

Feb. 23, 1954

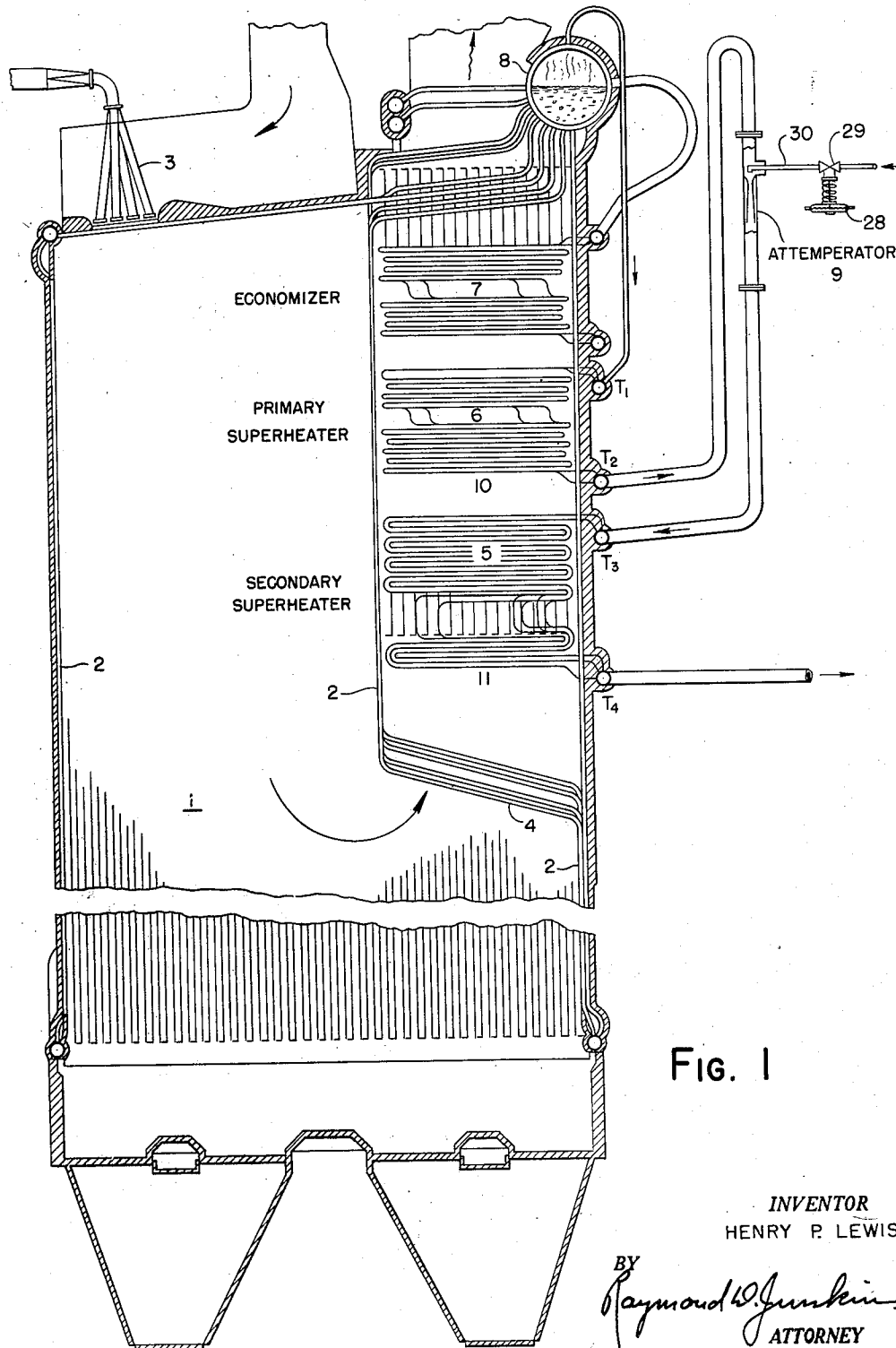
H. P. LEWIS

2,669,977

VAPOR GENERATOR OPERATION

Filed Aug. 21, 1951

2 Sheets-Sheet 1



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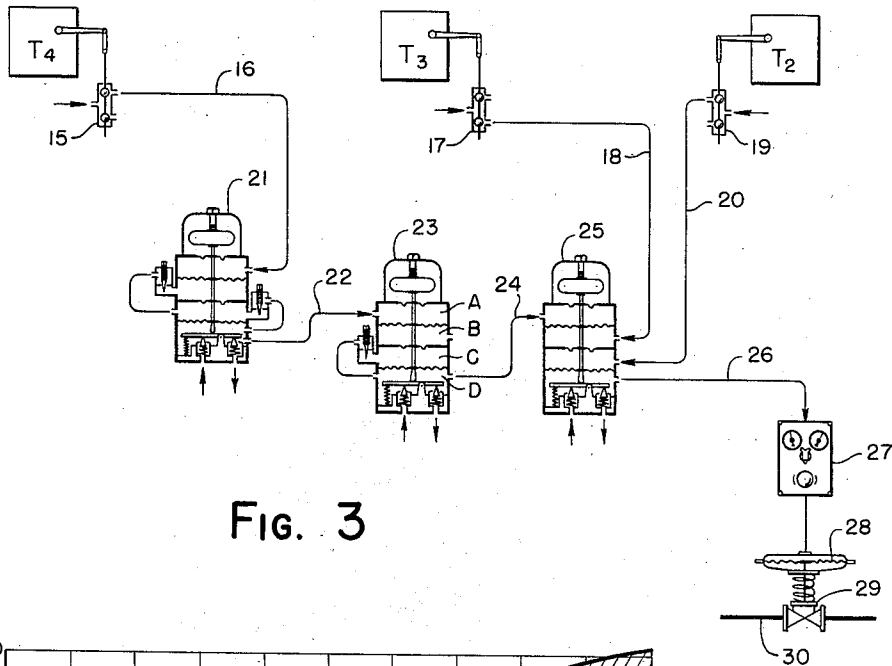


FIG. 3

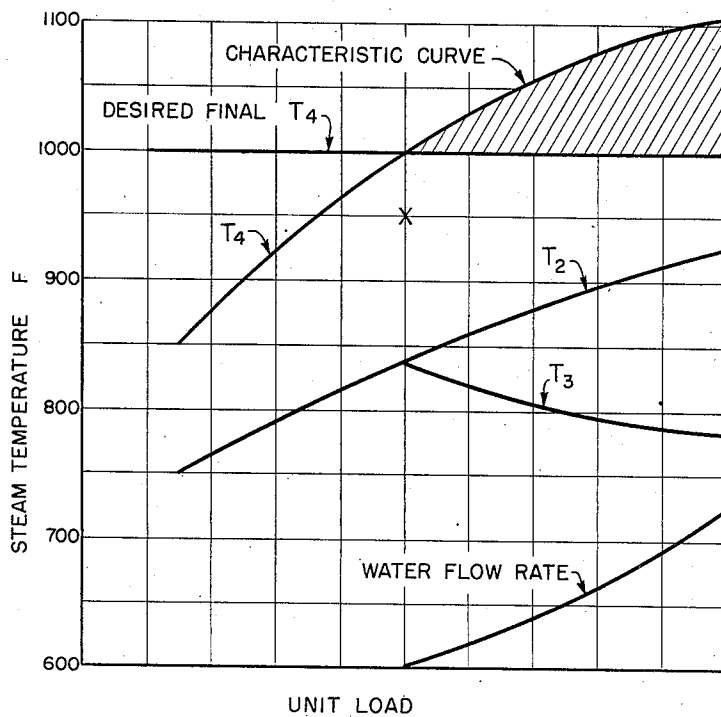


FIG. 2

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VAPOR GENERATOR OPERATION

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1

My invention lies in the field of power generation and particularly in the control of steam temperature in connection with present day vapor generators. Practically all central station capacity presently being installed, or on order, in the United States, has rated steam conditions above 800 p. s. i. g. and 800° FTT; the higher operating temperature being 1050° FTT at pressures from 1500 p. s. i. g. to 2000 p. s. i. g. and rated load from 500,000 to 1,000,000 lb. per hr. The problems involved in the generation and close control of the properties of steam are quite different now than was the case at the time of the inventions in this field which are shown in the prior art.

Superheat temperature control is particularly desirable in the generation of steam for the production of electrical energy in large central station power plants. In such plants the upper limit of superheat temperature is governed by the materials and construction of the turbine served by the steam. In the interest of turbine efficiency the temperature of the steam delivered to the turbine should be maintained within close optimum limits throughout a wide range of capacities.

As feed water temperatures progressively increase there is less and less work for the boiler proper, with the result that its convection heat-absorbing surface has disappeared to the point where the modern large utility unit consists of a water-walled furnace, one or more convection superheaters, an economizer and an air heater. Furnace design is now centering around sufficient water cooling surface to absorb the radiant heat to achieve the required relatively low furnace exit gas temperatures.

With the superheating of the steam in one or more convection type heat exchange surfaces, the size and cost of such surfaces becomes a material factor in the total cost of the unit and any improvement leading to a reduction in the size of superheaters becomes of considerable importance. Usually these surfaces must be made of expensive high-alloy tubing to satisfactorily handle the temperatures and pressures encountered.

It is thus a prime desideratum in the design of such a unit, to proportion the steam generating surfaces and the steam superheating surfaces to give the desired final steam temperature at normal operating or rated load. At peak load, in excess of the rated load, the final steam temperature will be in excess of that desired and correspondingly at lower rating the steam temperature will not equal that desired. This is due to the characteristic curve of convection type heat exchangers which

2

have a rising function with load (Fig. 2). It is false economy to design the superheater for desired final steam temperature at peak load, for all loads below that value would produce steam below the desired temperature. On the other hand, the design of the superheater to produce the desired final steam temperature at some rating below the expected operating or rated load would require an excessive cost of superheating surface and an excessive final steam temperature throughout the upper ratings with consequent danger to the turbine or the necessity of extracting some of the surplus heat from the final superheated steam.

To reach the desired high superheated steam temperature, but not exceed it, requires exceedingly careful proportioning of the heat absorbing surfaces both for generating steam and for superheating it. But even if the desired superheated steam temperature be just attained initially by very careful designing at expected or rated load, the superheated steam temperature will vary during operation by reason of changes in cleanliness of the heat absorbing surfaces. Slag will form and adhere to the heat absorbing surfaces in the furnace thereby reducing the effectiveness of such surfaces and raising the furnace outlet temperature of the products of combustion. Furnace outlet temperature will also change with percentage of excess air supplied for combustion, with the characteristics of the fuel burned, and with the rate of combustion and the corresponding rate of steam generation. All of these things will therefore affect the temperature of the gases leaving the furnace and supplied to the superheater surfaces whether the superheating elements are located in the furnace where they absorb some heat by radiation from the burning fuel and products of combustion or whether they are located beyond the furnace where they absorb heat by convection from the products of combustion only.

I preferably consider a unit which is designed to provide the desired final steam temperature at expected or rated load. Throughout an upper range of rating between this rated load and the peak load possibility of the unit I consider attestation of the steam to provide a substantially uniform final total steam temperature as close to the design value as possible. Attenuation is known and the particular invention disclosed herein is directed to a preferred method and apparatus for operating such a unit to provide as nearly uniform as possible final total steam temperature throughout a wide upper range of ratings.

My invention relates broadly to fluid heat ex-

3

change apparatus for attemperating vapors or gases. More specifically the invention relates to the control of a direct contact heat exchanger whereby such a fluid as superheated steam or superheated vapor may be maintained within desired temperature limits by spraying a lower temperature vaporizable liquid into the superheated steam or vapor. In the case of steam the liquid is water.

I have chosen to illustrate my invention as applied to a fuel fired vapor generator having a primary and a secondary superheater series connected with provision for spraying water into the flow path of the superheated steam between the two superheaters for tempering the steam and causing the total temperature of the steam leaving the unit to be maintained within desirable limits. It will be evident that my invention may be adapted to other arrangements of power producing or utilizing apparatus and that I have merely chosen by way of example to illustrate and describe one preferred embodiment.

With operation at or above the rating at which the superheating surfaces are designed to produce the desired final total temperature, the characteristic curve of such convection superheating surfaces indicates that the final temperature would be higher than optimum. This is clearly shown in Fig. 2 wherein the shaded portion indicates what might normally be an excess of temperature in the steam over an upper range of ratings. It is not economical to allow the final temperature to reach the indicated values and then to absorb the excess heat by desuperheating following the convection heating surfaces. Such construction and operation subjects the final superheating surfaces to a considerably greater temperature than would otherwise be necessary or desirable. The reduction of the excessively high final temperature by the introduction of vaporizable liquid provides thermal shock and other disagreeable conditions which are to be avoided. It has been found the most desirable construction and operation is to introduce attemperating vaporizable liquid between two sections of superheating surfaces which, with the proper control, will result in an end product very closely approximating the desired final total temperature. The superheating surfaces are thus not subjected to the greatly excessive temperatures, thermal shock is reduced and efficiency and steadiness of control is enhanced. My particular invention resides in a method and control system utilizing certain variables in the operation of the system as control indexes to the end that optimum final total steam temperature is closely approximated through a wide range of upper ratings.

The attemperator may be of the type disclosed and claimed in the patent to Fletcher et al. 2,550,683 wherein a superheated steam conduit has therein a venturi acting as a part of a thermal sleeve to protect the conduit against thermal stresses. Forwardly of the entrance of the venturi is a spray nozzle through which water is atomized in a conical spray which is enveloped by the high velocity superheated steam. The nozzle is thus disposed in a relatively low velocity zone so that there is a low pressure loss due to minimum turbulence created by the nozzle body. The water leaves the nozzle in the form of a spray cone with a hollow vortex, the outer limits of this cone being within the entrance surfaces of the venturi.

A principal object of the invention lies in the

4

continuous control of the rate of water supplied to the attemperator in accordance with selected variables in the operation of the unit to the end that the final temperature of the steam will be maintained within desired limits.

Another object is to control the attemperator in such a manner that the steam produced by the unit will be within desired limits of total temperature at different rates of output.

Another object is to control the rate of supply of water in accordance with load demand as well as to correct for departure of the condition of the produced steam from desired condition.

A further object is to control the attemperator responsive to an indication of demand as well as responsive to an indication of one or more variable conditions of the steam.

In the drawings:

Fig. 1 is a somewhat diagrammatic sectional elevation of a vapor generating unit having radiant generating surfaces and convection superheating surfaces.

Fig. 2 is a graph of characteristic values in connection with the operation of such a unit.

Fig. 3 is a schematic showing of the control system of my invention.

It will be appreciated that I am illustrating and describing my invention in a preferred mode of operation and combination of apparatus. For example, while I speak of steam generation and superheating the invention is useful in the generation and superheating of other vapors. Furthermore, while I particularly refer to the burning of pulverized coal in suspension it will be understood that the invention is applicable to a burning of other fuels in suspension, such for example as oil or gas and in fact to solid fuels burned on grates.

Fig. 1 shows in somewhat diagrammatic sectional elevation a typical vapor generator of the size and type herein contemplated and in connection with which I will explain my invention. The generator is of the radiant type having a furnace 1 which is fully fluid cooled with walls 2 of vertically closely spaced plain tubes constituting the vapor generating portion of the unit. Pulverized fuel and air are supplied for combustion through a plurality of burners 3 firing vertically downward from the uppermost portion of the primary furnace 1. Products of combustion pass from the furnace 1 in the direction of the arrow through the tube screen 4 over a secondary superheater surface 5 and then through a primary superheater 6 followed by a tubular economizer section 7. Total fuel and air for combustion may be under the control of stem pressure or some other demand index as is common practice. Furthermore, induced draft and forced draft may be controlled in normal fashion, the same forming no part of the present invention which is directed particularly to the control of the final temperature of the superheated steam leaving the unit.

It will be observed that steam from the separation drum 8 enters the primary superheater 6 at a location T₁ and leaves at a location T₂ to pass through an attemperator 9 preferably vertically located external of the unit casing. Steam leaving the attemperator 9 enters the secondary superheater 5 at a location T₃ and leaves at a location T₄ to the turbine or other point of usage. Hereinafter I will refer to the designation T₁, T₂, T₃ and T₄ as representing temperature values of the steam at the respective location in its serial path of flow through the primary superheater,

5

the attemperator and the secondary superheater, with the understanding that temperature T_4 is the final total temperature of the steam leaving the unit and which temperature is to be maintained as nearly as possible to an optimum value which in Fig. 2 I have indicated as 1000° F.T.T.

In Fig. 2 I indicate the normal characteristic curve of convection superheating surface as a rising function with the optimum value of 1000° F.T.T. crossing the unit rated load at X. In other words, the unit load X is the normal expected operating rating to which the generating and superheating surfaces are proportioned to attain at that rating a final steam temperature of 1000° F. The characteristic curve indicates that at ratings below X load the final temperature will tend to fall off, while at ratings above X load the temperature would tend to be greater than desired. It is through the upper range of rating that I employ attemperation to maintain or attain as nearly a uniform final total temperature of 1000° F. as is possible. In general the shaded area of Fig. 2 is in effect removed or nullified through attemperation by way of the present invention.

It will be noted that on this particular unit the steam flow is counterflow to the gas flow and the flue gas passes over the secondary superheater before contacting the primary superheater. Changes in steam temperature caused by changes in gas flow, excess air, ratings, etc. have been found to occur simultaneously at the primary superheater outlet (gas location 10) and at the secondary superheater outlet (gas location 11). Any disturbance is noted on final steam temperature T_4 as soon as it is detected at the primary superheater outlet T_2 . Thus a variation in temperature T_2 becomes a valuable index in controlling the final steam temperature T_4 .

In general I preferably use three indexes or variables of operation in the control of the rate of supply of water to the attemperator. These are desirably the temperatures T_2 , T_3 and T_4 . T_2 is the temperature of the steam leaving the primary superheater indicative of the heat level at the entrance to the attemperator. T_3 is the temperature of the steam leaving the attemperator, so that a knowledge of T_2 and T_3 indicates the effectiveness of the attemperation. T_4 is the final check-back temperature of the steam leaving the unit where the temperature is desirably to be maintained at optimum value and varies with T_3 , the inlet temperature to the secondary superheater, as well as with the heat absorption of the secondary superheater. I have found that these three temperatures cooperating in a method and control system are the most desirable guides to be utilized in the control of the attemperator of the present unit.

The temperature T_3 leaving the attemperator and entering the secondary superheater is very responsive to any changes in water flow to the attemperator. This temperature must vary inversely with boiler rating in order to maintain a constant final temperature at the superheater outlet T_4 by counteracting the rising characteristic of the secondary superheater. This is clearly shown in Fig. 2 wherein it is indicated that the water flow rate to the attemperator increases with rating and the effect of this increased water flow rate is clearly shown by the increasing divergence between T_2 and T_3 as rating increases. In other words, T_3 is lowered below the expected temperature at beginning of water supply so as to overcome the rising characteristic of the sec-

6

ondary superheater. At high ratings I require the maximum amount of attemperation hence a lower attemperator outlet temperature, whereas at lower ratings I require less water, until a point is reached where no attemperation is required and steam temperature leaving the attemperator is the same as the temperature entering the attemperator.

In general the primary impulse from T_2 is so adjusted as to call for a flow of attemperating water increasing with rating. T_3 is relatively insensitive and used as a readjusting factor against the primary control of T_2 . T_4 represents a final desired steam temperature and provides a check-back or readjustment to take care of irregularities in the heat transfer effect of the secondary superheater. While the primary control from T_2 is a rough control and the readjustment from T_3 is an approximate control to indicate whether the primary control has been satisfactory, it is seen that the final check-back control from T_4 is a vernier adjustment. The steam temperature leaving the attemperator and entering the secondary superheater is very responsive to any changes in water flow to the attemperator. This temperature must vary with boiler rating in order to maintain a constant final temperature at the superheater outlet T_4 .

In Fig. 3 I schematically indicate the temperature controllers T_2 , T_3 and T_4 which in known manner are receptive to the active element be it a thermocouple, resistance element or the like. Each of the controllers T_2 , T_3 and T_4 is arranged to position the movable element of a pilot valve which may be of the general type disclosed and claimed in the patent to Johnson 2,054,464. Pilot valve 15, under the control of T_4 , is arranged to continuously provide in the pipe 16 a fluid loading pressure bearing a desired relation to the value T_4 . In similar manner the pilot 17, under the control of controller T_3 , provides in pipe 18 a fluid loading pressure continuously representative of the value T_3 . Likewise the pilot 19 provides in the pipe 20 a fluid loading pressure continuously representative of the value T_2 .

At 21 I indicate an accelerating relay which may be of the type disclosed and claimed in the patent to Fitch 2,441,405. The output of the relay 21, available in the pipe 22, is introduced to the A chamber of a standardizing relay 23 which may be of the type disclosed and claimed in the patent to Gorrie Re. 21,804. The output of the relay 23, available in a pipe 24, is subjected upon the A chamber of a totalizing relay 25, to the B chamber of which is connected the pipe 18 and to the C chamber of which is connected the pipe 20. Thus the totalizing relay 25 is receptive of fluid loading pressures bearing definite relation to the values of T_4 , T_3 and T_2 respectively. The result, available in an outlet pipe 26, passes through a hand-automatic selector valve 27 to be effective upon the diaphragm 28 of a control valve 29 located in the water supply pipe 30 leading to the attemperator 9. Thus a positioning of the valve 29 controls the rate of supply of attemperating water to the attemperator 9.

It will be noted that the fluid loading pressure in the pipe 16, as well as in the pipe 20, increases with an increase in temperature T_4 or temperature T_2 . The loading pressure in the pipe 18 decreases with an increase in temperature T_3 . Thus if all three of the temperatures T_2 , T_3 and T_4 increase, the effect upon the relay 25 is in the same direction by each of the three loading pressures because the pressures effective in the

7

chambers A and C are increasing in the same direction and the pressure in the chamber B, opposing chambers A and C, is decreasing. Thus an increase in temperature T_2 , T_3 or T_4 will call basically for an increase in rate of water supply to the attemperor 9. This is in agreement with the curves of Fig. 2.

The various elements of the control system are provided with sensitivity and other adjustments so that the effect of the different indexes may be proportioned the one to the other as desired and also the characteristics of the different operating variables may be taken into account. For example, I consider that the temperature T_2 is a primary control and thus I give greater effect to the pressure established in the pipe 28, upon the relay 25, than I do to that which is effective upon the relay 25 through the pipes 18 or 24.

In operation it will be appreciated that, as rating increases toward the right of Fig. 2 past the rating X for which the superheating surfaces are designed, the general intent is for water flow rate to the attemperor to increase along the characteristic curve at the bottom of Fig. 2. The addition of this attempering water between the primary and secondary superheaters is to effect an elimination of the shaded area of the uppermost characteristic curve which otherwise would be a curve characteristic of temperature T_4 at the outlet of the secondary superheater.

In plotting T_2 the characteristic is relatively the same shape and parallel to the curve T_4 and I have already pointed out that temperature T_3 must fall off faster than temperature T_2 increases so as to anticipate the characteristic rise in temperature with rating of T_4 and thus overcompensate the steam by way of the attemperor to take care of the excess heat which would otherwise be put into the steam in the secondary superheater.

With temperature T_2 used as a primary or dominant controlling factor, effective upon relay 25, it will be seen that as T_2 varies with rating the valve 29 must be opened along some such characteristic curve as is shown in Fig. 2. Inasmuch as this is the primary and coarse corrective it will be appreciated that it is desirably most effective upon relay 25 as compared to the effect of the pressures from pipes 18 and 24. A secondary or servient readjusting effect is available through the pipe 18 under the control of temperature T_3 to show the result of adding the attempering water to the attemperor. Finally, the vernier adjustment by way of the loading pressure in pipe 24, under the control of servient temperature T_4 , is added into the system so that the final temperature T_4 will most nearly follow the desired final temperature as shown on Fig. 2.

It will be appreciated that I have chosen to illustrate and describe certain preferred embodiments of my invention but it will be understood that the invention may be carried out through other apparatus and means. For example, various types of temperature measuring and controlling instrumentalities may be used and it is not necessary to use fluid loading pressures but the control effects may be accomplished by other means. It is a principal object of my invention,

8

however, to interrelate the temperature T_2 , T_3 and T_4 in the control of the rate of supply of attempering water to an attemperor located between a primary and secondary superheaters in a unit of the general type being described.

What I claim as new and desire to secure by Letters Patent of the United States, is:

1. The combination including a first convection vapor superheater, an attemperor of the direct contact heat exchange type connected to receive vapor discharged from the first superheater, a second convection superheater connected to receive vapor discharged from the attemperor, said superheaters being subject to the flow of heating gases, means supplying vaporizable liquid to the attemperor for regulating the temperature of the vapor passing therethrough, a dominant temperature controller means responsive to an increase and decrease in the temperature of the vapor leaving the first superheater to increase and decrease respectively the supply of vaporizable liquid, a servient temperature controller means responsive to an increase or decrease in the temperature of the vapor leaving the attemperor to increase and decrease respectively the supply of vaporizable liquid, and a servient temperature controller means responsive to an increase and decrease in the temperature of the vapor leaving the second superheater to increase and decrease respectively the supply of vaporizable liquid.

2. The combination including a first convection vapor superheater, an attemperor of the direct contact heat exchange type connected to receive vapor discharged from the first superheater, a second convection superheater connected to receive vapor discharged from the attemperor, said superheaters being subject to the flow of heating gases, means supplying vaporizable liquid to the attemperor for regulating the temperature of the vapor passing therethrough, a primary controller means responsive to an increase and decrease in the temperature at the outlet of the first superheater to increase and decrease respectively the supply of vaporizable liquid, a modifying controller means responsive to an increase and decrease in the temperature of the vapor at the outlet of the attemperor to increase and decrease respectively the supply of vaporizable liquid, and a fine adjustment controller means responsive to an increase and decrease in the temperature of the vapor at the outlet of the second superheater to increase and decrease respectively the supply of vaporizable liquid jointly controlled by the primary and modifying controller means.

HENRY P. LEWIS.

References Cited in the file of this patent

Number	Name	Date
2,421,761	Rowand et al.	June 10, 1947
2,526,898	Powell et al.	Oct. 24, 1950
2,550,683	Fletcher et al.	May 1, 1951

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