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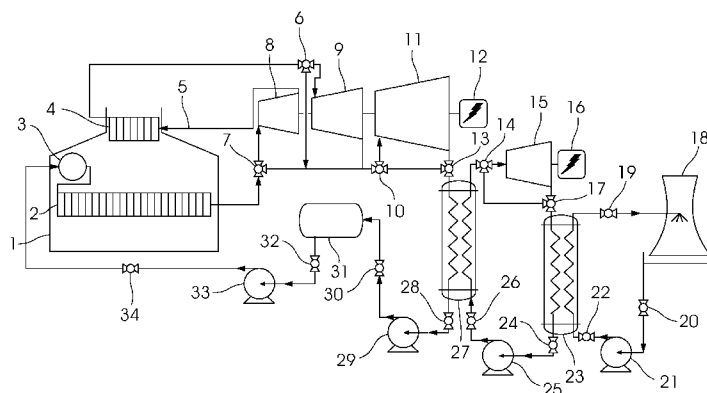


FIGURE 1

(57) Abstract: The invention relates to an apparatus and a method for generating power by combining a conventional, coal-fuelled Rankine power generation Cycle with an Organic Rankine power generation Cycle. The condenser of the conventional Rankine Cycle is a heat exchanger (27) providing the boiler for the Organic Rankine Cycle.

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**APPARATUS AND METHOD FOR ELECTRICAL
POWER PRODUCTION**

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FIELD OF THE INVENTION

This invention relates to apparatus and a method for use with a coal-fuelled Rankine power generation Cycle to produce increased usable electrical power from the input energy and in a manner which will increase the overall plant efficiency.

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BACKGROUND TO THE INVENTION

Current power production, particularly that utilizing fossil fuels, such as coal, and water as a working fluid, involves a significant amount of energy that goes to waste in conventional Rankine Cycle power stations. This is due to the required condensation of steam at the bottom of the cycle.

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This method of power generation is not completely efficient and can be improved upon.

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OBJECT OF THE INVENTION

It is the object of the present invention to create a higher efficiency cycle for power production, by utilizing at least some of the energy dissipated by the steam from the coal fired Rankine Cycle as it condenses.

SUMMARY OF THE INVENTION

According to this invention there is provided a plant for generating power by combining a conventional, coal-fuelled Rankine power generation Cycle with an Organic Rankine power generation Cycle and wherein a condenser of the conventional Rankine Cycle is a heat exchanger providing the boiler for the Organic Rankine Cycle.

The invention further provides for the working fluid in the Organic Rankine Cycle to be a hydrocarbon, preferably a nonflammable refrigerant; and for the hydrocarbon working fluid to be heated to a superheated state in the heat exchanger.

Further features of the invention provide for the superheated hydrocarbon working fluid to drive multiple turbines each with its own generator; and for the turbines to be expansion turbines of either radial or axial design.

Further features of the invention provide for the hydrocarbon working fluid to be condensed in a condenser using a wet cooling process, or using a dry cooling process selected from direct or indirect dry cooling, or using a wet cooling process wherein heat is transferred to water from an external natural source. The condenser will be of a plate design or shell and tube design with the cooling medium being water or air (or some other suitable fluid). In the case where the condenser would be a fluid to air condenser, the design would be of a fin and

tube design which can either be cooled using fans or natural cooling using cooling towers. In the case of water-cooling, the heat exchanger is to be a high volume exchanger.

- 5 Further features of the invention provide for multiple control valves to be placed between the different components of the plant to control the flow of working fluid for the two cycles; for the plant to be adapted for the primary steam Rankine Cycle turbines to be totally or partially bypassed and/or for the Organic Rankine Cycle turbines to be individually or totally bypassed.

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The invention further provides for a control system to control and monitor the combined cycles; and for the cycles to be throttled by controlling the load on the generators; and for the load on the generators to be controlled through the control valves and pump speeds on return pumps for both cycles.

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A further feature of the invention provides for the plant to include a hydrocarbon working fluid preheating heat exchanger to transfer energy from the heated hydrocarbon working fluid before it enters the condenser to the hydrocarbon working fluid entering the primary heat exchanger.

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A further feature of the invention provides for the plant to include a water preheating heat exchanger to transfer energy from the heated hydrocarbon working fluid, before it enters the condenser, to the water before it enters the steam drum.

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A water preheating heat exchanger is used to transfer energy from the steam from a high pressure cycle, in the steam turbine bypass circuit to the water before it enters the steam drum.

A further aspect of the invention provides for the conventional Rankine Cycle and/or Organic Rankine Cycle equipment to be provided in modular packs, or custom designed to the conditions found within the specific application or area.

- 5 According to a still further aspect of this invention there is provided a method of generating power by combining a conventional, coal-fuelled Rankine power generation Cycle with an Organic Rankine power generation Cycle.

10 The invention also provides for the condenser for the conventional Rankine Cycle to be used as the boiler for the Organic Rankine Cycle; and for the boiler to be a heat exchanger.

15 Further features of the invention provide for the flow of working fluid for the two cycles to be controlled using multiple control valves in working fluid lines; and for primary steam Rankine Cycle turbines to be totally or partially bypassed and/or for Organic Rankine Cycle turbines to be individually or totally bypassed.

20 Further features of the invention provide for the combined cycles to be controlled and monitored and for the cycles to be throttled by controlling the load on the generators; and for the load on the generators to be controlled through the control valves and pump speeds on return pumps for both cycles.

25 Further features of the invention provide for the transfer of energy from the heated hydrocarbon working fluid before it enters a condenser to the hydrocarbon working fluid entering the primary heat exchanger or to the water before it enters the steam drum.

BRIEF DESCRIPTION OF THE DRAWING

30 One embodiment of the invention is described below with reference to the accompanying drawing in which -

Figure 1: shows the schematic view of a complete combined cycle of the power generation system.

5 **DETAILED DESCRIPTION OF THE INVENTION**

Referring to Figure 1, apparatus in the form of a power plant for the generation of electrical power to be fed into an existing or a new power grid or to be used by a local power station's grid will include the illustrated components, which are
10 discussed together with other features below.

The invention relates to a method of generating power by combining a conventional, coal-fuelled Rankine power generation Cycle with an Organic Rankine power generation Cycle. This method will also be understood from the
15 description of the plant that follows.

The generator system for the primary, conventional Rankine Cycle will have a boiler assembly (1), which is coal or partially coal fired. This will boil the water in a steam drum (3), which is then superheated in the steam super-heaters (2) of
20 the boiler (1).

The superheated steam is used to drive a high pressure steam turbine (8). The steam returns from the high pressure steam turbine (8) to be reheated in the steam re-heaters (4) via the return steam line (5). The reheated steam is then fed
25 back to the intermediate pressure turbine (9) and then on to the low pressure turbine (11). The turbine set (8), (9) and (11) will drive a main generator (12) via a common shaft.

The working fluid in the Organic Rankine Cycle is a hydrocarbon, preferably a
30 nonflammable refrigerant. The invention provides for the condenser of the conventional Rankine Cycle to provide the boiler for the Organic Rankine Cycle.

This is achieved through heat exchanger (27). The heat exchanger (27) will be a high volume exchanger of either a shell and tube or plate design.

On exiting the low pressure turbine (11) the steam is thus used to heat the hydrocarbon working fluid of the Organic Rankine Cycle in a condensing hot well of the heat exchanger (27). The steam turbine set (8), (9) and (11) can also be partially or totally bypassed by the steam turbine bypass and control circuit made up of the relevant lines and control valves (6), (7), (10) and (13). This enables bypassing of the turbines and for the steam to go directly into heat exchanger (27) from the boiler (1).

The heat exchanger (27) is of a counter or cross flow type. The steam will condense therein, enabling the latent heat of condensation to heat the hydrocarbon working fluid to a superheated state.

The condensed and cooled water is pumped from the hot well of the heat exchanger (27) back into the boiler feeder tank (31) by the water feed pump (29). From the boiler feeder tank (31) it is pumped back into the boiler steam drum (3) by the boiler feed pump (33).

Water feed pump (29) and control valves (28) and (30) will control the flow rate of condensed water back to the boiler feed water tank (31). The boiler feed pump (33) and control valve (34) will control the water flow rate to the steam drum (3).

The superheated hydrocarbon working fluid will be used to drive Organic Rankine Cycle turbines (15). The turbines (15) may be expansion turbines of either radial (centrifugal) or axial flow design.

The superheated hydrocarbon working fluid may drive either single or multiple turbines (15). While only a single turbine (15) is shown, it may be preferable to have more than one such component.

Each Organic Rankine Cycle turbine (15) will in turn drive a generator (16) to produce electrical power. The generators (16) will either be direct current or alternating current and may be driven through a step down gearbox (not shown) or directly.

The process converts the thermal and pressure energy contained in the heated hydrocarbon working fluid to rotation kinetic energy of the turbine (15) which is in turn converted to electricity by the generators (16).

After exiting the Organic Rankine Cycle turbines (15), the hydrocarbon working fluid will be condensed in a water-cooled condenser (23). After it is condensed, the hydrocarbon working fluid will be pumped back into the heat exchanger (27) by the hydrocarbon working fluid feed pump (25).

As already mentioned, the steam turbine bypass and control circuit will allow for the total or partial bypass of the steam turbine sets (8), (9) and (11). Alternatively, bypass of the intermediate (9) and low pressure turbine (11) may be effected by control valve (6) or only the low pressure steam turbine (11) may be bypassed using control valves (10) and (13).

The Organic Rankine Cycle turbines (15) similarly have a bypass circuit controlled by control valves (14) and (17), which will allow for total or partial bypass of the Organic Rankine Cycle turbines (15). Each turbine (15) can also be individually bypassed, while still directing superheated hydrocarbon fluid to the other turbines.

The condenser (23), which is also a heat exchanger, will either be of a shell and tube design or of plate design in the case where the cooling medium is water, as illustrated in this embodiment.

The cooling water will be collected from an appropriate source. The cooling water will be pumped through the condenser (23) to provide adequate heat transfer to condense the hydrocarbon working fluid vapour back into a fluid. The cycle will utilize a cooling tower (18). The heat exchanger (23) will also be a high volume
5 exchanger.

A fin and tube condenser design may be used in the case where air is to be used as an alternative cooling medium. A fluid to air condenser can either be cooled using fans driven by electrical motors or natural cooling using cooling towers.

10

A cool water feed pump (21) and control valves (19), (20) and (22) will be used to control the flow rate of cooling water through the condenser (23) and the cooling tower (18).

15 The hydrocarbon working fluid feed pump (25) in conjunction with control valves (14), (17), (24) and (26) will be used to control the flow rate as well as power output of the Organic Rankine Cycle turbines (15) in relation to the energy throughput from the heat exchanger (27).

20 Water feed pump (29) and control valves (28) and (30) will control the flow rate of condensed water back to the boiler feed water tank (31). The boiler feed pump (33) and control valve (34) will control the water flow rate to the steam drum (3).

25 Either a single (as shown) or multiple return pumps (25) may be used to pump the hydrocarbon working fluid condensate from the condenser (23) back to the heat exchanger (27) to close the cycle. These pumps (25) would be driven by electrical motors or hydrocarbon working fluid turbines, or a combination of these methods depending on the requirement at that time.

30 Control Valve (7) will also control the steam flow rate from the steam superheaters (2) into the high pressure steam turbine (8). Control valve (6) will control

the steam flow rate from the steam re-heaters (4) to the intermediate pressure steam turbine (9) as well as bypass the intermediate turbine (9) if required.

Control valves (6), (7) and (10) are also jointly used to control the output of the steam turbine set (8), (9) and (11) in relation to the energy input from the boiler (1).

The control valves (6), (7), (10), (14) and (17) enable the primary steam Rankine Cycle turbines (8), (9) and (11) to be totally or partially bypassed and the Organic Rankine Cycle turbines (15) to be individually or totally bypassed.

The heat exchanger (27) operates at higher temperatures when the primary steam turbines (8), (9) and (11) are bypassed and can transfer up to the full thermal load of the boiler(1) to the working fluid for the Organic Rankine Cycle. The Organic Rankine Cycle turbines (15) will in turn operate at higher temperatures, pressures and outputs when the primary steam turbines (8), (9) and (11) are partially or totally bypassed and the generators (16) of the Organic Rankine Cycle will produce higher outputs under these conditions.

The Organic Rankine Cycle turbine bypass circuit serves to provide that suitable cooling performance of the heat exchanger (27) is maintained to ensure the continued operation of the primary steam Rankine Cycle in the event of a single or multiple Organic Rankine Cycle turbine (15) unit failure.

Similarly, the complete or partial steam turbine bypass circuit serves to provide that suitable heating performance of the heat exchanger (27) is maintained to ensure the continued operation of the Organic Rankine Cycle in the event of a single or multiple steam turbine unit failure.

The plant will also provide for preheating of the working fluids, that is both the hydrocarbon and/or the water.

A hydrocarbon preheating heat exchanger (not shown) will be used to transfer some of the energy from the hydrocarbon working fluid exiting the turbines (15) or from the Organic Rankine Cycle turbine bypass circuit [before it enters the condenser (23)] to the hydrocarbon working fluid entering the primary heat exchanger (27). The heat exchanger will be placed between the hydrocarbon working fluid return pump (25) and the heat exchanger (27).

A water preheating heat exchanger (not shown) will also be used to transfer some of the energy from the steam in the steam turbine bypass circuit to the water before it enters the steam drum (3), after it has passed through the boiler feed pump (33).

A further water preheating heat exchanger (not shown) will be used to transfer some of the energy from the hydrocarbon working fluid before it enters the Organic Rankine Cycle condenser (23) to the boiler feed water before it enters the steam drum (3), after it has passed through the boiler feed pump (33).

The combined cycles can be throttled by controlling the load on the generators (12) and (16) using the control valves and by adjusting the pump speeds on the return pumps for both cycles.

As already referred to, the invention provides for a number of control valves to be placed between the different components of the plant's cycle to control the flow of working fluid for the two cycles. A control system to control and monitor all aspects of the combined cycles will also be provided. Such a system will be within the design competence of one suitably skilled in the art. Its components and controls may either be manual, automated analog, electronic or a combination of these. The control valves which may be manually, hydraulically, pneumatically or electronically controlled are located between:

- (i) the heat exchanger and turbines on both cycles;

- (ii) the boiler and steam turbines;
- (iii) the turbines and the condenser on both cycles;
- (iv) the condenser and the return pumps on both cycles;
- (v) the return pumps for the hydrocarbon and the heat exchanger;
- 5 (vi) the return pumps for the water and the boiler feeder drum.

The control system will allow the overall operation of the plant to be monitored and the necessary activation of control valves and bypass circuits to suit current conditions or required output.

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The equipment for the combined conventional Rankine Cycle and Organic Rankine Cycle will be provided in modular packs, or custom designed to the conditions found within the specific application or area. This will allow modification of an existing conventional Rankine Cycle power generation plant in
15 accordance with the invention.

The invention provides a plant wherein most of the waste heat from the wet steam of the conventional Rankine Cycle can be transferred to the hydrocarbon working fluid of the Organic Rankine Cycle. Thus, the heat of condensation
20 normally lost during the condensation of the steam will now be used to heat the hydrocarbon working fluid of the Organic Rankine Cycle and produce additional power from the initial input energy.

During normal operation of the conventional Rankine Cycle equipment, the
25 amount of waste heat available will be determined by the state and volume flow of the steam exiting the low pressure turbine (11). This will (in conjunction with the efficiency of the heat exchanger and condenser and the temperature and volume flow of the available cooling medium) contribute to the generation capacity of the Organic Rankine power generation Cycle.

30

CLAIMS

1. A plant for generating power by combining a conventional, coal-fuelled Rankine power generation Cycle with an Organic Rankine power generation Cycle and wherein a condenser of the conventional Rankine Cycle is a heat exchanger providing the boiler for the Organic Rankine Cycle.
5
2. A plant as claimed in claim 1 in which the working fluid in the Organic Rankine Cycle is a hydrocarbon.
10
3. A plant as claimed in claim 2 in which the hydrocarbon is condensed in a condenser using a wet cooling process.
4. A plant as claimed in claim 2 in which the hydrocarbon is condensed in a condenser using a dry cooling process selected from direct or indirect dry cooling.
15
5. A plant as claimed in claim 2 in which the hydrocarbon is condensed in a condenser using a wet cooling process wherein heat is transferred to water from an external natural source.
20
6. A plant as claimed in claim 2 in which the hydrocarbon working fluid drives multiple turbines each with its own generator.
25
7. A plant as claimed in any of the preceding claims having control valves placed between the different components of the plant to control the flow of working fluid for the two cycles.
8. A plant as claimed in claim 7 adapted for the primary steam Rankine Cycle turbines to be totally or partially bypassed.
30

9. A plant as claimed in claim 7 or claim 8 adapted for the Organic Rankine Cycle turbines to be individually or totally bypassed.
- 5 10. A plant as claimed in any preceding claim having a control system to control and monitor the combined cycles.
11. A plant as claimed in claim 10 in which the cycles are throttled by controlling the load on the generators.
- 10 12. A plant as claimed in claim 11 in which the load on the generators is controlled through control valves in the working fluid lines and pump speeds on return pumps for both cycles.
- 15 13. A plant as claimed in any preceding claim having a hydrocarbon working fluid preheating heat exchanger to transfer energy from the heated hydrocarbon working fluid before it enters the condenser to the hydrocarbon working fluid entering the primary heat exchanger.
- 20 14. A plant as claimed in any preceding claim having a water preheating heat exchanger to transfer energy from the heated hydrocarbon working fluid before it enters the condenser to the water before it enters the steam drum.
- 25 15. Equipment for the plant as claimed in any one of the preceding claims which is provided in modular packs.
- 30 16. A method of generating power by combining a conventional, coal-fuelled Rankine power generation Cycle with an Organic Rankine power generation Cycle.

17. A method as claimed in claim 16 in which the condenser for the conventional Rankine Cycle is a heat exchanger which is used as the boiler for the Organic Rankine Cycle.
- 5 18. A method as claimed in claim 17 in which flow of working fluid for the two cycles is controlled using multiple control valves in working fluid lines.
- 10 19. A method as claimed in claim 18 in which primary steam Rankine Cycle turbines are totally or partially bypassed and/or Organic Rankine Cycle turbines to are individually or totally bypassed.
- 15 20. A method as claimed in any of claims 16 to 19 in which the combined cycles are controlled and monitored and the cycles are throttled by controlling the load on the generators through the control valves and pump speeds on return pumps for both cycles.
- 20 21. A method as claimed in any of claims 16 to 20 in which energy from the heated hydrocarbon working fluid, before it enters a condenser, is transferred to the hydrocarbon working fluid entering the primary heat exchanger.
- 25 22. A method as claimed in any of claims 16 to 21 in which energy from the heated hydrocarbon working fluid before it enters a condenser is transferred to the water before it enters the steam drum.

AMENDED CLAIMS

received by the International Bureau on 24 January 2011 (24.01.11)

1. A plant for generating power by combining a conventional, coal-fuelled Rankine power generation cycle with a hydrocarbon organic Rankine power generation cycle comprising a condenser of the conventional Rankine cycle as a primary heat exchanger providing the boiler for the organic Rankine cycle and including a hydrocarbon preheater heat exchanger for transferring energy from heated exhaust hydrocarbon working fluid exiting the turbine of the organic Rankine cycle to the condensed hydrocarbon working fluid prior to entry of the latter into the hydrocarbon cycle boiler.
2. A plant as claimed in claim 1 in which a water coolant heat exchanger is provided to condense the hydrocarbon working fluid discharged from the preheater.
3. A plant as claimed in claim 2 in which the hydrocarbon working fluid drives either a single or multiple turbines each with its own generator.
4. A plant as claimed in claim 3 in which the primary steam Rankine cycle turbines are totally or partially bypassed.
5. A plant as claimed in claim 3 or 4 in which the organic Rankine cycle turbines are individually or totally bypassed.
6. A plant as claimed in claim 5 in which the load on the generators is controlled through control valves in the working fluid lines and pump speeds on return pumps for both cycles.
7. A method of generating power comprising coal fueling a conventional Rankine power generation cycle and combining this with a

- hydrocarbon fueled organic Rankine power generation cycle and using the conventional Rankine cycle condenser as the primary heat exchanger for the hydrocarbon Rankine cycle boiler and using heat exhausted from the hydrocarbon Rankine cycle to preheat the hydrocarbon to transfer energy to the hydrocarbon prior to introduction into the hydrocarbon Rankine cycle boiler.
- 5
8. A method as claimed in claim 7 in which heat exhausted from the hydrocarbon Rankine cycle is also used to transfer energy to the water of the conventional Rankine cycle prior to its introduction into a steam drum for that cycle.
- 10
9. A method as claimed in claim 7 in which primary steam Rankine cycle turbines are totally or partially bypassed and/or the organic Rankine cycle turbines are also individually or totally bypassed.
- 15
10. A method as claimed in claims 7 or 8 in which the hydrocarbon is condensed in a wet or dry cooling process.
- 20
11. A method as claimed in claim 10 is a dry process selected from direct or indirect cooling.

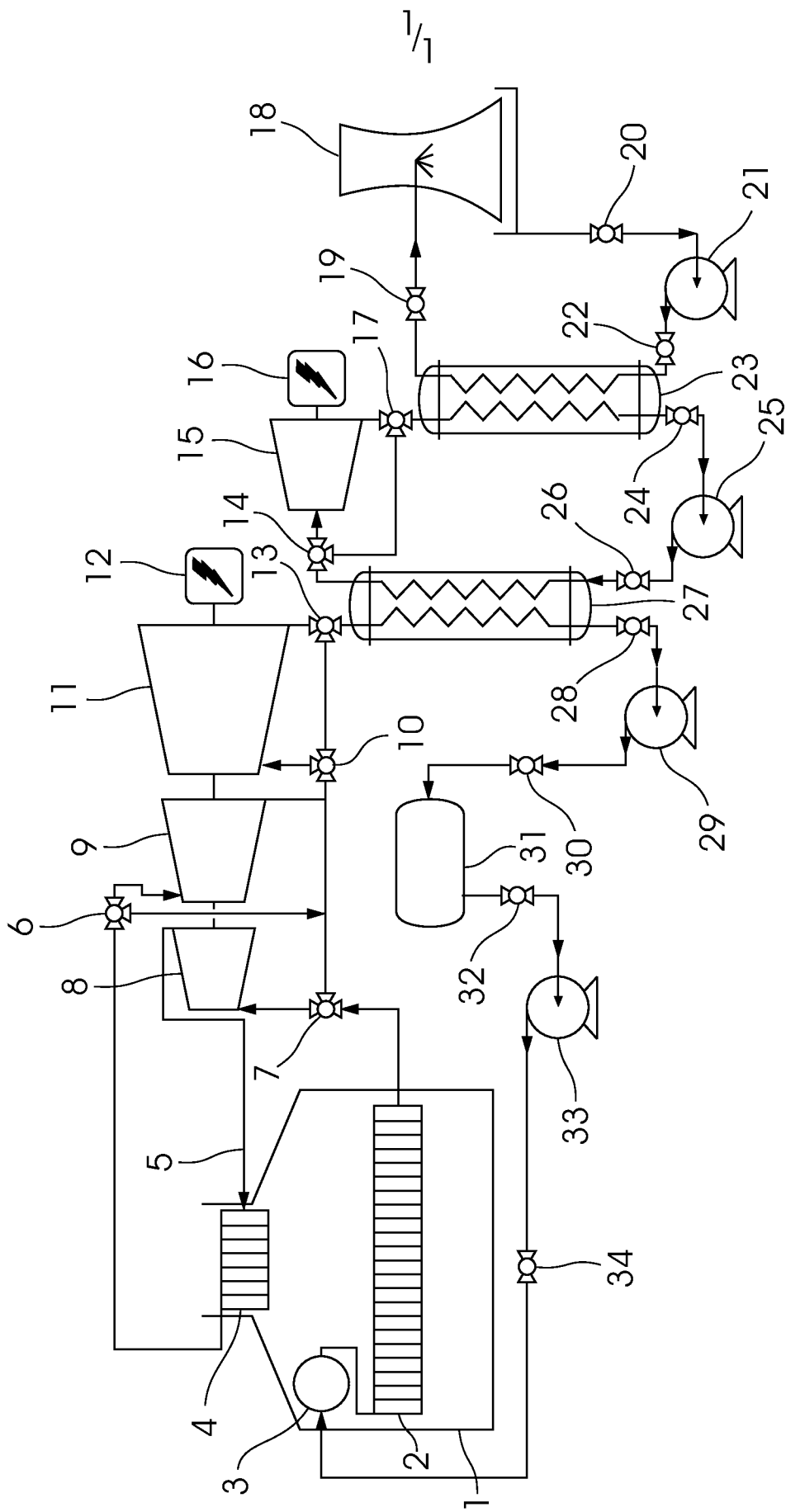


FIGURE 1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB 2010/054019

A. CLASSIFICATION OF SUBJECT MATTER

IPC⁸: **F01K 23/04** (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC⁸: F01K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPODOC, WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y A	US 6035643 A (ROSENBLATT) 14 March 2000 (14.03.2000) <i>abstract; fig. 1; column 3, line 65 - column 11, line 2;</i>	1-3,5,7,10,11, 16-18 8,19 12-14,20-22
Y A	GB 372907 A (WEIR ET AL.) 19 May 1932 (19.05.1932) <i>fig. 1; page 4, line 58 - page 5, line 9;</i>	8,19 9

☐ Further documents are listed in the continuation of Box C.☒ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search
11 November 2010 (11.11.2010)Date of mailing of the international search report
24 November 2010 (24.11.2010)Name and mailing address of the ISA/ AT
Austrian Patent Office
Dresdner Straße 87, A-1200 ViennaAuthorized officer
HÖRZER K.

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Telephone No. +43 / 1 / 534 24 / 359

Continuation of first sheet

Continuation No. II:

**Observations where certain claims were found unsearchable
(Continuation of item 2 of first sheet)**

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

Claims Nos.: 15 because they relate to subject matter not required to be searched by this Authority, namely:

Said claim 15 is just a conceptual formulation, which does not demand a technical action.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/IB 2010/054019

Patent document cited in search report			Publication date		Patent family member(s)	Publication date
US	A	6035643			HK A1 1037017	2007-07-06
					WO A1 0032909	2000-06-08
					EP A1 1135579	2001-09-26
					AU A 1445700	2000-06-19
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