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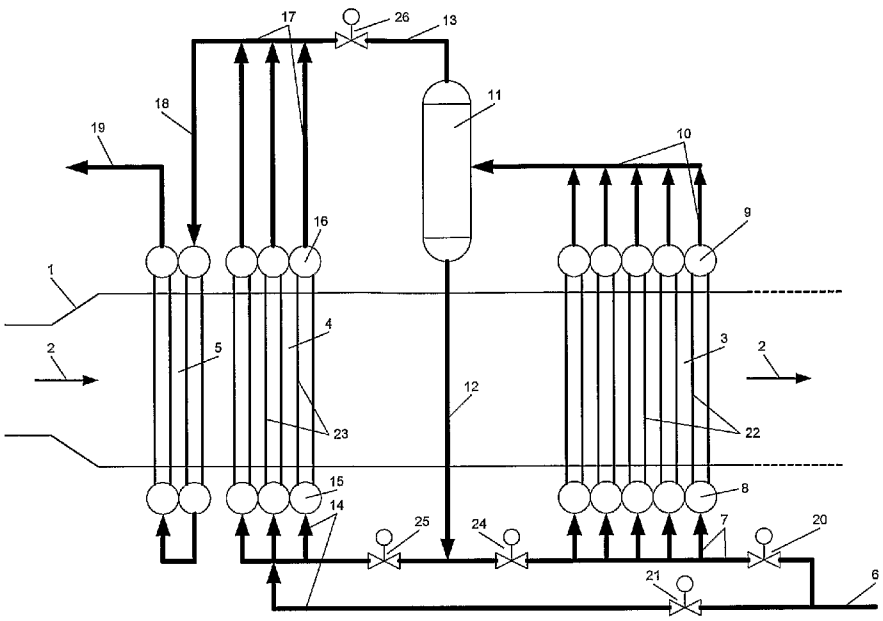
(54) Title: BOTTOM-FED STEAM GENERATOR WITH SEPARATOR AND DOWNCOMER CONDUIT



(57) Abstract: The present invention relates to a steam generator comprising a substantially horizontal gas conduit for guiding a heating gas flow and a single pass evaporator unit. The evaporator unit has at least one heat transfer section which is positioned at least partially in the heating gas flow. The heat transfer section comprises substantially vertically extending heat transfer tubes, which are at the lower region in fluid communication with an inlet conduit and at the upper region in fluid communication with an outlet conduit. A flow medium is supplied to the inlet conduit. The invention is characterized in that the evaporator unit comprises a separator and a downcomer conduit.

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Title: Bottom-fed steam generator with separator and downcomer conduit.

The present invention relates to a steam generator comprising a substantially horizontal gas conduit for guiding a heating gas flow, and a single pass evaporator unit having at least one heat transfer section positioned at least partially in the heating gas flow comprising substantially vertically extending heat transfer tubes, which are at the lower region in fluid communication with an inlet conduit for supplying a flow medium and at the upper region in fluid communication with an outlet conduit.

Single pass evaporator units can be operated as once-through evaporators, which can be used with the flow medium under sub-critical or supercritical circumstances.

A single pass evaporator unit as the opposite of a multi pass evaporator unit relates to an evaporator unit, wherein the flow medium only passes one time the heating gas in the gas conduit. For example, in a single pass evaporator the flow medium may pass the gas conduit only in an upward direction from the bottom to the top of an evaporator unit.

A once through evaporator unit as the opposite of a circulating evaporator unit relates to an evaporator unit wherein the flow medium only passes one time through the heat transfer tubes of the evaporator unit. The liquid phase of the flow medium is not circulating over the heat transfer tubes of the evaporator unit to obtain complete evaporization.

For example EP 0.944.801 discloses a once-through steam generator in a horizontal type of construction for a through-flow of the heating gas in an approximately horizontal direction. The described once-through steam generator comprises a number of approximately vertically disposed heat transfer tubes, which are connected in parallel for a through flow of a flow medium. The heat transfer tubes are arranged in parallel side by side in the horizontal gas conduit, which causes a different heating of each heat transfer tube. The heat transfer tubes, which are arranged upstream of the heating gas flow will be more heated, than the heat transfer

tubes which are arranged downstream. The different heating of each heat transfer tube causes a different vapor flow rate in each heat transfer tube. The most upstream arranged heat transfer tube in the heating gas flow will produce the most vapor and will therefore have the largest flow rate of flow medium.

A first problem which may occur especially in the most upstream positioned heat transfer tube, is that the supply of liquid is too low. The heat transfer tube may dry out and become overheated which could lead to damages. EP 0.944.801 provides a possible solution for this problem by optimizing the configuration of the heat transfer tubes. Each heat transfer tube is expediently configured for a higher flow rate of the flow medium than each heat transfer tube disposed downstream of it in the heating-gas direction. However, this proposed solution results in a more complex and large construction, for example of distribution and collection elements mounted at the ends of the heat transfer tubes.

A second problem arises when all heat transfer tubes generate superheated vapor (vapor quality equal or larger than one). This will cause temperature stratification over the height of the gas conduit. Heating gas temperature stratification is undesirable because it impairs thermal performance of both the steam generating system itself and possible gas side downstream heat transfer surfaces. This can be minimized by assuring that a number of the last downstream arranged heat transfer tubes will discharge a two-phase mixture of liquid and vapor to the outlet conduit. However, when this two-phase mixture has to be further superheated in a next heat transfer section, redistribution of the two-phase flow is required, which causes stability problems, when the two-phase mixture streams downwards.

Due to gravitational forces in a stream downwards, the mixture is separated in vapor and liquid. The vapor tends to rise which disturbs the downward flow of the mixture. The known steam generator of EP 0.944.801 also requires down flow and redistribution of the two-phase flow which impairs stability of operation.

It is an object of the present invention to overcome at least one of the above-mentioned drawbacks, at least partially, and/or to provide a useable alternative. In particular, it is an object of the invention to provide a steam generator having a single pass

evaporator unit without the negative effects of redistribution of a two-phase mixture of liquid and vapor.

This object is achieved by a steam generator as defined in claim 1. A steam generator according to the invention comprises a substantially horizontal gas conduit for guiding a heating gas flow and a single pass evaporator unit. The evaporator unit has at least one heat transfer section which is positioned at least partially in the heating gas flow. The heat transfer section comprises substantially vertically extending heat transfer tubes, which are at the lower region in fluid communication with an inlet conduit and at the upper region in fluid communication with an outlet conduit. A flow medium is supplied to the inlet conduit.

The invention is characterized in that the evaporator unit comprises a separator and a downcomer conduit.

The separator is meant for separating a two-phase mixture of liquid and vapor which is supplied via the outlet conduit of the single pass evaporator unit to the separator. The separator separately discharges the vapor and the liquid out of the two-phase mixture via a vapor outlet and a liquid outlet. This improves the efficiency of the steam generating process. The separator is via the liquid outlet in fluid communication with the inlet of the downcomer conduit. Advantageously, it is prohibited that vapor enters the downcomer conduit, which results in a lower risk on disturbances and efficiency losses in the steam generating process.

Herewith, in contrast to prior art steam generators according to the invention the separator substantially prevents a down flow of the two-phase mixture. The separator separates the liquid flow out of the two phase mixture, wherein according to the invention the liquid flow is supplied to the downcomer conduit. Advantageously, this results in a down flow of a substantially one phase liquid flow instead of a down flow of the two-phase mixture including the vapor flow.

The downcomer conduit is positioned substantially parallel to the heat transfer tubes. The downcomer conduit has a downcomer inlet at the upper region for a supply of liquid, which is in fluid communication with the liquid outlet of the separator and a downcomer outlet at the lower region which is in fluid communication with an inlet conduit of the heat transfer tubes of an evaporator unit. Due to the fluid communication the downcomer conduit provides a

hydrostatic balance between a hydrostatic head in the downcomer conduit and a hydrostatic head in the heat transfer tubes.

Advantageously, the downcomer prohibits that the amount of liquid in the heat transfer tubes becomes too little or too much. Herewith the level of liquid in the heat transfer tubes remains within an optimal range for a reliable heat transfer. Due to the hydrostatic pressure generated by hydrostatic balance between the downcomer conduit and the heat transfer tubes the risk of drying out and overheating of a heat transfer tube is reduced.

In addition, due to the presence of the downcomer conduit the height level of the liquid in the heat transfer tubes is controlled, which may reduce the amount of discharging liquid in a two-phase mixture at the upper region of the heat transfer tubes to the outlet conduit. Advantageously, due to an optimal control of the hydrostatic balance by the downcomer, the discharging of liquid out of the evaporator unit is minimized, which results in an increase of the stability of the process in the steam generator. Herewith, stability problems in a down flow of the flow medium are reduced.

Liquid may be supplied to the downcomer conduit from anywhere out of the steam generator. For example, liquid may be supplied from other outlets in the steam generator. Liquids anywhere in the steam generator, which could disturb the steam generating process may be discharged to the downcomer conduit, which advantageously optimizes the steam generating process. In addition the downcomer may be provided with an extra liquid supply, which further reduces the risk of drying out.

Preferably a control valve is arranged upstream of the heat transfer tubes to control the flow rate of the flow medium. In an embodiment according to the invention a liquid supply pump and a control valve is arranged in the inlet or supply conduit to force the flow medium through the heat transfer tubes and to control the flow rate of the flow medium. By controlling the flow rate it is possible to control the ratio of liquid and vapor in the two-phase mixture in the outlet conduit of the evaporator unit. Herewith the steam generating process may be optimized.

In a preferred embodiment according to the invention the steam generator is characterized in that the evaporator unit comprises two evaporator units, one generating superheated vapor and one generating

a two-phase mixture, both being bottom fed with flow medium, and a separator to separate the two-phase mixture, from which the liquid is redirected to the inlet of at least one of the two sections of heat transfer tubes.

Preferably the downcomer conduit is designed such that the heat transfer is negligible in comparison with the heat transfer in the heat transfer tubes. The heating surface may be relatively small in comparison with the inner volume of the downcomer conduit, the downcomer conduit may be isolated from the heating gas, or may even be arranged outside the heating gas conduit.

In addition a negligible friction pressure loss over the fluid communicating conduits provides a positive effect to the hydrostatic balance between the fluid columns in the heat transfer tubes and the downcomer conduit.

The flow medium is prevented from bypassing the heat transfer tubes when the liquid height level of a fluid in the self-leveling conduit remains below the liquid outlet of the separator. This is further accomplished by a lower height averaged density of the flow medium in the heat transfer tubes compared to the density of the fluid in the self-leveling conduit. The height averaged density of the flow medium in the evaporative heat transfer sections depends on the heat absorption of the evaporative heat transfer sections which is controlled by selection of an appropriate heat transfer surface area. Heat absorption causes the height averaged density of a fluid column of flow medium in the heat transfer tubes to be low compared to the height average density of a fluid column in the negligibly heated liquid in the self-leveling conduit.

A particular embodiment according to the invention is suitable in the case when the heat transfer section generating superheated vapor is eliminated. In that case only the heat transfer section generating a two-phase mixture remains, discharging the two-phase mixture into the separator, from which the liquid is redirected to the inlet conduit of the heat transfer tubes. Only saturated vapor is generated in that case.

In an advantageous embodiment of the steam generator according to the invention the steam generator further comprises a second single pass evaporator unit with a separate inlet conduit, which is connected in parallel to the inlet conduit of the first single pass

evaporator unit. In particular the second single pass evaporator unit may comprise substantially vertical positioned heat-transfer tubes, which are arranged in the heating gas flow in parallel to the heat-transfer tubes of the first single pass evaporator unit.

Advantageously, the inlet conduit of the second single pass evaporator comprises a control valve to control the flow rate of the flow medium into the heat transfer tubes.

Further preferred embodiments are defined in the depending claims.

The invention will now be explained in more detail with reference to the attached drawings which show a practical embodiment of the invention, but which should not be interpreted as being limiting. In these drawings:

figure 1 is a diagrammatic representation of a steam generator according to the invention having a separator and a downcomer conduit;

figure 2 is a diagrammatic representation of a steam generator according to the invention having a second evaporator unit added to the representation of the steam generator as shown in figure 1, whose inlet conduits are connected in parallel;

figure 3 is a diagrammatic representation of a steam generator according to the invention having a downcomer conduit connected to the inlet conduit of the second evaporator unit;

figure 4 is a diagrammatic representation of the steam generator according to the invention having two evaporator units as shown in figure 2, whose outlet conduits are connected to the separator of a self-leveling device;

figure 5 is a diagrammatic representation of a steam generator according to the invention having two evaporator units as shown in figure 3, whose outlet conduits are connected to the separator; and

Figure 6 is a diagrammatic representation of the steam generator according to the invention having two evaporator units, one generating superheated vapor and one generating a two-phase mixture, both being bottom fed with flow medium, and having a separator to separate the two-phase mixture, from which the liquid is redirected

to the inlet of at least one of the two sections of heat transfer tubes

In the attached figures the same reference numbers are used to indicate corresponding components.

Figure 1 is a diagrammatic representation of a steam generator according to the invention. The steam generator comprises an evaporator unit 3, which are positioned in a substantially horizontal gas conduit 1. A heating gas 2 flows through the gas conduit 1. A flow medium is supplied to a supply conduit 6, which is in fluid communication with a heat transfer section of the evaporator unit 3. The supply conduit 6 comprises a control valve 20 to control the flow rate of the flow medium. Via an inlet conduit 7 and distributing manifold the flow medium is distributed and supplied to distributing headers 8 and heat transfer tubes 22 of the heat transfer section which at least partially extend within the gas conduit 1. At the upper region of the evaporative heat transfer section 3 the flow medium is collected via collecting headers 9 and a collecting manifold 10. The flow medium enters the heat transfer tubes 22 in a single phase of liquid. The flow medium is heated by the heating gas flow 2 and is discharged in a two phase mixture of vapor and liquid to the collecting manifold 10.

Via collecting headers 9 and collecting manifold 10 a two-phase mixture of liquid and vapor is discharged to a separator 11. In the separator 11 the two-phase mixture of flow medium is divided into a liquid and a vapor flow. The flow medium in the liquid phase is discharged via a liquid outlet to the downcomer conduit 12 and the flow medium in the vapor phase is discharged via a vapor outlet to a vapor conduit 13.

Via the vapor conduit 13 the flow medium is supplied to a superheater 5, added for illustrative purposes only. In the superheater 5 the flow medium is superheated and discharged via conduit 19, which forms the outlet conduit of the steam generator.

Further, the evaporator unit 3 is via the distributing manifold 7 in fluid communication with a self-leveling device. The self-leveling device comprises a separator and a substantially vertical

conduit, a downcomer conduit 12, which is positioned in parallel to the heat transfer tubes 22 in the heat transfer section.

Flow medium from anywhere out of the steam generator may be supplied to the downcomer conduit. At the upper region the downcomer conduit is connected to the separator 11. Here, the downcomer conduit is also directly connected to the inlet conduit 7, such that the flow medium in the single phase of liquid may also enter the downcomer conduit 12. Due to the fluid communication a hydrostatic balance is obtained between the downcomer conduit 12 and the heat transfer tubes 22. The hydrostatic balance may ensure a minimum and maximum amount of flow medium in the single phase of liquid in each heat transfer tube 22. Herewith, it may be prevented that the evaporative heat transfer section would dry out or would discharge a two-phase mixture having a to large amount of liquid. The separation of liquid out of the two-phase mixture of liquid and vapor makes the steam generating process more stable. Only vapor is flowing through the vapor conduit 13 in a downwards direction, which makes the steam generating process more secure and efficient.

The downcomer conduit 12 of the self-leveling device may be provided with measuring elements to detect the minimum and/or maximum amount of flow medium in the self-leveling device. The measuring elements may give a signal to the operator when a critical state of the evaporator unit occurs. Alternatively the measuring elements may be used to automatically operate a control valve 20. If the maximum amount of flow medium in the self-levelling device is detected, the flow rate of the flow medium may be reduced by the control valve 20 in the supply conduit 6. Herewith the steam generator according to the invention is controllable for different steam generating loads.

Figure 2 shows a diagrammatic view of steam generator as shown in figure 1 in which a first single pass evaporator unit 3 is connected in parallel with at least one second single pass evaporator unit 4. The second single pass evaporator unit has a separate inlet conduit 14, which is connected in parallel to the inlet conduit 7 of the first single pass evaporator unit 3. Both single pass evaporator units comprise at least one row of substantially vertical heat transfer tubes 22, 23, which are positioned substantially perpendicular to a heating gas flow 2 in a substantially horizontal gas conduit 1.

At the lower region of the heat transfer tubes 22, 23 both evaporator units 3, 4 comprise distributing manifolds 7, 14 and distributing headers 8, 15. At the upper region of the heat transfer tubes 22, 23 both single pass evaporator units 3, 4 comprise collecting manifolds 10, 17 and collecting headers 9, 16. As indicated by arrows the flow medium in the first and second evaporator unit flows in an upward direction.

As in figure 1, the first evaporator unit is connected to a separator 11. The two-phase mixture is transported through the collecting manifold 10 to the separator 11. Flow medium in the liquid phase is separated from the two-phase mixture and discharged to the distributing manifold 7 via the self-levelling device. The flow medium in the vapor phase from the separator 11 is discharged to a vapor conduit 13. The vapor conduit 13 is in fluid communication with the collecting manifold 17 of the second evaporator unit 4. In this case the flow medium discharged from the heat transfer tubes 23 is superheated. Water as a flow medium is heated inside the heat transfer tubes 23 from inlet condition to superheated condition in one single pass. Superheated steam leaves the heat transfer tubes 23 of the evaporative heat transfer section 4 and passes through the collecting headers 16 into the collecting manifold 17. Here it mixes with the saturated vapor coming from the separator 11 via the vapor conduit 13. The superheated steam mixture leaves the single pass evaporator units 3,4 through the superheated steam conduit 18. The flow medium flows to the superheater 5. In the superheater 5 the flow medium is superheated and discharged via conduit 19, which forms the outlet conduit of the steam generator.

Figure 3 shows a diagrammatic representation of an alternative embodiment of the steam generator according to the invention. The illustrated steam generator corresponds with the steam generator shown in figure 2, but differs in that the downcomer conduit 12 is now in fluid communication with the inlet conduit 14 of the second single pass evaporator unit. In the separator 11 flow medium in the liquid phase is separated from the two-phase mixture out of conduit 10 and is discharged into the downcomer conduit 12, which functions as a self-levelling device. The down comer conduit 12 is in fluid communication with the second evaporator unit 4 to control by

hydrostatic balance the height level of fluid in the transfer tubes 23 of the second evaporator unit.

Figure 4 shows a diagrammatic representation of the steam generator according to the invention which corresponds to the representation of figure 2, but differs in that both evaporator units are now connected to the separator 11. Figure 4 shows an alternative embodiment of the invention as represented in figure 2 in which both the outlet conduits of the superheated vapor generating evaporator unit 4 and the two-phase mixture generating evaporator unit 3 are connected to the separator. Liquid is separated out of the two-phase mixtures coming from the first and second evaporator units 3,4. The separated liquid in the separator 11 is again discharged to the down comer conduit 12.

Figure 5 shows an alternative embodiment of the steam generator of figure 4. Figure 5 corresponds to figure 4, but differs in that the down comer conduit is now in fluid communication with the inlet conduit of the second evaporator unit. As shown in fig. 4, the height level of fluid in the second evaporator unit 12 which defines the hydrostatic head is controlled by hydrostatic balance with the height level of the fluid in the down comer conduit.

Figure 6 is a diagrammatic representation of a steam generator according to the invention. The steam generator comprises a first single pass evaporator unit 3, which is connected in parallel with at least one second single pass evaporator unit 4. The evaporator units are positioned in a substantially horizontal gas conduit 1. A heating gas 2 flows through the gas conduit 1. A flow medium in a single phase of liquid is supplied to a supply conduit 6 and via the inlet conduit 7 the flow medium is supplied to the heat transfer tubes 22.

The second single pass evaporator unit 4 has a separate inlet conduit 14, which is connected in parallel to the inlet conduit 7 of the first single pass evaporator unit 3, supplying flow medium to the heat transfer tubes 23.

At the lower region of the heat transfer tubes 22, 23 both evaporator units 3, 4 comprise distributing headers 8, 15. At the upper region of the heat transfer tubes 22, 23 both single pass evaporator units 3, 4 comprise outlet conduits 10, 17 and collecting headers 9, 16.

Via collecting headers 9 and outlet conduit 10 a two-phase mixture of liquid and vapor is discharged into a separator 11. In the separator 11 the two-phase mixture of flow medium is separated. The flow medium in the liquid phase is discharged to a down comer conduit 12, a substantially vertical conduit, which is positioned in parallel to the heat transfer tubes 22, 23 in the heat transfer sections, and the flow medium in the vapor phase is discharged to a vapor conduit 13.

Superheated vapor leaving the heat transfer tubes 23 of the evaporator unit 4 passes through the collecting headers 16 into the outlet conduit 17, where it mixes with the saturated vapor coming from the separator 11 via vapor conduit 13. The resulting superheated vapor mixture leaves the single pass evaporator units through the superheated vapor conduit 18.

The superheated vapor is further superheated in superheater 5, added for illustrative purposes only. The superheated vapor finally leaves the steam generator through superheated vapor conduit 19.

The self-leveling downcomer conduit 12 may be provided with measuring elements to detect the liquid height level. The measuring elements may be used to automatically operate the control valve 20. Alternatively the quality (the ratio between the amount of vapor and liquid) of the two-phase mixture in outlet conduit 10 may be used to automatically operate the control valve 20. The temperature of the superheated vapor in outlet conduit 17 or superheated vapor conduit 18 may be used to automatically operate the control valve 21.

By means of valves 24 and 25 in figure 6 the liquid from downcomer conduit 12 can be redirected entirely or partially to inlet conduits 7 and/or 14. The flow medium in the single phase of liquid may also enter the self-leveling downcomer conduit 12 from the inlet conduits 7 and/or 14. Due to the fluid communication a hydrostatic balance is obtained between the self-leveling downcomer conduit 12 and the heat transfer tubes 22 and/or 23.

Valve 26 in figure 6 may be closed when the steam generator is operated at supercritical pressures, when separation is not possible between water and steam. Closing valve 26 assures all flow is led to the inlet of evaporator unit 4.

Thus, according to the invention, a steam generator is provided which may provide a stable and more reliable steam generating

process, as a single pass evaporator, for operation at sub-critical and supercritical pressures, without the drawback of the redistribution of a two-phase mixture. Additionally, the steam generator according to the invention may be more efficient and may have a simple construction which may reduce costs in installation and maintenance.

Many variants are possible in addition to the embodiments shown in the above-mentioned figures without leaving the scope of protection as determined in the following claims.

C L A I M S

1. Steam generator comprising

- a substantially horizontal gas conduit (1) for guiding a heating gas flow (2);
- a single pass evaporator unit (3) having at least one heat transfer section positioned at least partially in the heating gas flow (2) comprising substantially vertically extending heat transfer tubes (22), which are at the lower region in fluid communication with an inlet conduit (7) for supplying a flow medium and at the upper region in fluid communication with an outlet conduit (10),

characterized in that the evaporator unit (3) comprises:

- a separator (11) for separating a two-phase mixture of liquid and vapor which is supplied via the outlet conduit (10) of the single pass evaporator unit (3) to the separator (11) and wherein the liquid out of the two-phase mixture is discharged via a liquid outlet and wherein the vapor out of the two-phase mixture is discharged via a vapor outlet of the separator (11); and
- a downcomer conduit (12), which is positioned substantially parallel to the heat transfer tubes (22) and which has a downcomer inlet at the upper region for a supply of liquid, which is in fluid communication with the liquid outlet of the separator (11) and a downcomer outlet at the lower region which is in fluid communication with an inlet conduit of the heat transfer tubes (22) or other heat transfer tubes (23) providing a hydrostatic balance between a hydrostatic head in the downcomer conduit (12) and a hydrostatic head in the heat transfer tubes.

2. Steam generator according to claim 1, wherein a control valve (20) is arranged upstream of the heat transfer tubes to control the flow rate of the flow medium.

3. Steam generator according to claim 1 or 2, wherein the downcomer conduit (12) is designed such that the heat transfer between the liquid in the downcomer conduit (12) and the heating gas flow (2) in comparison with the heat transfer between the flow medium in the heating transfer tubes with the heating gas flow (2) is negligible.

4. Steam generator according to one of the preceding claims, wherein the downcomer conduit (12) is arranged inside the gas conduit (1).

5. Steam generator according to one of the preceding claims, wherein the steam generator further comprises a second single pass evaporator unit (4) with a separate inlet conduit (14), which is connected in parallel to the inlet conduit (7) of the first single pass evaporator unit (3).

6. Steam generator according to claim 5, wherein the outlet of the downcomer conduit (12) is connected to the inlet conduit (14) of the second single pass evaporator unit (4).

7. Steam generator according to claim 5, wherein the downcomer conduit (12) is both connected to the inlet conduit (7) of the first evaporator unit (3) as to the inlet conduit (14) of the second single pass evaporator unit (4).

8. Single pass evaporator unit (3) comprising at least one heat transfer section positioned at least partially in the heating gas flow (2) comprising substantially vertically extending heat transfer tubes (22), which are at the lower region in fluid communication with an inlet conduit (7) for supplying a flow medium and at the upper region in fluid communication with an outlet conduit (10), **characterised in** that the evaporator unit comprises:
- a separator (11) for separating a two-phase mixture of liquid and vapor which is supplied via the outlet conduit (10) of the single pass evaporator unit (3) to the separator (11) and separately discharged via a vapor outlet and a liquid outlet of the separator (11); and
- a downcomer conduit (12), which is positioned substantially parallel to the heat transfer tubes (22) and which has a downcomer inlet at the upper region for a supply of liquid, which is in fluid communication with the liquid outlet of the separator (11) and a downcomer outlet in the lower region which is in fluid communication with the heat transfer tubes (22) providing a hydrostatic balance

between a hydrostatic head in the downcomer conduit with a hydrostatic head in the heat transfer tubes.

9. Installation comprising a gas producing apparatus emitting its hot gasses into a steam generator according to one of the claims 1-8.

10. Power plant for generating electricity comprising a steam generator according to one of the claims 1-8.

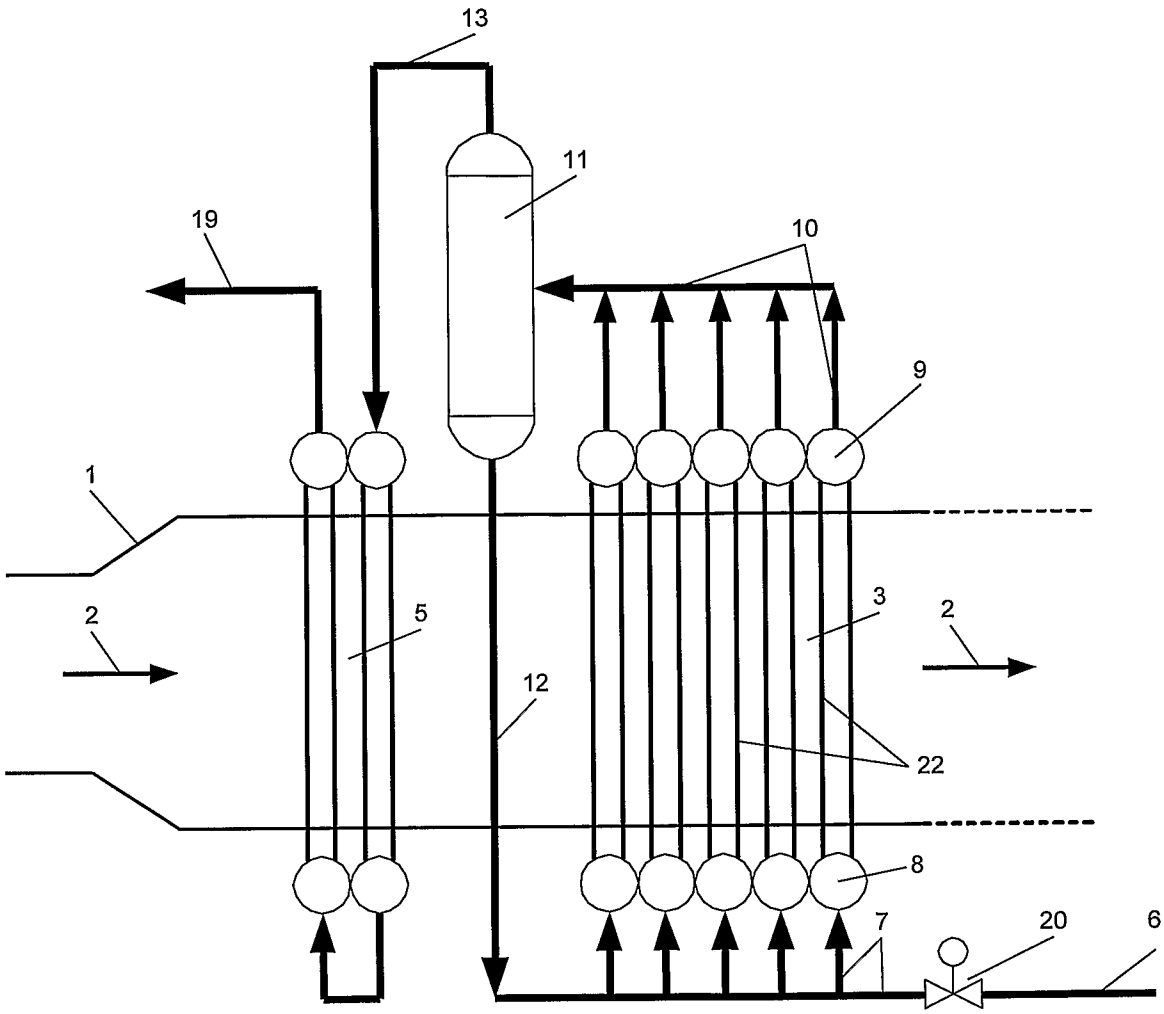

FIG. 1

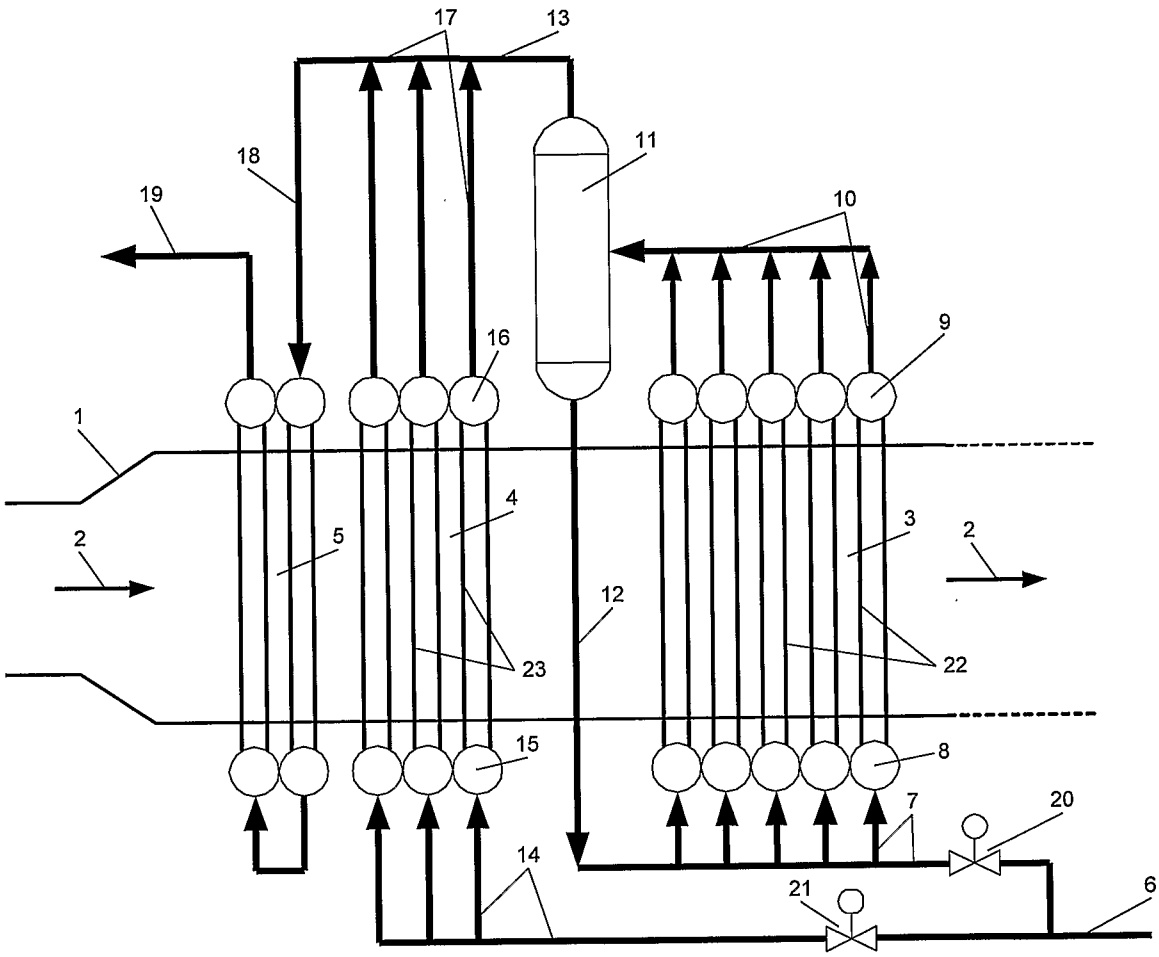

FIG. 2

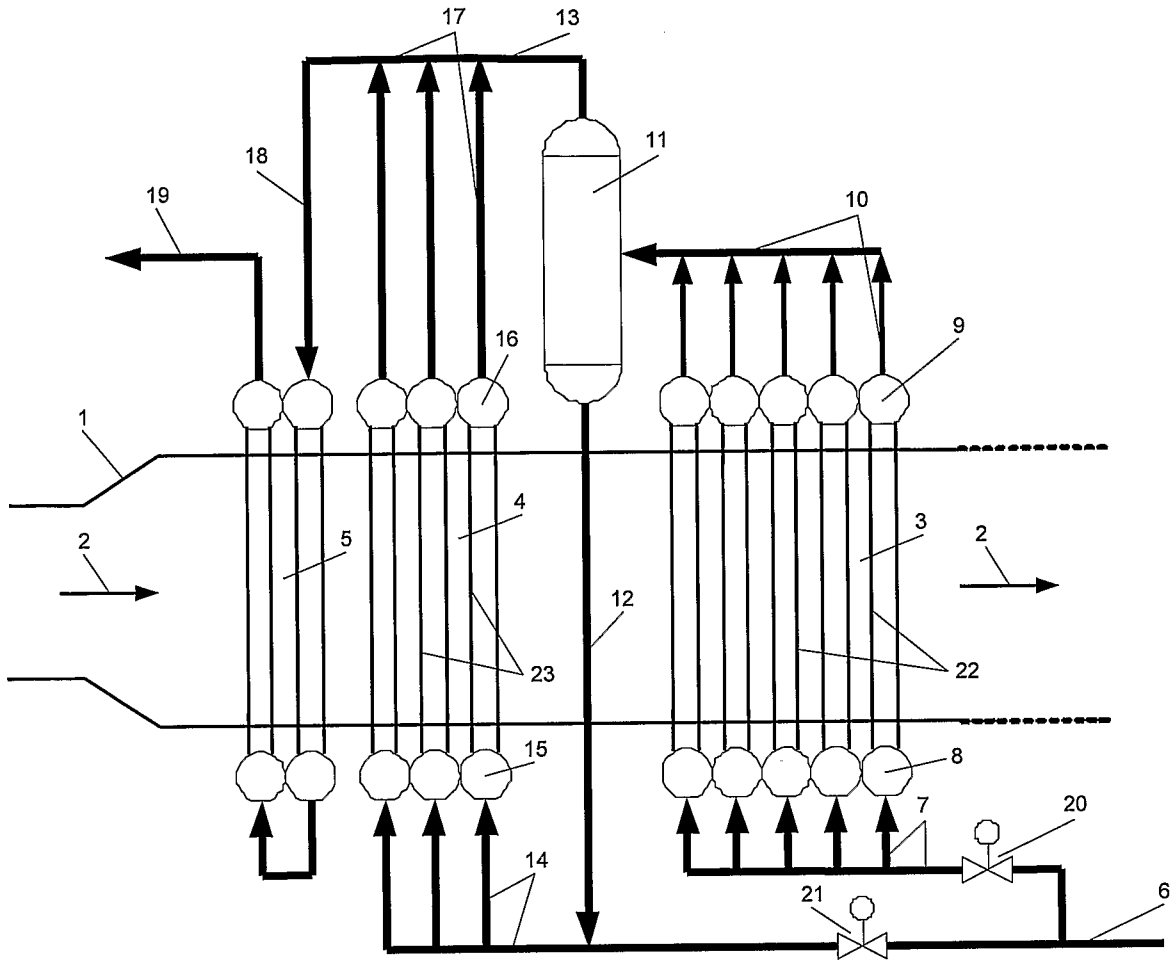

FIG. 3

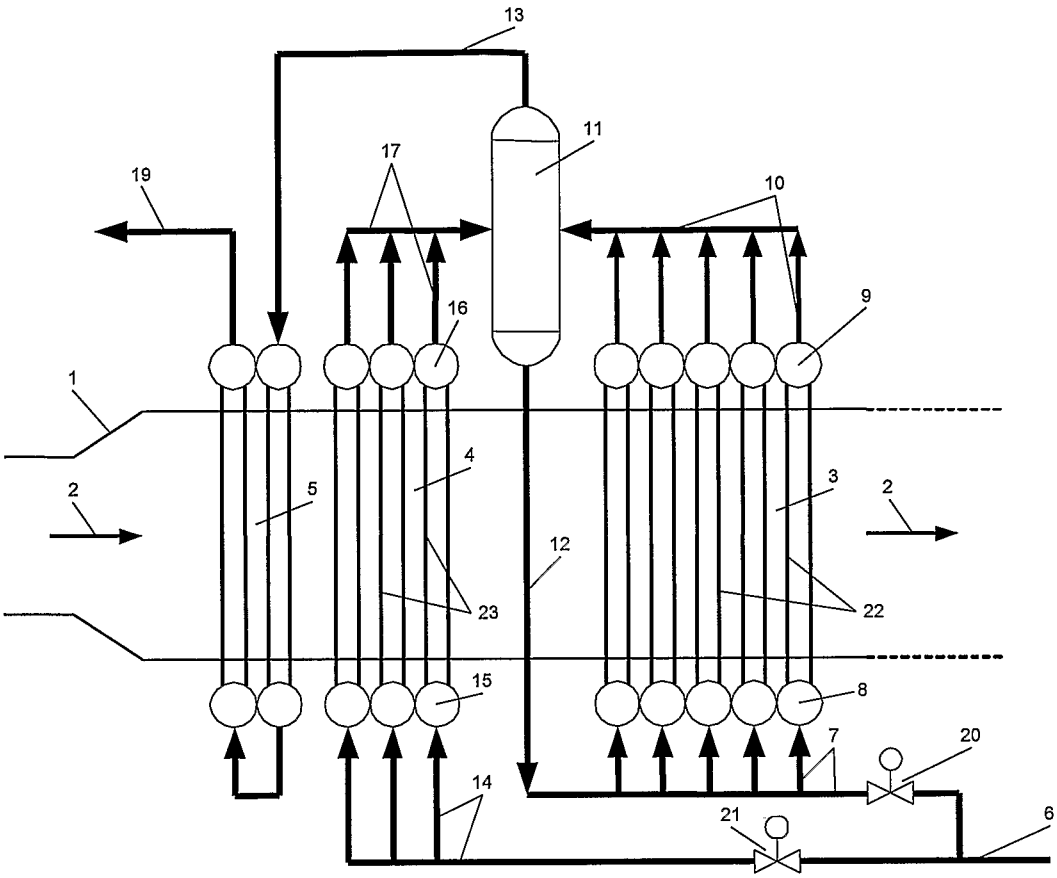

FIG.4

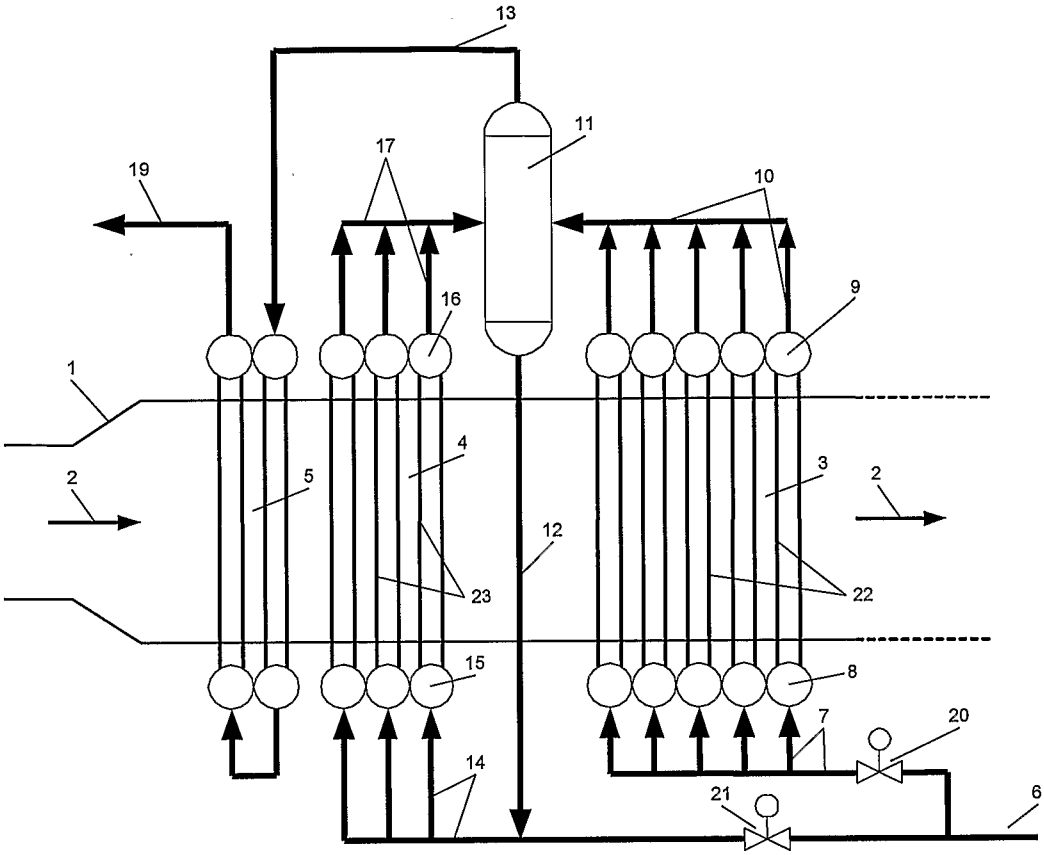

FIG.5

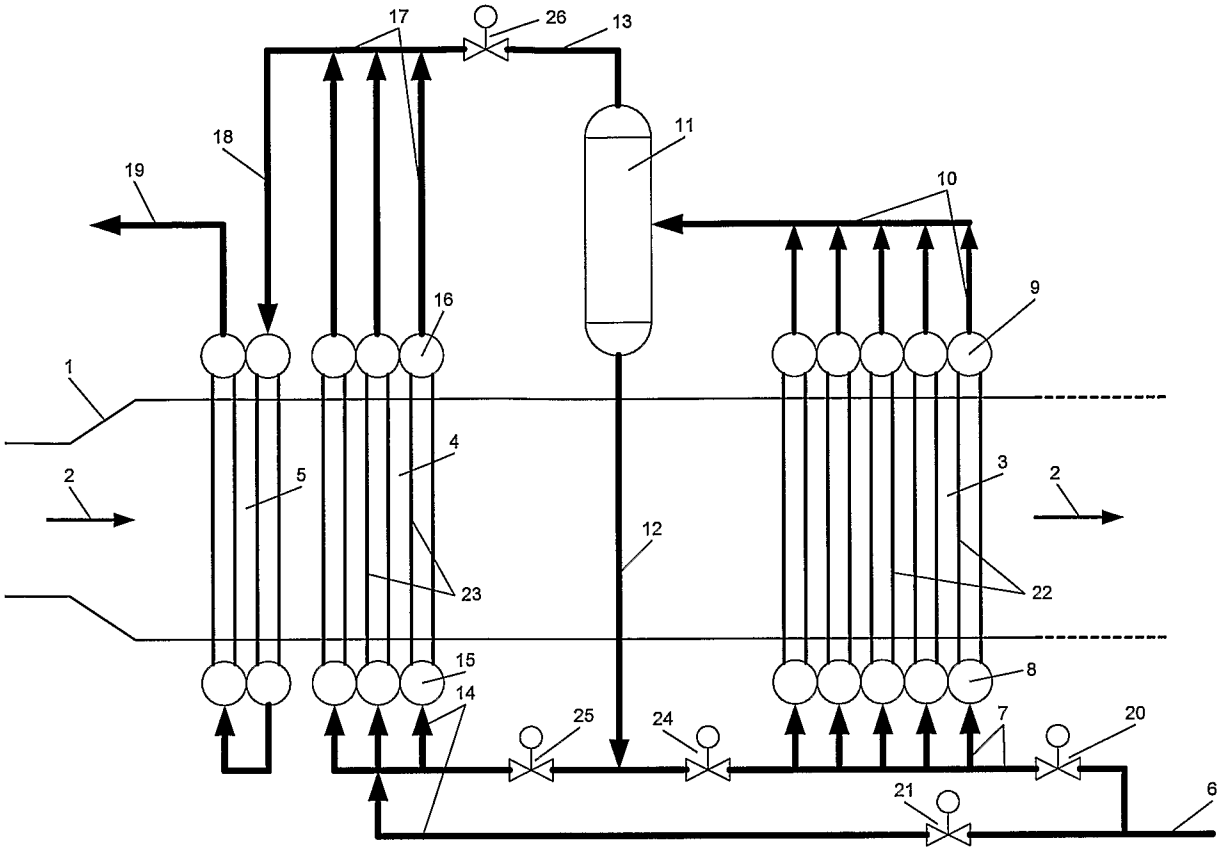

FIG. 6