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[33] **Switzerland**
[31] **10,038/67**

[54] FORCED THROUGH-FLOW STEAM GENERATOR

10 Claims, 2 Drawing Figs.

[52] **U.S. Cl.** **122/406**
[51] **Int. Cl.** **F22b 29/12**
[50] **Field of Search** 122/406S, 406SU, 448S, 451S, 479S

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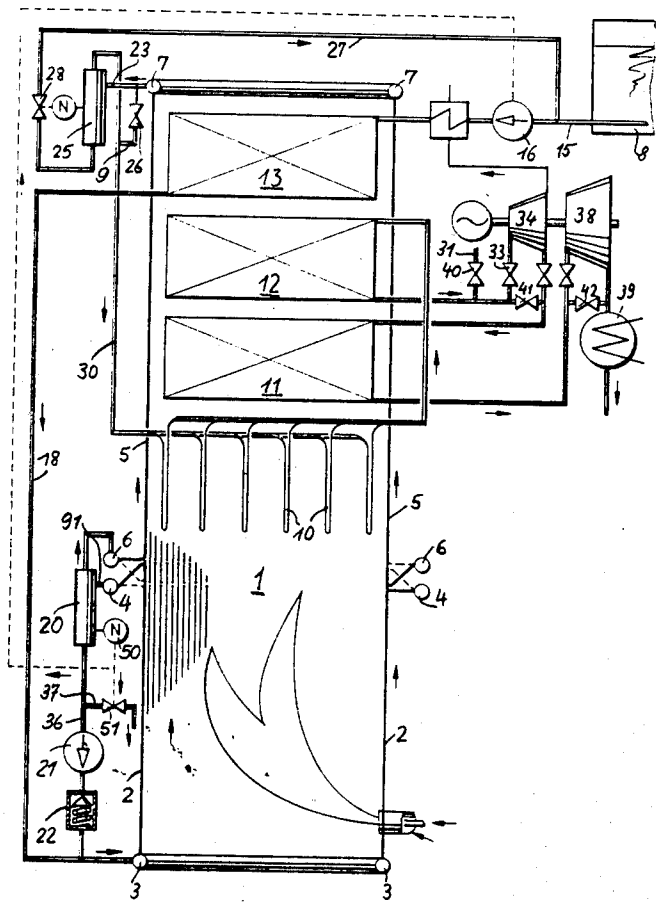
ABSTRACT: The steam generator is provided with a tap off point between the evaporator and first superheater and a second tap off point after the first superheater. The tap off points connect with a separator. A by-pass line is also positioned between the second superheater and turbines. Upon starting, working medium is tapped off and returned to the flow path between the feed water tank and evaporator. After starting, up to normal operation, the working medium is not tapped off and the steam generator functions as a once-through forced-flow system.



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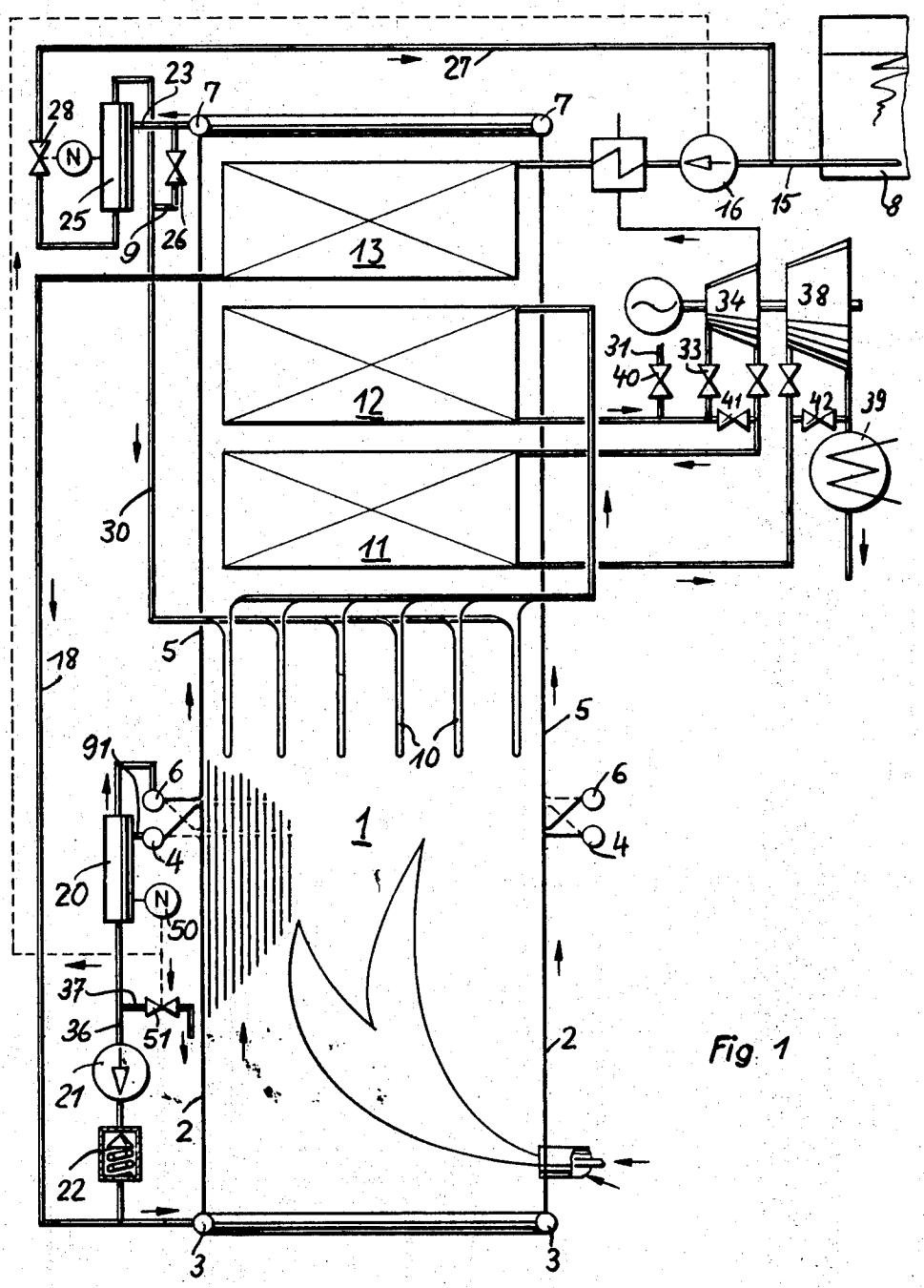

Fig. 1

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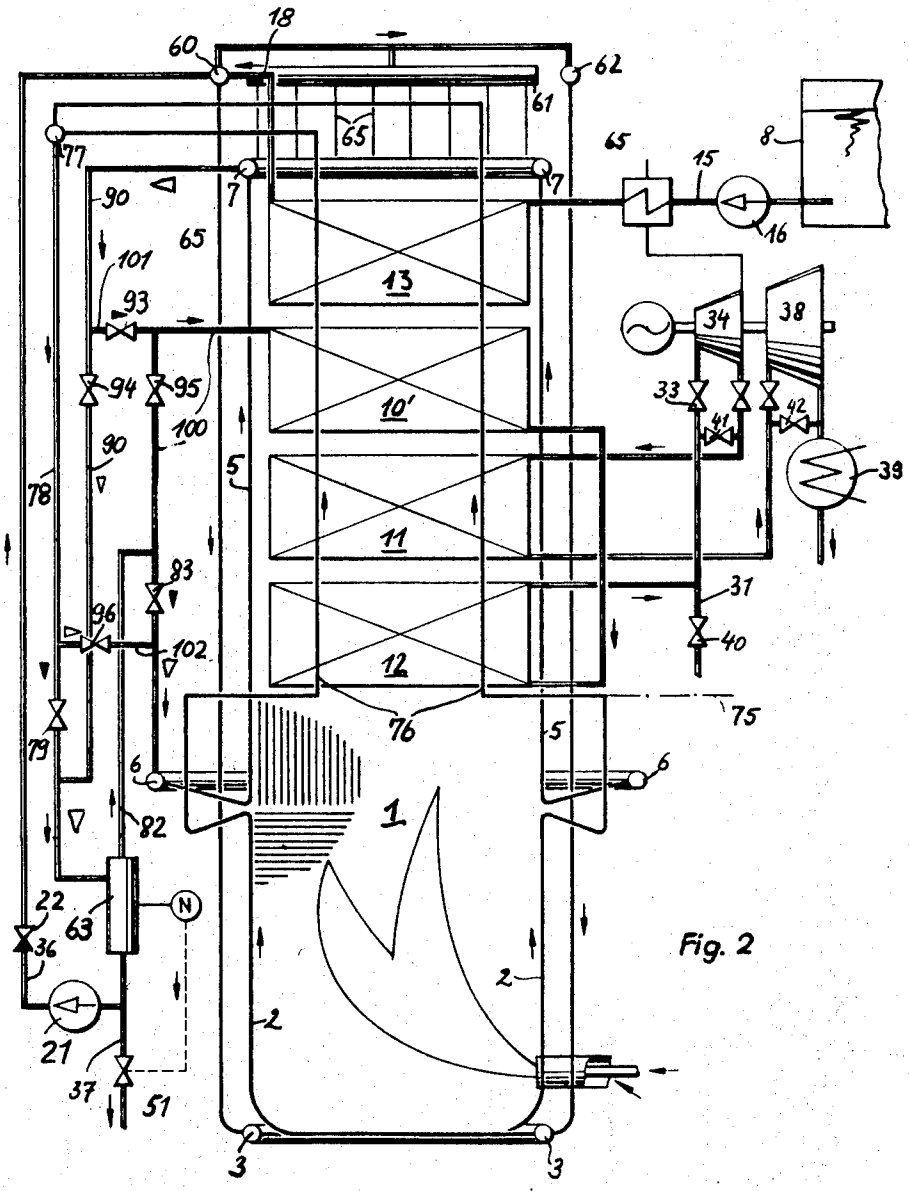

Fig. 2

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FORCED THROUGH-FLOW STEAM GENERATOR

This invention relates to a forced through-flow steam generator. More particularly, this invention relates to a forced through-flow steam generator having a combustion chamber formed of gas-tight tubular walls.

Steam generators have been known wherein a combustion chamber is formed of tubes which are welded to one another in gas-tight manner either directly or with strips or fins between adjacent tubes. In some instances, such combustion chambers have been divided into two sections which are arranged in sequence with respect to a flow of working medium passing therethrough. The lower of the sections has formed at least part of an evaporator while the upper section has formed a first superheater. These steam generators have also had at least one other superheater connected in the working medium flow, a steam turbine connected downstream of such other superheater and a by-pass line including a shut-off valve means for by-passing the working medium flow from the superheaters around the turbine.

Where these steam generators are to operate at relatively low pressures, the evaporators are designed to account for quite a large proportion of the tube walls of the combustion chamber. However, as the design pressure increases, this proportion decreases thus necessitating the use of superheater surfaces for lining the combustion chamber. Accordingly, with steam generators of this construction and particularly when they are intended to operate at high pressures, there is a danger that excessive temperature differences will occur at the boundary between the evaporator and the first superheater during starting because no steam will be available for cooling the superheater. This can be particularly damaging where the tubes are welded together in gas-tight manner.

Accordingly, it is an object of the invention to reduce the temperature differences at the boundary between the evaporator and first superheater of a gas-tight combustion chamber of a steam generator.

It is another object of the invention to cool the tube walls of a combustion chamber including an evaporator and first superheater from the beginning of steam generator starting.

Briefly, the invention provides a steam generator having a gas-tight tubular combustion chamber wall forming an evaporator and superheater with tap-off means for recirculating a portion of the working medium flow through the evaporator and superheater.

The steam generator is supplied with feed water from a feed water tank and is constructed with a combustion chamber which is divided into two sections in series with respect to the flow of working medium. The combustion chamber is formed of tubes which are welded to one another in gas-tight manner so that the lower section of the combustion chamber forms at least part of an evaporator and the upper section forms a first superheater. In addition, at least one further superheater is positioned in the working medium path within the combustion chamber and a steam turbine is connected to the downstream superheater. Also, a line with a shut off means therein leads from the line connecting the downstream superheater to the steam turbine for by-passing the working medium around the turbine. In order to tap-off the working medium a first working medium tap is positioned between the evaporator and the first superheater and a second working medium tap is positioned at the end of the first superheater. A water separator is connected to both tapping positions or a water separator is connected to each tapping position and a connection is made between the separator or separators for returning separated water to the working medium flow path between the feed water tank and the evaporator.

The steam generator can be started in such a way that there is little risk of danger arising from excessive temperature differences and that steam can be delivered quickly for heating the turbine. That is, during the early stages of starting, working medium is tapped off from the second tapping position and is passed through the water separator associated with that tapping position (or through the common separator if one is employed instead of two individual separators) and is recycled to the working medium flow path between the feed water tank and evaporator. Thereafter, at least during part of the later stages of starting, working medium is tapped off from the first tapping position, passed through the water separator associated with that tapping position (or the common water separator) and returned to the working medium flow path between the feed water tank and the evaporator. With this form of operation, the combustion chamber tube walls are cooled from the beginning of starting since water is circulated through the first superheater in addition to being circulated through the evaporator. In the later stages of starting, and as soon as sufficient steam is generated, the steam is superheated in the superheater downstream of the first superheater and is then used for preheating the turbine system.

These and other objects and advantages of the invention will become more apparent from the following detailed description and appended claims taken in conjunction with the accompanying drawings in which:

FIG. 1 schematically illustrates a forced through-flow steam generator of the invention with two liquid separators; and

FIG. 2 schematically illustrates a forced through-flow steam generator of the invention with one liquid separator.

Referring to FIG. 1, the steam generator has a combustion chamber 1 bounded by tubes which are welded to one another in gas-tight manner and which extend rectilinearly from a lower inlet header 3 to an upper discharge header 7. As regards the working medium flow, the combustion chamber tube system is subdivided into two sections in series of which the lower section forms an evaporator 2 and the upper section forms a first high-pressure superheater 5. At the upper end of the evaporator 2 the tubes are bent out of the combustion chamber wall and extend into a header 4. The header 4 is connected by a duct 91 which defines a first tapping position to a centrifugal water separator 20. At the lower end of the first superheater 5 the tubes are also bent outwardly and are connected to an inlet header 6 which is connected to the steam exit of the separator 20. The bends of the tubes 2 and 5 are alternatively disposed at different levels to provide an intermeshed transfer from the evaporator 2 to the superheater 5. Also, a duct 23 which defines a second tapping position connects the header 7 to a centrifugal water separator 25. The steam exit of this separator 25 is connected by a duct 30 to a second high-pressure superheater 10 of platen construction, the platens being arranged to lie above the flame created within the combustion chamber by the burner assembly.

The steam generator combustion chamber contains, in addition to the superheater 10, a final superheater 12 in the working medium flow path which functions as a convection heat exchanger and which is connected via a valve 33 to a high-pressure stage 34 of a steam turbine plant. A by-pass line 31 with a valve 40 is provided between the final superheater 12 and the high-pressure stage 34 in parallel with the high-pressure stage 34 for steam to be blown off during the initial stages of starting up. Also, a reheater 11 is interposed in the working medium flow path between the high-pressure stage 34 and a low-pressure stage 38 of the steam turbine plant, the reheater being located in the steam generator between the superheaters 10 and 12, respectively. The low-pressure stage 38 is further connected by an outlet line to a condenser 39 which in turn communicates with the tank 8. The high-pressure stage 34 and the low-pressure stage 38 of the steam turbine plant are each by-passed through a duct containing a by-pass valve 41, 42, respectively, connected between the inlet and outlet lines of each stage. The duct containing the valve 41 together with the duct containing the valve 42 constitute a by-pass line with shut-off means leading from the line connecting the downstream high-pressure superheater 12 and the turbine 34, 38. Alternatively, where no reheater is employed, this by-pass function is performed by the duct 31 and valve 40.

A feed water supply tank 8 supplies the feed water to the steam generator via a supply duct 15 which contains a feed pump 16 as well as a preheater (as shown) which connects to an outlet of the high-pressure stage 34 of the steam turbine.

The supply duct **15** connects with an economiser **13** positioned within the upper end of the combustion chamber to convey the feed water therethrough. The economiser **13**, in turn, is connected by a duct **18** to the inlet header **3** of the evaporator **2** to deliver the feed water to the inlet header **3**.

Also, the water exit of the separator **20** at the first tapping position is connected by a duct **36** which contains a circulating pump **21** and a non-return valve **22** downstream of the pump **21** to the duct **18** upstream of the inlet header **3** in order to recycle the water in the separator **20** into the evaporator **2**. The duct **36** also communicates with a duct **37** which contains a flow control valve **51** so that a proportion of the water in the duct **36** can be drawn off for purification purposes. In order to control the amount of water drawn off, a level regulator **50** is connected with the flow control valve **51** and the separator **20** to open and close the flow control valve **51** in response to the sensed water level in the separator **20**. The lever regulator **50** is also connected to the feed pump **16** in the supply duct **15** to control the flow of water fed into the economiser **13**.

Similarly, the water exit of the separator **25** at the second tapping position is connected by a duct **27** which contains a flow control valve **28** to the supply duct **15** upstream of the pump **16**. The flow control valve **28** is controlled by the water level in the separator **25** via a level regulator N connected into the separator **25**. Also, a duct **9** which contains a flow control valve **26** is connected between the duct **23** leading to the separator **25** and the duct leading from the separator **25** in order to provide a by-pass for the working medium leaving the discharge header **7**.

In operation, when the steam generator is first started up, the valve **26** in the duct **9** by-passing the separator **25** is closed and the by-pass valve **40** or the valves **41**, **42** are opened. Next, the feed pump **16** is actuated to supply feed water through the economiser **13** to the evaporator **2** and superheater **5** via the separator **20** and header **6**. Also, the circulating pump **21** is actuated to circulate feed water through the evaporator **2**, separator **20** and duct **36**. As the separator **20** is thus flooded, the level regulator **50** is rendered ineffective. The feed water then passes from the discharge header **7** through the duct **23** into the separator **25**. Excess water is returned from the separator **25** via the duct **27** to the duct **15** upstream of the feed pump.

The fire is then ignited whereupon saturated steam is gradually generated in the superheater **5**. This steam is separated in the separator **25** and, in the early stages, passes via the superheaters **10** and **12** and the by-pass line **31** to atmosphere or a degasser (not shown) or via the valve **41**, the reheater **11** and the valve **42** into the condenser **39**. In the later stages of the starting up procedure, the by-pass valve **40** or the valves **41**, **42** are closed and the steam is employed for preheating the high-pressure and low-pressure stages **34**, **38**, respectively, of the steam turbine. The reheater **11** is either brought into the flow or remains therein at this time. As the firing effect increases, the separator **25** and thereafter the superheater **5** are run dry. When this state is achieved the control of the feed pump **16** is transferred to the level regulator **50** on the separator **20** at the first tapping position. The regulator **50** then maintains the level in the separator **20** constant while the circulating pump **21** remains in operation up to approxiamtely 50 percent of full load to superimpose a recirculation of the working medium on the forced-flow of the working medium. When the load increases beyond 50 percent, the steam generator will then function in the manner of a pure once-through forced-flow system.

During normal operation of the steam generator, the valves **28**, **40**, **41** and **42** are closed and the recirculating pump **21** is deactivated. The feed water then passes from the tank **8** through the economiser **13** and the duct **18** into the evaporator **2** and from there via the header **4** into the separator **20**. The level regulator **50** regulates the rotational speed of the feed pump **16** in dependence on the water level and, by adjusting the valve **51**, regulates the amount of working medium discharged for purification through the duct **37**. This discharge working medium is returned to the working medium circuit through a desalting system (not shown). The steam separated in the separator **20** flows through the first superheater **5** to the header **7** from which one part of the steam is passed through the dry separator **25** to the duct **30** and the other part of the steam is passed through the duct **9** to the duct **30**. The steam in the duct **30** then passes through the platen superheater **10** to the final superheater **12**. Next, the steam flows through the high-pressure stage **34** to do work and, after being reheated in the reheater **11**, passes through the low-pressure stage **38** to the condenser **39**. After being condensed, the condensate in the condenser **39** is returned to the tank **8**.

Referring to FIG. 2, wherein like numerals have been used to indicate like parts as above, the steam generator is provided with only a single water separator which is connected to the two tapping positions.

The upper section of the combustion chamber **1** is formed from tubes which extend rectilinearly upwardly from below and are welded together in a gas-tight manner to form a first superheater **5**. The lower section which forms an evaporator **2**, however, is formed from tubes in which, in two opposite walls the tubes extend horizontally while in the remaining two walls the tubes are slightly inclined to the horizontal to form quasi-helical windings. These tubes are also welded to each other in gas-tight manner and the lower section is welded to the upper section. As above, the tubes of the evaporator **2** are bent outwardly where the lower section of the combustion chamber **1** meets the upper section. However, the tubes of the evaporator **2** return into the interior of the combustion chamber **1** within a plane **75** above the inlet header **6** of the superheater **5** tubes so as to form supporting tubes **76** for the heat exchangers **10'**, **11**, **12**, **13** which are heated by convection.

These supporting tubes **76** lead to a header **77** outside the combustion chamber **1**. The heater **77** is connected by a duct **78** which defines a first tapping position and contains a valve **79** to a centrifugal water separator **63**. The steam exit of the separator **63** communicates with the inlet header **6** via a duct **82** which is connected to the steam exit and leads to another duct **100** connected to the inlet header **6** intermediately of a pair of valves **83**, **95** therein.

The discharge header **7** communicates with the separator **63** via a duct **90** which defines a second tapping position and is connected to the duct **78** leading to the separator **63** at a point downstream of the valve **79**. The duct **90** also contains a valve **94** for controlling flow of the working medium therethrough. Thus, both tapping positions communicate in common with the separator **63**.

Similarly, in view of the juncture of the ducts **78**, **90** of the two headers **77**, **7**, the steam exit of the separator **63** is provided with two exit paths. That is, the duct **100** is connected downstream of the valve **95** therein to the second high-pressure superheater **10'** so that the steam in the duct **82** can flow to either the header **6** of the first superheater **5** or the second superheater **10'**. The discharge end of the second superheater **10'** is connected to the final superheater **12** which in turn is connected to the steam turbine **34**, **38**, as above.

The separator **63** may be by-passed by a duct **101** which contains a valve **94** and connects the duct **90** upstream of the valve **94** to the duct **100** between the valve **95** and the second superheater **10'**. A similar by-pass facility is provided by a duct **102** which contains a valve **96** and connects the duct **78** upstream of the valve **79** to the duct **100** downstream of the valve **83**.

The water exit of the separator **63** is connected by a duct **36** containing the circulating pump **21** and the non-return valve **22** to a header **60** along one combustion chamber wall from which the downcomers **65** extend to supply working medium to the lower header **3** of the evaporator **2**. The downcomers **65** may also perform supporting functions where appropriate. The header **60** is also supplied with feed water from the economiser **13** through the duct **18**. Headers **61** and **62** corresponding to the header **60** are provided for the remaining

combustion chamber walls and downcomer tubes **65** extend therefrom into the headers **3** of the evaporator **2**. In the interests of clarity, the downcomer tubes **65** are shown at a greater distance from the combustion chamber wall than is in fact the case.

In normal operation, the valves **94**, **95**, and **96** are closed and the valves **79**, **83** and **93** are opened, feed water is passed from the tank **8** by means of the pump **16** through the economiser **13**, the duct **18**, the headers **60**, **61** and **62** and the downcomer **65** into the evaporator **2**. After flowing through the evaporator, the working medium passes via the supporting tubes **76** into the header **77** and from there via the duct **78** into the separator **63** (see the solid triangular arrows). The separated steam passes via the ducts **82**, the valve **83** and the header **6** into the first superheater **5** and from there via the header **7** and the ducts **90** and **101** into the second superheater **10'**. After flowing through this superheater **10'**, the steam is finally superheated in the superheater **12** whereupon the steam flows through the high-pressure turbine stage **34** to perform work and, after being reheated in the reheater **11**, passes through the low-pressure turbine stage **38**. The condensate from the condenser **39** is returned to the feed water tank **8**.

For the starting up procedure, the valves **79**, **83** and **93** are first closed and the valves **94**, **95** and **96** are opened so that the water separator **63** is connected to the second tapping point. The working medium is conveyed by means of the feed pump **16** through the economiser **13** and is subsequently supplied through the ducts **18**, the headers **60**, **61** and **62** and the supporting tubes **65** to the headers **3** from which the working medium passes through the supporting tubes **76**, is collected in the header **77** and passes via the ducts **78** and **102** into the header **6** of the first superheater **5** thereby by-passing the separator **63** (see the open triangular arrows). After passing through the superheater **5** the working medium is collected in the header **7** and passes via the duct **90** and the valve **94** into the separator **63**. From the separator **63** the separated water is returned by means of the circulating pump **21** to the header **60**. Where appropriate, excess water can be discharged via the purification valve **51**, as above. Steam which is separated in the separator **63** passes via the ducts **82** and **100** and the valve **95** into the second superheater **10'** and from there via the final superheater **12** to the by-pass line **31** and valve **40** or to the by-pass line **31** and the by-pass line **41**, the reheater **11** and the by-pass valve **42** to the condenser **39**. In the later stages of the starting procedure, that is, with increasing temperature rise of the working medium, the water level in the separator **63** will drop to its normal level whereupon the valve **79** is slightly opened. As soon as slightly superheated steam is present in the duct **90**, the system is changed over, that is, the valve **79** is opened still further and the valves **83** and **93** are also opened while the valves **94**, **95** and **96** are closed. From this moment onwards the separator will be connected to the first tapping point and only vaporized working medium will flow through the superheater **5**.

I claim:

1. A forced through-flow steam generator comprising:

a feed water supply means;

a combustion chamber of gas-tight tubular walls, said walls having a lower section forming an evaporator connected to said supply means to receive feed water therefrom and an upper section forming a first superheater;

at least one other superheater disposed in said combustion chamber downstream of said first superheater;

a first tapping means connected between said tubes of said evaporator and said first superheater for receiving working medium passing from said evaporator to said first superheater;

a second tapping means connected to said first superheater at the exit thereof for receiving working medium passed from said first superheater;

a first separator connected in said first tapping means for separating the received working medium into steam and water;

a second separator connected to said second tapping means for separating the received working medium into steam and water;

first duct means connected to said first separator for returning separated water to the feed water flow path between said supply means and said evaporator and for supplying working medium to said first superheater; and

second duct means connected to said second separator for returning separated water to the feed water flow path between said supply means and said evaporator and for supplying separated steam to said other superheater.

2. A forced through-flow steam generator as set forth in claim **1** further comprising a steam turbine connected downstream of said other superheater, and by-pass means connected in parallel with said steam turbine to said other superheater for selectively by-passing the flow of working medium from said other superheater past said steam turbine.

3. A forced through-flow steam generator as set forth in claim **2** further comprising a reheater disposed in said combustion chamber, said reheater being connected in the working medium flow path between a high-pressure stage and low-pressure stage of said steam turbine.

4. A forced through-flow steam generator as set forth in claim **1** wherein said first duct means includes a circulating pump and a non-return valve downstream of said pump for passing the separated water into said feed water flow path between said supply means and said evaporator.

5. A forced through-flow steam generator as set forth in claim **1** wherein said second duct means includes a flow control valve for controlling the flow of separated water returned to said feed water flow path and means responsive to the level of water in said second separator for controlling said flow control valve.

6. A forced through-flow steam generator comprising:

a feed water supply means;

a combustion chamber of gas-tight tubular walls, said walls having a lower section forming an evaporator connected to said supply means to receive feed water therefrom and an upper section forming a first superheater;

at least one other superheater disposed in said combustion chamber downstream of said first superheater;

a first tapping means connected between said tubes of said evaporator and said first superheater for receiving working medium passing from said evaporator to said first superheater;

a second tapping means connected to said first superheater at the exit thereof for receiving working medium passed from said first superheater;

a separator for separating the received working medium into steam and water;

duct means connected to said separator for returning separated water to the feed water flow path between said supply means and said evaporator;

duct means connectable to said separator for supplying the separated steam to said other superheater when said separator receives working medium from said second tapping means; and

duct means connectable to said separator for supplying working medium to said first superheater when said separator receives working medium from said first tapping means.

7. A forced through-flow steam generator as set forth in claim **6** wherein said first tapping means includes a first header connected to the tubes of said evaporator, a first duct communicating said first header with said separator, a first valve in said first duct for controlling flow of working medium therethrough, and a first by-pass means upstream of said first valve connected in parallel with said separator between said first duct and said first superheater, and said second tapping means includes a second header connected to the tubes of said first superheater, a second duct communicating said second header with said first duct downstream of said first valve, a second valve in said second duct for controlling flow of working medium therethrough, and a second by-pass means up-

stream of said second valve connected between said second duct and said other superheater.

8. A forced through-flow steam generator as set forth in claim **7** which further comprises a by-pass means connected between said first tapping means downstream of said separator and said second by-pass means for conveying steam from said separator to said second superheater.

9. A forced through-flow steam generator as set forth in claim **6** which further comprises a by-pass means in said first tapping means in parallel with said separator for by-passing the working medium around said separator and a by-pass means connected between said second tapping means and a second superheater disposed in said combustion chamber for passing steam into said second superheater.

10. The method of starting up a forced through-flow steam generator comprising the steps of:

passing a flow of working medium through an evaporator and at least two superheaters within a combustion chamber of the steam generator;

passing the flow of working medium through a separator interconnected in the working medium flow between the first of said superheaters and the second of said superheaters during the initial phase of operation of the steam generator, and

tapping working medium from the flow of working medium between said first and second superheaters and returning the tapped working medium to the evaporator during said initial phase and tapping working medium from the flow of working medium between said evaporator and said first superheater and returning the tapped working medium to the evaporator at least at intervals during the remaining phases of starting up operation of the steam generator.