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- (54) **Title:** A METHOD AND APPARATUS FOR REMOVING CONTAMINANTS FROM PARTICULATE MATERIAL

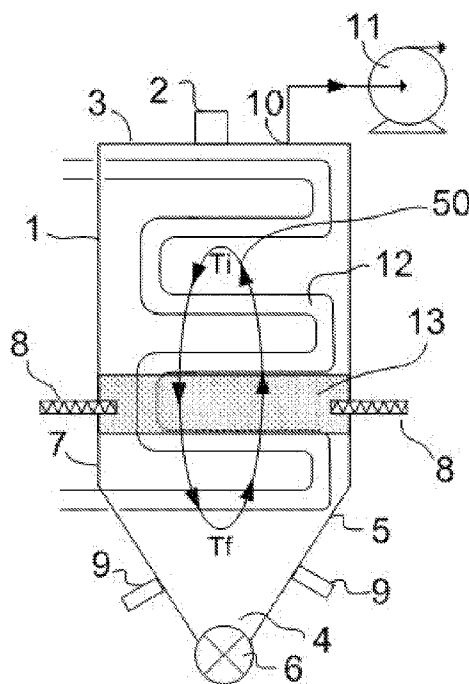


Fig. 1

(57) **Abstract:** Described is a method as well as an apparatus for removing vaporizable contaminants from a particulate material, by which method the contaminants are inhibited from escaping the compartment at the second end together with the particulate material and transporting the vaporized contaminants towards the first end together with the venting gas, said venting gas acting as a carrier gas, condensing contaminants onto said particulate material in a condensing temperature region having temperatures higher than the initial temperature but lower than the vaporizing temperature such that the contaminants are inhibited from escaping the compartment at the first end together with the venting gas such that said contaminants are continuously vaporized and condensed in an internal vaporization-condensation cycle in the compartment thereby gradually accumulating the contaminants in the compartment. The invention also relates to an apparatus for carrying out the method and the use of such apparatus.

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A METHOD AND APPARATUS FOR REMOVING CONTAMINANTS FROM PARTICULATE MATERIAL

5 The present invention relates to a method as well as an apparatus for removing vaporizable contaminants from a particulate material. The invention also relates to an apparatus for carrying out the method and the use of such apparatus.

10 Non-limiting examples of vaporizable contaminants include mercury, mercury compounds, volatile organic compounds, heavy metals, salts of ammonia and alkali chlorides. There is an increasing level of awareness concerning the emission of mercury and other contaminants from industrial plants, such as cement manufacturing plants. However, also in other situation where particulate material, such as soil and fly ash from power plants has been contaminated by vaporizable matter, there may be a need for removing these.

15 A method of the above mentioned kind is known from US 8,133,303. This known method involves removal of the vaporized mercury in a gas flow, cooling of said gas flow to condense the mercury, absorbing the condensed mercury on carbon particles and removing by filtering the mercury laden carbon particles from said gas. One major disadvantage of this method is that it requires several process steps and corresponding equipment, hence being relatively complex and expensive. Further, the spent carbon particles laden with mercury pollutants have either to be deposited as hazardous waste or to be cleaned in an additional process.

25 It is the object of the present invention to provide a method as well as an apparatus for removing vaporizable contaminants from a particulate material by which the aforementioned disadvantages are remedied or significantly reduced.

30 According to the present invention this is obtained by a method of the kind mentioned in the introduction, wherein vaporizable contaminants are condensed onto particulate material in a condensing temperature region at a first end of a compartment and transported together with the particulate material towards a

second end, and wherein the vaporizable contaminants from the particulate material are vaporized in a vaporizing temperature region at the second end and transported towards the first end with a venting gas such that the continuous vaporizing and condensing of said contaminants constitutes an internal
5 vaporization-condensation cycle in the compartment such that contaminants are accumulated in the compartment.

Hereby is obtained a method by which the content of vaporizable contaminants in the particulate material that is discharged from the compartment is lowered
10 relative to the content of vaporizable contaminants in the particulate material that is introduced into the compartment. This is due to the fact that vaporizable contaminants when heated will begin to vaporize and that vaporized contaminants due the counter-current flow of the venting gas will move towards colder areas of the compartment, i.e. in direction opposite to the direction of
15 movement of the particulate material, where said contaminants will condensate on colder particulate material. Hence, in this way, the concentration of vaporizable contaminants in the particulate material in the compartment will continuously increase and accumulate in the compartment. It is thus possible to increase the concentration of the vaporizable contaminants on a smaller fraction
20 of the particulate material.

The particulate material may in principle be transported through the compartment from the inlet to the outlet in any appropriate manner, such as by gravity as in a vertical hopper or by mechanical means as in a screw conveyor or a rotating
25 drum. In order to reduce the extent of moving parts and to provide an optimum bulk density and optimum contact between solids and gas of the particulate material to be treated it is preferred that the particulate material is transported through the compartment from the inlet to the outlet by gravity.

30 The heating of the particulate material may in principle be accomplished in any appropriate way. In a simple embodiment the heating may be effected by means of a simple heat source, such as a hotplate or a burner. However, in a preferred embodiment the heating of the particulate material is done by conducting a

heating medium through a number of conducting means, such as tubes or plates, arranged within the compartment in counter-current to the direction of transportation of the particulate material. In this way exhaust gases or other hot gases from a process plant may be used as heating medium.

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The method according to the invention may be exploited in various ways in terms of inter alia temperature, pressure and residence time depending on what contaminants are required to be removed and in what amounts. Thus, for example in some situations a substantial complete removal of vaporizable contaminants from the particulate material being discharged from the compartment is required, which would require a heating of the particulate material to a temperature above the boiling point of the vaporizable contaminants in question, whereas in other situations a partial removal and thus a lower temperature and/or residence time inside the compartment is sufficient. This would appear more clearly from the following.

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The concentration of vaporizable contaminants in the particulate material in the compartment continuously increases during operation of the apparatus. This means that at some point in time the concentration of vaporizable contaminants in the compartment will reach an upper limit, at which continued operation is no longer possible, if nothing is done. Thus, in one aspect of the invention, when at the latest said point in time is reached, the compartment mainly containing particulate material being substantially saturated with contaminants may simply be dismantled and replaced with a new or it may be at least partly emptied for material and reused.

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In another aspect of the invention a portion of the particulate material, in that part of the compartment, where the particulate material moves in direction towards an area, where a higher temperature prevails, may at least intermittently be extracted from the compartment. In this way the concentration of vaporizable contaminants may at least intermittently be reduced, thus allowing continued operation. In this aspect of the invention, it is required that the thus extracted particulate material over a given period of time has an higher average

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concentration than the particulate material being fed to the compartment during the same period of time. It is preferred that the particulate material is extracted from the compartment as close as possible to where the concentration of vaporizable contaminants in the particulate material is highest. In this way the
5 extracted vaporizable contaminants may be contained in as little amount of particulate material as possible, which would be advantageous if the material must be deposited.

A carrier or venting gas may be introduced into the compartment at one or more
10 locations and vented at one or more locations where the temperature in the compartment is lower. The vented gas may be reused as carrier gas or vented to the atmosphere. It is of course of importance that the flow of such carrier gas is sufficient to carry the vaporized contaminants to colder areas of the compartment, but not so high that contaminants are carried out of the
15 compartment, especially if the vented carrier gas is vented to the atmosphere.

As a non-limiting example, the cement manufacturing industry may be mentioned as an industry where the method according to the invention with great advantage may be used. Thus, in the cement manufacturing industry vaporizable
20 contaminants such as e.g. mercury may be found both in the raw materials and the fuels used in the cement production. Due to its low boiling point and high vapor pressure mercury normally leaves the preheater in vaporized form with the exhaust gases. When the raw mill is in operation, the majority of the mercury condenses on the raw meal in the mill resulting in that it is recycled to the
25 preheater together with the raw meal, thus creating a mercury loop between the preheater and the raw mill with increasing mercury concentration. Also the cement kiln dust, which is captured in a filter installation, filtering the outlet gas from the raw mill and the exhaust gases from the preheater, is under normal operation returned to the preheater, thus also contributing to the recirculation of
30 mercury. As the accumulation of circulating mercury cannot go on forever, a portion of the mercury corresponding to the amount introduced into the process with the raw materials and fuel must more or less continuously be removed. A common way to accomplish this is to extract a portion of the cement kiln dust

from the filter installation. Said extracted portion may either be deposited or added to the finish cement. In both situations it is of great advantage if the mercury concentration is as high as possible, hence as little amount of cement kiln filter dust as possible has to be deposited or added to the finish cement and
5 a decreased loss of raw materials is thus achieved. Thus, in a preferred embodiment of the invention the particulate material, which is introduced into the compartment, is cement kiln dust, which preferably is extracted from a filter installation, which is filtering the outlet gas from a raw mill and/or the exhaust gases from a preheater of a cement manufacturing plant. In this way the amount
10 of cement kiln dust, which has to be deposited or added to the finish cement, may be reduced, thus increasing the amount of cement kiln dust, which may be returned to the cement manufacturing process.

In cases where the particulate material is cement kiln dust, said dust may be
15 heated to any required temperature to obtain an acceptable content of vaporizable contaminants in the cement kiln dust which is discharged from the compartment and returned to the cement manufacturing process. However, should it for some reason be required that the cement kiln dust being discharged from the compartment and returned to the cement manufacturing process is
20 substantially free of mercury it is preferred that the cement kiln dust is heated to a temperature where the vapor pressure is sufficient to ensure that all the contained mercury is driven off. In this way, the amount of mercury laden cement kiln dust, which is to be deposited or added to the finish cement, may correspondingly be as little as possible in cases where it is at least intermittently
25 extracted from the compartment as close as possible to where the concentration of vaporizable contaminants in the cement kiln dust is highest. However, as the cement kiln dust may contain several different mercury compounds having different vapor pressure properties, the optimum temperature in terms of mercury removal and operating costs to which the cement kiln dust should be heated
30 depends on which mercury compounds are contained in the dust and in what amounts.

Removal of contaminants from fly ash from a power plants and/or waste incineration plants are another examples of use of the method according to the present invention, thus, in another embodiment of the invention, the particulate material, which is introduced into the compartment, is fly ash.

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In cases where the compartment is operated until it cannot contain more vaporizable contaminants, as described above with reference to aspect one, and then being dismounted and replaced with a new or at least partly emptied for cement kiln dust and reused, the amount of mercury laden cement kiln dust, which is to be deposited or added to the finish cement will always be as little as possible. Thus, this mode of operation would probably be the preferred, especially if the price of a new compartment is relatively low.

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The apparatus for carrying out the method for removing vaporizable contaminants from a particulate material comprises a compartment having a material inlet and a material outlet, means for transporting the particulate material through the compartment and means for heating the particulate material, and being characterized in that the heating means is of the counter-current kind ensuring that the particulate material over at least a part of its transportation through the compartment moves in direction towards an area, where a higher temperature prevails.

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It is preferred that the compartment is part of a vertical hopper, because the particulate material in a vertical hopper is transported through the vertical hopper from the inlet to the outlet by gravity.

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It is preferred that the compartment comprises a number of conducting means, such as tubes or plates, arranged within the compartment for conducting a heating medium in counter-current to the direction of transportation of the particulate material.

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Further, the compartment may comprise extracting means arranged in that part of the compartment, where the particulate material moves in direction towards an

area, where a higher temperature prevails for extracting a portion of the particulate material. It is preferred that such extracting means are arranged as close as possible to where the concentration of vaporizable contaminants in the particulate material is highest.

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In addition, the compartment may comprise means for introducing a carrier gas into the compartment and means for venting said carrier gas out of the compartment.

10 The present invention also includes use of an indirect counter-current heat exchanger for removing vaporizable contaminants from a particulate material, where the particulate material over at least a part of its transportation through the heat exchanger moves in direction towards an area, where a higher temperature prevails.

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The invention will now be explained in further details with reference to the drawing, being diagrammatical, and with its only figure showing an apparatus according to the invention.

20 Fig. 1 is a schematic view of an apparatus according to the invention. The apparatus comprises a compartment 1 here being the compartment of a vertical hopper having a material inlet 2 in a first end 3 of the compartment 1 for introducing particulate material into the compartment 1 and a material outlet 4 in a second end 5, which material outlet 4 may be provided in the form of a rotary
25 feeder 6, which is operable to control the velocity of movement of the particulate material through the compartment 1. The apparatus also comprises means for heating 12, said means for heating 12 in this example shown as a number of tubes 12, being arranged inside the compartment 1 for conducting a heating medium, such as hot gas, in counter-current mode relative to the direction of
30 movement of the particulate material. The tubes 12 pass through an outer side wall 7 of the compartment 1 into the second end 5 of the compartment 1, extends up through the container and pass through the outer side wall 7 near the first end 3.

As shown in Fig. 1 the apparatus may further comprise a number of screw conveyors 8 for extracting a portion of the particulate material out through the outer side wall 7 of the compartment 1, and a number of venting gas inlets 9 arranged in the second end 5 of the compartment 1 for introducing a carrier gas into the compartment 1, said carrier gas is vented through a number of venting gas outlets 10 in the first end 3 and drawn through the compartment 1 by means of a fan 11.

During operation of the shown apparatus, particulate material, such as cement kiln dust containing vaporizable contaminants is introduced into the compartment 1 through the material inlet 2. When the compartment 1 is filled up with the material the rotary feeder 6 at the material outlet 4 of the compartment 1 is started and the particulate begins to move down through the compartment 1. Simultaneously a hot heating medium, such as hot gas, is allowed to flow through the tubes 12 in direction from the second end 5 to the first end 3 of the compartment 1. In this way, the particulate material will be heated in counter-current mode as it moves down as a packed bed through the compartment 1.

As the particulate material moves down through the compartment 1 the vaporizable contaminants contained in the particulate material will begin to vaporize when heated above a vaporizing temperature T_v in a vaporizing temperature region 50 having temperatures lower than the final temperature T_f but higher than a vaporizing temperature T_v such that the contaminants are inhibited from escaping the compartment 1 at the second end 5 together with the particulate material. As the arrow 60 indicates the vaporized contaminants are transported towards the first end 3 together with the venting gas, said venting gas acting as a carrier gas, towards a condensing temperature region 13 having temperatures higher than the initial temperature T_i but lower than the vaporizing temperature T_v such that the contaminants are inhibited from escaping the compartment 1 at the first end 3, in which condensing temperature region 13 contaminants are condensed onto said particulate material and then transported together with the particulate material. This continuous vaporizing and condensing of the contaminants in the vaporizing temperature region 50 and the condensing

temperature region 13, respectively, facilitates an internal vaporization-condensation cycle as indicated by the arrow 60 in the compartment 1 such that contaminants are accumulated in the compartment 1.

5 In cases where the particulate material is cement kiln dust and the contaminants to be removed contains mercury such vaporization will typically occur at temperatures above 300 °C. The thus vaporized contaminants will then be transported towards colder areas of the compartment 1, i.e. upwards in the
10 flow of the venting gas, where said contaminants will condensate on colder particulate material. It is hereby obtained that the content of vaporizable contaminants in the particulate material that is discharged through the material outlet 4 from the compartment 1 is lowered relative to the content of vaporizable contaminants in the particulate material that is introduced through inlet 2 into the
15 compartment 1.

In certain situations it may be necessary to introduce a carrier gas through the venting gas inlets 9 into the compartment 1 to ensure that the vaporized contaminants are moved upwards in direction of colder areas. Said carrier gas
20 may when vented be returned to the venting gas inlets 9 for reuse as carrier gas or it may, in some cases be conducted to the main process, such as on a cement manufacturing plant.

Again, in cases where the particulate material is cement kiln dust and the
25 contaminants to be removed contains mercury, the cleaned cement kiln dust being discharged from the compartment 1 may be returned to kiln system and because it is heated to above 300 °C, it may be introduced into the cyclone preheater at a location where the temperature is about the same, which typically would be into the material inlet of the second cyclone stage (5 stage preheater),
30 then resulting in some energy savings. In the compartment 1, the mercury, possibly entrained in carrier gas flows upwards toward colder areas of the compartment 1 and in a condensing temperature region 13, the mercury condense on the surface of the colder cement kiln dust. Since the cement kiln

dust moves downward, the mercury will be vaporized again when the said cement kiln dust onto which the mercury has condensed reaches hotter areas. In this way an internal circulation of mercury in the compartment 1 takes place and thus an increase in concentration of mercury on cement kiln dust occurs over

5 time. In order to break the cycle, the cement kiln dust having a high, preferably the highest mercury content must be extracted in the condensing temperature region 13 by the screw conveyors 8. The mass fraction of mercury found in the removed cement kiln dust is controlled by the removal rate. The cement kiln dust extracted by the screw conveyors 8 can be added to the finish mill or disposed. In

10 order to increase the mercury capture in the compartment 1, a sorbent may be added to the cement kiln dust, such as $\text{Ca}(\text{OH})_2$, but most likely, if the cement kiln dust enters with a sufficient low temperature, it would be capable of capturing the mercury itself.

15 The shown apparatus may also be operated for longer period of time without extracting material by the screw conveyors or even until the particulate material cannot absorb more vaporizable contaminants. In the latter case the compartment 1 may be dismantled and replaced with a new or at least partly emptied for material, when the particulate material in the compartment cannot

20 absorb more vaporizable contaminants. In this way the extracted vaporizable contaminants may be contained in as little amount of particulate material as possible, which would be advantageous if the material must be deposited.

Claims

1. A method for removing vaporizable contaminants from a particulate material, said method comprising the steps of:

- 5 – introducing the particulate material through a material inlet (2) into a compartment (1) in a first end (3) of the compartment (1),
- transporting the particulate material from said material inlet (2) through the compartment (1) towards a second end (5) of the compartment (1),
- discharging the particulate material through a material outlet (4) in said
10 second end (5) of the compartment (1),
- heating the particulate material in the compartment (1) from an initial temperature (T_i) in the first end (3) to a final temperature (T_f) in the second end (5) using means for heating (12) the particulate material arranged in the compartment (1),
- 15 – introducing a venting gas through a gas inlet (9) into the compartment (1) in the second end (5) of the compartment (1),
- transporting the venting gas from said gas inlet (9) through the compartment (1) towards the first end (3) of the compartment (1) in counter-current flow with the transport of particulate material (1) from the
20 first end (3) to the second end (5),
- discharging the venting gas through a gas outlet (10) in said first end (3) of the compartment (1),
- vaporizing contaminants from the particulate material in a vaporizing temperature region (50) having temperatures lower than the final
25 temperature (T_f) but higher than a vaporizing temperature (T_v) such that the contaminants are inhibited from escaping the compartment (1) at the second end (5) together with the particulate material,
- transporting the vaporized contaminants towards the first end (3) together with the venting gas, said venting gas acting as a carrier gas,
- 30 – condensing contaminants onto said particulate material in a condensing temperature region (13) having temperatures higher than the initial temperature (T_i) but lower than the vaporizing temperature (T_v) such that

the contaminants are inhibited from escaping the compartment (1) at the first end (3) together with the venting gas, and

- continuously vaporizing and condensing said contaminants in an internal vaporization-condensation cycle in the compartment (1) such that contaminants are accumulated in the compartment (1).

2. A method according to claim 1, wherein the particulate material is transported through the compartment (1) from the first end (3) to the second end (5) by gravity.

3. A method according to claims 1 or 2, wherein the particulate material is heated by conducting a heating medium through the means for heating (12) from the second end (5) to the first end (3) in counter-current to the direction of transportation of the particulate material from the first end (3) to the second end (5).

4. A method according to any of the preceding claims, wherein the method further comprises the step of extracting particulate material from the compartment (1) in a region of the compartment comprising the highest possible concentration of contaminants in the particulate material or at least close to the highest possible concentration of contaminants in the particulate material.

5. A method according to any of the preceding claims, wherein the vaporizing temperature (T_f) is the boiling point of the vaporizable contaminants when contained in the particulate material.

6. A method according to any of the preceding claims, wherein the compartment is dismantled and replaced with a new, at the latest when the concentration of vaporizable contaminants in the compartment has reached an upper limit, at which continued operation is no longer feasible.

7. A method according to claim 6, wherein the upper limit of the concentration of vaporizable contaminants in the compartment (1) is preferably set to twice the

concentration of vaporizable contaminants in the compartment at the material inlet (2), or even more preferably set to ten times the concentration.

5 8. A method according to any of the preceding claims, wherein the compartment is at least partly emptied for material, at the latest when the concentration of vaporizable contaminants in the compartment has reached an upper limit, at which continued operation is no longer possible.

10 9. A method according to any of the preceding claims, wherein particulate material is at least intermittently extracted from the compartment (1).

15 10. A method according to any of the preceding claims, wherein the venting gas inlet (9) comprises a plurality of inlets (9) and wherein the venting gas outlet (10) comprises a plurality of outlets (10).

11. A method according to any of the preceding claims, wherein the particulate material, which is introduced into the compartment (1), is cement kiln dust.

20 12. A method according to any of the preceding claims, wherein the cement kiln dust is extracted from a filter installation, which is filtering the outlet gas from a raw mill and/or the exhaust gases from a preheater of a cement manufacturing plant.

25 13. An apparatus for removing vaporizable contaminants from a particulate material comprising a compartment (1) having an material inlet (2), a material outlet (4), a venting gas inlet (9), a venting gas outlet (10) and means for heating (12) the particulate material, said means for heating (12) being of the counter-current kind ensuring that the particulate material over at least a part of its transportation through the compartment (1) moves in a direction from a first end (3) having a low initial temperature (T_i) towards a second end (5) having a high final temperature (T_f).

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14. An apparatus according to claim 12, wherein the compartment (1) is part of a vertical hopper.

5 15. An apparatus according to claim 12, wherein the compartment (1) comprises means for heating (12), such as tubes or plates, arranged within the compartment (1) for conducting a heating medium in counter-current to the direction of transportation of the particulate material.

10 16. An apparatus according to claim 12, wherein the compartment (1) comprises extracting means (8) arranged in a region of the compartment comprising the highest possible concentration of contaminants in the particulate material or at least close to the highest possible concentration of contaminants in the particulate material during operation.

15 17. Use of a counter-current heat exchanger for removing vaporizable contaminants from a particulate material, where the particulate material over at least a part of its transportation through the heat exchanger moves in direction towards a high temperature region.

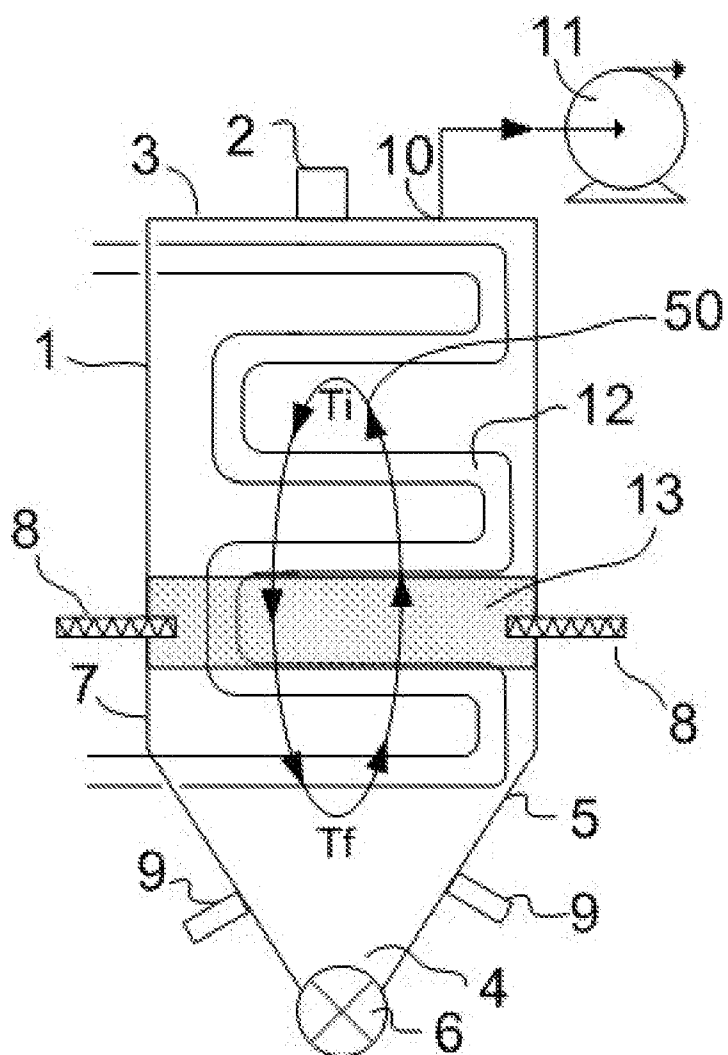


Fig. 1