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(54) Two-phase thermal energy conversion system.

(57) The system employs an evaporable liquid, such as water, and a gas which is not liquefiable within the operating temperature and pressure ranges, such as air. Hot water from source 10 is supplied by pump 16 through valve 18 to evaporator 12 where it is sprayed into air supplied by pump 23 through valve 24. The resulting increase in pressure or volume drives prime mover 14 (turbine or reciprocating piston engine) which in turn drives generator 15. The control device 36 receives inputs from sensors and controls valves 18 and 24 to achieve saturation in the evaporator 12. If the water consists of salt water, fresh water is derived as a condensation product from the prime mover.
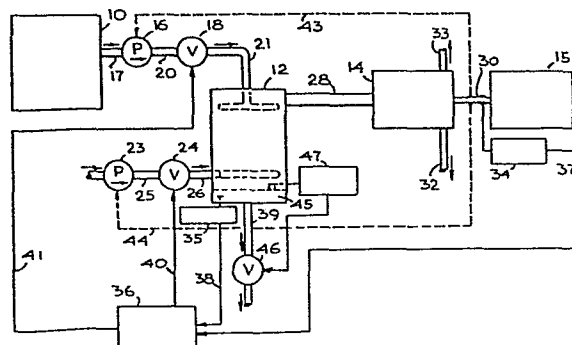
Fig. 1

EP 0 052 674 A1

TWO-PHASE THERMAL ENERGY CONVERSION SYSTEM

This invention relates generally to heat engines and more particularly relates to a two-phase thermal energy conversion system.

5   Many types of heat engines are known to the art. The most efficient of these at the present time is the steam turbine. However, even a steam turbine converts less than half of the heat of the steam into mechanical power. The remainder of the heat remains in the steam which without condensation is at or near atmospheric

10   pressure as it leaves the turbine. Hence, this steam has no additional realizable expanding force. It is usually condensed for reuse and the heat of condensation is generally lost to the system. Many disadvantages are encountered in the conventional methods employed for the disposal or use of this heat.

15   In accordance with the two-phase thermal energy conversion system of the invention, the heat of condensation can be converted to mechanical power with increased efficiency. It is of potential use in the conversion of solar energy. This is due to the fact that it will convert heat to energy contained in water below the boiling

20   point of water at atmospheric pressure. Such hot water may be stored conveniently and economically for use at a later time, for

example when no sunlight is available. Also, the system of the present invention may utilize sea water or other salt water. In this case, fresh water may be obtained as the output of a prime mover of the system. This is in addition to the mechanical power

5 obtainable form the heat of the water.

It is well known that water vapor forms and mixes with air when air and water are in intimate contact at temperatures which are, for example, below the boiling point of water. The amount of water vapor absorbed by the air until it is completely saturated

10 depends on the temperature of the mixture when the pressure remains constant, such as at atmospheric pressure. At higher temperatures the proportion of water vapor absorbed by the air increases. This increase of the water vapor rises rapidly as the temperature nears the boiling point of water. In that case the volume of water vapor

15 absorbed by the air is many times that of the volume of air. Hence an increase of the volume under constant pressure is achieved at temperatures at or below the boiling point of water.

Under those conditions, either the volume will increase or, if the volume is confined, the pressure will increase. Hence when

20 air and water are mixed at elevated temperatures until the air is saturated, the increase equals the vapor pressure of the water at the prevailing temperature of the mixture.

These principles are utilized in accordance with the present invention by mixing a first fluid consisting of a liquid evaporable

25 within a range of predetermined or operating temperatures and pressures and a second fluid consisting of a gas which cannot be liquefied within this predetermined temperature and pressure range. One or both of the two fluids is heated. The liquid may consist of water and the gas may consist of air. The water and air are mixed,

preferably to equilibrium at a given temperature, and the

equilibrium mixture is fed to a prime mover for extracting energy

from the mixture. The mixture is in equilibrium when the air is

saturated by water vapor at the temperature of the mixture. The

5 corresponding pressure is the equilibrium pressure for that

temperature.

In the drawings:

Fig. 1 is a schematic representation of a two-phase thermal

energy conversion system embodying the present invention and

10 utilizing a source of hot water;

Fig. 2 is a cross-sectional view of an evaporator which may

be used with the system of Fig. 1;

Fig. 3 is a chart relating the engine exhaust temperature in

degrees F to the engine efficiency in percent in a constant-volume

15 engine.

Fig. 4 is a schematic representation of a second embodiment

of the energy conversion system of the invention utilizing a boiler,

and two coupled prime movers which may each consist of a turbine;

and

20   Fig. 5 is a schematic representation of a third embodiment

of the energy conversion system of the present invention featuring a

gas turbine, the exhaust of which is mixed with water and feeds a

vapor turbine.

Fig. 1 illustrates a first embodiment of the two-phase

25 energy conversion system of the invention. The system of Fig. 1

includes a source of hot water 10, an evaporator 12, a prime mover

14 and a device for utilizing the energy of the prime mover such as

a generator 15.

The source of hot water 10 is connected to a pump 16 through

a conduit 17. Following the pump 16 is a controllable valve 18 connected to the pump by a conduit 20. The output of the valve 18 is connected to the evaporator or mixing chamber 12 by a conduit 21. The evaporator 12 may have the form shown in Fig. 2.

5   Ambient air is compressed by another pump 23 connected to a controllable valve 24 by a conduit 25. The air from the controllable valve 24 is fed to the evaporator 12 by a conduit 26.

In the evaporator 12 the hot water is mixed with the air in intimate contact. As a result, the air will absorb water vapor and

10   the mixture of air and vapor is fed by a conduit 28 into the prime mover 14. The prime mover 14 is connnected to the generator 15 by a mechanical shaft 30.

The water of the source 10 may be hot water obtained from a thermal source heated by solar energy. Alternatively, it may be

15   heated by the waste heat of some low temperature process such as the exhaust steam of a steam turbine. The temperature of the hot water may be below the boiling point of water but also may be at or near the boiling point of water, that is, at or near 212° F (100° C) at sea level pressure.

20   In accordance with the two-phase thermal conversion system of the present invention, the vapor pressure of the liquid such as water is utilized. This need not necessarily be the steam pressure above the boiling point of the liquid. The liquid could be any liquid which may be evaporated at a predetermined temperature and

25   pressure range which is the operating temperature and pressure. Similarly, instead of air, any gas may be used which does not liquefy at the operating temperature and pressure range. When a liquid such as water is combined with a gas and heat is added to the mixture, the vapor pressure of the liquid is added to the pressure

of the gas. This is in accordance with Dalton's Law of Partial

Pressures: the pressure of a mixture of gases such as a gas and a

vapor is the sum of the partial pressures of the individual gases

when they exist at the total volume and temperature of the mixture.

5   Hence it will be realized that the mixture of water vapor and air

will have either an enlarged volume or, with a fixed volume, an

increased pressure over that of either constituent alone.

It is this increased pressure which is utilized in

accordance with the present invention to extract mechanical energy

10 by the prime mover 14. In this process there is an optimum ratio of

water vapor to air which is that amount of water vapor sufficient to

saturate the air at the operating temperature and pressure.

As an example, if boiling water at atmospheric pressure is

mixed with air at the same temperature and pressure, and at constant

15 volume, the pressure is doubled. The air absorbs that amount of

water vapor which causesthe air to be saturated, thus developing a

pressure of twice atmospheric. At temperatures below the boiling

point of water, the equilibrium pressure at saturation will be less.

The following Table I may be used to calculate equilibrium

20 pressures and other operating characteristics of systems of the

present invention.

TABLE I

1	2	3	4	5	6	7	8
212	26.799	100	1150	1150	81	1231	0
200	33.639	79.7	1146	913	76	989	19.6
190	40.957	65.4	1142	747	72	819	33.5
180	50.22	53.4	1138	608	68	676	45.0
170	62.06	43.2	1134	490	65	555	54.9

TABLE I continued...

160	77.29	34.7	1130	392	61	453	63.2
150	97.07	27.6	1126	311	57	368	70.1
140	123.0	21.8	1122	245	53	298	75.8
130	157.33	17.0	1118	190	49	239	80.5
120	203.26	13.2	1114	147	46	193	84.3

Column 1 shows the temperature in degrees F of the mixture

10   of water and air within the prime mover 14. Column 2 gives the

total volume in cubic feet of one pound of vapor at the temperature

shown in Column 1. This may readily be obtained from a so-called

steam table. Such a table has been published for example by

Combustion Engineering-Superheater, Inc., 3rd Edition, 1940.

15   Column 3 indicates the percentage of water remaining in the

mixture as vapor. This is calculated on the assumption that the

original mixture contained one pound of vapor but at lower

temperatures and at reduced pressures this volume will contain

progressively less vapor. This is readily obtainable from the steam

20   table. The percentages are obtained by dividing the original volume

by the instant volume and multiplying by 100. This value is only

approximate in that the condensed vapor would also occupy some

volume.

Column 4 is the enthalpy of the vapor in btu/lb. The

25   enthalpy is simply the sum of the total internal energy in btu

(British thermal units) plus a product of the absolute pressure and

the volume. This set of figures is directly obtainable from a steam

table. It represents the amount of energy per pound at the

particular condition.

Column 5 shows the energy remaining in the vapor in btu units. This corresponds to the percentage of Column 3 times the energy per pound in Column 4.

Column 6 shows the energy in the air in btu. This is

5   obtainable from the handbook of the American Society of Heating and Air Conditioning Engineers (1958 Guide). It should be noted that the value for 212°F has been extrapolated.

Column 7 shows the total energy, which is the sum of columns 5 and 6. Finally Column 8 represents the efficiency in percent.

10   This is the original energy at 212°F in Column 7 minus the instant value in Column 7 divided by the original energy times 100. In other words, this is the efficiency that would result if the mixture were to be exhausted from the engine at that temperature at constant volume. This of course shows that this efficiency increases as the

15   exhaust temperature decreases.

It is desirable to control the rates of introduction of air and water to the mixing chamber 12 of Fig. 1 in accordance with the operating conditions of the prime mover 14. In Fig. 1 the condensed water may leave the prime mover 14 through conduit 32 while the air

20   and any remaining water vapor leaves through conduit 33. Where the prime mover 14 exhausts at atmospheric pressure, the conduits 32 and 33 may be open ended. However where the prime mover 14 is operated as part of a closed system, the conduits 32 and 33 may be connected respectively to the air inlet to the pump 23 and to the hot water

25   source 10.

A first sensor 34 is shown mounted on the prime mover drive shaft 30 to monitor the load demand upon the prime mover 14. A second sensor 35 is associated with the evaporator 12 for monitoring the temperature of the discharge water 45 leaving the evaporator.

These sensors 34 and 35 jointly feed into a control device 36 as·
shown by lines 37 and 38. The control device 36 in turn controls
the controllable valves 24 and 18 as shown by lines 40 and 41 so
that the rate of air flow is proportional to the prime mover load
5   demand while the rate of hot water flow is varied inversely with the
discharge water temperature. When controlled in this fashion, the
mixture in the conduit 28 is saturated and can be substantially at
the temperature of the hot water entering the evaporator 12.

It should be noted that the prime mover 14 may for example
10   be a vapor turbine. For maximum efficiency in the cycle of
operation of the present invention, the turbine should be of
substantially constant axial cross-section from inlet to outlet.

Alternatively, the prime mover 14 may comprise a
reciprocating engine. In this case, for example, hot water may be
15   sprayed into a cylinder that contains dry air, thus combining the
mixing chamber 12 within the prime mover 14. The hot water
vaporizes and humidifies the air. In this case, the pressure inside
the cylinder is increased by an amount which is only slightly less
than the vapor pressure of the injected water. Thereafter this
20   humid mixture expands, doing work on the piston under conditions of
increasing volume and decreasing pressure.

It is also feasible to drive the pumps 16 and 23 through the
prime mover 14. This is schematically indicated by broken lines 43
and 44.

25   Additionally, the water which accumulates in the evaporator
12 as shown at 45 may be vented outside through a valve 46 which is
controlled by a sensor 47 in accordance with the level of the water
45 in the evaporator 12.

It should be noted that the source of hot water may be sea

water or other salt water. In this case, the water recovered from conduit 32 from the prime mover will be fresh water which is obtained as a by-procuct of the energy conversion system of the invention.

5   Another form of piston engine which could be used compresses air to the vapor pressure of water above the atmospheric boiling point of the water at the top of the stroke. In this case either hot water or steam may be mixed with the air on the down stroke. The addition of the water or steam is effected at a rate to maintain

10   the maximum pressure over a portion of the stroke. This action is similar to that of a diesel cycle.

Referring now to Fig. 2, there is shown in greater detail one preferred arrangement of the evaporator 12. It comprises a comparatively large tank 50 which may be of cylindrical form. In

15   its interior region there is disposed a water spray unit 51 and an air inlet unit 52. A plurality of water spray nozzles or orifices 53 are formed along the water spray unit 51 which may simply be a pipe. It may be an elongated tube or a ring disposed about the top of the evaporator 12. The nozzles 53 may be directed in such a

20   direction to spray the water into the evaporator 12 in all directions or to spray generally downwardly only. A plurality of air discharge orifices 54 are formed in the air inlet unit 52. They are preferably directed generally upwardly toward the liquid spray unit 51. The air inlet unit is disposed near the bottom of the tank

25   50 but above the water level 45 in the bottom of the tank. A liquid drain line 39 is connected to the controllable valve 40 of Fig. 1. The air-vapor outlet line 28 is connected to a top region of the tank 50 above the fluid spray unit 51. A filter 56 may be disposed at the outlet end of the hot air conduit 28 to remove water

droplets.

Fig. 3, to which reference is now made, indicates the theoretical engine efficiency at constant volume of prime mover 14 as a function of the engine exhaust temperature in degrees F. The

5 chart of Fig. 3 was obtained from the efficiency in percent as shown in Column 8 of Table I.

A second embodiment of the thermal energy conversion system of the invention is illustrated in Fig. 4. This system comprises a conventional boiler 60 which may be heated by fuel entering the fuel

10 line 61. The water is heated until steam is obtained which is fed by conduit 62 into a first portion 65 of a prime mover. The prime mover portion 65 may be a steam turbine. The steam turbine 65 extracts heat from the steam and the steam pressure drops to a low value as it exits the steam turbine 65 through conduit 66 into a

15 second portion 67 of the prime mover via a rate of flow sensor 63. The prime mover portion 67 may also be a turbine such as a vapor turbine of constant volume. The rate of flow sensor 63 may for example include a Venturi tube or the like.

The steam at reduced pressure and temperature is now mixed

20 with air in the portion 67. To this end, ambient air may be pumped by a pump 68 and fed through a conduit 70 to a controllable valve 71 which in turn supplies the compressed air by conduit 72 to the turbine 67.

As before, the prime mover 67 may drive a drive shaft 74,

25 and an electric generator 75 or the like.

The rate of flow sensor 63 output is used to control the controllable valve 71 as indicated by the line 76. The control is such that the volumes of steam and air supplied to the prime mover 67 are in such proportions as to effect substantially optimum

condensation of the water vapor in the turbine 67. The air and any remaining water vapor are discharged through conduit 77 while the condensate or water is discharged through line 78. As shown by the broken line 80, the drive shaft 74 may be coupled to the pump 68 for

5 driving the pump.

It will be understood that the water discharged at conduit 78 may be fed back into the boiler 60 by a conventional feedwater pump. A closed system may be employed in which the air from conduit 77 is fed back into the pump 68, in which case the pressure of the

10 systsem is not tied to atmospheric pressure.

Where appropriate, as for examaple where the boiler 60 is replaced with a source of low pressure steam, the prime mover portion 65 may be dispensed with and the low pressure steam may be fed directly to the prime mover 67 via the rate of flow sensor 63.

15 This is represented in Fig. 4 by the broken lines 82 shown connecting directly between the pipes 62 and 66, bypassing the portion 65.

Another embodiment of the two-phase thermal energy conversion system of the invention is illustrated in Fig. 5 to which

20 reference is now made. Here a gas turbine 85 is fed from a fuel source 86.

The products of combustion of the gas turbine 85 are fed through a conduit 88 into another turbine 90 via a rate of flow sensor 87. The turbine 90 may be a vapor turbine. In this case, of

25 course, it is a gas which is hot rather than the liquid. The liquid may be water obtained from a source of water 91 which is pumped by a pump 92 past the controllable valve 93 and through a conduit 94 into the vapor turbine 90. By means of the rate of flow sensor 87 as shown by lead 96, the valve 93 is controlled. Thus the volume of

the hot gas from the exhaust of gas turbine 85 is proportional to the volume of water obtained through valve 93 to obtain substantially optimum condensation of the water vapor in vapor turbine 90. The exhaust gases and any remaining water vapor are discharged through line 97 while the condensate water itself is

5 discharged through line 98. The vapor turbine 90 may have an output shaft 10 to drive a generator 101 or some other useful work producing engine. The output shaft 10 may be connected as shown by dotted line 102 to the pump 92 for driving it. The turbines 85 and 90 are shown coupled together mechanically but it will be understood

10 that such a mechanical coupling may be dispensed with and the turbines may have independent power outputs if desired.

It will be understood that the water obtained from conduit 98 may be recycled by reinserting it into the water source 91. As a further alternative the block 85 may represent simply a burner for

15 fuel from the source 86 or may be any source of hot gas. The sensor 87 monitors the hot gas and controls the rate of water flow accordingly for mixing in the vapor turbine 90.

There has thus been disclosed a two-phase thermal energy conversion system. The system of the present invention may for

20 example utilize hot water which may be at or near the boiling point and a gas which is not liquefiable at the operating temperature and pressure, such as air. The system utilizes the fact that with a constant volume a pressure increase takes place when water is evaporated into dry air. This pressure increase may then be

25 utilized to drive a prime mover such for example as a turbine or a reciprocating piston engine. It is preferable in systems of the invention that the volume of water and the volume of air be controlled to effect substantially optimum condensation of the

evaporated liquid in the prime mover. Since the system of the

present invention operates preferably at relatively low temperatures

such as those at or below the boiling point of water, the prime

mover may be constructed of relatively inexpensive materials which

5   do not need to withstand high temperatures. It is also able to

operate on heat energy derived from waste heat of conventional steam

power systems which operate at high temperatures, as well as energy

from low grade heat sources such as geothermal, solar, and the like.

Because of the operation at relatively low maximum temperatures and

10   pressures, plastic working parts can be used and the mechanical

prime movers can be made very cheaply to handle large displacements.

The associated pumps and fans or blowers can also be small and

economical. Heat exchangers, where employed, can be similar to

automotive radiators.

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CLAIMS:

1. A two-phase energy conversion system comprising a source
of a first fluid which is evaporable within a predetermined range of
temperature and pressure, a source of a second fluid consisting of a
gas which is not liquefiable within the temperature and pressure

5 range, a heater for heating at least one of the fluids, a mixer for
mixing the fluids, a device for supplying the fluids under pressure
to the mixer, and a prime mover coupled to be driven by the mixture,
a sensor for monitoring at least one operating condition of the
prime mover, and a control mechanism responsive to the sensor for

10 controlling the ratio of flow rates of the first and second fluids
to the mixer so as to substantially saturate the second fluid with
the first fluid over a pressure range up to twice the absolute
pressure of the prime mover exhaust at equilibrium temperature.

15

2. The system of claim 1 wherein the first fluid is water
which is heated to a temperature not greater than its boiling point.

20

3. The system of claim 1 or claim 2 wherein the prime mover
is of substantially constant volume.

25   4. The system of any of claims 1-3 wherein the prime mover
is a turbine having substantially constant axial cross-sectional
area from inlet to outlet.

5. The system of any one of claims 2-4 wherein the water consists of salt water and wherein the exhaust from the prime mover is fresh water.

5

6. The system of any one of claims 2-5 wherein the sensor is coupled to monitor load demand on the prime mover and temperature of discharge water from the mixer and wherein the control mechanism is operative to control the flow rate of at least one of the fluids

10 to the mixer in accordance with signals from the sensor.

7. The system of claim 6 including first and second valves for respectively controlling the rates of flow of the first and

15 second fluids to the mixer such that the flow rate of the second fluid is proportional to prime mover load demand while the flow rate of the first fluid is varied inversely with the temperature of discharge water from the mixer.

20

8. The system of any one of claims 1-7 wherein the mixer is incorporated within the prime mover.

25 9. The system of claim 8 wherein the sensor is connected to monitor the flow rate of the first fluid to the prime mover for mixing therein, and wherein the control mechanism controls the flow rate of the second fluid to the prime mover in accordance with

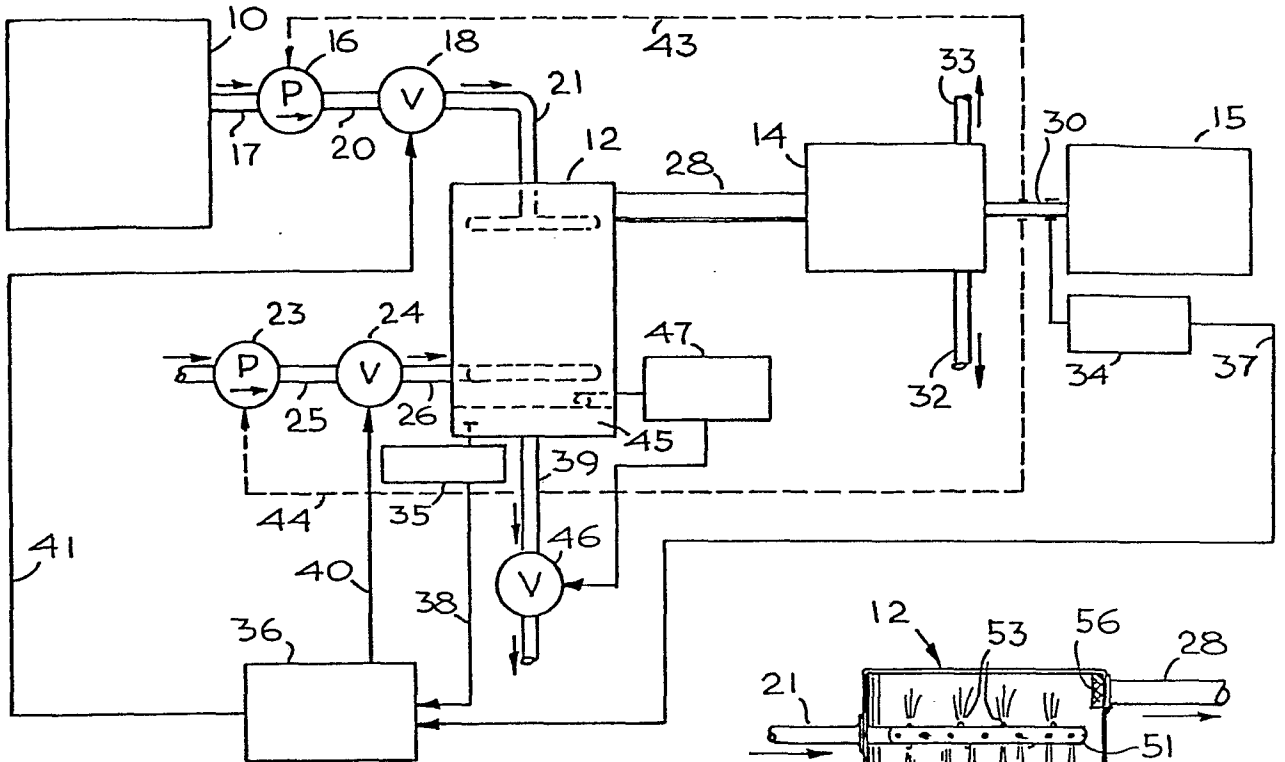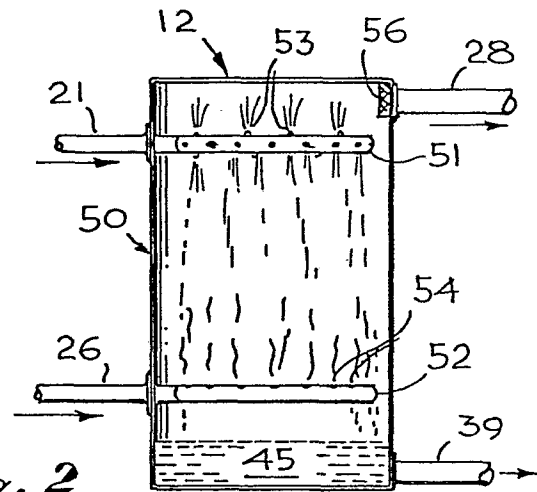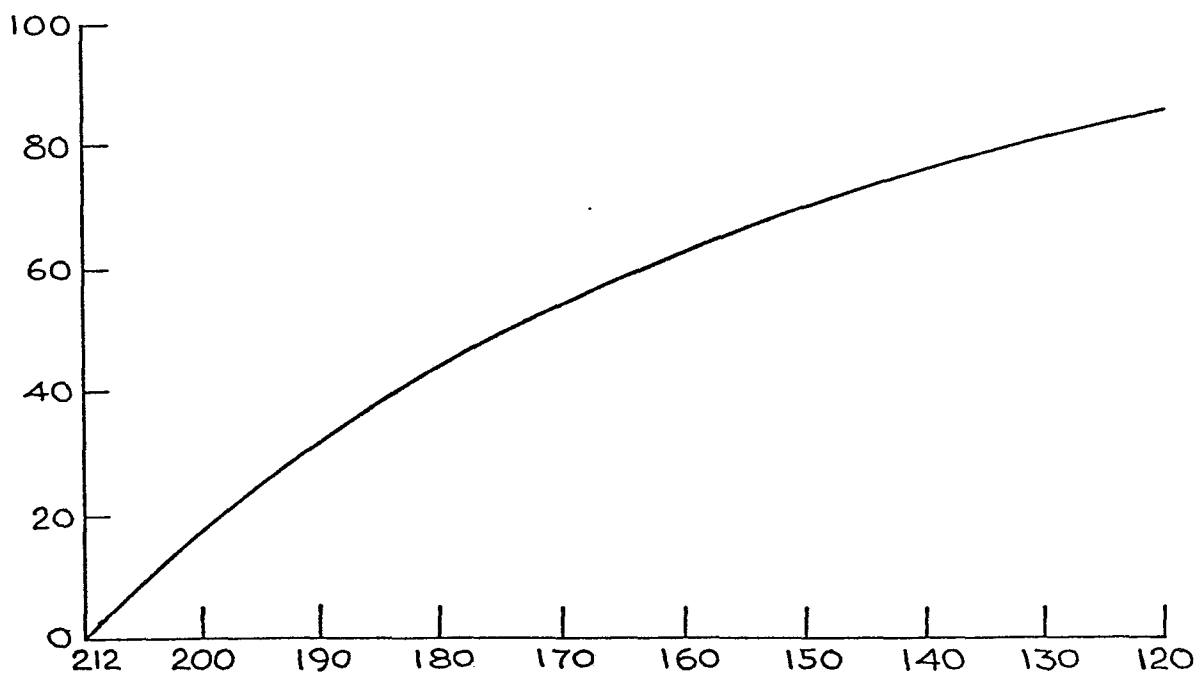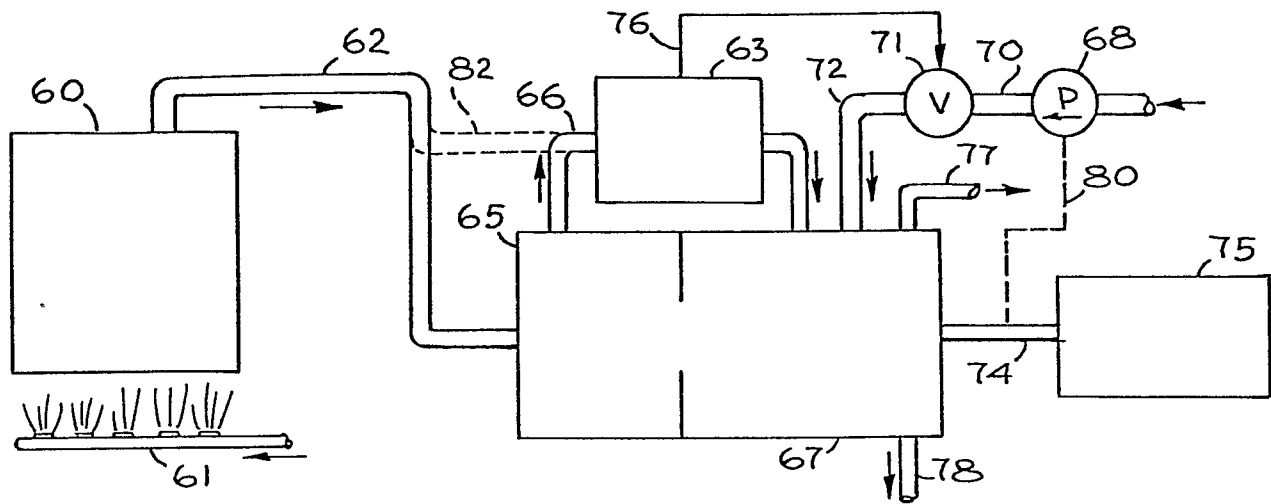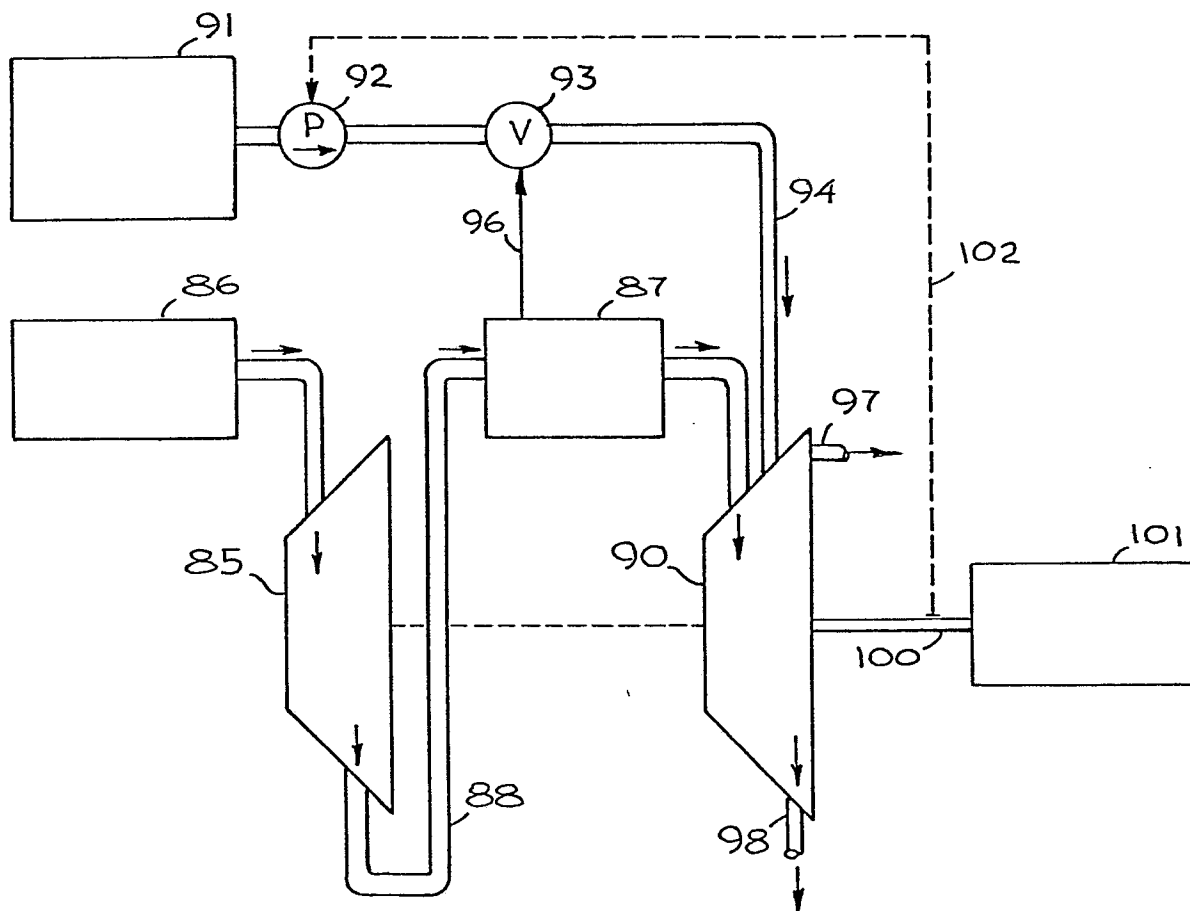signals from the sensor.

10.   The system of claim 8 wherein the sensor is connected to
5 monitor the flow rate of the second fluid to the prime mover for

mixing therein, and wherein the control mechanism is operative to

vary the flow rate of the first fluid to the prime mover in

accordance with signals from the sensor.

10

11. The system of any of claims 2-10 further including a

first pump connected to the first fluid source for pumping the hot

water and a first controllable valve connected to the pump for

controlling the water flow rate and a second pump for pumping

15 ambient air and a second controllable valve connected to the second

pump for establishing a predetermined flow rate of air to the mixer,

the first and second pumps being coupled to be driven by the prime

mover.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

EUROPEAN SEARCH REPORT

	DOCUMENTS CONSIDERED TO BE RELEVANT		CLASSIFICATION OF THE APPLICATION (Int. Cl.³)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
	US - A - 4 085 591 (BISSELL) * Column 3, column 4, lines 1-58; figures * --	1,2	F 01 K 21/04
	US - A - 4 106 294 (CZAJA) * Column 5, lines 47-68; column 6, lines 1-18; column 9, lines 15-41; figures * --	1,2,5	
	US - A - 3 878 680 (DAUVERGNE) * Column 2, lines 58-68; column 3, lines 1-13; figure 1 * --	1,11	TECHNICAL FIELDS SEARCHED (Int. Cl.³) F 01 K F 02 C F 01 D
	FR - A - 2 355 177 (BRADBURY) * Page 4; figure * --	3,4	
A	US - A - 3 101 592 (ROBERTSON) ----		

CATEGORY OF CITED DOCUMENTS

X: particularly relevant

A: technological background

O: non-written disclosure

P: intermediate document

T: theory or principle underlying the invention

E: conflicting application

D: document cited in the application

L: citation for other reasons

&: member of the same patent family.

corresponding document

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	20-07-1981	V. GHEEL