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(54) HIGH EFFICIENCY ORGANIC RANKINE CYCLE WITH FLEXIBLE HEAT DETACHMENT

(57) Organic Rankine cycle (300, 400, 500) comprising:
- an evaporator (1) where the pressurized fluid is heated, vaporized and brought into subcritical or supercritical conditions using the heat of a source;
- a turbine (2) where the fluid while expanding provides the useful work of the cycle;
- at least one pump (5, 5 ’) where the liquid is brought from the pressure of at least one condenser (4, 4’) to the evaporator pressure (1);
- a pre-heater (6), which using the same source supplies heat to the working fluid, bringing it to a temperature close to the vaporization temperature,

said organic Rankine cycle (300, 400, 500) further comprising
- a first recuperator (3) which receives a first portion of organic fluid vapor extracted from the turbine (2), and is connected to a first condenser (4), by means of a first circuit (10) at medium pressure;
- at least one second recuperator (3 ’, 403’, 404 ’) which receives a second portion organic fluid vapor leaving the turbine (2) and is connected to a second condenser (4’), by means of a second low pressure circuit (11), said organic Rankine cycle (300, 400, 500) being characterized by at least one further pre-heater (301, 301’) positioned in parallel with one or both of said first and second recuperator (3, 3’).

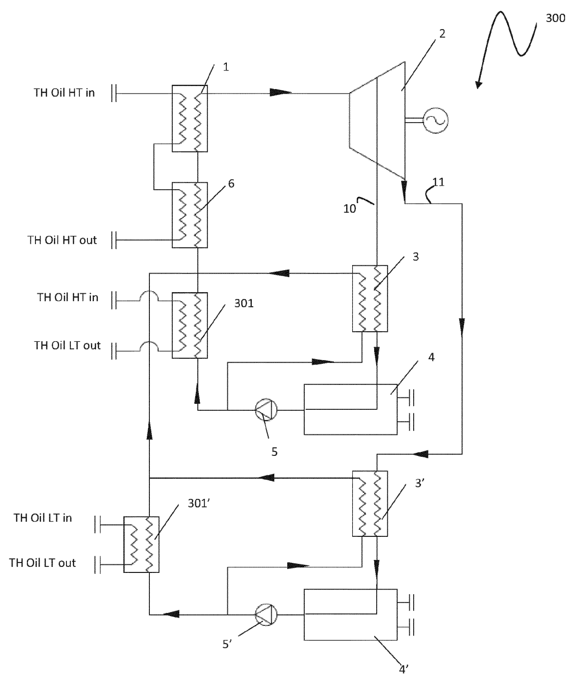

Fig.3

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Description

Technical field of the invention

[0001] The present invention relates to a high efficiency, innovative organic Rankine cycle plant with flexible heat detachment.

Background art

[0002] As is known, a thermodynamic cycle is defined as a finite succession of thermodynamic transformations (for example isotherm, isochore, isobaric or adiabatic) after which the system returns to its initial state. In particular, an ideal Rankine cycle is a thermodynamic cycle composed of two adiabatic transformations and two isobars with two phase changes, from liquid to vapor and from vapor to liquid. Its purpose is to turn heat into work. This cycle is generally adopted above all in thermoelectric power plants for the production of electricity and uses water as the driving fluid, both in liquid form and in vapor form, and the corresponding expansion takes place in the so-called steam turbine.

[0003] Together with Rankine cycles with water as the working fluid, organic Rankine cycles (ORC) have been hypothesized and implemented, which use high molecular mass organic fluids for the most diverse applications, in particular also for the exploitation of thermal sources at low-medium temperature. As in other steam cycles, the plant for an ORC cycle includes, by way of example, one or more pumps for feeding the organic working fluid, one or more heat exchangers to carry out the preheating, vaporization and eventual overheating or heating phases in supercritical conditions of the same working fluid, a steam turbine for the expansion of the fluid, mechanically connected to an electric generator or an operating machine. ORC cycles are also used for the production of electricity and for the exploitation of the heat recovered from the organic working fluid in the condenser.

[0004] Similar solutions are known to the state of the art in the field of steam turbines (e.g. bleed and condensation turbines).

[0005] As for ORC cycles, the organic fluids used in them are characterized by a high molecular mass and consequently generate high volumetric flows in the turbine, even for intermediate pressure values. This would make less efficient their bleeding from the turbine.

[0006] In addition, ORC cycles normally use working fluids which are overheated during the expansion in the turbine. Starting from overheated steam conditions, the heat exploitation by an external user, even by extracting the working fluid at intermediate pressure compared to the pressure drop in the turbine, is not thermodynamically very efficient, as the portion of de-overheating has a high temperature difference between the working fluid and the heat-transfer fluid of the thermal user. This leads to a significant loss of flow exergy, which does not occur in water vapor cycles. In fact, when heat is transferred to the thermal users through a condenser, the loss of efficiency is very significant due to the fact that in the de-overheating phase the organic vapor exchanges heat with the heat carrier of the user with a very high temperature difference.

[0007] An organic Rankine cycle system with flexible heat detachment, according to the known technique, is shown in Figure 1 and comprises two distinct recuperators 3, 3' which use respectively, medium and low-pressure steam portions extracted from the turbine 2 along two different circuits, a first medium pressure circuit 10 and a second low pressure circuit 11. In the medium pressure recuperator 3, the organic liquid coming from the first high temperature condenser 4 is preheated whereas in the second low pressure recuperator 3' the organic liquid coming from the second low temperature condenser 4' is preheated.

[0008] However, the organic Rankine cycle system according to the known technique fails to obtain an optimum efficiency in heat recovery.

[0009] There is therefore the need to define an organic Rankine cycle system which allows to overcome the aforementioned drawbacks and therefore is able to use the detached and flexible heat recovered from the organic working fluid in an extremely efficient way.

Summary of the invention

[0010] Aim of the present invention is therefore to detach in an extremely efficient and flexible way the heat recovery from the organic working fluid, by defining an organic Rankine cycle in which the steam expanding inside the turbine is separated in two flows, one of which is tapped inside the turbine and has an intermediate pressure value with respect to the pressure drop of the turbine as a whole.

[0011] In other words, the expansion inside the turbine of a portion of the vapor generated by the organic fluid is limited. The separation of a portion of the vapor takes place at a condensation pressure level, suitable to supply heat to the external user, whereas the remaining portion of the organic fluid vapor is expanded up to a lower pressure allowed by the heat absorption temperature of the thermal well (for example either a cooling tower or a dry cooler or air in a dry cooled direct air conditioner).

[0012] Therefore, the aim of the present invention is to maximize the electrical efficiency, despite the fact that part of the heat is extracted to supply it to the thermal users before having completed its expansion up to its minimum condensation pressure. The envisaged solution is then able to supply heat in a flexible way, as only the part of vapor necessary to satisfy the users condenses at intermediate pressure. If the heat required should vary over time, it is possible to vary the tapped quantity by effecting the complete expansion for the vapor portion not needed to satisfy the thermal user.

[0013] Furthermore, part of the heat contained in each of the two organic vapor flows, both the less expanded and the more expanded ones, is used in two recuperators at a medium and low pressure, which recover the heat downstream of the turbine in order to preheat the liquid of the organic fluid coming from the condensers. The addition of recuperators allows to significantly increase the electrical efficiency.

[0014] In particular, the present invention defines an organic Rankine cycle which allows the flexible heat detachment according to independent claim 1.

[0015] Further preferred and/or particularly advantageous embodiments of the invention are described according to the characteristics set out in the attached dependent claims.

Brief description of the drawings

[0016] The invention will now be described with reference to the annexed drawings, which illustrate some non-limiting examples of its implementation, in which:

- Figure 1 shows a diagram of an organic Rankine cycle with flexible heat detachment according to the prior art,
- Figure 2 shows a diagram of the organic Rankine cycle with flexible heat detachment in a first embodiment of the present invention,
- Figure 3 shows a schematic diagram of the organic Rankine cycle with flexible heat detachment in a second embodiment of the present invention,
- Figure 4 shows a schematic diagram of the organic Rankine cycle with flexible heat detachment in a third embodiment of the present invention,
- Figure 5 shows a schematic diagram of the organic Rankine cycle with flexible heat detachment in a fourth embodiment of the present invention,
- Figure 6 shows a schematic diagram of the organic Rankine cycle with flexible heat detachment in a fifth embodiment of the present invention.

Detailed description

[0017] The invention relates to a high efficiency heat detachment in an organic Rankine cycle. An organic Rankine cycle 100 according to the known art is shown in Figure 1 and comprises:

- an evaporator 1, where the pressurized fluid is heated, vaporized and possibly overheated or brought to supercritical conditions by using heat from an external source, for example a diathermic oil (TH oil HT in/out) or high temperature smokes coming from a biomass boiler or industrial heat recovery boiler;
- an expander (turbine) 2 where the fluid expanding (in an ideal iso-entropic manner) transfers the useful work of the cycle to the outside;
- a first recuperator 3 which receives steam at medium pressure, tapped from the turbine 2 and connected to a first condenser 4 at high temperature, of the water-steam or other heat transfer fluid cooled type, suitable for transferring heat to the thermal user, where the heat released by the working fluid is removed;
- a second recuperator 3' which receives steam at low pressure at the outlet of the turbine 2 and is connected to a second condenser 4' at low temperature of the water or air-cooled type, where further heat is released by the working fluid;
- a pump 5, 5' where the liquid is returned by the pressure of the condenser 4, 4' up to the pressure of the evaporator 1, and where the negative cycle work is exchanged (in an ideally iso-entropic way);
- a preheater 6, which by using for example the same source as the evaporator supplies heat to the working fluid bringing it up to a temperature close to the vaporization one.

[0018] Throughout the present description, the following is meant:

- for a high pressure, the pressure of the working fluid entering the turbine 2;
- for a medium or intermediate pressure, the pressure of the working fluid in a phase of the cycle (medium pressure circuit 10) in which the entire enthalpy drop of the turbine (or of the turbines, if there were more than one) has not been processed. The medium pressure circuit 10 has its origin at the midpoint of the turbine in which the entire enthalpic drop has not been processed and includes the first recuperator 3 and the first condenser 4;
- for a low pressure, the pressure of the working fluid in a phase of the cycle (low pressure circuit 11) in which the entire enthalpy drop of the turbine (or of the turbines, if there were more than one) was processed. The low-pressure circuit 11 originates from the turbine exiting at the point where the entire enthalpy drop has been processed, and comprises the second recuperator 3' and the second condenser 4';
- for a high temperature, the temperature of the working fluid in the first recuperator or in the first condenser; for a high temperature, the temperature of the hottest external source is also meant;
- for a low temperature, the temperature of the working fluid in the second recuperator or in the second condenser; for a low or medium temperature, the temperature of the least hot external source is also meant.

[0019] In this way, the exergy in both organic vapor flows coming from the turbine 2 and provide with a high temperature (as the organic vapor tapped or exiting from turbine, is normally overheated or under supercritical conditions and therefore is at a temperature higher than that of condensation) is used in the two condensers 4, 4' for the recovery of the internal heat of the organic fluid and mainly of the latent condensation heat, at a temperature close to the temperature of the heat user and/or of the heat sink.

[0020] A first embodiment of the present invention is shown in Figure 2. The proposed organic Rankine cycle 200 comprises two turbines 2, 2' positioned in series. The second turbine 2' is positioned downstream of the recuperator 3. In practice, the flow of the organic steam leaving the generator 3 is divided into two flows, the first of which will reach the condenser 4 at a high temperature, whereas the remaining steam flow will continue its expansion in the turbine 2'. The presence of only one recuperator 3 makes it simpler and more economic or at the expense of a slight reduction in the efficiency of the thermodynamic cycle of the same. Advantageously, also the realization of the low-pressure turbine 2' is more easily made through the low temperatures of the organic fluid to be expanded and through a reduced volumetric flow of organic vapor to be conveyed into the same turbine 2'.

[0021] In many cases, it will be advantageous to connect the two turbines to a common electric generator, equipped with two shafts.

[0022] Advantageously moreover, the detachment of the steam can also be carried out inside a single turbine with intermediate extraction. In both cases, the proposed diagram allows to regulate the quantity of expanded steam at intermediate and low-pressure levels, thus adapting the cycle to the actual quantity of heat required by the heat users at a medium temperature.

[0023] In the case of a single turbine with intermediate extraction, a second embodiment of the present invention is shown in Figure 3. The organic Rankine cycle 300 proposed here represents a more advanced solution of the diagram of Fig. 1. Compared with ORC 100, this ORC cycle 300 includes at least an additional preheater 301, 301' positioned in parallel to one or both the first and second recuperators 3, 3'. Said preheaters 301, 301' preheat the working fluid coming from the condensers 4, 4' by means of the same thermal source (TH oil HT in/out) and/or by means of a lower temperature thermal source (TH oil LT in/out).

[0024] Advantageously, the cycle 300 allows to further optimize the ORC plant performance should heat be added from a heat source at a lower temperature, without significant loss of efficiency of the same cycle. This is made possible bearing in mind that the heat capacity of the liquid is higher than the heat capacity of the vapor passing through the recuperator. Therefore, since the recuperator or both recuperators 3, 3' work with a lower flow of organic liquid, for the same vapor flow it will not be necessary to increase the heat exchange surfaces in order to guarantee the same preheating temperature.

[0025] For example, in applications which biomass or combustion wastes, the low-temperature circuit may be powered by an economizer of the combustion gases, thereby increasing the performance of the ORC cycle without the need for more fuel.

[0026] In any case, the presence of recuperator 3, 3' is still advantageous as it allows however to further increase the heat flow which can be used, and then the performance of the same cycle.

[0027] A third embodiment of the present invention is shown in Fig. 4. The organic Rankine cycle 400 proposed here represents an evolution of diagram 3. The cycle 400 differs from the cycle 300 in that the preheater 301' of the low-pressure circuit 11 is replaced by two preheaters 401', 402' in series between them and the recuperator 3' is replaced by two recuperators 403', 404' in series within each other. The preheaters 401', 402' and the respective recuperators 403', 404' are in parallel with each other.

[0028] Advantageously, the cycle 400 allows to use additional heat from a heat source at a lower temperature (LT source in/out) in order to increase the performance of the same cycle. The heat source could be for example the heat from a smoke condensation system and/or other low temperature sources.

[0029] If such source of additional heat should is not available, the heat of the condenser 4 at high temperature could also be used, then by introducing an additional innovative regeneration in the cycle.

[0030] Therefore, a fourth embodiment of the present invention is considered, according to which the heat exchanger 402' in parallel to the recuperator 404' extracts heat or directly from the condenser 4 at a high temperature (which provides heat by a medium-pressure steam condensation) or indirectly by means of a part of the fluid of the thermal user which has heated up in the condenser 4 at a high temperature (organic Rankine cycle 500, shown in Figure 5).

[0031] A fifth embodiment of the present invention is shown in Figure 6. This embodiment derives from the first embodiment, in which the proposed organic Rankine cycle 200 comprises two turbines 2, 2' positioned in series. In the case of Figure 6, the organic Rankine cycle 600 comprises at least one further preheater 601, 601' positioned in parallel to one or both of the first and second recuperators 3, 3'. Said pre-heaters 601, 601' preheat the working fluid coming from condensers 4, 4' by means of the same thermal source (TH oil HT in/out) and/or by means of a lower temperature thermal source (TH oil LT in/out).

[0032] As can be seen, the organic Rankine cycle 600 represents the combination of the diagrams of Figure 2 and Figure 3. Consequently, it reproduces the same advantages: the construction of the low-pressure turbine 2' is easier to make due to the low temperatures of the organic fluid to be expanded and the reduced volumetric flow of organic vapor to be conveyed into the turbine 2' itself; the cycle 600 also allows to further optimize the performance of the ORC plant if heat coming from a thermal source at a lower temperature should be added, without significant loss of efficiency of the cycle itself.

[0033] In addition to the embodiments of the invention as described above, it should be understood that there are numerous further variants. It must also be understood that said embodiments are only examples and do not limit neither the object of the invention, nor its applications, nor its possible configurations. On the contrary, although the above description makes it possible for the skilled person to carry out the present invention at least according to an exemplary configuration thereof, it must be understood that numerous variations of the described components are conceivable, without thereby departing from the object of the invention, as defined in the attached claims, interpreted literally and/or according to their legal equivalents.

Claims

1. Organic Rankine cycle (300, 400, 500) comprising:

- an evaporator (1) where the pressurized fluid is heated, vaporized and brought into subcritical or supercritical conditions using the heat of a source;
- a turbine (2) where the fluid while expanding provides the useful work of the cycle;
- at least one pump (5, 5 ') where the liquid is brought from the pressure of at least one condenser (4, 4') to the evaporator pressure (1);
- a pre-heater (6), which using the same source supplies heat to the working fluid, bringing it to a temperature close to the vaporization temperature,

said organic Rankine cycle (300, 400, 500) further comprising

- a first recuperator (3) which receives a first portion of organic fluid vapor extracted from the turbine (2), and is connected to a first condenser (4), by means of a first circuit (10) at medium pressure;
- at least one second recuperator (3 ', 403', 404 ') which receives a second portion organic fluid vapor leaving the turbine (2) and is connected to a second condenser (4'), by means of a second low pressure circuit (11), said organic Rankine cycle (300, 400, 500) being **characterized by** at least one further pre-heater (301, 301') positioned in parallel with one or both of said first and second recuperator (3, 3').

2. Organic Rankine cycle (300, 400, 500) according to claim 1, wherein in the first recuperator (3) the organic fluid coming from the first condenser (4) is preheated while in the second recuperator (3 ', 403 ', 404') the organic fluid coming from the second condenser (4 ') is preheated.

3. Organic Rankine cycle (300) according to claim 1 or 2, wherein said preheaters (301, 301 ') are configured to preheat the working fluid coming from the condensers (4, 4') through the same thermal source and / or by means of a lower temperature thermal source.

4. Organic Rankine cycle (400) according to claim 1 or 2, further comprising in the second low pressure circuit (11) two preheaters (401 ', 402') in series with each other and two recuperators (403 ', 404') also in series with each other.

5. Organic Rankine cycle (400) according to claim 4, wherein the preheaters (401', 402') and the respective recuperators (403', 404') are in parallel with each other.

6. Organic Rankine cycle (500) according to claim 5, wherein the heat exchanger (402') in parallel with the recuperator (404') takes heat either directly from the first condenser (4) or indirectly by means of a fluid portion of the thermal utility that is heated in the first condenser (4).

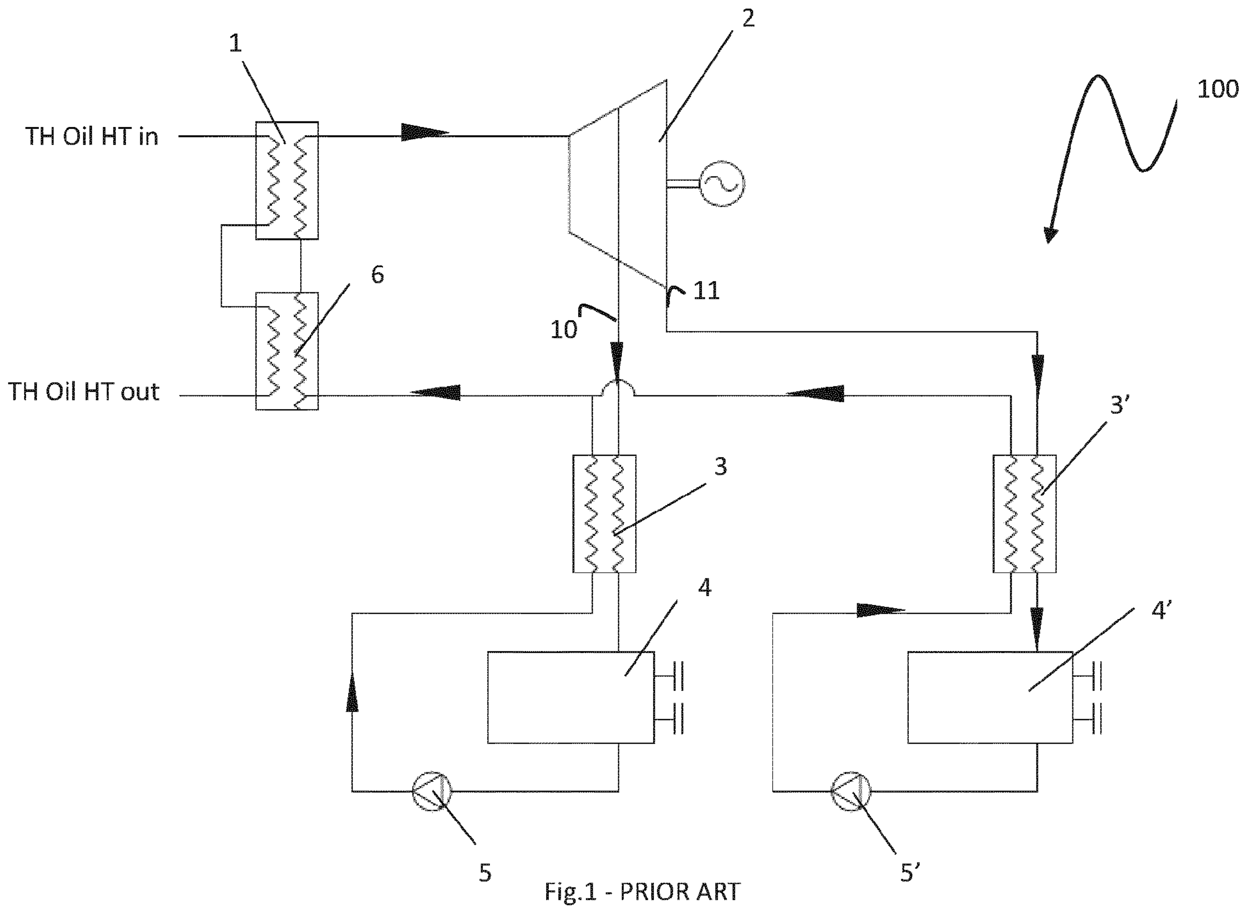


Fig.1 - PRIOR ART

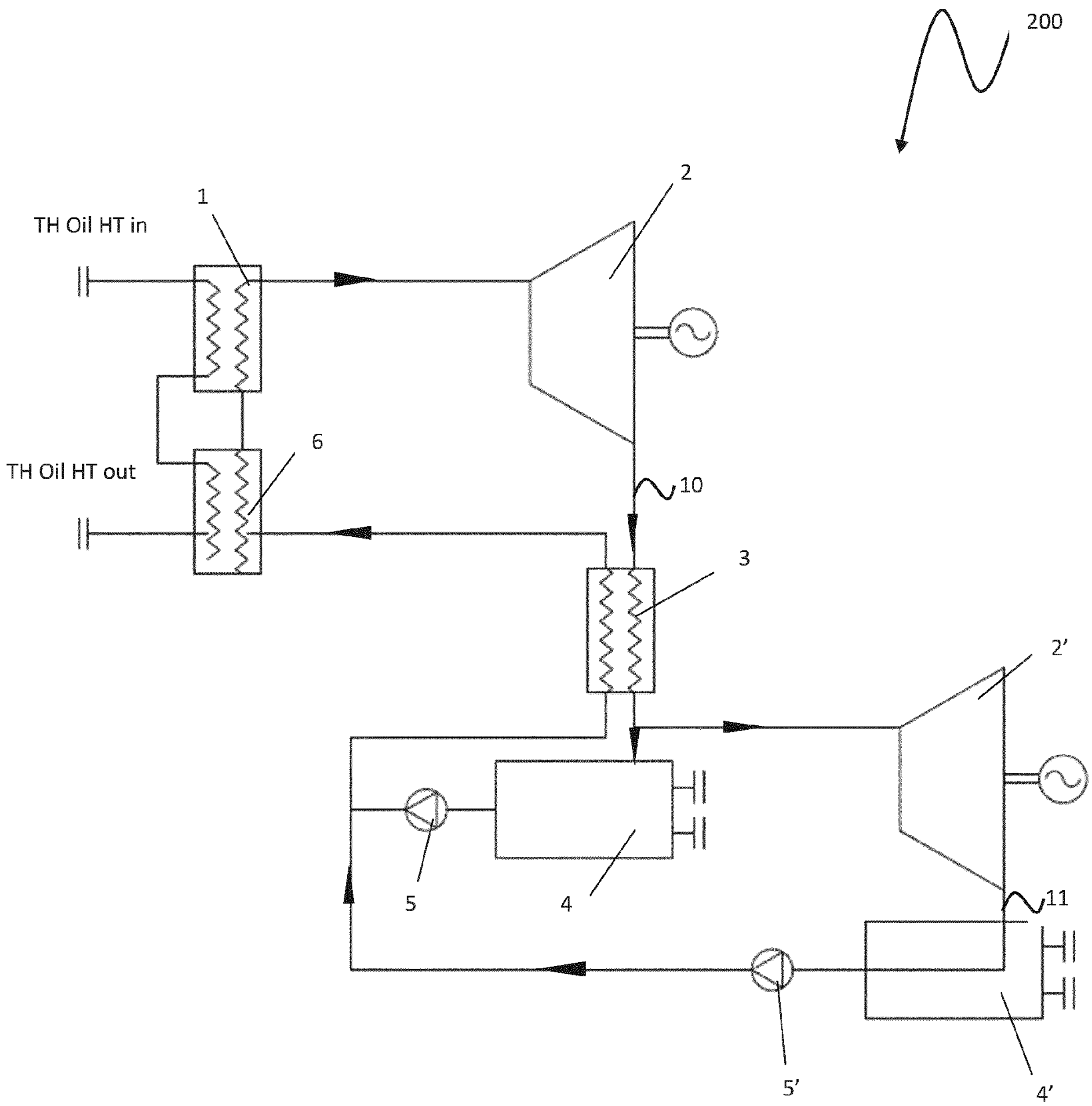


Fig.2

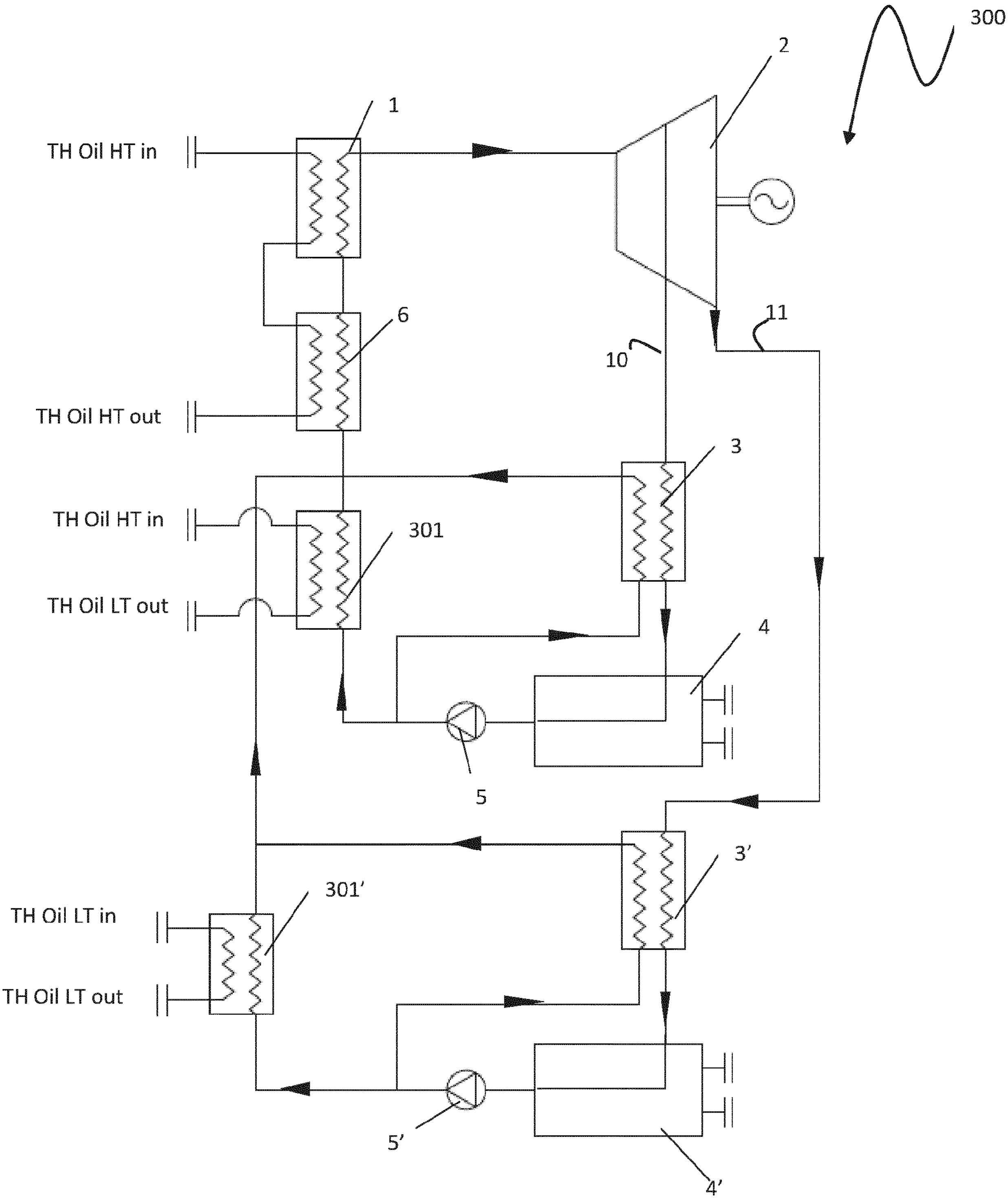

300
2
1
TH Oil HT in
TH Oil HT out
6
11
10
3
TH Oil HT in
301
TH Oil LT out
4
5
3'
301'
TH Oil LT in
TH Oil LT out
5'
4'

Fig.3

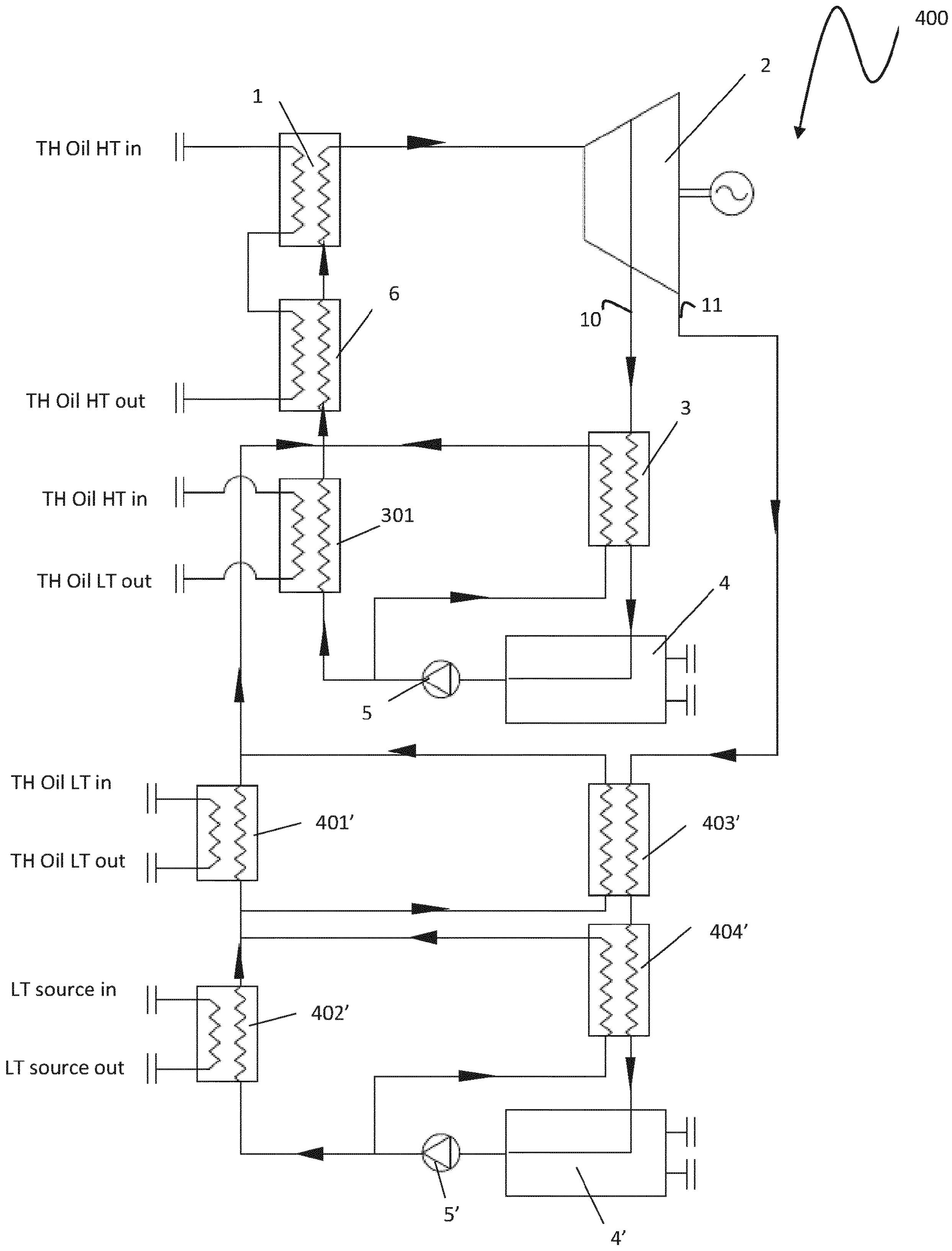

400
2
1
TH Oil HT in
6
10
11
TH Oil HT out
3
TH Oil HT in
301
TH Oil LT out
4
5
TH Oil LT in
401'
403'
TH Oil LT out
404'
LT source in
402'
LT source out
5'
4'

Fig.4

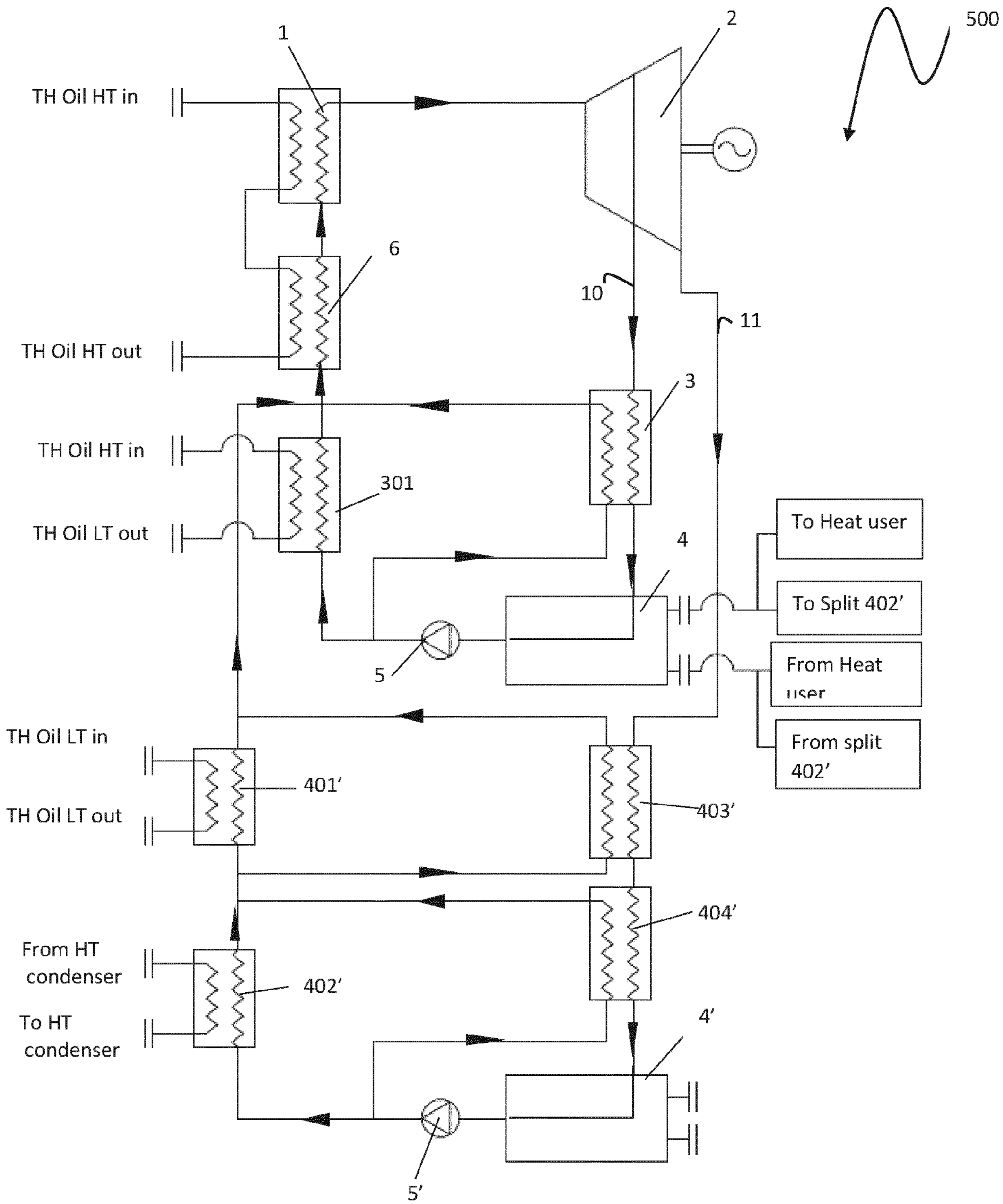
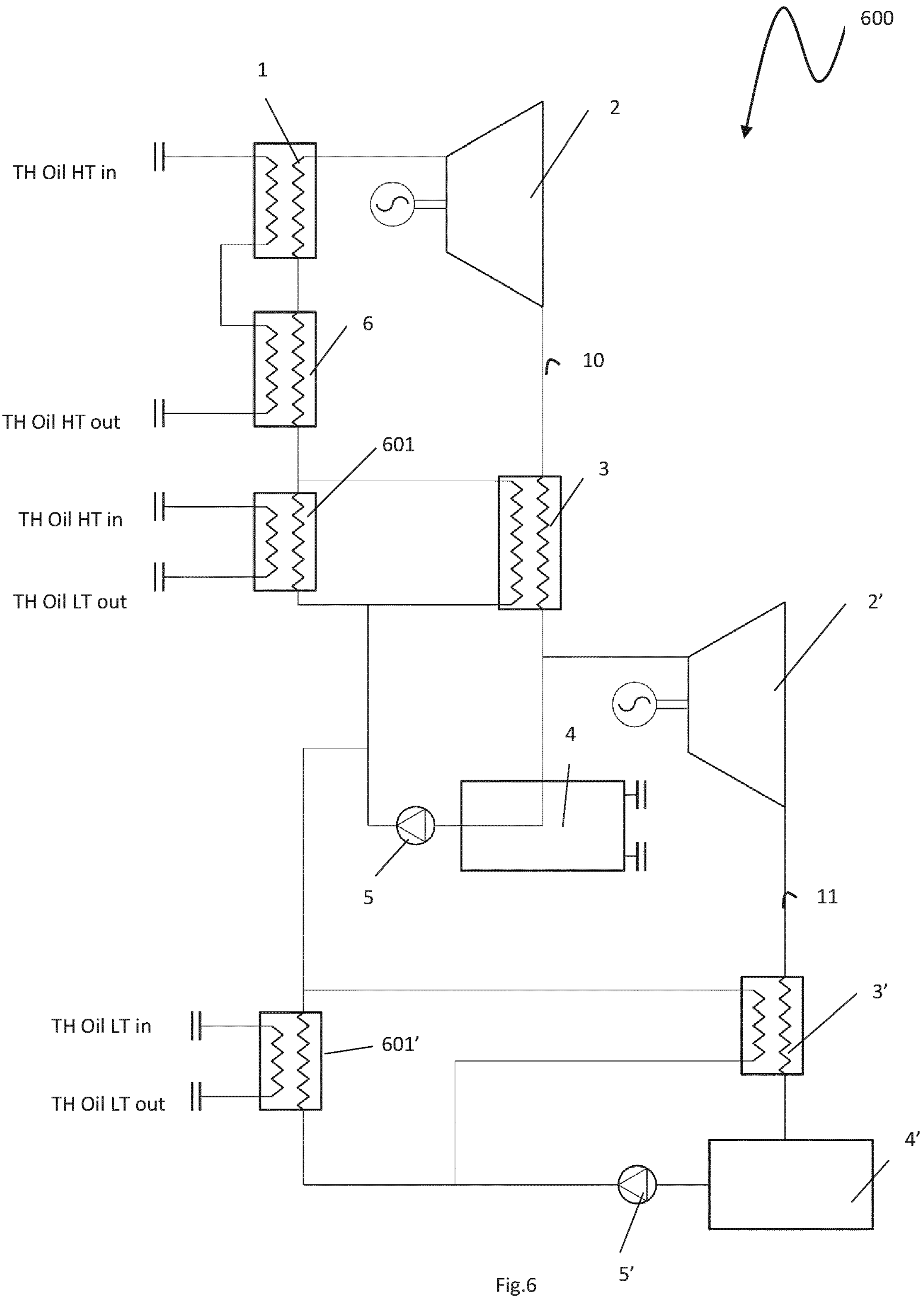

500
1
2
TH Oil HT in
TH Oil HT out
6
10
11
3
TH Oil HT in
301
TH Oil LT out
To Heat user
4
To Split 402'
5
From Heat user
From split 402'
TH Oil LT in
401'
TH Oil LT out
403'
404'
From HT condenser
402'
To HT condenser
4'
5'

Fig.5


600
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TH Oil LT out
2'
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3'
TH Oil LT in
601'
TH Oil LT out
4'
5'

Fig.6

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EUROPEAN SEARCH REPORT

Application Number
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F01K

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2

Place of search	Date of completion of the search	Examiner
Munich	29 March 2021	Varelas, Dimitrios

CATEGORY OF CITED DOCUMENTS

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