US 20120255302A1

(19) United States
(12) Patent Application Publication
Hugelman et al.
(10) Pub. No.: US 2012/0255302 A1
(43) Pub. Date: Oct. 11, 2012

(54) HEATING, COOLING AND POWER GENERATION SYSTEM

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(21) Appl. No.: 13/515,558

(22) PCT Filed: Dec. 28, 2010

(86) PCT No.: PCT/US10/03255

§ 371 (c)(1), (2), (4) Date: Jun. 13, 2012

Related U.S. Application Data

(60) Provisional application No. 61/284,936, filed on Dec. 28, 2009.

Publication Classification

(51) Int. Cl.
F01K 25/10 (2006.01)

(52) U.S. Cl. 60/651; 60/671

(57) ABSTRACT

A thermal separator/power generator uses the thermodynamic properties of refrigerant substances to provide supplemental heating, cooling, and power without emitting any additional greenhouse gases to the environment by utilizing waste or unused heat energy. This is accomplished through the combined operation of a Rankine Cycle Generator using a refrigerant, preferably a natural refrigerant such as NH3, as the working fluid, and a CO2 a vapor compression heat pump cycle, also called a Thermal Separator Module. The combined system is called a Thermal Separator/Power Generator. It produces electrical power and simultaneously produces secondary heating and water or air cooling as byproducts. In the combined vapor compression heat pump/Rankine power generator cycle, waste heat from external source(s) are recovered and used for heating in the Rankine power cycle. The CO2 heat pump provides cooling and optional space or process heating in lieu of heat boost efficiency for the Rankine power generator cycle.

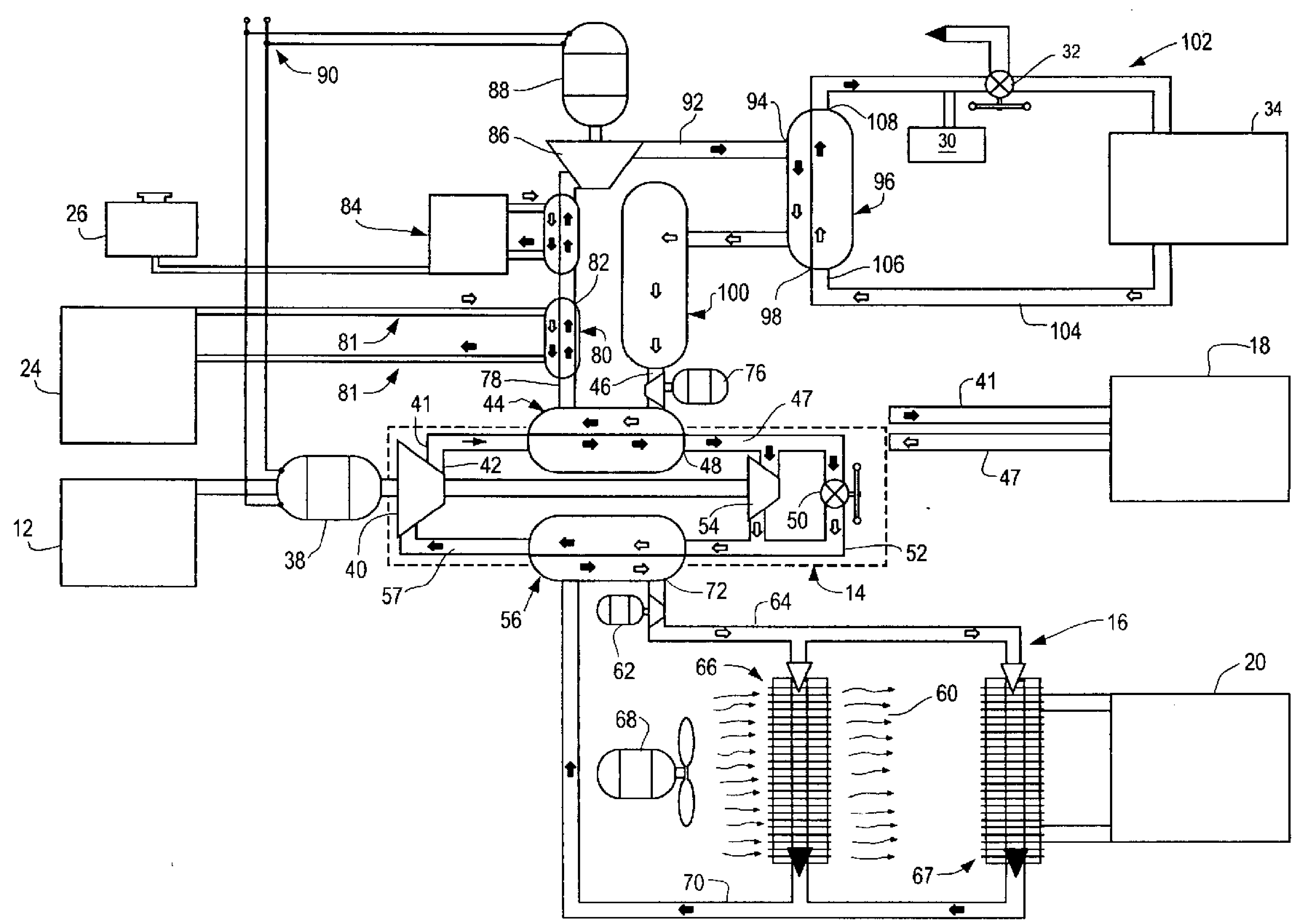
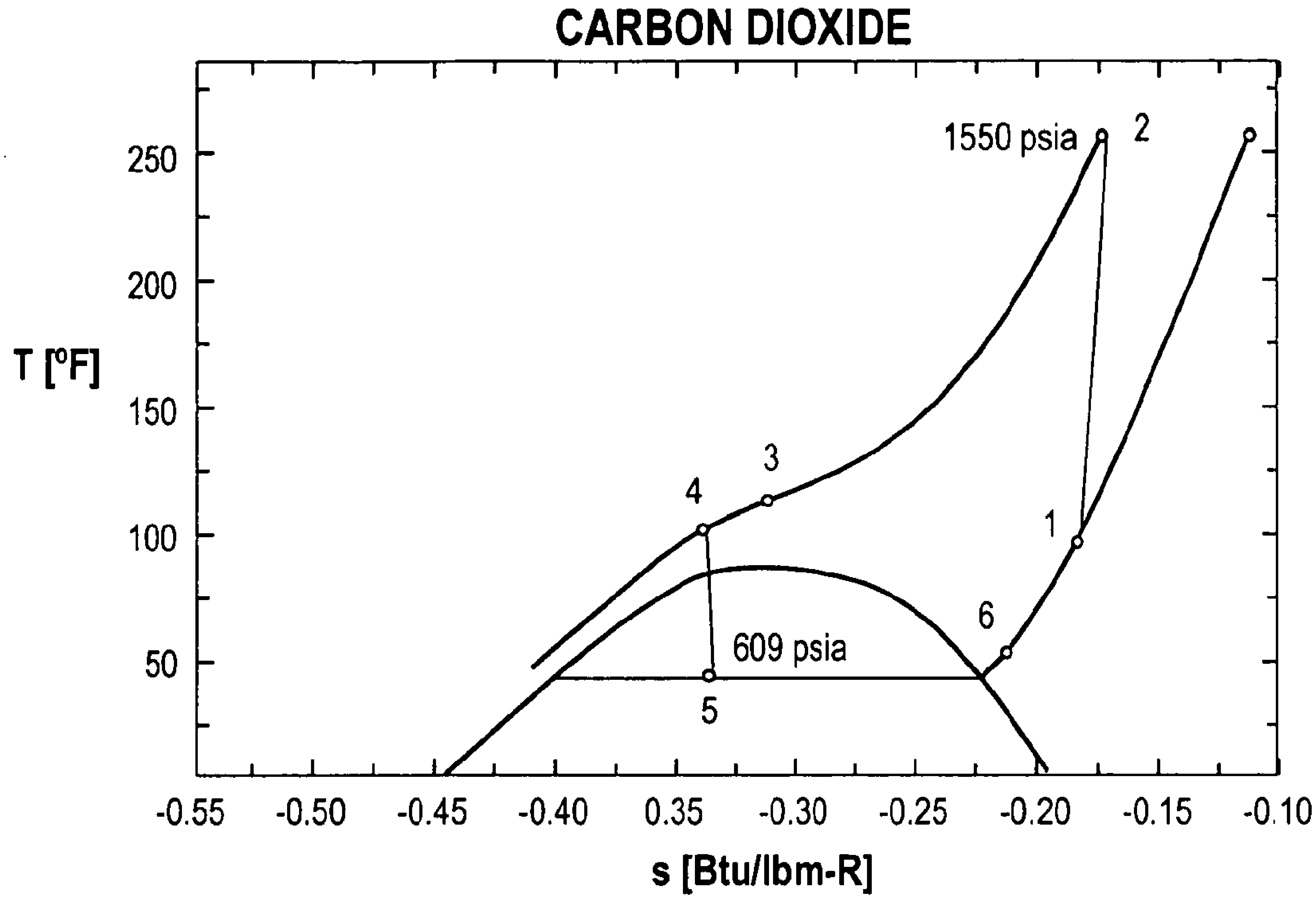


FIG. 1


CARBON DIOXIDE
T [°F]
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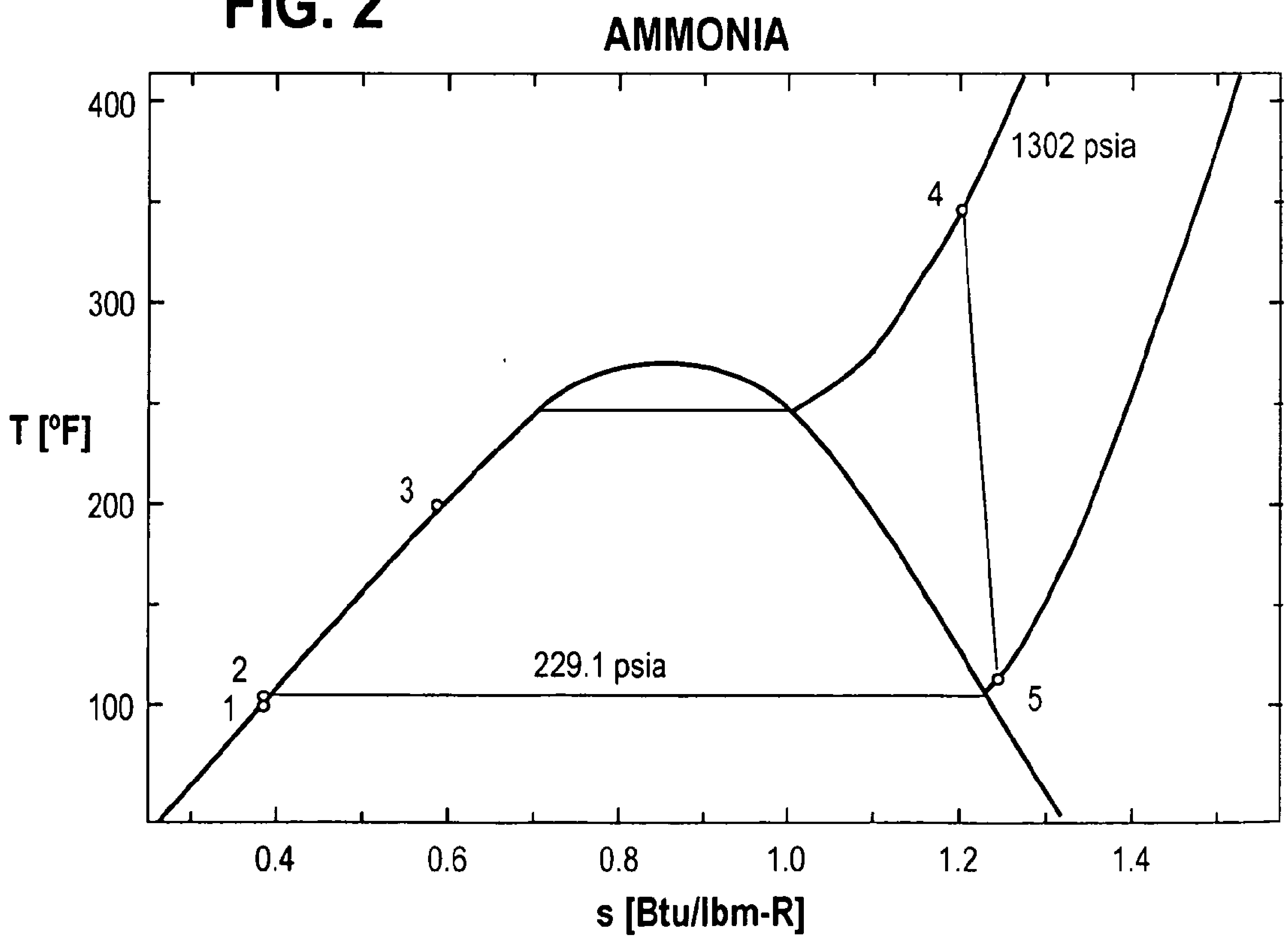
-0.10
s [Btu/lbm-R]

FIG. 2


AMMONIA
T [°F]
400
300
200
100
1302 psia
4
3
2
1
229.1 psia
5
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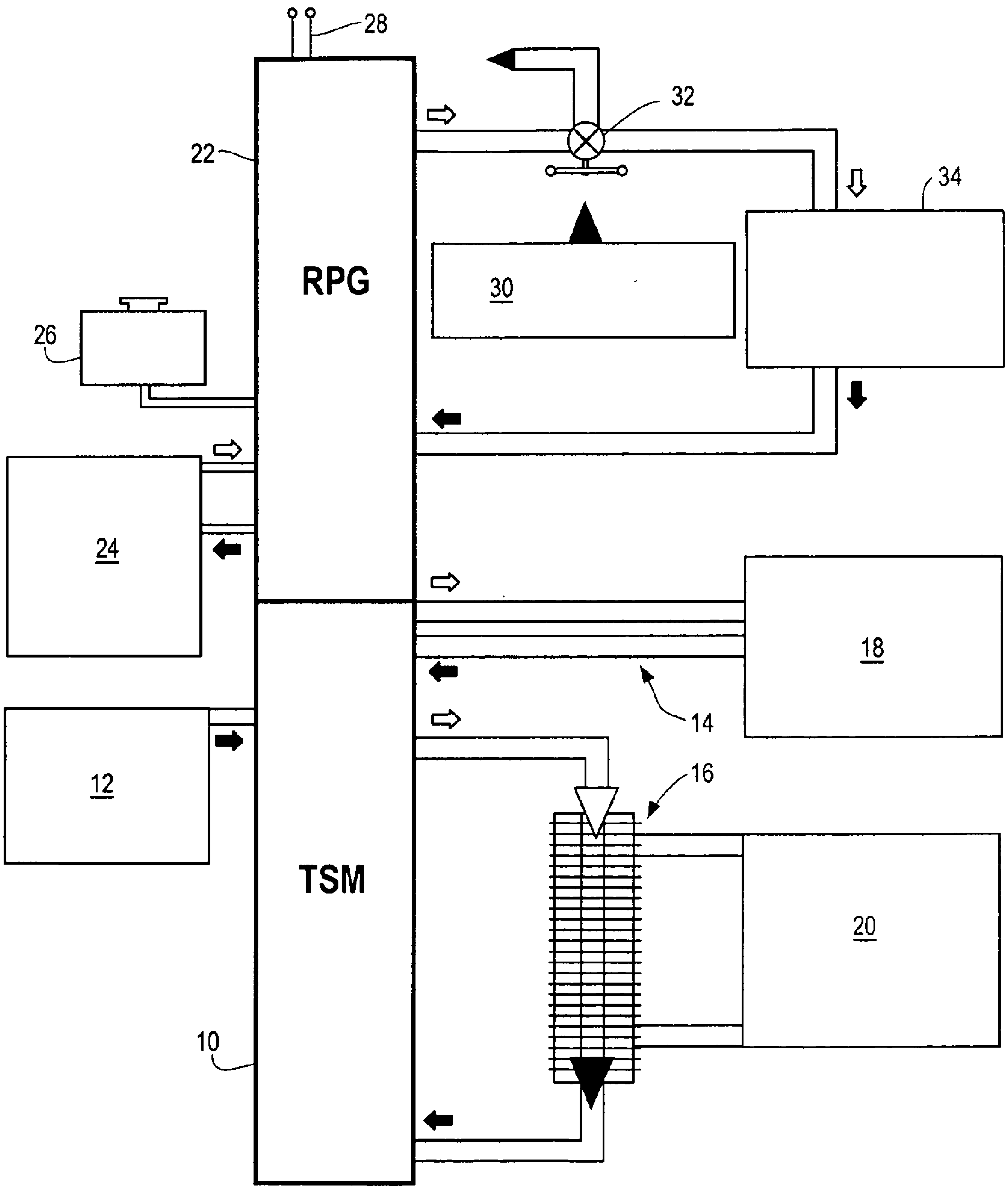
s [Btu/lbm-R]

FIG. 3



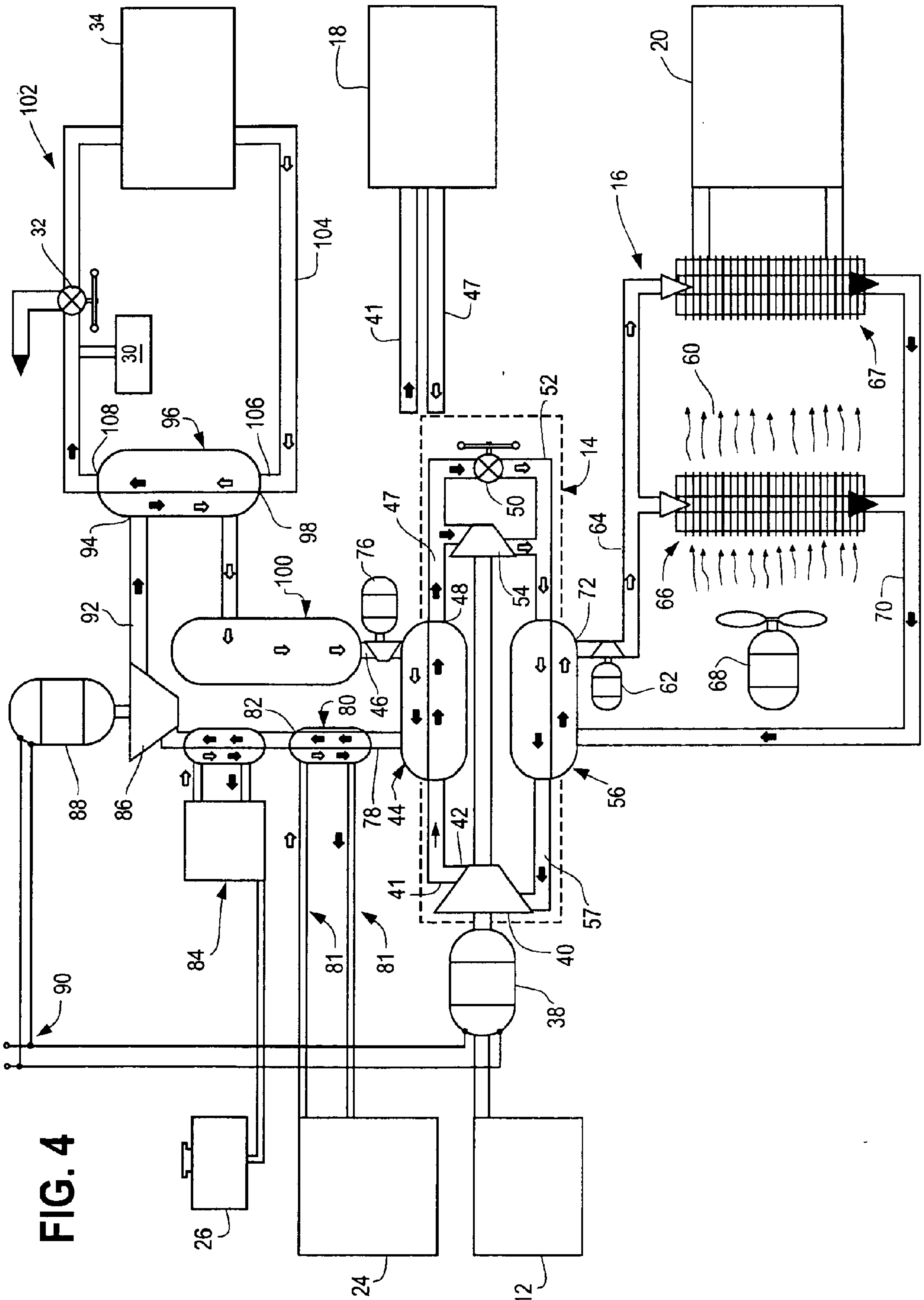

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FIG. 4

HEATING, COOLING AND POWER GENERATION SYSTEM

I. CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is based on and claims priority of U.S. provisional patent application 61/284,936 filed Dec. 28, 2009.

II. FIELD OF THE INVENTION

[0002] This invention relates to a more efficient and flexible method of providing Combined Cooling, Heating, and Power (CCHP); so-called Tri-generation. The invention embodies a mechanical/electrical power generation system that also produces selectable heating and cooling outputs in an environmentally clean and energy efficient way. A combined thermal separator/power generator uses the thermodynamic properties of natural working fluids to provide supplemental heating, cooling, and power without emitting any additional greenhouse gasses to the environment by use of waste or unused heat energy. This is accomplished through the combined operation of a Rankine cycle, using a refrigerant such as ammonia (NH_3) as the working fluid for power production; and a carbon dioxide (CO_2) heat pumping cycle. Simultaneous and usable energy output forms from this combined energy efficient cycle are mechanical power and/or electricity, and various options and combinations of usable thermal energy.

III. BACKGROUND OF THE INVENTION

[0003] Cogeneration, also called combined heat and power (CHP), is the use of a heat engine or a power station to sequentially generate mechanical and/or electrical power as well as useful heat. Conventional Rankine (i.e., water/steam) and Brayton cycle (i.e. gas turbine) assemblies have been combined in various forms to increase efficiencies advantaging heat recovery principles. Practical temperatures for a steam plant span H_2O boiling point to ~1200° F. yielding actual efficiencies well below 50%. A Brayton cycle gas turbine generator utilizes much higher input temperatures and typically yields higher flue gas output temperatures (~840° F. to ~1220° F.). Therefore system efficiency may be improved substantially by utilizing recovered heat from the Brayton cycle, typically ~1000° F., as a heat source for a "bottoming" Rankine steam cycle. These scenarios generally use higher quality (i.e. higher temperature) heat sources for operation.

[0004] A further conventional use for moderate quality heat (~212° F. to ~350° F.) that may be recovered from many processes is to drive absorption chillers for cooling. A plant which produces a combination of cooling, heating, and power (CCHP) is sometimes called trigeneration or more generally a polygeneration plant.

[0005] The efficient use and reclamation of prolifically available lower quality waste heat sources to help meet a facility's electrical, thermal, and mechanical power demands has become a global priority. Methods to apply medium grade waste heat (exampled hereafter 100° F.-400° F.) and much more abundant renewable low grade waste heat (<100° F.) to help meet the electrical, thermal, and mechanical power demands of society is a paramount need.

[0006] Due to increasing carbon emissions, and their contribution to global warming, there exists a parallel demand for low greenhouse gas (GHG) emission processes that rely on integrated, natural solutions. This is specifically evidenced by the high growth of two energy efficient market trends identified as vapor compression heat pump systems exampling those used in HVAC applications, as well as CHP systems. Little has been considered in relation to the combination of these two general systems due to practical considerations which have traditionally limited CHP to large scale, higher temperature operations.

[0007] Scenarios of CHP improvements for smaller scale, lower temperature (<400° F.) utilizations have been considered in recent art, however low temperature (<0° F. to 100° F.) thermal waste recovery is lesser applied in the capacity of use with CHP, as are small scale fixed or portable systems (<50 kW) using natural working fluids in lieu of water/steam or synthetic refrigerant working fluids. New trends building on this CHP background are integrated thermal use possibilities when a cold stream is provided as a by-product of the power producing cycle. Such CCHP tri-generation methods are exemplified as powered by exhaust heat from a prime mover or generator, etc. and the use of an absorption cycle using a refrigerant/absorbent pair such as ammonia/water. In such a system, a stream of medium to high temperature exhaust (waste) heat is utilized to generate a lower temperature cold stream. However, the known methods of CHP and CCHP have not lent sufficient consideration to other configurations utilizing natural refrigerants such as ammonia solely in the capacity of the power producing working fluid. Applicant's Thermal Separator/Power Generator ("TSPG") invention seeks to effectively exploit the thermodynamic properties of natural substances such as carbon dioxide, ammonia, and/or hydrocarbons to provide supplemental heating, cooling and power without emitting additional greenhouse gases to the environment, and to the extent possible, use available waste or unused heat energy.

[0008] This is accomplished through the combined operation of an ammonia (NH_3) Rankine cycle, and a carbon dioxide (CO_2) compressor/expander module arranged in a heat pumping cycle. The novel NH_3 refrigerant Rankine cycle power generator is heat assisted by a CO_2 heat pump with the total system supplying supplementary heat/cooling outputs. Simultaneous and usable energy output forms from this combined TSPG cycle are mechanical power and/or electricity, and various options and combinations of usable thermal energy. The TSPG unit is anticipated to conveniently serve the heating and cooling needs of a singular use or facility, or distributed uses. This can be directly and locally supplied, or distributed through a hydronic thermal grid (TG). This TG is a network which conveniently facilitates the transportation, amplification, and conversion of waste heat offering nearly limitless opportunities for the recovery and utilization of useful thermal energy that is typically thrown away. The benefits of the invention are made possible by a combination of two specific and sectional natural refrigerant systems. A Rankine cycle power generator (applicant's RPG) section might use synthetic refrigerant fluids or blends. A preferred embodiment would use a natural refrigerant working fluid such as ammonia (NH_3), which is heat boosted by a choice of options to a superheated vapor state. Secondary temperatures are also produced in the power generation cycle which are sufficient for uses such as heating domestic hot water or moderate space heating.

[0009] A CO_2 heat pump section thermally separates a hot and cold thermal stream from ambient or unused low temperature heat sources such as ambient air or geo-bodies. This thermal separation module (applicant's TSM) section when combined in a parallel preheat operation with the RPG section, adds a significant efficiency heat boost to the RPG cycle ultimately and optionally providing power, even for the TSM operation itself, as well as providing simultaneous space or process cooling. Applicant's TSM exploits the thermodynamic properties of carbon dioxide to efficiently provide full-time cooling sufficient for cooling applications and optionally (to electricity production) for off-the-electrical grid supplemental heating.

[0010] There is a need for, and applicant's invention provides a compact, modular product which is a type of natural refrigerant powered thermal and mechanical/electrical generator capable of supplying options of heating, cooling, refrigeration, hydraulic power, mechanical power, and electrical power in an integrated device serving both mobile and fixed off-the-electric grid applications. Applicant's invention will convert thermal energy from waste sources such as ambient air, geothermal or geoexchange, and solar sources into useable thermodynamic energy for mechanical applications such as power generation or for thermal uses.

[0011] Unlike fixed CHP utilities and/or other renewable and inflexible energy sources; applicant's unit could operate as a portable platform in harsh and variable conditions and be deployed in both fixed and mobile applications. As a "distributed" energy system, it can be brought online faster than central power plants, with increased system-wide reliability. Networked as a distributed node or as clustered arrays in concentrated locations to meet variable power growth capacities and thermal requirements, this concept promises to radically change the landscape of responsible and efficient thermal and electrical energy consumption, and the systems required to supply it. Even alternative heat sources such as solar and geo-exchange conveniently adapts and add even greater efficiency and power output.

IV. SUMMARY OF THE INVENTION

[0012] Applicant's invention embodies a Thermal Separator/Power Generator ("TSPG") for rapid user distribution and deployment as a standalone machine which might efficiently serve multiple simultaneous uses. Conveniently networked as a distributed node expandable with like machines via a thermal/electrical grid via rigid or flexible conduits for thermal/mechanical/electrical end-use applications; or also applied in arrays in concentrated locations, variable power growth capacities and thermal requirements may be met as needed in a modular fashion. Heating and cooling needs are advantaged as coexistent applications with power production. Hydraulic power inputs and/or outputs are options within the scope of mechanical power features. Increased efficiency benefits from boosted thermal gain which may be provided by modular ancillary add-on heat recovery components would directly access available heat sources such as solar, water bodies, and waste heat from vehicles or other processes.

[0013] Many studies have been completed comparing different refrigerants for use as working fluids for use in Rankine cycles, some of which have been commercialized. Most of these systems utilize synthetic derivative refrigerants and blends with toxic, flammable, or corrosive characteristics, although flammable hydrocarbon gases have also been considered.

[0014] Although natural refrigerant hydrocarbons are cited and studied, it is noteworthy that little work has been accomplished in the art in consideration of ammonia and carbon dioxide natural refrigerants combined in new ways for CCHP systems.

[0015] With new and increasing knowledge concerning the detrimental aspects of manmade synthetic refrigerants, natural refrigerants will serve the future in ever increasing energy management capacities. The use of natural refrigerant systems will be preferred for thermal, mechanical, or electrical utilizations if efficiencies of cost and performance can be provided. An object of the invention is to provide an improved efficiency thermodynamic system which provides all of the following attributes in a singular platform:

[0016] Full time thermal output suitable for heating applications 100 F to 130 F such as domestic hot water

[0017] Full time temperature output suitable for cooling applications such as air conditioning 35° F. to 55° F.

[0018] It is also an object to provide the same, single platform with the following options:

[0019] Electrical output in full and/or in part made operable by high temperature waste heat sources >400° F. and/or

[0020] Electrical output production assisted by medium temperature waste heat sources 100° F. to 399° F. and/or

[0021] Electrical output production assisted by low temperature waste heat sources −20° F. to 100° F. and/or

[0022] Electrical output in full and/or in part made operable by fueled consumption of sustainable bio fuels and/or

[0023] Electrical output in full and/or in part made operable by fueled consumption of fossil fuel

[0024] Selectable priority (in lieu of electrical output) thermal output suitable for heating applications 130° F. to 212° F.

[0025] The selection of a refrigerant for use of the power producing cycle of the RPG is a primary need. The unique properties of natural refrigerants must be taken into consideration for practical use. Apart from air and water, natural refrigerants basically divide into hydrocarbons, ammonia, and carbon dioxide. The most challenging characteristic of the hydrocarbon family refrigerants is their high flammability. Propane (R290), propylene (R1270), butane (R600) and isobutane (R600a) are examples. Such fluids have proved effective refrigerants, but safety design concerns for flammability may exclude them from practical consideration encompassing the mechanical/electrical complexities necessary for the RPG encompassing electrical output. The dominant characteristics of ammonia are a penetrating odor and toxicity. Despite these downsides, ammonia has been widely used for well over 100 years and has a good safety record. This may be partly due to the pungent smell made evident by even a small leak which helps assure proper maintenance of a sealed system.

[0026] Carbon dioxide is present in the soda we drink and the air we breathe and is non-flammable and non-toxic. Despite the high pressures associated with its use, carbon dioxide has been used as a refrigerant since 1862. Its use in an RPG cycle has not been seriously considered given its low critical temperature of <85° F.

[0027] The graphs illustrated in FIGS. **1** and **2** show CO_2 and NH_3 as potential candidates for use in a combined heat pump/Rankine cycle.

[0028] FIG. **1** shows a CO_2 Heat Pump Cycle

[0029] The carbon dioxide system operates as a transcritical vapor compression heat pump cycle with the following processes shown on its corresponding Temperature (T)—entropy (s) diagram:

[0030] Process 1-2: Compression

[0031] Process 2-3: Heat rejection

[0032] Process 3-4: High pressure side of the internal heat exchanger

[0033] Process 4-5: Refrigerant expansion

[0034] Process 5-6: Heat absorption

[0035] Process 6-1: Low pressure side of the internal heat exchanger

[0036] FIG. **1** shows ammonia Rankine Cycle

[0037] The ammonia cycle operates as a conventional power producing Rankine cycle with the following processes shown on its corresponding T-s diagram:

[0038] Process 1-2: Liquid pump

[0039] Process 2-3: Heat input from the CO_2 cycle

[0040] Process 3-4: Supplemental heat input

[0041] Process 4-5: Expansion (power production)

[0042] Process 5-1: Waste heat rejection

[0043] The cycles are linked to one another because the heat that is rejected in Process 2-3 from the CO_2 cycle is used to provide part (Process 2-3 in the ammonia cycle) of the overall heating that is required for the ammonia Rankine cycle to operate. The benefit is two-fold: 1) The CO_2 heat pump provides useful cooling that may be used to meet air conditioning or refrigeration needs, and 2) the heat that is provided by the CO_2 system to the RPG is provided at a much higher coefficient of performance ("COP") than the simple combustion of a fossil fuel which would normally have met the need.

[0044] Thermodynamic modeling of the TSPG system indicates that by supplementing a modest heat level input of <400 degrees Fahrenheit the full potential of the proposed features described can be attained. This would be accomplished by waste heat recovered from engine stacks or other on-site sources. However consideration has been given encompassing any condition whereby sufficient waste heat is not available for full power output, and conventional onboard combustion fuel (biodiesel, diesel, natural gas, propane, etc.) might be employed to assure full capabilities under all conditions.

[0045] The RPG section of the TSPG will not only produce electrical power, but will also simultaneously produce secondary (water or air) heating ~100° F. to ~130° F., which otherwise must be rejected, for use in applications such as domestic water heating. In operation, the TSM section of the TSPG generates hot liquid such as water at (~130° F. to ~200° F.) while simultaneously providing for (water or air) cooling ~35° F. to ~55° F. Combining the RPG and TSM sections together with a heat exchanger common to both sections allows construction of a Thermal Separator Power Generator (TSPG) package whereby thermal energy may extracted by the TSM from low temperature sources (<100 F) and used to efficiently boost temperature of the working fluid used in the RPG section which has a higher boiling point temperature. Applicant's TSPG invention results in mechanical/electrical power, heat, and cool at low energy consumed, if any, as additional purchased fuel/electrical energy consumption. This is based on available waste heat resources and priorities selected for the use of the energy reclaimed and used in whatever form.

[0046] Applicant's TSM is a modular, lightweight and extremely energy efficient portable packaged platform using environmentally responsible CO_2 as the refrigerant compound. The TSM provides hot and cold high-pressure CO_2 fluid energy streams from which to transfer thermal temperatures to low pressure, safe, easily handled and low cost hot and cold simultaneously available liquid (such as water) base thermal streams. These low-pressure water-base lines offer unlimited potential for meeting heating, cooling, and refrigeration first responder needs for emergency and disaster relief applications.

[0047] The TSM utilizes a CO_2 heat pumping cycle, whereby low quality thermal energy is efficiently elevated to significantly higher heat quality than is possible with conventional vapor compression technology using toxic HFC or other refrigerants.

[0048] The proposed technical departure utilizing the proposed methods would serve many thermal/electrical/mechanical processes simultaneously leaving a cold thermal stream for cooling applications. Heat energy generated with the TSM in this manner can recover more than three times the BTU's compared with electrical kW power equivalent BTU's, yielding a heating Coefficient of Performance efficiency >3, which is three or more times the electrical input to obtain it; a COP of 1. This equates to >300% efficiency compared with electricity assumed as 100%. When compared with fueled combustion equipment, the method additionally averts a preponderance of the inherent BTU efficiency stack losses resulting in COP efficiencies <1 and the inevitable, wasteful fuel consumption and supply logistics.

[0049] The TSM may integrate an Energy Recovery Module ("ERM") which utilizes the fluid-mechanical expansive properties of high pressure CO_2 gas to increase heat pumping efficiency by as much as one third. The net result would incorporate a CO_2 compressor with an expansion engine or ERM in an efficient TSM system design, which would increase heat pumping efficiency to a COP>3.5 or higher. Combined heating/cooling COP efficiencies may be six (6) or even higher. The outcome is a portable field deployable device, or a fixed heating and cooling unit with myriad applications/utilizations and very high efficiency.

[0050] Diverse power applications are available for shaft-coupling machinery such as hydraulic or pneumatic devices as well as electric generators. Potential layered applications are made possible by combining CO_2 transcritical heat pump technology with the power production capabilities of a Rankine Cycle Power Generator.

V. BRIEF DESCRIPTION OF THE DRAWINGS

[0051] FIG. **1** is a graph of a CO_2 heat pump cycle plotting temperature verses entropy.

[0052] FIG. **2** is a graph of an ammonia Rankine cycle plotting temperatures verses entropy.

[0053] FIG. **3** is a schematic depiction of the Thermal Separator Module and the Rankine Power Generator illustrating the orientation and applications of the combined two fluid loops.

[0054] FIG. **4** is a schematic diagram showing the fluid flow of the various fluid loops comprising the Thermal Separator Module and the Rankine Power Generator and the various pumps, compressors, condensers, and other components used in the loops.

VI. DETAILED DESCRIPTION OF THE INVENTION

[0055] Turning to FIGS. **3** and **4**, there is illustrated a schematic diagram of applicant's invention. There is a Thermal

Separator Module ("TSM") **10** that thermally separates and amplifies low grade or low quality heat sources that are generally less than 100° F., into individual, dual hot and cold thermal streams. This is conventionally known and practiced in current heat pump technology.

[0056] There is a drive motor **38** and compressor **40** to power a CO2 vapor compression cycle in the TSM **10** by any of a number of power sources indicated at **12**. These can be various forms of hydraulic power such as hydraulic power packs, wind hydraulics, farm implements, or other hydraulic means. The drive motor can also be conventionally powered by means of electrical energy.

[0057] As can be seen in FIG. **3**, the TSM has both a hot loop **14** and a cold loop **16**. The hot loop **14** has various applications **18** that it can satisfy a temperature boost up to ~250° F. for the RPG working fluid in a thermal exchange between TSM **10** and RPG **22**. An alternative use for this thermal energy may include hydronic applications such as hot water ~130° F. to ~180° F. for hydronic distribution, or secondary exchange air delivery/distribution, or secondary heat exchange of other similar singular or combined applications. The cold loop **16** also has various applications that it can satisfy (~25° F. to 55° F.). These include air conditioning/distribution, air conditioning hydronic delivery, secondary water cooling or chilling and other similar applications illustrated in block **20**.

[0058] The RPG) section is illustrated in FIG. **3** at **22**. In operation, the RPG is arranged combined by heat exchange with the CO_2 heat pumping TSM cycle. Using low temperature sources (<100° F.) which are available prolifically and may be amplified to higher temperatures ~200° F. for preheat of the working fluid in the RPG This enhances efficiency of the RPG when waste heat sources are insufficient to supply all the thermal capacity requirements of the RPG. One fluid loop at **24** in the RPG is provided to recover waste heat from various heat producing equipment such as vehicles, solar packs, heavy equipment, industrial/commercial processes, etc. If additional heat is further required to boost the temperature of the working fluid to its working state, it can be done at block **26** with a supplemental fuel tank/heater to supply exchanged secondary steam heat, direct fire burner, or other thermal power source providing >300° F. for ammonia superheating. The RPG may generate electrical power at **28** and be a feedback source of power for TSM power source **12**

[0059] At block **30**, unused warm/hot fluid such as water is diverted at valve **32** for undefined thermal regeneration uses or for heat rejection as and if necessary. However, alternatively and preferably, the warm/hot water may be used at block **34** for warm/hot water applications such as domestic hot water uses, storage, or processes, etc.

[0060] FIG. **4** illustrates in detail the components and fluid flow circuits of the TSM and RPG. The TSM heat pump high pressure hot loop **14** has the drive motor **38** that drives the compressor **40**. The compressor **40** compresses a refrigerant fluid **41**, preferably CO_2, to high pressures on the order of 1200-2400 psi and temperatures of preferably between 150° F. and 300° F. and discharges it at high pressure discharge **42**. This fluid **41** from discharge **42** then enters a segmented high pressure to high pressure heat exchanger Rankine cycle refrigerant boiler **44** which cools the fluid **41** from the inlet to the outlet of the boiler **44**. The fluid **41** remains at a high pressure on the order of 1200-2400 psi, with a very small pressure drop through the refrigerant boiler **44**, whereby heat from the fluid **41** is transferred from the fluid **41** to a second condensed cold Rankine cycle refrigerant fluid **46** (preferably NH_3), which is in another fluid flow circuit described later.

[0061] This process is described as high pressure gas of high temperature exchanging thermal energy to a high pressure Rankine refrigerant fluid of lower temperature. The refrigerant boiler **44** is similar to and more fully described in PCT/US2008/006827 filed May 30, 2008 which is incorporated herein by reference. However, in this dual high pressure embodiment, both TSM fluid **41** and the Rankine refrigerant fluid circuit are at high pressures; therefore, the entire heat exchanger shell must also be designed to safely handle these pressures. Other types and styles of heat exchangers can also be configured for use as known to those skilled in the art.

[0062] Thus, the high pressure fluid **41** (which is in a gaseous state) passes through a channel tube array in the heat exchanger gas boiler **44** where the fluid **41** is cooled to a warm gas **47** and discharged at the gas boiler **44** discharge **48**. As seen in FIG. **4**, the warm gas **47** may then by-pass through a throttle/expansion valve **50** which lowers the pressure and temperature of the gas **47** to a cold gas **52**. In parallel the throttle/expansion valve **50** controls all or a percentage of warm gas **47** which may be directed to be used by an energy recovery machine i.e., expansion engine **54** which is connected to the compressor **40** and assists in driving the compressor. The expansion engine **54** and compressor **40** may be combined into one machine such as disclosed in PCT/US2006/030759 and PCT/US2008/006845. This compressor/expansion engine has both expansion cylinders and compression cylinders disposed in the same engine. When an expansion engine is used, it will result in a drop in the temperature and pressure of the gas **47** to approximately 300-700 psi at 15° F. to 50° F. For a full description of the compression/expansion engine, see the above referenced applications.

[0063] In lieu of temperature boost from fluid **41** exchanged to the second Rankine refrigerant fluid **46**, there exists still another alternative, i.e., of hot liquid applications >130° F. in block **18**. As well known in the art, by diverting the hot gas around gas boiler **44** to a high pressure to low pressure gas cooler heat exchanger as previously described (exchanger, pipe/valving not shown) alternate thermal applications may be attained such as hot water >130° F. but must be realized at the expense of boost heat (efficiency) for the power generation circuit.

[0064] The warm gas **47** is then is routed to the expansion engine **54** and throttle/expansion valve **50** exiting either or both as a cold mixed gas/fluid **52** and into a high pressure to low pressure heat exchanger evaporator **56** where it is evaporated back to gas. In this process the cold gas **52** is warmed (as will be explained below) and exits the evaporator **56** as warmed gas **57**. The gas remains at close to the inlet pressure which is a pressure of approximately 300-700 psi, with a very small pressure drop through the evaporator **56**. The warmed gas **57** enters the compressor **40** at a low temperature but at pressure and temperature which assures the fluid is in a gaseous state as the cycle repeats.

[0065] In addition to RPG heat boost, when in operation the TSM vapor compression cycle heat extraction function therefore serves to leave a resultant full time supplemental cooling loop exampled and shown, supplied as a water or water/glycol cooling or refrigeration loop but may use other gas or liquid fluids. In this case, the cooling loop **16** provides cooled air **60** to a living or temperature cooled environment. It can also serve other low temperature applications such as previously described at block **20**. There is a low pressure liquid circulation pump **62** that pumps a water/glycol or similar solution at a low pressure and low temperature **64**. The solution **64** passes through a second stage heat exchanger **66** where ambient warm air forced by a fan **68** is blown over or through the heat exchanger **66**. Alternatively, a liquid (i.e., water based) heat exchanger **67** shown supplying block **20** for optional cooling uses. Warmed water/glycol solution **70** leaves the heat exchanger **66** and/or **67** and is pumped to the low pressure section of the evaporator **56**. The warmed water glycol solution **70** is cooled in the evaporator **56** and exits at discharge end **72** as a low pressure and low temperature solution **64**. The water/glycol solution in the heat exchanger **56** is physically separated from the cold Rankine cycle refrigerant **52** that is passing through the evaporator **56**. However, they are in thermal communication with each other so that the heat is removed from the warmed water/glycol solution **70** as it passes through the evaporator **56**. The cold water/glycol solution **64** is discharged at **72** and is then recirculated by the pump **62**.

[0066] The RPG **22** is illustrated in the top half of FIGS. **3** and **4**. The power producing Rankine cycle loop generally uses a relatively high subcritical boiling point refrigerant. A natural refrigerant such as NH_3 is preferable for use in the RPG **22**. At atmospheric pressure NH3 boiling point is −28° F. and compares favorably with other natural but flammable refrigerants such as Propane (−44° F.) and Butane at (−31° F.). However CO_2 boiling point is very low, −70° F. at ~5× atmospheric which helps explain why CO_2 is not a suitable candidate for the Rankine cycle working refrigerant. In this example, a high pressure liquid feed pump **76** pumps liquid NH_3 to one end of the gas boiler **44**. The liquid NH_3 is physically segregated from the hot high pressure refrigerant fluid **41** that is passing through the gas boiler **44** from the compressor **40**. However, the two fluids are in thermal communication so that heat from the high pressure refrigerant fluid **41** is transferred to the liquid NH_3 causing it to "boil" and transition to a gaseous state. The NH_3 gas leaves the gas boiler **44** as the high pressure warm gas **78**. As observed, the combined cycle uses the heat exchanged in gas boiler **44** from the CO_2 heat pump refrigerant fluid **41** discharged from the compressor **40** as pre-heat boosting the temperature of the NH_3 before it enters a second pre-heater or waste heat, heat exchanger **80**. At waste heat exchanger **80**, higher temperature heat from the operations described in block **24** is recovered and transferred to the high pressure preheated yet cooler temperature NH_3 This may be accomplished by means of a hot hydronic loop **81** that circulates a fluid from the waste heat recovery source at **24** to the NH_3 waste heat exchanger **80**, and then returns it to the source at **24**.

[0067] The NH_3 gas **78** exits the pre heater **80** at **82**. At this point, and only if necessary, the gas **82** is further heated by means of a heat source **84** to assure full capacity temperature and pressure adequate to power a turbine, piston machine, or other prime mover **86**. In this way further heat may be added only as required from conventional processes such as fueled combustion. The heat source **84** can be a standby fueled steam boiler, direct fire to the Rankine circuit, or other appropriate heat generating source and means of generating a topping temperature suitable to reach the superheated vapor heat thresholds desired. The fuel source can be an on-board fuel tank which allows the system to be portable. The benefit of this combined cycle is that approximately one quarter to one third of the heat input requirements of the RPG can be supplied by the CO_2 heat pump, from low temperature waste sources, and the balance required for full power production derived from medium and high temperature waste heat sources with provision for conventional heat topping of the Rankine cycle only as and if necessary/required. The sum waste heat recovery potentials would be anticipated to dramatically reduce or even eliminate the BTU heat input that typically comes from sources such as natural gas or bio or diesel fuel as conventionally supplied.

[0068] The prime mover **86** is powered by the NH_3 and drives a generator **88**. This generates electrical power **90**. Alternatively, the prime mover **86** may be any form of electrical or mechanical power generator that can be powered by the high temperature high pressure NH_3. Thus, mechanical, hydraulic or electric power can be produced. Another form of utilization of the gas **78** may be made by the expansion engine as disclosed in both US2006/030759 and PCT/US2008/006845.

[0069] A warm gas **92** exiting prime mover **86** at a mid pressure enters a high pressure side **94** of a high pressure fluid to low pressure fluid heat exchanger **96** which is a NH_3 condenser or gas cooler providing heat rejection of the power cycle. This cools and liquefies the NH_3 and, in this embodiment, discharges it at **98** as a mixed fluid or liquid to enter liquid storage tank receiver **100** for re-circulation by the pump **76**.

[0070] The last loop to consider is an RPG condenser loop **102**. Generally water **104** will be the heat transfer fluid medium. A pump, not illustrated, pumps the water **104** through the loop. Cool water **106** enters the heat exchanger **96** at **98**. Heat from the warm gas **92** is transferred to the cool water **106** as it passes through the exchanger **96**. When the water is discharged from the heat exchanger **96** at **108**, it is warm/hot water that may be heat rejected as described at block **30** but is also suitable for many domestic warm water applications as described at block **34**.

[0071] Thus there has been provided a Thermal Separator Power Generator that incorporates a thermal separator heat pump cycle and a Rankine power generator cycle. While the invention has been described in conjunction with a specific embodiment, it is evident that many alternatives, modifications and variations will be apparent to those skilled in the art in light of the foregoing description. Accordingly, it is intended to embrace all such alternatives, modifications and variations as fall within the spirit and scope of the appended claims.

What is claimed is:

1. A heating, cooling and power generation system comprising:

a thermal separator module for producing two fluid loops, a first high temperature fluid loop at a temperature substantially above ambient temperature and a second low temperature fluid loop at a temperature substantially less than ambient temperature, the thermal separator module comprising a CO_2 compressor, a high pressure heat exchanger Rankine refrigerant boiler a CO_2 gas expansion means, a heat exchanger evaporator means, and carbon dioxide flowing through the compressor, the high pressure heat exchanger Rankine refrigerant boiler, the CO_2 gas expansion means, and the heat exchanger evaporator means in a continuous circuit;

a Rankine cycle power generator system for generating power comprised of a serial flow system with a Rankine refrigerant fluid in the system, a fluid pump, the high pressure heat exchanger Rankine refrigerant boiler, at least one Rankine refrigerant heater, a prime mover for generating power from the expansion of the Rankine refrigerant fluid from a liquid to a gas, a heat rejection means, and means for returning the Rankine refrigerant to the pump;

the high pressure heat exchanger refrigerant boiler having high pressure fluid passageways through which the CO_2 passes and having other high pressure fluid passageways through which the Rankine refrigerant flows, the Rankine refrigerant and CO_2 passing through the high pressure heat exchanger Rankine refrigerant boiler in their separate passageways, but in thermal communication with each other.

2. The heating, cooling and power generation system of claim **1** wherein the Rankine refrigerant fluid is a natural refrigerant.

3. The heating, cooling and power generation system of claim **2** wherein the Rankine refrigerant fluid is ammonia.

4. The heating, cooling and power generation system of claim **1** and further comprising an energy recovery device for receiving energy from the CO_2 during its expansion process and converting it to work.

5. The heating, cooling and power generation system of claim **1** wherein the second heat exchanger evaporator is in serial fluid flow with the compressor and high pressure heat exchanger Rankine refrigerant boiler, the second heat exchanger evaporator providing a heat removal source to apply a cooling refrigeration stream.

6. The heating, cooling and power generation system of claim **1** and further comprising at least a fourth heat gas cooler heat exchanger in serial fluid flow with the prime mover for providing a heat removal means for removing heat from the Rankine refrigerant fluid.

7. The heating, cooling and power generation system of claim **1** wherein the prime mover is a turbine and the Rankine refrigerant fluid vaporizes to provide power to the turbine.

8. The heating, cooling and power generation system of claim **3** wherein the prime mover is a piston driven machine and the ammonia fluid vaporizes to provide power to the piston machine.

9. The heating, cooling and power generation system of claim **1** wherein the CO_2 is pumped from the compressor and enters the high pressure heat exchanger Rankine refrigerant boiler at a pressure of between 200 psi and 2500 psi.

10. The heating, cooling and power generation system of claim **1** and further comprising at least one auxiliary heat source to increase the temperature of the Rankine refrigerant fluid so that said refrigerant fluid has sufficient heat capacity to generate power when it enters the prime mover.

11. The heating, cooling and power generation system of claim **10** wherein the auxiliary heat source is a waste heat, heat exchanger system.

12. The heating, cooling and power generation system of claim **1** and further comprising heat exchanger means in the Rankine cycle power generator system for providing heat for a warm water loop.

13. The heating, cooling and power generation system of claim **1** wherein the second heat exchanger evaporator is fluidly connected to a pump for circulating cold fluid through an air conditioner for providing cool air.

14. The heating, cooling and power generation system of claim **1** wherein the Rankine refrigerant heater is a waste heat exchanger.

15. A method of operating an efficient heating, cooling and power generation system comprising:

providing a thermal separator for producing a first high temperature fluid loop and a second high temperature fluid loop by means of a high pressure CO_2 compressor for compressing CO_2 and supplying the highly compressed CO_2 to a high pressure heat exchanger Rankine refrigerant boiler, the compressor forcing the CO_2 through the high pressure heat exchanger, reducing the temperature of the CO_2 in the high pressure heat exchanger and utilizing the CO_2 in a hot water or energy recovery process that reduces the temperature of the CO_2, flowing the reduced temperature CO_2 through a second heat exchanger where the CO_2 removes heat from the second low temperature fluid loop, and returning the CO_2 to the compressor;

providing a Rankine cycle power generator system for generating power from a Rankine refrigerant fluid which converts heat energy from the fluid to mechanical energy, a pump for circulating the Rankine refrigerant fluid in a liquid state through the high pressure heat exchanger Rankine refrigerant boiler where it is warmed, passing the refrigerant fluid through a third heat exchanger, passing the refrigerant to a prime mover where the Rankine refrigerant fluid vaporizes and drives the prime mover, and

returning the Rankine refrigerant fluid the prime mover to the pump for recirculation.

16. The method of operating an efficient heating, cooling and power generation system of claim **15** and further comprising:

providing the high pressure heat exchanger refrigerant boiler with high pressure fluid passageways through which the CO_2 passes and other high pressure fluid passageways through which the Rankine refrigerant flows, the Rankine refrigerant and CO_2 passing through the high pressure heat exchanger Rankine refrigerant boiler in their separate passageways, but in thermal communication with each other.

17. The method of operating an efficient heating, cooling and power generation system of claim **16** and further comprising using ammonia as the Rankine refrigerant fluid.

18. The method of operating an efficient heating, cooling and power generation system of claim **16** and further comprising providing an energy recovery device for receiving energy from the CO_2 during its expansion process and converting it to work.

19. The method of operating an efficient heating, cooling and power generation system of claim **15** and further comprising providing at least a fourth heat gas cooler heat exchanger in serial fluid flow with the prime mover for providing a heat removal means for removing heat from the Rankine refrigerant fluid.

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