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(54) Title: A SYSTEM FOR HIGH EFFICIENCY ENERGY CONVERSION CYCLE BY RECYCLING LATENT HEAT OF VAPORIZATION

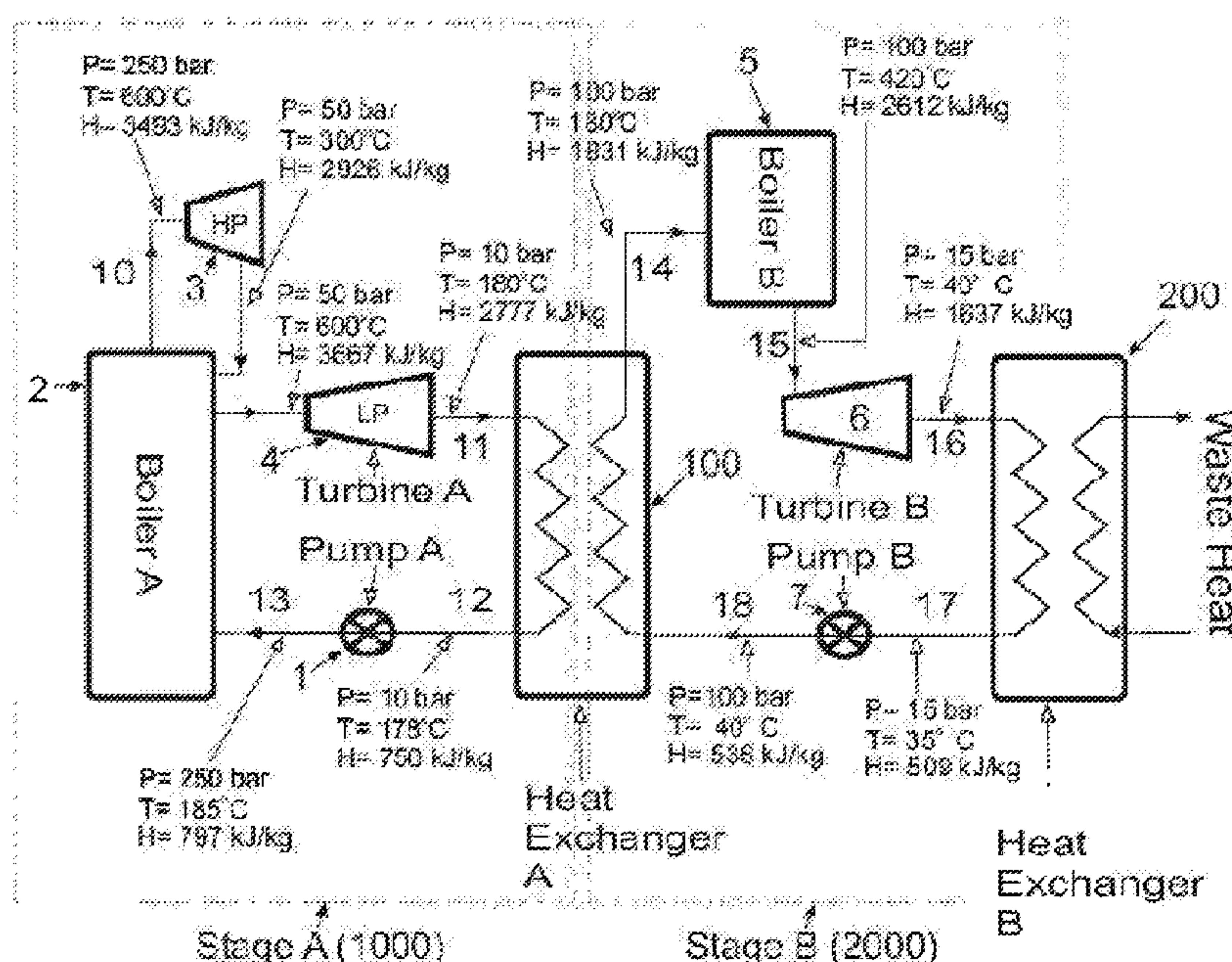


FIGURE 3

(57) Abrégé/Abstract:

An electric power generation apparatus (system) and method for high efficiency energy conversion cycle by recycling latent heat of vaporization is disclosed. In one implementation, the present invention enables to achieve an improved efficiency by reducing the

(57) **Abrégé(suite)/Abstract(continued):**

amount of waste heat that is rejected into the atmosphere in existing plant cycle designs by creating multiple turbine cycles where the latent heat of vaporization of the first cycle is injected into the input stage of the second cycle and the waste heat (latent heat of vaporization) of the second cycle into the input stage of the third cycle and so on. Only the waste heat of the final cycle is rejected into the atmosphere.

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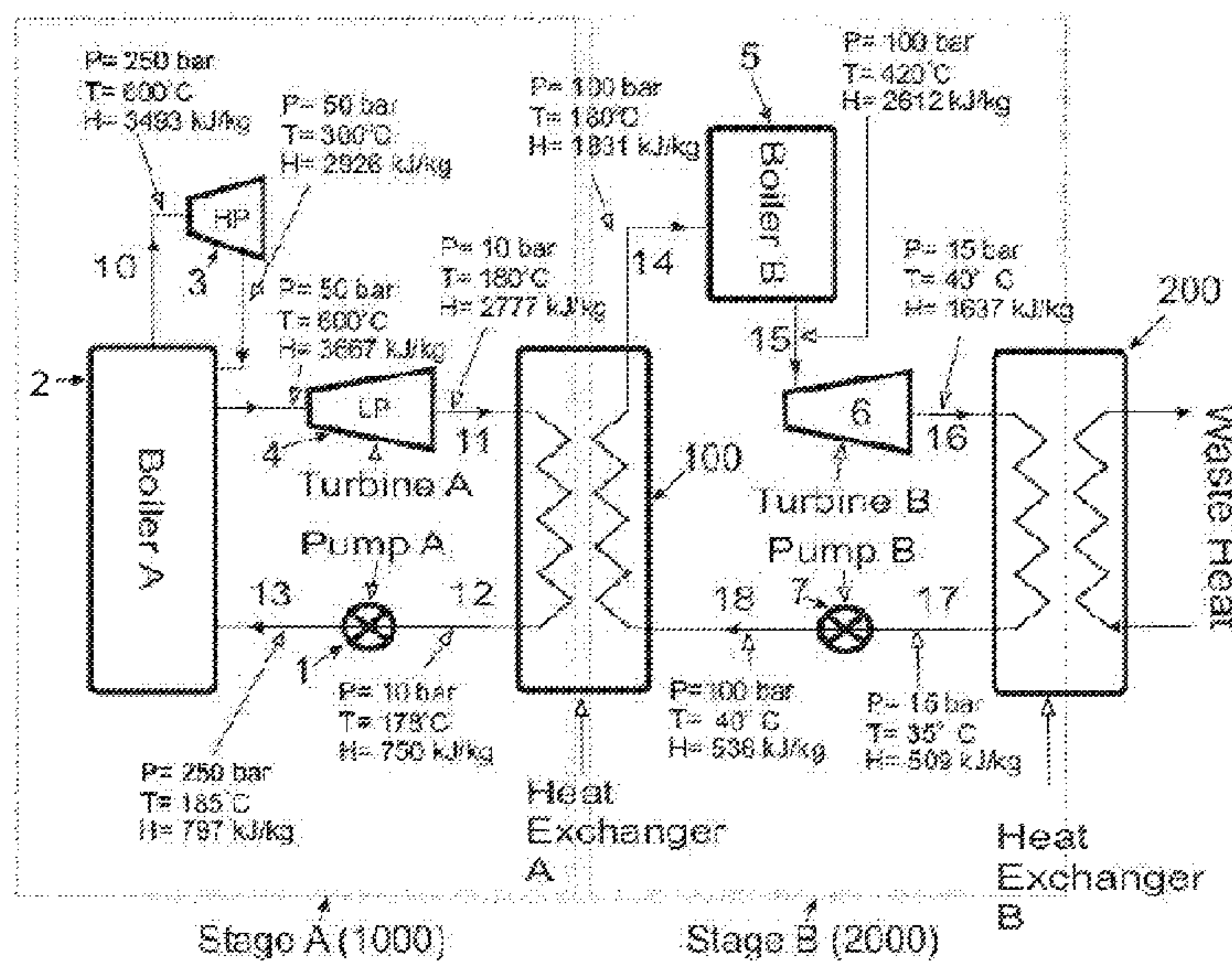


FIGURE 3

(57) Abstract: An electric power generation apparatus (system) and method for high efficiency energy conversion cycle by recycling latent heat of vaporization is disclosed. In one implementation, the present invention enables to achieve an improved efficiency by reducing the amount of waste heat that is rejected into the atmosphere in existing plant cycle designs by creating multiple turbine cycles where the latent heat of vaporization of the first cycle is injected into the input stage of the second cycle and the waste heat (latent heat of vaporization) of the second cycle into the input stage of the third cycle and so on. Only the waste heat of the final cycle is rejected into the atmosphere.

**A SYSTEM FOR HIGH EFFICIENCY ENERGY CONVERSION CYCLE BY
RECYCLING LATENT HEAT OF VAPORIZATION**

TECHNICAL FIELD OF THE INVENTION

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[001] The present subject matter described herein, in general, relates to electric power generation, and more particularly, towards a multi-stage system for efficiently driving electric power generating turbines.

10

BACKGROUND ART

[002] At present most of the world's electricity is generated by heating water into high pressure and temperature steam which is then used to rotate a turbine which rotates a generator to produce electricity. Any number of means can be used to heat the water such as solar, coal, gas, nuclear etc. As the high pressure steam enters the turbine, it collides with the turbine blades and imparts some of its energy to the turbine. After multiple collisions with the turbine blades, the steam has lost a significant amount of its energy and exits the turbine to enter a condenser at low pressure which cools the steam until it becomes water. A pump then pumps this water back into the high pressure input stage of the cycle where it is heated back into steam to repeat the cycle continuously.

[003] The problem with this setup is that the condenser has to remove the latent heat of vaporization to convert steam back to liquid so that the pumps can pump the fluid back to the start of the cycle with minimum energy requirement. This energy is then discarded to the surroundings as waste heat. In the case of water, the latent heat of vaporization is approximately 2257kJ/Kg, which is an extremely large amount of energy. This is between 40-60% (depending on the operating temperature) or more of the total heat energy added to the working fluid per cycle. Therefore, even the best power plants rarely achieve an

efficiency of even 40%. If this waste latent heat could also be utilized and converted into electricity, then a significant improvement in the efficiency of any power plant is possible.

[004] There are many existing power cycles, the problem with existing power cycle such
5 as the Rankine cycle and others is that their efficiency is greatly limited due the large amount of low quality waste heat that has to be rejected into the atmosphere or surroundings. Most of the latent heat of vaporization (or condensation) has to be rejected as waste heat and this greatly limits the efficiency of any cycle.

10 SUMMARY OF THE INVENTION

[005] This summary is provided to introduce concepts related to a system (apparatus), and method thereof for high efficiency energy conversion cycle by recycling latent heat of vaporization and the concepts are further described below in the detailed description. This
15 summary is not intended to identify essential features of the claimed subject matter nor is it intended for use in determining or limiting the scope of the claimed subject matter.

[006] **TECHNICAL PROBLEM:** The condenser has to remove the latent heat of vaporization to convert steam back to liquid so that the pumps can pump the fluid back to the
20 start of the cycle with minimum energy requirement. This energy (latent heat) is then discarded to the surroundings as waste heat. Therefore, even the best power plants rarely achieve an efficiency of even 40%.

[007] **TECHNICAL SOLUTION:** The present invention provides a mechanism to
25 efficiently and economically solve the above mention technical problem by transferring the latent heat of vaporization of any stage into the input stage of the next stage instead of rejecting it into the atmosphere, and thereby greatly increasing the efficiency of any power cycle.

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[008] In one implementation, a basic objective of the present invention is to overcome the disadvantages/drawbacks of the known art by increasing the conversion efficiency of heat into electricity of all existing and future power plants.

5 [009] In one implementation, the present invention provides the conversion of thermal energy into electrical energy in a power plant with higher efficiency than is possible with current technology.

10 [0010] In one implementation, the improved efficiency by the use of present invention is achieved by reducing the amount of waste heat that is rejected into the atmosphere in existing plant cycle designs.

15 [0011] In one implementation, the present invention provides a mechanism by creating multiple turbine cycles where the latent heat of vaporization of the first cycle is injected into the input stage of the second cycle and the waste heat (latent heat of vaporization) of the second cycle into the input stage of the third cycle and so on. Only the waste heat of the final cycle is rejected into the atmosphere.

20 [0012] In one implementation, the present invention enables the utilization of waste latent heat and converts the same into electricity, and thereby achieving a significant improvement in the efficiency of a power plant. The waste heat exchange mechanism can also be used with all heat based power systems even if the final output is some form of non electrical output.

25 [0013] In one implementation, by transferring the latent heat of vaporization of any stage into the input stage of the next stage instead of rejecting it into the atmosphere, the present invention increases the efficiency of any power cycle.

[0014] In one implementation, with proper choice of working fluids, turbine exit temperatures and pressures, the present invention enables the transfer of all the latent heat of

vaporization into the next stage thereby greatly reducing the amount of energy required to heat the working fluid of that stage to the desired temperature. This results in an extremely high efficiency for all stages after the first stage resulting in a very high overall efficiency.

5 [0015] To improve the overall performance of any power cycle by transferring the latent heat of vaporization of any stage into the input stage of the next stage instead of rejecting it into the atmosphere, embodiments of the present invention provide a plurality of aspects of the present application. The plurality of aspects provides a system/apparatus and method for high efficiency energy conversion cycle by recycling latent heat of vaporization. The
10 technical solutions are as follows:

[0016] In another aspect, a multi stage electric power generation apparatus with at least two stage system is disclosed. The electric power generation apparatus comprises a first stage power cycle comprising a first working fluid, boiler, turbine, heat exchanger, pumps etc., and
15 configured for electric power generation;
a second stage power cycle comprising a second working fluid, boiler, turbine, heat exchanger, pumps, etc., and configured for electric power generation; wherein the second working fluid absorbs the waste heat (latent heat of vaporization and/or condensation) generated from first stage cycle for electric power generation.

20

[0017] In another aspect, a method for generating electrical power using an electric power generation apparatus with at least two stage power cycle is disclosed. The method comprises:

- generating electricity, using a first stage power cycle comprising a first working fluid, boiler, turbine, heat exchanger, pumps, etc;
 - generating electricity, using a second stage latent heat exchange mechanism and turbine cycle comprising a second working fluid, the electrical power generation;
WHEREIN
- 25

- the second working fluid absorbs the waste heat (latent heat of vaporization and/or condensation) generated from first stage in the latent heat exchange mechanism for generating electrical power.

5 [0018] In one implementation of the present invention, the low quality waste heat of the first stage is transferred to the input stage of the second cycle, the waste heat of the second cycle transferred to the input stage of the third cycle and so on. The more stages there are, the greater will be the final overall efficiency, but there will come a time when adding more stages will have diminishing financial returns. In addition, it may not be possible to find a
10 sufficient number of working fluids with the right physical properties to have an unlimited number of stages. For the purposes of explaining the process in detail, two stages will be sufficient to explain the concept and therefore the rest of the explanation will be based on a two stage system.

15 BRIEF DESCRIPTION OF THE ACCOMPANYING DRAWINGS

[0019] The detailed description is described with reference to the accompanying figures. In the figures, the left-most digit(s) of a reference number identifies the figure in which the reference number first appears. The same numbers are used throughout the drawings to refer
20 like features and components.

[0020] Figure 1 illustrates a simplified schematic of existing power plant cycles (Prior-art).

[0021] Figure 2 illustrates a simplified schematic of a multistage cycle that will achieve
25 very high efficiencies, in accordance with an embodiment of the present subject matter.

[0022] Figure 3 illustrates an example of what a 2 stage system could look like if water and ammonia are used as working fluids, in accordance with an embodiment of the present subject matter.

6

[0023] Figure 4 illustrates a method for generating an electrical power using an electric power generation apparatus with at least two stage latent heat exchange mechanism, in accordance with an embodiment of the present subject matter.

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[0024] Figure 5 illustrates a method performed during the first stage latent heat exchange mechanism 1000, in accordance with an embodiment of the present subject matter.

[0025] Figure 6 illustrates a method performed during the second stage latent heat exchange mechanism 2000, in accordance with an embodiment of the present subject matter.

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DETAILED DESCRIPTION OF THE PRESENT INVENTION

[0026] The following clearly describes the technical solutions in the embodiments of the present invention with reference to the accompanying drawings in the embodiments of the present invention. Apparently, the described embodiments are merely a part rather than all of the embodiments of the present invention. All other embodiments obtained by a person of ordinary skill in the art based on the embodiments of the present invention without creative efforts shall fall within the protection scope of the present invention.

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[0027] A detailed description of one or more embodiments of the invention is provided below along with accompanying figures that illustrate the principles of the invention. The invention is described in connection with such embodiments, but the invention is not limited to any embodiment. The scope of the invention is limited only by the claims and the invention encompasses numerous alternatives, modifications and equivalents. Numerous specific details are set forth in the following description in order to provide a thorough understanding of the invention. These details are provided for the purpose of example and the invention may be practiced according to the claims without some or all of these specific details. For the purpose of clarity, technical material that is known in the technical fields

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related to the invention has not been described in detail so that the invention is not unnecessarily obscured.

[0028] It may be noted that, it will be understood that a basic minimum understanding of Thermodynamics exists with the reader in order to understand the explanation.

[0029] Referring now to figure 1 illustrates basic layout of existing plant cycles as a prior-art.

[0030] While aspects are described for high efficiency energy conversion cycle by recycling latent heat of vaporization may be implemented in any number of different systems, environments, and/or configurations, the embodiments are described in the context of the following exemplary system.

[0031] Referring now to figure 2 illustrates a simplified schematic of a multistage cycle that will achieve very high efficiencies, in accordance with an embodiment of the present subject matter.

[0032] In one implementation, the low quality waste heat of the first stage is transferred to the input stage of the second cycle, the waste heat of the second cycle transferred to the input stage of the third cycle and so on. The more stages there are, the greater will be the final overall efficiency, but there will come a time when adding more stages will have diminishing financial returns. In addition, it may not be possible to find a sufficient number of working fluids with the right physical properties to have an unlimited number of stages.

25

[0033] In one implementation, for the purposes of explaining the process in detail, two stages will be sufficient to explain the concept and therefore the rest of the explanation will be based on a two stage system.

[0034] Referring now to figure 3 illustrates an example of what a 2 stage system could look like if water and ammonia are used as working fluids, in accordance with an embodiment of the present subject matter.

5 [0035] In one implementation, for purposes of simplicity only a high pressure and low pressure turbine are shown in stage A 1000, and only a single stage turbine has been shown in stage B 2000. In addition, all existing techniques such as regenerative heat, open feed water heater and other minor modifications already in existence to improve cycle efficiencies and performance have been intentionally left out. All existing techniques at efficiency
10 improvement may still be used in every stage of the proposed improved design. All values of thermo physical properties mentioned in this entire document have been taken from the National Institute of Standards and Technology (NIST) website at www.nist.com or more specifically from webbook.nist.gov/chemistry/fluid/.

15 [0036] In one implementation, there may be a wide range of fluids that can be employed in the various stages 1000 or 2000 of the improved system, but for the purposes of explanation, we will in this document assume that water is used in stage A 1000 as a first working fluid and Ammonia will be used in stage B 2000 as a second working fluid. Stage A 1000 is the first stage and liquid water is sent from point 13 into the boiler A 2 at high pressure of say
20 250 bar (or any other desired pressure) by pump A 1. Here, in boiler 2 it is heated to a high temperature of say 600°C (or any other desired temperature) and exits from boiler A 2 at point 10 as a supercritical or heated fluid. This high temperature and pressure supercritical fluid is then expanded in a high pressure turbine 3 and after a significant temperature and pressure drop is sent back to the boiler A 2 to be reheated back to 600°C at 50 bar (or any
25 other desired temperature and pressure) and sent to a low pressure turbine 4 for final energy extraction to produce electricity.

[0037] In existing systems, the steam/vapour exits the turbine at point 11 at near vacuum conditions and the latent heat of vaporization (or condensation) is removed as waste heat in

the condenser using cooling water. This allows the steam to be converted back into a liquid at point 12 so that it can be pumped back into the system at high pressure to repeat the cycle.

[0038] In the present invention, the steam exits the low pressure turbine A 4 at point 11 at sufficiently high pressure and temperature so as to allow for its latent heat energy transfer to the second working fluid which in the example used is ammonia, this is where the first major deviation from prior-art is made. Naturally this may result in a slight decrease in the efficiency in stage A 1000 when compared with existing prior-art, however, all the latent heat of vaporization of stage A 1000 will be transferred to the working fluid of stage B 2000 in heat exchanger A100 instead of being wasted into the atmosphere as is the case with existing prior-art. In this process of transferring the latent heat energy to stage B 2000, the steam/vapour of stage A 1000 is converted back into a liquid at point 12 so that it may be pumped back into the input stage 13 at high pressure by condensate pump A 1.

[0039] In one implementation, as stage B 2000 has already absorbed the large amount of latent heat energy of stage A 1000, much less additional energy needs to be added in stage B 2000 to achieve the desired temperature. By absorbing the latent heat energy of the steam in stage A 1000 in heat exchanger A 100 the ammonia has already been converted to a high temperature and pressure vapour at point 14. It may be understood by a person skilled in the art that, in this example, with the pressures and temperatures chosen, the ammonia is a vapour at point 14. However, the working fluid B in this case ammonia can exit heat exchanger A 100 as a liquid, vapour, or super critical liquid or super critical vapour at point 14 depending on the operating pressures desired for stage B. It then enters boiler B 5 where it is heated to the desired temperature before entering turbine B 6 at point 15. On exiting turbine B 6 at low pressure at point 16 the ammonia enters heat exchanger B 100 where it is cooled until it becomes liquid at point 17. Pump B 7 then pumps the liquid ammonia to the high pressure (that may be sub critical, critical or super critical pressure) point 18.

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[0040] In one implementation, as a significant amount of the total amount of energy added in stage B 2000 was obtained from the transfer of the latent heat of vaporization of stage A 1000 to stage B 2000, much less additional energy is required in stage B 2000 to get the ammonia to the desired temperature. Therefore, all stages after the first stage will operate at
5 very high efficiencies which will more than compensate for the slight efficiency drop in stage A 1000.

[0041] In one implementation, each stage may be isolated from the other stages and none of the different stage fluids mix.
10

[0042] In one implementation, different fluids may be used in each stage. A person skilled in the art will understand that same fluid may also be used in subsequent stages, but at a lower pressure.

15 [0043] In one implementation, different pressures and temperatures may be used in each stage as desired and as per the requirement of the system/power plant.

[0044] In one implementation, the present invention enables to use any of existing techniques such as regenerative heat, open feed water heater, a multi stage turbines, and the
20 like can continue to be used in each individual stage.

[0045] In one implementation, the present invention may be used with any heat source that may include but not limited to coal, solar, nuclear, and the like.

25 [0046] In one implementation, the latent heat of vaporization of any stage may be transferred into the input of the next stage at a temperature and pressure sufficiently high so as to cause a complete or partial phase change from liquid to vapour or super critical vapour and in the process the vapour of the first stage may be converted into liquid.

[0047] In one implementation, the turbine exit pressure in all but the last stage may be above atmospheric temperature and pressure.

[0048] In one implementation, any number of stages and choice of working fluids may be
5 chosen depending individual requirements.

[0049] In one implementation, it may be understood that the first stage efficiency of heat to electricity conversion may be slightly reduced with respect to what is possible in current designs. The subsequent stages may have a “virtual” efficiency that may even exceed 100%,
10 and is explained in below sections.

[0050] In one implementation, for best results (although not essential), the working fluid of stage A 1000 may have the highest critical point temperature. Each subsequent stage e.g., 2000 may have a working fluid with a lower critical point temperature then the previous
15 stage. Therefore, water would generally be the choice of fluid for the first stage.

[0051] In one implementation, the present invention may be used as the lower stage of a gas fired plant.

[0052] In one implementation, in addition to a heat exchanger 100, a heat pump can also
20 be used to transfer heat from one stage to the next. Although the heat pump would consume energy and reduce the efficiency, it would also allow for removal of the temperature drop that may have to be maintained in some cases in the heat exchanger in order to transfer energy. The absence of a temperature drop in the heat exchanger would give a better
25 efficiency and this would help in negating the energy consumed by the heat pump. For example, a heat exchanger could be used to transfer the bulk of the energy while maintaining a temperature difference, and the final amount of energy could be transferred using a heat pump so that no temperature difference exists. This may be useful in the end stages.

12

[0053] In one implementation, a multi stage electric power generation apparatus with at least two stage system is disclosed. The electric power generation apparatus comprises of: a first stage power cycle 1000 comprising a first working fluid (not shown), and configured for electric power generation, and thereby generating waste heat(latent heat of vaporization and/or condensation); a second stage power cycle 2000 comprising a second working fluid (not shown), and configured for electric power generation, and thereby generating waste heat(latent heat of vaporization and/or condensation); WHEREIN the second working fluid absorbs all the waste heat(latent heat of vaporization and/or condensation) generated from first stage power cycle for the purpose of electric power generation.

[0054] In one implementation, the first power generating stage comprises: a first means 1 configured to pass the first working fluid at a high pressure, a second means 2 configured to receive the first working fluid at the high pressure; heat the first working fluid to a high temperature to generate a heated or superheated fluid or vapour; a third means 3 and fourth means 4 configured to receive the heated fluid/vapour, and expand it till it drops to a certain temperature and pressure, and the working fluid exits the power extraction stage at low pressure and temperature with its waste heat (latent heat of vaporization and/or condensation).

[0055] In one implementation, the present invention comprises a heat exchanger mechanism 100, wherein the heat exchanger mechanism 100 is configured to transfer the waste heat (latent heat of vaporization and/or condensation) generated from the first stage 1000 to the second working fluid in the second stage 2000, and converts the second working fluid into a high temperature and pressure fluid or vapour.

[0056] In one implementation, the heat exchanger mechanism 100 is configured to receive, during the first stage power cycle 1000, the first working fluid vapours from the fourth means 4, and cool it till it is converted to liquid form, and pass it to the first means 1; or receive,

13

during the second stage power cycle 2000, the second working fluid vapours from the seventh means 7, and heat it with the waste energy of stage A 1000.

[0057] In one implementation, the second stage power cycle, comprises a fifth means 5
5 configured to: receive the second working fluid in liquid or vapour form at a high temperature and pressure,; and heat the second working fluid in liquid or vapour form to high temperature and pressure vapour; a sixth means 6 configured to receive the heated vapour at the high temperature and pressure, and generate electric power from the vapours, and exit the power extraction stage at low pressure and temperature with its latent heat of vaporization
10 and/or condensation to enter a heat exchanger 200 where its waste heat (latent heat) is either transferred to the next stage or rejected to the atmosphere; a seventh means 7 configured to pass the second working fluid in liquid form at a high pressure.

[0058] Referring now to figure 4 illustrates a method for generating an electrical power
15 using an electric power generation apparatus with at least two stage latent heat exchange mechanism, in accordance with an embodiment of the present subject matter.

[0059] The order in which the method is described is not intended to be construed as a limitation, and any number of the described method blocks can be combined in any order to
20 implement the method or alternate methods. Additionally, individual blocks may be deleted from the method without departing from the scope of the subject matter described herein. Furthermore, the method can be implemented in any suitable hardware, firmware, or combination thereof. However, for ease of explanation, in the embodiments described below, the method may be considered to be implemented in the above described electric power
25 generation apparatus.

[0060] At block 402, electrical power is generated using first working fluid. The method of generation is explained in description of figure 5.

14

[0061] At block 404, the latent heat of vaporization and/or condensation (waste heat) of the first working fluid is transferred to a second working fluid which is physically isolated from the first fluid. In the process the first working fluid is converted from vapour to liquid phase.

5

[0062] At block 406, the second working fluid after absorbing all the waste heat of the first stage may be further heated to obtain the desired temperature for the purpose of generating useable power. The method of generation is explained in description of figure 6.

10 [0063] At block 408, after power extraction, the remaining energy of the second working fluid (waste heat) may be transferred to a third working fluid or to the surrounding as waste heat.

[0064] Referring now to figure 5 illustrates a method performed during the first stage
15 power cycle 1000, in accordance with an embodiment of the present subject matter.

[0065] At block 502, the first working fluid at a high pressure is passed using a first means
1.

20 [0066] At block 504, the first working fluid at the high pressure is received by a second means 2. The second means 2 heats the first working fluid to a high temperature to generate a heated fluid.

[0067] At block 506, the heated fluid is received by a third means 3 and fourth means 4.
25 The means 3 and 4 expands it till it drops to a certain temperature and pressure for the purposes of power generation.

[0068] At block 508, any existing means for enhancing efficiency may also be utilized as desired.

15

[0069] At block 510, the waste heat (latent heat) generated in this stage is transferred to the second stage working fluid in latent heat exchange mechanism A 100. In the process, the first working fluid is converted back to liquid phase and again provided to the first mean 1 and the
5 cycle is repeated in 1000

[0070] Referring now to figure 6 illustrates a method performed during the second stage power cycle 2000, in accordance with an embodiment of the present subject matter.

10 [0071] At block 602, the second working fluid at a high pressure is passed using a seventh means 7.

[0072] At block 604, the second working fluid of stage B 2000 absorbs all the waste heat (latent heat of vaporization /condensation) of the first working fluid of stage A 1000 and in
15 the process significantly raises its temperature and energy content.

[0073] At block 606, the second working fluid at high temperature and pressure exits from the heat exchanger mechanism 100 wherein the latent heat from stage A 1000 is provided to the second working fluid, is received by the fifth means 5 at a high temperature and pressure
20 and further heated if desired to the final temperature.

[0074] At block 608, the second working fluid enters the sixth means 6 at high temperature and pressure for the purposes of energy generation.

25 [0075] At block 610, any existing means for enhancing efficiency may also be utilized as desired.

[0076] At block 612, the excess waste heat generated in second stage 2000 is either transferred to a third working fluid or emitted or ejected out into the atmosphere by the heat

exchanger 200. In the process, the second working fluid is converted back to liquid phase and again provided to the seventh mean 7 and the cycle is repeated in stage B 2000.

[0077] It is to be noted that the massive amount of energy that is released in a phase change of steam to liquid water can only be removed with a phase change (complete or partial) in another liquid which in this example is ammonia. The alternative is to use the existing technique of massive amounts of cooling water from rivers or oceans in which case the latent heat is lost to the environment as low temperature waste heat. The present invention enables to transfer all the latent energy of a working fluid at relatively low pressure into the high pressure input stage of another turbine cycle. With proper choice of working fluids, pressures, and temperatures it is possible to achieve any efficiency one desires.

[0078] In one implementation, the choice of temperatures and pressures or coolants used are just an example to help in understanding the process, and any temperature or pressure or coolant could be used depending on individual situations. The important point is that the latent heat is not rejected into the atmosphere as waste heat but is transferred into the next stage with proper choice of turbine exit pressures and temperatures depending on the coolant. The reason why we can exceed the limits set by the Carnot Equations is that they were never really applicable to any system that utilizes a phase change in order to extract energy from heat. The obvious example to support this statement is the very fact that no system in operation has come even remotely close to the efficiencies defined by the Carnot Equations. In any system employing a phase change the actual maximum efficiency under ideal conditions should be described as :

$$\text{Efficiency} = \frac{Q_{in} - \Delta H_{vap}}{Q_{in}} = 1 - \frac{\Delta H_{vap}}{Q_{in}}$$

25 Where Q_{in} is the total energy input per kilogram in units of KJ/Kg

And ΔH_{vap} is the latent heat of vaporization in kJ/Kg at the turbine exit pressure.

[0079] In the above equation, the steam exiting the turbine is not a saturated vapour. If a saturated vapour is allowed or desired, the latent heat value should be adjusted accordingly.

In the event that two stages as described earlier in the document are used the equation would be as:

$$\text{Efficiency} = \frac{(Q_{\text{in}}^{\text{A}} - \Delta H_{\text{vap}}^{\text{A}}) + (\Delta H_{\text{vap}}^{\text{A}} + \varepsilon(Q_{\text{in}}^{\text{B}} - \Delta H_{\text{vap}}^{\text{B}}))}{Q_{\text{in}}^{\text{A}} + \varepsilon Q_{\text{in}}^{\text{B}}} = \frac{Q_{\text{in}}^{\text{A}} + \varepsilon Q_{\text{in}}^{\text{B}} - \varepsilon \Delta H_{\text{vap}}^{\text{B}}}{Q_{\text{in}}^{\text{A}} + \varepsilon Q_{\text{in}}^{\text{B}}} = 1 - \frac{\varepsilon \Delta H_{\text{vap}}^{\text{B}}}{Q_{\text{in}}^{\text{A}} + \varepsilon Q_{\text{in}}^{\text{B}}}$$

Where Q_{in}^{A} is the energy input per kilogram in units of KJ/Kg in stage A

5 And Q_{in}^{B} is the energy input per kilogram in units of KJ/Kg in stage B

And $\Delta H_{\text{vap}}^{\text{A}}$ is the latent heat of vaporization in kJ/Kg at the turbine exit pressure in stage A

And $\Delta H_{\text{vap}}^{\text{B}}$ is the latent heat of vaporization in kJ/Kg at the turbine exit pressure in stage B

And ε is the flow factor to compensate for the different flow rates that may exist between stages A and B and would be defined as (mass flow rate of stage B)/(mass flow rate of stage

10 A)

Similarly, for more than 2 stages the equation would be as

$$\text{Efficiency} = 1 - \frac{\varepsilon_n \Delta H_{\text{vap}}^{\text{n}}}{Q_{\text{in}}^{\text{A}} + \varepsilon_{\text{B}} Q_{\text{in}}^{\text{B}} + \dots + \varepsilon_n Q_{\text{in}}^{\text{n}}}$$

Where n is the number of stages and ε_n is the mass flow rate in stage n divided by the mass flow rate of stage A.

15 If energy losses are to be taken into account, the equation would be

$$\text{Efficiency} = 1 - \frac{\varepsilon_n \Delta H_{\text{vap}}^{\text{n}} + E_{\text{t}}}{Q_{\text{in}}^{\text{A}} + \varepsilon_{\text{B}} Q_{\text{in}}^{\text{B}} + \dots + \varepsilon_n Q_{\text{in}}^{\text{n}}}$$

Where E_{t} is the total energy loss in the entire system.

[0080] Naturally from the above equations, the following observations/ understanding can be made:

20

1) The greater the number of stages, the greater will be the overall efficiency.

2) With an unlimited number of stages in an ideal system, the efficiency would approach 100%. However, in practice it will be difficult to find enough working fluids to do so and with diminishing output in each additional stage, it would be probably best to limit it to 3 or 4 stages to optimize both output and financial returns.

25

3) It may seem from the equations that one could simply choose a working fluid with a low latent heat of vaporization to increase the efficiency of the system. This is

actually the opposite of what would happen. The equations represent what would happen in ideal conditions where there is no energy, heat, friction, or other losses. In real conditions if a fluid of low latent heat was used, the condensate and feed water pumps would require a large fraction of the total amount of energy produced. Apart from its chemical properties, water is the obvious best choice due to its very large latent heat of vaporization. The higher the latent heat of vaporization, the greater the expansion volume that occurs upon phase change, and it is this very large expansion ratio of steam that allows it to drive turbines efficiently and have a very small relative power requirement for the condensate and feed water pumps.

- 4) Only the latent heat of the final stage is rejected to the atmosphere.
- 5) The above equations will apply to any system that uses a phase change to convert heat energy into any other form of useable energy.
- 6) In current designs, to try and maximize energy extraction the steam generally exits the turbine as a saturated vapour and causes damage to the low pressure turbine blades. In this design, that is not necessary which will extend turbine blade life.

WORKING EXAMPLE: THEORETICAL RESULTS

[0081] The following example will show the advantage of the design explained in this document. Its sole purpose is only to help in explaining the concept and in no way limits the protection scope of the design in any aspect whatsoever to the fluids, temperatures and pressures used to explain the process. If it is assume that at point 10 the super critical fluid is at 600°C and 250 bar pressure then it has an Enthalpy of 3493kJ/Kg. In current designs (assuming no reheat or any other efficiency increasing technique), on exiting the turbine at 0.1 bar it still has an enthalpy of about 2450kJ/Kg of which about 2257kJ/Kg is the latent heat of vaporization (or condensation) which is removed to the atmosphere as low quality waste heat resulting in an efficiency of only about 35% $((3493-2257)/3493)$. Now all we have to do is to make sure this waste heat of 2257kJ/Kg is not wasted into the atmosphere and we have an extremely efficient system.

[0082] As an example, if at point 11, let the steam leave the turbine and enter condenser A at say 180°C and a pressure of 10 bar, the enthalpy would be about 2777kJ/Kg on exiting the turbine. In condenser A this heat energy is transferred to Stage B in which the working fluid is Ammonia at say 100 bar at point 18 with a temperature of 40°C and enthalpy of 536kJ/Kg.

5 The fluids in cycles A and B are completely isolated from each other and it is essential that there is no direct contact of the fluids at any place. This allows the different stages to operate at different pressures and temperatures and one can control them according to their requirements. At 100 bar Ammonia will undergo a phase change above 125.17°C whereas the steam in stage A at 10 bar will change phase below 179.88°C. This temperature
10 difference will allow for the energy transfer from stage A to B in heat exchanger A and as the Ammonia goes from liquid phase to a vapour phase, the steam in stage A cools down to a liquid which can then be pumped to a higher pressure to continue the cycle. The large amount of energy released by a phase change of steam to liquid water can only be absorbed because the ammonia changes phase from liquid to vapour. When the ammonia leaves the heat
15 exchanger A at 180°C with an Enthalpy of 1831kJ/Kg, it has absorbed all the latent energy available in the water in stage A.

[0083] The flow rate of stage B could be higher or lower than that of stage A so as to match the amount of energy that needs to be transferred between stages. In heat exchanger A
20 the steam releases 2027kJ/Kg (2777kJ/Kg-750kJ/Kg) whereas the ammonia can absorb only 1295kJ/Kg (1831kJ/Kg-536kJ/Kg). To transfer all this energy in this particular example, the mass flow rate of Ammonia would have to be 1.56 (2027kJ/Kg/1295kJ/Kg) times greater than the mass flow rate of water in order to absorb all the energy required to convert it to liquid. If a lower or higher flow rate ratio is preferred for the ammonia cycle, one need only
25 to simply increase or decrease the turbine exit pressure and temperature of stage A according to the requirements.

[0084] It is assumed that about a 50°C temperature difference is maintained in the heat exchanger to allow for energy transfer from one stage to the next and a heat pump can be

used for the final amount of energy transfer if desired or necessary. If a lower or higher temperature difference is desirable, the calculations would be adjusted accordingly. A heat pump can also be used to transfer heat from one stage to the next in which case the temperature difference could be zero or even negative if required in certain cases. This would
 5 result in a slightly higher efficiency for each stage but the energy used by the heat pump must also be taken into consideration to determine if it is beneficial to do so.

[0085] Although, the system shown in figure 3 may have reduced the efficiency of stage A slightly, we have transferred the latent heat of stage A into the input of stage B and made the
 10 working fluid a high pressure vapour at point 14 and all that is needed is a little extra energy in boiler B to take the ammonia temperature from 180°C to 420°C or about 781kJ/Kg as shown in fig. 3 (2612kJ/Kg-1831kJ/Kg=781kJ/Kg). By comparison 3484kJ/Kg is added in stage A. This gives a 'virtual' efficiency for stage B as $((2612-1637)/(2612-1831))*100 = 125\%$. The average efficiency for the first two stages is (total energy output) / (total energy
 15 input) = $((3493-2926)+(3667-2777)+1.56*(2612-1637))/((3493-750+3667-2926+1.56*(2612-1831))) = 63.3\%$. This figure of course is an approximation since no energy losses have been taken into account. However, with just 2 simple (utilizing only 1 reheat in stage A) stages, the design has already greatly exceeded all performance limits possible with current design systems. The third stage will result in an efficiency that will exceed those set by the Carnot
 20 equations thus invalidating them. With an unlimited number of stages and ideal systems, one could actually approach near 100% efficiency.

[0086] Exemplary embodiments discussed above may provide certain advantages. Though not required to practice aspects of the disclosure, these advantages may include:

- 25
- that the cost per unit of power will decrease. Pollution will be reduced as less fuel will have to be burnt for the same amount of electricity output.
 - on a planet which is facing a significant danger of a runaway increase in temperature due to pollution, this will provide significant relief.

- Another benefit is that the existing electricity generating capacity will increase significantly with relatively small additional investment.

[0087] It may be noted and understood by the person skilled in the art that there are various means used in the present invention. Each means is a specific device for performing specific functions as disclosed above. For example,

First means and Seventh means may include but not limited to pumps and the like devices having similar functionality or purpose as that of the pump.

Second means and Fifth means may include but not limited to boilers and the like devices having similar functionality or purpose as that of the boilers.

Third means, Fourth means, and Sixth means may include but not limited to high pressure turbines, low pressure turbines, and the like devices having similar functionality or purpose as that of the high / low pressure turbines.

[0088] Although implementations for a system for high efficiency energy conversion cycle by recycling latent heat of vaporization have been described in language specific to structural features and/or methods, it is to be understood that the appended claims are not necessarily limited to the specific features or methods described. Rather, the specific features and methods are disclosed as examples of implementations for a system for high efficiency energy conversion cycle by recycling latent heat of vaporization.

[0089] The examples mentioned in this entire document are meant only to assist in understanding the basic concept of the design and in no way limit the scope of the design. The important point is that the latent heat of vaporization/condensation (waste heat) is transferred into subsequent stages to increase the efficiency of heat to electricity conversion instead of rejecting it to the atmosphere as is the current practice. All designs with minor modifications or alterations that seek to utilize the latent heat of vaporization/condensation (waste heat) as described in this document are also covered by the scope of this patent.

CLAIMS

1. A multi stage electric power generation apparatus with at least two stage latent heat (waste heat) exchange mechanism, the electric power generation apparatus comprising:

5 a first stage power cycle comprising a first working fluid, and configured for electric power generation, and thereby generating a turbine exit vapour containing energy of latent heat of vaporization and/or condensation (waste heat);

a second stage power cycle comprising a second working fluid, and configured for electric power generation; WHEREIN

10 the second working fluid absorbs the latent heat of vaporization and/or condensation (waste heat) generated from the first stage power cycle for electric power generation.

2. The apparatus as claimed in claim 1, wherein the first working fluid is heated to a vapour and the second working fluid is heated to a vapour having an operating temperature and pressure independent of the first working fluid.

3. The apparatus as claimed in claim 1, wherein the first stage power cycle comprises:

a first means configured to pass the first working fluid at a high pressure;

20 a second means configured to:

receive the first working fluid at the high pressure; and

heat the first working fluid to a high temperature, to generate a heated fluid/vapour;

25 a third and fourth means configured to receive the heated fluid/vapour, and expand it till it drops to a certain temperature and pressure, thereby passing the heated fluid with dropped temperature and pressure to a waste heat exchange mechanism.

4. The apparatus as claimed in claim 1 comprises a heat exchanger mechanism, wherein the heat exchanger mechanism is configured to:

transfer the waste heat generated from the first stage power cycle to the second working fluid in the second stage power cycle.

5. The apparatus as claimed in claim 1, wherein the second stage power cycle,
5 comprises:

a fifth means configured to:

receive the second working fluid in liquid or vapour form at a high temperature and pressure; and

10 heat the second working fluid in vapour form to the preferred operating temperature;

a sixth means configured to:

15 receive the heated vapour at the high temperature and pressure, and generate electric power from the vapours which exit the power generation device at a low temperature and pressure and enters another heat exchanger to either transfer its waste heat to a third stage power cycle or ejected to the atmosphere;

a seventh means configured to pass the second working fluid at a high pressure;

20 6. The apparatus as claimed in any of the preceding claims, wherein heat exchanger mechanism is configured to:

receive, during the first stage power cycle, the first working fluid vapours from the fourth means, and cool it till it is converted to liquid form, and pass it to the first means; or

25 receive, during the second stage power cycle, the second working fluid vapours from the sixth means, and cool it till it is converted to liquid form, and pass it to the seventh means.

7. The apparatus as claimed in claim 1, wherein all the working fluids are selected from a group of fluids suitable for use as a working fluid and are operated at pressures and temperatures independent of each other and therefore different pressures and temperatures can be used in all stages as required.

5

8. The apparatus as claimed in claim 1, wherein preferably, different working fluids are used for different stages and are physically isolated and cannot mix.

9. The apparatus as claimed in claim 1 wherein the latent heat of vaporization of the first stage is transferred to the second stage at a pressure and temperature sufficiently high causing a significant increase in temperature and energy content and a phase change from liquid to vapour or supercritical vapour of the second working fluid and in the process the vapour of the first stage is converted to liquid.

10. The apparatus as claimed in claim 9 wherein the phase change from liquid to vapour or supercritical vapour of the second working fluid is a complete phase change or a partial phase change.

11. The apparatus as claimed in claim 1, wherein the fluids are chosen with physical properties allowing for easy transfer of latent heat energy from one stage to the next in the latent heat exchange mechanism.

12. The apparatus as claimed in claim 1 wherein the waste heat exchange mechanism adapted to be used with all heat based power systems even if the final output is some form of non electrical output.

13. The apparatus as claimed in claim 1, wherein any of the individual stages are adapted to operate at sub critical, critical, or super critical temperatures and pressures as desired.

14. A method for generating an electrical power using an electric power generation apparatus with at least two stage power cycle, the method comprising:

5 generating, in a first stage power cycle comprising a first working fluid, the electrical power, and a turbine exit vapour containing waste heat (latent heat of vaporization and/or condensation);

generating, in a second stage power cycle comprising a second working fluid, the electrical power generation, and waste heat(latent heat of vaporization and/or condensation); WHEREIN

10 the second working fluid absorbs the waste heat (latent heat of vaporization and/or condensation) generated from first stage in a heat exchange mechanism for generating electrical power.

15. The method as claimed in claim 14, comprises:

15 passing, by a first means, the first working fluid at a high pressure;
receiving, by a second means, the first working fluid at the high pressure;
heating, by the second means the first working fluid to a high temperature;
receiving, by a third means, the heated fluid, and expanding it till it drops to a certain temperature and pressure, thereby passing the heated fluid with dropped temperature and pressure to the second means for reheating the fluid with dropped temperature and pressure, wherein the heated fluid with dropped temperature and pressure is reheated;

20 generating, by a fourth means, the electrical power from the vapours generated at a high temperature and low or intermediate pressure; and

25 generating, by a fourth means, a low temperature and pressure exit vapour containing energy of latent heat of vaporization and/or condensation.

16. The method as claimed in claim 14, comprises exchanging, using a heat exchanger mechanism, the latent heat of vaporization and/or condensation generated from the first stage

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power cycle to the second working fluid in the second stage power cycle , and converts the second working fluid into a heated fluid undergoing phase change or vapour.

17. The method as claimed in claim 14, comprises:

5 receiving, using a fifth means, the second working fluid in heated fluid undergoing phase change or vapour form, from the heat exchanger mechanism, at a high temperature and pressure,;

heating, using the fifth means, the second working fluid in vapour form to the required temperature;

10 receiving, using a sixth means, heated vapour at the high temperature and pressure, and generating the electrical power from the vapours generated and exiting the sixth means at a low temperature and pressure, containing a latent heat of vaporization and/or condensation;

passing, using a seventh means, the second working fluid at a high pressure.

15

18. The method as claimed in claim 14, comprises:

receiving, using heat exchanger mechanism, during the first stage power cycle, the first working fluid vapours from the fourth means, and cool it till it is converted to liquid form, and pass it to the first means; or

20 receive, using a heat exchanger mechanism, during the second stage power cycle, the second working fluid vapours from the sixth means, and cool it till it is converted to liquid form, and pass it to the seventh means; and

emitting or transferring to the next stage, using heat exchanger mechanism, the latent heat of vaporization after the second stage power cycle.

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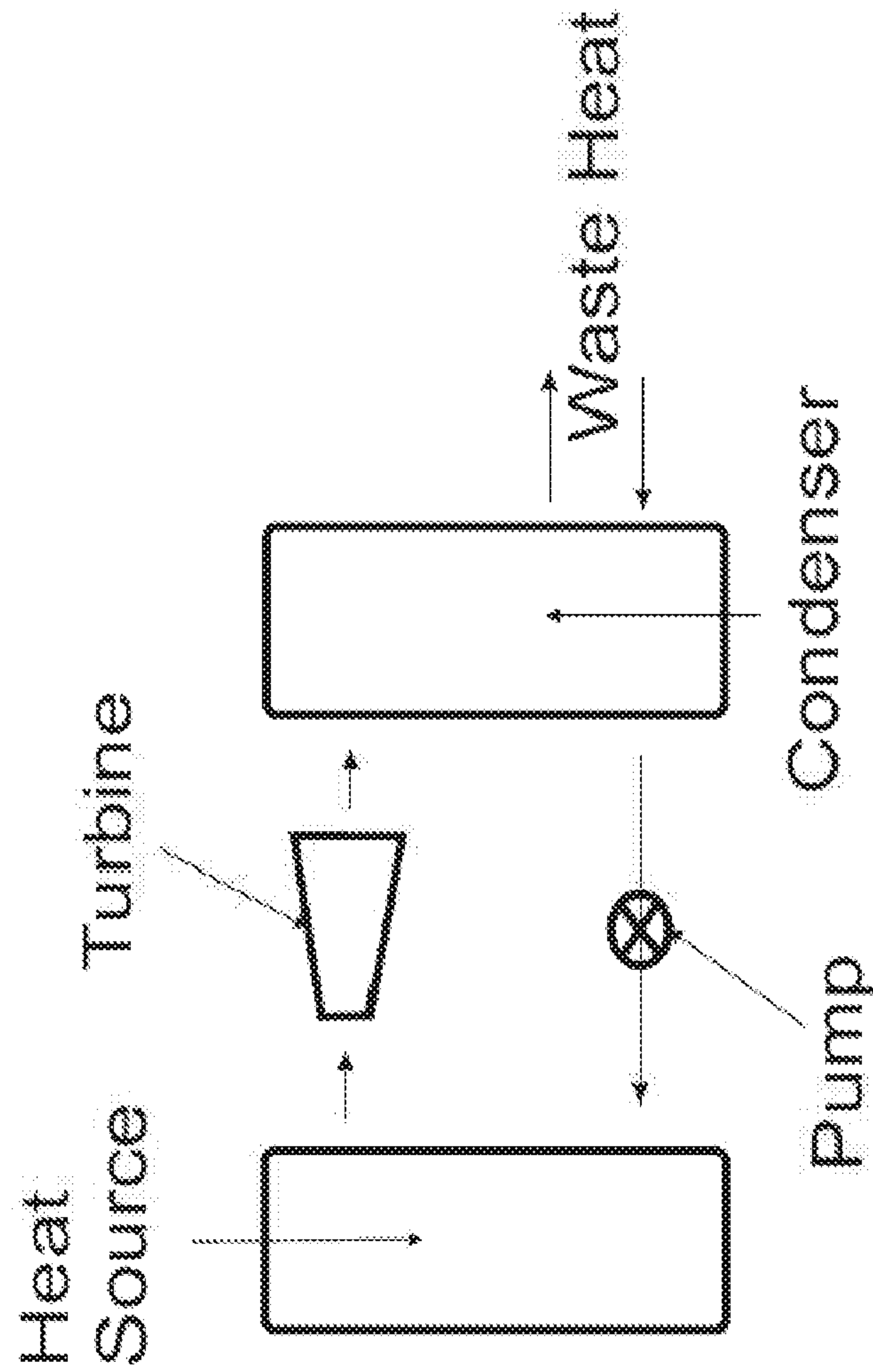


FIGURE 1 (PRIOR-ART)

2/6

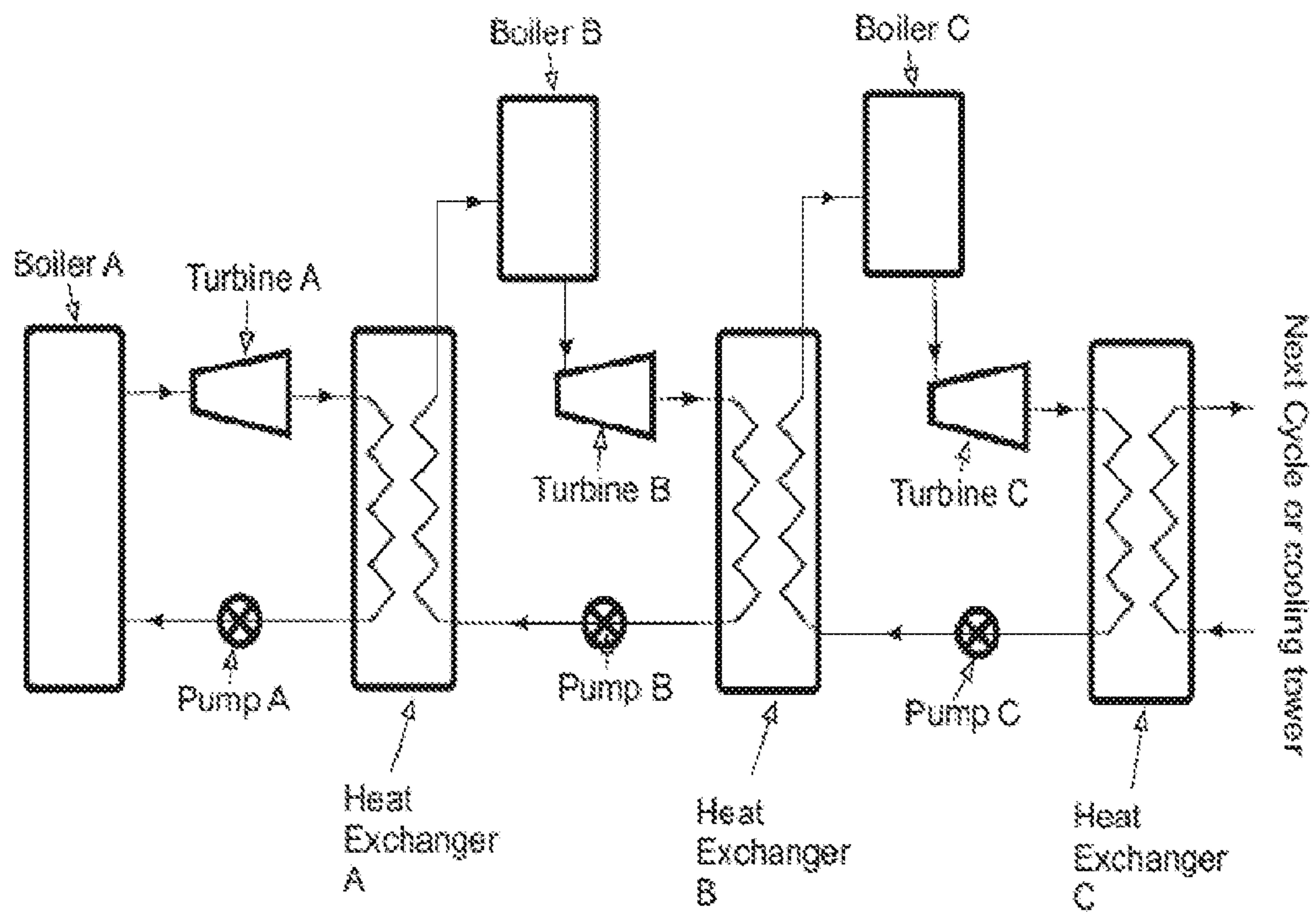


FIGURE 2

3/6

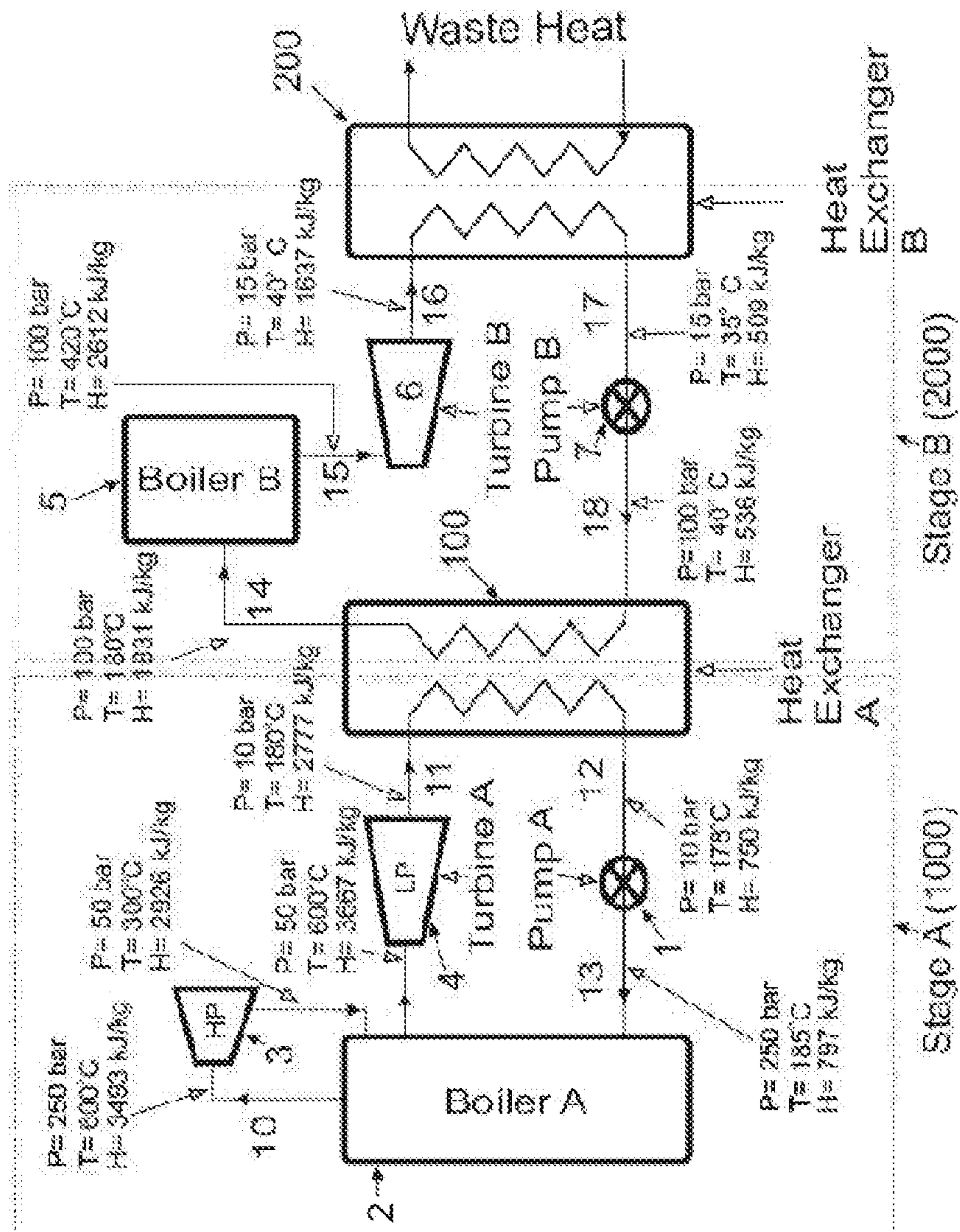


FIGURE 3

4/6

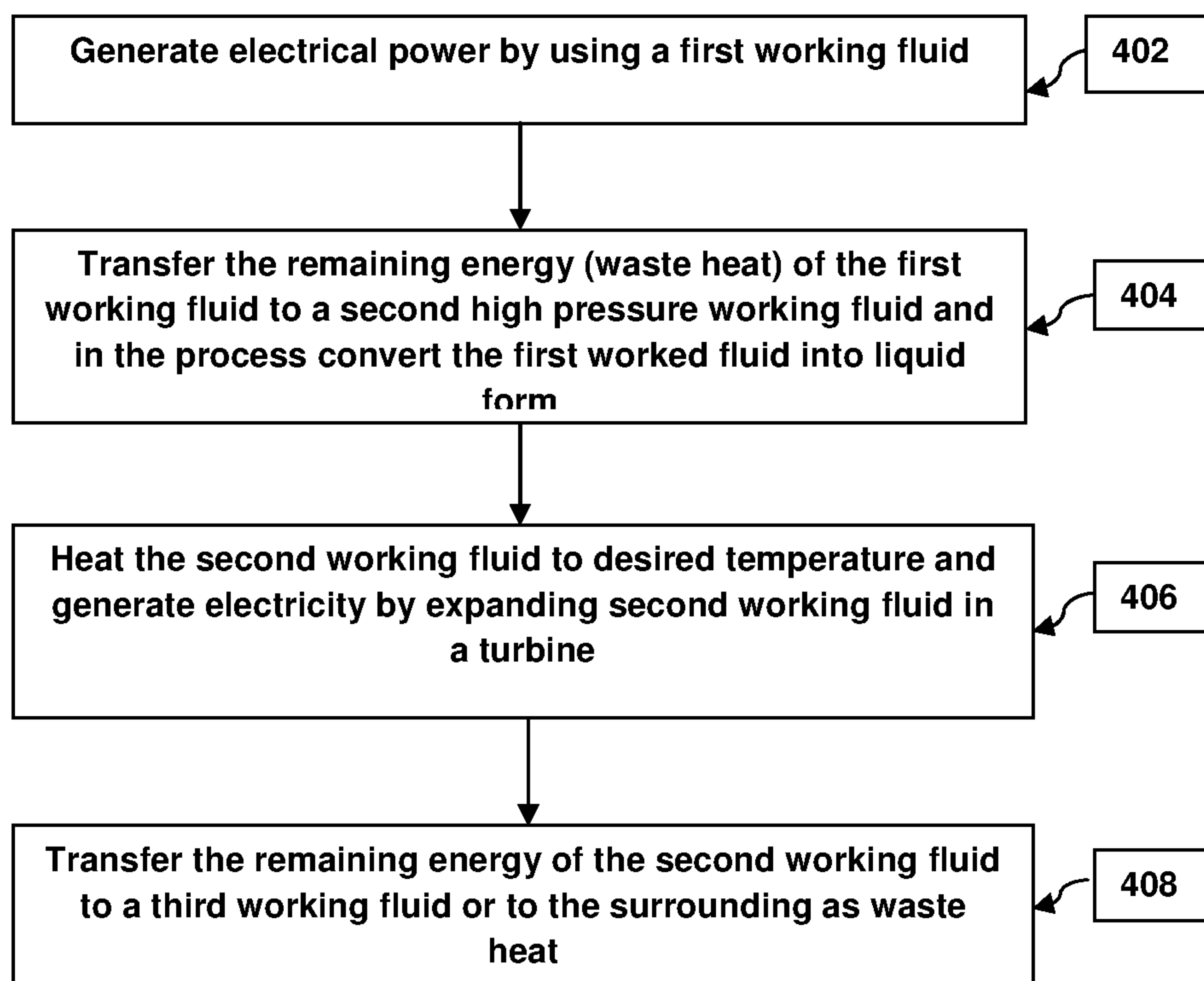


FIGURE 4

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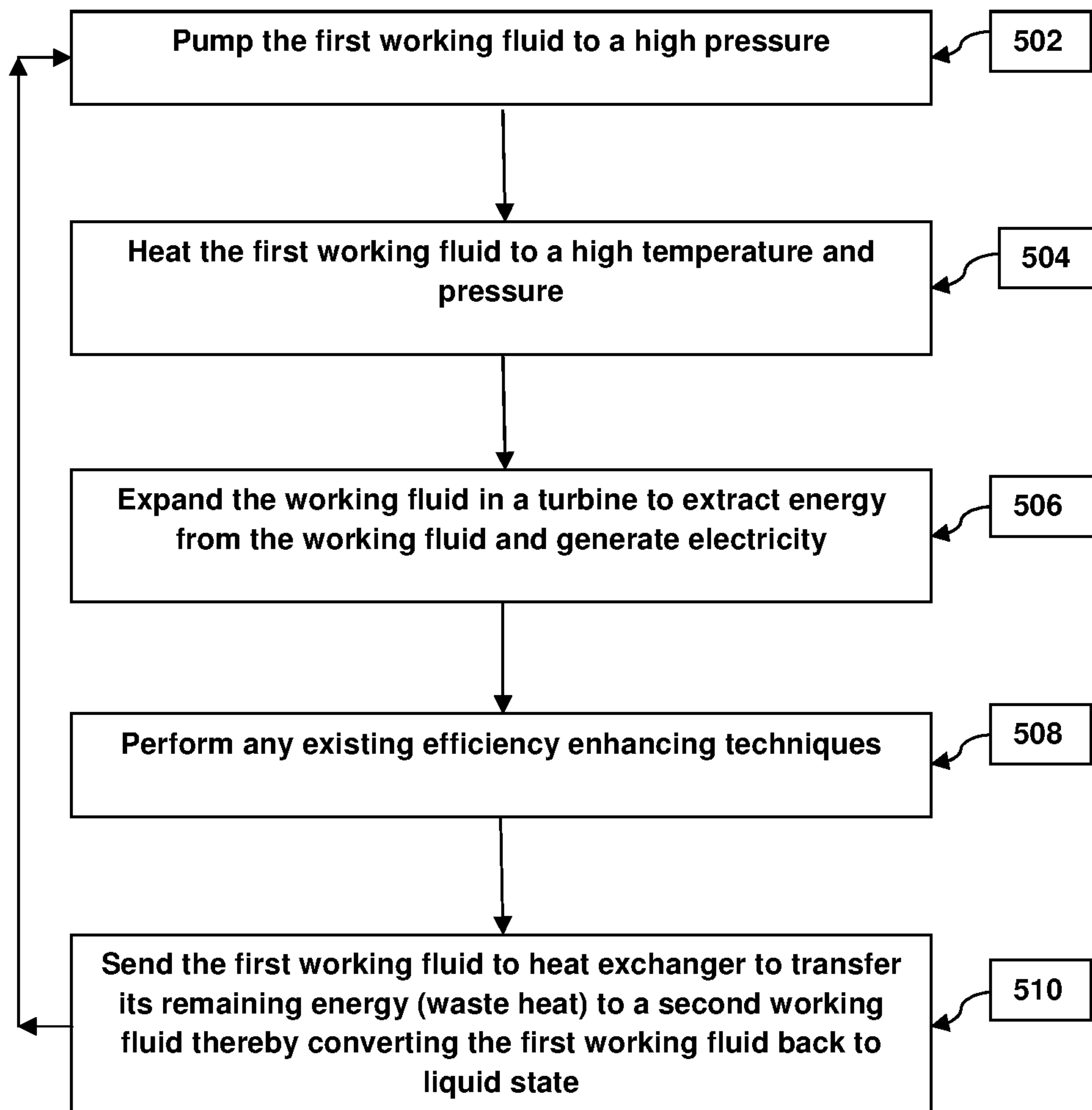


FIGURE 5

6/6

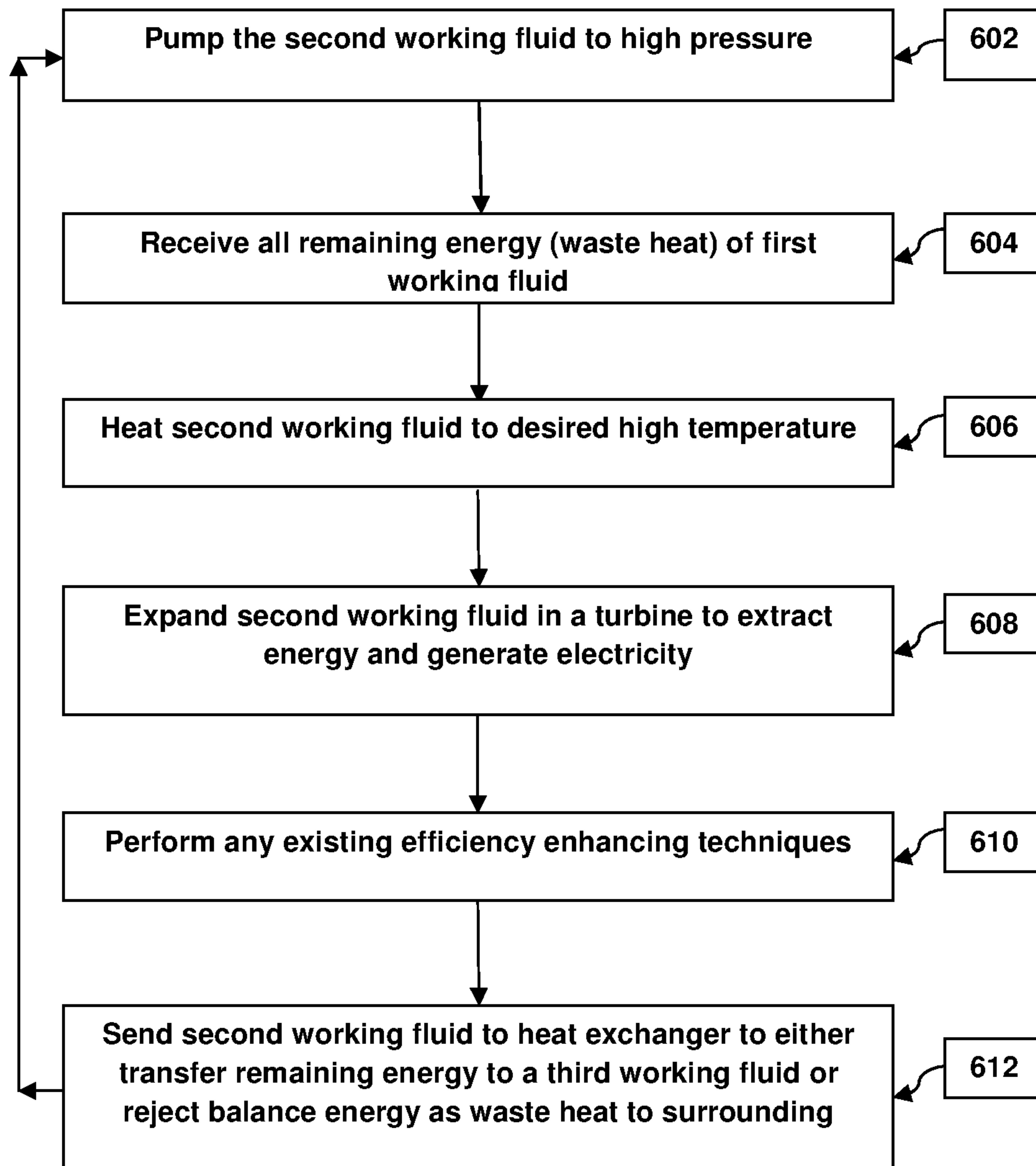


FIGURE 6

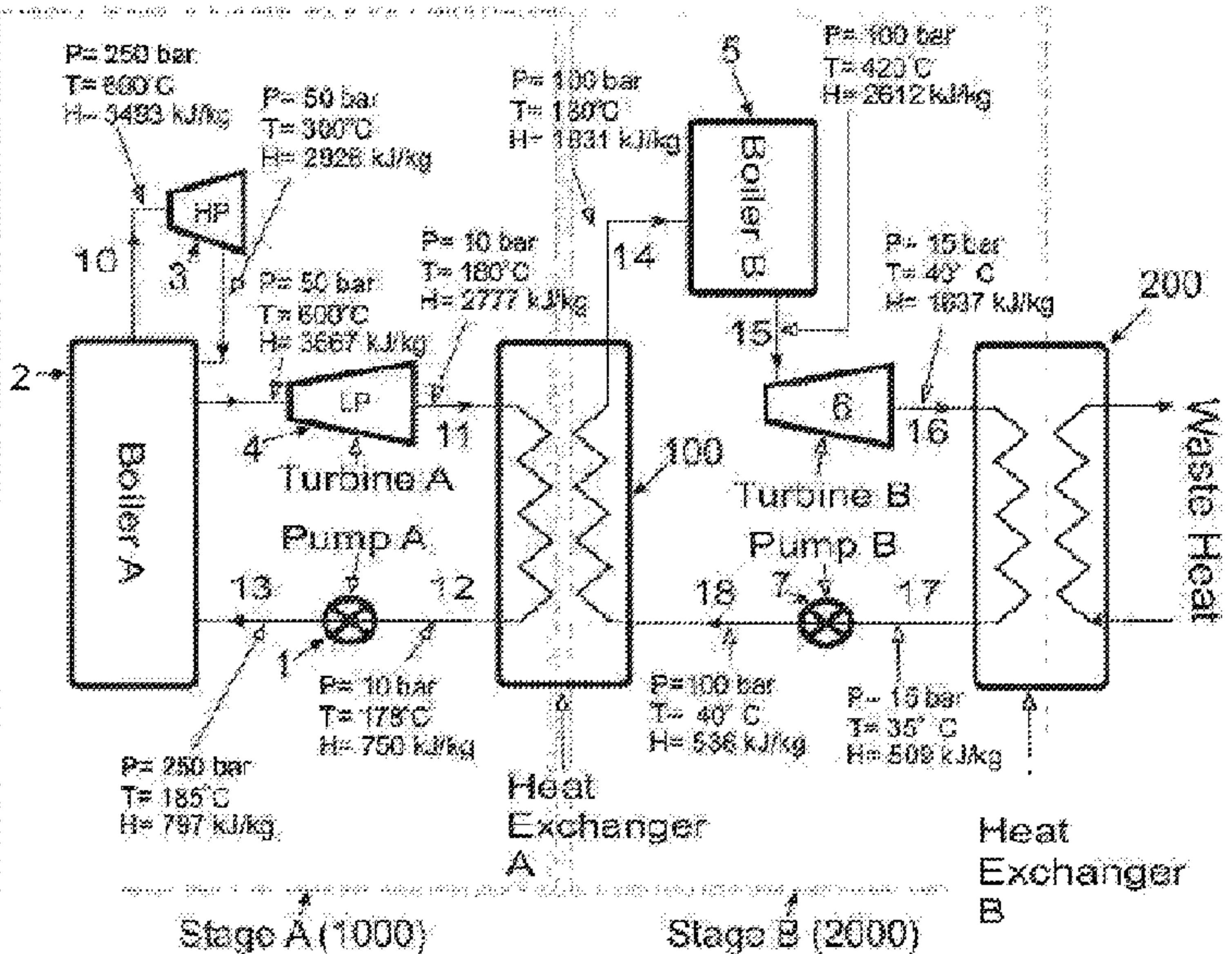


FIGURE 3