Oct. 19, 1965 H. GERBER ETAL 3,212,477

FORCED FLOW STEAM GENERATOR AND METHOD OF STARTING SAME

Filed Sept. 5, 1963 3 Sheets-Sheet 1

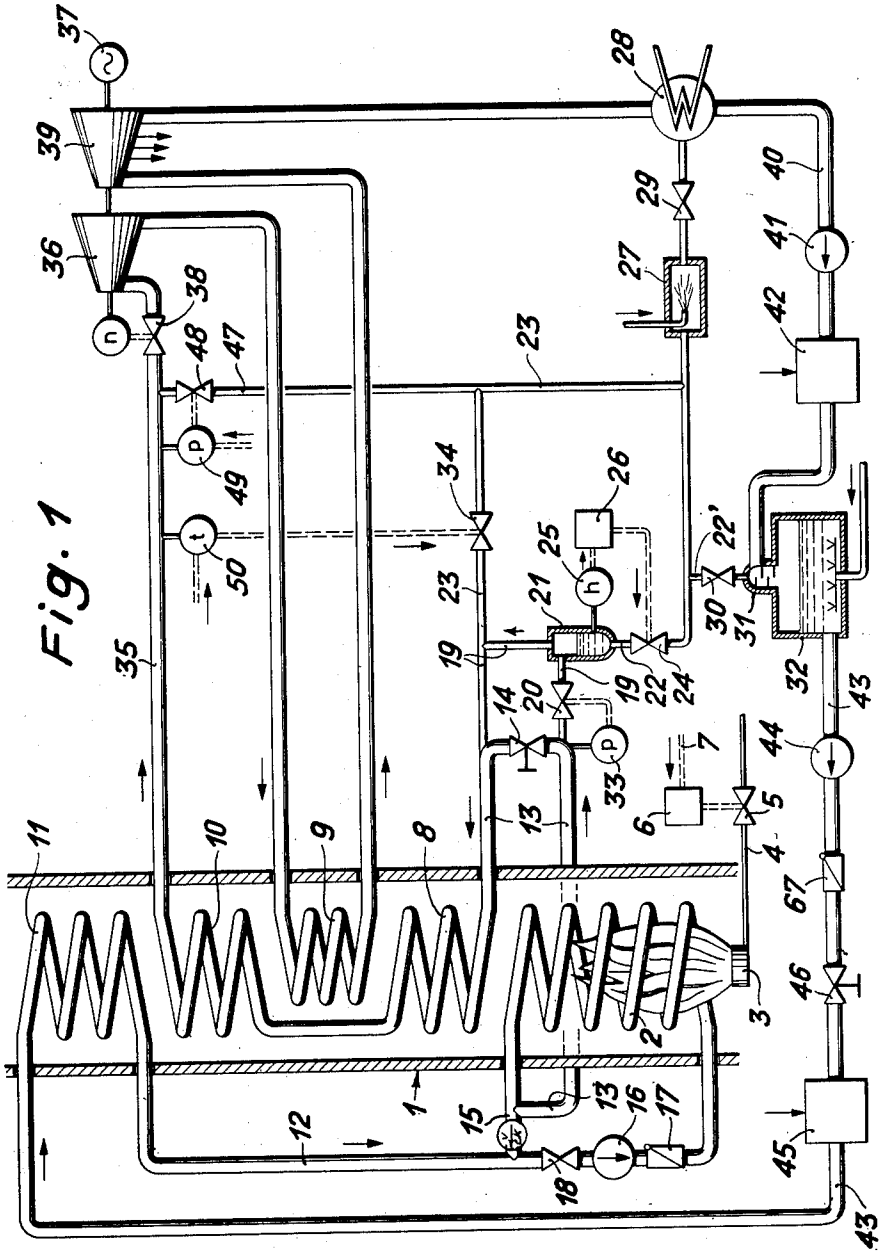

Fig. 1

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Fig. 2

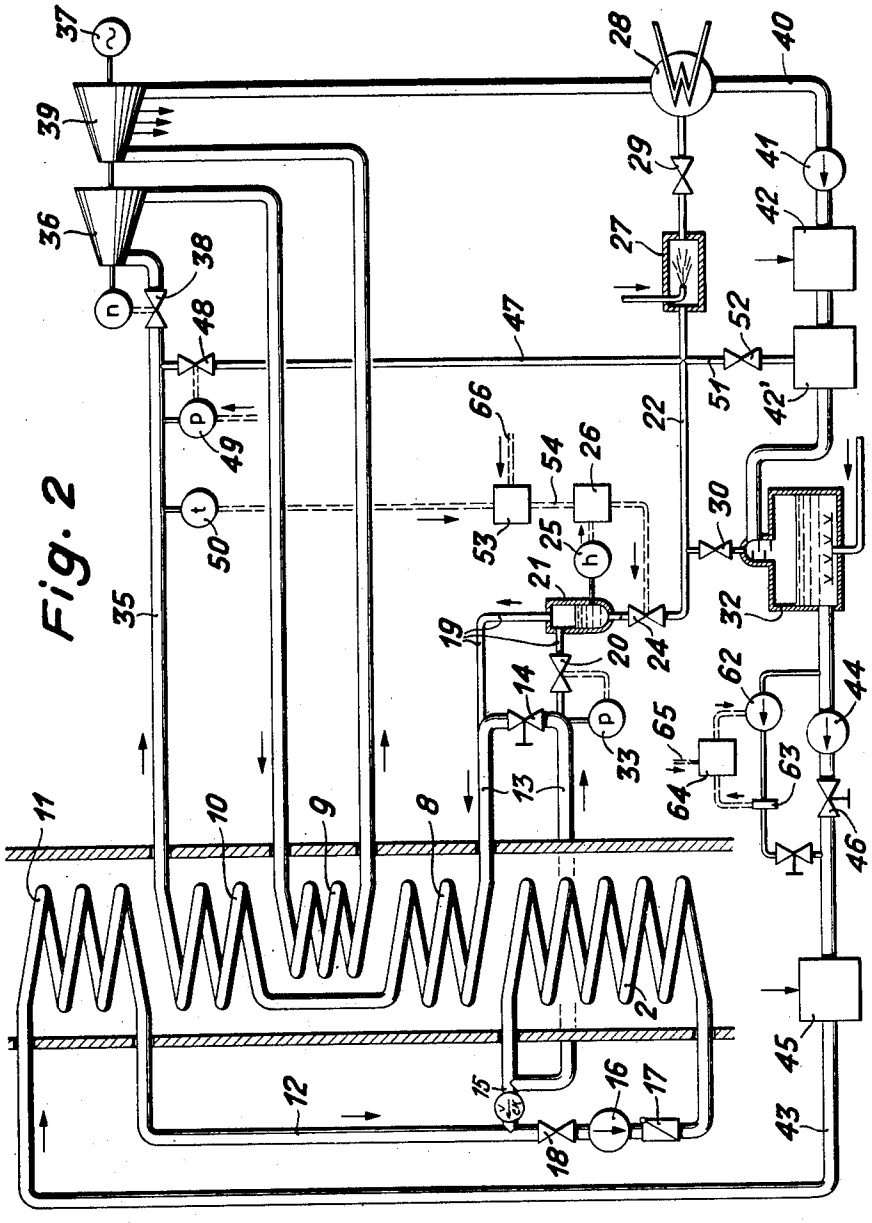

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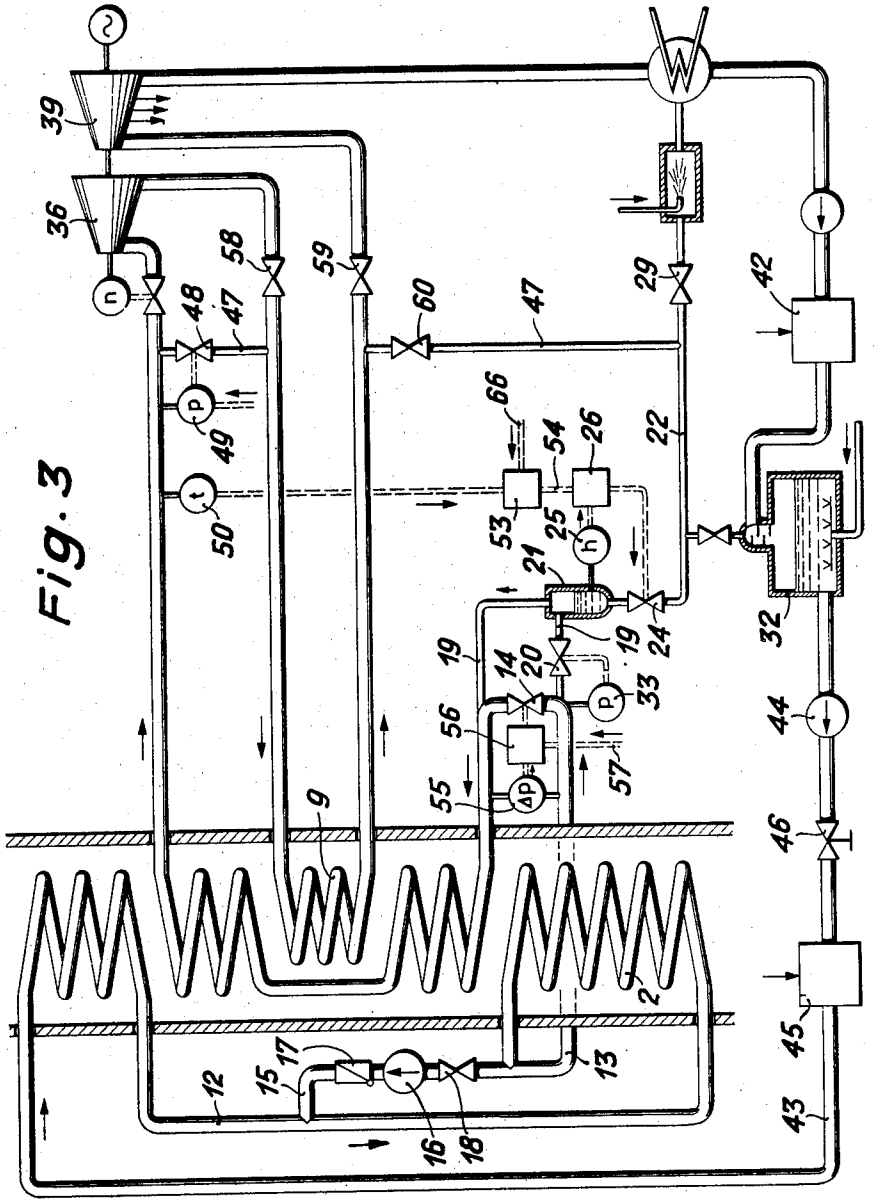
Fig. 3



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FORCED FLOW STEAM GENERATOR AND METHOD OF STARTING SAME

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The present invention relates to a method of starting a forced flow steam generator whereby operating medium is recirculated through a part of the heating sections and no operating medium flows through the balance of the heating sections of the steam generator during the starting period.

In a known starting method of a force flow steam generator wherein a valve is interposed between an evaporating section and a superheating section and a pipe is connected upstream of said valve for returning operating medium to the feedwater reservoir, operating medium is pumped by the feed pump from the feedwater reservoir through an economizer and an evaporator and is returned through the aforesaid pipe to the feedwater reservoir while the superheater which is placed in a slightly heated portion of the steam generator remains dry. When the circulating operating medium contains sufficient steam which is separated from water in a separator placed downstream of the evaporator, the valve upstream of the superheater is opened and the separated steam is used for cooling the superheater. This method, which is generally quite satisfactory, is not suitable for steam generating plants wherein the superheater heating surfaces are rather highly heated and cannot be operated dry for any appreciable time.

It is an object of the present invention to provide a method of starting a forced flow steam generator wherein steam is available within a minimum period of time for cooling the superheater heating surfaces. In the method according to the invention the feedwater supply to the steam generator is stopped. Operating medium contained in the heating section of the steam generator which is exposed to radiant heat produced by burning fuel is recirculated and heated in said section. Upon obtaining a predetermined pressure operating medium is taken from the radiant heat heated section and partly expanded, at least a portion of the steam produced thereby is conducted into the heating sections which are arranged downstream of the radiant heat section, the feedwater supply is started and fuel supply is increased, the pressure of the steam in the heating sections downstream of the radiant heat section is increased and upon substantial equalization of the pressure of the operating medium in the heating section downstream of the radiant heat heated section and in the latter the operating medium is conducted directly from the radiant heat section into the subsequent heating sections. In the method according to the invention at first only the operating medium contained in the heating section which is exposed to radiant heat is heated and partly evaporated so that after a very short time and with a minimum of firing intensity, which is not harmful to the subsequent heating sections, steam is available for cooling the subsequent heating surfaces. When this is the case the feedwater supply is started and gradually increased so that operating medium is conducted into the radiant heat section at a gradually increasing rate. The method according to the inventon permits considerable shortening of the starting operation whereby fuel consumption is reduced.

A further object of the invention is the provision of a forced flow steam generator suitable for performing the aforedescribed method. The steam generator according

to the invention comprises a plurality of heating sections through which operating medium flows consecutively, a valve interposed between a heating section which is exposed to radiant heat generated by combustion of fuel, and a heating section arranged downstream of said radiant heat section, and a by-pass conduit connected downstream of the last of the heating sections through which operating medium flows consecutively. The steam generator according to the invention comprises means for recirculating the operating medium through the heating section which is exposed to radiant heat, a by-pass conduit for by-passing operating medium around the valve interposed between the radiant heat section and the subsequent heating section, and a valve and a water separator interposed in said by-pass conduit. The separator is shunted with respect to the normal flow of the operating medium through the steam generator. The last mentioned by-pass conduit and the separator interposed therein are designed to withstand the normal operating pressure of the steam generator.

The novel features which are considered characteristic of the invention are set forth with partciularity in the appended claims. The invention itself, however, and additional objects and advantages thereof will best be understood from the following description of embodiments thereof when read in connection with the accompanying drawing wherein:

FIG. 1 is a diagrammatic illustration of a forced flow steam generator according to the invention.

FIG. 2 is a diagrammatic illustration of a modified steam generator according to the invention.

FIG. 3 is a diagrammatic illustration of yet another modification of a steam generator according to the invention.

Like parts are designated by like numerals in the several figures.

Referring more particularly to FIG. 1 of the drawing, numeral **1** designates a forced flow steam generator having a heating section **2** which is essentially heated by radiant heat produced by fuel burning means **3**. The latter is supplied with fuel through a pipe **4**, the fuel supply being controlled by a valve **5**. The valve **5** is actuated by a servomotor **6** which is operated according to signals supplied through a conduit **7** and produced in an apparatus, not shown, which is responsive to the load on the steam generator and/or by an apparatus, not shown, for starting the steam generator.

The steam generator comprises a plurality of heating sections which are consecutively arranged in the stream of hot gases produced by the firing apparatus **3**. A heating section which receives operating medium from the heating section **2** and which receives heat mostly by convection serves as a superheater **8**; the subsequent section in the stream of hot gases is a reheater **9**. The next section constitutes a second superheater **10** and is followed with respect to the stream of hot gases by an economizer **11**. The economizer **11** is connected to the radiant heat heated section **2** by means of a pipe **12**. This pipe is also connected by a pipe **13** to the superheater **8**. A valve **14** is provided in the pipe **13** for controlling flow of operating medium into the superheater **8**. The radiant heat heated section **2** is connected by a pipe **15** to the pipe **12**. A valve **18**, a circulating pump **16**, and a check valve **17** are interposed in the pipe **12** downstream of the connection between the pipes **15** and **12**.

A by-pass pipe **19** is connected to the pipe **13** upstream of the valve **14**. A valve **20** and a water separator **21** are interposed in the pipe **19**. A blowdown pipe **22** is connected to the water space of the separator **21** and is provided with a valve **24** which is controlled in response to the water level in the separator **21**. For this purpose a device **25** which is responsive to the water level in the

separator 21, produces signals which actuate a motor operator 26 for actuating the valve 24. An injection cooler 27 and a valve 29 are interposed in the pipe 22 which terminates in a condenser 28. A pipe 22' provided with a valve 30 connects the pipe 22 to a degasifier 31 associated with a feedwater reservoir 32.

The valve 20 in the by-pass pipe 19 is actuated by a pressure regulator 33 which is responsive to the pressure of the operating medium in the pipe 13 upstream of the valve 14. Downstream of the water separator 21 in pipe 23 provided with a valve 34 is connected to the pipe 19 and terminates in the pipe 22 upstream of the injection cooler 27.

The outlet of the superheater 10 is connected to a steam main 35 conducting steam into the high pressure part 36 of a turbine operating an electric generator 37. A valve 38 which is controlled in response to the speed of the turbine is interposed in the steam main 35. The aforementioned reheater 9 is arranged between the outlet of the high pressure part 36 and the inlet of a low pressure part 39 of the steam turbine which exhausts into the condenser 28. The condensate is conducted from the condenser 28 through a pipe 40 to the feedwater reservoir 32. A condensate pump 41 and a steam-heated feedwater preheater are interposed in the pipe 40. Feedwater is supplied by the reservoir 32 to a pipe 43 wherein a feed pump 44, a check valve 67, a valve 46 and a steam-heated preheater 45 are consecutively arranged. The pipe 43 is connected to the inlet of the economizer 11.

A by-pass pipe 47 is connected to the steam main 35 upstream of the valve 38 and is provided with a valve 48. The pipe 47 terminates in the pipe 23 which is connected to the by-pass pipe 19. The by-pass valve 48 is actuated by a pressure regulator 49 which is responsive to the pressure of the steam in the steam main 35 and which also receives set point signals from a starting apparatus, not shown. The valve 34 in the pipe 23 is controlled by a temperature regulator 50 which is responsive to the temperature of the steam in the steam main 35 and which also receives set point signals from a starting apparatus, not shown.

Operation of the method according to the invention:

If there is a possibility that the part of the tube system through which operating medium is recirculated is not entirely filled with water before starting the generator, water is pumped from the reservoir 32 through the economizer 11, the radiant heat surface 2, the separator 21, and is returned through the pipe 22 to the reservoir 32 while the valve 14 is closed. It is of advantage to close the valve 20 in the by-pass conduit 19 while the feed pump 44 is running and to increase the pressure of the operating medium to, for example, the critical pressure of the operating medium. Thereupon feedwater supply to the radiant heat section 2 is stopped by closing the valve 46. The valve 14 in the pipe 13, the valve 38 in the steam main 35 and the valve 29 in the conduit 22 are closed, whereas the by-pass valve 48 and the valve 30 are open. The valve 18 is opened and the circulating pump 16 started for recirculating the operating medium contained in the radiant heat section 2 through the check valve 17 and the pipe 15. Thereupon the combustion apparatus 3 is lighted for heating the circulating operating medium and increasing the pressure thereof. Upon reaching a predetermined pressure of the operating medium in the heating section 2 the pressure-sensitive regulator 33 opens the valve 20 in the by-pass pipe 19. Operating medium can now flow from the heating section 2 through the conduits 13 and 19 and the water separator 21 whereby the operating medium is partly expanded. The steam separated in the separator 21 flows through the conduit 19 into the superheaters 8 and 10 and cools the latter before flowing through the steam main 35, the by-pass pipe 47 and the pipes 23, 22 and 22' to the reservoir 32. When sufficient cooling steam is available steam may be withdrawn through the pipes 19 and 23 in order to increase the temperature of the superheater heating surfaces 8 and 10. This temperature increase is controlled by the temperature sensitive device 50 which actuates the valve 34 for controlling the amount of steam removed through the pipe 23. Opening of the valve 34 causes increase of the amount of steam diverted from the superheater 8 so that the amount of cooling steam passing through the superheaters 8 and 10 is reduced and the temperature of the superheaters is increased.

The water separated in the separator 21 is conducted through pipes 22 and 22' into the degasifier 31. When the steam in the steam main 35 has sufficient pressure and temperature the valve 38 may be slightly opened to admit at least a portion of the steam issuing from the superheater 10 to the turbine plant 36, 39 for heating same and to the reheater 9. The feed pump 44 is now started to operate at a minimum output and the valve 46 is opened while the output of the firing apparatus 3 is simultaneously increased. The set point value of the regulator 49 is increased to effect a rise of the pressure of the steam in the superheaters 8 and 10. The feedwater supply is increased by increasing the opening of the valve 46 and/or by gradually increasing the speed at which the pump 44 is operated. When the pressures of the operating medium upstream and downstream of the valve 14 are substantially equal this valve is opened. Upon reaching sufficient steam pressure in the steam main 35 the by-pass valve 48 may be closed and the turbine plant started.

If, upon starting the feed pump 44 the temperature and/or pressure of the operating medium drops at the outlet of the radiant heat section 2 so that there is a possibility that the valve 20 closes, the feed pump 44 is preferably operated discontinuously, i.e., repeatedly started and stopped. In this way, the feedwater supply is gradually increased to the feedwater supply for normal operation.

When there is sufficient heat energy accumulated in the reservoir 32 the valve 29 in the pipe 22 is opened to conduct a portion of the operating medium in the pipe 22 through the injection cooler 27 into the condenser 28.

In the embodiment of the invention shown in FIG. 2 a pipe corresponding to the pipe 23 branching from the by-pass pipe 19 and containing the valve 34, as shown in FIG. 1, is omitted. The signals produced by the temperature sensitive device 50 are conducted to a limiting element 53 which receives, through a conduit 54, signals corresponding to the water level in the separator 21 from the water level regulator 26. During advanced starting operation of the steam generator a starting device, not shown, or the operator supplies signals through a conduit 66 corresponding to the desired steam temperature in the steam main 35 which signals are gradually increased until the desired live steam temperature is obtained. The set point signals arriving through the conduit 66 are compared in the limiting device 53 with the actual steam temperatures. The device 53 feeds an increasing signal into the conduit 54 when the actual steam temperature is lower than the desired steam temperature. The signals in the conduit 54 are superposed on the signals produced by the device 26 so that the valve 24 is opened. In this way the entire water content of the separator 21 may be drained and steam may be removed through the pipe 22. If the actual steam temperature is higher than the desired steam temperature, the signal in the conduit 54 becomes smaller and the valve 24 is closed until the water level regulator 26 comes into action.

In lieu of the aforedescribed arrangement an arrangement may be provided wherein the signals in the pipe 54 and the signals produced by the regulator 26 are conducted into a selecting device which actuates the valve 24 in the aforedescribed manner.

In the arrangement shown in FIG. 2 an auxiliary feed pump 62 is arranged in parallel relation to the main feed pump 44, the capacity of the auxiliary feed pump being about 10% of the maximum capacity of the main feed pump. The auxiliary feed pump 62 is controlled by a

regulator **64** which is responsive to a flowmeter **63** and receives set point signals from a starting device, not shown, through a conduit **65**. When the starting operation is sufficiently advanced so that cooling steam flows through the heating surfaces **8** and **10** the auxiliary feed pump **62** is started. If the output of the auxiliary feed pump is too small as to correspond to the increased output of the firing apparatus, the auxiliary feed pump may be stopped and the main feed pump **44** is started and its output is gradually increased to the normal operating value.

In the arrangement shown in FIG. 2 a feedwater preheater **42'** is interposed in the condensate pipe **40** in addition to the steam-heated preheater **42** shown in FIG. 1. The preheater **42'** receives steam from the by-pass pipe **47** through a pipe **51** provided with a valve **52**. The pipe **51** is also connected by means of the pipe **22** to the water space of the separator **21**.

In the embodiment shown in FIG. 3 the circulating pump **16** is at the outlet of the tube system **2** in contradistinction to FIG. 1 wherein the circulation pump **16** is at the inlet of the radiant heat section **2**. In the arrangement shown in FIG. 3 a pressure difference sensitive device **55** is connected to the pipe **13** for measuring the difference of the pressures at the inlet and at the outlet of the valve **14**. The device **55** produces signals which control the operation of a servomotor **56** for actuating the valve **14**. The servomotor receives through a conduit **57** a signal corresponding to the maximum permissible pressure difference. The signal in the conduit **57** may be supplied from a starting device, not shown. The servomotor **56** opens the valve **14** only when the difference between the pressure upstream and downstream of the valve **14** is lower than the aforesaid maximum permissible pressure difference. In this way the valve **14** is unloaded prior to opening and fluttering is avoided.

In contradistinction to the arrangements shown in FIGS. 1 and 2 the by-pass pipe **47** is not directly connected to the pipe **22** but is connected to the inlet and outlet of the reheater **9** which may be separated from the high pressure turbine **36** and the low pressure turbine **39** by means of valves **58** and **59**. A valve **60** is provided in the portion of the by-pass pipe **47** connecting the outlet of the reheater **9** to the pipe **22**.

We claim:

1. A method of starting a forced flow steam generator having feedwater supply means, first heating conduits exposed to radiant heat generated by burning fuel and connected to said feedwater supply means for receiving feedwater therefrom, and second heating conduits receiving heat by convection and arranged to receive operating medium from said first heating conduits, said methods comprising:

filling said first conduits with feedwater,

stopping supply of feedwater to said first conduits and stopping flow of operating medium from said first conduits to said second conduits,

circulating and recirculating the operating medium in said first conduits and heating by radiant heat and simultaneously raising the pressure of the operating medium in said first conduits,

diverting operating medium from the outlet of said first conduits upon reaching a predetermined pressure of the operating medium in said first conduits and partly expanding the diverted operating medium,

conducting at least a portion of the diverted operating medium into said second conduits,

starting feedwater supply to said first conduits and increasing radiant heat supply thereto,

increasing the pressure of the operating medium in said second conduits, and

passing the operating medium from said first conduits into said second conduits upon reaching a pressure of the operating medium in said second conduits which pressure is substantially equal to the pressure in said first conduits.

2. A method as defined in claim **1** wherein feedwater is supplied intermittently to said first conduits after starting feedwater supply thereto.

3. A method as defined in claim **1** wherein feedwater is at first supplied at a relatively small rate to said first conduits after starting feedwater supply thereto and is thereupon separately supplied at a relatively great rate to said first conduits.

4. A method as defined in claim **1** wherein the pressure of the operating medium contained in said first conduits is raised before recirculation of the operating medium in said first conduits is started.

5. A forced flow stream generator comprising:

means for burning fuel and producing radiant heat,

first heating conduits located to receive radiant heat produced by said fuel burning means,

said first heating conduits forming a circuit,

means interposed in said circuit for circulating and recirculating operating medium exclusively through said circuit,

means for supplying feedwater to said first conduits,

second heating conduits receiving heat by convection and connected to said first heating conduits for receiving operating medium therefrom,

a steam main connected to said second conduits for receiving operating medium therefrom,

by-pass means connected to said steam main and to said feedwater supply means for by-passing operating medium around said second and said first conduits,

valve means interposed between said first and second conduits,

a by-pass conduit for by-passing operating medium around said valve means,

a throttle means and a water separator interposed in series relation in said by-pass conduit, and

control means connected to said throttle means and to said first conduits for opening said throttle means when the pressure in said first conduits exceeds a predetermined value, and conversely, for maintaining a predetermined pressure in said first conduits.

6. A forced flow steam generator as defined in claim **5** comprising a pipe connected to said by-pass conduit downstream of said water separator, a valve interposed in said last mentioned pipe, a temperature sensitive means operatively connected to said steam main and to said last mentioned valve for opening the latter upon a drop of the temperature of the steam in the steam main below a predetermined temperature and conversely.

7. A forced flow steam generator as defined in claim **5** comprising a blowdown pipe connected to said water separator, a valve in said blowdown pipe, means responsive to the water level in said water separator and connected to said valve for opening the latter upon a rise of the water level in said separator above a predetermined level and conversely, a temperature responsive means operatively connected to said steam main and to said water level responsive means for additionally actuating said valve in said blowdown pipe in an opening sense upon a drop of the temperature of the steam in the steam main below a predetermined value and conversely, and for allowing said water level responsive means to actuate said valve in said blowdown pipe upon obtaining the desired normal operating temperature in said steam main.

8. A forced flow steam generator as defined in claim **5** wherein said means for supplying feedwater to said first conduits comprises a main feed pump, and an auxiliary feed pump arranged in shunted relation to said main feed pump.

9. A forced flow steam generator according to claim **8** comprising means responsive to the rate of flow of feedwater through said auxiliary feed pump and connected to said auxiliary feed pump for increasing the rate of flow of

feedwater therethrough upon a decrease of said flow rate below a predetermined flow rate, and conversely.

10. A forced flow steam generator as defined in claim **5** comprising means responsive to the difference of pressure of the operating medium upstream and downstream of said valve means and connected to the latter for opening said valve means when said difference is below a predetermined value, and conversely.

11. A forced flow steam generator as defined in claim **5** comprising a steam reheater forming part of said by-pass means.

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