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(54) **Apparatus, device and method for filtering fine particulate matter from exhaust gas**

Vorrichtung, Gerät und Verfahren zum Filtern feinen Schwebstoffteilchen aus Abgas

Appareil, dispositif et procédé pour filtrer de la matière particulaire fine de gaz d'échappement

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Description

[0001] The subject-matter of the invention relates to an apparatus, a device and a method for filtering fine particulate matter from exhaust gas. The subject-matter of the invention can be applied for cleaning exhaust gas combustion facilities such as stoves, furnaces, boilers, combustion chambers and burning appliances, which are combusting solid combustionable matter, such as wood, straw, second-rate cereals, unsuitable for food, or other fuels, such as liquid or gaseous fuels, such as diesel or heating oil. Further, the filter device may also be used for cleaning of exhaust gas from diesel internal-combustion engines.

[0002] In the application, the combustion of wood, as a preferred solid combustionable matter, is used as an example. However, it has to be understand, that the term "wood" can be replaced by any one other combustionable matter. The combustion of wood generally includes the following steps: (i) solid wood fuel is fed into a combustion chamber, (ii) wood is burnt and (iii) exhaust gas exits through the chimney into the atmosphere. Studies have shown that wood combustion is responsible for high emissions of fine particles and polycyclic aromatic hydrocarbons (PAH) which are associated with increased mortality and cardiovascular diseases (see Non-Patent Documents 1 and 2). Negative effects are likely in lower respiratory symptoms and reduced lung function in children and chronic obstructive pulmonary disease and reduced lung function in adults. As fine particles are associated with a strong negative health effect, it is urgent to prevent aerosol emissions into the atmosphere.

[0003] Electrostatic precipitators are the most common choice ensuring high removal efficiency for the complete particle size range. Most of the fine particles from exhaust gas are collected in the electrostatic precipitators and remain in the gas cleaning system.

[0004] The electrostatic precipitators need periodical cleaning and further disposal of the collected aerosol, which is mainly soot in case of wood combustion. In small scale wood combustion, the discharge of collected soot from known electrostatic precipitators is carried out manually. Due to possible high concentrations of PAH in the precipitated aerosol, the discharge of soot from the electrostatic precipitators needs to be carried out carefully and demands the use of individual protection means to exclude direct contact with the aerosol (see Non-Patent Document 1). The same problems might appear with disposal of the collected aerosol. The collected aerosol with a high PAH concentration might be identified as special waste and the disposal of this waste increases the costs of the gas cleaning system.

[0005] Non-Patent Document 1: Hueglin, Ch., Gaegauf, Gh., Knzel, S., and Burtscher, H. (1997) "Characterization of wood combustion particles: Morphology, mobility, and photoelectric activity", Environmental Science and Technology, Vol. 31, No. 12, 3439-3447.

[0006] Non-Patent Document 2: Nussbaumer, Th. (2003), "Combustion and co-combustion of biomass: Fundamentals, technologies, and primary measures for emission reduction", Energy & Fuels, Vol. 17, 1510-1521.

[0007] There are technical solutions where the aerosol, collected in an electrostatic precipitator , is discharged direct into the combustion chamber and is further burnt. In one case, this takes place in a wet electrostatic precipitator, in which the collected aerosol together with condensate flows back into the combustion chamber. In another solution, a dry electrostatic precipitator is cleaned manually when the combustion facility is switched-off. The collected aerosol is directed into the combustion chamber and is further burnt during the next combustion cycle. There are several problems of the discharge of the soot in the state-of-the-art electrostatic precipitators. In case of high gas temperatures, the condensate could evaporate and the discharge of collected soot into the combustion chamber would be strongly reduced, and the collected soot would be reentrained into the clean gas flow. If the collected soot is cleaned and delivered into the combustion chamber of the switched-off dry electrostatic precipitator , the loading of the cold combustion chamber with wood could provoke the exit of soot into the ambient air which would be dangerous for human health. The manual cleaning of an electrostatic precipitator results in direct contact with soot, thus demanding the use of individual protection means.

[0008] Small wood combustion needs the development of a method of cleaning of exhaust gas which would be characterized by low emission of fine particles; in the method the cleaning of collected aerosol would be performed automatically; the direct contact with collected soot would be excluded and the soot would be re-consumed. Accordingly, small wood combustion needs the development of a "Close-Clean-Combustion"-method (3C-method).

[0009] The results of use of electrostatic precipitators for gas cleaning from different wood combustion facilities are presented in Non-Patent Document 3. The electrostatic precipitators show high mass and fractional collection efficiency. However, the operation of the electrostatic precipitators leads to problems which could limit precipitators collection efficiency and stability of operation, e.g. loss of operation stability due to loading of the high voltage isolator (HVI) with aerosol; problems with operation control due to loading of temperature sensors by soot; decrease of efficiency due to spark-over discharges in the electrostatic precipitator ionizer; loss of energy by gas cooling in the electrostatic precipitator; irritating sound from the spark-over discharges; limited possibility for quick maintenance and re-placement of the electrostatic precipitators, etc.

[0010] Non-Patent Document 3: Kiener, S., Turowski, P., Hartmann, H,, and Schmoeckel, G. (2010) "Bewertung kostengonstiger Staubabscheider für Einzelfeuerstätten und Zentralheizungskessel", Berichte aus dem TFZ N 23, Straubing. (http://www.tfz.bayern.de/sonstiges/15951/23_bericht_internet_geschuetzt.pdf)

[0011] Document JP 2009 072 730 A discloses a dust collector having a powder mixing treatment means capable of mixing effectively utilizable soot with an additive to enhance the soot to a state easier to utilize. The dust collector comprises an electric precipitator or a filter apparatus adapted to the dust collection mechanism provided in an exhaust gas passing chamber. An additive supply mechanism is constituted so that an additive supply port is provided above the precipitation region of a dust collection hopper to supply the additive having to be mixed with the soot falling to the dust collection hopper and is equipped with a blow-through type rotary valve to scatter the additive moved to the supply port so as to eject or sprinkle the same and mixed with the soot falling to the dust collection hopper. Further, a feed-out control mechanism performs control so as to use the rotary valve or the like to draw out the mixture of the soot accumulated in the dust collection hopper and the additive to the outside.

[0012] Document DE 33 10 933 A1 discloses a device for removing solid constituents from the exhaust gases of internal combustion engines, in which large formations of solid constituents are produced with the aid of a coagulator and these are separated from the exhaust gas in a downstream separating device and discharged into a storage container, from where the solid constituents are fed back to the suction side of the internal combustion engine by carrier media during selected operating conditions of the internal combustion engine.

[0013] Document JP-2000140686 relates to a fly ash recovering device for collecting and recovering the fly ash contained in a waste gas from a coal burning boiler by an electrostatic precipitator. A recovering line withdraws the fly ash from the middle of a waste line and introduces it into a reutilizing silo connected to the waste line for introducing the fly ash from dust collecting chambers at the upperstream side of the electrostatic precipitator to a waste silo. Line switching valves at the waste line side are provided. The fly ash is discharged and separately recovered.

[0014] Therefore, it is a problem to provide an apparatus, a device, and a method, which are capable to increase the fraction of fine particulate matter removed from exhaust gas, wherein the efforts for maintenance are decreased and the use is made more comfortable to the user.

[0015] The problem is solved by the filter device having the features of claim 1, the apparatus having the features of claim 13 and the method using a device the features of claim 15. Preferred embodiments are defined in the dependent claims.

Filter device according to an aspect

[0016] An aspect of the invention is related to a filter device for filtering fine particulate matter from exhaust gas comprising:

- an exhaust gas inlet;
- an exhaust gas outlet;
- a precipitator device; and
- an outfall sewer with a particle discharge valve,

wherein, when the filter device is in use, the exhaust gas flowing from the exhaust gas inlet to the exhaust gas outlet passes the precipitator device along a first gas flow direction F1, which is substantially vertically downwards,
wherein the precipitator device is capable of at least partially removing fine particulate matter from the exhaust gas;
wherein the outfall sewer is configured to collect the removed fine particulate matter, wherein the particle discharge valve is configured to automatically discharge the collected fine particulate matter,
wherein the outfall sewer and/or the particle discharge valve is spaced apart from the precipitator device along the first gas flow direction F1 so that fine particulate matter is transportable by means of gravity and/or by means of dragging with the exhaust gas flow along the first gas flow direction F1 from the precipitator device to the outfall sewer.

[0017] Advantageously, the manual efforts for maintenance of the filter device are minimized. Since the fine particulate matter is transported from the collector along the first gas flow direction F1 towards the outfall sewer, a sedimentation of fine particulate matter at not intended locations along the exhaust gas path are prevented. Particularly, the fine particulate matter removed from the exhaust gas at the collector has not to be transported against the exhaust gas flow, which would bear the risk that the fine particulate matter, which is not ionized at this stage any more, is exhausted together with the exhaust gas through a chimney. In other words, the filter device is less prone to the re-entrainment of collected fine particulate matter into the cleaned exhaust gas, which decreases the emission and increases the collection efficiency. Since the particle discharge valve can be operated automatically for periodically discharging the fine particulate matter collected in the outfall sewer, a frequent manual cleaning can be omitted.

[0018] Particularly, the filter device ensures not only effective collection of fine particulate matter, but also allows effective re-consumption of collected aerosol, since the valve is directly or indirectly connectable to the combustion chamber.

[0019] The exhaust gas can be generated by combusting any combustionable matter, such as any solid, liquid or gaseous combustionable matter. Depending on the choice of combustionable matter and the combustion process the exhaust gas resulting from the combustion contains more or less fine particulate matter. In particular the burning of solid combustionable matter, such as biomass, wood, waste, coal, etc., or the combustion of liquid matter, such as diesel fuel, heavy oil, crude oil, etc, generates fine particulate matter during the combustion process.

[0020] The term fine particulate matter describes particles with an aerodynamic diameter of less than about 10 μm, which move in a gas like a sphere of unit density (1 gram per cubic centimeter) with a diameter of 10 micrometers. The particle diameters range from less than 10 nm to more than 10 micrometers. These dimensions represent the continuum from a few nanometers up to the size where particles can no longer be carried by a gas. In other words the fine particulate matter can form an aerosol together with the carrying gas.

[0021] The exhaust gas flows generally from a combustion chamber through the chimney into the environment. In order to clean the exhaust gas the filter device can be installed within the chimney. The exhaust gas entries the filter device through the exhaust gas inlet, which can be formed as an opening or a pipe connection. After filtering the filtered exhaust gas leaves the filter device through the exhaust gas outlet, which can be formed as an opening or a pipe connection. In this application, the exhaust gas flow direction from the exhaust gas inlet to the exhaust gas outlet is named "downstream". Accordingly, the exhaust gas inlet is arranged upstream of the exhaust gas outlet and the exhaust gas outlet is arranged downstream of the exhaust gas inlet.

[0022] The precipitator device removes the fine particulate matter from the exhaust gas. The precipitator device may comprise a wall flow filter, a particle filter or an electrostatic precipitator. The particles removed from the exhaust gas can stick together and form agglomerates and, thus, these have to be discharged from the filter device in order to prevent a blockage of the filter device. When using the filter device the exhaust gas is flowing downstream along a first gas flow direction F1 through the precipitator device. An outfall sewer with a particle discharge valve is arranged downstream of the precipitator device. In other words the outfall sewer and/or the particle discharge valve can be spaced apart along the first gas flow direction F1 from the precipitator device. As an advantage the removed particles and/or agglomerates have to be transported along the exhaust gas flow towards the outfall sewer, and thus the flow of the exhaust gas may support this transportation.

[0023] Further, the first gas flow direction F1 is directed substantially vertically downwards. In other words, when the filter device is in use, the first gas flow direction F1 is vertically directed towards the earth's center with a deviation less than about ±45 degrees, preferably less than about ±30 degrees, preferably less than about ±15 degrees, and most preferably less than about ±5 degrees from the vertical direction.

[0024] The outfall sewer is configured to collect the removed fine particulate matter. In other words the particles and agglomerates removed from the exahust gas by means of the precipitator device are collected in the outfall sewer and less than about 20%, preferably less than about 10%, more preferably less than about 5%, preferably less than about 1% of the removed mass of the fine particulate matter is transported beyond the outfall sewer and exhausted through the chimney.

[0025] The particle discharge valve is configured to automatically discharge the collected fine particulate matter. The automatic discharge can be triggered by exceeding a threshold value or threshold mass of collected matter in the outfall sewer. Additionally or alternatively the discharge can be triggered periodically within a determined time interval of 1 hour, 1 day, 1 week or the like. The particle discharge valve can be connected via a particle discharge duct to a dust bin or to a device for combusting the collected fine particulate matter. Preferably the collected fine particulate matter can be provided to the combustion process already generated the exhaust gas, which was filtered by means of the filtering device.

[0026] In a preferred embodiment the electrostatic precipitator device comprises:

- an ionizer for ionizing the exhaust gas flowing through the precipitator device;
- a collector, for collecting fine particulate matter from the ionized exhaust gas, wherein the collector is spaced apart from the ionizer along the first gas flow direction F1 by a plenum chamber connecting the ionizer and the collector; and
- a cleaning device for removing fine particle matter adhering at the collector.

[0027] Advantageously, the electrostatic precipitator has a simple design, is robust and does not need manual collector cleaning. Furthermore, the electrostatic precipitator has a small size, preferably to fit within a 150 mm or 120 mm diameter in a chimney pipe. As a further advantage the pressure drop between the exhaust gas inlet and the exhaust gas outlet of the filter device is lower compared to other filtering techniques such like wand flow filters. Particularly, in cases where the exhaust gas flow is only caused by the thermodynamic lift in the chimney a pressure drop caused by the filter device may cause unsafe operating conditions of the combustion. Therefore, the pressure drop caused by the electrostatic precipitator may be less than 10 Pa, preferably less than 5 Pa, more preferably less than 2 Pa or less than 1 Pa. In other words, when the filter device is in use, the exhaust gas pressure at the ionizer differs from the exhaust gas pressure at the collector by less than 10 Pa, 5 Pa, 2 Pa, or 1 Pa.

[0028] Preferably, the ionizer of the precipitator device comprises:

-- a screen electrode,
-- a high voltage isolator,
-- a high voltage rod, having a top end which at least partially penetrates the high voltage isolator and a bottom end comprising a high voltage corona discharge electrode, wherein the high voltage rod is at least partially axially installed inside of the screen electrode.

[0029] Advantageously, the high voltage isolator can be within the flow path of the exhaust gas, which would keep the aggregation of fine particulate matter at the high voltage isolator low. Consequently, the probability of spark-over discharges is decreased and, thus, the noise emission is also decreased. Furthermore, a manual cleaning of the high voltage isolator would not be necessary. In order to solve the problem of noise decrease alone the electrostatic precipitator, as described in this application, could be provided in a exhaust gas duct without the further features of the filter device, in particular without the outfall sewer and without the discharge valve.

[0030] The screen electrode may be formed as a cylinder and the high voltage rod may be axially installed within the screen electrode. The screen electrode may be mounted axially to a housing of the filter device. Advantageously, a cylindrical filter device housing can be easily integrated into the chimney or fitted between two parts of the chimney.

[0031] The high voltage isolator may be configured to withstand a voltage of greater than about 200 Volts, preferably greater than about 400 Volts, more preferably greater than about 1000 Volts, more preferably greater than about 2000 Volts or 4000 Volts.

[0032] Preferably the collector of the precipitator device has a cylindrical shape and wherein the cleaning device comprises:

-- a brush which is rotatably arranged inside the cylindrical collector,
-- an operating device for rotating the brush, and
-- a plate for removing fine particulate matter from the brush.

[0033] The brush may be of a material resistant to the exhaust gas, i.e. the high gas temperature and corrosion. For example the brush be made of corrosion resistant metal like stainless steel, brass and the like. The collector may be formed cylindrically, wherein the brush is cleaning the inside face of the cylindrical collector by rotation of the brush around its own axis. The brush may be driven by a driving device, which can be an electrical motor. Preferably, the brush is formed as a conveyor screw, which conveys the particulate matter along the first gas flow direction F1, i.e. downstream, during the rotation of the brush.

[0034] A supporting high voltage rod may electrically connect a high voltage source with the high voltage rod, wherein the supporting high voltage rod at least partially penetrates the top end of the high voltage rod, and the axis of the supporting high voltage rod and the axis of the high voltage rod are orthogonal to each other. The supporting high voltage rod may also completely penetrate the top end of the high voltage rod.

[0035] The filter device may comprise a temperature sensor, which may be located at or in the high voltage isolator. The temperature sensor may be included into the body of the high voltage isolator or be arranged in a hole of the high voltage isolator body.

[0036] The screen electrode may comprise double-walls. In this case the temperature sensor may be located in a free space between the double-walls of the screen electrode.

[0037] Advantageously, the maintenance of the temperature sensor is simplified, since the temperature sensor is not located in the particle loaded exhaust gas flow, which would reduce the stability of the electrostatic precipitator operation.

[0038] Preferably, the electrostatic precipitator is at least partially or completely catalytically coated.

[0039] Preferably, the electrostatic precipitator is installed inside of an output duct, which can be a pipe like a chimney pipe and which can be single pieced with the exhaust gas outlet, wherein a gap between the electrostatic precipitator housing and the output duct is formed. More preferably, a second direction F2 of the exhaust gas flow in the gap is opposite to the first direction F1 of the exhaust gas flow, when the filter device is in use. Further, the output duct has a cross-section area S_1 and the electrostatic precipitator housing has a cross-section area S_2 , wherein the equation $S_2 \leq S_1/2$ is preferably fulfilled in order to minimize the pressure drop over the filter device.

Apparatus according to an aspect

[0040] An aspect of the invention is related to an apparatus for combusting solid combustionable matter comprising:

- a combustion chamber;
- a feeding device for feeding the combustion chamber with the solid combustionable matter;
- a filter device according to the invention,
  wherein the exhaust gas inlet of the filter device is fluidly connected to the combustion chamber via an exhaust gas duct;
  wherein the particle discharge valve of the filter device is fluidly connected to the feed device via a fine particle discharge duct.

[0041] Alternatively, an aspect of the invention is related to an apparatus for combusting solid combustionable matter comprising:

- a combustion chamber;
- a filter device according to the invention,
  wherein the exhaust gas inlet of the filter device is fluidly connected to the combustion chamber via an exhaust gas duct;
  wherein the particle discharge valve of the filter device is fluidly (directly) connected to the combustion chamber.

[0042] The combustion chamber is configured to combust or burn a fuel, which is in this case a solid combus-

tionable matter or solid fuel, like wood, coal or the like. It has to be emphasized that the removing functionality of the filter device can also be obtained, when combusting a fluid or gaseous fuel, such as diesel or heavy oil.

[0043] The feeding device can be an automatic feeder, which is capable to feed a predetermined amount of combustionable matter or fuel into the combustion chamber in order to generate a predetermined amount of heat energy. The particle removed from the exhaust gas are provided from the filter device to the feeding device by means of the fine particle discharge duct connecting the particle discharge valve of the filter device with the feed system. Advantageously, the fine particulate matter is not reintroduced directly into the combustion chamber, which prevents a contamination of the combustion chamber during maintenance or an incomplete combustion of the reintroduced fine particulate matter when the temperature in the combustion chamber is too low. Particularly, when starting the combustion process the temperature in the combustion chamber slowly rises until the operating temperature is reached. The fine particulate matter, however, is only combusted properly when this operating temperature is present. Therefore, the feeding device may be configured to keep the fine particulate matter provided by the filter device until the operating temperature is reached in the combustion chamber. Exemplarily, the volume of combustionable matter in the feeding device, which is storable between a feeding opening of the combustion chamber and a opening of the feeding device connected to the fine particle discharge duct may be sufficient to provide the combustion chamber with fuel until the operating temperature is reached. Thus, a complete combustion of the fine particulate matter can be obtained.

[0044] Preferably, the fine particle discharge duct is configured to convey the fine particulate matter from the particle discharge valve to the feeding device by gravity. Thus, the fine particle discharge duct may extend substantially vertically from the particle discharge valve to the feeding device.

Method according to an aspect

[0045] An aspect of the invention is related to a method for combusting solid combustionable matter comprising to steps of:

- feeding a solid combustionable matter by means of a feeding device into a combustion chamber;
- combusting the solid combustionable matter thereby generating exhaust gas;
- leading the exhaust gas to a filter device according to the invention;
- removing fine particulate matter from the exhaust gas by means of the filter device;
- periodically discharging the removed fine particulate matter into the feeding device;
- mixing the removed fine particulate matter with the solid combustionable matter;
- feeding the mixture into the combustion chamber; and
- combusting the mixture of removed fine particulate matter and the solid combustionable matter in the combustion chamber.

[0046] Thus, a "Close-Clean-Combustion" method (3C-method) for exhaust gas cleaning, which ensures stable operation, effective exhaust gas cleaning and effective re-consumption of collected fine particulate matter is provided.

[0047] Additional objects, advantages and features of the present invention will now be described in greater detail, by way of example, with reference to preferred embodiments depicted in the drawing in which:

Figure 1 illustrates a known apparatus for combusting wood and cleaning the exhaust gas by means of a electrostatic precipitator;
Figure 2 illustrates a known electrostatic precipitator for cleaning of exhaust gas;
Figure 3 shows a preferred embodiment of the electrostatic precipitator according to the invention;
Figure 4 shows a detailed view of the ionizer of the electrostatic precipitator of Fig. 3;
Figure 5 shows preferred embodiments of a high voltage isolator in the electrostatic precipitator of Fig. 3;
Figure 6 shows preferred locations of a temperature sensor in the electrostatic precipitator of Fig. 3;
Figure 7 illustrates a preferred embodiment of an apparatus for combusting a solid fuel according to the invention;
Figure 8 illustrates another preferred embodiment of an apparatus for combusting a solid fuel according to the invention;
Figure 9 illustrates another preferred embodiment of an apparatus for combusting a solid fuel according to the invention.

[0048] **Figure 1** shows a known apparatus 1 for combusting wood, as an exemplary solid combustionable matter, comprising an electrostatic precipitator 4 for cleaning of the exhaust gas generated by the combustion, according to document US 4 675 029 A. The known apparatus for cleaning of exhaust gas from wood combustion, especially for combustion of wood pellets 3a and/or chips, comprises a combustion appliance 1 a with a combustion chamber 2. A solid fuel feed system 3 provides the combustion chamber with solid combustionable matter. The direction W of the movement of the wood pellets 3a is shown by an arrow. An electrostatic precipitator 4 for collecting the fine particulate matter and/or aerosol contained in the exhaust gas generated by the combustion process is installed downstream of the combustion appliance 1 a. An input duct 5 connects the com-

bustion chamber 2 with the electrostatic precipitator 4. An output duct 6 connects the electrostatic precipitator 4 with a chimney (not shown). The direction F of the exhaust gas flow in the electrostatic precipitator 4 coincides with direction F of the gas flow in the input duct 5 and the output duct 6.

[0049] The known method for exhaust gas cleaning from combustion comprises the collection of particles in the electrostatic precipitator 4, which are directly discharged back into the combustion chamber 2 through the input duct 5.

[0050] **Figure 2** shows a known electrostatic precipitator 4 for cleaning of the exhaust gas according to document DE 10 2008 049 211 A1. The state-of-the-art electrostatic precipitator 4 shown in Fig. 2 comprises a separate pipe-form-housing ionizer 9, a pipe-form-housing collector 10 and a plenum chamber 11 which connects the ionizer 9 and the collector 10. The direction F1 of the gas flow in the ionizer 9 and the direction F2 of gas flow in the collector 10 are opposite. The ionizer 9 comprises a screen electrode 12, a high voltage isolator 13 which is installed in an isolator housing 14, a high voltage rod 15 which passes by its top end 15a through the high voltage isolator 13 and the high voltage rod 15 is axially installed inside of the screen electrode 12, and a high voltage corona discharge electrode 16 which is installed at a bottom end 15b of the high voltage rod 15. A charging zone 17 is formed between the corona discharge electrode 16 and the ionizer 9 pipe-form-housing. The grounded collector 10 comprises a brush 18, which is axially installed in the collector 10 pipe-form housing, and a device 19 capable to rotate the brush. The rotation of the brush 18 can be carried out constantly or periodically in predetermined time-intervals. The collector 10 is supplied with a thin plate (20) for cleaning of the brush 18.

[0051] **Figures 3 and 4** disclose a filter device 4A having an electrostatic precipitator 4B according to the present invention. Since some of the features and elements of the filter device 4A are corresponding to the features and elements shown in Fig. 2, corresponding elements are labeled with identical reference signs. The electrostatic precipitator 4B of the filter device 4A can comprise housing 21, which can be a single pipe-form-housing 21, wherein the housing is electrically grounded. The electrostatic precipitator 4B can be installed inside an output duct 6 with a gap 8 between the precipitator housing 21 and the output duct 6. The electrostatic precipitator 4B is configured that, when in use, the exhaust gas entries the electrostatic precipitator via the exhaust gas inlet 5 and flows through the housing 21 along a first exhaust gas flow direction F1. Subsequently, the exhaust gas flows through the gap 8 back along a second exhaust gas flow direction F2, which is opposite to the first exhaust gas flow direction F1. Therefore, the cross-sectional area of the housing 21 and the gap 8 is preferably identical.

[0052] An ionizer 22 is installed above (i.e. according to the first exhaust gas flow direction F1 upstream of) a collector 23 in the housing 21. Whereas the direction of the exhaust gas flow in the ionizer 9 and collector 10 in the state-of-the-art electrostatic precipitator is opposite (cf. Fig. 2), in the electrostatic precipitator shown in Fig. 3 the direction of the exhaust gas flow through the ionizer 22 and the collector 23 is the identical.

[0053] The ionizer 22 comprises a screen electrode 12, a high voltage isolator 13 which is installed in an isolator housing 14, a high voltage rod 15 which is fixed with its top end 15a at the high voltage isolator 13 and the high voltage rod 15 is axially installed inside of the screen electrode 12, and a high voltage corona discharge electrode 16 which is installed at a bottom end 15b of the high voltage rod 15. A charging zone 17 is formed between the corona discharge electrode 16 and the housing 21.

[0054] A cleaning device 24 is maintained in the plenum chamber between the ionizer 22 and the collector 23. The cleaning device 24 is connected by its bottom to an axis 25 of a brush 18 and cleaning elements 26 of the cleaning device 24 are positioned in the charging zone 17 of the ionizer 22. The cleaning elements are preferably positioned near to the wall of the precipitator housing 21 to be capable to clean the wall.

[0055] The cleaning device 24 is configured to minimized the pressure drop occurring when exhaust gas is flowing through the cleaning device 24. Therefore, the mechanical fixture of the axis may be formed of struts having a small resistance regarding the flowing exhaust gas. The brush 18 is axially installed in the collector part of the precipitator housing 21. The position of the precipitator housing 21 in the output duct 6 can be fixed by the elements 27, which may be struts squeezing the housing 21 against the inner wall of the output duct 6. The brush 18 is connected to a driving device M which ensures the rotation of the brush 18. The brush 18 can be cleaned by gliding over a thin plate 20 removing the particles from the brush 18.

[0056] A valve 7 is installed in the output duct 6 below (i.e. according to the first exhaust gas flow direction F1 downstream of) the collector 23. The valve 7 can part of the electrostatic precipitator 4B or alternatively a part of the output duct 6. The valve closes a outfall sewer 7a, which is collecting the particles removed from the collector by means of the brush 18. The valve can be opened and closed by means of the valve actuator V. This opening and closing can be performed periodically in predetermined time-intervals or depending on the amount of collected material present in the outfall sewer 7a.

[0057] As shown in Fig. 3 the electrostatic precipitator 4B is installed inside of the output duct 6 with a gap 8 between the electrostatic precipitator housing 21 and the output duct 6. A second direction F2 of the exhaust gas flow in the output duct 6 in the gap 8 between the electrostatic precipitator housing 21 and the output duct 6 is opposite to the first direction F1 of the exhaust gas flow in the electrostatic precipitator 4B. The electrostatic precipitator 4B is preferably installed in such a way in the output duct 6 that the pressure drop in the gas duct 6 is

minimized. The output duct 6 has a cross-section area S_1, while S_2 is the cross-section area of the electrostatic precipitator housing 21. A setup with minimized pressure drop is realized when the equation $S_2 \leq S_1/2$ is fulfilled.

[0058] Preferably, the high voltage rod 15 only partly penetrates by its top end into the high voltage isolator 13 to ensure stable operation. A supporting high voltage rod 28 may be axially installed inside of the high voltage isolator 13, wherein the supporting rod 28 is connected to a high voltage unit (not shown). The supporting rod 28 penetrates through the top end 15a of the high voltage rod 15 and fixes the position of the high voltage rod 15 in the high voltage isolator 13. The axis of the supporting rod 28 and the axis of the high voltage rod 15 are preferably orthogonal to each other. The high voltage isolator 13 can be mounted to the isolator housing 14, which is connected to the screen electrode 12 and is at the same ground potential. The electrostatic precipitator can be such designed that the high voltage isolator housing 14 might be installed without a gap or with a gap regarding to the precipitator housing 21.

[0059] To ensure long-term stable operation and to minimize the probability of short-currents through the isolator surface, it is preferred that the lateral surface of the high voltage isolator 13 is formed non-smooth. For example, the high voltage isolator could be provided with a wave-form lateral surface as shown in view (a) of **Figure 5**. Beneath the wave-form lateral surface the high voltage isolator could be formed conical with respect to the axis of the high voltage rod 15 as shown in view (b) of Fig. 5. These schematic views of the high voltage isolators 13a and 13b are only examples. The high voltage isolator 13 could be manufactured in different forms. For example, a high voltage insulator 13 can be such designed that it has large-diameter left and right parts and a reduced-diameter middle part. An axial orifice passes through the large-diameter left part, through the middle part and ends inside of the large-diameter right part. A high voltage supporting rod 28 is installed inside of the axial orifice. An orthogonal orifice is in the reduced-diameter middle part of the high voltage insulator 13. The high voltage rod 15 is installed with its top part 15a in this orifice. The supporting rod 28 passes through the top end 15a of the high voltage rod 15 and fixes its position in the high voltage isolator 13.

[0060] As shown in **Figure 6** a temperature sensor 29 may be provided to the electrostatic precipitator 4B in order to ensure effective control of electrostatic precipitator operation. The temperature sensor 29 may be located inside of the body of the high voltage isolator 13, as shown in view (a) of Fig. 6, for example in an opening of the high voltage isolator 13 towards the high voltage isolator housing 14. Alternatively, the temperature sensor 29 can be located in the wall of the high voltage isolator housing 14, as shown in view (b) of Fig. 6. Alternatively, the screen electrode 12 has double-walls, as shown in view (c) of Fig. 6, and the temperature sensor 29 is installed in the free space between these walls in order to ensure stable operation.

[0061] **Figure 7** discloses an apparatus 1 for combusting a solid fuel, such as wood, and for cleaning the exhaust gas from wood combustion. An output duct 6 fluidly connects a solid fuel feed system 3 and the chimney (not shown). A filter device 4A with an electrostatic precipitator 4B, such as shown in Figures 3 to 6, is installed inside of the output duct 6 with a gap 8 between the electrostatic precipitator housing 21 and the output duct 6. A valve 7 is installed in the output duct 6 vertically below the electrostatic precipitator 4B and above the solid fuel feed system 3. The fine particulate matter or aerosol collected in the electrostatic precipitator 4B is discharged into a outfall sewer 7a above valve 7. The valve can be part of the output duct 6 as well as a part of the electrostatic precipitator 4B. The valve 7 can be automatically, periodically opened into the solid fuel feed system 3. The opening of the valve can be triggered by the amount or weight of material in the outfall sewer 7a. For example, the weight of the material can apply a force against a spring, wherein the valve is opened when the force generated by the weight exceeds a predetermined amount. Alternatively or additionally, the valve may be opened by a valve driving device V, which may be electronically controlled. The valve driving device may comprise a motor or an electrical actuator.

[0062] The second direction F2 of the exhaust gas flow in the output duct 6 in the gap 8 between the electrostatic precipitator housing 21 and the output duct 6 is opposite to the first direction F1 of the exhaust gas flow in the electrostatic precipitator 4B. The electrostatic precipitator 4B is preferably installed in such a way in the output duct 6 that the pressure drop in the gas duct 6 is minimized. The output duct 6 has a cross-section area S_1, while S_2 is the cross-section area of the electrostatic precipitator housing 21. A setup with minimized pressure drop is realized when the equation $S_2 \leq S_1/2$ is fulfilled.

[0063] The output duct 6 can be coated with a thermo-isolating and/or sound-isolating layer. This reduces the loss of energy and decreases the negative influence of the noise from spark-over discharges in the electrostatic precipitator 4B.

[0064] In the apparatus for cleaning of exhaust gas from wood combustion, instead of the electrostatic precipitator 4B, any other precipitators like wall flow filters can be installed in the output duct 6 with a gap 8 between the precipitator housing and the output duct 6. In such an embodiment, the collected aerosol falls down from the precipitator into the output duct 6 directly onto the valve 7. The precipitator can be supplied with any cleaning system and control system which controls the precipitator operation parameters.

[0065] In the apparatus for cleaning of exhaust gas from wood combustion at least one precipitator is installed in the output duct 6. To ensure effective gas cleaning at high gas flow rates (from combustion facilities with high thermal power output), the apparatus may comprise two or more precipitators, such as filters and/or electro-

static precipitators.

[0066] In the apparatus for cleaning of exhaust gas from wood combustion, the electrostatic precipitator, or filter, or electrostatic precipitators and filters together, are preferably manufactured with a possibility to be replaced. Accordingly, the design of the apparatus must ensure easy re-placement, cleaning and repair of the installed electrostatic precipitator(s) and/or filter(s). Thus, in the apparatus according to the present invention, the output duct 6, as shown in Fig. 3, is preferably manufactured with an opening 32 with a cup through which the electrostatic precipitator(s) and/or filter(s) can be maintained in the output duct 6.

[0067] In the apparatus for cleaning of exhaust gas from wood combustion, a filter device 4A with an electrostatic precipitator 4B and/or a filter, being installed in the output duct 6, may be integrated into the combustion facility 1a. The combustion facility 1a with integrated electrostatic precipitator 4B is depicted in **Figure 8**. The output duct 6 is integrated into the combustion facility 1 a. The exhaust gas from the combustion chamber 2 flows into the electrostatic precipitator 4B through the input duct 5, which is integrated into the combustion facility 1 a. The valve 7 is installed inside of the output duct 6 and is also integrated into the combustion facility 1. The mixing of the collected aerosol with wood takes place in the part of the solid fuel feed system 3 which is integrated into the combustion facility 1 a.

[0068] The output duct 6 may be a part of the housing of the combustion facility 1 a. In this embodiment, the first direction F1 of exhaust gas flow in the electrostatic precipitator 4A is opposite to the second direction F2 of exhaust gas flow in the gap 8 formed by the housing 21 of the electrostatic precipitator 4B and the housing 1b of the combustion facility 1 a.

[0069] In the apparatus for cleaning of exhaust gas from wood combustion, the electrostatic precipitator 4B (or electrostatic precipitators, or filter, or filters, or electrostatic precipitator(s) and filter(s) together) is preferably catalytically coated. The use of a catalyst allows to oxidize soot particles collected on the lateral surface of the precipitator housing 21. The use of a catalyst also reduces the gaseous emissions from wood combustion facility.

[0070] To ensure effective reduction of particle emissions with minimum investment and operation costs, the electrostatic precipitator needs to have a small size, robust design, ensure stable operation (stable position of the high voltage rods in the high voltage insulator, low loading of the high voltage isolator with soot, effective control of gas temperature and in-time switch-on and switch-off of the electrostatic precipitator), and ensures effective particle charging and cleaning of the electrostatic precipitator , low re-entrainment of collected aerosol into the clean gas, effective discharge and re-consumption of the collected aerosol.

[0071] **Figure 9** shows an apparatus 1 having a filter device 4A with an electrostatic precipitator 4B according to the present invention. The apparatus does not comprise an automatic solid fuel feed system (like wood-pellets and/or wood chips boilers, or mixed-pellets boilers, etc.), but is manually feed with combustionable matter or fuel, for example wood-logs.

[0072] Like the apparatus presented in Fig. 7 the electrostatic precipitator 4B is installed in the output duct 6 with a gap 8 between the electrostatic precipitator housing 21 and, according to the first direction F1 of the exhaust gas flow in the electrostatic precipitator 4B, the downstream end 6A of the output duct 6 is closed and the upstream end 6B of the output duct 6 is opened. The valve 7 is installed in the downstream end 6A of the output duct 6, and there is a closed space 30 in the downstream end 6A of the output duct 6 below valve 7, wherein a container 31 is installed in the closed space 30 for collecting the fine particulate matter. The material collected in container 31 could be further re-consumed in the combustion facility 1 a when filled in manually.

[0073] The operation of the apparatus 1 is now described in view of Figures 3, 4, 7 and 8. The combustionable matter, such as biomass, wood, wood-pellets or wood-chips, is delivered by the solid fuel feed system 3 into the combustion chamber 2 of the combustion facility 1 a. The combustionable matter is burnt and particle loaded exhaust gas flows from the combustion chamber 2 through the input gas duct 5 into the electrostatic precipitator 4B. When high voltage is applied, the corona discharge is generated on the sharp point of the HV electrode 16. In the charging zone 17, particles are electrically charged. Then charged particles are transported by the exhaust gas flow into the collector 23 of the electrostatic precipitator 4B, where particles are collected on the grounded surface of the collector 23 and brush 18. The brush 18 is periodically rotated and the collected fine particulate matter falls down in the form of large flocks. During rotation of the brush 18, the cleaning elements 26 of the cleaning device 24 clean the inner surface of the grounded electrode of the ionizer 22 in the charging zone 17. The aerosol which is collected in the ionizing zone 17 falls down on the brush 18 and is further delivered by the brush from the collector 23 to the outfall sewer 7a.

[0074] The cleaned exhaust gas exits from the electrostatic precipitator 4B into the gas "dead zone" which is between the electrostatic precipitator 4B and the valve 7. As the cross-section of the output duct 6 is larger than the cross-section of the electrostatic precipitator housing 21, the gas flow expands in the "dead zone" and its velocity is reduced. As the gas velocity is reduced, the coarse particles (flocks) fall down from the electrostatic precipitator collector 23 onto the valve 7. Part of the charged particles which passed the electrostatic precipitator 4B are collected on the lateral walls of the output duct 6 in the "dead zone" under the influence of electric forces, such as space charge electric field and image forces. These charged fine particles are also collected by the flocks, which fall down due to electrostatic agglomeration. Such precipitation of particles is possible due to the low gas velocity in the "dead zone". These phenom-

ena increase the efficiency of gas cleaning. The valve 7 is periodically opened and the collected aerosol falls down into the opening of the solid fuel feed system 3. The collected matter is soot and is provided to the solid fuel feed system 3 is mixed with the wood, preferably wood-pellets, 3a. The mixture of wood and soot is burnt in the combustion chamber 2. The clean exhaust gas flows out of the electrostatic precipitator 4A, through the gap 8 and the output duct 6 into the chimney, and it is discharged into the atmosphere.

[0075] The electrostatic precipitator 4B may be operated under hot gas conditions (gas temperature over 300°C, for example wood-logs combustion in the stoves). In such case, when the exhaust gas flows through the gap 8, there is a temperature gradient in the gap 8 due to a temperature difference between the electrostatic precipitator housing 21 and the output duct 6, wherein the temperature of the duct wall is lower than the temperature of the electrostatic precipitator 4B and the direction of the gradient vector is from the electrostatic precipitator housing 21 to the output duct 6 wall. Due to the gradient of the temperature, additionally the thermophoretic sedimentation of a part of the fine particles, which are still in the gas flow downstream the electrostatic precipitator , takes place. Fine particles are precipitated on the outside lateral surface of the electrostatic precipitator housing 21 and on the inner wall of the output duct 6. This increases the cleaning efficiency of the apparatus. Periodically, the collected particulate matter in the form of large flocks falls down from the gap 8 onto the valve 7 and is further reconsumed.

[0076] The operation of the electrostatic precipitator 4B may be controlled by a control system (not shown in the figures). One of the functions of the control unit may be the switch-off of the supply of the electrostatic precipitator 4B with high voltage. This happens when the temperature of the exhaust gas flow reaches the corresponding values and the temperature sensor gives the corresponding signal to the control system. As the temperature sensor 29 in the proposed electrostatic precipitator 4B is installed in the particle-free or low particle concentration zone, the sensor is not loaded with soot, and the electrostatic precipitator 4B is switched on and off without time delay, thereby ensuring stable operation of the electrostatic precipitator 4B.

[0077] The electrostatic precipitator 4B, the apparatus 1 and the method for exhaust gas cleaning according to the present invention ensure an effective cleaning of exhaust gas from combustion. The electrostatic precipitator mean mass collection efficiency is 85 % and fractional collection efficiency is more than 90 %. These excellent numbers are achieved as the electrostatic precipitator 4B according to the present invention is installed inside of the output duct, and thus the outside surface of the electrostatic precipitator housing 21 is used as an additional collection electrode for fine particles. Furthermore, employing a catalytic coating extends the possibility for gas cleaning to the gaseous components and PAH in the exhaust gas.

[0078] Furthermore, stable operation for different combustion conditions is ensured, as the high voltage isolator 13 is installed in the hot gas flow and does not need any heating system against condensate of the moisture on the isolator surface. In addition, the developed surface of the high voltage isolator 13 increases the way for leakage currents and decreases the probability of surface short-currents, whereas the maintenance of the temperature sensor 29 in the particle free or low concentration zone improves the electrostatic precipitator control. As the electrostatic precipitator 4B is installed in the output gas duct 6, the electrostatic precipitator 4B according to the present invention does not need any thermo-isolation of the electrostatic precipitator housing 21. Moreover, the coating of the output duct with an isolation layer reduces the energy loss and minimizes the negative influence of the sound from the electrostatic precipitator 4B.

[0079] The apparatus 1 according to the present invention has an improved design compared to the apparatuses known in the prior art. The electrostatic precipitator according to the present invention has a robust ionizer and collector section, and has a reduced size in comparison with state-of-the-art electrostatic precipitators. In addition, the electrostatic precipitator is operated at low pressure drop, can easily be maintained, automatically cleaned, replaced and repaired. Furthermore, the design of the electrostatic precipitator as a tube-form module advantageously reduces the investment and maintenance costs of the apparatus.

[0080] The electrostatic precipitator according to the present invention is suitable for different wood and biomass combustion facilities, as it can be easily installed into the gas duct, which connects the combustion facility and the chimney. The electrostatic precipitator can further be maintained inside of a chimney and can be integrated into the combustion facility.

[0081] The "Clean-Closed-Combustion" method and apparatus according to the present invention ensures effective reconsumption of the collected soot. In Germany, the annual emission of fine particles (mainly soot) from wood and biomass combustion is about 24 000 tons. Accordingly, the use of the gas cleaning system according to the present invention with a collection efficiency of 85% allows to collect in the electrostatic precipitator about 20 000 tons of soot and the reconsumption (combustion) of the aerosol would allow to use the soot additionally as 20 000 tons of fuel for heat generation. Thus, the reconsumption of soot solves problems with respect to the disposal of collected aerosol and saves about 20 000 tons of wood which is burnt for heat generation.

Example:

[0082] The electrostatic precipitator according to the present invention was connected with the outlet of a wood-logs stove via the input duct and with a chimney via the output duct. The electrostatic precipitator was op-

erated under hot gas conditions. Every day, the combustion unit was in operation for about five to six hours. Under hot gas conditions, the mass collection efficiency varied from 10% up to 35% when the electrostatic precipitator was switched off. This value increased with increase of the difference between the temperature of the electrostatic precipitator housing and the temperature of the output duct. By switching on the high voltage unit (operation voltage and current U = 11 kV and I = 1 mA), the mass collection efficiency of the electrostatic precipitator increased up to a mean value of 85%. The fractional collection efficiency for particles with a mean size larger than 0.1 μm was over 90% and for particles larger than 1 μm almost 100%. The pressure drop in the electrostatic precipitator was below 10 Pa.

List of reference signs

[0083]

1	apparatus for combusting
1a	combustion appliance
2	combustion chamber
3	solid fuel feed device
3a	wood pellets
4	electrostatic precipitator
4A	filter device 4A
4B	electrostatic precipitator
5	input duct
6	output duct
7	valve
7a	outfall sewer
8	gap
9	ionizer
10	collector
11	plenum chamber
12	screen electrode
13	high voltage isolator 13
14	isolator housing 14
15	high voltage rod 15
15a	top end of high voltage rod 15
15b	bottom end of high voltage rod 15
16	high voltage corona discharge electrode
17	charging zone
18	brush
19	rotating device
20	plate
21	housing
22	ionizer
23	collector
24	cleaning device
25	axis of the brush 18
26	cleaning elements
27	fixing elements
28	supporting rod
29	temperature sensor
30	closed space
31	container
F1	first direction F1 of the gas flow
F2	second direction F2 of gas flow
V	valve actuator
M	driving device

Claims

1. A filter device (4A) for filtering fine particulate matter comprising particles with an aerodynamic diameter of less than about 10μm from exhaust gas comprising:

- an exhaust gas inlet (5);
- an exhaust gas outlet (6);
- an electrostatic precipitator device (4B) for removing the fine particle matter from the exhaust gas; and
- an outfall sewer (7a) with a particle discharge valve (7),

wherein, when the filter device is in use, the exhaust gas flowing from the exhaust gas inlet (5) to the exhaust gas outlet (6) passes the precipitator device along a first gas flow direction (F1), which is substantially vertically downwards,
wherein the electrostatic precipitator device (4B) is capable of at least partially removing fine particulate matter from the exhaust gas;
wherein the outfall sewer (7a) is configured to collect the removed fine particulate matter,
wherein the particle discharge valve (7) is configured to automatically discharge the collected fine particulate matter,
wherein the outfall sewer (7a) and/or the particle discharge valve (7) is spaced apart from the electrostatic precipitator device (4B) along the first gas flow direction (F1) so that fine particulate matter is transportable by means of gravity and/or by means of dragging with the exhaust gas flow along the first gas flow direction (F1) from the precipitator device to the outfall sewer (7a).

2. The filter device (4A) according to claim 1, wherein the electrostatic precipitator device (4B) comprises:

- an ionizer (22) for ionizing the exhaust gas flowing through the precipitator device in a charging zone (17);
- a collector (23), for collecting fine particulate matter from the ionized exhaust gas, wherein the collector (23) is spaced apart from the ionizer (22) along the first gas flow direction (F1); and
- a cleaning device (24) for removing fine particle matter adhering at the inner wall of a housing (21) of the electrostatic precipitator (4B) in the charging zone (17).

3. The filter device (4A) according to claim 2, wherein the ionizer (22) of the electrostatic precipitator device (4B) comprises:

-- a screen electrode (12),
-- a high voltage isolator (13),
-- a high voltage rod (15), having a top end (15a) which at least partially penetrates the high voltage isolator (13) and a bottom end (15b) comprising a high voltage corona discharge electrode (16), wherein the high voltage rod (15) is at least partially axially installed inside of the screen electrode (12).

4. The filter device (4A) according to claim 2 or 3, wherein the collector (23) of the electrostatic precipitator device (4B) has a cylindrical shape and wherein the cleaning device comprises:

-- a brush (18) which is rotatably arranged inside the cylindrical collector (23),
-- an operating device for rotating the brush (18), and
-- a plate for removing fine particulate matter from the brush (18).

5. The filter device (4A) according to any one of claims 2 to 4, wherein a supporting high voltage rod (28) electrically connects a high voltage source with the high voltage rod (15), wherein the supporting high voltage rod (28) at least partially penetrates the top end (15a) of the high voltage rod (15), and the axis of the supporting high voltage rod (28) and the axis of the high voltage rod (15) are orthogonal to each other.

6. The filter device (4A) according to any one of claims 2 to 5, wherein the high voltage isolator (13) comprises a temperature sensor (29).

7. The filter device (4A) according to any one of claims 2 to 6, wherein the screen electrode (12) has double-walls.

8. The filter device (4A) according to claim 7, wherein the temperature sensor (29) is located in a free space between the double-walls of the screen electrode (12).

9. The filter device (4A) according to any one of claims 2 to 8, wherein the electrostatic precipitator is at least partially catalytically coated.

10. The filter device (4A) according to any one of claims 2 to 9, wherein the electrostatic precipitator (4B) is installed inside of an output duct (6) with a gap (8) between a electrostatic precipitator housing (21) and the output duct (6).

11. The filter device (4A) according to claim 10, wherein, when the filter device is in use, a second direction (F2) of the exhaust gas flow in the gap 8 is opposite to the first direction (F1) of the exhaust gas flow.

12. The filter device (4A) according to claim 10 or 11, wherein the output duct (6) has a cross-section area S_1 and the electrostatic precipitator housing (21) has a cross-section area S_2, wherein the equation $S_2 \leq S_1/2$ is fulfilled.

13. An apparatus (1) for combusting solid combustionable matter comprising:

- a combustion chamber (2);
- a filter device (4A) according to any one of claims 1 to 12,
wherein the exhaust gas inlet (5) of the filter device (4A) is fluidly connected to the combustion chamber (2) via an exhaust gas duct (6);
wherein the particle discharge valve (7) of the filter device (4A) is fluidly connected to the combustion chamber (2) or
wherein the particle discharge valve (7) of the filter device (4A) is fluidly connected to a feeding device (3) for feeding the combustion chamber (2) with the solid combustionable matter (3a).

14. The apparatus (1) according to claim 13, wherein connection of the particle discharge valve (7) to the combustion chamber (2) or to the feeding device (3) is provided by means of a fine particle discharge duct, which substantially extends along the vertical direction.

15. A method for combusting solid combustionable matter comprising the steps of:

- feeding a solid combustionable matter (3a) by means of a feeding device into a combustion chamber (2);
- combusting the solid combustionable matter (3a) thereby generating exhaust gas;
- leading the exhaust gas to a filter device (4A) according to any one of the claims 1 to 10;
- removing fine particulate matter from the exhaust gas by means of the filter device (4A);
- periodically discharging the removed fine particulate matter into the feeding device (3);
- mixing the removed fine particulate matter with the solid combustionable matter (3a);
- feeding the mixture into the combustion chamber (2); and
- combusting the mixture of removed fine particulate matter and the solid combustionable matter (3a) in the combustion chamber (2).

Patentansprüche

1. Filtervorrichtung (4A) zum Filtern eines feinen teilchenförmigen Materials, das Teilchen mit einem aerodynamischen Durchmesser von weniger als etwa 10 μm umfasst, aus einem Abgas, umfassend:

   - einen Abgaseinlass (5),
   - einen Abgasauslass (6),
   - eine elektrostatische Abscheidungsvorrichtung (4B) zum Entfernen des feinen teilchenförmigen Materials aus dem Abgas und
   - einen Transportkanal (7a) mit einem Teilchenaustragventil (7),

   wobei, wenn die Filtervorrichtung verwendet wird, das Abgas, das von dem Abgaseinlass (5) zu dem Abgasauslass (6) strömt, entlang einer ersten Gasströmungsrichtung (F1), die im Wesentlichen vertikal abwärts ist, an der Abscheidungsvorrichtung vorbeiströmt,
   wobei die elektrostatische Abscheidungsvorrichtung (4B) das feine teilchenförmige Material zumindest teilweise aus dem Abgas entfernen kann,
   wobei der Transportkanal (7a) zum Sammeln des entfernten feinen teilchenförmigen Materials ausgebildet ist,
   wobei das Teilchenaustragventil (7) zum automatischen Austragen des gesammelten feinen teilchenförmigen Materials ausgebildet ist,
   wobei der Transportkanal (7a) und/oder das Teilchenaustragventil (7) entlang der ersten Gasströmungsrichtung (F1) von der elektrostatischen Abscheidungsvorrichtung (4B) beabstandet ist oder sind, so dass das feine teilchenförmige Material mittels der Schwerkraft und/oder mittels eines Mitreißens mit dem Abgasstrom entlang der ersten Gasströmungsrichtung (F1) von der Abscheidungsvorrichtung zu dem Transportkanal (7a) transportiert werden kann.

2. Filtervorrichtung (4A) nach Anspruch 1, wobei die elektrostatische Abscheidungsvorrichtung (4B) umfasst:

   - eine Ionisiereinrichtung (22) zum Ionisieren des Abgases, das durch die Abscheidungsvorrichtung strömt, in einer Aufladungszone (17),
   - eine Sammeleinrichtung (23) zum Sammeln des feinen teilchenförmigen Materials von dem ionisierten Abgas, wobei die Sammeleinrichtung (23) entlang der ersten Gasströmungsrichtung (F1) von der Ionisiereinrichtung (22) beabstandet ist, und
   - eine Reinigungsvorrichtung (24) zum Entfernen des feinen teilchenförmigen Materials, das an der Innenwand eines Gehäuses (21) der elektrostatischen Abscheidungsvorrichtung (4B) in der Aufladungszone (17) anhaftet.

3. Filtervorrichtung (4A) nach Anspruch 2, wobei die Ionisiereinrichtung (22) der elektrostatischen Abscheidungsvorrichtung (4B) umfasst:

   - eine Siebelektrode (12),
   - einen Hochspannungsisolator (13),
   - einen Hochspannungsstab (15), der ein oberes Ende (15a), das zumindest teilweise den Hochspannungsisolator (13) durchdringt, und ein unteres Ende (15b) aufweist, das eine Hochspannungskoronaentladungselektrode (16) umfasst, wobei der Hochspannungsstab (15) zumindest teilweise axial innerhalb der Siebelektrode (12) installiert ist.

4. Filtervorrichtung (4A) nach Anspruch 2 oder 3, wobei die Sammeleinrichtung (23) der elektrostatischen Abscheidungsvorrichtung (4B) eine zylindrische Form aufweist und wobei die Reinigungsvorrichtung umfasst:

   - eine Bürste (18), die drehbar innerhalb der zylindrischen Sammeleinrichtung (23) angeordnet ist,
   - eine Betätigungsvorrichtung zum Drehen der Bürste (18) und
   - eine Platte zum Entfernen von feinem teilchenförmigen Material von der Bürste (18).

5. Filtervorrichtung (4A) nach einem der Ansprüche 2 bis 4, wobei ein Hochspannungsträgerstab (28) eine Hochspannungsquelle elektrisch mit dem Hochspannungsstab (15) verbindet, wobei der Hochspannungsträgerstab (28) zumindest teilweise das obere Ende (15a) des Hochspannungsstabs (15) durchdringt und die Achse des Hochspannungsträgerstabs (28) und die Achse des Hochspannungsstabs (15) orthogonal zueinander sind.

6. Filtervorrichtung (4A) nach einem der Ansprüche 2 bis 5, wobei der Hochspannungsisolator (13) einen Temperatursensor (29) umfasst.

7. Filtervorrichtung (4A) nach einem der Ansprüche 2 bis 6, wobei die Siebelektrode (12) Doppelwände aufweist.

8. Filtervorrichtung (4A) nach Anspruch 7, wobei sich der Temperatursensor (29) in einem freien Raum zwischen den Doppelwänden der Siebelektrode (12) befindet.

9. Filtervorrichtung (4A) nach einem der Ansprüche 2 bis 8, wobei die elektrostatische Abscheidungsvorrichtung zumindest teilweise katalytisch beschichtet

ist.

10. Filtervorrichtung (4A) nach einem der Ansprüche 2 bis 9, wobei die elektrostatische Abscheidungsvorrichtung (4B) innerhalb eines Abgabekanals (6) mit einem Spalt (8) zwischen einem Gehäuse (21) der elektrostatischen Abscheidungsvorrichtung und dem Abgabekanal (6) installiert ist.

11. Filtervorrichtung (4A) nach Anspruch 10, wobei, wenn die Filtervorrichtung verwendet wird, eine zweite Richtung (F2) des Abgasstroms in dem Spalt (8) entgegengesetzt zu der ersten Richtung (F1) des Abgasstroms ist.

12. Filtervorrichtung (4A) nach Anspruch 10 oder 11, wobei der Abgabekanal (6) eine Querschnittsfläche S_1 aufweist und das Gehäuse (21) der elektrostatischen Abscheidungsvorrichtung eine Querschnittsfläche S_2 aufweist, wobei die Gleichung $S_2 \leq S_1/2$ erfüllt ist.

13. Vorrichtung (1) zum Verbrennen eines festen brennbaren Materials, umfassend:

- eine Brennkammer (2),
- eine Filtervorrichtung (4A) nach einem der Ansprüche 1 bis 12,

wobei der Abgaseinlass (5) der Filtervorrichtung (4A) über einen Abgaskanal (6) fluidmäßig mit der Brennkammer (2) verbunden ist,
wobei das Teilchenaustragventil (7) der Filtervorrichtung (4A) fluidmäßig mit der Brennkammer (2) verbunden ist oder
wobei das Teilchenaustragventil (7) der Filtervorrichtung (4A) fluidmäßig mit einer Zuführungsvorrichtung (3) zum Zuführen des festen brennbaren Materials (3a) zu der Brennkammer (2) verbunden ist.

14. Vorrichtung (1) nach Anspruch 13, wobei die Verbindung des Teilchenaustragventils (7) mit der Brennkammer (2) oder mit der Zuführungsvorrichtung (3) mittels eines Austragkanals für feine Teilchen bereitgestellt wird, der sich im Wesentlichen entlang der vertikalen Richtung erstreckt.

15. Verfahren zum Verbrennen eines festen brennbaren Materials, umfassend die Schritte des:

- Zuführens eines festen brennbaren Materials (3a) mittels einer Zuführungsvorrichtung in eine Brennkammer (2),
- Verbrennens des festen brennbaren Materials (3a), wodurch ein Abgas erzeugt wird,
- Leitens des Abgases zu einer Filtervorrichtung (4A) nach einem der Ansprüche 1 bis 10,
- Entfernens von feinem teilchenförmigen Material aus dem Abgas mittels der Filtervorrichtung (4A),
- periodischen Austragens des entfernten feinen teilchenförmigen Materials in die Zuführungsvorrichtung (3),
- Mischens des entfernten feinen teilchenförmigen Materials mit dem festen brennbaren Material (3a),
- Zuführens des Gemischs in die Brennkammer (2) und
- Verbrennens des Gemischs aus dem entfernten feinen teilchenförmigen Material und dem festen brennbaren Material (3a) in der Brennkammer (2).

Revendications

1. Dispositif de filtrage (4A) destiné à filtrer de la matière particulaire fine comprenant des particules présentant un diamètre aérodynamique inférieur à 10 μm environ à partir de gaz d'échappement comprenant :

- une entrée de gaz d'échappement (5) ;
- une sortie de gaz d'échappement (6) ;
- un dispositif de précipitation électrostatique (4B) destiné à éliminer la matière particulaire fine du gaz d'échappement ; et
- un collecteur d'évacuation (7a) avec une vanne de déchargement de particules (7),

dans lequel, lorsque le dispositif de filtrage est utilisé, le gaz d'échappement circulant de l'entrée de gaz d'échappement (5) vers la sortie de gaz d'échappement (6) passe par le dispositif de précipitation suivant une première direction d'écoulement de gaz (F1), qui est orientée sensiblement verticalement vers le bas,
dans lequel le dispositif de précipitation électrostatique (4B) est capable de retirer au moins partiellement la matière particulaire fine du gaz d'échappement ;
dans lequel le collecteur d'évacuation (7a) est configuré de manière à collecter la matière particulaire fine retirée,
dans lequel la vanne de déchargement de particules (7) est configurée de manière à décharger automatiquement la matière particulaire fine collectée,
dans lequel le collecteur d'évacuation (7a) et/ou la vanne de déchargement de particules (7) est espacé par rapport au dispositif de précipitation électrostatique (4B) suivant la première direction d'écoulement de gaz (F1) de telle sorte que la matière particulaire fine peut être transportée au moyen de la gravité et/ou par entraînement par le courant de gaz d'échappement suivant la première direction d'écoulement de gaz (F1) depuis le dispositif de précipitation vers le collecteur d'évacuation (7a).

2. Dispositif de filtrage (4A) selon la revendication 1, dans lequel le dispositif de précipitation électrostatique (4B) comprend :

- un ionisateur (22) destiné à ioniser le gaz d'échappement circulant à travers le dispositif de précipitation dans une zone de chargement (17) ;
- un collecteur (23), destiné à collecter la matière particulaire fine à partir du gaz d'échappement ionisé, dans lequel le collecteur (23) est séparé de l'élément d'ionisation (22) suivant une première direction d'écoulement de gaz (F1) ; et
- un dispositif de nettoyage (24) destiné à éliminer la matière particulaire fine adhérant sur la paroi interne d'un logement (21) du dispositif de précipitation électrostatique (4B) dans la zone de chargement (17).

3. Dispositif de filtrage (4A) selon la revendication 2, dans lequel l'élément d'ionisation (22) du dispositif de précipitation électrostatique (4B) comprend :

- une électrode formant écran (12),
- un isolateur à haute tension (13),
- une tige à haute tension (15), comportant une extrémité supérieure (15a) qui pénètre au moins partiellement dans l'isolateur à haute tension (13) et une extrémité inférieure (15b) comprenant une électrode de décharge corona à haute tension (16), dans lequel la tige à haute tension (15) est au moins partiellement installée axialement à l'intérieur de l'électrode formant écran (12).

4. Dispositif de filtrage (4A) selon la revendication 2 ou 3, dans lequel le collecteur (23) du dispositif de précipitation électrostatique (4B) présente une forme cylindrique et dans lequel le dispositif de nettoyage comprend :

- une brosse (18) qui est agencée de manière à pouvoir tourner à l'intérieur du collecteur cylindrique (23),
- un dispositif d'entraînement destiné à faire tourner la brosse (18), et
- une plaque destinée à éliminer la matière particulaire fine de la brosse (18).

5. Dispositif de filtrage (4A) selon l'une quelconque des revendications 2 à 4, dans lequel une tige de support à haute tension (28) est reliée électriquement à une source de haute tension par la tige à haute tension (15), dans lequel la tige de support à haute tension (28) pénètre au moins partiellement l'extrémité supérieure (15a) de la tige à haute tension (15), et l'axe de la tige de support à haute tension (28) et l'axe de la tige à haute tension (15) sont orthogonaux l'un par rapport à l'autre.

6. Dispositif de filtrage (4A) selon l'une quelconque des revendications 2 à 5, dans lequel l'isolateur à haute tension (13) comprend un capteur de température (29).

7. Dispositif de filtrage (4A) selon l'une quelconque des revendications 2 à 6, dans lequel l'électrode formant écran (12) comporte des doubles parois.

8. Dispositif de filtrage (4A) selon la revendication 7, dans lequel le capteur de température (29) est situé dans un espace libre entre les doubles parois de l'électrode formant écran (12).

9. Dispositif de filtrage (4A) selon l'une quelconque des revendications 2 à 8, dans lequel le dispositif de précipitation électrostatique est au moins partiellement revêtu catalytiquement.

10. Dispositif de filtrage (4A) selon l'une quelconque des revendications 2 à 9, dans lequel le dispositif de précipitation électrostatique (4B) est installé à l'intérieur d'un conduit de sortie (6) avec un jeu (8) entre le logement de dispositif de précipitation électrostatique (21) et le conduit de sortie (6).

11. Dispositif de filtrage (4A) selon la revendication 10, dans lequel, lorsque le dispositif de filtrage est utilisé, une seconde direction (F2) de l'écoulement de gaz d'échappement dans le jeu (8) est opposée à la première direction (F1) de l'écoulement de gaz d'échappement.

12. Dispositif de filtrage (4A) selon la revendication 10 ou 11, dans lequel le conduit de sortie (6) présente une aire de section transversale S1 et le logement de dispositif de précipitation électrostatique (21) présente une aire de section transversale S2, dans lequel l'équation $S2 \leq S1/2$ est satisfaite.

13. Dispositif (1) destiné à assurer la combustion de matière combustible solide comprenant :

- une chambre de combustion (2) ;
- un dispositif de filtrage (4A) selon l'une quelconque des revendications 1 à 12,

dans lequel l'entrée de gaz d'échappement (5) du dispositif de filtrage (4A) est raccordée de manière fluidique à la chambre de combustion (2) par l'intermédiaire d'un conduit de gaz d'échappement (6) ;
dans lequel la vanne de déchargement de particules (7) du dispositif de filtrage (4A) est raccordée de manière fluidique à la chambre de combustion (2) ou
dans lequel la vanne de déchargement de par-

ticules (7) du dispositif de filtrage (4A) est raccordée de manière fluidique à un dispositif d'alimentation (3) afin d'assurer l'alimentation de la chambre de combustion (2) par la matière combustible solide (3a).

14. Dispositif (1) selon la revendication 13, dans lequel le raccordement de la vanne de déchargement de particules (7) à la chambre de combustion (2) ou au dispositif d'alimentation (3) est assuré au moyen d'un conduit de déchargement de particules fines, qui s'étend sensiblement suivant la direction verticale.

15. Procédé de combustion de matière combustible solide comprenant les étapes de :

- introduction d'une matière combustible solide (3a) au moyen d'un dispositif d'alimentation dans une chambre de combustion (2) ;
- combustion de la matière combustible solide (3a) produisant ainsi un gaz d'échappement ;
- acheminement du gaz d'échappement vers un dispositif de filtrage (4A) selon l'une quelconque des revendications 1 à 10 ;
- élimination de la matière particulaire fine du gaz d'échappement au moyen du dispositif de filtrage (4A) ;
- déchargement périodique de la matière particulaire fine retirée dans le dispositif d'alimentation (3) ;
- mélange de la matière particulaire fine retirée avec la matière combustible solide (3a) ;
- introduction du mélange dans la chambre de combustion (2) ; et
- combustion du mélange de la matière particulaire fine retirée et de la matière combustible solide (3a) dans la chambre de combustion (2).

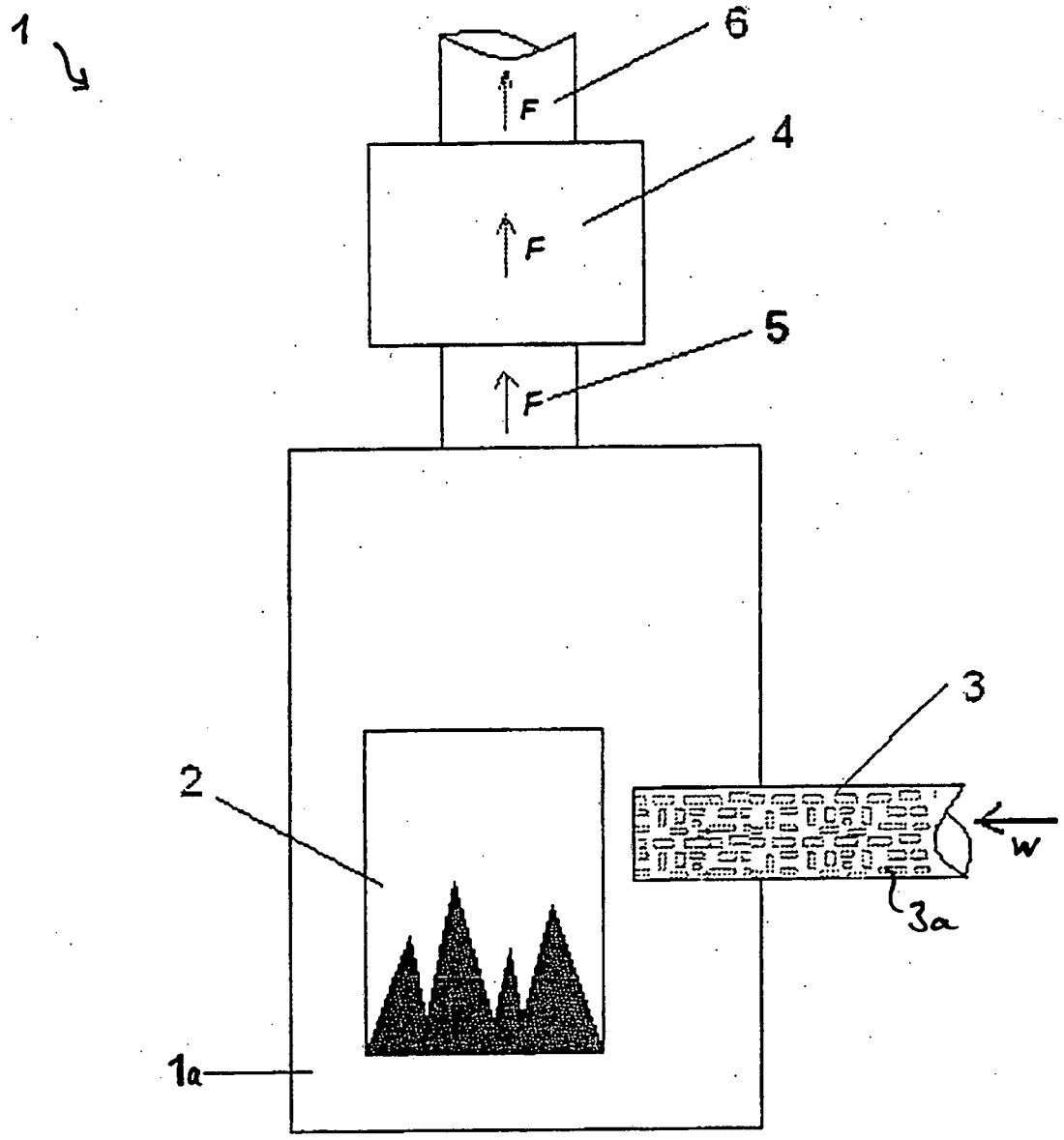


Fig.1

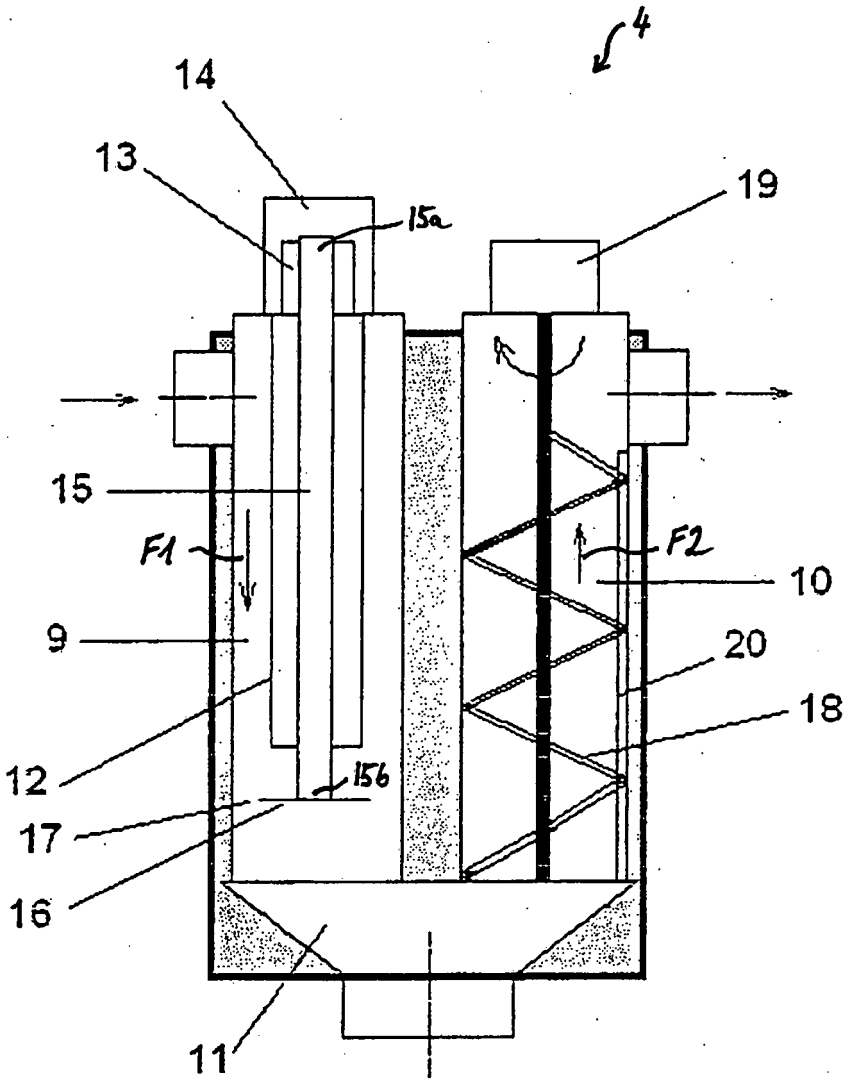


Fig.2

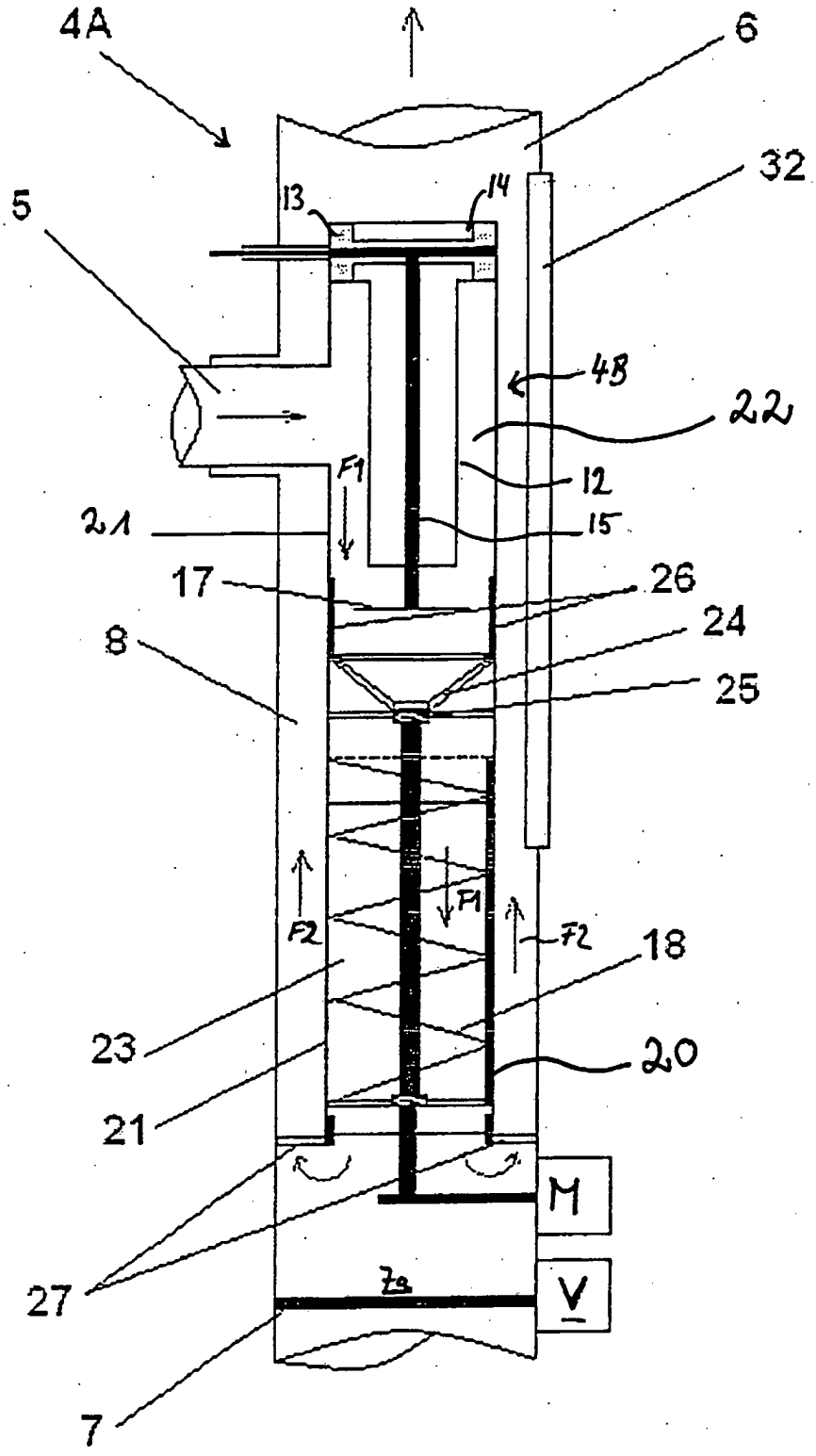

4A
6
32
5
13
14
48
22
F1
12
21
15
17
26
24
8
25
F2
F1
F2
18
23
20
21
M
27
V
7

Fig. 3

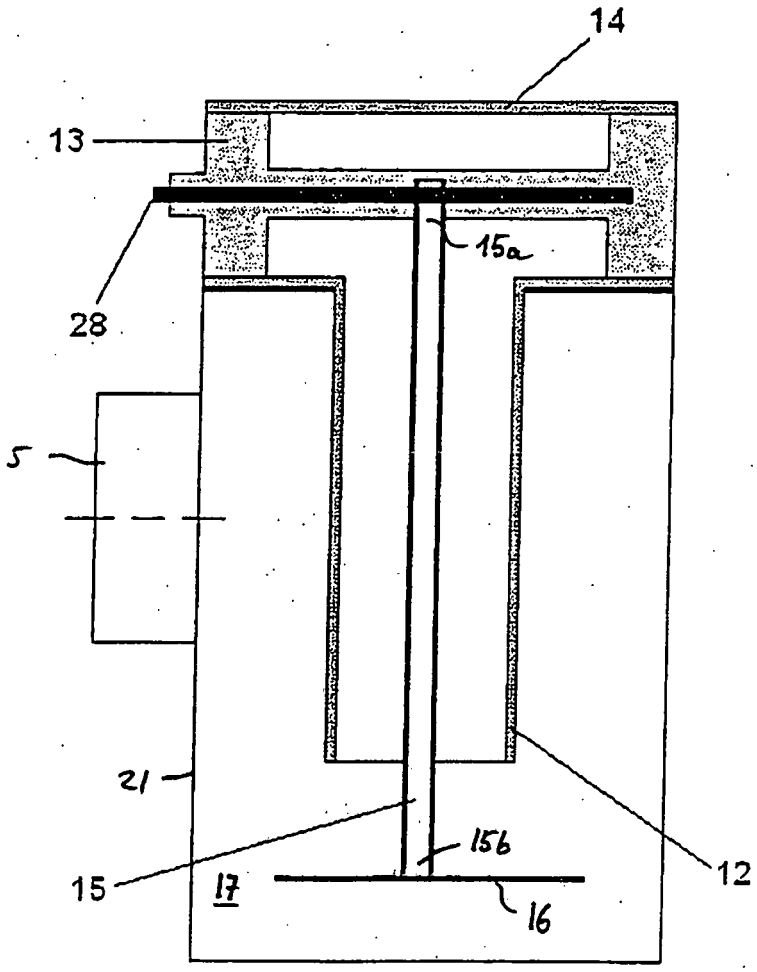


Fig. 4

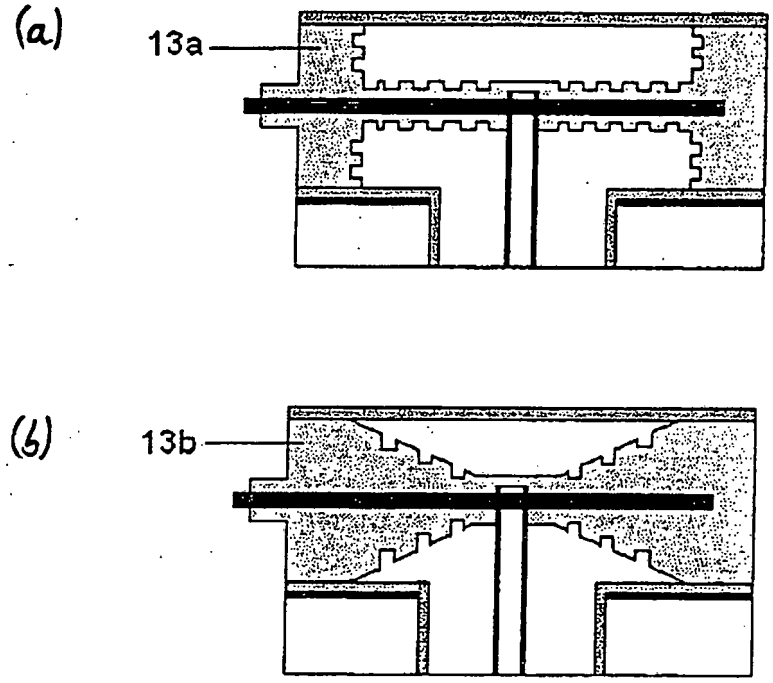


Fig. 5

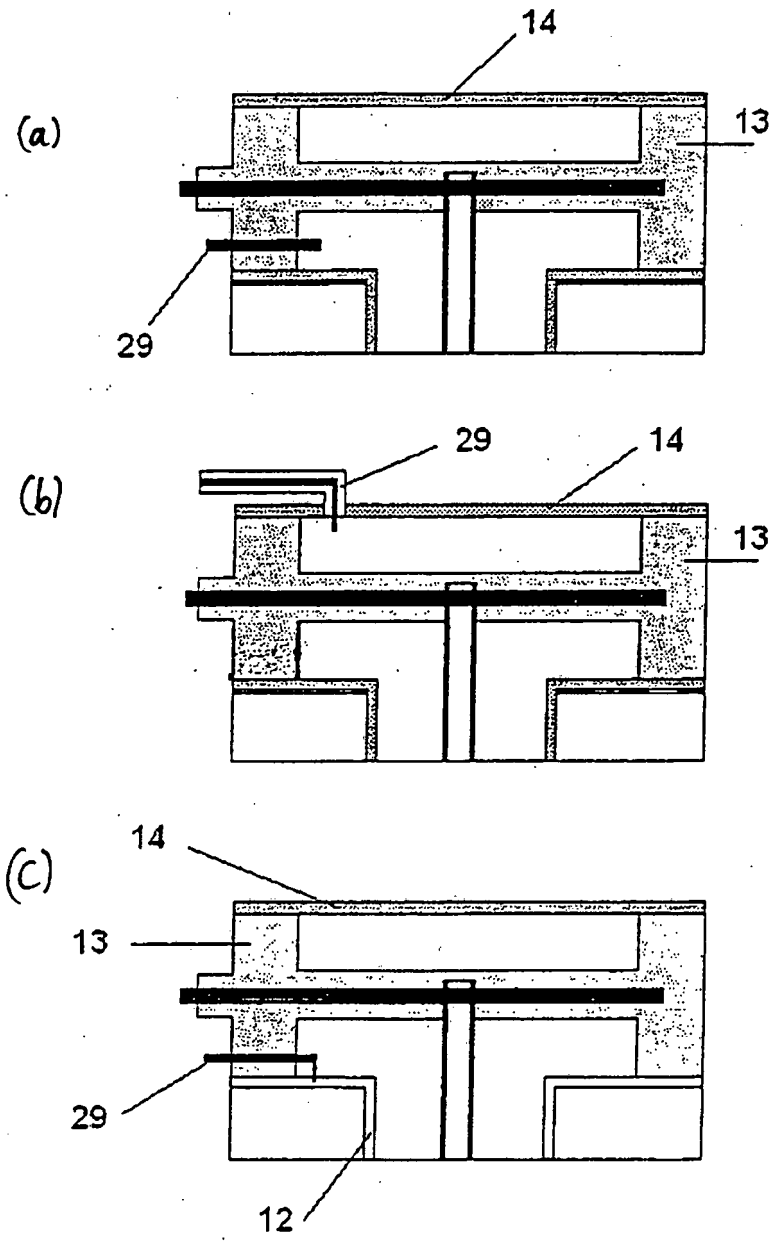


Fig. 6

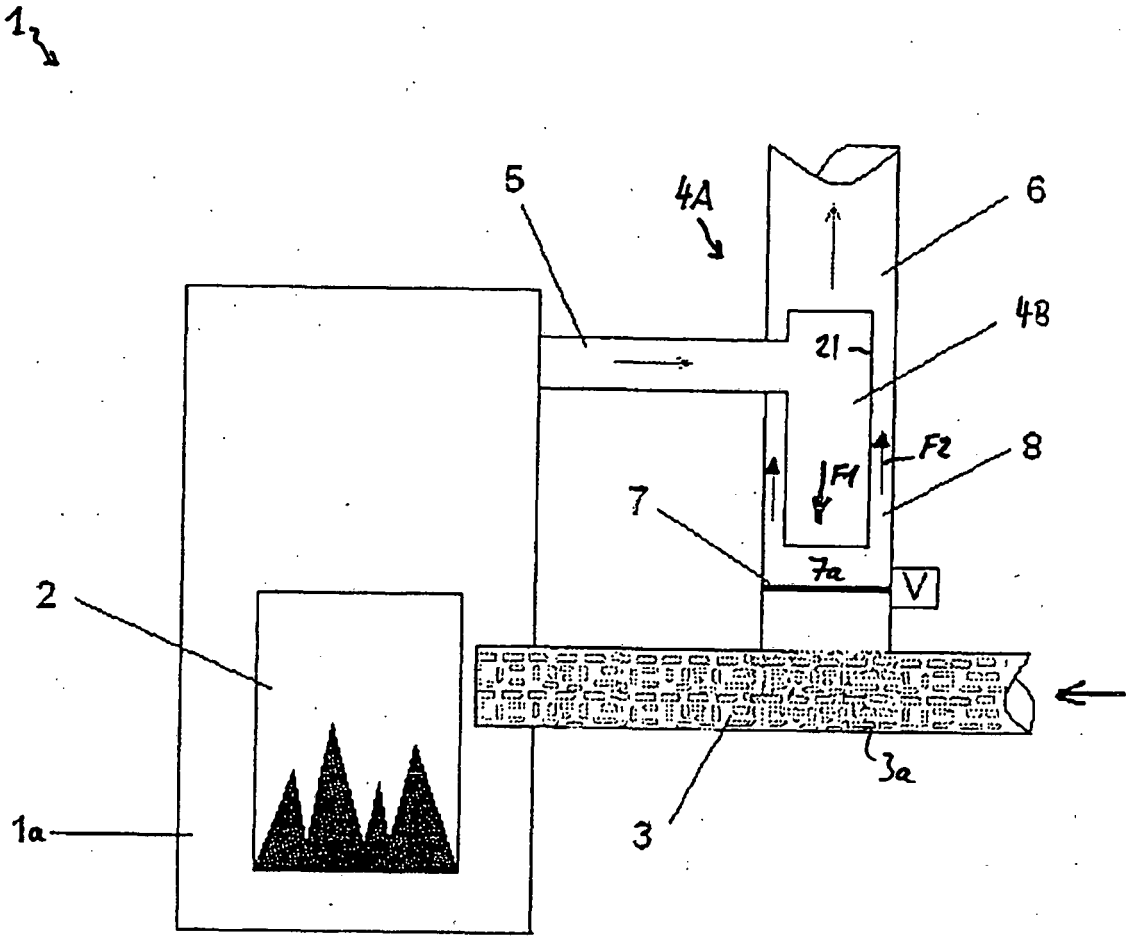


fig. 7

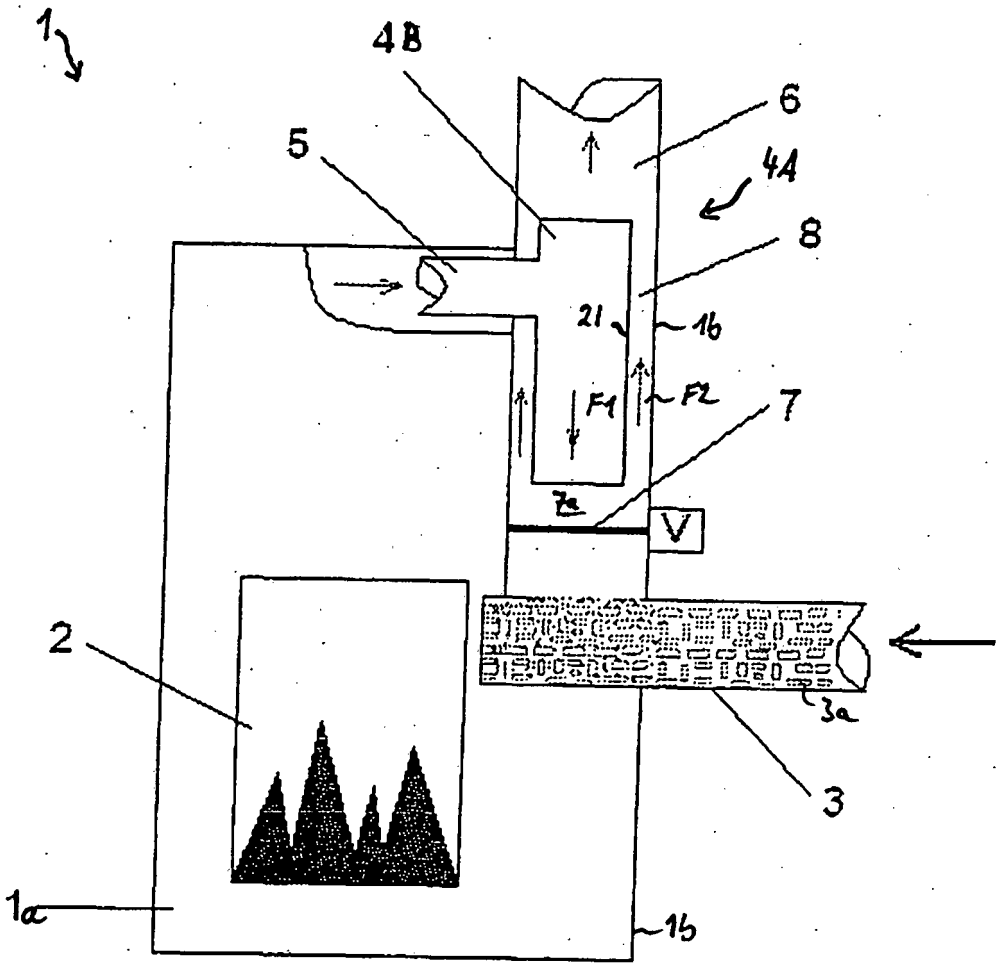


Fig. 8

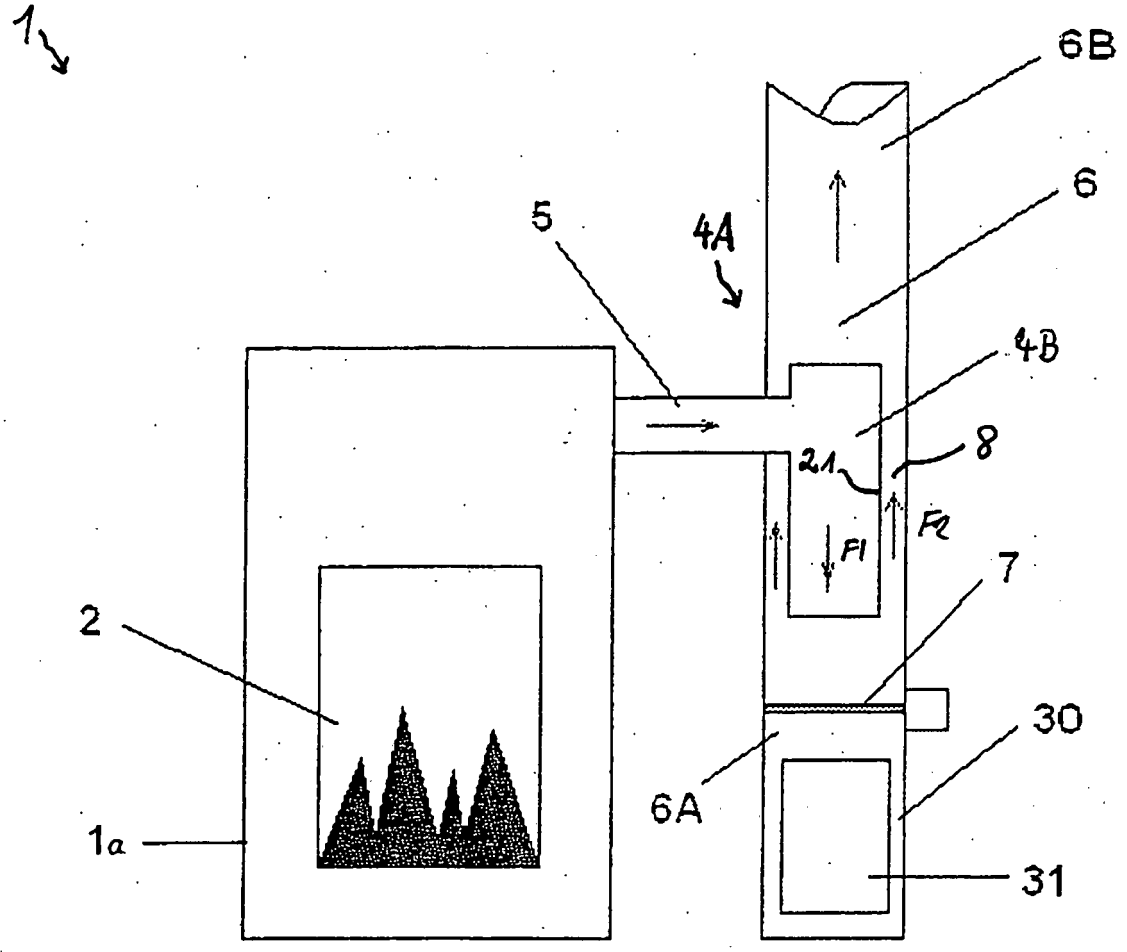


Fig. 9

REFERENCES CITED IN THE DESCRIPTION

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