MODIFIED RANKINE CYCLE WITHOUT HEAT REJECTION, DRIVEN BY A WET-VAPOR-REGION THERMOCOMPRESSOR

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ABSTRACT

The disclosed concept relates to a novel modified and simplified Rankine steam-turbine cycle without rejection of heat in the cycle, which is driven by a thermocompressor (ejector) operating in the wet-vapor region, to the end of achieving of the maximum possible (~100%) thermal efficiency of the thus modified Rankine cycle. Wet-vapor mixture circulating within the thermocompressor is being separated in a cylindrical separation tank, so that the saturated water is pumped to a water heater where it receives the cycle heat input, while the saturated vapor is expanded in a backpressure steam turbine producing useful mechanical work and is then recirculated back to the thermocompressor, where it is being re-pressurized by the primary fluid (pumped and heated saturated water). The concept can be applied to steam-turbine-cycle power-plants fueled by: coal or solid/liquid/waste fuel, nuclear fuel (using boiling water reactors, pressurized water reactors, pressurized heavy-water reactors, gas-cooled reactors, molten salt reactors or liquid-metal-cooled fast reactors) or renewable energy sources (Solar energy, biomass, geothermal), The concept can also be used in the form of the bottoming steam-turbine-cycle part of a combined gas-turbine/steam-turbine cycle power plant.

8 Claims, 23 Drawing Sheets

I suggest Fig. 20.

PATENT CLAIMS

The invention claimed is:

1. A **modified** Rankine-cycle power-plant **without cycle-heat rejection** driven by a **thermocompressor** (ejector) operating in the **wet-vapor region**, consisting of the following interconnected equipment/processes:

a) a **wet-vapor-region thermocompressor/ejector** (**10**), consisting of: a **nozzle** (**11**) , typically a supersonic one, for acceleration of the high-pressure high-temperature liquid of a working fluid, typically subcooled water or low-quality liquid-gas (water-vapor) mixture, a **conical part** (**12**) of the **ejector mixing chamber** for admission of exhausted wet vapor from a **backpressure steam turbine** (**1**), a **long constant-diameter part** (**14**) of the said mixing chamber for mixing and deceleration/acceleration of the liquid-gas (water-vapor) mixture, typically in the form of one or more normal shock waves, and a **subsonic diffuser** for final (subsonic) deceleration of the mixed liquid-gas (water-vapor) mixture;

b) a **cylindrical separator/separation tank** (**2**) for as-complete-as-possible **separation** of the wet liquid-gas (water-vapor) mixture exiting the said diffuser (**15**) of the said thermocompressor (**10**), using a **dry-pipe steam separator** having of a lot of holes at the top and two holes at the bottom half, whereas the turbulently moving steam-water mixture is directed through the top half holes of the dry pipe and forced to separate between water and steam, whereby the separated steam flows to the said backpressure steam turbine (**1**) and the separated water drops down to the bulk liquid through bottom holes;

c) the said **backpressure steam turbine** (**1**) for adiabatic expansion of the saturated vapor (gas fraction) separated in the said **cylindrical separation tank** (**2**), exhausting wet vapor to the said **conical part** (**12**) of the said **mixing chamber** of the said thermocompressor (**10**), driving a load (**8**) via a connecting shaft;

d) a **steam compressor 18** preceding the said backpressure steam turbine (**1**), mounted on the same connecting shaft with the said load **8** and driven by the said backpressure steam turbine (**1**), which serves for **precompression** of the secondary ejector fluid, that is, saturated steam/vapor separated in the said cylindrical separation tank (**2**), **prior to its**

expansion in the said backpressure steam turbine (**1**), thus **artificially increasing** the **pressure recovery ratio** of the said wet-vapor thermocompressor (**10**) which is obtainable at an **ejector entrainment ratio** (ratio of mass flow rates of suction and driving fluid) defined by the vapor quality at the outlet of the said diffuser (**15**), so that it matches the chosen **expansion pressure ratio** of the said backpressure steam turbine (**1**);

e) the said **load** (**8**), typically an **electric generator**, driven by the said backpressure steam turbine (**1**) via the said connecting shaft, so that it converts mechanical energy of the said steam turbine (**1**) into the generator's electrical energy supplied to the grid;

f) a **condensate pump** (**3**) for pressurizing and circulation of the liquid working fluid (saturated water) separated in the said cylindrical separation tank (**2**);

g) a **stop valve** (**4**) at the discharge side of the said **condensate pump** (**3**) for starting up of the said pump (**3**) and of the entire working-fluid circulation loop;

h) a **liquid/water heater (heat exchanger)** (**5**) for isobaric heat addition to the liquid working fluid, typically subcooled water or a low-quality water-vapor mixture, either **directly heated** by any fuel or **indirectly heated** by heat exchange with any source of heat contained in a **primary heat-exchange fluid**, thereby supplying the heated liquid working fluid to the said **nozzle** (**11**) of the said **thermocompressor** (**10**), to the end of **re-pressurizing** of the **secondary ejector fluid** (exhausted wet vapor from the said backpressure steam turbine (**1**)); and

i) a **method for regulation** of the cycle output/load of the proposed modified Rankine-cycle power-plant without cycle-heat rejection in working regimes **other than the nominal working regime**, using both (a) **qualitative regulation** of the cycle output/load by alteration of the **steam-turbine inlet temperature** via the cycle heat input and/or (b) **quantitative regulation** of the cycle output/load by alteration of the **steam-turbine mass flow rate** using **bypassing** of the said backpressure steam turbine (**1**) via a **bypass valve** and a subsequent **external cooling** of the corresponding portion of the steam-turbine **bypass** mass flow rate using an **external water or air cooler** (**17**), up to the steam-turbine (**1**) outlet temperature existing in the **nominal** cycle working regime.

2. The configuration of the modified Rankine-cycle power-plant without cycle-heat rejection and driven by a wet-vapor-region thermocompressor of **Claim 1**, with a sole difference being the use of an **additional heat exchanger/superheater** (**6**) for isobaric heat addition to the saturated vapor (gas fraction) separated in the said cylindrical separation tank (**2**), to the end **superheating** of the saturated vapor and thus enabling the said backpressure steam turbine (**1**) to operate with **superheated steam** at its **inlet**, resulting in an **increased** steam-turbine **specific work** for the same expansion pressure ratio; whereby the said steam compressor (**18**) precedes the said additional heat exchanger/superheater (**6**) of the saturated vapor (the gas fraction separated in the said cylindrical separation tank (**2**)), which itself precedes the said backpressure steam turbine (**1**).

3. The configuration of the modified Rankine-cycle power-plant without cycle-heat rejection and driven by a wet-vapor-region thermocompressor of **Claim 1**, whereby the said **cylindrical separator/separation tank** (**2**) used for as-complete-as-possible **separation** of the wet liquid-gas (water-vapor) mixture exiting the said diffuser (**15**) of the said thermocompressor (**10**), using: (i) a **baffle-plate steam separator** having the said cylindrical separation tank (**2**) fitted with typically two (2) to three (3) **baffle plates**, which serve to change the direction of the incoming steam flow when the steam strikes the baffle plates, prompting heavier water particles contained in the steam-water mixture to fall down to the bottom of the separation tank, while the separated steam is freed from water particles and passed to the said backpressure steam turbine (**1**); or (ii) a **centrifugal/cyclone steam separator** for more turbulent flows, having the said cylindrical separation tank (**2**) fitted with at least one cyclone, which utilizes **centrifugal force** to separate water and steam from the steam-water mixture, whereby the steam-water mixture is forced to move around the cyclone and make the rotation.

4. The configuration of the modified Rankine-cycle power-plant without cycle-heat rejection and driven by a wet-vapor-region thermocompressor of **Claim 2**, whereby the said **cylindrical separator/separation tank** (**2**) used for as-complete-as-possible **separation** of the wet liquid-gas (water-vapor) mixture exiting the said diffuser (**15**) of the said thermocompressor (**10**), using: (i) a **baffle-plate steam separator** having the said cylindrical separation tank (**2**) fitted with typically two (2) to three (3) **baffle plates**, which serve to change the direction of the incoming steam flow when the steam strikes the baffle plates, prompting heavier water particles contained in the steam-water mixture to fall down to the bottom of the separation tank, while the separated steam is freed from water particles and passed to the said backpressure steam turbine (**1**); or (ii) a **centrifugal/cyclone steam separator** for more turbulent flows, having the said cylindrical separation tank (**2**) fitted with at least one cyclone, which utilizes **centrifugal force** to separate water and steam from the steam-water mixture, whereby the steam-water mixture is forced to move around the cyclone and make the rotation.

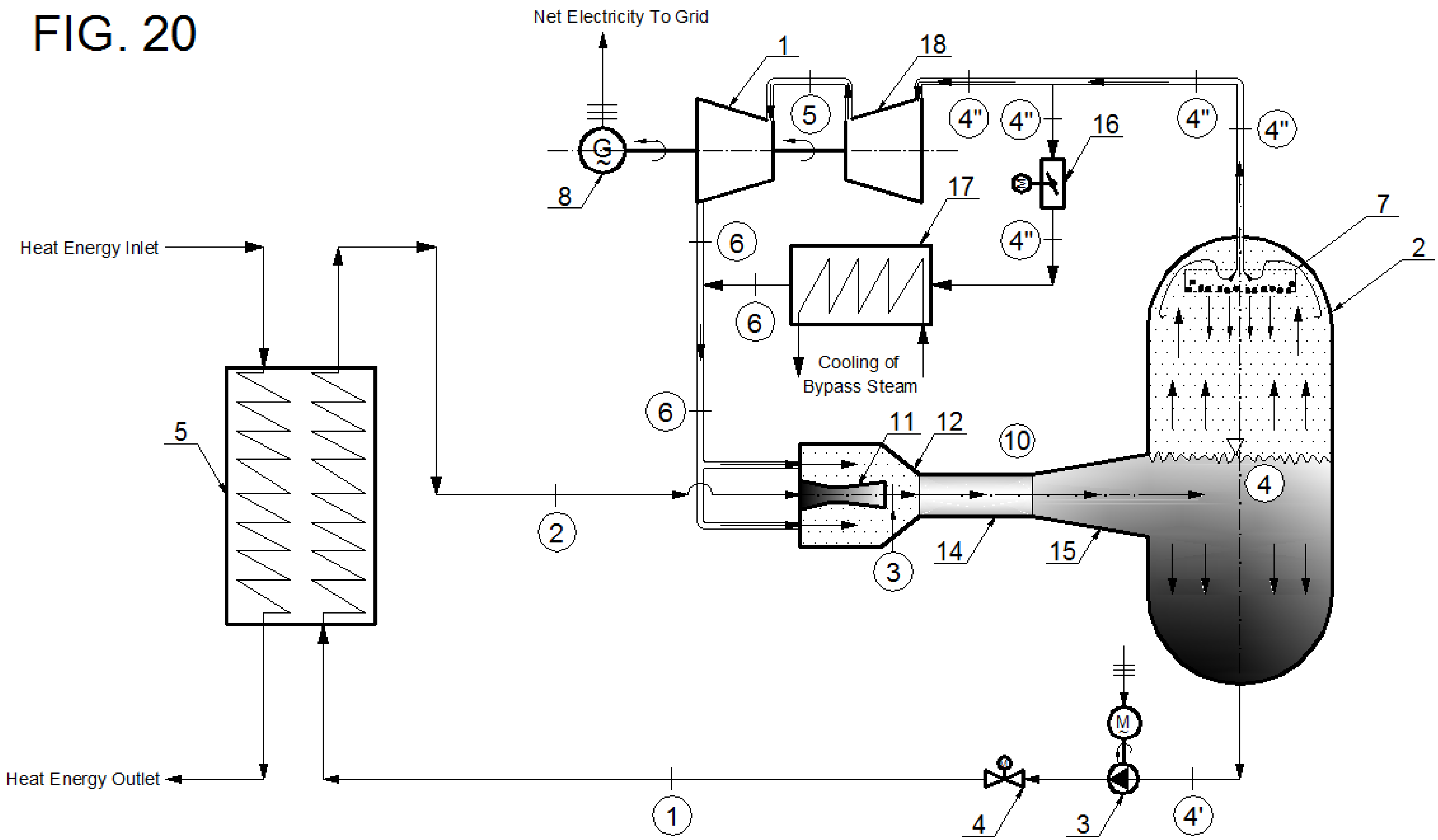
5. The configuration of the modified Rankine-cycle power-plant configuration without cycle-heat rejection and driven by a wet-vapor-region thermocompressor of **Claim 1**, which uses either of the following **heat sources** transferring the cycle heat to the said liquid/water heater (**5**) by an **indirect heat exchange**: (a) a **solid, liquid or gaseous fossil fuel** (coal, fuel oil, solid/liquid waste fuel, natural gas, synthesis gas or any other waste gas); (b) **renewable energy sources** in the form of either **Solar energy**, **biomass** or **geothermal energy**, (c) the waste heat of a **natural-gas-fired combined cycle** (**50**), or (d) any of the following types of **commercial nuclear reactors**: a light-water-moderated **pressurized-water thermal nuclear reactor** (**30**), a heavy-water-moderated **pressurized-heavy-water thermal nuclear reactor**, a light-water-moderated **boiling-water thermal nuclear reactor** (**40**), a graphite-moderated **molten salt thermal nuclear reactor**, a graphite-moderated **gas-cooled thermal nuclear reactor** (using a suitable cooling gas, such as helium, CO_2 or any suitable mixture of gases), or a **liquid-metal-cooled fast-neutron nuclear reactor**.

6. The configuration of the modified Rankine-cycle power-plant configuration without cycle-heat rejection and driven by a wet-vapor-region thermocompressor of **Claim 2**, which uses either of the following **heat sources** transferring the cycle heat both to the said liquid/water heater (**5**) and the said superheater (**6**) by an **indirect heat exchange**: (a) a **solid, liquid or gaseous fossil fuel** (coal, fuel oil, solid/liquid waste fuel, natural gas, synthesis gas or any other waste gas); (b) **renewable energy sources** in the form of either **Solar energy**, **biomass** or **geothermal energy**, (c) the waste heat of a **natural-gas-fired combined cycle** (**50**), or (d) any of the following types of **commercial nuclear reactors**: a light-water-moderated **pressurized-water thermal nuclear reactor** (**30**), a heavy-water-moderated **pressurized-heavy-water thermal nuclear reactor**, a light-water-moderated **boiling-water thermal nuclear reactor** (**40**), a graphite-moderated **molten salt thermal nuclear reactor**, a graphite-moderated **gas-cooled thermal nuclear reactor** (using a suitable cooling gas, such as helium, CO_2 or any suitable mixture of gases), or a **liquid-metal-cooled fast-neutron nuclear reactor**.

7. The configuration of the modified Rankine-cycle power-plant configuration without cycle-heat rejection and driven by a wet-vapor-region thermocompressor of **Claim 3**, which uses either of the following **heat sources** transferring the cycle heat to the said liquid/water heater (**5**) by an **indirect heat exchange**: (a) a **solid, liquid or gaseous fossil fuel** (coal, fuel oil, solid/liquid waste fuel, natural gas, synthesis gas or any other waste gas); (b) **renewable energy sources** in the form of either **Solar energy**, **biomass** or **geothermal energy**, (c) the waste heat of a **natural-gas-fired combined cycle** (**50**), or (d) any of the following types of **commercial nuclear reactors**: a light-water-moderated **pressurized-water thermal nuclear reactor** (**30**), a heavy-water-moderated **pressurized-heavy-water thermal nuclear reactor**, a light-water-moderated **boiling-water thermal nuclear reactor** (**40**), a graphite-moderated **molten salt thermal nuclear reactor**, a graphite-moderated **gas-cooled thermal nuclear reactor** (using a suitable cooling gas, such as helium, CO_2 or any suitable mixture of gases), or a **liquid-metal-cooled fast-neutron nuclear reactor.**

8. The configuration of the modified Rankine-cycle power-plant configuration without cycle-heat rejection and driven by a wet-vapor-region thermocompressor of **Claim 4**, which uses either of the following **heat sources** transferring the cycle heat both to the said liquid/water heater (**5**) and the said superheater (**6**) by an **indirect heat exchange**: (a) a **solid, liquid or gaseous fossil fuel** (coal, fuel oil, solid/liquid waste fuel, natural gas, synthesis gas or any other waste gas); (b) **renewable energy sources** in the form of either **Solar energy**, **biomass** or **geothermal energy**, (c) the waste heat of a **natural-gas-fired combined cycle** (**50**), or (d) any of the following types of **commercial nuclear reactors**: a light-water-moderated **pressurized-water thermal nuclear reactor** (**30**), a heavy-water-moderated **pressurized-heavy-water thermal nuclear reactor**, a light-water-moderated **boiling-water thermal nuclear reactor** (**40**), a graphite-moderated **molten salt thermal nuclear reactor**, a graphite-moderated **gas-cooled thermal nuclear reactor** (using a suitable cooling gas, such as helium, CO_2 or any suitable mixture of gases), or a **liquid-metal-cooled fast-neutron nuclear reactor**.

FIG. 20



Net Electricity To Grid
1
18
5
4"
4"
16
4"
4"
8
17
4"
7
2
Heat Energy Inlet
6
6
Cooling of
Bypass Steam
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Heat Energy Outlet
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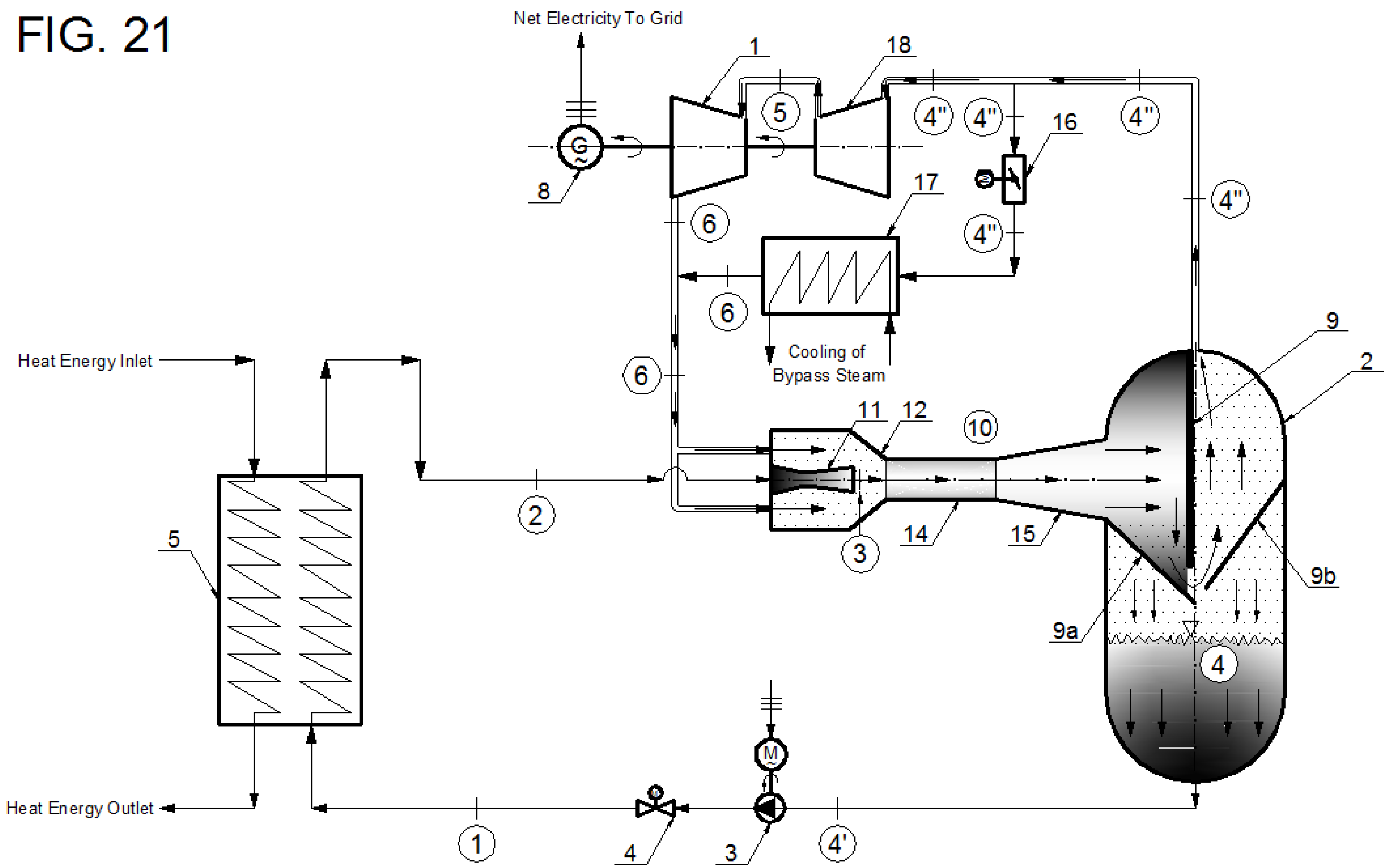
FIG. 21



Net Electricity To Grid
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Heat Energy Inlet
Cooling of
Bypass Steam
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Heat Energy Outlet
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FIG. 22

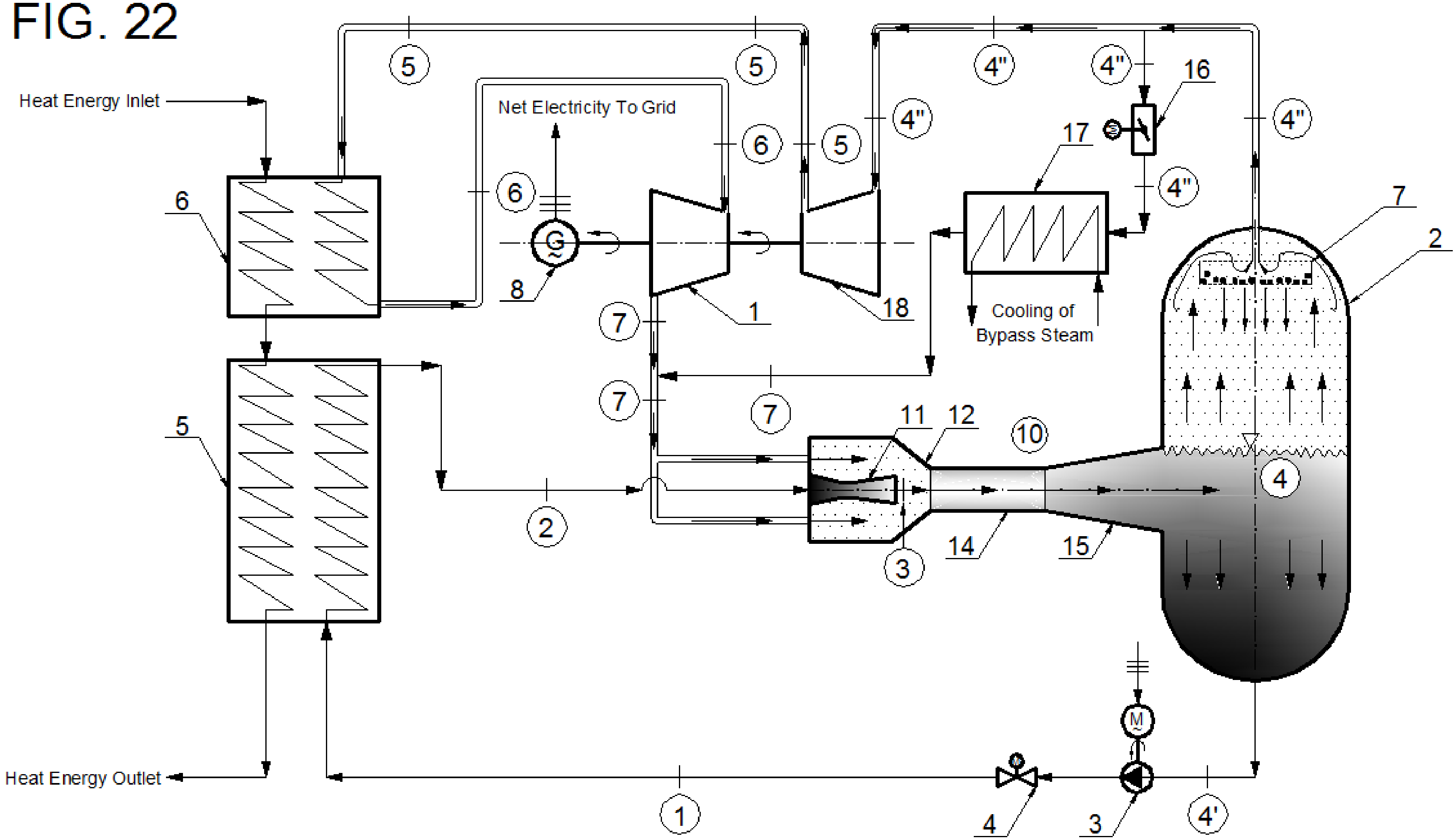
Heat Energy Inlet
Net Electricity To Grid
Cooling of
Bypass Steam
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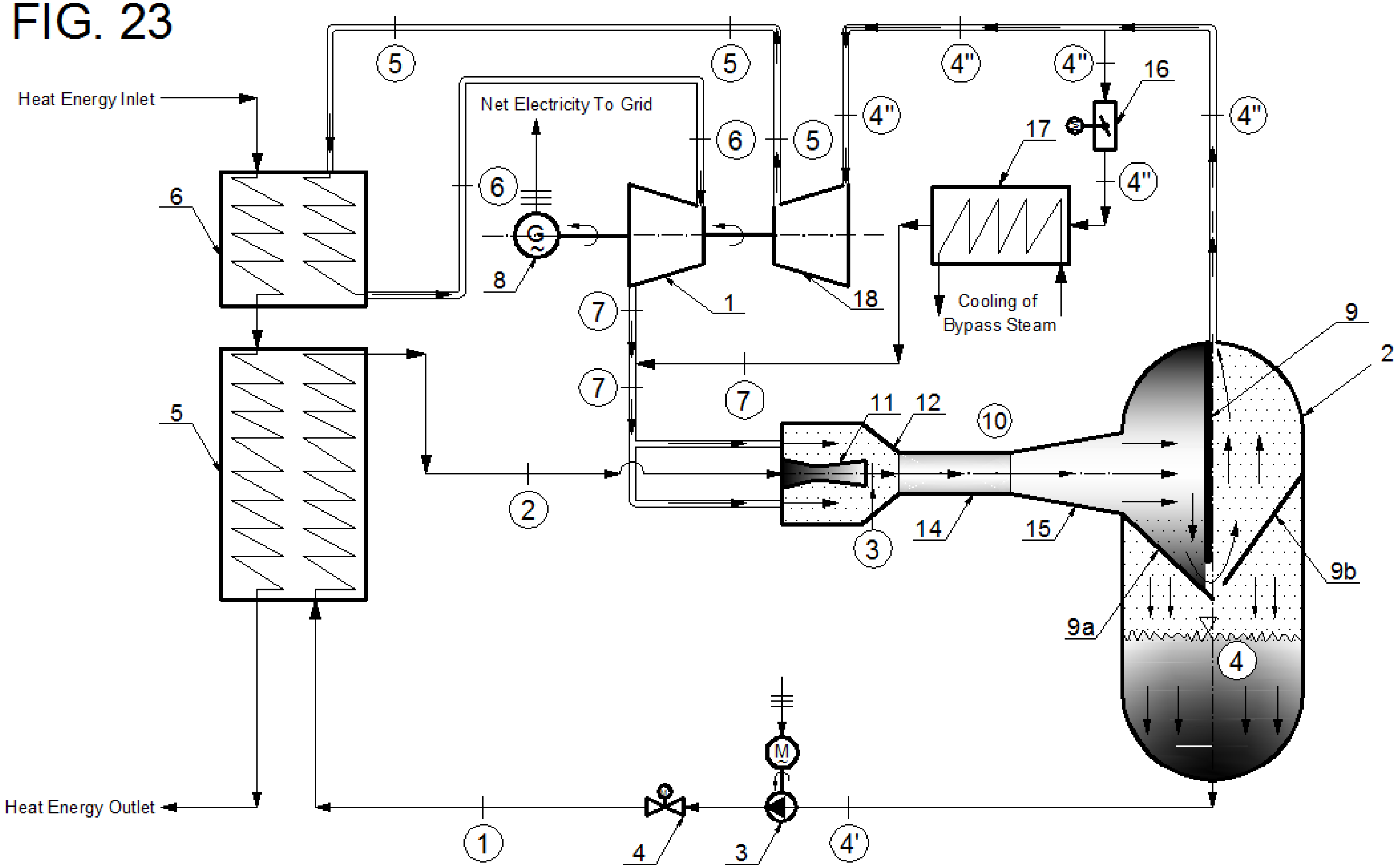
FIG. 23


Heat Energy Inlet
Net Electricity To Grid
Cooling of Bypass Steam
Heat Energy Outlet
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9b
9a
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