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(54) **Gasification plant, in particular for methane, comprising a Stirling engine**

(57) A gasification plant (1) of a combustible gas in liquid state in general, and of liquid methane in particular, which achieves unusually compact dimensions, impeccable ecological behaviour, and improved energy balance, comprises a fluid path (5) extending between a tank (3a) containing the gas in liquid state, for example a tank of a methane-tanker (3), and a tank (4a) containing the gas in gasified state, for example a gasholder (4a) of

a storage station (4), a Stirling engine with respective cold cylinder and hot cylinder arranged along said path, and a heat exchanger arranged along said path and crossed by the fluid, said heat exchanger being in heat exchange relationship with said cold cylinder and substantially thermally insulated from the environment, so as to maintain the cold cylinder at a temperature much below then the ambient temperature, with recovery and transformation of the latent heat into mechanical energy.

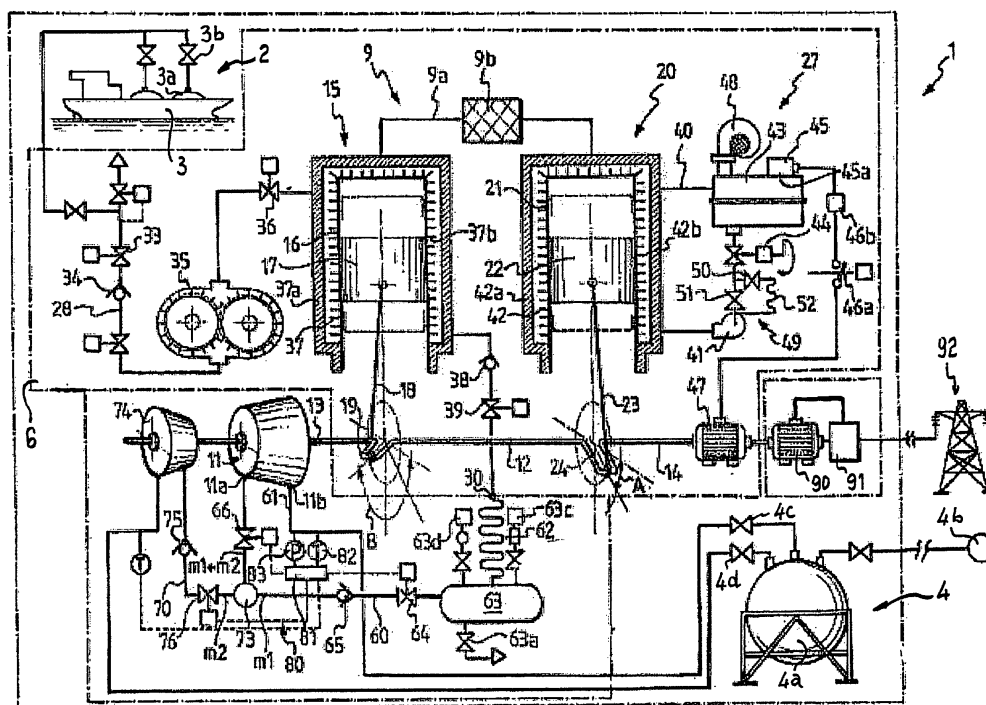


FIG. 1

Description

Field of application

[0001] The present invention refers to a gasification plant, or gasifier, of a gas in liquid state in general, and of liquid methane in particular, of the type comprising a fluid path extending from a tank containing the gas in liquid state, for example a tank of a methane-tanker, to a tank containing the gas in gasified state, for example a gasholder, and gasification means of the gas in liquid state arranged along said path.

Background of the invention

[0002] Known plants of the specified type comprise a fluid path, extending from a tank containing the gas in liquid state, for example a tank of a methane-tanker, to a tank, for example a gasholder, containing the gas in gasified state in conditions suitable for sending it to a distribution network, as well as gasification means provided along said fluid path.

[0003] In accordance with the prior art the gasification means consist of heat exchangers that are crossed by the gas in liquid state to put it in heat exchange relationship with the environment, so as to cause its gasification. In these plants the heat exchangers reach very large sizes, with all of the drawbacks that follow. It has been suggested to support the heat exchangers with appropriate ovens, arranged along the fluid path and crossed by the gas in liquid state, in order to promote its gasification, by means of the combustion of a fraction of the gas coming out from the plant itself. A reduction in size of the heat exchangers has thus been obtained, but the plant has become more complicated. Moreover, it must be observed an energy yield worsening of the plant itself since a part of the gas arriving at the plant is burnt in the environment of the plant itself without being able to reach the distribution network.

[0004] The problem underlying the present invention is that of devising a plant of the type specified that has structural and functional characteristics such as to overcome the cited drawbacks with reference to plants of the

prior art.

Summary of the invention

[0005] The idea of solution forming the basis of the present invention is to exploit the energy relative to the change in state as mechanical energy.

[0006] Based upon such an idea of solution and to solve the aforementioned technical problem the present invention provides a gasification plant, or gasifier, of the type specified above, which is **characterised in that** said gasification means comprise a Stirling engine, with respective so-called cold cylinder and so-called hot cylinder, as well as a heat exchanger arranged along said

fluid path and crossed by said fluid, said heat exchanger being in heat exchange relationship with said cold cylinder, so as to maintain the cold cylinder at a temperature much lower than the ambient temperature, with transformation of the latent heat relative to the change in state from gas in liquid state to gas in compressed state, into useful kinetic mechanical energy.

[0007] Advantageously the gasification plant comprises an electric generator actuated by the Stirling engine for the transformation of said useful kinetic mechanical energy into electric energy intended for a distribution network.

[0008] Further characteristics and advantages of the gasifier according to the present invention shall be observed from the following description of an example embodiment thereof given as indicative and not limiting purposes, with reference to the attached figure.

Detailed description of the figure

[0009] The attached single figure 1 represents a schematic view of a gasifier according to the invention.

Detailed description of the invention

[0010] With reference to the attached figure, a gasification plant, or gasifier, for the gasification of a gas, for example methane, from liquid state to gas state is globally and schematically indicated with 1.

[0011] In particular, the plant comprises a mooring station 2 of a methane-tanker 3, provided with tanks 3a of liquid methane.

[0012] The plant also comprises a storage station 4 of the methane in gas state, comprising a tank or gasholder 4a connected to a distribution network 4b of the methane to the users.

[0013] The gasifier comprises a fluid path globally indicated with 5, extending from the tank 3a to the gasholder 4a. Along the path 5 gasification means 6 are arranged that shall be described below.

[0014] In particular, the path 5 is subdivided into a duct 28 extended between the tank 3a and a connection 30, into a duct 60, 61 extended between the connection 30 and the gasholder 4a. Along the duct 28 there are the gasification means 6, which are in the form of a Stirling engine 9.

[0015] The Stirling engine 9, which has a cylinder-piston unit 15, with a cylinder 16, the so-called cold cylinder, and a piston 17, acting through a connecting rod 18 and crank 19 on a crankshaft 12, as well as a cylinder-piston unit 20, with a cylinder 21, the so-called hot cylinder, and a piston 22, acting through a connecting rod 23 and crank 24, on the crankshaft 12.

[0016] The two cylinder-piston units 15 and 20 are arranged with their axes parallel and the relative connecting rods are connected to cranks angularly spaced by 90°. In particular, indicating the angular phase of the crank 24 of the cylinder-piston unit 20 with A and indicating the

angular phase of the crank 19 of the cylinder-piston unit 15 with B, the two angular phases are in a 90° angular relationship ($B-A=90^\circ$). It is also possible to arrange the two cylinder-piston units with their axes perpendicular. In this case, the two connecting rods are connected to a single crank (or two angularly coinciding cranks). It is also possible to arrange the two cylinder-piston units collinear, that is, with the respective axes coinciding in a single axis.

[0017] The Stirling engine 9 also comprises thermal means 25, provided to maintain the two cylinders 16 and 21 at a predetermined temperature difference. Indeed, it is thanks to this temperature difference maintained between the cylinders that the Stirling engine operates.

[0018] The thermal means 25 comprise cooling means 26 associated with the cylinder 16, the so-called cold cylinder, to maintain it at a temperature much lower than ambient temperature, and heating means 27, associated with the cylinder 21, the so-called hot cylinder, to maintain it at a temperature much greater than the ambient temperature.

[0019] The cooling means 26 comprise the fluid duct 28, extending from the tank 3a up to the connection 30. The tank 3a is equipped with a gate valve 3b.

[0020] It should be noted that instead of methane it is possible to use any combustible gas and/or mixtures of combustible gases, without for this reason departing from the scope of protection of the invention.

[0021] A gate valve 33, a check valve 34, suitable for preventing the reflow of the fluid into the tank 3a, a pump 35, of the cryogenic type, actuated by an electric motor not shown, a gate valve 36, a heat exchanger 37, arranged around the cylinder 16, so as to put the fluid, i.e. the liquid methane, in heat exchange relationship with the cylinder itself, a check valve 38, suitable for preventing the reflux of the fluid into the exchanger 37 and another gate valve 39 are arranged along the fluid duct 28. Such elements follow one another along the duct 28 in the same order with which they have been listed starting from the tank 3a up to the connection 30.

[0022] The heat exchanger 37 on the side facing the outwards is equipped with heat insulation 37a, to avoid the passage of heat from the environment to the exchanger, whereas on the side facing the cylinder 16 it is equipped with finings 37b to facilitate the heat exchange with the fluid contained in the cylinder.

[0023] It should be noted that the cryogenic pump 35 is adjustable for speed, through an appropriate adjustment of the electric actuation motor, to adjust the speed of the Stirling engine.

[0024] The heating means 27 comprise a closed circuit 40 of a thermoconvector fluid, for example demineralised water. Along the circuit 40 there are a circulation pump 41, actuated by an electric motor not shown, a heat exchanger 42, arranged around the cylinder 21, so as to put the thermoconvector fluid, i.e. the demineralised water, in heat exchange relationship with the cylinder itself, a tank 43, and a gate valve 44 of the proportional type.

For the heating of the demineralised water a heater 45 is provided, advantageously a microwave heater, known under the commercial name magnetron 45a, fed, through a remote control switch 46a, and a regulator 46b, by an electric generator 47 actuated by the crankshaft 12. In order to maintain the water contained in the tank 43 stirred, a stirrer, not shown, is provided, which is driven by an electric motor not shown. A fan 48 is provided to serve the magnetron 45a.

[0025] The electric generator 47 supplies energy to the electric motors of the cryogenic pump 35, of the circulation pump 41 and to the electric motor of the agitator and of the fan.

[0026] The heat exchanger 42 on the side facing the outwards is equipped with heat insulation 42a to avoid the passage of heat from the exchanger to the outside, whereas on the side facing the cylinder 21 it is equipped with finings 42b to facilitate the heat exchange with the fluid contained in the cylinder.

[0027] In the closed circuit 40, between the proportional gate valve 44 and the pump 41, a deviation 49, which can be activated with suitable control of gate valves 50 and 51 is preferably provided, a heat exchanger 52 being provided on said deviation, to put the demineralised water in heat exchange relationship with the environment.

[0028] The Stirling engine is completed with a duct 9a extending between the cylinders 15 and 20 for the alternating transfer from one to the other of the fluid contained in the cylinders. Such a fluid is a pressurised gas, for example helium at 140 atm. Along the duct 9a, there is a finely divided metallic material 9b, with regeneration function.

[0029] In order to recovery the mechanical pressure energy of the methane coming out from the Stirling engine, the gasifier according to the invention comprises a piston engine 11, with a respective crankshaft 13, collinear to the drive shaft 12, to constitute a single shaft 14.

[0030] The piston engine 11 is fed with compressed methane through the supply duct 60 and sends the methane through the duct 61 to the gasholder 4a of the storage station 4.

[0031] In the piston engine 11 the compressed methane expands substantially like an elastic spring and is sent to the gasholder at each stroke. Substantially, there is a yield that is equal to the mechanical yield of a spring, i.e. substantially unitary in the absence of friction.

[0032] The supply duct 60 extends from the connection 30 up to an inlet mouth 11a of the engine 11. Along the supply duct 60 there area heat exchanger 62, in heat exchange relationship with the environment, a rest chamber 63, an electrically driven gate valve 64, a check valve 65 and an electrically driven gate valve 66.

[0033] The rest chamber 63, of suitable volume, is equipped with a discharge tap 63a, with a thermometer 63c and with a manometer 63d.

[0034] The discharge duct 61 extends between a discharge mouth 11b of the engine 11 and the gasholder 4 through a gate valve 4c.

[0035] It should be noted that the piston engine 11 can be any known alternating or rotary volumetric motor, but also any rotary flow motor, for example a turbine.

[0036] An auxiliary supply duct 70 is provided which extends between the gasholder 4a, through an on-off valve 4d, and a connection 73 that is arranged along the supply duct 60, in a position located between the check valve 65 and the gate valve 66.

[0037] Along the duct 70 act a compressor 74, actuated by the shaft 14, a check valve 75 and an electrically driven gate valve 76.

[0038] It should be noted that the compressor 74 can be of the type using pistons or of the flow type, for example a turbocompressor.

[0039] In order to obtain an output of an emission of methane at a suitable pressure and temperature and suitable for the storage station, automatically, a closed loop control circuit is provided for, globally indicated with 80, to control the electrically driven gate valves 64, 66, 76. The circuit, *per se* conventional, comprises a control unit 81 fed with the desired values for the pressure and temperature of the fluid coming out from the engine 11, also fed with the actual temperature and pressure values measured by thermometers 82 and 84 and by manometers 83, or more precisely by appropriate transducers, suitable for comparing said actual values with the desired values and consequently for controlling the gates valves with the differential values.

[0040] On the shaft 14 an electric generator 90 is fitted, connected to an electric cabinet 91, to dispense electric energy to a distribution network 92.

[0041] The operation is described below. The methane is contained in the tank 3a in liquid state and is conserved at atmospheric pressure and at a temperature of about -98°C.

[0042] The methane is taken from the tank 3a along the duct 28 by the cryogenic pump 35 in a predetermined amount m1, variable with the speed of the cryogenic pump 35, as necessary for the operation of the Stirling engine on the cold cylinder side, and it is transferred at a desired pressure, preferably 120 bar absolute, into the heat exchanger 37.

[0043] In the exchanger 37, the methane gasifies, i.e. it changes state passing from liquid state to compressed gas state. During such a gasification step it receives the vaporisation energy from the helium gas contained in the cylinder 16. Consequently, the helium contained in the cylinder 16 cools down.

[0044] In this way, the cylinder 16 is maintained at a temperature much lower than the ambient temperature. The methane that has become gaseous leaves the exchanger 37 through the duct 28 pushed by the new liquid methane injected through the cryogenic pump 35 into the exchanger 37, again through the duct 28 up to the connection 30. The cryogenic pump 35 transmits the pulse energy necessary to raise the pressure up to 120 bars absolute to the liquid methane and produces the transportation motion of the methane along the duct 28, thus

through the exchanger 62 until the rest chamber 63 is reached.

[0045] In the closed circuit 40 demineralised water is put in circulation, heated by the magnetron 45a at a temperature preferably of 180°C. Travelling in the exchanger 42, the hot water gives off heat and determines the heating of the helium gas contained in the cylinder 21. In this way, the helium is taken to a temperature much higher than the ambient temperature.

[0046] It should be noted that in the case in which the magnetron is not activated, a circulation of water is nevertheless maintained in the branch 49, thanks to the suitable manoeuvring of the gate valves 50 and 51. In this way, the water travels through the heat exchanger 52 in heat exchange relationship with the environment, in such a way maintaining the temperature of the helium gas in the hot cylinder substantially equal to the ambient temperature. In both cases a temperature difference is produced between cold cylinder 16 and hot cylinder 21. In the first case the difference would be of 218°C whereas in the second case the temperature difference would be of about 110 °C.

[0047] In both cases, thanks to the aforementioned temperature difference between cold cylinder and hot cylinder, the Stirling engine is able to operate with the alternating transfer of the helium gas between the two cylinders and with delivery of mechanical energy to the crankshaft 12.

[0048] It should be noted that the Stirling engine thus provides kinetic mechanical energy, corresponding to the latent heat relative to the change in state from liquid state to compressed gas state, and it also provides compressed methane substantially at a temperature of -98°C to the connection 30, intended for the piston engine 11.

[0049] As far as the piston engine 11 is concerned, the compressed methane provided to the connection 30 is pushed to cross the heat exchanger 62 that is in heat exchange relationship with the atmosphere and therefore its temperature substantially increases until it approaches the atmospheric temperature.

[0050] The methane is thus injected into the rest chamber 63. Here, as the methane stops, the reconversion of all of the pulse and kinetic energy received through the cryogenic pump 35 into internal energy takes place, reaching an average temperature of 70°C. The pressure of the methane in the rest chamber 63 is substantially 120 bars absolute.

[0051] The compressed methane at this point contains sufficient potential energy to supply again mechanical energy. The compressed methane through the duct 60 feeds the engine 11 from which it is discharged through the duct 61. The methane in the engine 11 gives off internal energy and such internal energy, substantially elastic energy, turns into useful mechanical energy on the crankshaft 13.

[0052] In other words, the mechanical energy of the pressurised gas turns into kinetic mechanical energy delivered to the crankshaft. The yield of this transformation

is that of a passage of energy from mechanical energy into mechanical energy that, in the absence of friction, would be unitary, and, depending only upon friction, may even reach 0.98.

[0053] In order to avoid the discharge towards the gasholder of the methane that has worked in the engine 11 taking place at a low temperature (even -90°C), the compressed methane that arrives from the rest chamber 63 in the connection 73 is added to the compressed methane from the compressor 74 in an amount m_2 , coming from the same gasholder, through the auxiliary duct 70.

[0054] The compressor 74, compressing the methane taken from the gasholder up to 120 bar absolute, sends it to the connection 73 at a temperature of about 400°C . In this connection the mixing of the two amounts m_1 and m_2 of methane takes place. The methane resulting from the mixture (m_1+m_2) shall have a temperature close to 300°C , according to the value selected for m_2 . Therefore, the mixture (m_1+m_2) will allow the engine 11 to discharge the methane towards the gasholder at not less than -20°C : this being a value that is compatible with the requirements of the gasholder.

[0055] It should be noted that the temperature and pressure coming out from the piston engine 11 are constantly monitored through the temperature and pressure transducers 82, 83. Similarly, a transducer 84 is provided that measures the temperature in the duct 70 at the inlet of the compressor 74. The signals in output from the transducers are sent constantly to a control unit 81 that compares it with reference signals to emit control signals to the valve 64 that controls the flow rate m_1 and to the valve 76 that also controls the flow rate m_2 .

[0056] The present invention provides, more generally, a method for transforming the latent heat of methane, or of another combustible gas, in liquefied state into usable mechanical energy, for example, to generate electric energy. This method comprises the step of put the methane or other gas or mixture of gases in liquid state in heat exchange relationship with the so-called cold cylinder of a Stirling engine, for example connected with an electric generator.

[0057] The main advantage of the present invention lies in the fact that it provides a gasifier of unusually compact size, with impeccable ecological behaviour, and improved energy balance.

[0058] Of course, a man skilled in the art can bring numerous modifications and variants to the gasifier and to the method described above, in order to satisfy contingent and specific needs, all of which, however, fall within the scope of protection of the present invention, as defined by the following claims.

Claims

1. Gasification plant (1) of a combustible gas in liquid state in general, and of liquid methane in particular, of the type comprising a fluid path (5) extending be-

tween a tank (3a) containing the gas in liquid state, for example a tank of a methane-tanker (3), and a tank (4a) containing the gas in gasified state, for example a gasholder (4a) of a storage station (4), and gasification means of the gas arranged along said path, **characterised in that** said gasification means comprise a Stirling engine with respective cold cylinder and hot cylinder, and a heat exchanger arranged along said path and crossed by the fluid, said heat exchanger being in heat exchange relationship with said cold cylinder and substantially thermally insulated from the environment, so as to maintain the cold cylinder at a temperature much lower than the ambient temperature, with recovery and transformation of the latent heat into mechanical energy.

2. Gasification plant according to claim 1, **characterised in that** it comprises an electric generator actuated by the Stirling engine, with transformation of the mechanical energy into electric energy to be sent into a distribution network.

3. Gasification plant according to claim 1 or 2, **characterised in that** it comprises a further heat exchanger, in communication with a tank of a hot fluid serving a magnetron and in heat exchange relationship with said hot cylinder.

4. Gasification plant according to claim 1, 2 or 3, **characterised in that** said heat exchanger (37) is thermally insulated from the environment.

5. Gasification plant according to claim 3 or 4, **characterised in that** said further heat exchanger (42) is thermally insulated from the environment.

6. Gasification plant according to claim 4 or 5, **characterised in that** said tank (43) of a hot fluid is interlocked to a heater (45).

7. Gasification plant according to claim 6, **characterised in that** the heater (45) is a magnetron (45a).

8. Gasification plant according to any one of claims 4 to 7, **characterised in that** it comprises a deviation (49) on a circuit (40) crossed by said hot fluid and a heat exchanger (52) along said deviation (49) in heat exchange relationship with the environment.

9. Gasification plant according to any one of the previous claims, **characterised in that** it comprises a volumetric or flow motor (11) fed with compressed methane coming out from the Stirling engine (9).

10. Gasification plant according to claim 9, **characterised in that** the Stirling engine (9) and the volumetric or flow motor (11) are connected to respective crankshafts (12, 13) for controlling an electric generator

(90).

11. Gasification plant according to claim 9 or 10, **characterised in that** it comprises a rest chamber (63), of predetermined volume, arranged on a supply duct (60) of the volumetric or flow motor (11). 5
12. Gasification plant according to claims 9 to 11, **characterised in that** it comprises an auxiliary supply duct (70) for said volumetric or flow motor (11), to feed it with methane taken from the gasholder in a predetermined amount and taken to a predetermined temperature and pressure by a compressor (74). 10
13. Method for transforming the latent heat of a combustible gas in liquid state in general and of liquid methane in particular into useful mechanical energy, **characterised in that** it comprises the step of putting the gas in liquid state in heat exchange relationship with the cold cylinder of a Stirling engine. 15 20

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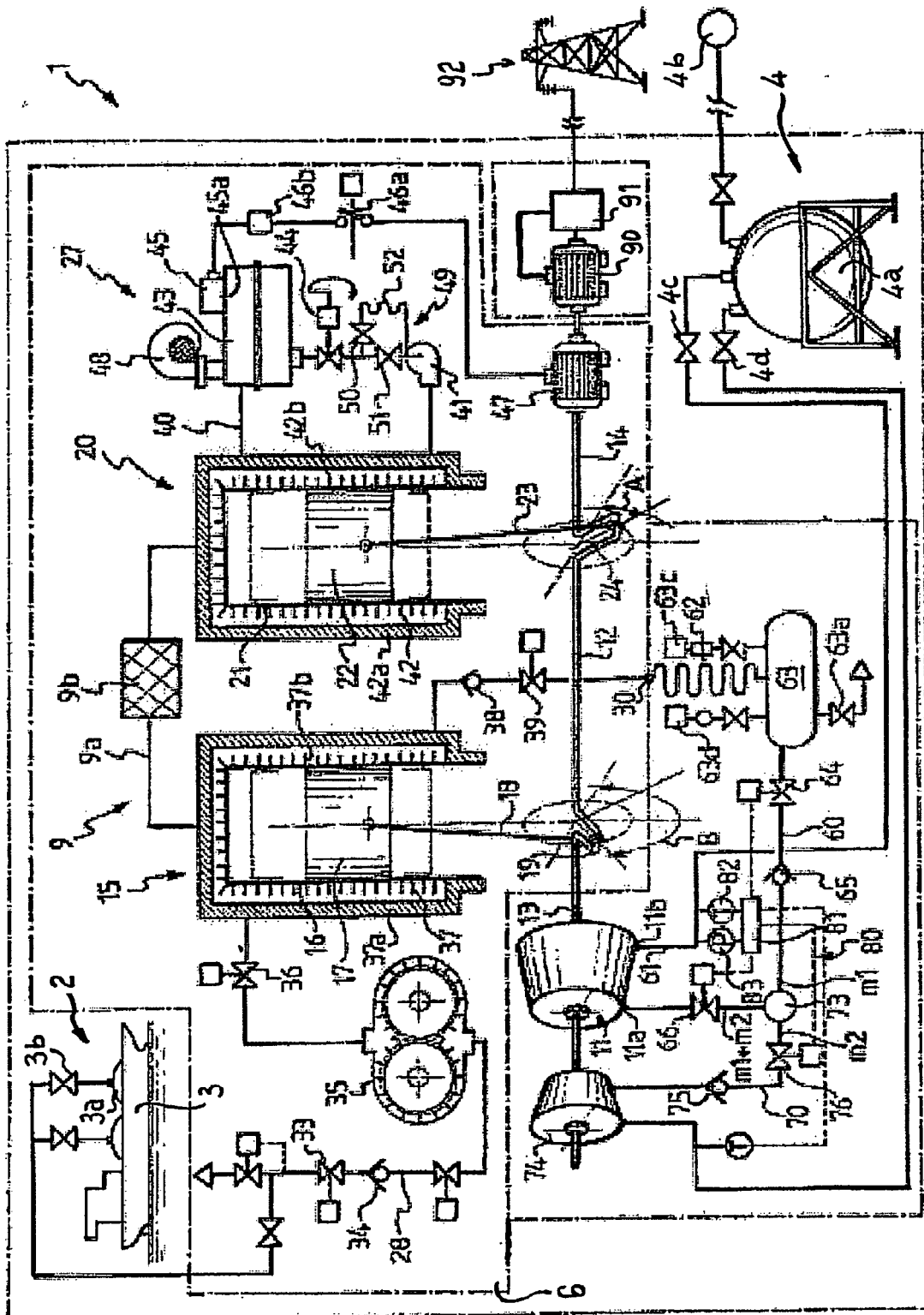


FIG. 1



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Application Number
EP 08 42 5357

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