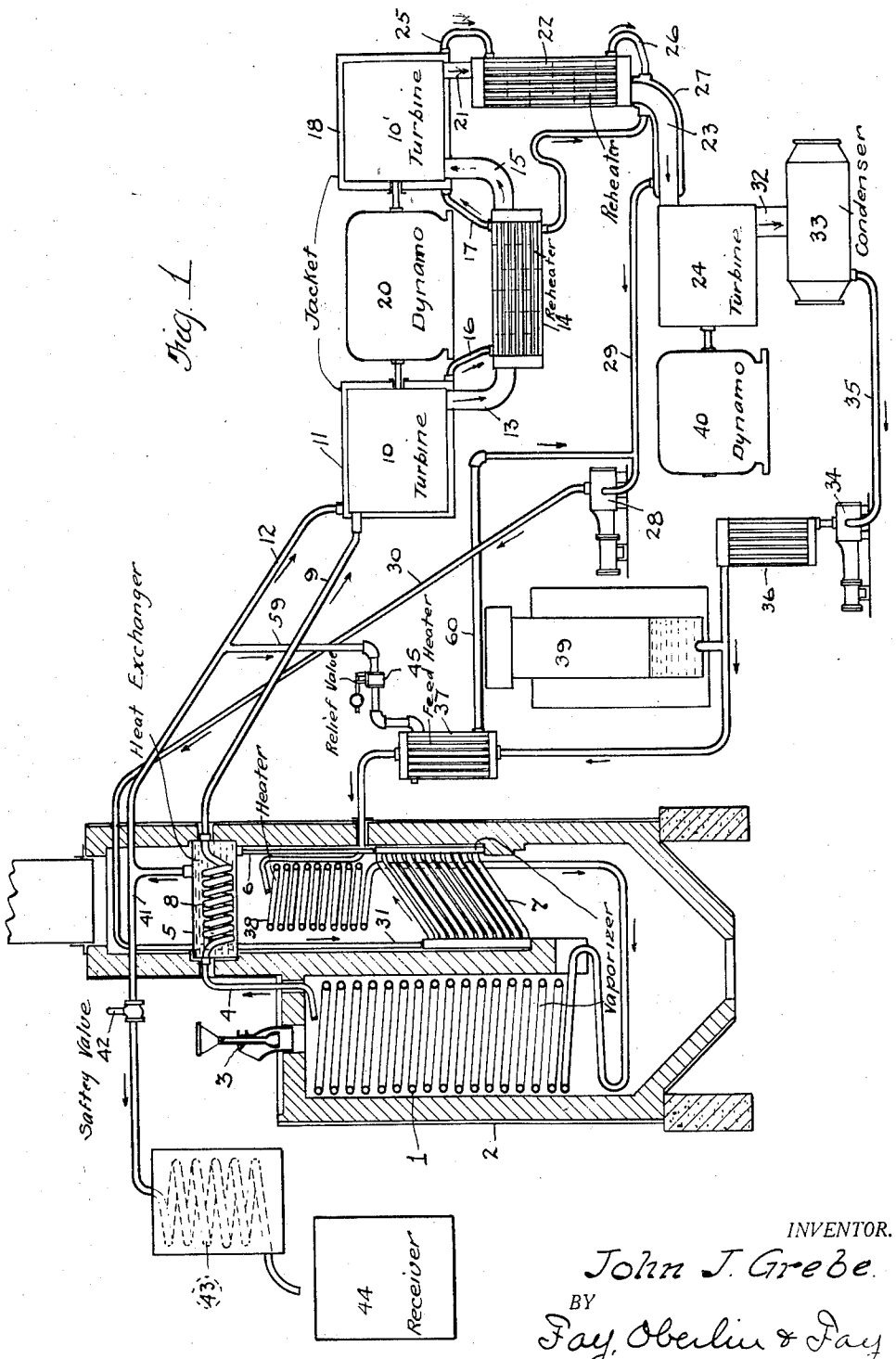
June 6, 1933. J. J. GREBE 1,912,938

HEAT ENERGY SYSTEM

Original Filed Jan. 26, 1927 2 Sheets-Sheet 1



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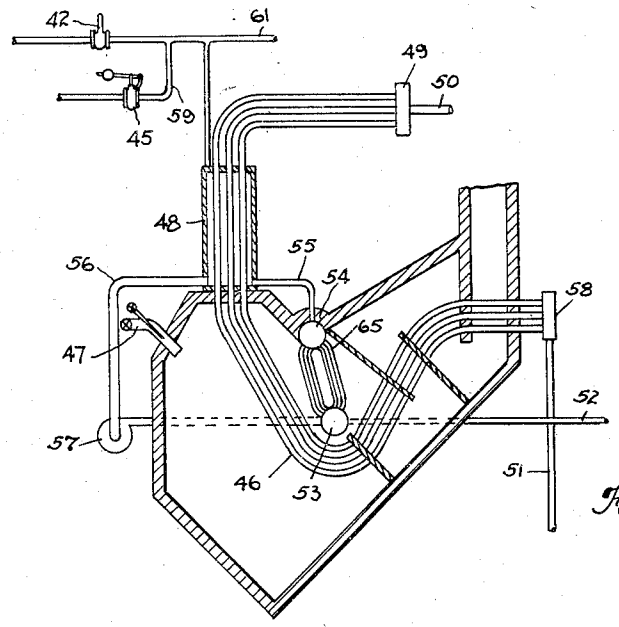


Fig. 2

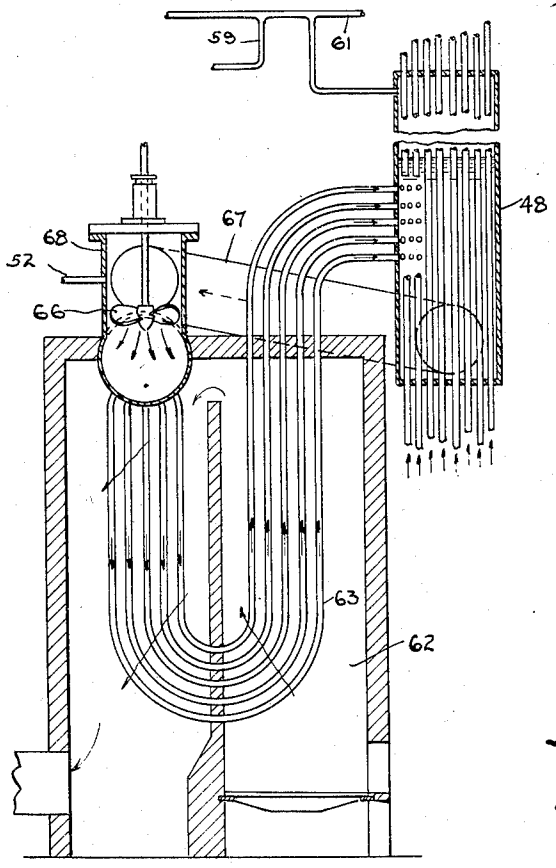


Fig. 3

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1,912,938

UNITED STATES PATENT OFFICE

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HEAT ENERGY SYSTEM

Original application filed January 26, 1927, Serial No. 163,609. Divided and this application filed February 2, 1929. Serial No. 336,980.

Steam at high temperature ranges offers advantages as a heat-energy agent but practical limitations, until recently believed insuperable, have stood in the way of its use or application. The present invention has among its objects the provision of a cycle employing such agent and in a manner available for power purposes or in more general applications as may be desired. A further object is to provide a method of and apparatus for one pass generation of vapors at high pressure, without the difficulties and dangers heretofore attendant thereon. Other objects and advantages will appear as the description proceeds.

In my co-pending application Serial No. 163,609, filed January 26, 1927, of which the present application is a division, I have set forth the power plant features of the present invention.

To the accomplishment of the foregoing and related ends, the invention, then, consists of the features hereinafter fully described, and particularly pointed out in the claims, the following description and the annexed drawings setting forth in detail but several of various ways in which the principle of the invention may be employed.

In said annexed drawings:

Fig. 1 shows in diagrammatic fashion one form of apparatus which may be used for carrying out the invention. Fig. 2 shows a modification of the heating portion of the apparatus shown in Fig. 1. Fig. 3 shows a method of heating the high-boiling point liquid with a separate heat source.

In its general aspects, the invention contemplates employing steam at high temperatures and providing a heat compensating or balancing system in transfer relation wherein any unvaporized liquid coming from the tubes exposed to furnace heat will be vaporized and may be superheated as desired. Such steam may be used as an agent for high temperature heating, in chemical work, or for other purposes, or it may be used for power generation. As an additional feature, the steam may be reheated during and after use thus making further use more efficient.

Where operating at pressures over 1000 pounds per square inch, it is very desirable that the steam generator be of tube type and may be a substantially continuous coil, without vapor or liquid drums. The pipe or pipes coming from the furnace containing fluid in partially or completely vaporized form is passed in heat exchange relation with a fluid having higher-boiling point in liquid state, said latter fluid operating at low pressures. This may take the form of an exchanger with separate passages for the partially or completely vaporized low-boiling point liquid and for the high-boiling point agent, or for instance, a coil for the partially or completely vaporized low-boiling point liquid passing through a drum containing the high-boiling point agent either in liquid or vapor state or both. With the steam thus brought into relation with the higher-boiling point agent heated from the furnace, if the temperature of the steam should exceed that of the high-boiling point agent, heat will be given up to the latter by the steam, but on the other hand when the temperature of the partially or completely vaporized liquid is below that of the high-boiling point agent, as in normal condition, or in case of a sudden load increase on the steam system, the high-boiling point agent will supply heat to the steam. In this manner not only is a tendency to an equalization had at all times but the low pressure high-boiling point agent acts to supply reserve capacity immediately available for the steam system itself and without incurring the hazards incident to storage of a large body of liquid and vapor under very high pressure, or the expense contingent with large high pressure containers for vapor and fluid.

As high-boiling point substance or agent, I may employ diphenyl oxide, or in some instances naphthalene, diphenyl, aluminum bromide, silicon bromide, tin bromide, mercury, phenanthrene, mineral oils, etc. or mixtures of these and others of like nature.

After using the steam to give up heat in any apparatus desired, it may be brought in heat transfer relation with the high-boiling point agent again, whereby the steam temperature is again raised to allow a more economical

further use, and such procedure may be again repeated at later steps.

In Fig. 1 of the accompanying drawings, the reference character 1 designates a steam generator with tube or coil in a furnace 2 which may be heated by suitable means, for example, by powdered fuel supplied by feeder 3. From the furnace the steam or steam and liquid pipe 4 passes to a drum 5 which may be exposed in the path of the hot products of combustion and containing a high-boiling point agent, for instance, diphenyl oxide. The drum is connected by pipe 6 with a tubular heater 7 located in a hotter portion of the chamber or setting. The conduit or duct 8 for the fluid products of the low-boiling point liquid through the drum containing the high-boiling point agent connects by a pipe 9 to a point of use for the steam; here a turbine 10. A jacket 11 about the turbine is heated by the vapor of the high-boiling point liquid coming from drum 5 by way of pipe 12. From the turbine 10 the steam exhausts through a pipe 13 to a reheater 14 which contains passages for the steam to a pipe 15 leading to another turbine 10′. Other passages in the reheater 14 receive the high-boiling point heating agent from the jacket 11 by a pipe 16 and thence forward it by a pipe 17 to the jacket 18 about the turbine 10′. A dynamo 20 is illustrated as driven by the turbines. From the turbine 10′, a pipe 21 carries the exhaust steam to a reheater 22 and its passageways connect to outlet pipe 23 leading to a further turbine 24. A pipe 25 leads the high-boiling point agent from the jacket 18 to the compartments about the steam passageways in the reheater 22, and a pipe 26 hence leads to a jacket 27 about the steam pipe 23. A pump 28 returns the high-boiling point agent through pipes 29, 30 and 31 to the heater 7 in the furnace.

From the turbine 24, illustrated as driving a dynamo 40, the steam exhausts by a pipe 32 to a condenser 33, whence a pump 34 returns the condensate through pipe 35, feed heaters 36 and 37 to a preheater coil 38 and thence again to steam generator 1. An accumulator 39 may be connected in the condensate line, if desired.

In an equipment on this order, steam may be generated at any desired pressure and such equipment is particularly applicable for use with extremely high pressures limited only by the strength of the apparatus used, the hazards of operating at such pressures being greatly minimized by my arrangement, in that there is a relatively small body of high pressure fluid in existence at any given time. An ample heat reserve capacity is provided, however, as has been seen, in the body of high-boiling point agent, operating at low pressures, but which is in such heat relation with the steam system as to constitute a heat energy cycle therewith. Thus ample heat reserve is provided for taking care of fluctuations in heat supply and steam demand, and as effectively as with large expensive high pressure steam drums. The heat transfer with the high-boiling point agent affords an effective means for vaporizing any unvaporized low-boiling point liquid coming from the tubes exposed to furnace heat, as well as being an effective equalizer for maintaining a relatively uniform superheat for the steam delivered for use. The number of reheat stages can be varied to suit conditions. The more such stages used, the greater the efficiency total in the system, the isothermal expansion then involving a series of steps in which the temperature may range between for illustration, say 725° and 650° F. For power plant purposes in some cases it will be sufficient to apply the heat of the high-boiling point agent to the jackets of the turbines only and omit the intermediate reheaters. Or where preferred, the reheaters may be provided and the heating jackets may be omitted. All such details will of course necessarily vary with the particular kind of plant, the size of the plant, conditions of operation, etc., and any or all of the features of the invention may be applied, as desired.

The fluid products of the low-boiling point liquid, I have found, may be maintained at a relatively uniform degree of superheat by holding the vapor of the high-boiling point fluid at approximately a uniform pressure. One preferred way of doing this is shown, wherein pipe 59 is connected to the high boiling point vapor line 12, and leads to a uniform pressure valve 45 which maintains the high-boiling point fluid at uniform pressure by by-passing part or all of the vapor when its pressure rises above a predetermined point. While the so by-passed vapor can be utilized or condensed in any convenient manner, I prefer to pass it into a feed water heater 37 where it will give up its heat and when condensed will flow to the feed pump for high-boiling point agent and be returned to the vaporizer. Operating in this manner has a further advantage in that it provides a convenient method of absorbing excess heat from the high-boiling point agent in the low-boiling point liquid, thus acting as an aid to the stabilization of the entire system.

Not only will the usual safety-valve precautions be applied on the steam line out of the boiler, but ordinarily it is also advisable to apply a large capacity safety-valve to the high-boiling point agent system, for instance a safety-valve 42 with connection 41 to the drum and on the other side to a cooling coil 43 and receiving tank 44. In this manner, in case the pressure of the vapor of the high-boiling point agent becomes excessive, or in the event of a break in the steam line within the drum 5, the contents, which in some instances might be of combustible character,

will merely be driven out and cooled and caught in storage.

Fig. 2 shows a modification of the vapor generation portion of Fig. 1 wherein the tubes 46 are substantially parallel and pass in heat transfer relation directly through bath 48 of higher-boiling point agent. Tubes 46 end, for instance, in steam header 49 from whence steam main 50 leads to the point of steam usage. The low-boiling point liquid is fed to tubes 46 through liquid header 58 and feed pipe 51 connected to suitable heaters and feed pump. The high-boiling point agent is vaporized in tubes 65 connecting headers 53 and 54, the vapor passing by means of pipe 55 to temperature balancer 48 where it gives up part of its available heat to the fluid products of the low-boiling point liquid. The vapor of the high-boiling point agent then passes out of balancer 48 by means of pipe 61 to points of further use such as jacketing, reheating, etc. When condensed, the liquid is returned to drum 53 by pipe 52 in any convenient manner. The bath of high-boiling point agent 48 is maintained at a relatively constant pressure and temperature by means of a uniform pressure valve 45 or like mechanism connected to main 61 by pipe 59. The vapor by-passed through valve 45 passes to points of usage or a condenser from whence it is returned to the vaporizer by means of pipe 52. A connection 56 is made between temperature balancer 48 and drum 53 to return condensed liquid to vaporizer 65. In some cases it may be desirable to increase the rate of circulation through vaporizer 65 in which case a pump 57 may be used to advantage. The use of temperature balancer 48 with this type boiler equalizes the temperature between tubes and permits attaining a uniform degree of superheat, as desired.

Fig. 3 shows a modification of Fig. 2 wherein the high-boiling point agent is heated by any convenient means other than in contact with the same source of heat used to vaporize the low-boiling point liquid. For example, a separately fired furnace 62 may be used wherein the high-boiling point agent in passing through suitable tubes 63 is partially vaporized and passes to temperature balancer 48 where it normally gives up part of its heat, as previously described. The vapor then passes out of temperature balancer 48 through pipe 61 to points of usage as previously described, from whence it is returned in condensed form by pipe 52 to container 68 for recycling. Liquid from temperature balancer 48 is then drawn through main 67 to container 68 by circulator 66 which forces same into tubes 63 for recycling. In some instances such forced circulation has been found desirable since in general it increases the efficiency of heat absorption and decreases the decomposition of the fluid to a minimum. While only one method of heating the high-boiling point agent has been described, it will be obvious to anyone versed in the art that many other methods of heating could be utilized without departing from the spirit of my invention, for instance, by using oil, gas, a waste heat economizer, a condenser boiler, or the like.

One pass steam boilers operating at pressures below the critical pressure have heretofore been unsuccessful in large units due to the steam generating tubes becoming overheated, as is well known to the art. The Bensen boiler overcame this difficulty by generating steam at pressures at or above the critical pressure of water, thus keeping the tubes filled with a dense fluid at all times which minimizes overheating and consequent damage. The steam so generated is then expanded to a useable lower pressure and reheated before use. This method, however, involves excessively thick tubes and high pressure equipment with consequent losses in heat transfer and compression energy at the boiler feed pumps. I have discovered, however, that high pressure steam can be successfully generated in a drumless boiler in combination with a suitable supplemental heater or temperature balancer of the type just described.

In order to avoid the difficulties of overheating and burning tubes, I allow the liquid being vaporized in generator 1, or as the case may be, to pass through the tubes exposed to direct heat, normally without reaching the stage of complete evaporation. The mixed vapor and liquid then pass to the supplemental heater or temperature balancer where the evaporation is completed by means of the heat of a high-boiling point agent in heat transfer relation. One of the principal advantages of producing high pressure steam in this manner is that the steam is generated at the useable pressure and by maintaining some liquid in the tubes exposed to direct heat, the danger of overheating and burning is avoided.

In the operation of a bi-fluid system of the type described, the boiling points of the two liquids should preferably be widely separated. Two such liquids, the use of which will be described, are water and diphenyl oxide which have boiling points of 212 and 496° F., respectively. The diphenyl oxide may be safely held and boiled at 700 to 750° F. and a saturated water vapor temperature of 600° F. may then be chosen which corresponds to a vapor pressure of 1500 pounds per sq. in. absolute. Diphenyl oxide at 700° F. will have a vapor pressure of 108 pounds per sq. in. absolute which at this temperature is not too high to permit the use of steel drums and standard well tried construction. These drums, due to the pressure being moderate, can be made large without incurring inordinate construction charges, so that a rel-

atively large body of diphenyl oxide may be safely and economically used, in which large body a correspondingly large amount of heat may be stored.

With the temperature difference indicated between the two fluids in the system, the heat absorption from the furnace to the water may be limited, if desired, to less than sufficient under normal conditions to evaporate all of the water supplied to the water boiler, the balance of the heat being supplied to the water in the temperature balancing heat exchanger by the diphenyl oxide.

The ratio of heat transfer surfaces in the boiler itself and in the heat exchanger may be so chosen that under normal operating conditions the steam may be superheated, say, to 650° F. or even to a temperature approximating that of the diphenyl oxide bath, thereby making it more effective in a power generating cycle. In similar manner, these principles apply equally well when other high and low-boiling point liquids are concerned.

The relatively large amount of diphenyl oxide in the system maintained in active heat transfer relation with the water system presents the advantages of heat storage incident to the use of the tube and drum type of water boiler heretofore employed for moderate pressures, constituting in effect an equivalent of the latter adapted to generate high pressure-high temperature steam without the hazards incident to maintaining a large body of fluid under such high pressure.

The heat required for a suddenly increased demand for steam will be supplied from the stored up heat in the diphenyl oxide by transfer in the heat exchanger. Conversely, a rise in superheat of steam, which would follow a suddenly decreased demand therefor, will be markedly reduced by transfer of heat from the superheated steam to the diphenyl oxide. Such actions follow upon the lag in the effect of furnace controls, actuated automatically or manually, in response to temperature or pressure changes in the steam systems following demand changes, since, owing to the large amount of diphenyl oxide employed, temperature and pressure changes therein will follow slowly relative to similar changes in the small amount of water in the water system.

There is effected, consequently, an equalizing action between the two fluids tending to maintain pressure and temperature conditions of steam vapor more closely at the desired points in the face of changing demands therefor than is otherwise possible, the peaks and valleys representing severe fluctuations in pressure and temperature conditions of the water vapor being flattened out by the heat inertia stabilizing effect of the diphenyl oxide which in heat transfer relation thereto may either supply to or take up heat from the steam as conditions require.

There is, accordingly, made possible a high pressure vapor generator adapted to supply a vapor at substantially uniform pressure and temperature to meet varying and suddenly changing rates of demand, the limitations of flash type and one pass rapid evaporation systems being overcome by the use in heat exchange relation with the said vapor system of a relatively large body of a higher-boiling point agent at higher temperature but at lower pressure in a circulation type of tube and drum boiler, making the whole ensemble a safer construction than the equivalent drum and tube type single fluid boiler for the low boiling point liquid heretofore proposed. There is also presented the added advantage of a high temperature superheating and reheating medium available for use in a power generation or other heat cycle, the advantages of which are well known to those skilled in the art.

While I have described my invention in terms of water as the low-boiling point motive fluid, I do not wish to be limited to that fluid since I have found that in some instances other fluids may be employed, for instance, alcohol, acetone, chlor-organic compounds, organic hydrocarbon compounds, inorganic compounds, etc.

Other modes of applying the principle of my invention may be employed, change being made in the details disclosed, provided the steps or means stated in any of the following claims, or the equivalent of such, be employed.

I therefore particularly point out and distinctly claim as my invention:—

1. In a one pass apparatus for generating relatively uniform pressure and temperature vapor from a low boiling point liquid exposed to a source of heat and then immediately to a temperature-balancing heat transfer with a body of hot heat-storing fluid of lower pressure, the combination including a drum for a temperature-balancing fluid, a heater for said fluid, inlet and outlet connections between said drum and heater, and a tubular duct for conducting a low boiling point liquid in exposure to a source of heat and then immediately through said drum containing said temperature-balancing fluid and in indirect contact with a liquid portion thereof, said duct being proportioned so that normally a substantial proportion of the evaporation of the low boiling point liquid is done by heat absorbed from said body of temperature-balancing fluid.

2. In a method wherein steam is generated from water under pressure in tubes, in one pass through a heating zone, the steps which comprise subjecting such water in a portion of said pass to a source of heat to normally produce a mixture of steam and water wherein the steam predominates and the water is present in substantial percentage, whereby the one pass tubes exposed to said source of

heat are protected from injury by over-heating, because of the presence therein of unvaporized liquid throughout the length thereof, subjecting such mixed fluid immediately to a temperature-balancing heat exchange with a body of a heat-storing fluid having a higher boiling point in liquid state than water under the same pressure, said higher boiling point agent being at least partially vaporized and at a temperature sufficiently high to produce the desired working temperature for the steam, whereby the complete evaporation of the water is assured and variations in temperature incident to fluctuating steam demand are reduced.

3. In a method wherein steam is generated from water under pressure in tubes, in one pass through a heating zone, the steps which comprise subjecting such water in a portion of said pass to a source of heat to normally produce a mixture of steam and water wherein the steam predominates and the water is present in substantial percentage, whereby the one pass tubes exposed to said source of heat are protected from injury by over-heating, because of the presence therein of unvaporized liquid throughout the length thereof, subjecting such mixed fluid immediately to a temperature-balancing heat exchange with a body of hot diphenyl oxide under moderate pressure, said diphenyl oxide preferably being partially vaporized and at a temperature approaching but above the desired working temperature for the steam, whereby the complete evaporation of the water is assured and variations in temperature incident to fluctuating steam demand are reduced.

4. In a method of the character described, the steps which comprise passing a current of water under pressure through a one pass heating zone wherein it is converted into steam in two consecutive stages by heating it first with heat from burning fuel to normally produce steam having a substantial percentage of unvaporized water therein, and secondly with a body of hot products of a high boiling point heat-storing liquid obtained by heating same while controlling the temperature of the said products at a temperature level which will not only convert any water unvaporized in the first stage to steam but will continuously maintain the flow of said steam, thus produced, at approximately the desired temperature.

5. In a method of the character described involving the treating of a fluid which under normal conditions of operation may vary in state from partially vaporized condition to superheated condition, the step which consists in bringing said fluid, converted at least in part from the liquid to the vaporized state and having a low boiling point in liquid state, into a reversible heat-transfer relation with a liquid portion of a hot body of heat-storing fluid, whereby the hot high boiling point agent acts by reversible heat-transfer with the low boiling point agent to reduce variations in temperature of the vapor of the low boiling point agent incident to fluctuating demands therefor.

6. In a method of the character described involving the treating of a fluid which under normal conditions of operation may vary in state from partially vaporized condition to superheated condition, the step which consists in bringing water, converted at least in part to the vaporized state, into reversible heat-transfer relation with a liquid portion of a heat-storing fluid having a higher boiling point in liquid state than water, said higher boiling point agent being at a proper temperature to reduce variations in steam temperature incident to fluctuating steam flow and to maintain approximately the desired working steam temperature.

7. In a method of the character described involving the treating of a fluid which under normal conditions of operation may vary in state from partially vaporized condition to superheated condition, the step which consists in bringing water, converted at least in part to the vaporized state, into reversible heat-transfer relation with a liquid portion of a body of diphenyl oxide maintained at a moderate pressure and at a temperature approximating but above the desired working proper temperature for the steam, whereby the said hot diphenyl oxide acts by reversible heat-transfer with the steam to insure at least the complete generation thereof and to reduce variations in steam temperature incident to fluctuating steam flow.

8. In a method of producing super-heated steam in one pass at high pressure but substantially below the critical pressure thereof, the steps which comprise heating said water to normally convert it at least in part to the vaporized state, and immediately subjecting the products of such step to a reversible heat-transfer with a body of diphenyl oxide maintained at a moderate pressure and at a temperature sufficiently high to produce the desired working temperature for the steam, whereby the said hot diphenyl oxide acts in reversible heat-transfer with the steam to insure the complete evaporation of the water and to reduce variations in the superheat temperature of the steam incident to fluctuating steam flow.

9. In a method of producing superheated steam in one pass at high pressure but substantially below the critical pressure thereof, the steps which comprise heating said water to normally convert it at least in part to the vaporized state, and immediately subjecting the products of such step to a reversible heat transfer with at least the liquid portion of a fluid body of high boiling point agent maintained at a moderate pressure and

at a temperature sufficiently high to produce the desired working temperature for the steam, whereby the said hot high boiling point agent acts in reversible heat transfer with the steam to insure the complete evaporation of the water and to reduce variations in the superheat temperature of the steam incident to fluctuating steam flow.

Signed by me this 30th day of January, 1929.

JOHN J. GREBE.