief description of the figures

In the following the invention will be described in greater detail, in connection with preferred embodiments, with reference to the attached drawings, in which

Figure 1 is a schematic view of the structure of the apparatus according to the present invention;

Figures 2A and 2B schematically show the time response of prior art apparatuses and the apparatus of the present invention;

Figure 3 is a schematic view of the outer housing of one embodiment of the apparatus;

Figure 4 is a schematic view of the sensor housing of one embodiment of the apparatus; and

Figure 5 shows outer housing and the sensor housing of figures 3 and 4 arranged inside each other.

Detailed description of the invention

The figure 1 shows schematically the structure of the apparatus for electrically monitoring aerosol particles, especially particles having diameter less than $1\ \mu\text{m}$. The apparatus comprises two within each other arranged housings A, B. The apparatus comprises an outer housing A and a sensor

housing B arranged inside the outer housing A. In one embodiment the sensor housing is connected to virtual ground and the outer housing to real ground. A sample aerosol flow is received or intake into the sensor housing B from a measurement space outside of the outer housing A. The measurement space may be ventilation channel, industrial gas channel, industrial exhaust channel, or a room or any other channel or space comprising aerosol with aerosol particles. The apparatus is arranged to operate in non-collective measurement mode in which a sample aerosol flow is taken into the sensor housing B and further exhausted from the apparatus without collecting the aerosol particles of the sample aerosol flow. The apparatus may be arranged at least partly inside the measurement space or it may be provided in fluid connection with the measurement space such that the sample aerosol flow may be taken in from the measurement space and exhausted back to the measurement space or another space. The apparatus further comprises a control assembly 30, schematically shown in figure 1. The control assembly 30 is arranged outside of the outer housing A and the sensor housing B. The control assembly 30 is arranged to provide an essentially particle free ionized gas flow into the sensor housing B for electrically charging aerosol particles in the sample aerosol flow. The apparatus further comprises an ion trap provided inside the sensor housing B for removing free ions not attached to the particles of the sample aerosol flow. The ion trap is provided with an ion trap voltage from the control assembly 30. The ion trap is arranged inside the sensor housing B. According to the above mentioned all the supplies, electrical, gas and sample supplies are brought into the sensor housing B from outside of the outer housing A.

The apparatus is arranged to measure electrical current escaping from the apparatus together with the charged particles. The measurement results of the escaping current are further used for calculating particle concentrations. Figures 2A and 2B show schematically the time response of non-collective particle sensors showing the current escaping with one electrically charged particle. Figure 2A shows a time response of a prior art apparatus for electrically monitoring particles in non-collective manner. The prior art apparatus comprises a sensor housing from which the electrically charged particles are exhausted. The apparatus detects the current I escaping from the sensor housing until it finds a real ground from the surroundings. At time moment T_1 a particle is electrically charged inside the sensor housing and at time moment T_2 the charged particles is exhausted from the sensor housing. At the time moment T_2 the measurement apparatus detects the current I escaping from the apparatus together with the particle. The apparatus detects this escaping current I of the particle as far as the

electrostatic field generated by the particle has an essential strength on the surface of the sensor housing. The weakening of the corresponding field flux takes place gradually and is affected by the dimensions and geometry of the conductive surfaces and flow conditions around the sensor. T3 represents a time moment, when the current has reached some negligible level. The time between T2 and T3 thus defines the time response of the apparatus. In this kind of prior art apparatus the time response varies depending on the flow conditions and surroundings of the apparatus. Figure 2B shows the time response of the present invention. At time moment T1' a particle is electrically charged and at time moment T2' the electrically charged particle is exhausted from the sensor housing. At the time moment T2' the measurement apparatus detects the current I escaping from the sensor housing together with the particle. The apparatus detects this escaping current I of the particle until the particle reaches the outer housing at time moment T3'. When the electrically charged particle is exhausted from the intermediate space between the sensor housing and the outer housing at time moment T3', the apparatus does not detect the electrical charge, and current, carried by the particle as the outer housing forms a faraday cage. Therefore, the time response of the apparatus according to the present invention is defined by the distance and flow field between the sensor housing and the outer housing. This enables the time response of the present invention to be fixed and further to be minimized by minimizing the distance between the sensor housing and the outer housing. The sensor housing and the outer housing are electrically separated from each other. This electrical separation means in this context that the sensor housing and the outer housing may be connected to each other only with a current measurement circuit.

The figure 3 shows in greater detail one embodiment of an outer housing A of the apparatus for monitoring fine particles, especially particles having diameter less than 1 μm . The outer housing A is formed from an electrically conductive material such as stainless steel. Also other electrically conductive materials may be used. As shown in figure 2, the outer housing A consists of two parts which are detachably connected to each other with a flange joint. The outer housing A also comprises an inlet opening 5 for receiving sample aerosol flow inside the apparatus and an exhaust opening 3 for exhausting the sample aerosol flow from the apparatus. The outer housing A also comprises a base part for connecting the control assembly 30 to the apparatus in electrically insulated manner. Therefore, the outer housing A forms a faraday cage, as it forms an enclosure formed by electrically conductive material.

Figure 4 shows one embodiment of the sensor housing B of the apparatus for monitoring fine particles, especially particles having diameter less than $1\ \mu\text{m}$. The sensor housing B is formed from an electrically conductive material, such as stainless steel. Also other electrically conductive materials may be used. The sensor housing B comprises nozzle head 6 through which ionized substantially particle free gas is fed into the inlet chamber 4 of the sensor housing B. The sensor housing B is further provided with an inlet 2 for receiving or taking in sample aerosol flow into the inlet chamber 4 of the sensor housing B. The sensor housing B is also provided with an ion trap 12 arranged in an ion trap chamber 22 for removing free ions not attached to the particles of the sample aerosol flow. The sensor housing B also forms a faraday cage, as it forms an enclosure formed by electrically conductive material.

Figure 5 shows the apparatus 1 assembled such that the sensor housing B, outer housing and the control assembly are configured together to form the apparatus 1. As shown in figure 4, the apparatus comprises the outer housing A for forming an outer casing of the apparatus 1 and the sensor housing B arranged inside the outer housing A for receiving a sample aerosol flow and electrically monitoring particles in the sample aerosol flow. The control assembly is provided in connection with the outer housing A and outside of the outer housing A. The sensor housing B and the outer housing A are formed from electrically conductive material and electrically separated from each other, as seen in figure 4. Thus in the present invention the outer housing A and the sensor housing B are formed as nested faraday cages.

As shown in figure 5, the apparatus comprises a first insulation arrangement 36, 40 provided between the outer housing A and the sensor housing B for electrically insulating the sensor housing B from the outer housing A. The first insulation arrangement comprises an insulation element 36 provided between the inner surface of the outer housing A and the outer surface of the sensor housing B. The insulation arrangement further comprises a gap 40 between the insulation element and the outer surface of the sensor housing B. The gap 40 may form sheath gas flow channel 40 for supplying sheath gas between the outer housing A and the sensor housing B. The insulator element 36 may be any suitable electrically insulating material. The outer housing A and the sensor housing may also be separated from each other at least partly with an intermediate space 42 provided between the outer housing A and the sensor housing B. The intermediate space 42 also electrically separates the sensor housing B and the outer housing A from

each other. The sensor housing B and the outer housing A may be connected to each other by a current measurement circuit.

The apparatus 1 may be connected to an aerosol duct or a space inside comprising aerosol. Thus the apparatus 1 is arranged to monitor fine
5 particles in the aerosol of the space to which it is connected. The aerosol duct may be exhaust duct of an industrial process or a ventilation duct. Alternatively aerosol duct may be any space comprising aerosol or any duct or channel having an aerosol flow. In one embodiment the aerosol duct itself may form the outer housing surrounding the sensor housing B. Thus the
10 aerosol duct provides a faraday cage over the sensor housing B. In one embodiment the sensor housing B may be fixed rigidly inside a flow channel or aerosol duct such that the flow channel forms the outer housing. When the flow channel is formed from an electrically conductive material it also functions as a faraday cage.

15 The sensor housing B comprises a sample inlet 2 for guiding a sample aerosol flow into the apparatus 1. The sample inlet 2 is in fluid communication with the aerosol duct and inside of the sensor housing B. In figure 4 the sample inlet 2 comprises an inlet conduit arranged to intake sample aerosol flow from outside of the outer housing A such that the
20 sample aerosol flow does not flow to the intermediate space 42. Thus the inlet conduit 2 extends from the inlet opening 5 of the outer housing A into the sensor housing B and is electrically insulated from the outer housing A. The sensor housing B preferably also comprises a sample outlet 10 through which the analyzed sample aerosol flow is exhausted from the sensor
25 housing B. Accordingly the apparatus 1 does not collect or store the sample aerosol. In the embodiment of figure 4 the sample aerosol flow is exhausted from the sample outlet 10 to the intermediate space 42 and further out of the exhaust opening 3 of the outer housing A. In an alternative embodiment the apparatus may also comprise a sample-inlet arrangement comprising one or
30 more sample inlets 2. The sensor housing B comprises an inlet chamber 4 and the sample inlet 2 is arranged to provide a fluid communication between the aerosol duct and the inlet chamber 4.

The apparatus is further arranged to feed an essentially particle free ionized gas flow into the sensor housing B for electrically charging aerosol particles in the
35 sample aerosol flow. The apparatus comprises a gas supply for supplying clean particle free gas into the inlet chamber 4 of the sensor housing B. The gas supply may comprise a gas supply connection via which the clean gas

may be brought from a gas source. The gas may be cleaned in a filter or the like for essentially removing particles from the gas. The clean gas may be air or some other suitable gas. Thus the apparatus 1 comprises a clean gas supply channel 16 through which the clean gas is fed into the sensor housing B of the apparatus 1. The clean gas supply channel 16 is in fluid communication with a nozzle head 6 provided to the sensor housing B. The nozzle head 6 opens into the inlet chamber 4. Alternatively the nozzle head 6 may be provided to the clean gas supply channel 16. The clean gas supply is also provided with an ionization means 14 for ionizing at least a portion of the clean gas before or during feeding the clean gas from the nozzle head 6 into the inlet chamber 4. In the embodiment of figure 4 the ionization means comprise a corona needle 14 extending in the clean gas supply channel 16. The nozzle head 6 and the corona needle 14 are advantageously arranged such that corona needle 14 extends essentially to the vicinity of the nozzle head 6. This helps the corona needle 14 to stay clean and improves the ion production. The corona needle 14 is isolated from the clean gas flow channel 16 and the sensor housing B by one or more electrical insulators 38. According to the above mentioned the gas supply channel 16 is arranged to provide an essentially particle free ionized gas flow to the inlet chamber 4. The clean gas supply channel 16 is arranged to the supplying substantially particle free gas in to the sensor housing B from outside of the outer housing A. Thus the voltage source of the corona needle 14 is provided outside of the outer housing A. The clean gas may be supplied from the control assembly 30 or from another clean gas source provided outside of the outer housing A. The corona needle 14 or some other corresponding charging conductor is also arranged to supply charging voltage into the sensor housing B from outside of the outer housing A for ionizing the substantially particle free gas. According to the above mentioned the clean gas and the charging voltage are both supplied into the sensor housing B from outside of the two nested faraday cages A, B, which eliminates or at least reduces interferences caused by the gas supply and the charging voltage. The clean gas supply channel 16 and the charging conductor 14 are both electrically insulated from the outer housing A and the sensor housing B.

The sample aerosol flow may be sucked into the sensor housing with a pump. IN an alternative embodiment, as shown in figure 5, the sensor housing B is provided with an ejector 24. The ejector 24 comprises a converging-diverging nozzle 24 forming thus a converging-diverging flow channel, the throat 8 of the ejector 24. The ejector 24 is a pump-like device utilizing Venturi effect of a converging-diverging nozzle to convert the pressure energy of a main fluid flow to kinetic energy which creates a low pressure zone that draws in and entrains suction for a

side fluid flow. The main fluid flow and the side fluid flow are at least partly mixed in the ejector 24. The main fluid flow and the side fluid flow are fed through an ejector inlet opening into the ejector throat 8. After passing through the throat 8 of the ejector 24, the mixed fluid expands and the velocity is reduced which results in recompressing the mixed fluids by converting velocity energy back into pressure energy. In an alternative embodiment the apparatus may also comprise one or more clean gas supply channels 16, corona needles 14 and ejectors 24.

In the embodiment of figure 5 the essentially particle free ionized gas flow is fed to the throat 8 of the ejector as a main flow. Therefore the clean gas supply channel 16 and the nozzle head 6 are arranged to feed the essentially particle free gas flow at a high velocity into the throat 8. The velocity of the essentially particle free gas flow is preferably sonic or close to sonic. In the ejector 24 the essentially particle free gas flow forms a suction to the sample inlet 2 such that the sample aerosol flow may be sucked into the inlet chamber 4. The sample aerosol flow forms a side flow of the ejector 24. The flow rate of the sample aerosol flow A is depended essentially only on the geometry of ejector 24 and the flow rate of the essentially particle free ionized gas flow. In a preferred embodiment the ratio of the main flow to the side flow is small, preferably less than 1:1 and more preferably less than 1:3. According to the above mentioned there is no need for actively feed the sample aerosol flow into the apparatus 1, but it may be sucked by the by means of the clean gas supply and the ejector 24.

The essentially particle free ionized gas flow and the sample aerosol flow are mixed in the inlet chamber 4 and in the ejector 24 such that the particles of the sample aerosol flow are electrically charged during the mixing by the ionized clean gas flow. The sensor housing B further comprises ion trapping chamber 22 provided with at least one ion trap 12 for removing ions that are not attached to the particles of the sample aerosol flow. The ion trap 12 may be metal wire or some other kind of electrode, such as plate electrode or net-like electrode. The ion tarp 12 is provided with a collection voltage for removing the mentioned free ions. The voltage used for trapping free ions depends on design parameters of the apparatus 1, but typically the ion trap 12 voltage is 10v - 30kV. The ion trap 12 voltage may also be adjusted to removed nuclei mode particles or even the smallest particles in the accumulation mode. The ion trap 12, and also ion trap conductor (not shown) is electrically insulated and separated from the sensor housing C and the outer housing A. An ion trap insulator 44 may be provided between the sensor housing and the ion rap 12. The ion trap voltage source may be provided to the control assembly 30 or in another location outside of the outer

housing A. Thus also the ion trap voltage is supplied into the sensor housing B with an ion trap conductor from outside of the outer housing A.

The control assembly 30 may comprise electronics and other means for controlling the apparatus and carrying out the measurement functions. The control
5 assembly 30 may also be arranged to feed the electrical current to the ionization device 14 and the ion trap 12. Furthermore, the control assembly 30 may also be arranged to supply the essentially particle free gas to the clean gas supply channel 16. This means that all the supplies for operating the apparatus are provided from outside of the outer housing A. The supplies may
10 comprise one or more of the following: at least one voltage supply, at least one gas or aerosol supply and at least one heat supply. The voltage supply may comprise charging voltage supply and ion trap voltage supply. The gas supply may comprise clean gas supply and the sample aerosol flow. The apparatus may further comprise heating means arranged outside of the outer housing for
15 providing heat supply into the sensor housing B.

Particles of the aerosol in the aerosol duct are monitored by measuring the electrical charge carried by the electrically charged particles of the sample aerosol flow. In a preferred embodiment particles of the aerosol are monitored by measuring the electrical charge escaping with the electrically charged particles
20 from the apparatus 1. The measurement of the charge carried by the electrically charged particles may be measured by many alternative ways. In one embodiment the charge carried by the electrically charged particles is measured by measuring the net current escaping from the sample outlet 10 or the discharge opening 3. To be able to measure the small currents, typically at pA level, the
25 whole apparatus 1 is isolated from the surrounding systems. An electrometer may be arranged between the sensor housing B and the outer housing A. With this kind of setup, the electrometer may measure the charge escaping from the isolated apparatus 1 together with the electrically charged particles. In other words this kind of setup measures the escaping current.

30 In the present invention the apparatus is provided with an outer housing A forming a first faraday cage and with a sensor housing B arranged inside the outer housing A and forming a second faraday cage. The control assembly 30 and all the supplies for operating the apparatus are provided outside the nested first and second faraday cage. This kind of arrangement enables providing fixed time
35 response and also to minimize the time response.

It is apparent to a person skilled in the art that as technology advances, the basic idea of the invention can be implemented in various ways. The

invention and its embodiments are therefore not restricted to the above examples, but they may vary within the scope of the claims.

Claims

1. An apparatus (1) for electrically monitoring particles in an aerosol in non-collective manner such that a sample aerosol flow is arranged to flow through the apparatus, the apparatus (1) comprising a sensor housing (B) for receiving a sample aerosol flow and electrically monitoring particles in the sample aerosol flow, **characterized** in that the apparatus (1) further comprises an outer housing (A) for forming an outer casing of the apparatus (1), the sensor housing (B) being arranged inside the outer housing (A), and that the sensor housing (B) and the outer housing (A) are formed from electrically conductive material and electrically separated from each other.
2. An apparatus (1) according to claim 1, **characterized** in that the outer housing (A) and the sensor housing (B) are formed as nested faraday cages.
3. An apparatus (1) according to any one of claims 1 or 2, **characterized** in that the apparatus comprises a first insulation arrangement (36, 40) for electrically insulating the sensor housing (B) from the outer housing (A).
4. An apparatus (1) according to any one of claims 1 to 3, **characterized** in that the apparatus comprises an intermediate space (42) provided between the outer housing (A) and the sensor housing (B).
5. An apparatus (1) according to any one of claims 1 to 4, **characterized** in that the sensor housing (B) is arranged to intake the sample aerosol flow from outside of the outer housing (A).
6. An apparatus (1) according to any one of claims 1 to 5, **characterized** in that the apparatus (1) comprises charging means (14, 16) arranged to electrically charge particles inside the sensor housing (B).
7. An apparatus (1) according to claim 6, **characterized** in that charging means (14, 16) are arranged to supply ionized substantially particle free gas into the sensor housing (B) for electrically charge particles inside the sensor housing (B).
8. An apparatus (1) according to claim 6 or 7, **characterized** in that the charging means (14, 16) comprise a gas supply channel (16) supplying substantially particle free gas in to the sensor housing (B) from outside of the outer housing (A).

9. An apparatus (1) according to any one of claim 6 to 8, **characterized** in that the charging means (14, 16) comprise a charging conductor (14) arranged to supply charging voltage into the sensor housing (B) from outside of the outer housing (A) for ionizing the substantially particle free gas.

5

10. An apparatus (1) according to any one of claims 1 to 9, **characterized** in that apparatus further comprises an ion trap electrode (12) inside the sensor housing (B) for removing ions not attached to particles, and that the ion trap electrode (12) is electrically connected to an ion trap voltage source provided outside of the outer housing (A).

10

11. An apparatus (1) according to any one of claims 1 to 10, **characterized** in that apparatus comprises heating means arranged outside of the outer housing (A).

15

12. The apparatus according to any one of claims 1 to 11, **characterized** in that the sensor housing (B) an ejector (24) for sucking the sample aerosol flow into the sensor housing (B).

20

13. The apparatus according to any one of claims 1 to 12, **characterized** in that all supplies arranged for operating the apparatus are provided outside of the outer housing (A).

25

14. The apparatus according to claim 13, **characterized** in that the supplies comprise on or more of the following: at least voltage supply, at least one gas or aerosol supply and at least one heat supply.

15. The apparatus according to any one of claims 1 to 14, **characterized** in that the outer housing (A) and the sensor housing (B) are connected to each other through a current measurement circuit measuring the current escaping from the apparatus with electrically charged particles.

30

16. The apparatus according to any one of claims 1 to 15, **characterized** in that the sensor housing (B) is fixed inside an aerosol channel provided from electrically conductive material, and that the aerosol channel forms the outer housing (A).

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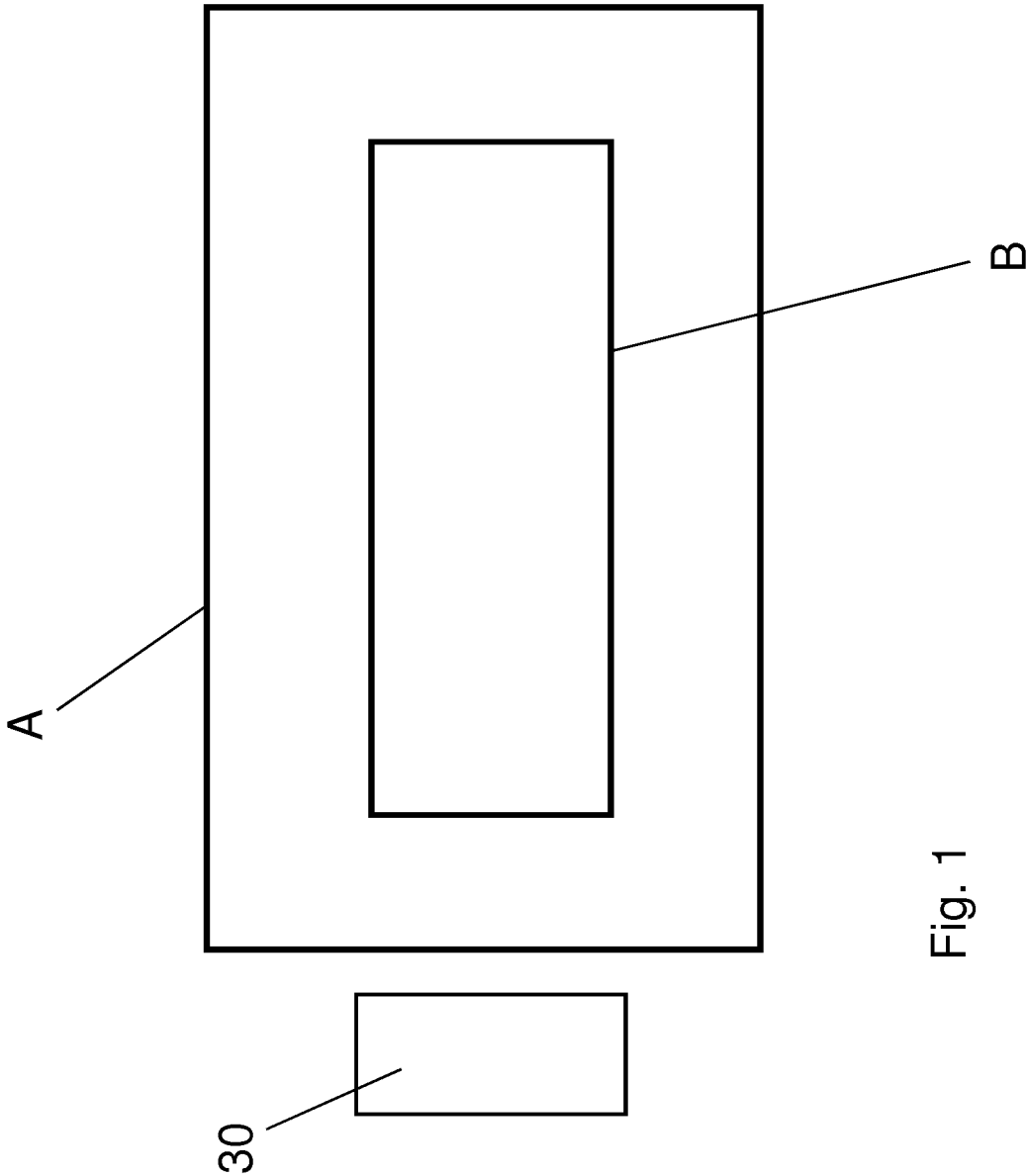


Fig. 1

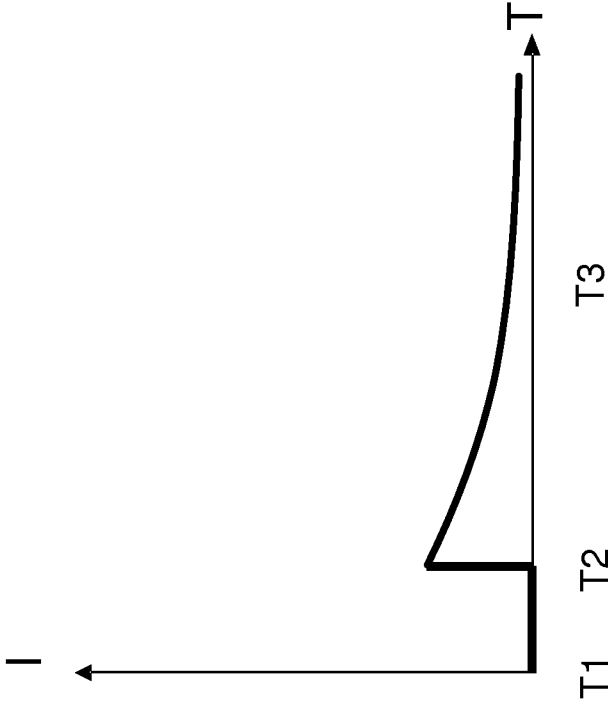


Fig. 2A

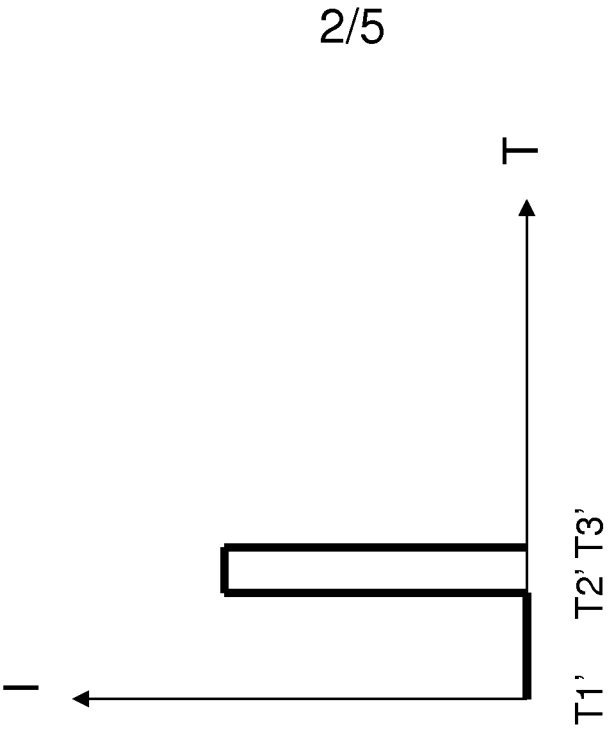


Fig. 2B

3/5

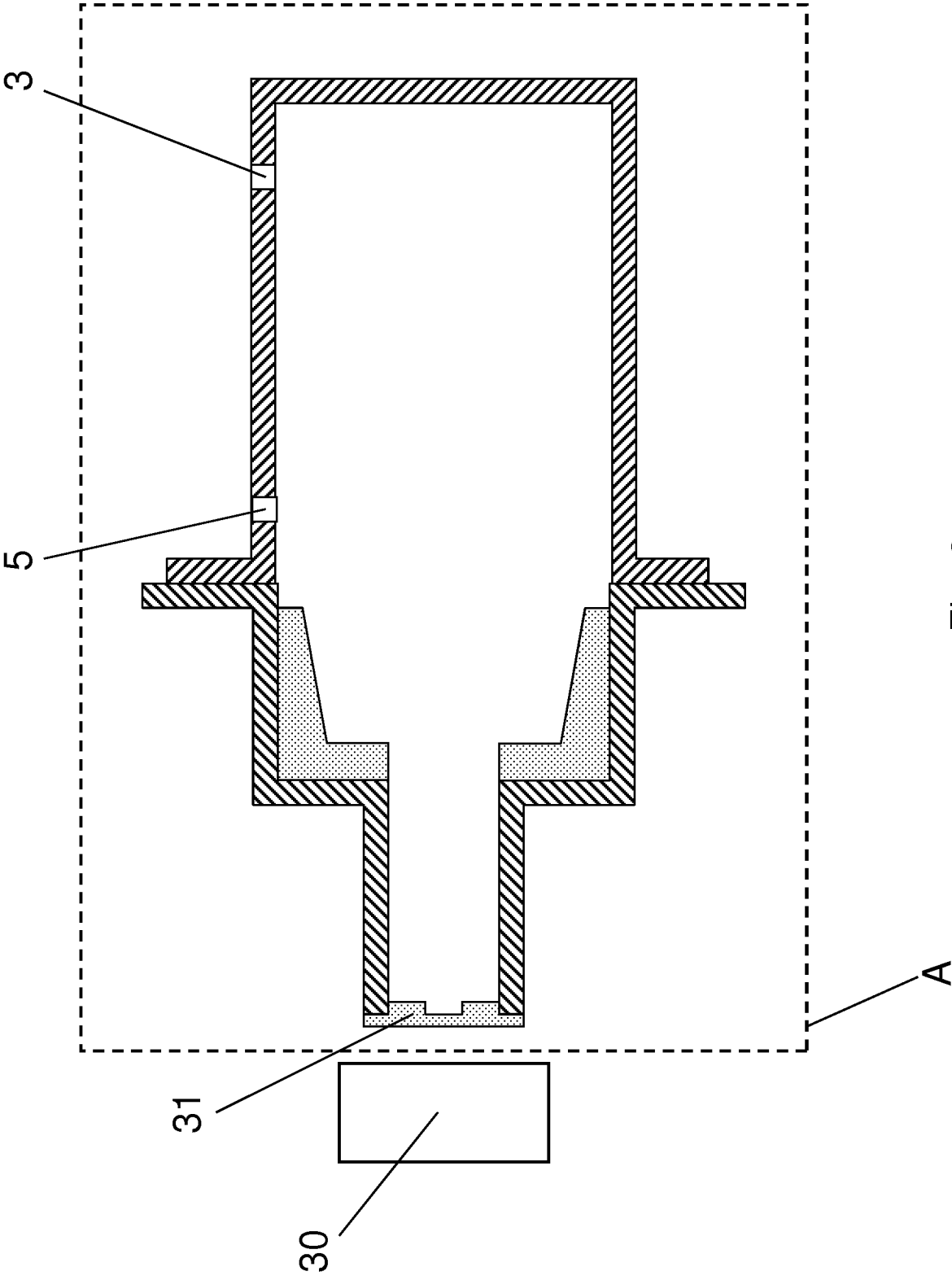


Fig. 3

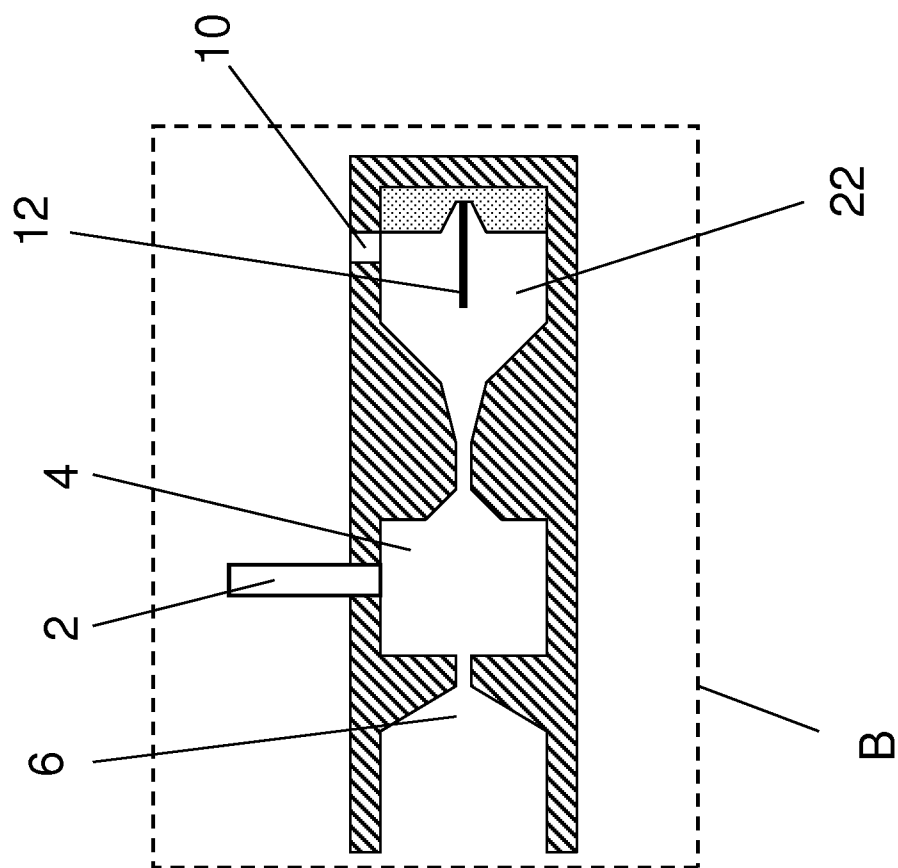


Fig. 4

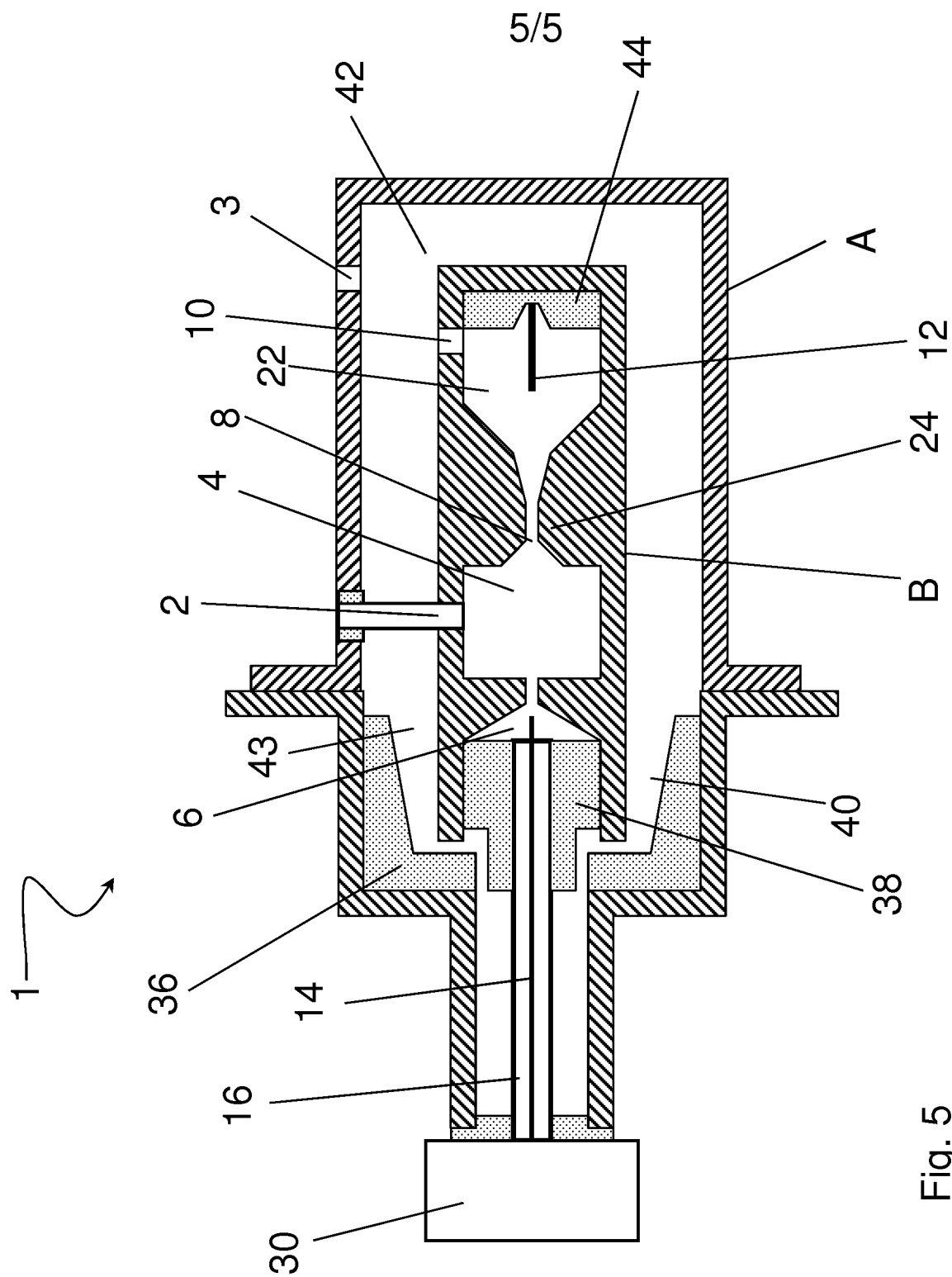


Fig. 5