

[72] Inventor **Paul C. Zmola**
Bloomfield, Conn.
[21] Appl. No. **888,020**
[22] Filed **Dec. 24, 1969**
[45] Patented **Apr. 27, 1971**
[73] Assignee **Combustion Engineering, Inc.**
Windsor, Conn.

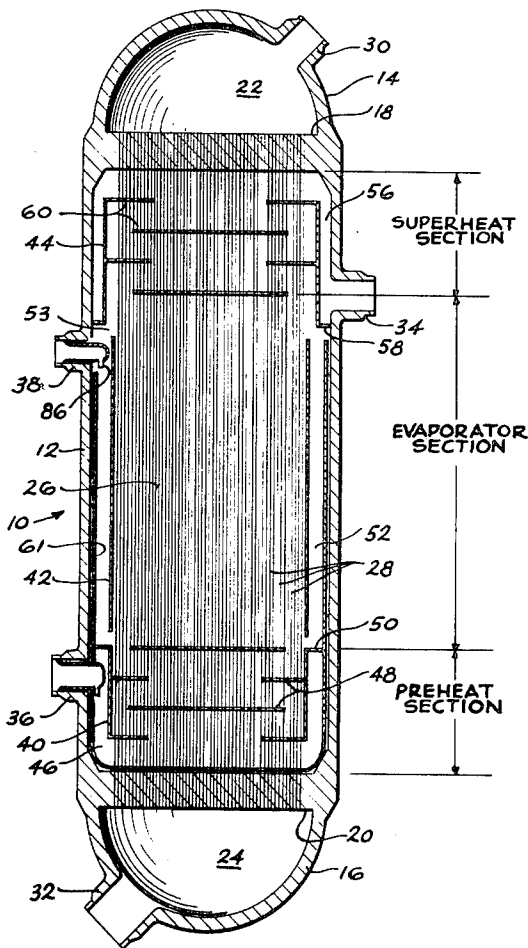
Primary Examiner—Kenneth W. Sprague
Attorneys—Carlton F. Bryant, Eldon H. Luther, Robert L.
Olson, John F. Carney, Richard H. Berneike, Edward L.
Kochey, Jr. and Lawrence P. Kessler

[54] **SHELL-AND-TUBE STEAM GENERATOR WITH
ECONOMIZER**
17 Claims, 3 Drawing Figs.

[52] U.S. Cl. 122/32,
122/406
[51] Int. Cl. F22b 1/06
[50] Field of Search 122/32, 33,
34, 406

[56] **References Cited**
UNITED STATES PATENTS
3,147,743 10/1964 Romanos. 122/32
3,385,268 5/1968 Sprague 122/32

ABSTRACT: A shell and tube vapor-generator is provided in which vaporizable liquid is transformed into vapor by passing it in heat transfer relation with heating fluid conducted through the tubes and a method for operating the same. The vaporizable liquid is preheated to about saturation temperature before being passed to the vapor-generating section of the unit. At full load operation the liquid is preheated by passing it in indirect heat transfer relation with the heating fluid conducted through the tubes. At low load operation it is preheated by condensing a portion of the vapor produced in the vapor-generating section and at intermediate loads preheating is accomplished by a combination of the two.



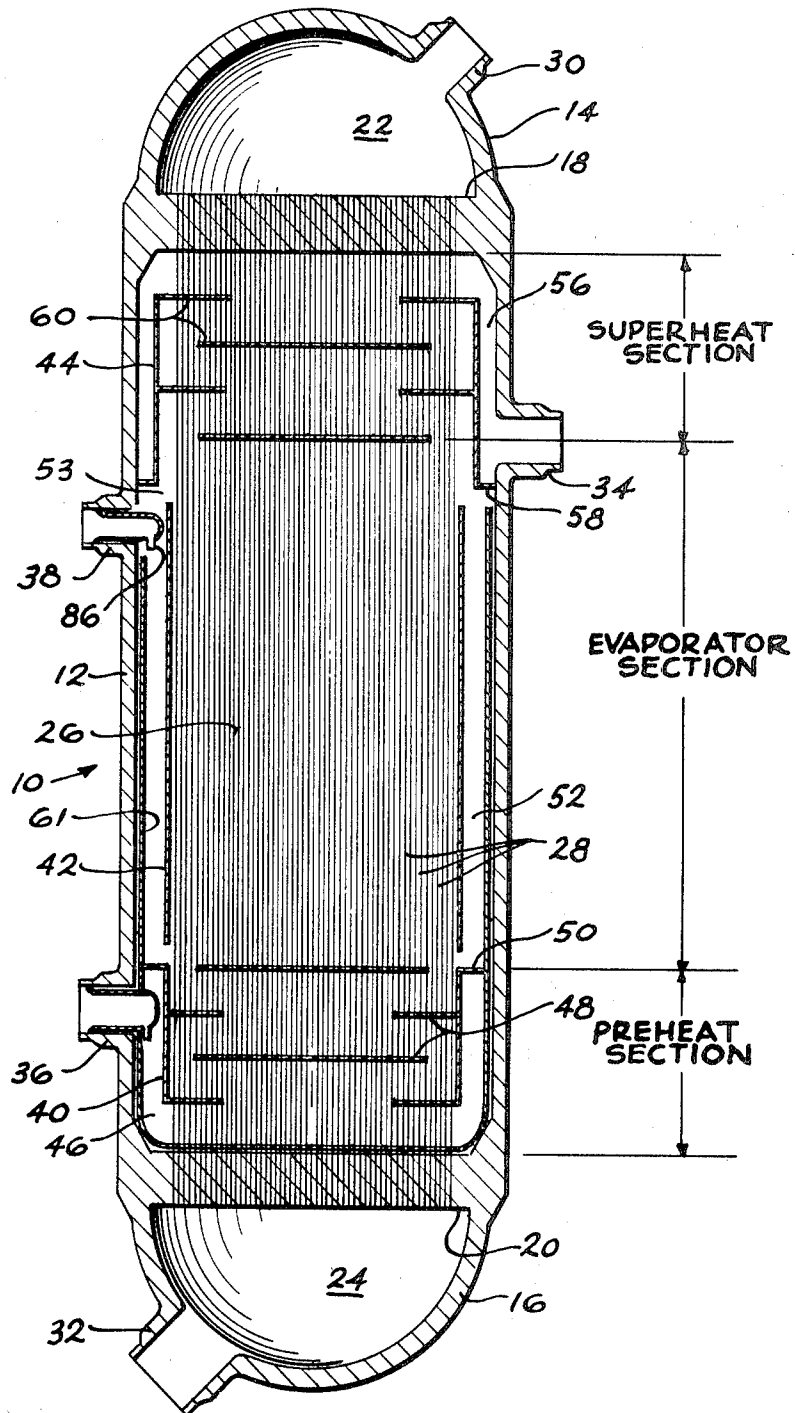


FIG-1

INVENTOR
PAUL C. ZMOLA

BY

John F. Carney
ATTORNEY

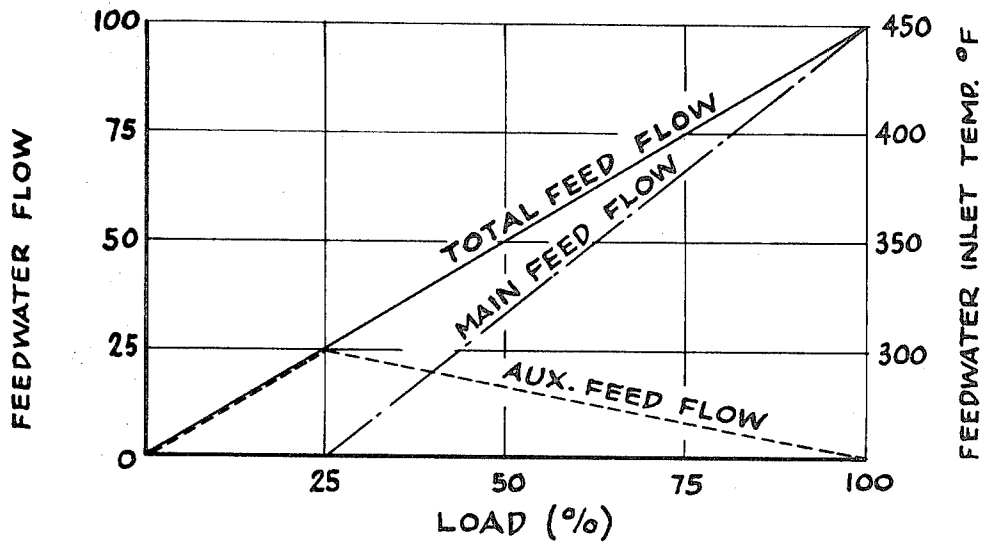


FIG-3

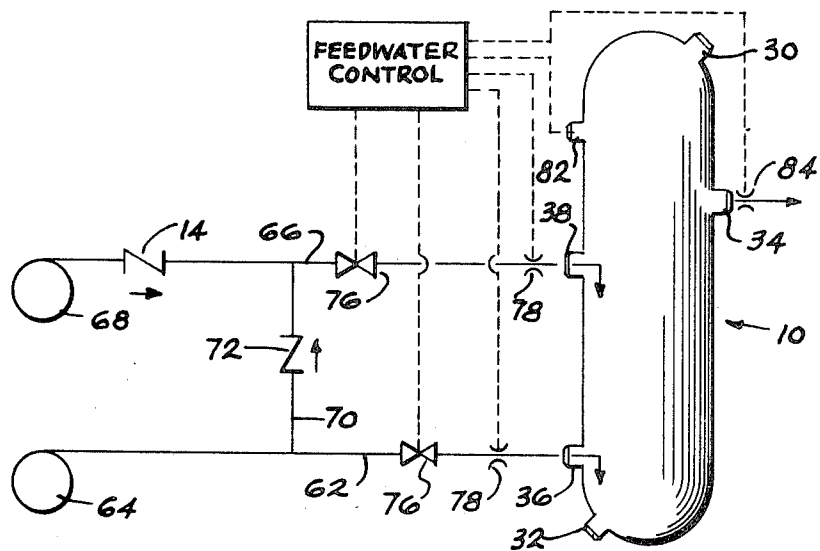


FIG-2

INVENTOR.
PAUL C. ZMOLA

BY *John F. Carney*
ATTORNEY

SHELL-AND-TUBE STEAM GENERATOR WITH ECONOMIZER

BACKGROUND OF THE INVENTION

The present invention relates in general to vapor generators of the shell- and tube-type wherein vaporizable liquid is transformed into vapor by passing it in heat exchange relation with a heating fluid that is conducted through the tubes. In vapor generators of this type, it is desirable to preheat feed liquid admitted to the unit to above saturation temperature prior to passing it to the evaporator section. This is done for two principle reasons. First, it reduces thermal gradients within certain of the component parts of the unit with which the feed liquid comes in contact, thereby reducing the danger of overstressing these elements. And secondly, it causes boiling heat transfer to occur along substantially the full length of the heat exchange surface in the evaporator section thereby resulting in the unit's operating at greater thermal efficiency.

It is generally well known that the most effective manner of heating vaporizable liquids in such units is by the transfer of heat to the liquid from the heating fluid. This is due to the considerably greater temperature head existing between the hot and cold fluids that is made available. However, it is also well known that to preheat the feed liquid in this manner will expose some of the component parts of the unit to the inlet temperature of the incoming liquid. Although feed liquid inlet temperatures may not be so low as to be harmful at full load operation of the vapor generator, they decrease in proportion to the reduction in load on the unit and at low loads they are sufficiently low as to subject the exposed component parts of the vessel to undue thermal stressing. Because such stressing cannot be tolerated in shell and tube vapor-generators, it has previously been the practice to preheat the incoming feedwater by immediately contacting it with some of the vapor generated in the evaporator section. While such practice is effective to raise the temperature of the feed liquid above undesirable limits, it results in a sacrifice to the efficiency of vapor generator operation.

The significance of this sacrifice in efficiency is considerable. In prior art vapor generators of the type wherein feedwater is preheated over the full load range by condensation of vapor, approximately 15,000 square feet of additional heating surface is required as compared with the amount of heating surface necessary for constructing vapor generators of the herein-disclosed type and of comparable capacity. This increase in required heating surface, of course, results in concomitant increase in fabrication costs of the unit.

Thus, the present invention is directed toward the solution of the problem of achieving greater thermal efficiencies within vapor generators of the disclosed type without exposing the pressure shell to undue thermal stressing.

SUMMARY OF THE INVENTION

Accordingly, the invention comprises a novel method of operating a vapor generator of the shell- and tube-type in which vaporizable liquid is passed in indirect heat transfer relation with the heating fluid. Prior to admitting the vaporizable liquid, referred to as feedwater, to the evaporator section of the vapor generator it is heated to about saturation temperature such that evaporation of the liquid will occur substantially immediately upon entrance of the liquid into the evaporator section. At full load operation of the unit, the feedwater, whose inlet temperature is above that considered to be deleterious to the structural integrity of the pressure shell, is heated entirely by passing it in indirect heat transfer relation with heating fluid that is conducted through the tubes. During periods of low load operation of the unit, when the feedwater inlet temperature is relatively low and therefore considered to be harmful, heating of the feedwater is accomplished entirely by passing it directly in contact with some of the vapor generated in the evaporator section. At intermediate loads the feedwater is preheated, in part by the

condensation of vapor and in part by the evaporation of heat from the heating fluid. Controls are provided to regulate operation of the vapor generator in order to effect feedwater preheating by the transfer of heat from the heating fluid in amounts proportional to the load on the vapor generator.

For a better understanding of the invention, its operating advantages and the specific objects obtained by its use, reference should be made to the accompanying drawings and description which relate to various embodiments of the invention.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is an elevational section of a vapor generator embodying the present invention;

FIG. 2 is a schematic representation of the feedwater delivery system for the vapor generator of FIG. 1 and including controls therefor; and

FIG. 3 is a plot illustrating the relationship between the vapor generator load and the manner by which feedwater preheating is effected.

DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIG. 1 there is shown a shell and tube vapor-generator unit 10. The unit comprises a vertically elongated cylindrical pressure shell 12 closed at its opposite ends by upper and lower domed closure members 14 and 16, respectively. Within the shell upper and lower transversely extending tube sheets, 18 and 20, respectively, are integrally attached to the shell wall and divide its interior into axially spaced chambers indicated as heating fluid inlet chamber 22, heating fluid outlet chamber 24, and vapor-generating chamber 26. A plurality of straight, fluid-conducting heat exchange tubes 28 extend through the vapor-generating chamber 26 between the two tube sheets and communicating with the respective heating fluid inlet and outlet chambers 22 and 24. Heating fluid inlet and outlet nozzles 30 and 32 communicate with the respective inlet and outlet chambers 22 and 24 in order to conduct heating fluid from a source (not shown) through the vapor-generating unit.

The wall of the pressure shell 12 is penetrated at three longitudinally spaced points by nozzles 34, 36, and 38. The uppermost nozzle 34 is a vapor outlet nozzle and serves to conduct vapor generated within the shell to a point of use. The other two nozzles are feedwater inlet nozzles with the lowermost nozzle 36 being the primary feed flow nozzle and the nozzle indicated as 38, located between this nozzle and the vapor outlet nozzle, being the secondary feed flow nozzle.

The tubes 28 are arranged in a bundle and are surrounded by baffle means concentrically spaced from the wall of the shell to define annular fluid flow passages. In the disclosed embodiment of the invention, three separate baffles 40, 42, and 44 comprise the baffle means. The first, indicated as 40 extends from a level spaced above the upper surface of the lower tube sheet 20 to a level just above the primary feed flow nozzle 36. The annular passage 46 surrounding this baffle is termed the primary feedwater flow passage. That region of the tube bundle enclosed by the baffle 40 is termed the preheat section and contains a plurality of axially spaced transverse baffle plates 48 that serve to conduct liquid admitted to this section of the shell in crossflow relation to the tubes 28 that extend through this region of the tube bundle. An annular transverse plate 50 closes the upper end of the passage 46 to prevent the admission of liquid thereto except that which passes through the flow nozzle 36.

The second baffle 42 extends from a level just above the transverse plate 50 to a level just above the secondary feed flow nozzle 38. In practice, this baffle need extend only far enough below the nozzle 38 to prevent cold feed liquid droplets from impinging on the tubes 28. The annular passage 52 surrounding this baffle is termed the secondary feed flow passage and it surrounds the tube bundle in the evaporator section. The passage 52 is caused to communicate at both its

upper and lower ends with the evaporator section. The opening at the lower end of the passage is intended to conduct heated feedwater to the evaporator section while that, indicated as 53, at the upper end serves to pass vapor generated in the evaporator section into the upper end of the passage.

The third baffle, 44, encloses the upper region of the tube bundle which is termed the superheat section for the baffle 44 extends to a level vertically spaced from the lower surface of the upper tube sheet 18 and the flow passage 56 defined by the baffle communicates with the nozzle 34 and is termed the vapor outlet passage. At its lower end the passage 56 is closed by annular transverse plate 58. A plurality of axially spaced transverse baffle plates 60 are disposed in the superheat section of the tube bundle and serve to direct vapor admitted to this region in crossflow relation to the tubes 28.

The lower areas of the pressure shell 12 and tube sheet 20 especially those areas that are subject to contact by the feedwater admitted through nozzles 36 and 38 may be covered by a thermal shield 61 that is slightly spaced from the surfaces of the respective members. In this way the affected shell parts will be enabled to tolerate contact by lower temperature feedwater than would otherwise be permitted.

The system for delivering feedwater to the vapor generator 10, together with the controls therefor, is shown in FIG. 2. In general, the system comprises two separate supply lines connected between a vaporizable liquid source (not shown) and the respective feedwater inlet nozzles 36 and 38 on the vapor generator. The first line, indicated as primary feedline 62, contains a primary feed pump 64 and connects with the primary feedwater inlet nozzle 36. The second line, indicated as secondary feedline 66, contains a feed pump 68 and connects with the feedwater inlet nozzle 38. Appropriate flow-regulating valve 76 and flowmeter 78 are interposed in the respective feedlines for controlling in conjunction with the controller 80 the rate of flow of feedwater to the respective inlet nozzles. Additional control elements in the form of sensing elements 82 and 84 are employed for sensing load demand on the unit. According to the basic mode of operation of the arrangement as hereinafter more completely set forth all of the feedwater admitted to the vapor generator 10 through inlet nozzle 36 and then passed through the preheat section of the tube bundle will be supplied through line 62 while that admitted to the unit through inlet nozzle 38 and thence passed through passage 52 will be supplied through line 66. In order to impart flexibility to the feedwater delivery system, however, a bypass line 70 containing check valve 72 can interconnect supply lines 62 and 66 and an additional check valve 74 installed in line 66 as shown in FIG. 2. By means of this arrangement the pump 64 can be employed to deliver a portion, or all, of the liquid supplied to the inlet nozzle 38 in addition to that which is supplied to nozzle 36.

Going now to the operation of the herein-described invention, heating fluid from a source (not shown) is circulated through the vapor generator 10 by being passed serially through inlet nozzle 30, inlet chamber 22, tubes 28, outlet chamber 24, and outlet nozzle 32. At the same time, feedwater is admitted to the unit in a manner whereby it will pass in heat exchange relation with the tubes 28 in the tube bundle enclosed within the vapor generating section 26. The feedwater is evaporated in passing through the chamber 26 and emerges therefrom through vapor outlet passage 56 and nozzle 34 as superheated vapor.

According to the invention feedwater is admitted to the vapor generator in accordance with the plot illustrated in FIG. 3. At full load conditions, when the feedwater inlet temperature is sufficiently high (about 450° F.) as to not establish counterthermal stresses within the shell parts with which it contacts, the feedwater controller 80 is effective to cause all of the feedwater admitted to the unit to be supplied by means of the primary feed pump 64 and line 62 to the inlet nozzle 36. From the nozzle 36 the feedwater is discharged into the passage 46 from whence it enters the preheat section of

the tube bundle. In the preheat section the liquid is directed by the transverse baffle plates 48 in crossflow relation to the tubes 28 where the liquid is heated to about saturation temperature by the indirect transfer of heat from the heating fluid conducted through the tubes. At low load conditions, that is from 0 percent to 25 percent load, when the feedwater inlet temperature will be less than 300° F., and therefore sufficiently low to cause thermal shocking of the shell parts, the feedwater controller 80 is effective to pass all of the feedwater to the vapor generator through line 66 by way of the feed nozzle 38. From feedwater inlet nozzle 38 the liquid is separated by means of spray nozzles 80 or the like into the annular passage 52 where it immediately comes in contact with a portion of the vapor generated in the evaporator section of the tube bundle. This vapor will be drawn into the passage 52 through the space 53 existing between the baffles 42 and 44 by the aspirating effect caused by the condensation of vapor in the passage. In giving up its heat of vaporization to cooler feed flow the vapor raises the temperature of the feedwater to about saturation temperature at which the establishment of thermal stresses in the shell parts will not occur.

At intermediate load conditions, those between 25 percent and 100 percent, the controller 80 operates regulating valve 76 in both of the supply lines 62 and 66 to admit feedwater to the unit through both of the feedwater inlet nozzles 36 and 38. Within this range of operation, as load on the unit increases, the regulator 76 are operated to pass proportionately greater amounts of liquid through line 62 to the nozzle 36 and proportionately lesser amounts through line 66. Thus preheated feedwater is caused to enter the tube bundle after being preheated in part by flowing through the preheat section thereof and in part by condensing a portion of the vapor generated in the evaporator section.

It will be appreciated that vapor generators of the disclosed type are operated for the greatest portion of the time in the upper load ranges, or at full load, such that, by means of the herein-described apparatus and method of operation, the principal amount of feedwater preheating that occurs within the unit is done by bypassing the liquid through the preheater section of the tube bundle where its temperature is raised by the indirect transfer of heat from the heating fluid. Only at low loads, and to a minor extent at intermediate loads, must feedwater preheating be accomplished by the less efficient manner of condensing a portion of the vapor generated in the evaporator section of the tube bundle. The result gives rise to a vapor generator of the shell- and tube-type that is considerably more efficient in operation as compared with similar units of the prior art. This increased efficiency manifests itself as a reduction in unit fabrication costs since vapor generators of the described type of given vapor-producing capacity require considerably less heating surface than prior art units having the same capacity. Alternatively, the increased efficiency can manifest itself as a unit capable of generating steam at a higher pressure for a given size and primary side operating conditions. It will be understood that various changes in the details, materials, arrangements of parts and adaptation to other operating conditions which have been herein described and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.

I claim:

1. The method of operating a vapor generator including a vessel containing a bundle of heat exchange tubes having an evaporator portion comprising the steps of:

- a. passing a heating fluid through said tubes;
- b. supplying a vaporizable liquid to said vessel for circulation through said evaporator portion;
- c. preheating said vaporizable liquid prior to admitting it to said evaporator portion;
- i. when the inlet temperature of said liquid is high, by passing it in indirect heat exchange relation with said heating fluid,

- ii. when the inlet temperature of said liquid is relatively low, by passing it in direct contact with vapor from said evaporator portion, and
 - iii. when the inlet temperature of said liquid is intermediate said high and low temperatures, by passing part of said liquid in indirect heat transfer relation with said heating fluid and part in direct contact with vapor from said evaporator portion; and
 - d. vaporizing the preheated liquid by directing it in relation to the tubes in said evaporator portion.
2. The method of operating a vapor generator as recited in claim 1 wherein proportionately greater amounts of vaporizable liquid are preheated by heat transfer from said heating fluid as the inlet temperature of the liquid is increased.
3. The method of operating a vapor generator as recited in claim 2 in which the amount of vaporizable liquid passed in heat exchange relation with said vapor is decreased as the amount of vaporizable liquid passed in heat exchange relation with said heating fluid is increased.
4. The method of operating a vapor generator as recited in claim 1 wherein all of the vaporizable liquid is preheated by heat transfer from said vapor at liquid inlet temperatures of up to about 300° F., and all of said vaporizable liquid is preheated by heat transfer from said heating fluid at liquid temperatures of about 400° F. or higher.
5. The method of operating a vapor generator including a vessel containing a bundle of heat exchange tubes having an evaporator portion comprising the steps of:
- a. passing a heating fluid through said tubes;
 - b. supplying a vaporizable liquid to said vessel for circulation through said evaporator portion;
 - c. preheating said vaporizable liquid prior to admitting it to said evaporator portion:
 - i. when the load on the vapor generator is high, by passing it in indirect heat exchange relation with said heating fluid;
 - ii. when the load on the vapor generator is relatively low, by passing it in direct contact with vapor from said evaporator portion; and
 - iii. when the load on the vapor generator is intermediate said high and low loads, by passing part of said liquid in indirect heat transfer relation with said heating fluid and part in direct contact with vapor from said evaporator portion; and
 - d. vaporizing the preheated liquid by directing it in relation to the tubes in said evaporator portion.
6. The method of operating a vapor generator as recited in claim 5 wherein proportionately greater amounts of vaporizable liquid are preheated by transfer from said heating fluid as the inlet temperature of the liquid is increased.
7. The method of operating a vapor generator as recited in claim 6 in which the amount of vaporizable liquid passed in heat exchange relation with said vapor is decreased as the amount of vaporizable liquid passed in heat exchange relation with said heating fluid is increased.
8. The method of operating a vapor generator as recited in claim 5 wherein all of the vaporizable liquid is preheated by heat transfer from said vapor at liquid inlet temperatures of up to about 300° F., and all of said vaporizable liquid is preheated by heat transfer from said heating fluid at liquid inlet temperatures of about 440° F., or higher.
9. The method of operating a vapor generator as recited in claim 5 further including the step of superheating that part of the vapor from the evaporator portion that does not preheat

the vaporizable liquid.

10. A vapor generator comprising:

- a. a vertically elongated pressure vessel;
- b. axially spaced tube sheets dividing the vessel into heating fluid inlet and outlet chamber and a vapor-generating chamber therebetween;
- c. a bundle of tubes extending through said vapor-generating chamber and having their ends communicating with said heating fluid inlet and outlet chambers for circulation of heating fluid through said tubes;
- d. means within said vapor-generating chamber defining an evaporator section and a preheat section;
- e. baffle means surrounding said tube bundle in concentrically spaced relation from the wall of said vessel to form an annular passage therebetween; said flow passage being in fluid communication with said evaporator section at the lower end thereof;
- f. means for admitting a portion of the vapor generated in said evaporator section to said annular flow passage;
- g. means for supplying vaporizable liquid to said vapor generator including:
 - i. first supply for passing said liquid to said annular flow passage into heat exchange relation with the vapor present therein; and
 - ii. second supply means for passing said liquid directly to said preheat section.

11. A vapor generator as recited in claim 10 wherein said baffle means is in open fluid communication with said evaporator section at the top and bottom ends thereof and the opening at the top of the said baffle means is effective to admit vapor from said evaporator section to said flow passage while that at the bottom admits heated liquid to said evaporator section.

12. A vapor generator as recited in claim 11 wherein said liquid is heated to substantially its saturation temperature in said flow passage.

13. A vapor generator as recited in claim 10 including control means for regulating the supply of vaporizable liquid through said first and second supply means in response to changes in the temperature of the liquid being passed.

14. A vapor generator as recited in claim 10 including control means for regulating the supply of vaporizable liquid through said first and second supply means in response to changes in load on said vapor generator. amounts

15. A vapor generator as recited in claim 14 wherein said control means includes means for passing all of the liquid supplied to said vapor generator through said first supply means during low load operation of said vapor generator, means for passing all of the liquid supplied to said vapor generator through said first supply means during high load operation of said vapor generator, and means for passing liquid through both of said supply means in controlled amounts during intermediate load operation of said vapor generator.

16. A vapor generator as recited in claim 11 wherein said preheat section includes means for directing the flowing liquid in crossflow relation to the tubes extending therethrough.

17. A vapor generator as recited in claim 16 including means defining a superheat section in said vapor-generating chamber disposed above said evaporator section and said means including means for directing the flowing fluid in crossflow relation to the tubes extending therethrough.

UNITED STATES PATENT OFFICE CERTIFICATE OF CORRECTION

Patent No. 3,576,178 Dated April 27, 1971

Inventor(s) Paul C. Zmola

It is certified that error appears in the above-identified patent and that said Letters Patent are hereby corrected as shown below:

Column 5, line 24, after "liquid" insert --inlet--;
Column 5, line 25, replace "400°F." with --440°F.--;
Column 5, line 49, before "transfer" insert --heat--;
Column 6, line 16, after "annular" insert --flow--;
Column 6, line 23, after "supply" insert --means--;
Column 6, line 31, before "said" cancel "the";
Column 6, line 45, after "generator." cancel "amounts";
Column 6, line 61, after "section" cancel "and".

Signed and sealed this 1st day of August 1972.

(SEAL)
Attest:

EDWARD M. FLETCHER, JR.
Attesting Officer

ROBERT GOTTSCHALK
Commissioner of Patents