

**APPARATUS AND METHOD FOR REDUCING PARTICULATE EMISSIONS AND
FIRE SPACE**

The invention relates to an apparatus for reducing particulate
5 emissions from flue gases in a fire space comprising a firebox,
wherein the apparatus includes

- an electrode which can be arranged in the firebox in the
area of the flame or in the immediate vicinity of the flame in
order to generate an electric field and move particles charged
10 by the flame by means of the electric field,
- an insulation arranged so as to cover a part of the elec-
trode that is exposed to flue gases in order to prevent the
electrode from getting dirty,
- a grounding surface,
- 15 - a collector for collecting charged particles, and
- a power supply connected to the electrode for generating
a voltage of 1-100 kV, preferably 10-30 kV, in order to generate
the electric field between the electrode and the grounding
surface.

20 The invention also relates to a fire space and to a method for
reducing particulate emissions from flue gases in a fire space.

Particulate emissions from residential combustion in residen-
tial areas degrade air quality and have an impact on both
25 health and the environment. Carbon soot emissions from an in-
complete combustion contribute to global warming by absorbing
solar radiation and changing the reflectivity of glaciers. The
EU thus monitors emissions from residential combustion and
there is consequently a need for new technology to reduce
30 emissions from residential combustion.

The use of electrostatic filters to reduce particulate emis-
sions from flue gases is known from the prior art. These are,
however, more suitable for larger-scale combustion plants and

are expensive to implement in conjunction with fire spaces used in residential combustion.

The publication DE 102012023453 A1 known from the prior art
5 discloses a reduction of particles in flue gases by using an electrode in a firebox in order to generate an electric field in the area of the flame and to collect the particles on the surface of the electrode. The action of the apparatus is based on the fact that the particles generated in the combustion
10 process are electrically charged by the electrons and ions generated in the combustion process, that is to say that the particles are naturally charged by the flame. Due to the electric charge, the particles move in the electric field towards or away from the electrode. A problem with this type of appa-
15 ratus, however, is that a plasma forms in the area of the flame as a result of combustion, which causes a short circuit in the electrode and thereby the failure of the apparatus. On the other hand, if the electrode is arranged further away from the flame, the lifetime of the ions is quite short and their charge
20 is neutralized before they have time to travel in the electric field to the electrode. A further problem of the apparatus is that the electrode gets dirty, which can cause a short circuit that prevents the apparatus from working.

25 An object of the present invention is to provide an apparatus for reducing particulate emissions that is a more efficient and more reliable than the apparatuses of the prior art. The characteristic features of an apparatus according to the invention are set out in the attached patent claim 1. A further
30 object of the invention is to provide a fire space that is environmentally friendlier and produces lower particulate emissions than the fire spaces of the prior art. The characteristic features of a fire space according to the invention are set out in the attached patent claim 12. A still further

object of the invention is to provide a method for reducing particulate emissions from flue gases in a fire space by means of which particulate emissions are reduced. The characteristic features of a method according to the invention are set out in the attached patent claim 14.

The object of an apparatus according to the invention is achieved with an apparatus for reducing particulate emissions from flue gases in a fire space comprising a firebox, wherein the apparatus includes an electrode which can be arranged in the firebox in the area of the flame or in the vicinity of the flame in order to generate an electric field and move particles charged by the flame by means of the electric field, wherein the electrode includes an insulation arranged so as to cover a part of the electrode that is exposed to flue gases in order to prevent the electrode from getting dirty. The apparatus further includes a power supply for supplying a voltage to the electrode in order to generate the electric field, a transformer for converting the voltage level of the electricity supplied by the power supply to a voltage level of 1-100 kV, preferably 10-30 kV, and a collector for collecting charged particles which can be arranged in the firebox in the area of the flame or in the immediate vicinity of the flame. The apparatus is configured to allow a leakage current of 0.001 mA - 5.0 mA, preferably 0.1-5.0 mA, most preferably 2.0-3.0 mA, through the insulation in order to charge the particles. The insulation and the collector are configured to act as collector surfaces for the charged particles, at which collector surfaces the particles are oxidized under the effect of the temperature.

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In the apparatus according to the invention, the particles collected on the insulation of the electrode or preferably mainly on the collector burn when the electrode and the collector are arranged in the area of the flame or close to it,

so that a separate step of collecting particles is not required as collected particles are oxidized on the collection surfaces under the effect of the temperature. The insulation protects the electrode from getting dirty and prevents a complete short circuit and breakdown between the electrode and the firebox. The charging of the particles already produced naturally by the flame is supplemented by the leakage current, so that an increasing number of particles can be collected on the collector surfaces.

In the context of this application, the voltage unit V denotes AC voltage, unless it is specifically indicated that it is DC voltage DCV.

Cleaning has been found to be effective in particular with leakage currents of 2.0-3.0 mA at a voltage of 10-30 kV. The upper limit of the voltage level is determined by economic constraints, as a wattage of the apparatus becomes quite high at higher voltages. The lower limit, on the other hand, is determined by the efficiency of the filtering.

Preferably, the apparatus is used in conjunction with a so-called radiant fire space, i.e. it is not used in boiler structures intended to heat liquids.

The apparatus according to the invention is simple and comprises relatively few components that can fail. The apparatus is thus an economical investment for residential-combustion fire spaces and is simple in terms of its operation. It is suitable for use in conjunction with new fire spaces or for retrofitting old fire spaces. The cleaning efficiency that can be achieved with the apparatus is 50-90% of the total mass of particulate emissions.

In this context, "particles" mainly denotes carbon soot, mixed in with which there can also be some other particles in small concentrations.

5 Preferably, the fire space is a so-called batch-fuelled fire space and not, for example, a continuously operable industrial boiler. In this context, "batch fuelled" denotes a fire space the fuel of which is dispensed in batches rather than, for example, automatically for a continuous combustion. In this
10 connection, a batch-fuelled fire space is in particular a residential-combustion fire space that is used in households with a wattage of less than 50 kW. The benefit that can be achieved with the apparatus according to the invention is particularly pronounced in batch-fuelled fire spaces, where conditions of
15 incomplete combustion are quantitatively much higher than in continuously fuelled fire spaces.

Alternatively to a batch-fuelled fire space, the invention can also be applied to continuously fuelled household pellet stoves
20 with a wattage of less than 50 kW, which comprise an automatic feeding with a small hopper.

Preferably, the power supply and the insulation together are configured to enable a leakage current by means of which a
25 corona discharge is produced through the insulation of the electrode in order to charge the particles. The magnitude of the leakage current that can be achieved can be influenced by both factors, the use of the power supply and the characteristics of the insulation. A corona discharge effectively charges
30 the particles located in its area, but does not cause a complete short circuit of the apparatus.

The voltage required for an efficient filtering and the resulting leakage current can be significantly influenced by the

arrangement, shape and number of electrodes. A general rule of thumb for the design can be that, the lower the voltage is, the higher the leakage current needed to produce a corona discharge, and the higher the voltage is, the lower the leakage
5 current that is needed.

The insulation of the electrode covers the electrode in such a manner that a complete short circuit with the plasma of the flame is prevented. In other words, particles are collected in
10 proximity to the electrode thanks to the leakage current, preferably thanks to the charging of the particles brought about by the corona discharge, which steers the charged particles to the collector, while further away from the electrode the flame naturally charges the particles, which collect on the surface
15 of the insulation of the electrode.

Preferably, the apparatus includes an additional insulation arranged so as to cover a part of the electrode that runs through a duct comprised by the fire space for the introduction
20 of the electrode into the firebox. The purpose of the additional insulation is to prevent a leakage of current close to the surface of the fire space. This improves cleaning efficiency as leakage only occurs in the area of the flame where it is supposed to occur.

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Preferably, the apparatus includes a grounding. It can thereby be ensured that the apparatus is safe to use.

Preferably, the apparatus also includes a grounding surface,
30 which is formed inside the firebox in order to intensify the electric field. The grounding surface makes it possible to collect a part of the particles with the same charge as the electrode and helps to strengthen the electric field. In other

words, the grounding surface preferably acts as a particle collector.

“Collecting surfaces” generally denotes, for example, the surface of the grounding surface acting as a collector or the
5 outer surface of the insulation.

The grounding surface can be arranged on a wall of the firebox in the area of the electric field in order to reinforce the
10 electric field. A part of the particles thus collects on a side of the firebox.

The grounding surface is preferably arranged in the area of the flame or in an area in the vicinity of the flame where the
15 temperature is above 500 °C. This ensures that the particles are also burned off the grounding surface.

Preferably, the electrode is rod-shaped. A rod-shaped electrode is easy to manufacture and insulate. Moreover, a rod-shaped
20 electrode is also easier to attach and to introduce into the firebox than a flat electrode.

According to a preferred embodiment in which the electrode is rod-shaped, the insulation includes a sheath arranged so as to
25 partially surround the rod-shaped electrode and a plug arranged in the sheath so as to cover the end of the electrode. In such a design of the insulation, the leakage current is automatically conducted outward from the electrode along the seam between the sheath and the plug and causes a preferably controlled corona discharge in order to charge the particles.
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The electrode can be flat in shape. An electrode with a flat shape produces a very homogeneous electric field, which renders the collection of particles on the surface of the insulation

of the electrode and on the corresponding grounding surface more efficient.

The plane of an electrode with a flat shape can be arranged in the direction of travel of the flue gases. The generated electric field is thus as wide as possible in the direction of travel of the particles moving in the flue gas, which ensures that as many particles as possible have time to travel in the electric field to the surface of the insulation of the electrode or to the grounding surface acting as collecting surfaces before they are driven together with the flue gas flow in the fire space towards the flue ducts and out of the area of influence of the electric field.

Preferably, the power supply is configured to create a negative polarity in the electrode. Studies have found that combustion produces more negatively charged particles, so that a higher cleaning efficiency is achieved by using an electrode with a negative polarity, wherein the leakage current that occurs through the electrode, preferably a corona discharge, also charges the particles negatively. The charged particles are thus of the same sign and do not neutralize one another.

Preferably, the insulation is configured for a selected leakage current by means of one or more of the following characteristics of the insulation: thickness of the insulation; material of the insulation; length of the air gap between the insulation and the electrode; discontinuity of the insulation; shape of the insulation. By changing one or more of the aforementioned characteristics, it is possible to influence the insulating capacity of the insulation and thereby the magnitude of the leakage current. The insulation can have small discontinuities via which a potential corona discharge occurs. A discontinuity

can also be a point at which a thickness of the insulation is less than elsewhere around the electrode.

Preferably, the insulation of the electrode is a material with
5 a crystal structure that recovers after a corona discharge. Such a material is particularly suitable for applications in which a corona discharge occurs regularly but the insulation is also required to provide a continuous insulating capacity.

10 Preferably, the insulation of the electrode is a mica insulation. The conditions at the location of the electrode in the area of the flame or in its vicinity are technically very demanding for a material due to the high temperatures. A mica insulation has been found to be highly resistant to high tem-
15 peratures and to the conditions otherwise prevailing in the area of the flame even when used over long periods of time and to simultaneously allow a sufficient leakage current for the invention to work. Characteristics of mica insulation include a recovering crystal structure which recovers after a corona
20 discharge, which is important for the invention.

Alternatively, the material of the insulation can be HBN (hexagonal boron nitride). HBN is a highly versatile material the conductivity of which can be regulated by means of the crystal
25 structure. HBN is a durable material which is self-repairing, for example it can repair fissures where present. HBN is currently an expensive material, but may become more economically viable in the future.

30 Preferably, the additional insulation is aluminium oxide. Aluminium oxide is more resistant to high temperatures than mica, the material preferably used for the insulation, without leakage currents occurring.

According to one embodiment, the apparatus also includes a second electrode, and the polarities of the electrodes are the same in order to optimize the charging of the particles. By using two electrodes, it is possible to ensure a charging of particles over a wider area in the firebox, which reduces the significance of the phenomenon of the natural charging of particles by the flame in the collection of particles.

Preferably, the power supply includes a transformer to increase the voltage supplied by the power supply to the electrode to a desired current level. The transformer can include a microprocessor, a control and driver circuit, a protection circuit, and a high-voltage conversion.

By using such a transformer, it is possible to convert the energy of, for example, an ordinary grid or DC power supply easily and inexpensively into the operating voltage required for operation of the electrode, which is high relative to the input voltage. Thanks to the high operating voltage and the relatively high frequency used (in the order of kHz or Mhz) and to the waveform, the power consumption of the apparatus can be remarkably low, at a level of 1-50 W, preferably 1-20 W.

Instead of alternating current, the power supplied by the power supply can be alternatively implemented as direct current, preferably in a range of 12-40 VDC. This simplifies the implementation of the device, as no grid voltage conversion is required and the device can be connected to an existing DC power supply. This could be, for example, a power supply that supplies other electronics already located in the fire space or, for example, a TEC solution for supplying power discussed later on. On the other hand, a correct grounding of the apparatus during installation becomes more important in this alternative,

as grounding occurs via a separate protective grounding conductor and not via the grid power supply cable. Ordinary residential buildings rarely have ready grounding points in different rooms in the manner of industrial plants, so that the
5 installation and path of a separate protective conductor must be considered on a case-by-case basis.

The power supplied by the power supply can also be realized with grid power, so that the apparatus is otherwise similar to
10 the one described in the foregoing, but either an external or internal grid power conversion circuit (ac/dc transformer) is added to the apparatus. Either an external so-called consumer transformer (standard) or some other solution is used in the variant using grid power. This is necessary if there is no
15 direct current available in the area of the fire space or, for example, at various demo and presentation sites.

According to one embodiment, the power supply includes an independent thermoelectric generator. With a thermoelectric generator,
20 it is possible to utilize the temperature difference between the area outside of the fire space or the outer surface of the firebox and the conditions in the firebox in order to generate, based on the Seebeck effect, an electric current which can be utilized for a relatively low-power operation of
25 the apparatus. This makes it possible for the apparatus to be realized without conductors to an on-site grid socket or grid supply or, alternatively, enables operation in places where electricity is not available, such as in traditional cottage saunas. In this variant as well, it is necessary to ensure that
30 the apparatus is grounded, for example by means of a protective grounding conductor that runs to a known grounding structure near the property or to an existing grounding point.

According to one embodiment, the power supply includes a physically small battery or accumulator with which electricity consumption can be balanced when the device is partially or entirely supplied by the aforementioned thermoelectric generator or by some other "off-grid" solution such as, for example, an external solar panel system or the like which does not form part of the device. It must be taken into account, however, that modern residential solar power systems already include a dc/ac inverter as a standard component, so that the system provides the consumer with AC power and not DC power like the older small "summer cottage" systems. Modern solar power systems generally also include an accumulator if the consumer so chooses. If in a further variant it is found to be necessary and useful for the consumer for the apparatus of the embodiment to be rechargeable, the electrical energy used by the apparatus can be stored, for example, at times when electricity prices are lower and consumed from the battery/accumulator at times when energy prices are higher. Or it can render possible the use of different portable solutions.

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The electrode can be formed as part of the structure of the fire space. The electrode thereby does not affect the flue gas flow in the fire space. Such a structure is easy to implement in a new fire space, but more difficult in existing fire spaces. In some models, the electrode can be a replacement for existing removable baffles that influence flows in the fire space.

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Alternatively, the electrode is a piece separate from the structure of the fire space that is placed in the firebox. Such a variant enables a very easy retrofitting.

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According to one embodiment, the transformer is configured to supply the electrode with a pulsed or mixed current. A pulsed power supply can reduce the energy consumption of the

apparatus, especially in a relatively high kHz range compared to a frequency, for example 50/60 Hz, of household grid power.

The apparatus can include control means comprising a controller
5 for regulating the leakage current according to a fire state. Conditions in the firebox change as the fire progresses, which influences the insulating capacity of the insulation via the temperature as well as the magnitude of the leakage current. With the control means, it is possible to try to standardize
10 the magnitude of leakage current. In practice, the controller can be implemented inside a microprocessor, in addition to which a separate "controller" component can be provided in cases where the microprocessor used is not able to react fast enough, for example, to the fire state and the control cycle
15 is not optimal.

According to one embodiment, the control means includes an actuator for moving the electrode inside the insulation in order to regulate the air gap between the electrode and the
20 plug based on the control of the controller. In this case, the controller controls the actuator in order to move the electrode. The length of the air gap affects the magnitude of the leakage current and thus the cleaning efficiency of the apparatus.

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Alternatively or in addition to the embodiment described in the foregoing, the controller can be configured to set the voltage produced by the power supply according to a calibration curve. It is possible to program a predefined curve for the
30 controller or control unit, which curve optimizes the output voltage level for example in relation to the measured current or temperature, in addition to the control carried out by the actual controller based on, for example, a control curve and the set parameters of the controller. The curve can be

generated experimentally by searching for optimal setting ranges and limit values, or computationally based on theories in order to predict the optimal limit values. In addition, the calibration curve can contain different computational correction factors, which would allow, for example, a different optimized method of control depending on the type of fireplace in addition to a basic calculation. This method of control is more multidimensional than a purely measurement-based control curve.

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Preferably, the controller is a P, I, PI or PID controller.

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The object of a fire space according to the invention is achieved with a fire space which includes a firebox for burning a fuel, preferably wood, and an apparatus for reducing particulates from flue gases according to any one of the embodiments described in the foregoing. Particulate emissions from a fire space according to the invention are remarkably low compared to a conventional fire space. In a combustion event occurring in a fire space, a phase of complete combustion is rarely reached and generally combustion is incomplete, which produces the particulate emissions. As it is difficult to prevent a phase of incomplete combustion, the particles are prevented from escaping into the environment by using an apparatus according to the invention and thus by oxidizing the particles before they can leave the fire space.

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The fire space according to the invention can be, for example, a fireplace, a fireplace insert, a sauna stove or a stove, although it can also be, for example, a pellet stove or the like.

Preferably, the electrode is arranged in the firebox in the area of the flame or in an area in the vicinity of the flame

where the temperature is above 500 °C in order to oxidize the particles on the surface of the insulation of the electrode. This area can also be after the baffle plate of the fire space or in other parts of the flue system that are hot enough. The position of the electrode is very important so that particles collecting on the insulation of the electrode or on the grounding surface are at a sufficiently high temperature so as to be oxidized.

Alternatively, a catalytic structure can be used as a collecting surface for collecting particles. The collected particles are thus oxidized at temperatures of up to 150 degrees Celsius.

According to one embodiment, particles are removed from the flue gas by the apparatus according to the invention, which allows the use of a separate catalyst downstream in the flue in order to remove gaseous pollutants. The use of a catalytic converter was previously not possible because the large quantity of particles in the flue gas quickly prevented the catalytic converter from working.

Preferably, the electrode is at least partially in contact with the flame. This optimizes the generation of a corona discharge.

Preferably, the electrode is arranged in the middle of the firebox in an area at a distance away from the walls of the firebox, which distance represents 10-25% of the width of the firebox at the electrode. In other words, the electrode is arranged in an area in the middle of the firebox that spans 50-80% of the total width of the firebox. Such an arrangement of the electrode ensures that the distance of travel of the particles from the flue gas flow to the surface of the insulation of the electrode or preferably to the collector is short enough to allow the particles travelling through the electric

field in the flue gas to reach the surface of the insulation of the electrode before they are carried away by the flue gas out of the area of influence of the electric field.

5 The object of a method according to the invention is achieved with a method for reducing particulate emissions from flue gases in a fire space comprising a firebox, in which method a voltage is supplied to an electrode by a power supply, a voltage level of the electricity supplied by the power supply is con-
10 verted by means of a transformer to a voltage level of 1-100 kV, preferably 10-30 kV, and at least a part of the electrode that is exposed to flue gases is protected with insulation in order to prevent the electrode from getting dirty. In addition, in the method, an electric field is generated in the firebox
15 by means of the electrode arranged in the area of the flame or in the immediate vicinity of the flame in order to move particles charged by the flame by means of the electric field towards the electrode, and a leakage current from the electrode of 0.001 mA - 5 mA, preferably 2.0-3.0 mA, is conducted through
20 the insulation in order to charge the particles. Furthermore, in the method, the charged particles are collected by means of a collector arranged in the firebox in the area of the flame or in the immediate vicinity of the flame and by means of the electrode, and the collected particles are oxidized under the
25 effect of the temperature.

In the method according to the invention, the collection of particles is based on two parallel phenomena, the natural charging of particles brought about by the flame and the charg-
30 ing brought about by the leakage current, wherein their combined effect allows charged particles to be collected on collecting surfaces in the electric field. The particles on the collecting surfaces oxidize, i.e. burn off, and do not need to be collected separately.

Preferably, the leakage current causes a corona discharge. The corona discharge imparts a strong charge to particles, but does not cause a breakdown and complete short-circuit of the apparatus.

Preferably, in the method, a magnitude of the leakage current is regulated according to a fire state by means of a controller comprised by the control means of the apparatus. A performance of the apparatus can thus be optimized in all fire conditions, whereby emissions can be reduced.

The invention, which is not limited to the embodiments described in the following, is explained in more detail with reference to the attached figures, wherein

- Figure 1a shows a cross-sectional side view of an apparatus according to a first embodiment used in a fireplace,
- Figure 1b shows a cross-sectional front view of an apparatus according to a first embodiment used in a fireplace,
- Figure 2 shows a cross-sectional front view of an apparatus according to a second embodiment used in a fireplace,
- Figure 3 shows a cross-sectional side view of an apparatus according to a third embodiment used in a sauna stove,
- Figure 4 shows a cross-sectional side view of an apparatus according to a fourth embodiment used in a sauna stove,
- Figure 5 shows a cross-sectional front view of an apparatus according to a fifth embodiment used in a fireplace,

The apparatus according to the invention can be used in conjunction with a fireplace, a sauna stove, a stove or an analogous fire space. In this connection, Figures 1a - 2 illustrate a first and a second embodiment of an apparatus according to the invention, in which the apparatus 10 is conjoined with a batch-fuelled fireplace 40, while Figures 3 and 4 in turn illustrate an embodiment in which the apparatus 10 is in conjunction with a sauna stove 42.

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Figure 1a shows a first embodiment of an apparatus 10 according to the invention arranged in the firebox 14 of a fireplace 40 acting as a fire space 12. In all embodiments, the basic parts of the apparatus 10 according to the invention include at least one electrode 16 arranged in the area of the flame 18 or in its vicinity, an insulation 24 which surrounds the electrode 16 and protects the electrode from flue gases S, a collector 25, which is preferably a grounding surface 20, a power supply 22, and a transformer 30. The action of the apparatus 10 is based on the ability of the current that leaks from the electrode 16 through the insulation 24, which preferably takes the form of a corona discharge, to charge collected particles. The operation of the apparatus 10 is also in part based on the movement of particles 15 naturally charged by the flame further away from the electrode towards or away from the electrode 16, depending on the potential of the electrode, in an electric field E. The electric field E generated by the electrode 16 transports the preferably negatively charged particles 15 towards the collector 25 away from electrode 16, which is also negatively charged. Finally, the particles 15 adhere to the surface of the collector 25. Any positively charged particles travel to the surface of the insulation 24 of the electrode 16.

The particles 15 that collect on both the surface 26 of the insulation 24 of the electrode 16 and on the collector 25 are oxidized, in other words burned, at these respective locations in the firebox as a result of the prevailing temperature and thus only generate carbon dioxide and pure ash. In the figures, wood to be burned in the fire space 12 is designated by the reference number 46, the grate through which the primary air supply into the firebox 14 takes place is designated by the reference number 48, and the door is designated by the reference number 52.

Figure 1b shows a preferred variant of the apparatus 10 in which two rod-shaped electrodes 16 are employed on both sides of the fire space 12. According to Figure 1b, both the electrode 16 and its surrounding insulation 24 run through the wall structure of the fire space 12. In this embodiment, the insulation 24 includes a sheath 27 surrounding the lateral surfaces of the rod-shaped electrode 16 and a plug 29 which closes the sheath 27 at the end 31 of the electrode. Preferably, the leakage current from the electrode 16 through the insulation 24 occurs along the seam between the sheath 27 and the plug 29 and causes a corona discharge away from the electrode 16. The corona discharge effectively charges particles to the potential of the electrode 16, preferably negatively when a negative electrode 16 is used.

The first embodiment illustrated in Figures 1a and 1b differs from the second embodiment of Figure 2 with respect to the number of electrodes. In the first embodiment of Figures 1a and 1b, the electrode 16 used in the apparatus 10 is rod-shaped. In Figure 1b, two rod-shaped electrodes 16 are preferably provided, but it should be understood that only one electrode or even three electrodes 16 could be provided. When only one electrode is used, the polarity of that electrode is

preferably negative, because most of the particles naturally charged by the flame are also negatively charged. If two or three electrodes are used, it is still preferable for the electrodes to be of the same polarity in order to avoid the generation of differently charged particles that would cancel each other out. Preferably, a plane 32 of the electrode 16 is arranged parallel to the flue gas flow S.

For the efficiency of the apparatus, it is important that the electrode 16 is arranged in the firebox 14 in the area of or in proximity to the flame 18 where the temperature is above 500 °C in order to oxidize the particles collected on the surface 26 of the insulation 24 of the electrode 16. This temperature is generally already reached by a first batch of wood, but this depends on the combustion device.

The strength of the electric field around the electrode affects how effectively the device collects particles. As the strength of the field increases, particles are collected over a larger area in relation to the electrode and in greater quantities over time. The strength of the electric field varies with the voltage level used; for a homogeneous electric field the formula is $E = V/d$, where E is the strength of the electric field, V is the voltage and d is the distance. Moreover, the shape of the generated field, and thus the shape, number and arrangement of the electrodes employed, has an impact. In practice, the design is limited by the structure and materials of the fire space. A further aim is to optimize the dwell time of the flue gas in the area of influence of the electric field. The shape and course of the flues of the fire space with which the flue gases are conducted from the firebox to the chimney are taken into account here. In general, flue gases can move in the firebox at a speed of 0.2-2 m/s, which must be taken into account together with the position of the electrodes and the

size of the firebox when designing the required strength of the electric field. The electrode is preferably arranged in such a manner that the electric field extends over a wide area in the direction of flow of the flue gas. Preferably, the electrode is in the middle of the flue gas flow, assuming that the flue gas flow is laminar. Preferably, the electrode, or at least one of the electrodes, must be in the middle of the flue gas flow, where most of the particles are in motion. Consequently, at least one electrode is arranged at a distance from the walls of the firebox in an area that spans the middle of the flue gas flow. The distance d of the electrode 16 from the walls 38 of the firebox 14 can be 5-30%, preferably 10-25%, of the width of the firebox 14.

The apparatus 10 according to the invention includes, as shown in Figure 1a, a collector 25, which is preferably a grounding surface 20 formed in the firebox 14 close to the electrode 16. The grounding surface 20 can be, for example, a metal plate 44 attached to the wall 38 of the firebox 14 as shown in Figure 1a or it can be a metallic structure integrated into the wall 38 of the firebox 14. The electric field E formed by the electrode 16 is directed towards the grounding surface 20 so that, thanks to the grounding surface 20 on the wall 38 of the firebox 14, the entire width of the firebox can be covered by the electric field E , which draws particles 15 charged by the flame 18 towards the electrode 16 and particles of an opposite sign towards the grounding surface.

For the voltage to be supplied to the electrode, a sealed duct can be made in the structure of the fire space through which electrical conductors are run to the electrode or, alternatively, the electrode can extend through the duct partially outside the fire space, so that it is enough for the electrical conductors to be thermally resistant to lower temperatures in

contrast to a situation where the electrical conductors are arranged inside the fire space. It is also possible to use a rail in the duct for the electrical connection, so that the rail is exposed to the hottest temperatures. Compared to a
5 cable, using a rail also has a positive effect on the lifespan and fault tolerance of the electrical conductor.

For the apparatus 10 to work, it is essential that each electrode 16 of the apparatus 10 is coated with an insulation 24,
10 which prevents particles from collecting directly on the surface of the electrode 16. This is essential in order to prevent a complete short circuit of the electrode with the plasma formed by the flame. As the electrode and the insulation are arranged in the area of the flame or close to it where the
15 temperature is high, the selection of the insulation material is important for the durability of the insulation. The electrode runs through the wall of the fire space to the outside of the fire space, so as to permit an influx of cooler air via the electrode, at the end of the electrode between the elec-
20 trode and the insulation, while hot air of the electrode is removed from between the insulation and the electrode from inside the insulation. A thickness of an insulation layer used in this case can be 0.5-5 mm, preferably 1-2 mm. To compensate the highest thermal peaks, it is conceivable to form, in con-
25 junction with the basic insulation of the electrode, a thermal shield by means of a coating or some other separate additional material.

Preferably, a mica insulation can be used as the insulation.
30 Micas, i.e. the group of silicate minerals known as micas, are resistant to high temperatures without cooling. A thickness of a layer of mica insulation can be 0.5-30 mm, preferably 5-20 mm. For durability, mica insulation is preferably used in large insulating layers of 5-20 mm, so that the outer part of the

thicker layer protects the inner part. The temperature in the area of the flame can be 800-1200 °C. Mica insulation is suitable for operating temperatures of 600-800 °C, so it can be arranged at a suitable distance from the flame.

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Alternatively to mica insulation, it is also possible for the insulation used to be an HBN (hexagonal boron nitride), a CFRC (carbon fibre-reinforced carbon), a C/C (carbon-carbon) or an RCC (reinforced carbon-carbon) composite material in which carbon fibre is mixed into a graphite matrix. The composites in question are, however, currently very expensive, but may become more competitive in terms of their price in the future.

As the material of the electrode, it is possible to use, for example, stainless steel or some other material suitable for the intended usage such as carbon-based compounds, for example glassy carbon, the electrical conductivity of which improves as the temperature rises to the operating temperature.

Figure 2 shows a second embodiment of the apparatus 10 according to the invention, in which the apparatus 10 includes a single rod-shaped electrode 16. The advantage of a rod-shaped electrode is its small surface area, which has very little impact on the flue gas flow in the fire space, although, on the other hand, it provides a smaller functional surface area for collecting particles on the surface of the insulation of the electrode than a flat electrode. The surface area of the electrode is, however, of little importance because a large proportion of the particles collect on the surface of the collector.

According to Figure 1b, two rod-shaped electrodes 16 are provided, in the same polarity and at a distance from each other. The same power supply can be used when two electrodes are used.

Alternatively, two parallel power supplies can be used, provided that the power supply can be designed and built compact enough in terms of its physical dimensions.

5 In its simplest form, the power supply used in the apparatus according to the invention can be a grid power supply with a grid power of 100-240 V in a frequency range of 50-60 Hz at the point of use, which grid power supply is connected to a transformer. In this connection, the transformer 30 includes,
10 at least preferably as shown in Figure 1a, a rectifier circuit 34 that converts the supply voltage to a voltage to be supplied to the electrode in the order of kV, an ac/dc converter 36 that converts the supply power received by the device to the levels required by the electronics. Preferably, the transformer also
15 includes a controller for controlling the voltage supply in a desired manner, safety circuits which protect the user and the device, and basic diagnostics, for example indicator LEDs, to indicate to the user the operating status of the apparatus and potential fault conditions. A separate user interface (UI) for
20 controlling the performance of the apparatus and displaying status information or alarms to the user can also be implemented, for example wirelessly as a mobile application. The controller, the basic diagnostics and the user interface are not illustrated in the figures. Instead of a controller, it is
25 possible to use a power supply in which a controller manages both the current and the voltage based on a control curve and calibration.

The status data of the apparatus can be linked so as to be
30 utilized in building management solutions, for example in objects like a holiday village which comprise a plurality of fire spaces. In an example variant, it is inferred from the status data whether the fire space is in a combustion phase or cold, and the data can be used for a further calculation, for example

in connection with a measurement or monitoring of emissions or for a calculation of operating hours. The status data can also be subsequently routed to, for example, a heating system of a home using IoT technology, so that when a fire is burning in the fire space, the central system of the building can proactively reduce other heating, even if, for example, the room-specific temperature measurement does not yet react to the heat caused by the fire space.

10 The controller can be, for example, a microcontroller, so that the control of the apparatus is based on programmed sequences and functions, such as a defined temperature of the fire at which the device turns on, and on incoming signals. The controller can also be an FPGA controller (field-programmable gate array) in cases where more advanced functions or computation is required. The controller can output low-level device diagnostics to a user, for example with separate LED signals or analogous means, as well as enable more detailed diagnostics for the manufacturer. Safety circuits can be in part direct or
15
20 disconnecting protective circuits.

According to one embodiment, the apparatus according to the invention can be implemented with commercially available solutions. According to a first embodiment, the high voltage generated by the apparatus is produced by a laboratory power supply. A ready power supply that produces kV-class DC voltage with a small current is quite expensive and generally has to be ordered from a company specialized in the field. Moreover, its physical size is significantly larger than what is appropriate for the product in a real-world environment, e.g. in
25
30 consumer use. An example of a laboratory power supply is the ST series model manufactured by SPELLMAN HIGH VOLTAGE ELECTRONICS CORPORATION marketed under the product name ST225*10.

Alternatively, the implementation can integrate a combination of commercially available solutions. In this case, the power supply can be a power supply manufactured by Yui Da Electrics Co., Ltd. marketed under the YD series product name YD-044S.

5 The integration of commercially available solutions at the component level is possible, but challenging as the components are not optimized with respect to one another. Alternatively, the apparatus can also be implemented using hobbyist components or off-the-shelf components of an industrial size class.

10

In both variants, the power supply includes the necessary transformer. The converter circuit used in the transformer can be a transformer manufactured by Osram marketed under the product name OT FIT 8/220...240/180 CS PC SC of the OPTOTRONIC

15 series. The controller used can be the Curiosity Development Board series model Curiosity 8-Bit Development Board / DM164137 manufactured by Microchip Technology. The electrode used can in turn be any metal or steel electrode of dimensions suitable for the intended use, while the employed insulation can be the

20 Alumina Single Bore Tubes series model ASB00809 manufactured by LSP Industrial Ceramics Inc.

25

The user interface can be, for example, an entity implemented by means of an application or display panel of a mobile device

with which the user can establish a status or function of the device and, for example, the operating hours or other additional information such as, for example, diagnostic data in the event of a fault.

30

Preferably, the voltage level used in the electrode with a direct current (DC) is 1 kV - 100 kV, preferably 10 - 30 kV. Particle collection is inefficient at a voltage level that is too low. A voltage level that is too high entails the necessary safeguards and insulation materials as well as user safety

measures and an increase in the consumption of electrical energy used by the apparatus. Instead of one static voltage value, the voltage level can also be controlled, for example, in relation to the temperature of the firebox or through some
5 other control circuit or a pre-modelled control curve.

As an alternative to using pure DC current, it is also possible to use pure AC current or to supply different pulse waves or the like with the base voltage.

10

As an alternative to using grid power as the power supply, the apparatus according to the invention can also be implemented using power supplies based on a thermoelectric phenomenon, i.e. a thermoelectric generator. As already explained earlier, the
15 wattage required by the apparatus according to the invention is only in the order of watts, or tens of watts. Power is consumed in the charging of the insulation in the manner of a capacitor and in the losses of the electronics. The maintenance of the electric field itself consumes very little energy. A
20 power supply based on a thermoelectric phenomenon can make use of the Seebeck effect, wherein the power supply generates electricity from a temperature difference. The electrical power produced depends on the magnitude of the temperature difference. One part of the power supply is arranged at least partly
25 outside the fire space at a much lower temperature and a second part is arranged in the firebox where the temperature is several hundred degrees.

Although the electrode 16 in Figures 1a - 4 is shown as a
30 separate piece to be installed in the firebox 14, the invention can also be implemented using an electrode integrated into the structure of the fire space. This can be achieved, for example, by integrating the steel material of the electrode into the brick or other wall material that forms the wall of the firebox.

Alternatively, the electrode can be integrated into a structure that guides the flue gases of the fire space, as in Figure 3, where the electrode 16 is attached to a flue gas air guide 50, wherein the fire space 12 is a sauna stove 42.

5

A fire space according to the invention denotes a fire space in which an apparatus according to the invention is arranged. The fire space is preferably a so-called batch-fuelled fire space, which means that the heat output produced by the fire space is at most 2-50, preferably 4-15 kW. Preferably, the fire space is intended for the batch burning of wood or wood-based products such as pellets.

According to one embodiment, the apparatus according to the invention can comprise control means 37 comprising a controller 39 for regulating the magnitude of the leakage current according to the fire conditions. As the temperature of the flame and of the firebox varies in different fire states, the insulating capacity of the insulation and thus its ability to leak current also varies. The control means 37 can be implemented according to the first embodiment shown in Figure 1a in such a manner that the supply of current or voltage or both is transformed by means of a controller, which is preferably the controller 39, of the power supply 22 so as to optimize the leakage current under different conditions. When the temperature of the firebox decreases, the insulating capacity of the insulation increases, which is compensated by increasing the voltage so as to provide a sufficient leakage current for an efficient charging of the particles. Alternatively, when the temperature of the firebox rises, the insulating capacity of the insulation decreases, so that the current can be restricted so as to avert a breakdown.

According to the second embodiment illustrated in Figure 1b, the magnitude of the leakage current can be influenced by changing the length of the air gap 33 between the electrode 16 and the insulation 24 by moving the electrode 16. The electrode
5 16 can be connected to an actuator 41 to this end, which can be, for example, a spindle motor which moves the electrode 16 inside the insulation 24 relative to the plug 29 of the insulation 24. When the temperature of the firebox rises, the length of the air gap 33 is increased, and when the temperature
10 falls it is in turn reduced. The actuator 41 can be controlled by means of the controller 39 comprised by the control means 37. Preferably, the controller is a PID controller.

In the embodiment shown in Figure 5, the electrode 16 is a T-
15 shaped piece, so that it covers a large area of the flue. Alternatively, the electrode can also be L-shaped or shaped analogously.

A length of the electrode of the apparatus according to the
20 invention is preferably 10-60 cm when it is rod-shaped, while a diameter can be 1-20 mm, preferably 8-12 mm. On the other hand, in cases where the electrode used is flat, it can be 10-100 cm high and 10-60 cm wide, and 0.5-12 mm thick. A combined
25 thickness of the electrode and the insulation can be, for example, 30-50 mm. The position of the electrode is such that the electrode is at least partially in contact with the flame or in the immediate vicinity of the flame where the temperature is above 500 °C. The grounding surface used can be smaller in size than the electrode and is preferably arranged in the area
30 of the electric field generated by the electrode.

An apparatus according to a preferred embodiment is implemented using a power supply voltage of 30 kV, a 10 mm steel tube as the electrode, and a mica mixture as the insulation material

in the form of a tube with an outer diameter of 30 mm and an inner diameter of 10 mm. The mica mixture can include 90% natural mica powder mixed with 10% synthetic resin binder such as, for example, silicone or epoxy. An example of such a mixture
5 is the insulation known under the product name Micanite from the manufacturer Dumico. In addition, the tube forming the insulation in the apparatus has a plug that is 10 mm thick and an adjustable air gap between the electrode and the plug that is 30 mm in length. With such a structure of the apparatus, a
10 leakage current of approximately 1 mA and a cleaning efficiency of 75% are achieved.

In an embodiment that does not form part of the invention, it is also conceivable for an apparatus according to the inven-
15 tion, scaled according to the intended application, to be utilized in batch-fuelled and continuously fired fire spaces in the size class of a boiler.

CLAIMS

1. An apparatus (10) for reducing particulate emissions from flue gases (S) in a fire space (12) comprising a firebox (14),
5 wherein the apparatus (10) includes
- an electrode (16) to can be arranged in the firebox (14) in area of a flame (18) or in immediate vicinity of the flame (18) in order to form an electric field (E) and move particles (15) charged by the flame (18) by means of the electric field
10 (E),
 - an insulation (24) arranged to cover a part of the electrode (16) exposed to flue gases (S) in order to prevent the electrode (16) from getting dirty,
 - a grounding surface (20),
 - 15 - a collector (25) for collecting charged particles (15), and
 - a power supply (22) connected to the electrode (16) for generating a voltage of 1-100 kV, preferably 10-30 kV, in order to generate the electric field (E) between the electrode (16)
20 and the grounding surface (20),
- characterized** in that the power supply (22) and the insulation (24) are configured to allow a leakage current of 0.001 mA - 5.0 mA, preferably 0.1 mA - 5.0 mA, most preferably 2.0 mA - 3.0 mA, through the insulation (24), by means of which a corona
25 discharge is provided through the insulation (24) of the electrode (16) in order to charge the particles (15), wherein the insulation (24) and the collector (25) are configured to act as collector surfaces for the charged particles (15) in order to oxidize the particles (15) under the effect of the temper-
30 ature.
2. The apparatus according to claim 1, **characterized** in that the power supply (22) includes a transformer (30) for

converting the voltage of a grid current supplied to the power supply (22) to a voltage of 1-100 kV, preferably 10-30 kV.

3. The apparatus according to claim 1 or 2, **characterized** in
5 that the collector (25) is a grounding surface (20).

4. The apparatus according to any one of claims 1-3, **characterized** in that the insulation (24) is configured for a selected leakage current by means of one or more of the following
10 characteristics of the insulation (24): thickness of the insulation (24); material of the insulation (24); length of an air gap (33) between the insulation (24) and the electrode (16); discontinuity of the insulation (24); shape of the insulation (24).

15

5. The apparatus according to any one of claims 1-4, **characterized** in that the electrode (16) is rod-shaped.

6. The apparatus according to claim 5, **characterized** in that
20 the insulation (24) includes a sheath (27) arranged to partially surround the rod-shaped electrode (16) and a plug (29) arranged in the sheath (27) to cover the end (31) of the electrode (16).

25 7. The apparatus according to any one of claims 1-6, **characterized** in that the insulation (24) of the electrode (16) is a material with a crystal structure that recovers after a corona discharge.

30 8. The apparatus according to any one of claims 7-4, **characterized** in that the insulation (24) is a mica insulation.

9. The apparatus according to any one of claims 1-8, **characterized** in that the apparatus (10) includes an additional

insulation (54) arranged to cover a part of the electrode (16) that runs through a duct (56) comprised by the fire space (40) for the introduction of the electrode (16) into the firebox (14).

5

10. The apparatus according to any one of claims 9-4, **characterized** in that the additional insulation (54) is aluminium oxide.

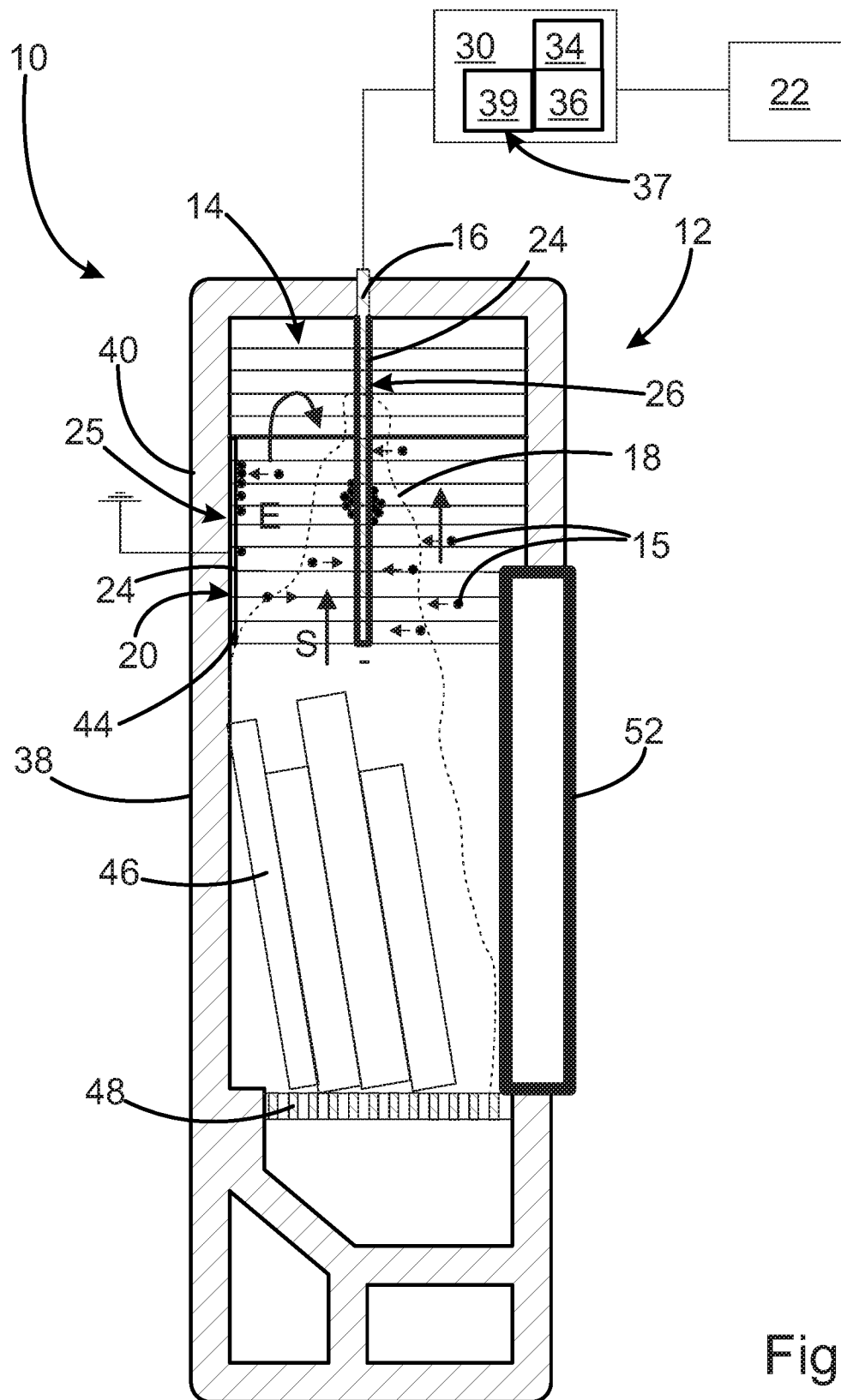
10 11. The apparatus according to any one of claims 1-10, **characterized** in that the apparatus (10) includes control means (37) comprising a controller (39) for regulating the leakage current according to a fire state and the control means (37) comprises an actuator (41) for moving the electrode (16) inside the in-
15 sulation (24) in order to regulate an air gap (33) between the electrode (16) and the plug (29) based on the control of the controller (39).

12. A fire space (12) which includes a firebox (14) for burning
20 a fuel, preferably wood, and an apparatus (10) for reducing particulates (15) from flue gases (S), **characterized** in that the apparatus (10) is an apparatus (10) according to any one of claims 1-11.

25 13. The fire space according to claim 12, **characterized** in that the electrode (16) is arranged in the firebox (14) in the area of the flame (18) or in an area in the vicinity of the flame (18) where the temperature is above 500°C in order to oxidize particles (15) on the surface (26) of the insulation
30 (24) of the electrode (16) and the collector (25).

14. A method (10) for reducing particulate emissions from flue gases (S) in a fire space (12) comprising a firebox (14), in which method

- a voltage difference of 1-100 kV, preferably 10-30 kV, is formed between an electrode (16) and a grounding surface (20) by means of a power supply (22) connected to the electrode (16) in order to generate an electric field (E) in the firebox (14)
 - 5 by means of the electrode (16) arranged in the area of the flame (18) or in the direct vicinity of a flame (18) in order to move particles (15) charged by the flame (18) towards the electrode (16) by means of the electric field (E), and
 - at least a part of the electrode (16) that is exposed to
 - 10 flue gases (S) is protected with insulation (24) in order to prevent the electrode (16) from getting dirty,
 - the charged particles (15) are collected by means of a collector (25) arranged in the firebox (14) in the area of the flame (18) or in the immediate vicinity of the flame (18) and
 - 15 by means of the electrode (16),
- characterized** in that, in addition, in the method
- 0.001 mA - 5.0 mA, preferably 0.1 - 5.0 mA, most preferably 2.0 - 3.0 mA, of leakage current is conducted from the electrode (16) through the insulation (24) so as to bring about a corona
 - 20 discharge through the insulation (24) in order to charge the particles (15),
 - the collected particles (15) are oxidized under the effect of the temperature.
- 25 15. The method according to claim 14, **characterized** in that the magnitude of the leakage current is regulated according to a fire state by means of a controller (39) comprised by the control means (37) of the apparatus (10).



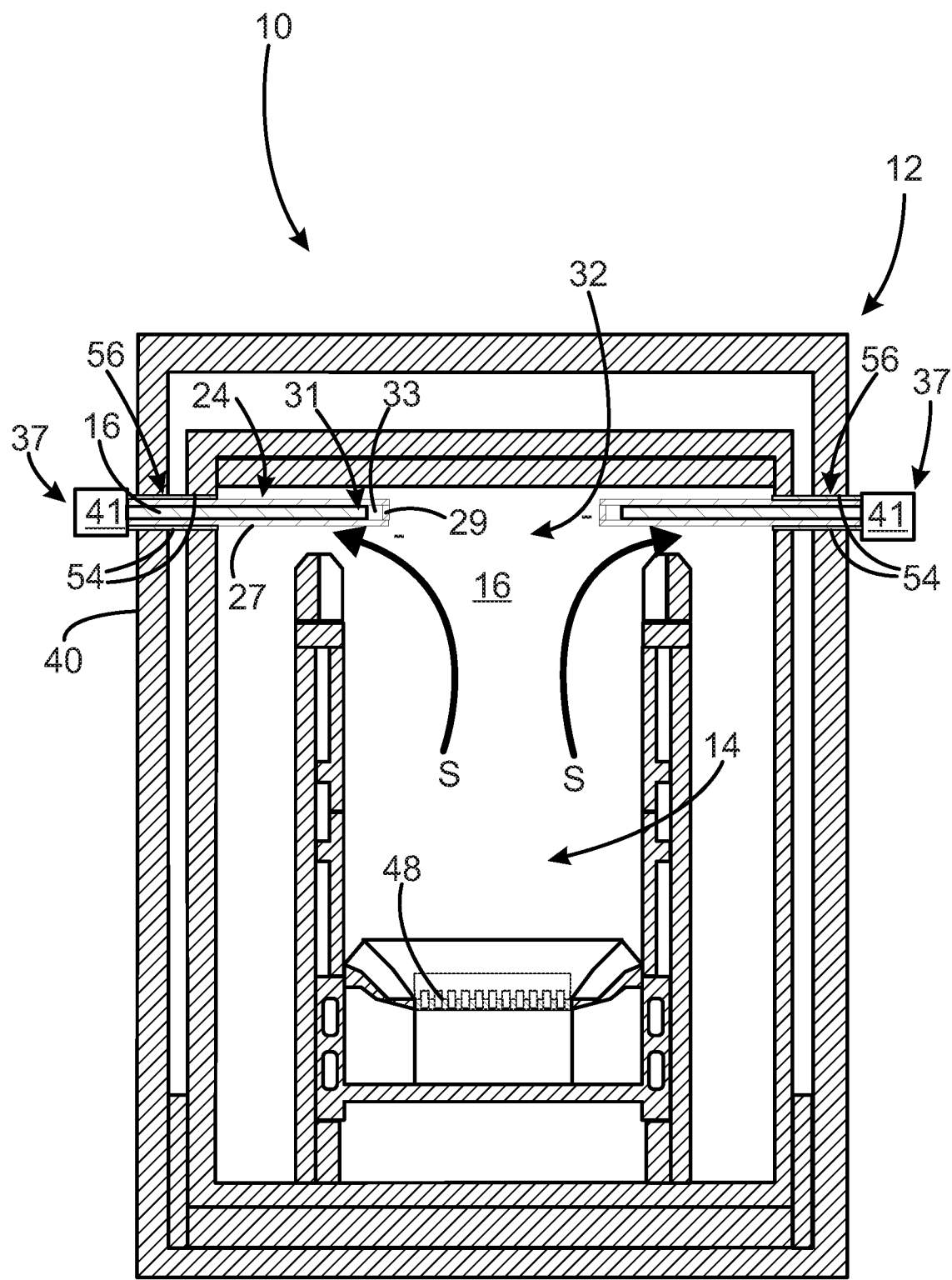


Fig. 1b

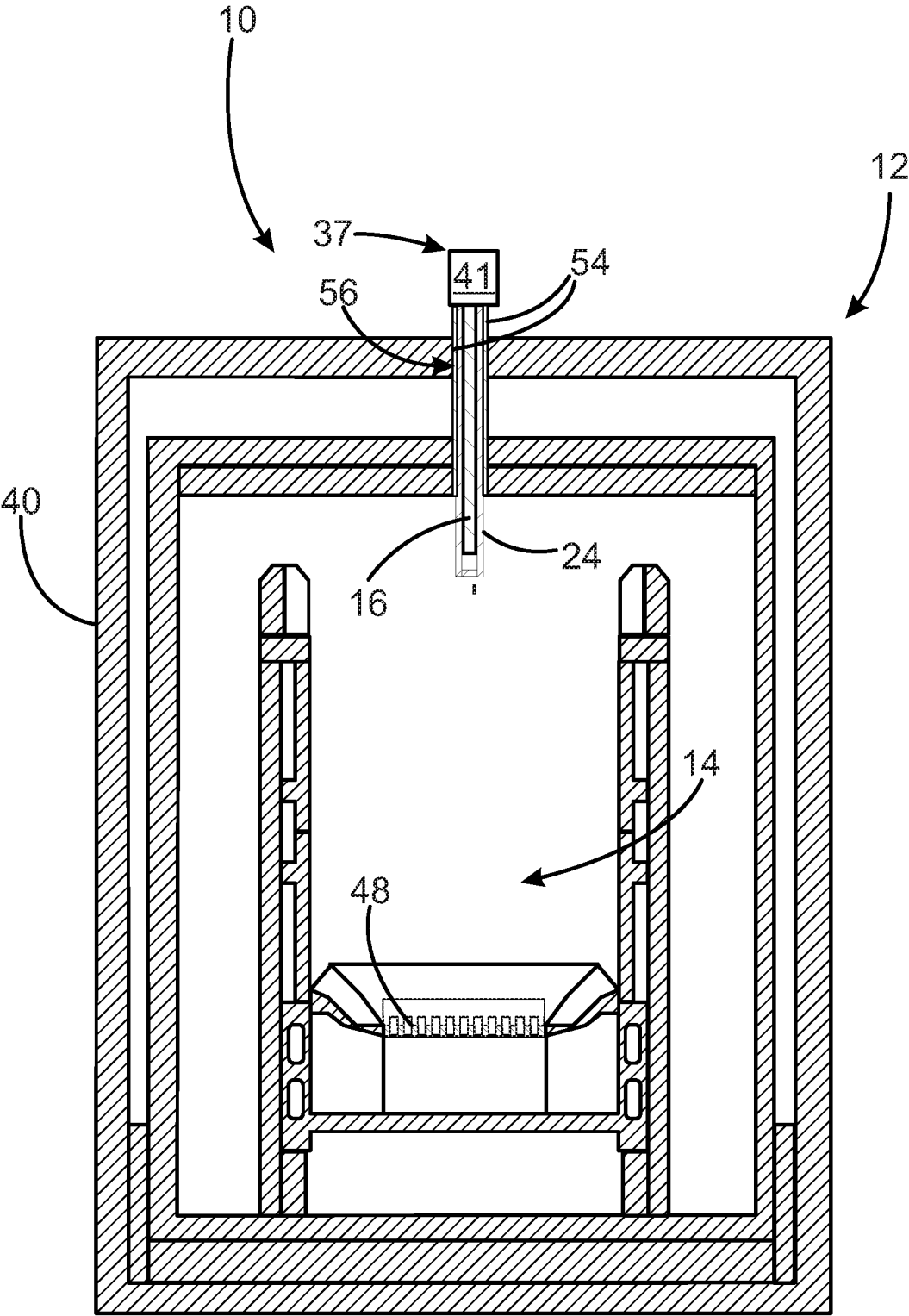


Fig. 2

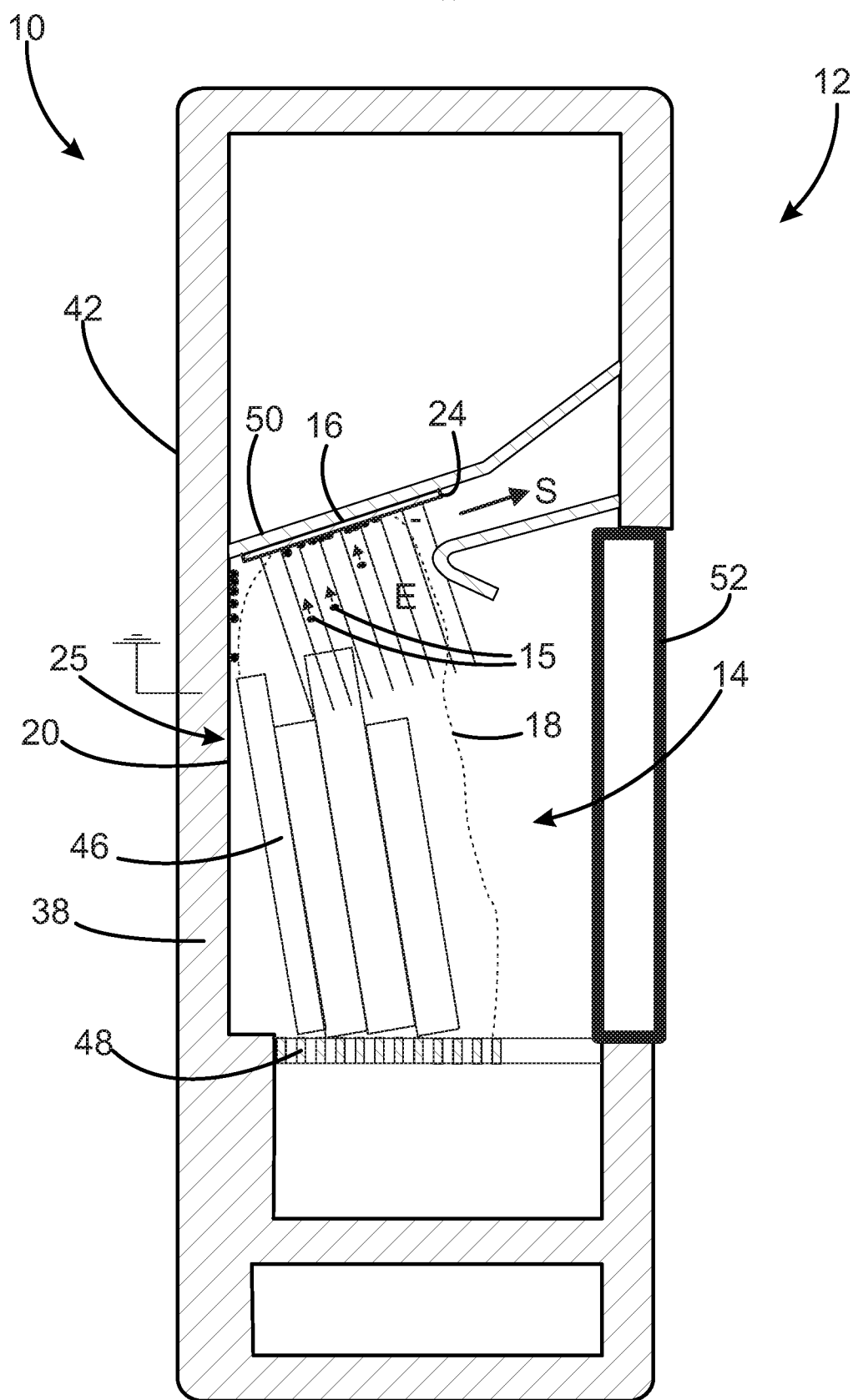


Fig. 3

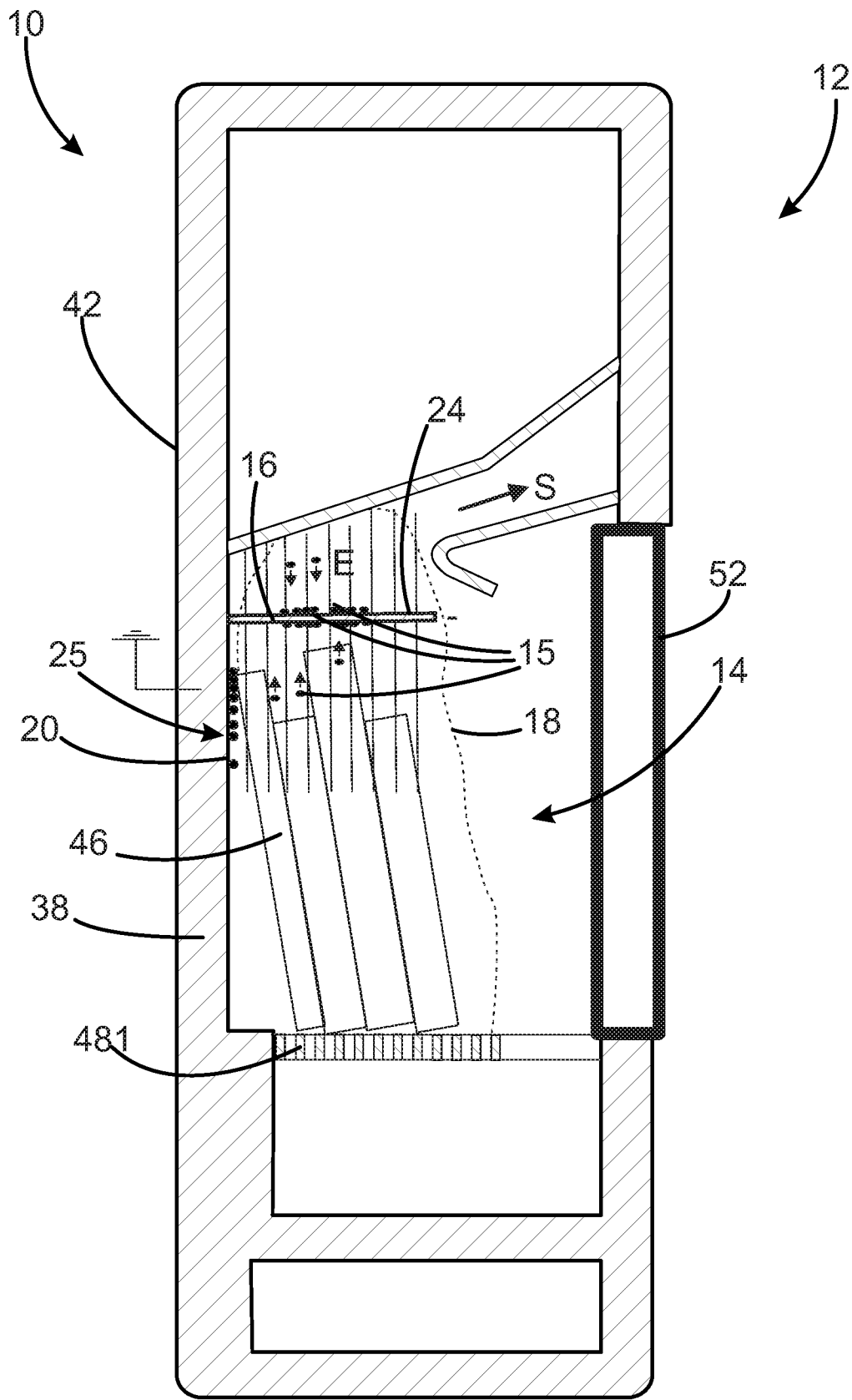


Fig. 4

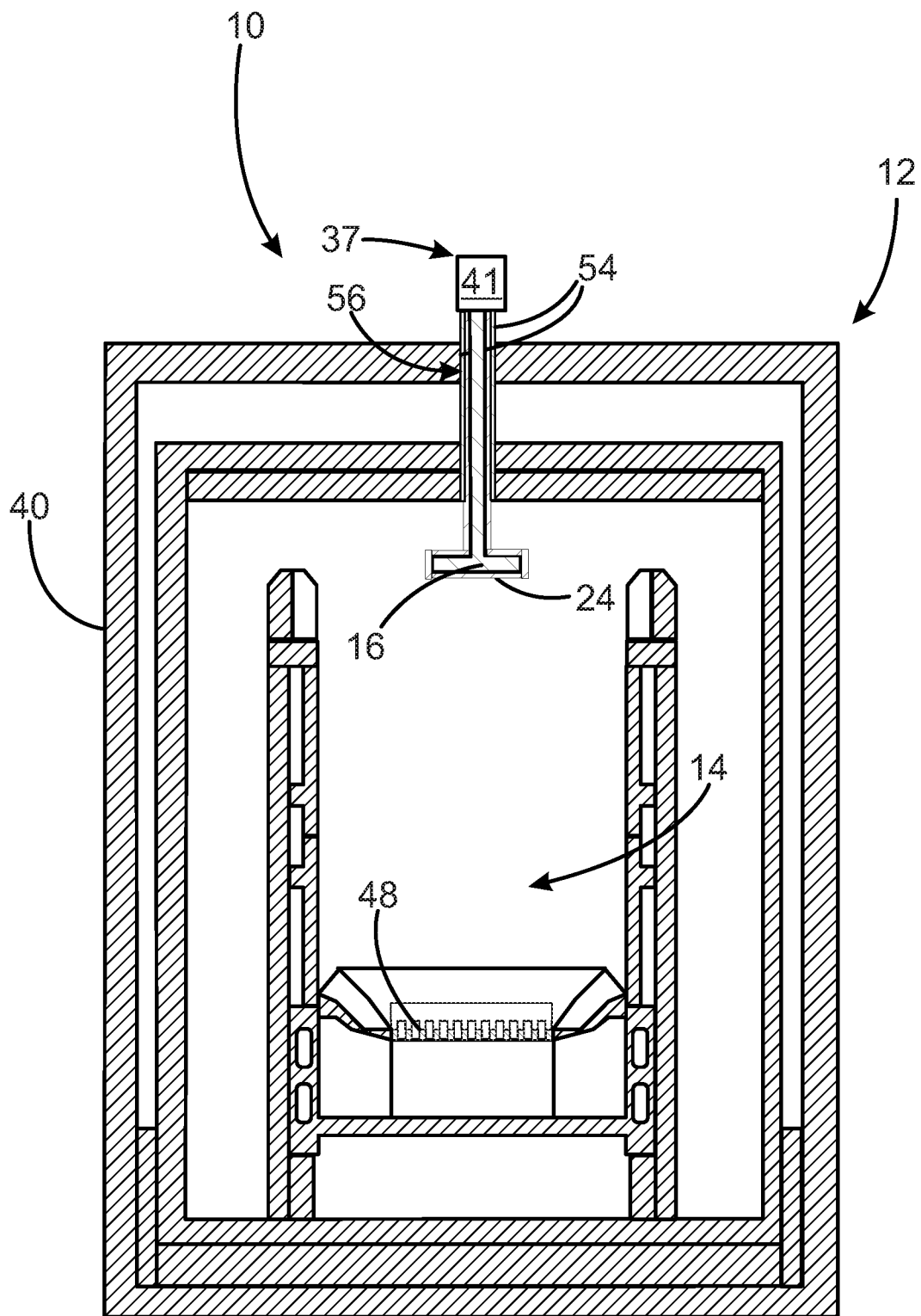


Fig. 5

INTERNATIONAL SEARCH REPORT

International application No

PCT/FI2024/050293

A. CLASSIFICATION OF SUBJECT MATTER INV. F23B60/02 F23J15/02 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) F23B F23J 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.
A	SUHONEN H. ET AL: "Novel fine particle reduction method for wood stoves based on high-temperature electric collection of naturally charged soot particles", JOURNAL OF CLEANER PRODUCTION, vol. 312, 1 August 2021 (2021-08-01), page 127831, XP093201475, AMSTERDAM, NL ISSN: 0959-6526, DOI: 10.1016/j.jclepro.2021.127831 the whole document ----- -/-	1 - 15
☒ Further documents are listed in the continuation of Box C. ☒ See patent family annex.		
* Special categories of cited documents : "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier application or patent but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family		
Date of the actual completion of the international search 5 September 2024		Date of mailing of the international search report 18/09/2024
Name and mailing address of the ISA/ European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016		Authorized officer Theis, Gilbert

INTERNATIONAL SEARCH REPORT

International application No
PCT/FI2024/050293

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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