Aug. 5, 1969 R. E. RICE 3,459,160

VAPOR GENERATOR

Filed July 31, 1967

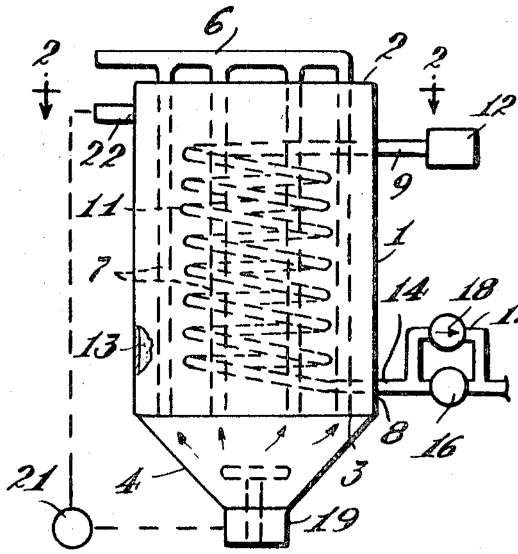

Fig. 1

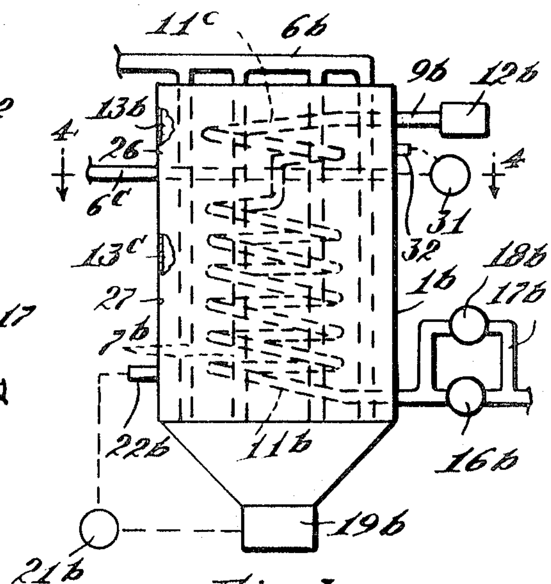

Fig. 3

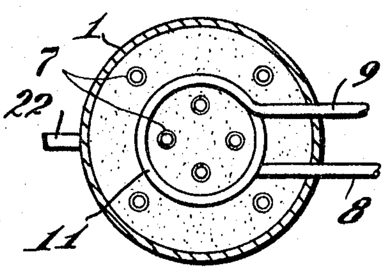

Fig. 2

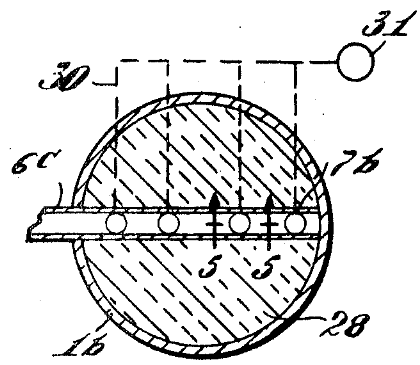

Fig. 4

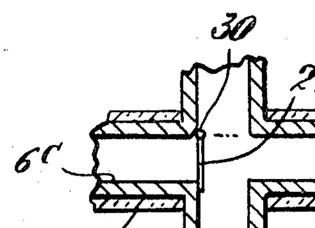

Fig. 5

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VAPOR GENERATOR

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ABSTRACT OF THE DISCLOSURE

Apparatus comprising a boiler and a heater with space therebetween, heat-storage material in the space, means responsive to the temperature of the material for controlling the heater and means responsive to the pressure in the boiler for controlling the supply of liquid to the boiler, said means operating independently of each other.

This invention relates to power plants which are particularly adapted to propulsion of vehicles and which utilize heat-storage materials such as sodium hydroxide or other alkali-metal hydroxides. When freshly charged with heat such material may have a temperature of 900 F. or higher and during the operating cycle its temperature at certain points in the system may drop to 300 F. or lower. Withdrawal of heat for vehicle propulsion may be subsequent to or concurrent with charging.

Heat engines of the turbine type or reciprocating engines such as the Stirling or the conventional steam engine may be used as heat-to-power conversion devices. The turbine has the advantage of low weight; the Stirling engine, high efficiency; and a reciprocating engine, the ability to start under load.

For efficient operation such engines must be supplied with high pressure super-heated vapor whose state is controlled within reasonably close limits. The state of the vapor is determined by any two of its properties, the temperature and pressure being most conveniently used in the present invention. The state of steam may, for example, be fixed within a range suitable for a reciprocating engine by maintaining its temperature in the range of 500 to 700 F. and its pressure at approximately 500 p.s.i. Higher temperatures are undesirable because of deleterious effects on lubricants and metals. The turbine can utilize steam at temperatures of 950 F. and higher, at similar or higher pressures.

In the conventional fuel-fired steam generating system the tubular generating elements have fluid, water or moving steam in direct contact with one side, e.g. the inside surfaces of the tubes, and the high-temperature combustion products of the fuel in contact with the other side. The temperature of the combustion products is high enough to damage the tubes unless the water is present or the steam is moving past the surface fast enough to provide the necessary cooling. When the steam or other vapor is used to drive an engine whose speed and power output must be independently variable over wide ranges, a widely varying demand on the generator for vapor results. To obtain reasonable efficiency from the engine, the generator must maintain the desired state of the vapor in spite of the varying demand.

These limitations and requirements lead to complicated and costly systems of controls. An extensive patent literature exists on such control systems. Typical examples are 1,283,109; 1,724,996; 1,732,796 and 3,111,936. These show the need in the conventional steam boiler for controlling steam pressure, steam temperature, boiler water level, water injection rate, burner fuel rate, and burner air rate, in order to satisfy the varying demand by the engine with steam of controlled state.

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Objects of the present invention are to produce a power plant which is simple and economical in construction, which produces vapor at predetermined pressure and temperature with a minimum of controls, which operates an engine efficiently throughout wide temperature variations of the source of heat, which is capable of delivering vapor at maximum rate instantly on demand, which permits the heater to operate at maximum efficiency at all times, which minimizes air pollution in the exhaust, which permits the heat source to be operated at a rate corresponding approximately to the average rather than the maximum demand, which requires a relatively small burner, which allows the boiler to run dry without damage, and which is durable, economical, and reliable in use.

According to this invention the apparatus comprises a boiler having an inlet and outlet for connection to a source of liquid supply and to the engine respectively, a casing surrounding the boiler, a heater in the casing for heating the boiler with space between the boiler and heater, heat-storage material substantially filling said space to serve as a thermal buffer between boiler and heater and to store heat for heating the boiler while the heat demand of the boiler is greater than the heater is supplying at any time, means responsive to the temperature of said material for controlling said heater, and means responsive to the pressure in the boiler for controlling the supply of liquid to the boiler, said means operating independently of each other. Preferably said heat-storage material consists essentially of sodium hydroxide or other alkali-metal hydroxide. While the heater preferably comprises an oil burner it may utilize other sources of heat such as electricity with resistance wires or rods instead of flues.

For the purpose of illustration typical embodiments of the invention are shown in the accompanying drawings in which:

FIG. 1 is a diagrammatic side view of one embodiment;

FIG. 2 is a section on line **2—2** of FIG. 1;

FIG. 3 is a diagrammatic side view of still another embodiment;

FIG. 4 is a section on line **4—4** of FIG. 3; and

FIG. 5 is a section on line **5—5** of FIG. 4.

The embodiment shown in FIGS. 1 and 2 comprises a casing **1** having an upper chamber defined by a top **2** and a bottom **3** and a lower combustion chamber **4**, all of which may be surrounded by thermal insulation (not shown). Extending through the upper chamber from the combustion chamber to an exhaust manifold **6** are gas flues **7**. Extending from an inlet **8** to an outlet **9** is a boiler coil **11** leading to an engine or other vapor-operated device **12**, the coil being spaced from the flues **7**. The space between coil and flues is filled with sodium hydroxide or other heat-storage material **13**. Leading to the inlet **8** is a liquid supply duct **14** containing a pump **16**. Extending around the pump is by-pass **17** containing a valve **18** responsive to the pressure between inlet **8** and pump **16** to by-pass liquid around the pump when the pressure reaches a predetermined maximum. A fuel burner **19** is controlled by a valve **21** responsive to a thermostat **22** buried in the heat-storage material **13** near the top **2** for closing fuel valve **21** when the temperature of the heat-storage material reaches a predetermined maximum of 650 F. and opening it when the temperature of the material reaches a predetermined minimum of 625 F., which is above the melting point of the material (605 F.).

The pump **16** delivers liquid at a substantially constant rate which is somewhat in excess of the maximum required by the boiler, the excess circulating through the by-pass **17**. The characteristics of the by-pass valve **18** are such that the pressure drop across it changes only slightly as the flow rate through it varies from maximum to minimum, and it maintains a substantially constant pressure in the liquid delivered to the inlet **8** to the boiler. Thus, the desired pressure at **8**, e.g. 600 p.s.i., can be maintained within sufficiently narrow limits regardless of whether the engine is demanding vapor at maximum rate when delivering maximum power, or whether it is demanding almost no vapor when delivering little or no power. The coil **11** is designed with a length and cross-section such that the pressure drop between entrance **8** and exit **9** at maximum through-put is small; consequently the aforesaid control of pressure at entrance **8** provides adequate control over the pressure of the vapor delivered at exit **9**. Since the coil is completely surrounded by the heat-storing material which is limited to a maximum temperature of 650 F., the coil cannot be overheated even if no water enters.

The coil **11** is designed with enough surface to permit evaporation of all the liquid in its lower sections, the vapor being superheated in the upper part. While the temperature of the material surrounding the lower part where boiling occurs may vary over a wide range, the temperature of the material surrounding the upper part is held within a relatively narrow range. Sufficient heat transfer surface is provided between the material and the upper turns of the coil, and between coil and vapor, to insure that the temperature of the superheated vapor leaving the coil is close to that of the surrounding material.

The burner is designed to produce heat at a rate slightly in excess of the average rate required by the boiler to satisfy the varying demand of the engine. Thus as the demand varies several different modes of operation of the generator occur:

Mode *a*—The heating rate may equal the demand, and the average temperature of the material remains constant;

Mode *b*—The heating rate may be greater than the demand, the difference being stored by the material;

Mode *c*—The heating rate may be less than the demand, and the material delivers the difference from storage.

When operating in Mode *a* the burner is turned on and the temperature in the vicinity of the thermostat remains constant. In Mode *b* the temperature of the material will rise more or less rapidly as heat is stored to 650 F. when the burner will turn off. In Mode *c* the temperature near the thermostat will drop more or less rapidly as heat is delivered from storage to the boiler. At 625 F. the burner will start, the temperature continuing to fall but more slowly until the melting point is reached at 605 F. where the temperature will remain constant while the material delivers to the boiler, from storage, its latent heat of fusion. Sufficient material is provided to meet the maximum demand for heat from storage without causing an appreciable further drop in temperature. By thus utilizing the latent heat of fusion the temperature of the vapor is prevented from falling below a predetermined minimum which approximates the melting point of the heat-storage material but of course is somewhat less than the melting point because of the temperature gradient between the material and vapor.

Thus, with extraordinarily simple controls, the thermally buffed generator delivers steam of controlled temperature and pressure at widely varying rates.

The embodiment shown in FIGS. 3 to 5 is like that shown in FIGS. 1 and 2 and corresponding parts are correspondingly designated. However it differs as follows: The casing **1***b* is divided into upper and lower compartments **26** and **27** by a partition **28** of insulation and the melting point of the heat-storage material **13***b* in the upper compartment is higher than that of the material **13***c* in the lower compartment. For example, the upper material may be LiOH with a melting point of 880 F. and the lower material may be NaOH with a melting point of 605 F. In addition to the exhaust **6***b* the flues **7***b* have

a second exhaust **6***c* in the partition **28**. At the junctions between the flues and second exhaust are valves **29** for diverting the exhaust gases from exhaust **6***b* to the exhaust **6***c* when in the broken-line position shown in FIG. 5. The valves **29** are moved by linkage **30** and an actuator **31** controlled by a thermostat **32** buried in the heat-storage material **13***b* in the upper compartment **26** which is set to move the valves to diverting position when the material reaches a predetermined maximum temperature, e.g. 950 F. and to reverse this action when the temperature drops to a lower temperature slightly above the material melting point, e.g. 900 F. The thermostat **22***b* controlling the burner **19***b* is located near the bottom of the lower compartment **27**. The steam generating coil has a lower part located in the heat-storage material **13***c*, and a continuation located in the heat-storage material **13***b*. Both compartments can be heated by a single burner with independent control of their individual heating rates as illustrated, or alternatively two independently controlled burners may be provided, one for each section.

During operation the pump **16***b*, by-pass **17***b* and by-pass valve **18***b* are used as described above to control the pressure of water introduced into the steam generating coil **11***b* and the pressure of the steam issuing from **11***c* at **9***b*.

The upper and lower sections **26** and **27** operate independently in all of the three modes described above, with the lower section supplying the relatively large amount of heat required to evaporate liquid and the upper section supplying the lesser heat for superheating the vapor. The selection of heat-storing materials is determined by their thermal characteristics and cost. For superheating steam to a temperature of 850 to 950 F., suitable for operating a turbine, LiOH with its melting point of 880 F. and latent heat of 375 B.t.u./lb. (largest among the alkali metal hydroxides) may be used for the upper section. Its modes of operation are analogous to those described above with respect to control of heat supply, control temperatures and melting point of the heat-storage material. As heat-storage material for the lower section, NaOH is preferred. Used in substantially greater amount, its lower cost (1/10 that of LiOH and lowest of the alkali metal hydroxides) is important.

The thermostat **22***b* may be set to turn off burner **19***b* when the temperature of the NaOH in its vicinity rises to 900 F. and to turn it on when the NaOH drops to approximately 700 F. When operating in Mode *a* the temperature of the NaOH remains constant. When operating in Mode *b* the temperature of the NaOH rises to 900 F. and the burner turns off.

In Mode *c* the temperature drops from 900 F. to 700 F. before the burner turns on, while each pound of NaOH supplies 100 B.t.u. of heat. This insures that the on-off cycling rate of the burner will be low even when vapor is demanded at maximum rate, thus insuring efficient burner operation, minimum air-polluting combustion products, and long operating life of components. As operation in Mode *c* continues, the temperature of the NaOH drops, with the burner on, to its melting point of 605 F. where the latent heat of fusion (70 B.t.u./lb.) is delivered to the boiler at substantially constant temperature. Continued operation in Mode *c* causes a further drop in temperature of the NaOH during which it delivers sensible heat and latent heat accompanying a change in crystal structure, the latter effect being substantially complete when the temperature has dropped to about 350 F. Thus a practical temperature range for operation is approximately 900 F. to 350 F., which corresponds to heat delivery of approximately 405 B.t.u. per pound of NaOH.

With sufficient heat-transfer surface between the NaOH and the outer surface of the coil, and enough inner surface, and with a temperature of about 350 F. in the NaOH in the vicinity of thermostat **22***b*, at the maximum rate of introduction of water the water will be completely vaporized before entering the upper section of the coil.

While the apparatus is preferably operated through a temperature range which extends on both sides of the melting point of heat-storage material so as to utilize the latent heat of fusion, the invention is also useful where the operating range is disposed wholly above or below the melting point.

It should be understood that the present disclosure is for the purpose of illustration only and that this invention includes all modifications and equivalents which fall within the scope of the appended claims.

I claim:

1. For supplying heated fluid at a predetermined state and at a temperature above a predetermined minimum, apparatus comprising a fluid heating tube having an inlet for connection to a source of liquid supply and an outlet, a casing surrounding the tube, a heater in the casing for heating the tube with space between the tube and heater, heat-storage material substantially filling said space to serve as a buffer between the tube and heater and to store heat for heating the tube while the heat demand is greater than the heater is supplying at any time, means responsive to the temperature of said material for controlling said heater, the heat-storage material in the region of said outlet having a melting point within a range of temperature variation high enough to maintain the fluid above said minimum so that the latent heat of fusion of the material supplements the heater when the demand exceeds the capacity of the heater, and wherein the outlet is at the upper end of the tube and the heat-storage material in the upper part of said space has a melting point higher than that of the material in the lower part of the space.

2. Apparatus according to claim **1** wherein said melting point of the material in said upper part is within the desired temperature range of the fluid, delivered by the tube.

3. Apparatus according to claim **1** wherein said space is divided into upper and lower compartments for said materials respectively and the apparatus has means for controlling the heat supplied to the upper compartment without correspondingly controlling the heat supplied to the lower compartment.

4. Apparatus according to claim **3** wherein said last means is responsive to the temperature in said upper compartment.

5. Apparatus according to claim **3** wherein the means for controlling said heater is responsive to the temperature in said lower compartment.

6. Apparatus according to claim **1** wherein the temperatures of the materials in said upper part and said lower part are independently controlled.

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CHARLES J. MYHRE, Primary Examiner

U.S. Cl. X.R.

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