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(54) **Waste heat recovery system**

(57) A system 40 and a method for recovering of waste heat are disclosed in which in a heat recovery cycle 54 waste heat is stored in a storage 46, in a heat pump cycle 12 the heat in the storage 46 is upgraded to heat in a high temperature storage 26, and in a heat engine cycle 28 the upgraded heat in the high temperature storage 62 is used for generating electricity.

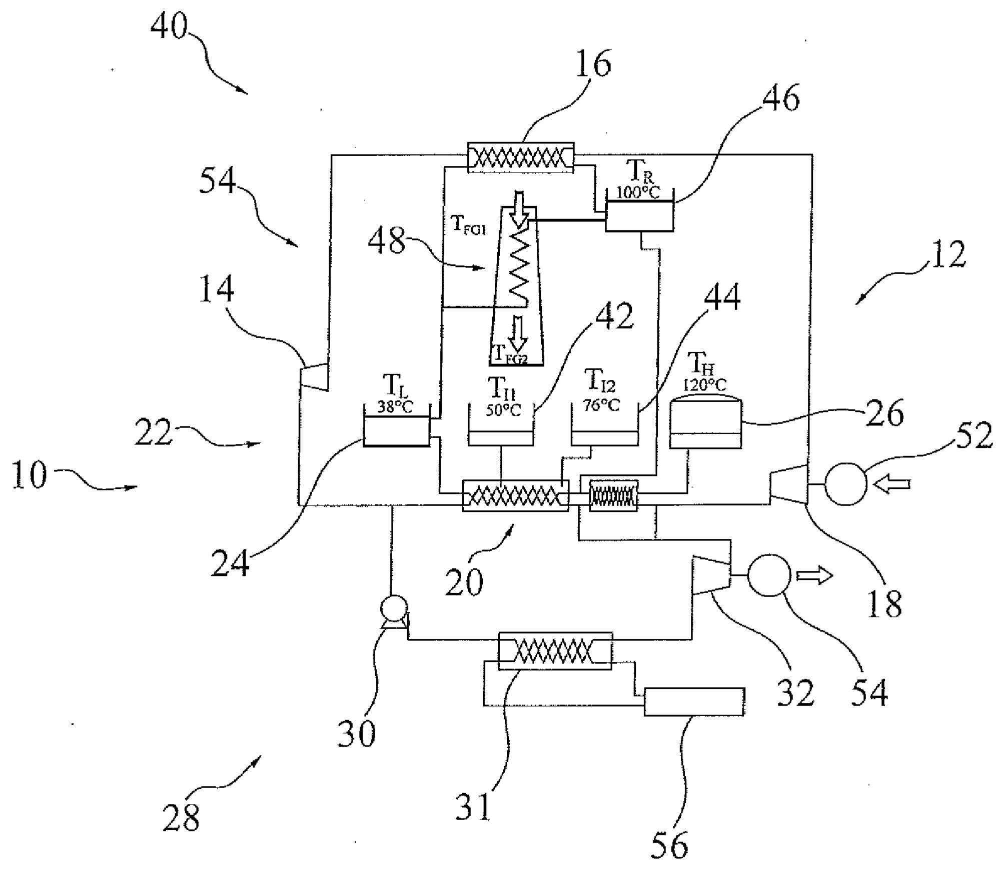

Fig. 4

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Description

FIELD OF THE INVENTION

[0001] The invention relates to the field of storing energy. In particular, the invention relates to a method for recovering of waste heat and a waste heat recovery system.

BACKGROUND OF THE INVENTION

[0002] Many industrial processes uses heat as energy carrier. For example, in conventional power plants steam is produced by heating water with coal, fuel or nuclear energy. In most engines, fuel is burnt to heat air. Although a part of the generated heat is converted into mechanical energy, a large part of the generated heat leaves the process (e. g. the plant or the engine) without further use. Such heat may be called waste heat. In general, waste heat may refer to heat produced by machines, electrical equipment and industrial processes that is produced as a by-product by the operation of the respective device or process.

[0003] To increase the overall efficiency of the industrial process, waste heat may be used to generate electricity. For example, the waste heat may be stored in a thermoelectric energy storage system and may be later used to generate electricity. In this case, the increase in efficiency of the overall system directly relates to the efficiency of the waste heat recovery system.

DESCRIPTION OF THE INVENTION

[0004] It is an object of the invention to increase the efficiency factor of an industrial process generating waste heat.

[0005] This object is achieved by the subject-matter of the independent claims. Further exemplary embodiments are evident from the dependent claims and the following description.

[0006] An aspect of the invention relates to a method for recovering of waste heat.

[0007] According to an embodiment of the invention, the method comprises the step of heating, in a heat recovery cycle, a thermal storage medium with waste heat from a continuous waste heat source to a heat recovery temperature. The heat recovery temperature may be below a waste heat temperature. For example, water as thermal storage medium is heated from a low temperature to the heat recovery temperature by flue gas at the waste heat temperature. For example, the waste heat recovery temperature may be the boiling point of the water. The heated thermal storage medium may be stored in a heat recovery storage, for example an isolated tank. In such a way, in the heat recovery cycle which may be seen as a heat collection step, waste heat may be extracted from a continuous fluid flow (flue gas) and may be transferred to a thermal storage medium that may be stored in a heat recovery storage for future use.

[0008] According to an embodiment of the invention, the method comprises the step of transferring, in a heat pump cycle, heat from the thermal storage medium at the heat recovery temperature via a working fluid to a thermal storage medium at a temperature above the heat recovery temperature. The temperature above the heat recovery temperature may be referred to as high temperature and the heat recovery temperature may be referred to as intermediate temperature. For example, the expanded working fluid is heated in a heat exchanger by a stream of thermal storage medium at the heat recovery temperature flowing from the heat recovery storage to a low temperature storage. After that, the working fluid is compressed (by adding mechanical energy) and is used for heating a further stream of thermal storage medium to the high temperature. In the end of the cycle, the compressed working fluid may be expanded and heated again. In such a way, the heat pump cycle may be seen as an upgrading step for upgrading the waste heat to a higher temperature.

[0009] It has to be understood that the terms "high", "intermediate" and "low" may only indicate that the thermal storage medium in the high temperature storage is hotter than the thermal storage medium in the intermediate temperature storage, which is hotter than the thermal storage medium in the low temperature storage. Also, the thermal storage medium or the working fluid in the high temperature heat exchanger may be hotter as the thermal storage medium or the working fluid in the low temperature heat exchanger.

[0010] According to an embodiment of the invention, the method comprises the step of transferring, in a heat engine cycle, heat in the thermal storage medium of the high temperature to a compressed working fluid and generating mechanical energy by expanding the working fluid. In the heat engine cycle, the heat recovered in the heat recovery cycle and upgraded in the heat pump cycle may be used for generating mechanical energy, for example for driving an electrical motor and for generating electricity. Such, the heat engine cycle may be seen as a energy generation step.

[0011] It is either possible that at least two of the cycles, i. e. the heat recovery cycle, the heat pump cycle and the heat engine cycle run in parallel. However, to save equipment, in particular heat exchangers and lines, at least the heat pump cycle and the heat engine cycle are executed consecutive.

[0012] A further aspect of the invention relates to a waste heat recovery system.

[0013] According to an embodiment of the invention, the system comprises a thermal storage circuit with a low temperature storage, a heat recovery storage and a high temperature storage. The storages may be tanks connected by lines in which the thermal storage medium is transferred by pumps and valves.

[0014] According to an embodiment of the invention, the system comprises a heat exchanger in the thermal storage circuit for heating a thermal storage medium flowing from the low temperature storage to the heat recovery storage. This heat exchanger may be used for heating thermal storage medium flowing from the low temperature storage to the heat recovery storage with a continuous waste heat source, for example flue gas. The heat recovery cycle of the system may comprise the heat exchanger, the low temperature storage and the heat recovery storage. Such, the heat recovery cycle may be adapted to execute the heat collection step mentioned above.

[0015] According to an embodiment of the invention, the system comprises a heat pump cycle containing a working fluid and comprising an expander for expanding the working fluid and a compressor for compressing the working fluid. The heat pump cycle further comprises a first heat exchanger for heating the expanded working fluid by cooling thermal storage medium from the heat recovery storage and a second heat exchanger for heating thermal storage medium flowing to the high temperature storage by cooling the compressed working fluid. With the heat pump cycle, the waste heat stored in the heat recovery storage may be upgraded to a higher temperature. Such, the heat pump cycle may be adapted to execute the upgrading step mentioned above.

[0016] According to an embodiment of the invention, the system comprises a heat engine cycle containing a working fluid and comprising a pump for compressing the working fluid and a turbine for expanding the working fluid. The heat engine cycle comprises a further heat exchanger for heating the compressed working fluid by cooling thermal storage medium flowing from the high temperature storage to the low temperature storage. The further heat exchanger may be the second heat exchanger used for heating the thermal storage medium.

[0017] Further, the heat engine cycle may comprise a (third) heat exchanger for cooling the expanded working fluid, for example a condenser. By expanding the working fluid, the turbine generates mechanical work that may be used for driving an electrical motor. Such, the heat engine cycle may be adapted to execute the energy generation step mentioned above.

[0018] The waste heat recovery system may be seen as a thermoelectric energy storage system that utilizes waste heat in a flue gas. The waste heat may be stored in the storages of the thermo electric storage system and may be used for generating electricity later. The operation of the thermo electric energy storage may utilize waste heat from flue gases or equivalent heat source.

[0019] The waste heat recovery system as described in the above and in the following may allow continuous harvesting (collecting) of waste heat whenever the heat is available, upgrading of the heat by a heat pump operating on demand at the time of cheap electricity, and on-demand production of electricity by heat engine.

[0020] The waste heat recovery system combines the concept of a thermoelectric energy storage, that may be based on a transcritical thermodynamic cycle, and the possibility of using low grade waste heat to improve the efficiency factor of the thermoelectric energy storage by partially recovering this waste heat.

[0021] The waste heat recovery system may elaborate the functionality of waste heat utilization with a thermoelectric energy storage in settings such as waste heat recovery from flue gases of combined cycle power plants.

[0022] It has to be understood that features of the method as described in the above and in the following may be features of the system as described in the above and in the following.

[0023] If technically possible but not explicitly mentioned, also combinations of embodiments of the invention described in the above and in the following may be embodiments of the method and the system.

[0024] These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0025] The subject matter of the invention will be explained in more detail in the following text with reference to exemplary embodiments which are illustrated in the attached drawings.

Fig.1 schematically shows the charging cycle of a thermoelectric energy storage for a heat recovery system according to an embodiment of the invention.

Fig.2 schematically shows the discharging cycle of a thermoelectric energy storage for a heat recovery system according to an embodiment of the invention.

Fig. 3 shows a diagram indicating an example of the heat pump cycle and heat engine cycle of the thermoelectric storage.

Fig. 4 schematically shows a heat recovery system according to an embodiment of the invention with the heat recovery cycle in operation.

Fig 5 shows a diagram indicating an example of a heat recovery cycle according to an embodiment of the invention.

Fig.6 schematically shows the heat recovery system of Fig. 4 with the heat pump cycle in operation.

Fig 7 shows a diagram indicating an example of a heat pump cycle according to an embodiment of the invention.

Fig.8 schematically shows the heat recovery system of Fig. 4 with the heat engine cycle in operation.

Fig 9 shows a diagram indicating an example of a heat engine cycle according to an embodiment of the invention.

Fig. 10 schematically shows the heat recovery system of Fig. 4 with the additional heat engine cycle in operation.

Fig. 11 schematically shows a heat recovery system according to a further embodiment of the invention with the heat recovery cycle in operation.

Fig. 12 schematically shows the heat recovery system of Fig. 11 with the heat pump cycle in operation.

Fig. 13 schematically shows the heat recovery system of Fig. 11 with the heat engine cycle in operation.

Fig. 14 shows a diagram indicating an example of a heat pump cycle and a heat engine cycle according to an embodiment of the invention.

[0026] The reference symbols used in the drawings, and their meanings, are listed in summary form in the list of reference symbols. In principle, identical parts are provided with the same reference symbols in the figures.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0027] In the following the concept of a thermoelectric energy storage based on a transcritical thermodynamic cycle will be explained with reference to Fig. 1, Fig. 2 and Fig. 3.

[0028] Fig.1 shows the charging cycle 12 or heat pump cycle 12 of a thermoelectric energy storage 10. The charging cycle 12 comprises an expander 14, a heat exchanger 16, a pump 18 and a heat exchanger 20 (in general, all heat exchangers mentioned in the above and in the following are counter current heat exchangers). The heat exchanger may be a gas cooler and gas heater for the working fluid. The thermoelectric energy storage 10 comprises further a thermal storage circuit 22 with a low temperature storage 24 and a high temperature storage 26. As indicated by the dashed line, thermal storage medium may flow from the low temperature storage 24 to the high temperature storage 26 (and vice versa). The charging cycle 12 contains a working fluid flowing through lines indicated by the continuous line. The working fluid heated by waste heat in the heat exchanger 16 and compressed by the compressor 18 is used for heating the thermal storage medium in the heat exchanger 20. After that the working fluid is expanded in the expander 14 and heated in the heat exchanger 26.

[0029] Fig. 2 shows the discharging cycle 28 or heat engine cycle 28 of the thermoelectric energy storage 10. The working fluid (dotted line) flows through a pump 30 compressing the working fluid, is heated in the heat exchanger 20 and expanded in a turbine 32 generating mechanical energy. After that, the working fluid is condensed in a condenser 31.

[0030] The operation of the thermoelectric energy storage 10 comprises two energy conversion modes. In the first mode (charging cycle 12), first the storage 22 is charged by a heat pump operation (low-temperature heat is upgraded to high-temperature heat by work of the compressor 18). The high-temperature heat may be stored for a time needed. When electricity production is required, the cycle 12 is reversed and the stored heat is used as a heat source for a heat engine (discharging cycle) 28 which produces electricity with a turbine 32 coupled with a generator.

[0031] The basic design of the thermoelectric energy storage 10 uses the storage of heat in hot water (the thermal storage medium) and CO_2 as the working fluid operating in a transcritical thermodynamic cycle. As a result, the storage 10 operates at rather low temperatures, and may benefit significantly from using low-grade waste heat (typical usable range of waste heat temperature about 40 to 100°C, or up to 400°C in some situations).

[0032] Fig. 2 shows an ideal T-s diagram of the thermoelectric energy storage 10 charged with utilization of waste heat at temperature T_{WH}. The vertical axis of the diagram indicates the temperature T, the vertical axis the entropy s. Further, in the diagram, lines indicating states of equal pressure (isobars) and lines of equal energy of the working fluid CO_2 are shown.

[0033] The T-s diagram shows an example of the charging and discharging processes of the thermoelectric storage 10. The charging cycle 12 is adapted to execute the charging process 34 and the discharging cycle 28 is adapted to execute the discharging process 38. The diagram of Fig. 3 is ideal and additional losses are present in a real system.

[0034] The charging process 34 is indicated by the dashed line, and uses a heat source at temperature T_{WH} (about 80 °C) to reduce the electric work needed to charge the storage (the work is proportional in the diagram to the area enclosed by the line outlining the charging process 34). In particular, in the compressor 18, the working fluid is heated isentropic from T_{WH} to T_H, the temperature of the high temperature storage 26 (about 130 °C), as indicated by temperature profile 34a. In the heat exchanger 20, the working fluid is cooled isobaric from T_H to T_L, the temperature of the low temperature storage (about 20 °C), as indicated by temperature profile 34b. After that the working fluid is expanded in the expander 14 isentropic to a temperature of about 15 °C (temperature profile 34c) and isobaric heated to T_{WH} in the heat exchanger 16 (temperature profile 34d).

[0035] By executing the discharging process 36, the discharging cycle 28 on the other hand may use the ambient at temperature T_A (about 10 °C) as a heat sink, which allows an increase of the electric work produced from the storage by the heat engine (proportional to the area enclosed by the discharging process 36). In particular, the working fluid is heated isobaric in the heat exchanger 20 from T_L to T_H, as indicated by temperature profile 36a. In the turbine 32, the working fluid is expanded isentropic from T_H to T_A (temperature profile 36b). In the condenser 31, the working fluid is condensed (temperature profile 36c) and after that compressed to T_L by pump 30 (temperature profile 36d). During the state changes of the temperature profiles 34b, 34d, 36a, the working fluid is transcritical since these temperature profiles are above the critical point of the working fluid.

[0036] The thermoelectric energy storage 10 described in the above and in the following is designed to fulfill functions and comply with constraints as follows:

> The system is to utilize waste heat in the range of temperatures of about 40 to 100°C in order to improve thermoelectric energy storage round-trip-efficiency (defined as ratio of the electric energy output to electric energy input to the system) at sites with waste heat available.
>
> The system allows electric energy storage, i.e. the system includes a mode of operation in which the recovered heat is further upgraded to a higher temperature by a heat pump, which consumes/stores the electric energy.

[0037] The considered waste heat sources may be frequently not timewise correlated with the ideal times to charge or discharge the thermoelectric energy storage 10. Therefore the system should allow harvesting of the waste heat energy whenever it is available, regardless of the other modes of operations of the thermoelectric energy storage 10.

[0038] Fig. 4, 6, 8 and 10 show a first embodiment of a heat recovery system 40. The heat recovery system comprises a thermoelectric energy storage 10 with a charging cycle 12 and a discharging cycle 28 similar to the cycles shown in Fig. 1 and Fig. 2.

[0039] The thermal storage circuit 22 further comprises a first intermediate temperature storage 42, a second intermediate temperature storage 44, a heat recovery storage 46 and a heat exchanger 48 for heating a stream of thermal storage medium flowing from the low temperature storage 24 to the heat recovery storage 46 with flue gas. The storages 24, 42, and 44 may be tanks at ambient pressure, wherein the storage 26 may be a pressurized tank in which liquid water with a temperature above 100 °C may be stored.

[0040] The storages 42, 44 are used for better matching the temperature profile of the thermal storage medium in the heat exchanger 20 with the temperature profile of the working fluid. Therefore, the heat exchanger 20 is a split stream heat exchanger 20 and the storages 42, 44 are connected to the heat exchanger 20 such that a stream between the low temperature storage 24 and the high temperature storage 26 may be split into two streams with one stream redirected to one of the storages 42, 44 or may be joined with a stream from one of the storages 42, 44.

[0041] Mechanical work may be introduced into the system over a motor 52, which drives the compressor 18. The mechanical work generated by the turbine 32 may be converted into electricity by a generator 54.

[0042] Cooling water 56 at ambient temperature, for example from a river, is used as medium for cooling the working fluid in the condenser 31.

[0043] The heat recovery system 40 and the thermoelectric energy storage system 10 are designed to operate in four modes of operation that can be combined depending on the momentary availability of the waste heat and the cost of electricity.

[0044] The first mode or the heat recovery cycle 54 of the system 40 for the recovery of waste heat will be explained with respect to Fig. 4 and Fig. 5.

[0045] The heat recovery cycle 54 operates whenever the waste heat source is available, for example the waste heat source is a flue gas. The heat from the flue gas is transferred into the water that is pumped from the low temperature storage (at a temperature T_L of 38°C) to an intermediate storage, the heat recovery storage 46 (at a temperature T_R of 100°C), storing the water that was heated by the heat recovered from the waste heat source.

[0046] Fig. 4 shows a diagram analog to the diagram of Fig. 3 with a temperature profile 56 of the flue gas and a temperature profile 58 of the water used as thermal storage medium in the heat exchanger 48. The temperature profiles 56, 58 may be seen in relation to the isobars of the CO_2 used as working fluid in the heat pump cycle 12 and the heat engine cycle 28. While the flue gas cools down from a temperature T_{FG1} above the temperature T_R to a temperature T_{FG2} above the temperature T_L, the water heats up from T_L to T_R.

[0047] In many cases the waste heat source will be available practically continuously (base load coal power plants, geothermal or depleted geothermal sources, industrial waste heat, etc.), but in some cases it will be available for harvesting only during a part of the day (for example at peak power plants or waste heat from intermittent industrial processes).

[0048] The second mode or the heat pump cycle 12 of the system 40 for the upgrade of heat by a heat pump will be explained with respect to Fig. 6 and Fig. 7.

[0049] In the heat pump cycle 12, the heat in the hot water stored in the heat recovery storage 46 is upgraded by operating the CO_2 heat pump. In this mode the heat pump cycle 12 consumes electric energy, converting it into heat at a higher grade (i. e. a higher temperature) than the heat recovered from the waste heat source.

[0050] In the heat recovery cycle 12, water from the storage 46 at 100°C is pumped through the countercurrent heat exchanger 16 to heat CO_2 that is the heat pump working fluid. The water is cooled to 38°C and stored in the low temperature storage 24. On the CO_2 side the temperature of the CO_2 is increased by the compressor 18 to about 125°C, and the heat is transferred with the heat exchanger 20 to water stored in the storages 24, 42, 44, 26.

[0051] The heat exchanger 20 comprises a split stream system with a low temperature part 20a, an intermediate part 20b and a high temperature part 20c connected together in series. During charging of the system 10, thermal storage medium flows from the low temperature storage 24 through the parts 20a, 20b, 20c to the high temperature storage 26. The first intermediate temperature storage 42 is connected between the parts 20a and 20b with a and the second intermediate temperature storage 44 is connected between the parts 20b and 20c.

[0052] The heat recovery system 40 is adapted to generate different flowrates in the different parts 20a, 20b, 20c of the heat exchanger joining streams of thermal storage medium from the intermediate storages 42, 44 with a stream between the low temperature storage 24 and the high temperature storage 26 and/or by splitting this stream into two stream and redirecting one of the two stream into one of the intermediate storages 42, 44.

[0053] The second Mode or the heat pump process may be operated at times of cheap electricity. The net electric power absorbed by the heat pump cycle is proportional to the temperature difference of the heat recovered from the flue gases (or other heat source) and the desired temperature of the hot water storage and the amount of water heated by the heat pump cycle.

[0054] Fig. 7 shows a diagram analog to the diagrams of Fig. 3 and Fig. 5, with a temperature profile 34 of the working fluid in the CO2 heat pump cycle 12, a temperature profile 60 of the thermal storage medium in the heat exchanger 16 and a temperature profile 62 of the thermal storage medium in the heat exchanger 20.

[0055] The thermal storage medium in the heat exchanger 16 flowing from the heat recovery storage 46 to the low temperature storage 24 is cooled from T_R (about 38 °C) to T_L (about 100 °C), while the working fluid is heated isobaric from a slight lower temperature as T_R

[0056] (about 35 °C) to a slight lower temperature as T_L (about 95 °C). This is indicated by the temperature profiles 60 and 34d. In principle, the temperature profile 60 is the reverse temperature profile 58 of Fig. 5.

[0057] Due to the split stream heat exchanger 20, the temperature profile 34b of the working fluid is matched with the temperature profile 62 of the thermal storage medium. In the first part 20a of the heat exchanger 20, the thermal storage medium is heated from T_L (about 38°C) to T_{I1} (about 50 °C, temperature profile 62a) while the working fluid is cooled from a temperature slightly higher as T_{I1} (about 52 °C) to a temperature slightly higher as T_L (about 40 °C). In the second part 20b, the thermal storage medium is heated from T_{I1} to T_{I2} (about 75 °C, temperature profile 62b) while the working fluid is cooled from a temperature slightly higher as T_{I2} (about 80 °C) to the temperature slightly higher as T_{I1}. In the third part 20c, the thermal storage medium is heated from T_{I2} to T_H (about 120 °C, temperature profile 62c) while the working fluid is cooled from a temperature slightly higher as T_H (about 130 °C) to the temperature slightly higher as T_{I2}.

[0058] The work lost in the charging cycle 12 is the area in the diagram between the temperature profile of the working fluid and the temperature profile of the thermal storage medium. Due to the matching of the profiles 34b and 62, this work is minimized and the efficiency factor of the heat pump cycle 12 is increased.

[0059] The third mode or the heat engine cycle 28 of the system 40 for the generation of electricity from the upgraded heat will be explained with respect to Fig. 8 and Fig. 9.

[0060] In the third mode the heat engine cycle 28 is run to produce electricity from the upgraded heat produced by the second mode. The water stored at the temperature TH and the split stream tanks 42, 44 is used to heat pressurized CO_2 that circulates in the heat engine circuit 28. The CO_2 subsequently expands in the turbine 32 to produce electricity in the generator 54. The CO_2 is condensed by cooling medium available externally, for example river water 56 or by air coolers 56.

[0061] Fig. 9 shows a diagram analog to the diagrams of Fig. 3, 5 and 7, with a temperature profile 36 of the working fluid in the CO_2 heat engine cycle 28, a temperature profile 64 of the thermal storage medium in the heat exchanger 20 and a temperature profile 66 of the condenser cooling water in the condenser 56.

[0062] Due to the split stream heat exchanger 20, the temperature profile 36a of the working fluid is matched with the temperature profile 64 of the thermal storage medium. Due to the matching of the profiles 36a and 64, the work lost is minimized and the efficiency factor of the heat engine cycle 28 is increased.

[0063] In the first part 20a of the heat exchanger 20, the thermal storage medium is cooled from T_{I1} to T_L (temperature profile 64a) while the compressed working fluid is heated from a temperature slightly lower as T_L (about 34 °C) to a temperature slightly higher as T_{I1} (about 45 °C). In the second part 20b, the thermal storage medium is cooled from T_{I2} to T_{I1} (temperature profile 64b) while the working fluid is heated from the temperature slightly lower as T_{I1} to a temperature slightly lower as T_{I2} (about 72 °C). In the third part 20c, the thermal storage medium is cooled from T_H to T_{I2} (temperature profile 64c) while the working fluid is heated from the temperature slightly lower as T_{I2} to a temperature slightly lower as T_H (about 117 °C). In principle, the temperature profiles 64a, 64b and 64 c are the reverse temperature profiles 62a, 62b and 62c of Fig. 7.

[0064] The expanded working fluid in the condenser 31 is condensed at about 20 °C, while being cooled with a cooling medium with a temperature profile 66.

[0065] The third mode may be normally operated at times of highest electricity prices.

[0066] The forth mode or an additional heat engine cycle 68 of the system 40 for the (direct) generation of electricity from recovered heat will be explained with respect to Fig. 10.

[0067] In the forth mode or the additional heat engine cycle 68 the heat recovered in the first mode 12 (in the heat recovery cycle 54), i. e the non-upgraded heat, is used for electricity production. The forth mode may be run as needed from the point of view of optimal operation of the plant (for example to fully use the heat that is not upgraded). Alternatively, it can be used to continuously produce electricity from the waste heat recovery if that is preferred (except when the third mode, i. e. the heat engine cycle 28, is running). Hence, the first mode and the forth mode may run in parallel, if the heat is available continuously during peak demand.

[0068] The heat exchanger 20 has a further split (i.e. is equipped with suitable valves and stream splitters to redirect the flow) between a part 20d and a part 20e. The split between the parts 20d and 20e is in the part 20c of the heat exchanger 20. A stream of storage medium from the heat recovery storage 46 to the low temperature storage 24 is heating the working fluid in the heat pump cycle 28.

[0069] The operation modes as described in the above may be combined. All the modes may run in parallel in principle (for example, if a separate heat exchanger is used in the heat engine cycle 28 and the heat pump cycle 28).

[0070] The third and forth mode may run in parallel, only if the heat engine cycle 28 may be specifically designed for that purpose (in particular the turbine 32).

[0071] The second and forth mode may be in practice exclusive on economical basis.

[0072] The forth mode might not be used, if the thermoelectric energy storage operation is optimized in such a way that all the heat is always upgraded by the second Mode and used in the third mode.

[0073] Fig. 12, 13 and 14 show a second embodiment of a heat recovery system 140. The main difference between the heat recovery system 40 and the heat recovery system 140 is that the heat recovery storage 46 has been unified with the second intermediate storage 44 to the storage 146 and the heat exchanger 28 has been replaced by a split stream heat exchanger 128 receiving thermal storage medium from the first intermediate storage 42.

[0074] The heat recovery system 140 is designed to minimize the specific consumption of electric energy during charging, i.e. to maximize the round-trip efficiency of the storage (round trip efficiency may be defined as the electric energy discharged from the storage to the electric energy input to the storage during charging).

[0075] In Fig. 14 a T-s diagram with ideal cycles representing the charging cycle or process 134 and the discharging cycle or process 136 is shown. The diagram in Fig. 14 is similar to the diagram diagram in Fig. 3 showing the charging and discharging of the thermoelectric energy storage 10 with the usage of waste heat at temperature T_{WH}. The temperature profile 134a, 134b, 134c, 134d, 136a, 136b 136c or 136d corresponds to the respective temperature profile 34a, 34b, 34c, 34d, 36a, 36b 36c or 36d in Fig. 3, only the temperatures may be different.

[0076] The work needed for charging or discharging is proportional to the area enclosed by the cycles 134, 136. To maximize the round trip efficiency, the charging work should be minimized given the underlying constraints, such as the temperature T_{WH} of the available waste heat.

[0077] In this embodiment, the waste heat is available at temperature T_{WH} (around 75°C). In the embodiment of the heat recovery system shown in the Fig. 4 to 10, the waste heat has a temperature T_{WH} above the boiling temperature of water, thus the water may be heated up to 100 °C under ambient pressure. In the present embodiment, the temperature T_{WH} may be lower. The cold temperature for condensation in the condenser 31 of the heat engine is assumed at T_C of about 15°C.

[0078] The storage 26 for upgraded heat is assumed at a temperature T_H of 120°C. For high efficiency, the thermodynamic cycles require furthermore heat sources/sinks at a temperature T_L of about 30°C (point VII in the T-s diagram) and a temperature of about T_{I1} 50°C (point I in the diagram). These sources and sinks are provided by the low temperature storage 24 and the intermediate storage 42.

[0079] Given the storage temperature T_H (120°C) and the waste heat source temperature T_{WH} (75°C), together with the requirement to close the charging and discharging cycles, the highest round trip efficiency is achieved (in ideal case) if the points II and IV in the charging diagram are at the same temperature, corresponding to the same water tank. Thus, the storage 146 is used as heat recovery storage and second intermediate storage.

[0080] The heat recovery system 140 is designed to operate in three modes of operation that can be combined depending on the momentary availability of the waste heat and the cost of electricity.

[0081] The first mode or the heat recovery cycle 54 of the system 40 for the recovery or harvesting of waste heat will be explained with respect to Fig. 11.

[0082] In a closed system, the other modes (the heat pump cycle 12 and the heat engine cycle 28) need the correct ratios of thermal storage medium in the different storages 24, 42, 146, 26, when the correct ratios of flowrates in the parts 20a, 20b, 20c of the heat exchanger 20 should be set and none of the storages 24, 42, 146, 26 should run out of thermal storage medium.

[0083] In this case, the heat harvesting process 54 needs to upgrade heat from the lowest two storages 24, 42 (in the example at temperatures of 30 and 50°C) to the intermediate storage 146 at 75°C. This is performed in the heat exchanger 148 with a single split at 50°C that allows joining the streams from tanks at 30 and 50°C.

[0084] As in the first mode of recovery system 40, the thermal storage medium is heated by a flue gas to the temperature of the storage 146.

[0085] The second mode or the heat pump cycle 12 of the system 140 for the upgrade of heat by a heat pump will be explained with respect to Fig. 12.

[0086] The water from the intermediate storage tank 146 at $T_{HW} = T_R = T_{I2}$ (about 75°C) is used for two purposes: A first part of the water is used as the heat source in the evaporator (heat exchanger) 16 of the heat pump cycle 12. In the heat exchanger 16, the water is cooled to T_{I1} (about 50°C) in this process and stored back in the storage 42. Another part of the water is heated from 75°C to 120°C in the gas cooler of the heat pump (heat exchanger 20, in particular its part 20c) and stored in the high temperature storage 26 for discharging.

[0087] The heat pump cycle 12 operates in this point as a reversed Brayton cycle, and is principally used to split the water at $T_{WH} = T_{I2}$ (75°C) to the high and low temperature levels T_{I1} and T_{I2}, absorbing the electric energy to be stored by compressor work.

[0088] The third mode or the heat engine cycle 28 of the system 140 for the generation of electricity from the upgraded heat will be explained with respect to Fig. 13.

[0089] The discharging process or heat engine cycle 28 is up to the temperatures close to that in the embodiment shown in Fig. 8 and 9, and also the thermodynamic cycle is ideally the same. During this process, water will be used from storages 26 and 146 at temperatures T_H (120 °C) and T_{I2} (75°C), cooled and stored back in storages 24 and 42 at T_L (30 °C) and T_{I2} (50°C). In the next storage sequence, the cooled water will be re-heated to 75°C in the first mode.

[0090] If the waste heat source is at high enough temperature T_{WH}, the forth mode of the heat recovery system 140 (i.e. discharging from the intermediate storage temperature T_{I2}) may also be implemented with the heat recovery system 40.

[0091] The capacity and length of operation of the different modes is a matter of optimization of the thermoelectric energy storage plant. The power of the charging or discharging may be independently designed to fit favorably to the periods of cheap and expensive electricity and the availability of waste heat at given site.

[0092] The heat recovery system 40, 140 described here is an open system and may require external cooling for condensation of the working fluid in discharging modes, e.g. by air coolers, or external water for cooling.

[0093] The example considered here uses heat extracted from flue gases from a gas fired combined cycle plant as the heat source, but in principle any source of heat at suitable temperatures (temperature range from about 30°C and above can be considered, depending on the temperature of the cold sink) with sufficient energy available can be applicable.

[0094] The heat sources may include flue gases from coal fired power plants, combined heat and power plants when heat is not used (if properly designed the hot water storage can be shared with the CHP system, using the hot water for electricity generation or heating, depending on demand), incineration plants, geothermal heat sources (including depleted geothermal sites), and industrial waste heat. Other options include synergies with solar power plants, urban waste heat (e.g. sewage), and utilization of temperature difference between deep sea, surface sea and air temperature.

[0095] To summarize, according to an embodiment of the invention, the method for recovering of waste heat, comprises the steps of: in the heat recovery cycle 54, heating a thermal storage medium with waste heat from a continuous waste heat source to a heat recovery temperature T_R; in the heat pump cycle (12, transferring heat from the thermal storage medium at the heat recovery temperature T_R via a working fluid to a thermal storage medium at the temperature T_H above the heat recovery temperature T_R; and in the heat engine cycle 28, transferring heat in the thermal storage medium of the high temperature T_H to a working fluid and generating mechanical energy by expanding the working fluid.

[0096] According to an embodiment of the invention, in the heat recovery cycle 28, a thermal storage medium at a low temperature T_L is heated to the heat recovery temperature T_R in the heat exchanger 16.

[0097] According to an embodiment of the invention, in the heat pump cycle 12, the expanded working fluid is heated by cooling the thermal storage medium of the heat recovery temperature T_R to the low temperature T_L.

[0098] According to an embodiment of the invention, in the heat pump cycle 12, a stream of thermal storage medium with a first flowrate at the low temperature T_L is heated by the compressed working fluid to a first intermediate temperature T_{I1}, wherein the stream with a first flowrate is mixed with a stream of thermal storage medium of a second intermediate temperature T_{I2} or is split into two flows to generate a stream of thermal storage medium of a second flowrate, wherein the stream of the second flowrate is heated by the compressed working fluid to the high temperature T_H.

[0099] According to an embodiment of the invention, the high temperature T_H, the intermediate temperature T_{I1}, T_{I2} and the low temperature the first flowrate and the second flowrate are set, such that a temperature profile 62, 64 of the thermal storage medium during heating or cooling is matched with a temperature profile 34b, 36a of the working fluid. In such a way, by minimizing the area between the temperature profiles, the efficiency of the heat pump cycle 12 and the heat engine cycle 28 may be increased. For example, a maximum temperature difference between the thermal storage medium and the working fluid may be kept below 20%, in particular below 15%, of the temperature difference between the low temperature storage 24 and the high temperature storage 26.

[0100] According to an embodiment of the invention, in the heat recovery cycle 54, a thermal storage medium at a low temperature T_L is heated with waste heat, mixed with a thermal storage medium at a first intermediate temperature T_{I1} and heated to the heat recovery temperature T_R, which is the second intermediate temperature T_{I2}.

[0101] According to an embodiment of the invention, in the heat pump cycle 12, the expanded working fluid is heated by cooling a first stream of thermal storage medium at the second intermediate temperature TI2 to the first intermediate temperature T_{I1}.

[0102] According to an embodiment of the invention, in the heat pump cycle 12, a second stream of thermal storage medium at the second intermediate temperature T_{I2} is heated by the compressed working fluid to the high temperature T_H.

[0103] According to an embodiment of the invention, in the heat pump cycle 12, the working fluid is compressed in a compressor 18 by an electrical motor 52, for example by using surplus electrical energy whenever available.

[0104] According to an embodiment of the invention, in the heat engine cycle 28, the thermal storage medium of high temperature T_H is cooled by the compressed working fluid to a second intermediate temperature T_{I2} and mixed with a working fluid of the second intermediate temperature T_{I2} to generate a different flowrate.

[0105] According to an embodiment of the invention, in the heat engine cycle 28, the thermal storage medium of the second intermediate temperature T_{I2} is cooled to a first intermediate temperature T_{I1} and split into two streams to generate a further different flowrate, wherein one of the streams is cooled by the working fluid to the low temperature T_L.

[0106] According to an embodiment of the invention, in the heat engine cycle 28 and/or the heat pump cycle 12, during heat transfer between the working fluid and the thermal storage medium, the working fluid is transcritical (i. e. has a temperature between the low and the high temperature that are set such that the working fluid is transcritical during heat transfer).

[0107] According to an embodiment of the invention, in the heat engine 28 cycle and/or the heat pump cycle 12, during heat transfer between the working fluid and the thermal storage medium, a flowrate of the thermal storage medium between a low and an intermediate temperature and a flowrate of the thermal storage medium between the intermediate and a high temperature are set, such that during heat transfer, the maximal temperature difference between the thermal storage medium and the working fluid is minimal (for example below 10 °C).

[0108] According to an embodiment of the invention, the method comprises further the step of: in an additional heat engine cycle 68, transferring heat in the thermal storage medium with the heat recovery temperature T_R to a compressed working fluid and generating mechanical energy by expanding the working fluid.

[0109] According to an embodiment of the invention, in the heat engine cycle 28 or the additional heat engine cycle 68, the working fluid is expanded in a turbine 32 driving an electrical generator 54.

[0110] According to an embodiment of the invention, the thermal storage medium is or comprises water.

[0111] According to an embodiment of the invention, the working fluid is or comprises carbon dioxide.

[0112] According to an embodiment of the invention, a waste heat recovery system 40, 140 comprises a thermal storage circuit 22 with a low temperature storage 24, a heat recovery storage 46, 146 and a high temperature storage 26; a heat exchanger 48, 148 for heating a thermal storage medium flowing from the low temperature storage 24 to the heat recovery storage 46, 146 with waste heat; a heat pump cycle 12 containing a working fluid and comprising an expander 14 for expanding the working fluid and a compressor 18 for compressing the working fluid; and a heat engine cycle 28 containing a working fluid and comprising a pump 30 for compressing the working fluid and a turbine 32 for expanding the working fluid.

[0113] According to an embodiment of the invention, the heat pump cycle 12 comprises a heat exchanger 16 for heating the expanded working fluid by cooling thermal storage medium from the heat recovery storage 46, 146.

[0114] According to an embodiment of the invention, the heat pump cycle 12 comprises a second heat exchanger 20 for heating thermal storage medium flowing to the high temperature storage 26 by cooling the compressed working fluid.

[0115] According to an embodiment of the invention, the heat engine cycle 28 comprises a second heat exchanger 20 for heating the compressed working fluid by cooling thermal storage medium flowing from the high temperature storage 26 to the low temperature storage 24.

[0116] According to an embodiment of the invention, the heat engine cycle 28 comprises a condenser 31 for cooling the expanded working fluid.

[0117] According to an embodiment of the invention, the second heat exchanger 20 for cooling or heating the compressed working fluid of the heat pump cycle 12 and/or the heat engine cycle 28 comprises an internal stream splitter for generating different flowrates in the heat exchanger 20 during heat transfer, wherein the stream splitter mixes a stream of thermal storage medium in the heat exchanger 20 with thermal storage medium from an intermediate temperature storage 42, 44, 146 or splits the stream in the heat exchanger 20 into a stream to be further heated and a stream to the intermediate temperature storage 42, 44, 146.

[0118] According to an embodiment of the invention, in the heat pump cycle 12 cooled thermal storage medium from the heat recovery storage 46 is cooled to the low temperature T_L and flows to the low temperature storage 24.

[0119] According to an embodiment of the invention, in the heat pump cycle 12 thermal storage medium from the low temperature storage 24 flows through the second heat exchanger 20 and is heated to the high temperature T_H.

[0120] According to an embodiment of the invention, the thermal storage circuit comprises a first intermediate temperature storage 42 and the heat recovery storage 146 is a second intermediate temperature storage.

[0121] According to an embodiment of the invention, in the heat recovery cycle 54, thermal storage medium from the low temperature storage 24 and the first intermediate temperature storage 42 is mixed while being heated to the second intermediate temperature T_{I2} for the second intermediate temperature storage 146.

[0122] According to an embodiment of the invention, in the heat pump cycle 12, thermal storage medium from the second intermediate temperature storage 146 is cooled in the first heat exchanger 16 to the first intermediate temperature T_{I1} for the first intermediate temperature storage 42.

[0123] According to an embodiment of the invention, in the heat pump cycle 12, thermal storage medium from the second intermediate temperature storage 146, i. e. the heat recovery storage, is heated by the compressed working fluid to the high temperature T_H for the high temperature storage 26.

[0124] While the invention has been illustrated and described in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art and practising the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the word "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. A single processor or controller or other unit may fulfil the functions of several items recited in the claims. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference symbol in the claims should not be construed as limiting the scope.

LIST OF REFERENCE SYMBOLS

[0125]

10	thermoelectric storage system
12	charging cycle / heat pump cycle
14	expander
16	heat exchanger
18	compressor
20	heat exchanger
22	thermal storage circuit
24	low temperature storage
26	high temperature storage
28	discharging cycle / heat engine cycle
30	pump
31	condenser
32	turbine
34, 134	charging process, temperature profile of working fluid
36, 136	discharging process, temperature profile of working fluid
40, 140	heat recovery system
42	first intermediate temperature storage
44	first intermediate temperature storage
46, 146	heat recovery storage
48, 148	heat exchanger
50	motor
52	generator
54	heat recovery cycle
56	temperature profile of flue gas
58	temperature profile of thermal storage medium
60	temperature profile of thermal storage medium
62	temperature profile of thermal storage medium
64	temperature profile of thermal storage medium
66	temperature of cooling medium
68	additional heat engine cycle

Claims

1. A method for recovering of waste heat, comprising the steps of:

in a heat recovery cycle (54), heating a thermal storage medium with waste heat from a continuous waste heat source to a heat recovery temperature (T_R);
in a heat pump cycle (12), transferring heat from the thermal storage medium at the heat recovery temperature (T_R) via a working fluid to a thermal storage medium at a temperature (T_H) above

the heat recovery temperature (T_R);
in a heat engine cycle (28), transferring heat in the thermal storage medium of the high temperature (T_H) to a working fluid and generating mechanical energy by expanding the working fluid.

2. The method of claim 1,
wherein in the heat recovery cycle (28), a thermal storage medium at a low temperature (T_L) is heated to the heat recovery temperature (T_R).

3. The method of claim 1 or 2,
wherein in the heat pump cycle (12), the working fluid is heated by cooling the thermal storage medium of the heat recovery temperature (T_R) to a low temperature (T_L).

4. The method of one of the preceding claims,
wherein in the heat pump cycle (12), a stream of thermal storage medium with a first flowrate at a low temperature (T_L) is heated by the working fluid to a first intermediate temperature (T_{I1}),
wherein the stream with a first flowrate is mixed with a stream of thermal storage medium or is split into two flows to generate a stream of thermal storage medium of a second flowrate,
wherein the stream of the second flowrate is heated by the working fluid to the high temperature (T_H).

5. The method of claim 1,
wherein in the heat recovery cycle (54), a thermal storage medium at a low temperature (T_L) is heated with waste heat, mixed with a thermal storage medium at a first intermediate temperature (T_{I1}) and heated to the heat recovery temperature (T_R), which is a second intermediate temperature (T_{I2}).

6. The method of claim 5,
wherein in the heat pump cycle (12), the working fluid is heated by cooling a first stream of thermal storage medium at the second intermediate temperature (T_{I2}) to the first intermediate temperature (T_{I1});
wherein in the heat pump cycle (12), a second stream of thermal storage medium at the second intermediate temperature (T_{I2}) is heated by the working fluid to the high temperature (T_H).

7. The method of one of the preceding claims,
wherein in the heat engine cycle (28), the thermal storage medium of high temperature (T_H) is cooled by the working fluid to a second intermediate temperature (T_{I2}) and mixed with a working fluid of the second intermediate temperature (T_{I2}) to generate a different flowrate;
wherein in the heat engine cycle (28), the thermal storage medium of the second intermediate temperature (T_{I2}) is cooled to a first intermediate temperature (T_{I1}) and split into two streams to generate a further different flowrate, wherein one of the streams is cooled by the working fluid to the low temperature (T_L).

8. The method of one of the preceding claims,
wherein in the heat engine cycle (28) and/or the heat pump cycle (12), during heat transfer between the working fluid and the thermal storage medium, the working fluid is transcritical.

9. The method of one of the preceding claims,
wherein in the heat engine (28) cycle and/or the heat pump cycle (12), during heat transfer between the working fluid and the thermal storage medium, a flowrate of the thermal storage medium between a low and an intermediate temperature and a flowrate of the thermal storage medium between the intermediate and a high temperature are set, such that during heat transfer, the maximal temperature difference between the thermal storage medium and the working fluid is minimal.

10. The method of one of the preceding claims, further comprising the step of:

in an additional heat engine cycle (68), transferring heat in the thermal storage medium with the heat recovery temperature (T_R) to a compressed working fluid and generating mechanical energy by expanding the working fluid.

11. The method of one of the preceding claims,
wherein the working fluid comprises carbon dioxide.

12. A waste heat recovery system (40, 140), comprising:

a thermal storage circuit (22) with a low temperature storage (24), a heat recovery storage (46, 146) and a high temperature storage (26);
a heat exchanger (48, 148) for heating a thermal storage medium flowing from the low temperature storage (24) to the heat recovery storage (46, 146) with waste heat;
a heat pump cycle (12) containing a working fluid and comprising an expander (14) for expanding the working fluid and a compressor (18) for compressing the working fluid,
a heat engine cycle (28) containing a working fluid and comprising a pump (30) for compressing the working fluid and a turbine (32) for expanding the working fluid;
wherein the heat pump cycle (12) comprises a heat exchanger (16) for heating the expanded working fluid by cooling thermal storage medium from the heat recovery storage (46, 146);
wherein the heat pump cycle (12) comprises a heat exchanger (20) for heating thermal storage medium flowing to the high temperature storage

(26) by cooling the compressed working fluid; wherein the heat engine cycle (28) comprises a heat exchanger (20) for heating the compressed working fluid by cooling thermal storage medium flowing from the high temperature storage (26) to the low temperature storage (24).

13. The system (40, 140) of claim 12, wherein the heat exchanger (20) for cooling or heating the compressed working fluid comprises an internal stream splitter for generating different flowrates in the heat exchanger (20) during heat transfer, wherein the stream splitter mixes a stream of thermal storage medium in the heat exchanger (20) with thermal storage medium from an intermediate temperature storage (42, 44, 146) or splits the stream in the heat exchanger (20) into a stream to be further heated and a stream to the intermediate temperature storage (42, 44, 146).

14. The system (40) of claim 12 or 13, wherein in the heat pump cycle (12) cooled thermal storage medium from the heat recovery storage (46) is cooled to the low temperature (T_L) and flows to the low temperature storage (24); wherein in the heat pump cycle (12) thermal storage medium from the low temperature storage (24) flows through the (second) heat exchanger (20) and is heated to the high temperature (T_H).

15. The system (140) of claim 12 or 13, wherein the thermal storage circuit comprises a first intermediate temperature storage (42) and the heat recovery storage (146) is a second intermediate temperature storage; wherein, in the heat recovery cycle (54), thermal storage medium from the low temperature storage (24) and the first intermediate temperature storage (42) is mixed while being heated to the second intermediate temperature (T_{I2}) for the second intermediate temperature storage (146); wherein, in the heat pump cycle (12), thermal storage medium from the second intermediate temperature storage (146) is cooled in the (first) heat exchanger (16) to the first intermediate temperature (T_{I1}) for the first intermediate temperature storage (42); wherein, in the heat pump cycle (12), thermal storage medium from the second intermediate temperature storage (146) is heated by the compressed working fluid to the high temperature (T_H) for the high temperature storage (26).

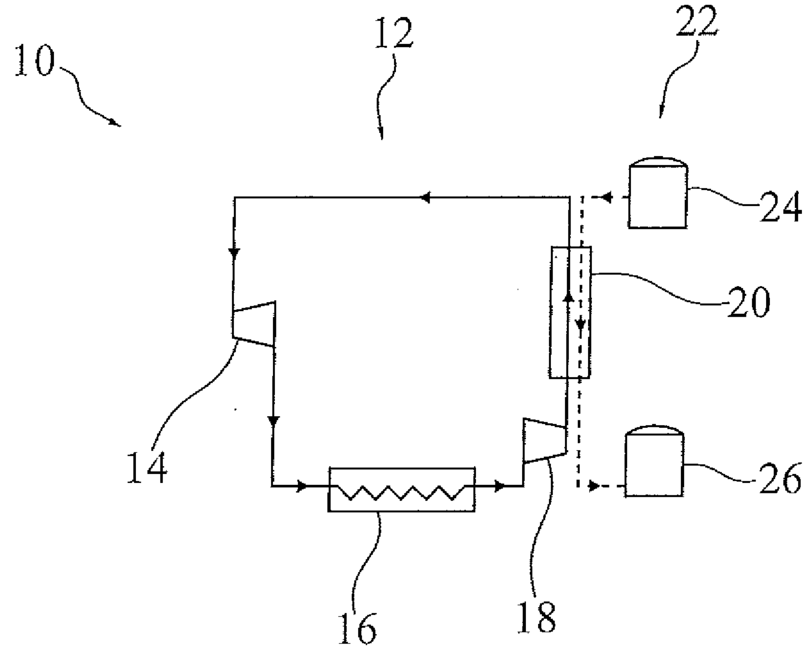


Fig. 1

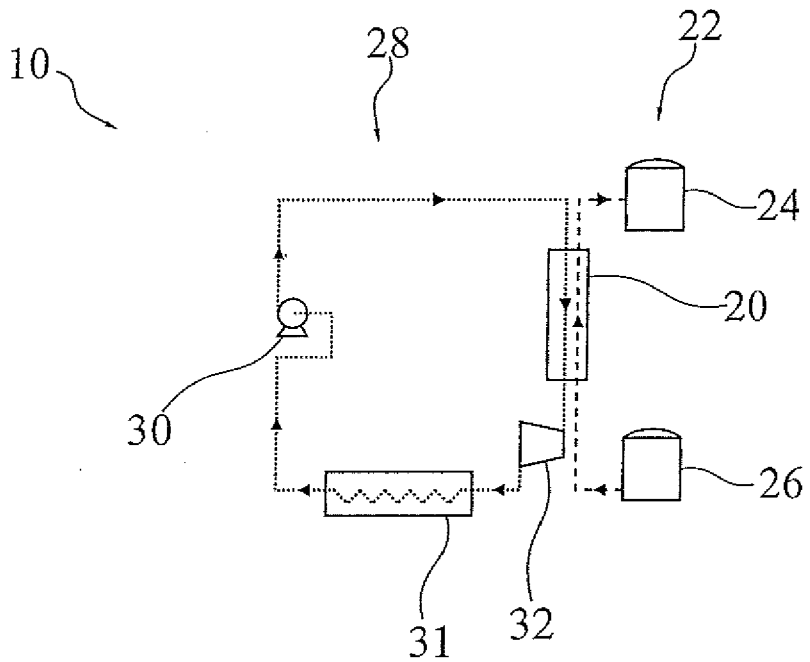


Fig. 2

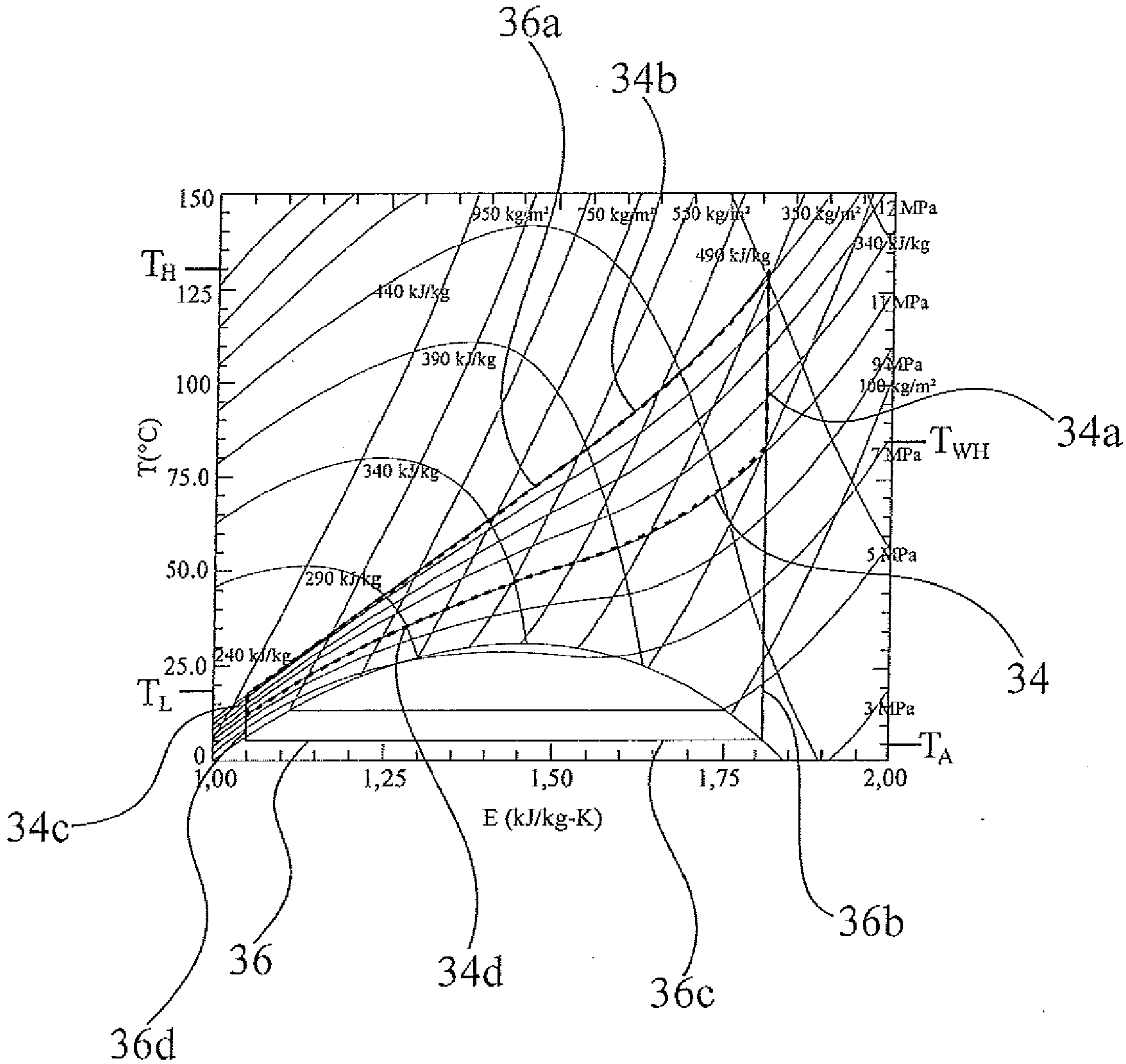

36a
34b
150
125
100
75.0
50.0
25.0
0
T(°C)
T_H
T_L
950 kg/m³
750 kg/m³
550 kg/m³
350 kg/m³
12 MPa
340 kJ/kg
490 kJ/kg
440 kJ/kg
17 MPa
390 kJ/kg
9 MPa
100 kg/m³
T_{WH}
34a
340 kJ/kg
7 MPa
290 kJ/kg
5 MPa
34
240 kJ/kg
3 MPa
T_A
1,00
1,25
1,50
1,75
2,00
E (kJ/kg-K)
34c
36b
36
34d
36c
36d

Fig. 3

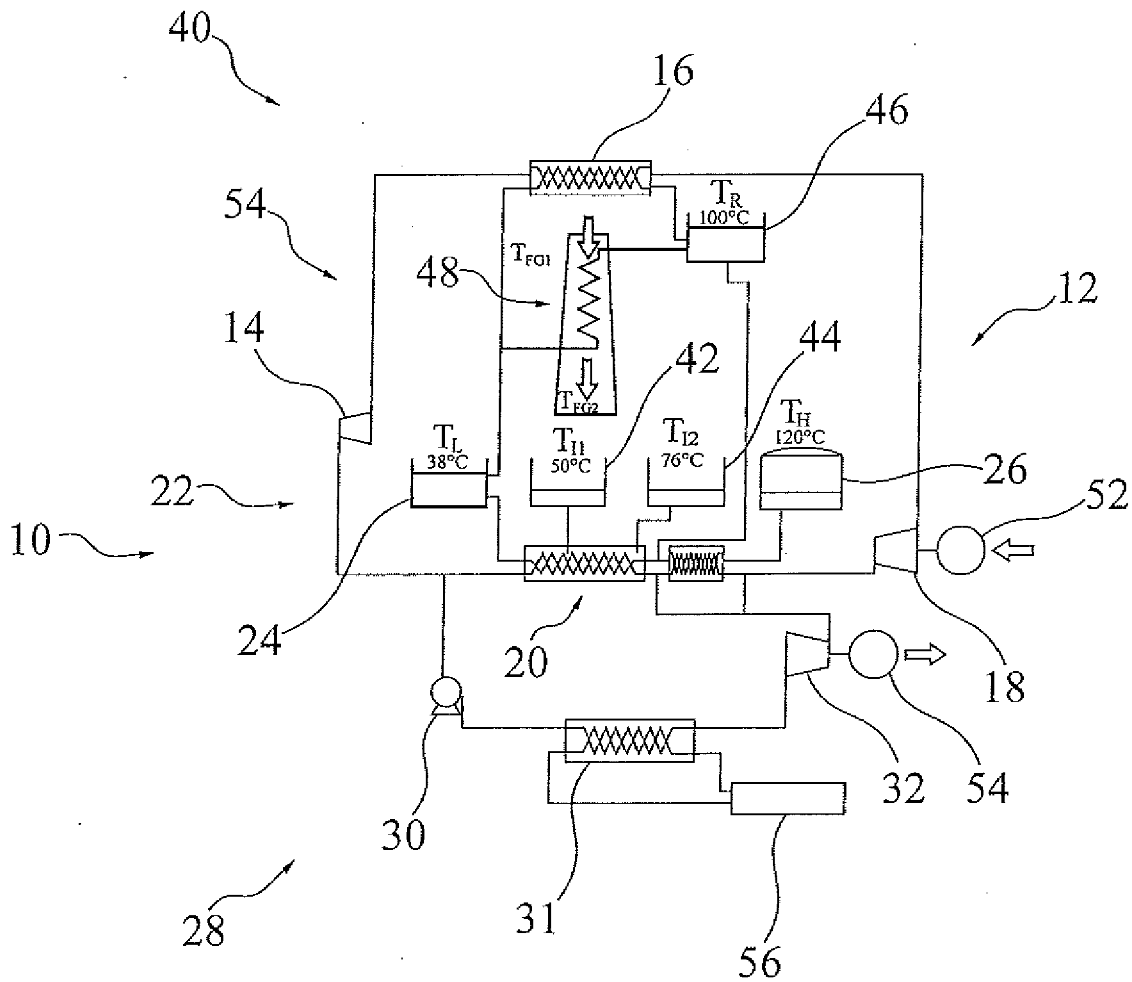
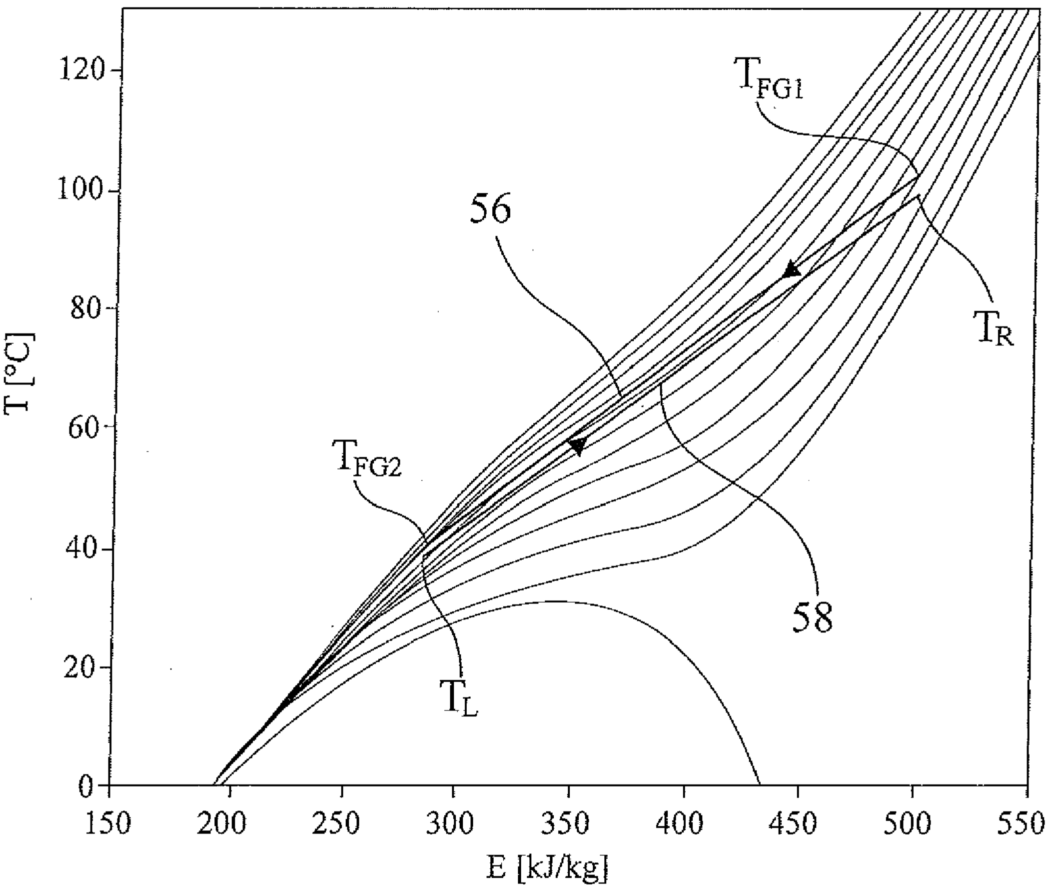

40
16
46
54
T_R
100°C
T_{FG1}
48
12
14
44
42
T_{FG2}
T_H
120°C
T_L
38°C
T_{I1}
50°C
T_{I2}
76°C
26
52
22
10
24
20
18
30
32
54
28
31
56

Fig. 4



120
100
80
60
40
20
0
T [°C]
150
200
250
300
350
400
450
500
550
E [kJ/kg]
T_{FG1}
56
T_R
T_{FG2}
58
T_L

Fig. 5

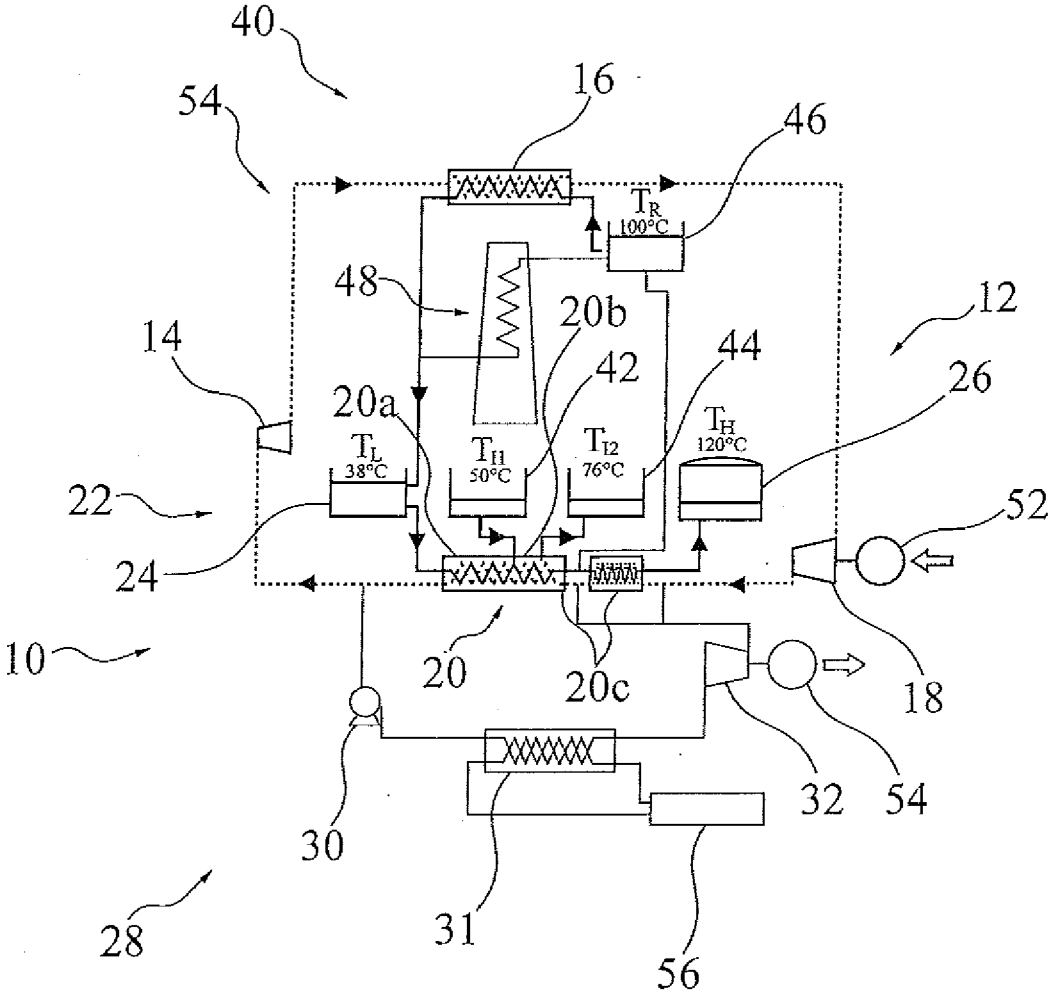

40
54
16
46
T_R
100°C
48
20b
12
14
42
44
26
20a
T_{I1}
50°C
T_{I2}
76°C
T_H
120°C
T_L
38°C
22
52
24
10
20
20c
18
30
32
54
28
31
56

Fig. 6

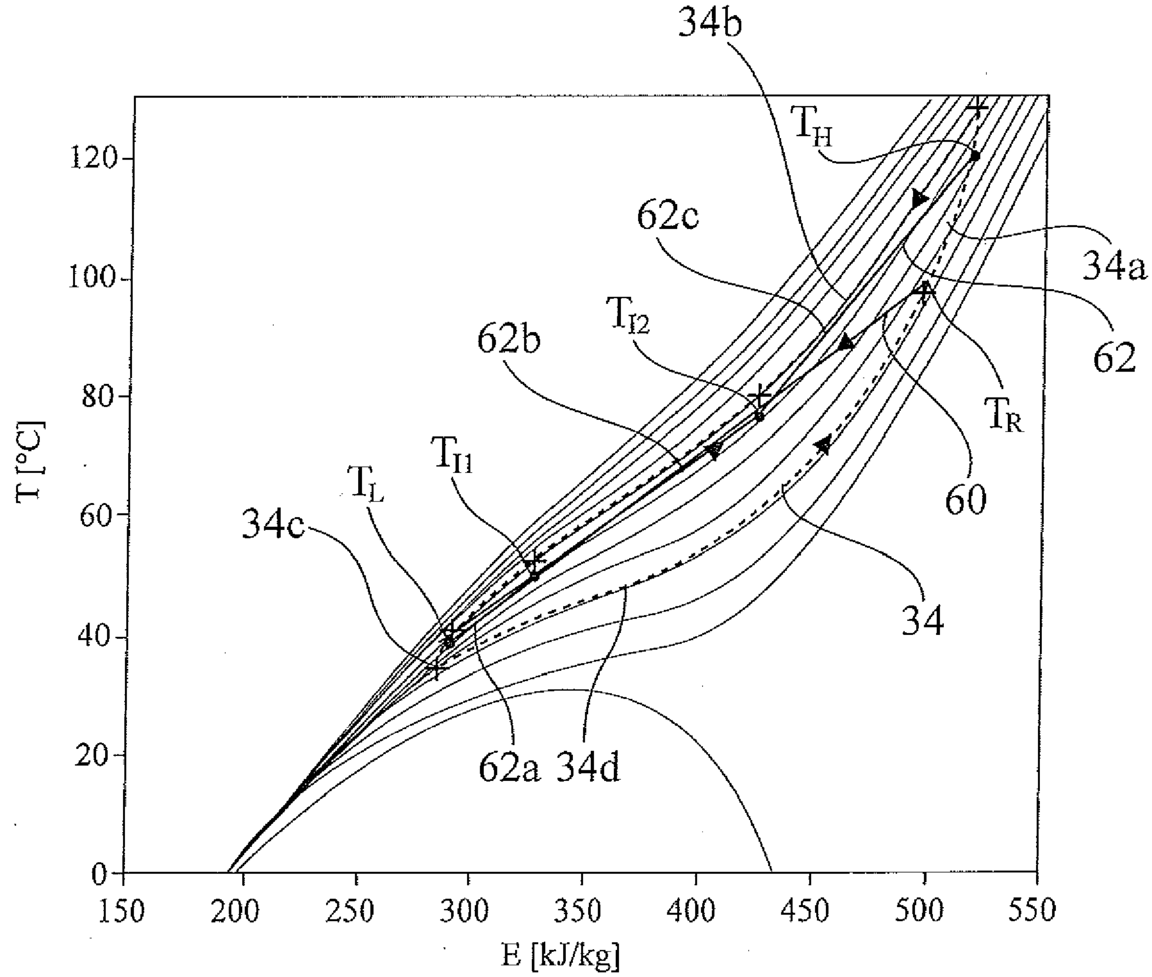

34b
T_H
62c
34a
100
62
T_I2
62b
80
T_R
T [°C]
T_I1
60
T_L
60
34c
40
34
20
62a 34d
0
150 200 250 300 350 400 450 500 550
E [kJ/kg]
120

Fig. 7

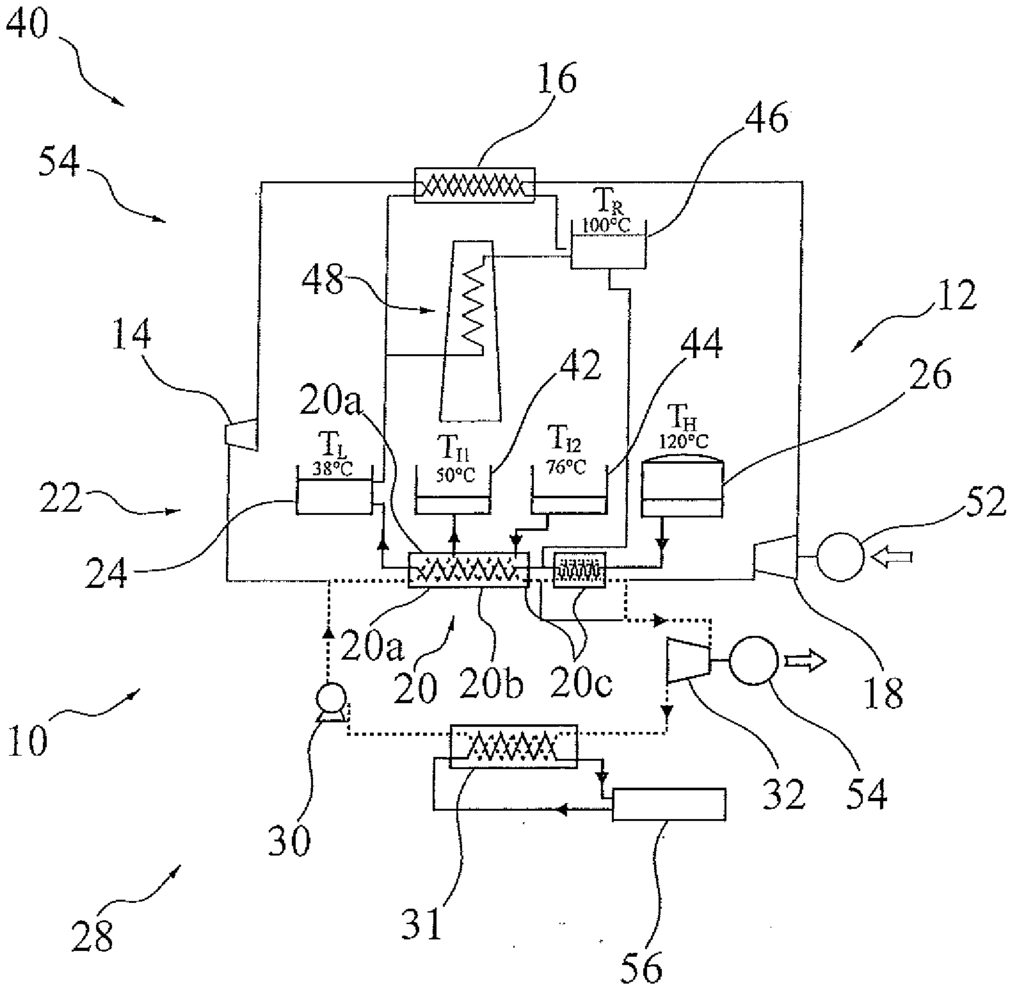
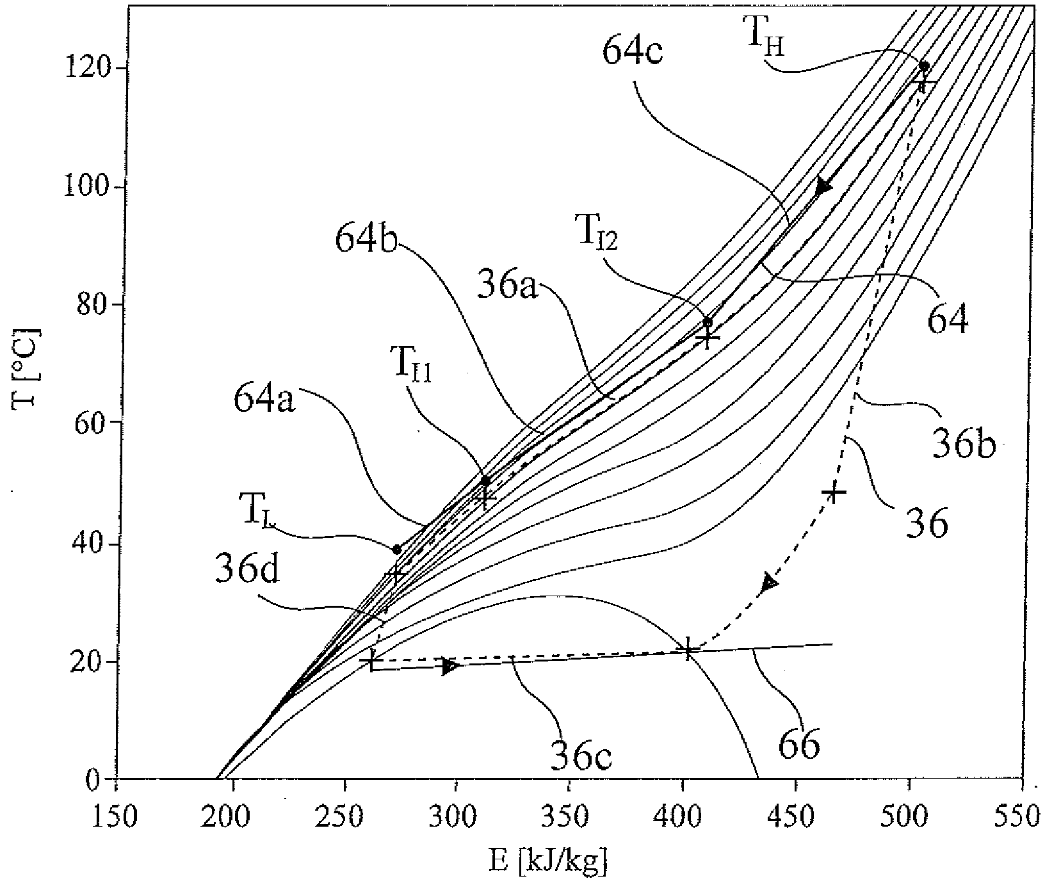

40
16
46
54
T_R
100°C
48
12
14
42
44
26
20a
T_H
120°C
T_L
38°C
T_{I1}
50°C
T_{I2}
76°C
22
52
24
20a
20
20b
20c
18
10
32
54
30
31
28
56

Fig. 8



T [°C]
E [kJ/kg]
0
20
40
60
80
100
120
150
200
250
300
350
400
450
500
550
T_H
64c
T_{I2}
64b
36a
64
T_{I1}
64a
36b
T_L
36
36d
36c
66

Fig. 9

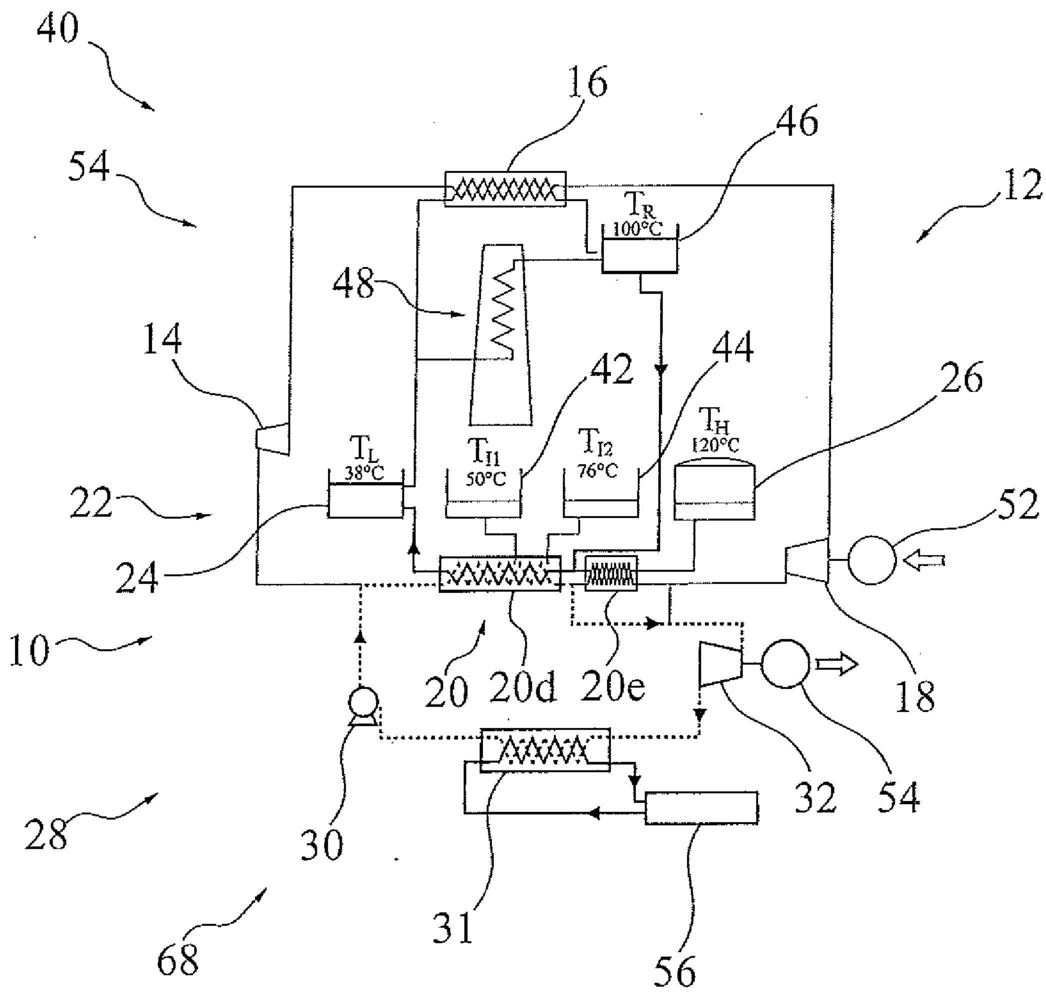

40
16
46
54
12
48
14
42
44
26
T_R 100°C
T_L 38°C
T_{I1} 50°C
T_{I2} 76°C
T_H 120°C
22
52
24
10
20
20d
20e
18
32
54
28
30
31
68
56

Fig. 10

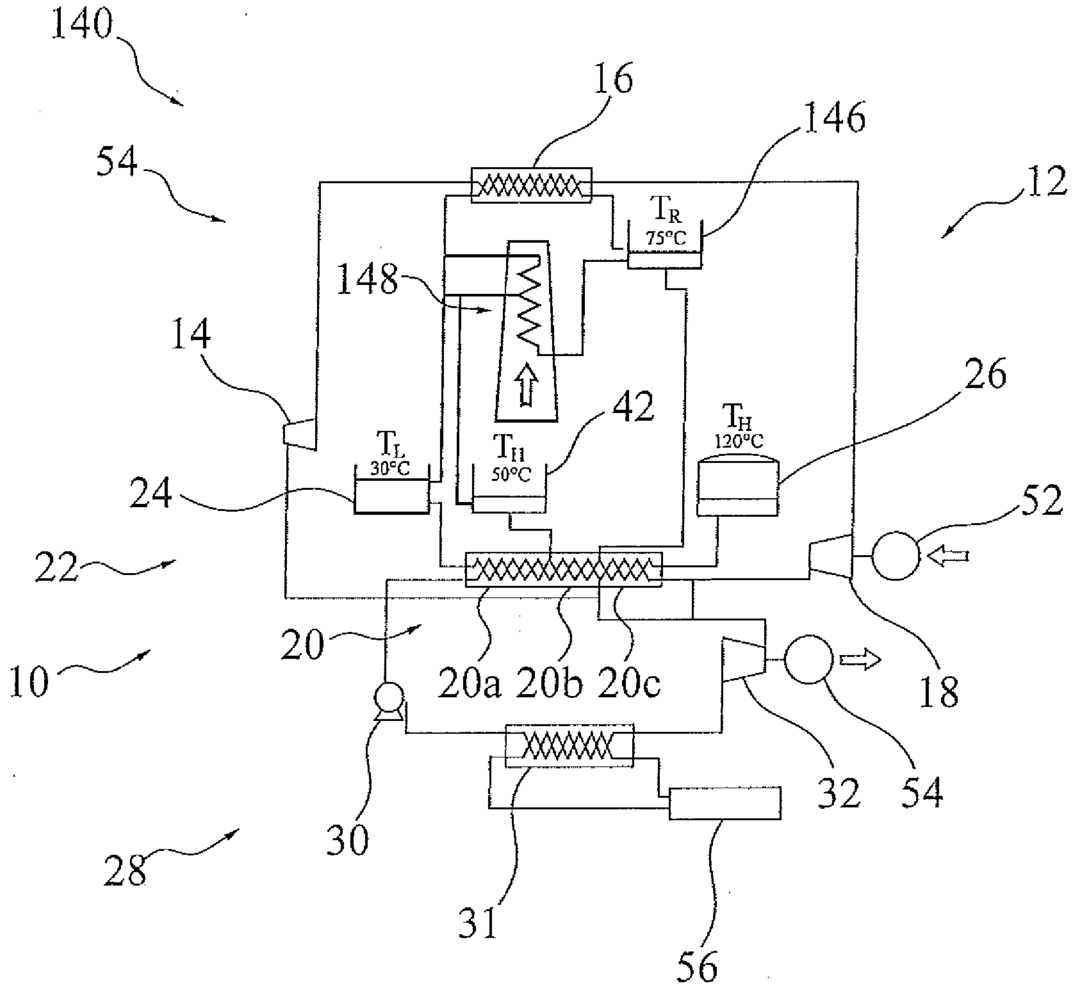

140
16
146
54
12
T_R
75°C
148
14
26
42
T_H
120°C
T_L
30°C
T_H
50°C
24
52
22
20
20a 20b 20c
10
18
32
54
30
28
31
56

Fig. 11

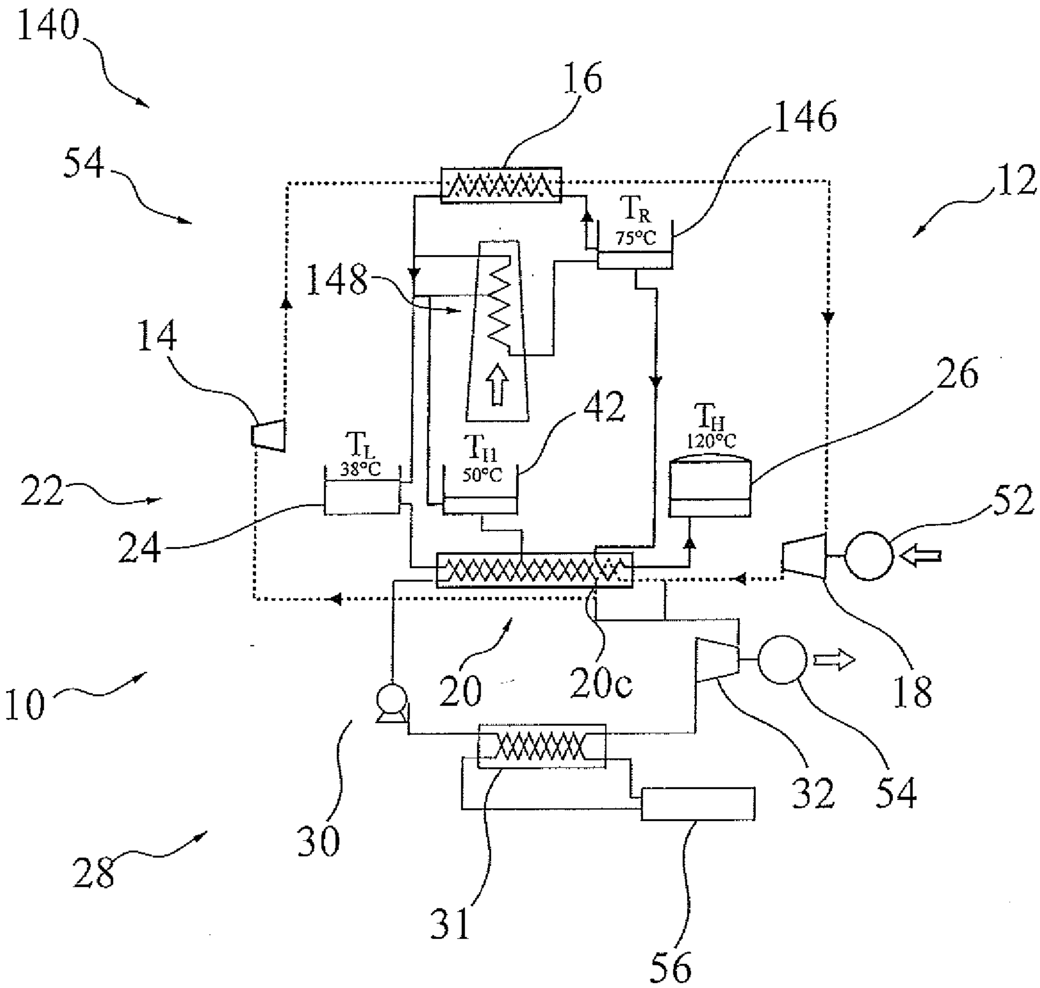

140
16
146
54
12
T_R
75°C
148
14
26
42
T_H
120°C
T_L
38°C
T_H
50°C
22
52
24
20
20c
18
10
32
54
30
28
31
56

Fig. 12

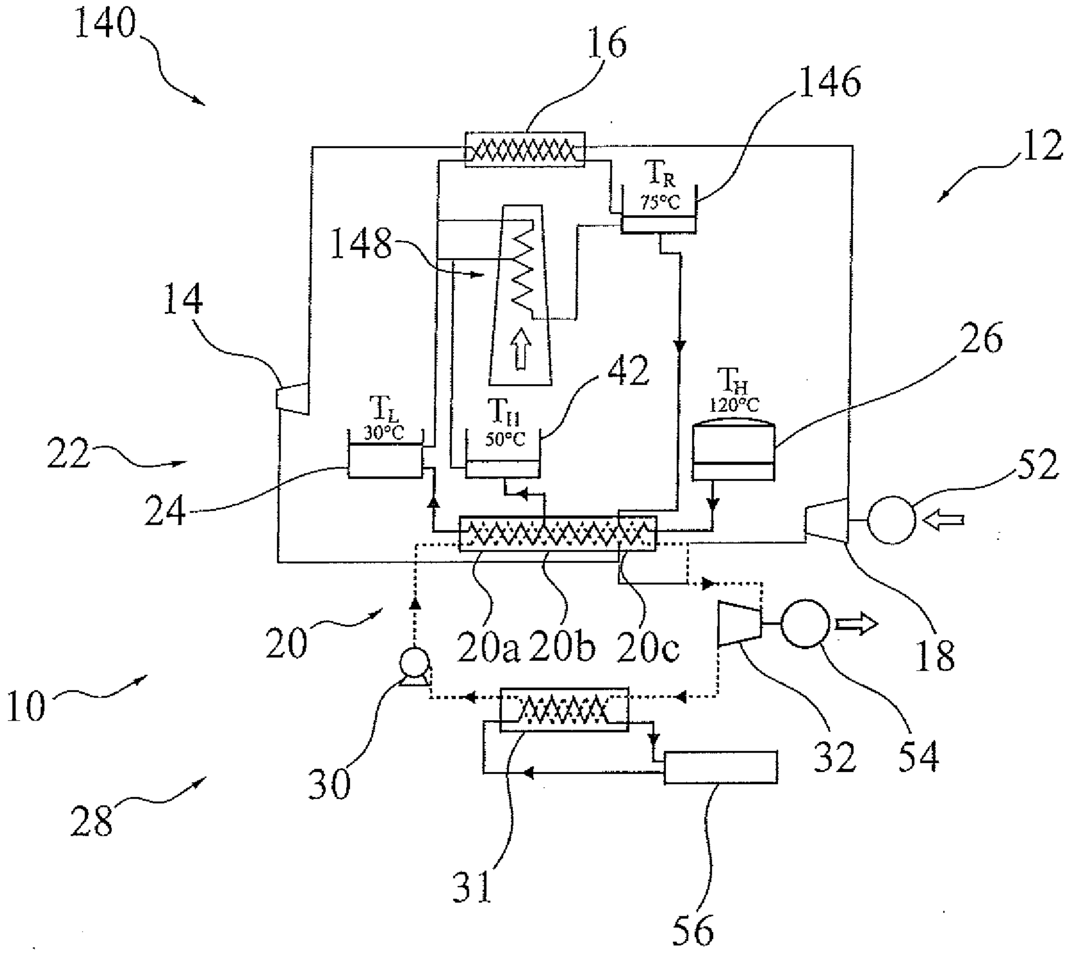

140
16
146
12
T_R
75°C
148
14
26
42
T_H
120°C
T_L
30°C
T_{I1}
50°C
22
52
24
20
20a
20b
20c
18
10
30
32
54
28
31
56

Fig. 13

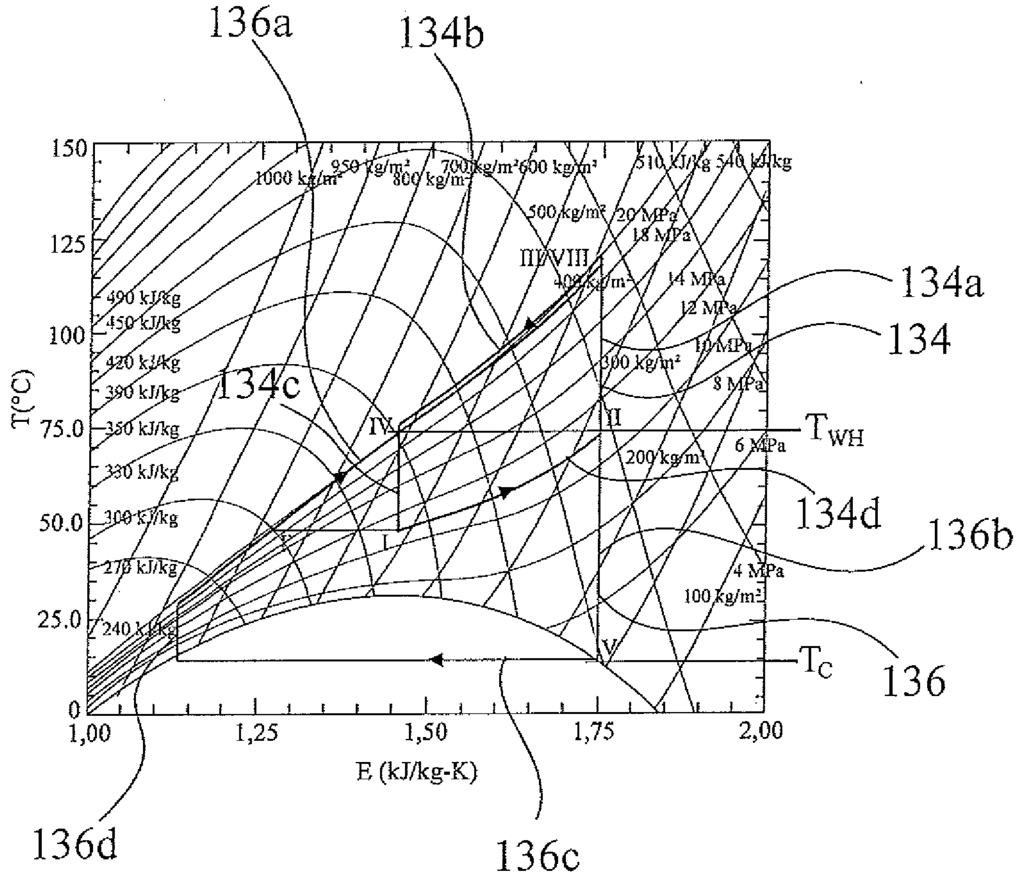

136a
134b
134a
134
134c
134d
136b
136
136d
136c
T(°C)
E (kJ/kg-K)
TWH
TC
III/VIII
IV
II
I
V
1000 kg/m²
950 kg/m²
800 kg/m²
700 kg/m²
600 kg/m²
500 kg/m²
400 kg/m²
300 kg/m²
200 kg/m²
100 kg/m²
510 kJ/kg
540 kJ/kg
490 kJ/kg
450 kJ/kg
420 kJ/kg
390 kJ/kg
350 kJ/kg
330 kJ/kg
300 kJ/kg
270 kJ/kg
240 kJ/kg
20 MPa
18 MPa
14 MPa
12 MPa
10 MPa
8 MPa
6 MPa
4 MPa
150
125
100
75.0
50.0
25.0
0
1,00
1,25
1,50
1,75
2,00

Fig. 14

Europäisches Patentamt
European Patent Office
Office européen des brevets

EUROPEAN SEARCH REPORT

Application Number
EP 10 18 7523

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 2010/006942 A2 (ABB RESEARCH LTD [CH]; OHLER CHRISTIAN [CH]; MERCANGOEZ MEHMET [CH]) 21 January 2010 (2010-01-21)	1	INV. F01K3/12 F01K25/10
A	* figures 1,3,4 * -----	12	

TECHNICAL FIELDS SEARCHED (IPC)

F01K

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
Munich	25 October 2011	Coquau, Stéphane

CATEGORY OF CITED DOCUMENTS

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