



(51) International Patent Classification:
F01K 25/06 (2006.01)

(21) International Application Number:
PCT/SE2013/051059

(22) International Filing Date:
11 September 2013 (11.09.2013)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
1200554-2 12 September 2012 (12.09.2012) SE
1200711-8 22 November 2012 (22.11.2012) SE
1300364-5 21 May 2013 (21.05.2013) SE

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(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:

— with international search report (Art. 21(3))

[Continued on next page]

(54) Title: METHOD FOR IMPROVING THE PERFORMANCE OF THERMODYNAMIC CYCLES

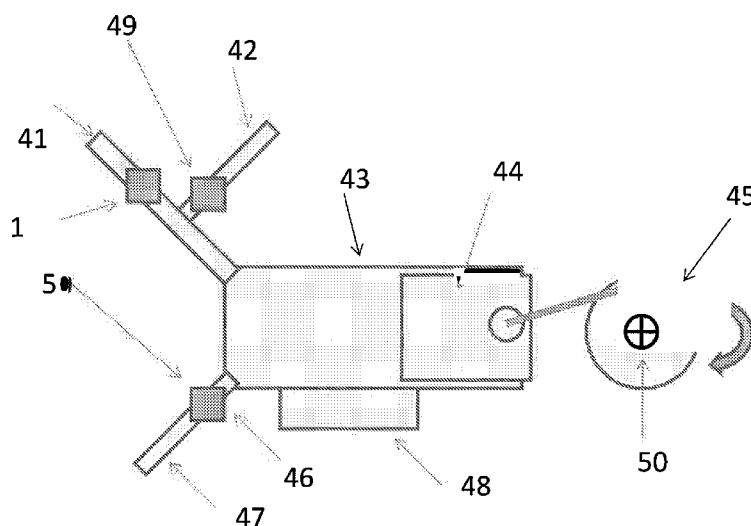


Fig. 2

(57) Abstract: A method for improving the performance of thermodynamic cycles, particularly based on CO₂ gas absorbed in a liquid absorbent used as working- fluid in a system comprising at least one CO₂ gas absorber, at least one heat exchanger and a device for converting gas expansion work to mechanical work. Said working fluid is fed to the device for releasing said CO₂ gas under pressure by heat supplied from an external heating source operating at least at 70°C, preferably at 80 to 90°C or higher, wherein the device being selected from the group consisting a modified 2-stroke engine, a turbocharger and a turbine.

- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

METHOD FOR IMPROVING THE PERFORMANCE OF THERMODYNAMIC CYCLES**Field of the invention**

Reference is made to PCT/SE/2012/050319 with priority from SE 1100208-6 (filed 22.03.2011), US application 61/468 474 (filed 28.03.2011) and SE 1100596-4 (filed 16.08.2011), these documents are included by way of reference. These documents describe a novel thermodynamic cycle for energy and cold production from heat below 160°C, called C3 or "Carbon Carrier Cycle".

In the Carbon Carrier Cycle, C3, heat is used to chemically desorb CO₂ from a carrier medium or working fluid. After the CO₂ has expanded so as to create electricity, for instance, it is chemically absorbed into the carrier medium during cooling. The chemical absorption is very efficient at creating low pressure, and the CO₂ can be expanded to temperatures as low as -78°C resulting in high power output, despite of low heat source temperatures.

All technical solutions for energy conversion are in constant need of improvement, cost reduction, size reduction, increased plant availability, and improved integration into existing infrastructure. As examples, (i) turbines are usually the most expensive parts of thermodynamic cycles, therefore any cheaper solution can be competitive even if efficiency is sacrificed, (ii) equipment size can enable or prevent usage in certain applications, therefore even marginal improvements (most often size reductions) can have significant effects, (iii) systems are rarely stand-alone, but form rather part of a more complex architecture, therefore smart integration of all material and energy streams is highly desirable.

This text describes current problems in detail and discloses various ways of solving said problems.

5 **Background of the invention**

The invention disclosed here solves the problem of the current art, namely that the overall performance of the energy generation system is too low in terms of footprint, costs per kWh generated, or lack of integration. Various partial
10 solutions can be used alone or in combination. Various embodiments are described showing preferred ways of solving said problems.

Summary of the invention

15 One object of the invention is to achieve a method by which the performance of thermodynamic cycles, particularly the performance of the C3 (Carbon Carrier Cycle) based on CO₂ gas absorbed in a liquid absorbent used as working fluid in a system is improved.

20 This object is achieved according to the invention by a method for improving performance of thermodynamic cycles, particularly the performance of the C3 (Carbon Carrier Cycle) based on CO₂ gas absorbed in a liquid absorbent used as working fluid in a system comprising at least one CO₂ gas absorber,
25 heat exchangers, at least one pump device and a pipe system for transport of said working fluid through the system, and a device for converting gas expansion work to mechanical work, characterized by:

- feeding said working fluid to the device for releasing said CO₂ gas under pressure by heat supplied from an external heating source operating at least at 70°C, preferably at 80 to 90°C or higher, wherein the device being selected from the group consisting a modified 2-stroke engine, a turbocharger and a turbine.

Preferred embodiments are defined in the appending dependent claims.

Brief description of the drawings

The invention is described in more detail below in the form of non-limited examples, reference being made to the appended drawings, in which

- Fig. 1 represents a generalized view of a Carbon Carrier Cycle from a system perspective,

- Fig. 2 is a schematic view of a piston engine in its stripping stage for converting energy in the form of pressurized gas into mechanical rotation of a rotating axis, and

- Fig. 3 is a schematic view of said piston engine in Fig. 2 in its adsorption stage.

Description of preferred embodiments

Fig. 1 illustrates a generalized view of the Carbon Carrier Cycle from a system perspective having an essentially closed loop comprising a liquid pump 6, a pre-reactor (which can for most practical purposes be considered as heat exchanger and preferably forms a part of a heat exchanger 12, a reactor 7, a booster 19, an expansion system 15, an absorber system 3 and a cooling system 4. The pump 6 increases the pressure of a CO₂ gas liquid absorbent, where the pre-reactor and the reactor 7

release the CO₂ by thermal heat. The possible booster 19 further heats the high pressure CO₂ before it enters the expansion device 15 to produce electricity. The expanded gas optionally enters a heat exchanger 35 for extracting low temperature either for external cooling applications or cooling the absorbent before absorption. The expanded CO₂ gas is chemically absorbed or converted to CO₂ gas liquid absorbent in the absorption system 3 during cooling by the cooling system 4 for the process to repeat.

The invention will be described with reference to the below examples.

Example 1

A piston engine is used as an expansion device for turbine replacement since said piston engine is a suitable means for converting energy in the form of pressurized gas into mechanical rotation of a rotating axis to which an electrical generator may be coupled. It may be less efficient than turbines, but as piston engines are mass-produced, they can be considerably cheaper, and therefore the cost per kWh generated can be lower.

Fig. 2 shows the working principle of such a piston engine.

Only one cylinder is shown, but it should be understood that a plurality of cylinders can be used in the invention such that an almost continuous mode of operation can be achieved. In the C3 cycle, CO₂-loaded liquid absorbent, e.g. a mixture of dibutylamine and Carbitol solvent which contains between 1 and 99% of the theoretical maximum of CO₂ (chemically bonded as per the a.m. disclosures), is pumped through an inlet 1 as "rich liquid absorbent" into a cylinder 43 of an engine,

which resembles a 2-stroke engine. The inlet 41 is provided with a valve 40 and an outlet 42 for hot pressurized CO₂ gas, the outlet 42 provided with a valve 49 is placed down streams of the valve 40 as seen in the flow direction of the rich liquid absorbent. The rich liquid absorbent is heated through heat supply 48 and is optionally even pre-heated before entry through inlet 1. CO₂ gas is produced in the cylinder, expanding and driving a piston 44 and a crankshaft 45 connected thereto. An electricity generator (not shown) may be coupled to the crankshaft 5 so as to produce electric energy. After the CO₂ gas has expanded a valve 49 is opened which allows the CO₂ gas to proceed to an absorption stage (see Fig. 2). The CO₂-depleted absorbent ("lean, hot absorbent") is exiting through an outlet 47. Preferably, the outlet 47 is at the bottom of the cylinder 43 such that the lean, hot absorbent and the CO₂ gas can exit the cylinder 43 simultaneously. Valves 49, 40 and 46 are opened and closed as required. Following the gas evolution, the piston 44 will move to the left, as seen in Fig. 1, the cylinder is essentially emptied of both the liquid absorbent and the CO₂ gas, and the process can start again. A pump is preferably pumping out the lean hot absorbent through outlet 47 as the pressure in the cylinder 43 can be below 1 bar. It is evident, that the control of valve opening times and injection / ejection periods of the liquid absorbent and the CO₂ gas is a balancing and optimization task not un-similar to conventional combustion engine management.

Now referring to Fig. 2, the absorption process proceeds as follows: CO₂ gas enters the absorption engine or cylinder 43 through inlet 41 and valve 40. The cylinder volume is close to its maximum at this stage, i.e. the piston 43 is positioned at the right hand side of Fig. 2. Lean, cold absorbent is pumped, preferably sprayed into cylinder 43 through an inlet 52 and

valve 53, causing the CO₂ gas to be absorbed in the absorbent and further causing the pressure in the cylinder 43 to drop to near vacuum. This in turn causes the piston 44 to move the left, as seen in Fig. 2. The absorbent is cooled by a cold supply 54, and exits the cylinder 43 through outlet 47 and valve 46. Thereafter, the cycle starts again. Valve opening times and adjustment to the piston position are optimized carefully. Optionally, a gas expansion turbine is placed between the desorber and the absorber engine, however, the pressurized gas from the desorber is usually more useful for pushing back the piston (to the right). Both the desorber and the adsorption engines can be connected to the same axis 51, or on a separate axis each. The engines may contain internal devices for agitation and more intensive heat transfer (both heating and cooling).

Compared with other solutions, such as turbines, the mode described in this example allows a higher degree of discharge of rich loaded absorbent, i.e. the total amount of liquid per kWh generated can be lower. In terms of dimensions, assuming a flow of 5 kg CO₂ per second for a 600 kW generator, the required absorbent flow will be about 100 kg/s. Accordingly, an engine with 10 cylinders of 25 liter each operating at 1 rpm is an appropriate engine size (or 10 cylinders, 12 liter volume per cylinder, 2 rpm). A similar construction can be realized using a rotary Wankel engine.

Example 2

In example 2 the use of one or more turbochargers as expansion device is described. Similar to the piston engine configuration in example 1, turbochargers such as used in trucks, are non-optimized for e.g. CO₂ expansion, however, they

are cheap due to mass fabrication. An additional benefit is that a plurality of turbochargers or expanders can be used such that variable heat supplies can be accommodated, simply by using only one, two, three or as many as technically ideal at a certain load or demand. A single turbine usually has a very narrow performance regime.

Example 3

Counter-current absorption of CO₂ in a spray reactor, and reducing the space requirement of the absorber section.

According to the referenced documents, lean absorbent is sprayed into the absorption reactor in the form of droplets, e.g. between 50 and 200 micrometer in size. These droplets are heated by the exothermic absorption of CO₂, and it turned out to be useful to operate this absorption section in a countercurrent mode, and also to collect liquid at least once and to re-spray partially loaded, and preferably cooled absorbent again into the CO₂ gas stream. In this way, a cold rich absorbent stream can be collected at the point where the CO₂ gas enters the absorber section. Preferably, the absorber is placed horizontally such that liquid can be collected at the bottom of this section. Also, agitation devices, e.g. a transport screw, can be installed e.g. at the bottom of the absorber, in order to pump absorbent and improve the heat discharge to a cooling medium. It should be understood that the spray can be generated in various ways, both in a traditional absorption reactor and in engine configurations as per Example 1 and 2. The absorbent liquid may be pumped through filters or nozzles which generate the spray, or the absorbent liquid may be pumped onto a rotating disc or rotary atomizer, such as generally known from the powder production or painting industry, or similar devices which disintegrates

the liquid mechanically into droplets. Other known engineering solutions are conceivable including wiped-film arrangements which help to agitate the absorbent and accelerate the uptake of CO₂ gas by the absorbent. Cooling elements may be included in the absorber in a way and at adequate spacing such that CO₂ gas can flow unhindered within the absorber volume. Combinations of the mentioned techniques, such as spray, cooled walls, recycle of absorbent and agitation are useful and within the scope of the invention.

A way of compacting the C3 unit is to employ a Venturi scrubber design downstream of a turbine. Here, the gas flow is accelerated as the flow channel for CO₂ gas is converging and therefore narrowed. Lean, cold absorbent enters the gas flow near or at this narrow channel. The high gas speed serves to disintegrate the liquid absorbent into the desired small gas droplets. As the channel widens, saturated absorbent droplets will contact the wall of the diverging section, and can be cooled such that CO₂ evaporation is limited. Various Venturi and cyclone designs can be chosen such that turbulence before and after the narrow throat section, residence time of droplets in the gas stream etc., number of spray nozzles etc., can be reduced or optimized, respectively.

Similarly, a small turbine can be used, partly for compacting the C3, partly for using the high gas speed at the exit of the turbine – which as such means loss of kinetic energy – for disintegrating the liquid, possibly even in combination with the Venturi design mentioned above. It will be understood that the choice of technology is a balance between parameters such as space requirement, desired product ratio (electricity versus cold), turbine or expansion device costs and so forth. This choice depends on the application.

Example 4

An amine/solvent liquid absorption medium yields CO₂ gas upon heating and it is practical to use heat exchangers which allow easy escape of gas as soon as said liquid absorbent is heated. Suitable heat exchangers are those known in the art e.g. for evaporation of R134a, butane or similar liquids. Said heat exchangers heating up rich, i.e. CO₂ loaded absorbent, may form part of the desorber or stripper section, and their gas outlets may directly be in connection with the pipe leading to the turbine or expansion device.

A booster section, sometimes referred to as superheating section, as described in a.m. disclosures, may be employed in order to selectively heat the CO₂ gas before it enters the expansion device.

Example 5

A geothermal heat source may be used since heat of about 90°C is available from geothermal sources in 2-3 km depth. Temperatures above 110°C are very difficult to obtain at reasonable costs, except at certain places e.g. with volcanic activity (e.g. Iceland). It is highly useful to couple the production of 90°C water streams, and the electricity production using the C3 cycle, to district heating networks. In this sense, a highly useful configuration is given by using a 20°C temperature delta (i.e. 90-70°C) for the C3 cycle, and the residual flow (70-40 or 30°C) for heating of buildings. Maximizing the temperature difference (delta) between hot water production and cold water re-injection into the ground is beneficial for the overall economy.

Example 6

Effluents from power plants may be used as heat source. At power plants, hot water streams between 120 or 110 down to 90°C are available. Where possible, these streams are diluted to a lower temperature, such as 70 or 80°C, for pumping into district heating networks. It is highly efficient to use the C3 cycle for electricity production near the power plant, where the C3 cycle serves as first cooling device for the hot water stream. Ideally, the C3 is used to cool the hot water effluent down to 70 or 80°C.

Example 7

Preferred cosolvents and amines. Preferred amines as absorbents are described in the referenced documents. It turned out that certain cosolvents are very beneficial for a) reducing the viscosity of the CO₂-loaded absorbent, b) preventing crystallization of loaded absorbent, c) providing lubrication for movable parts in pumps etc, d) preventing foaming of absorbent during the stripping stage, and e) optimizing the spraying performance during absorption or during flash evaporation in the stripper section. Particularly useful cosolvents are glycol ethers, such as mono- or dialkyl-substituted oligomers of ethylene or propylene oxides. "Carbitol solvent", or diethylene glycol monoethylether is one of the preferred cosolvents due to good price/performance ratio. Carbitol and butylcarbitol are also preferred for highly alkaline amines (whereby "highly" means pK_b values below 3,3) such as diaza-bicyclo-undecene, 1-Methylimidazole and other strong amines (see references). A useful ratio of

dibutylamine and Carbitol is 2 weight parts amine and 1 weight part Carbitol, or preferably less Carbitol.

It is also noteworthy that certain solvents are capable of reducing the energy required for desorption of CO₂, or the exothermicity of the CO₂ absorption reaction. It was noted that the mixing of amine and solvents such as ethylene glycol, Carbitol Solvent, phenol, cresols, glycerol and the like generates heat. This heat (calculated as product of mass, heat capacity and temperature increase) can be expressed in terms of energy per mass CO₂ which can be absorbed in the mass of amine used in the specific experiment. It is found that this energy (in the order of 100-300 kJ/kg CO₂) is about 50% of the measured reduction of the absorption enthalpy or energy. Also, pure carbamates such as the reaction product of 2 moles dibutylamine and 1 mole CO₂, were dissolved in Carbitol, ethylene glycol, methanol and the like. Surprisingly, the mixture is cooling down (by some 8-12 ° C). Also this energy (in the order of 100-300 kJ/kg CO₂) can be related to the amount of CO₂ which is absorbed in the respective sample, and again the value is in the order of 50 % of the absorption enthalpy. Without wishing to be bound by scientific theory, we assume that the observed energy changes reflect a change in the reaction energetics. In practice, it is found that the absorption enthalpy for the amine + CO₂ → products reaction is reduced from ca. 1800 kJ/kg CO₂ to about 1100 kJ/kg CO₂ (as measured from the slope of a logarithmic pressure versus 1/T diagram (also referred to as "van't Hoff diagram")).

Example 8

Mixed carbamates: tertiary amines such as MDEA are known to offer relatively low absorption enthalpies and are therefore

being studied in the carbon capture field. Typically, they require water as reaction partner for the formation of bicarbonates or carbonates. Unfortunately, tertiary amines show low reaction speeds and therefore have to be "activated" e.g. using piperazine, with limited success. Water-free systems were studied here comprising tertiary and secondary/primary amines. It was found that such systems absorb significantly more (50% and more) CO₂ than given by dialkylamine → carbamate stoichiometry. It can thus be speculated that tertiary amines are protonated and can form counterions for e.g. carbamate anions. Surprisingly, very low absorption enthalpies, in the order of 800-1100 kJ/kg CO₂, are found for such systems, including equimolar mixtures of dibutylamine and trihexylamine, or dibutylamine and MDEA (N-methyldiethanolamine), both optionally in solvents as described above. Also surprisingly, high reaction speeds were measured in such water-free CO₂ absorption liquids comprising tertiary and secondary/primary amines. Useful tertiary amines include MDEA, trialkylamines with alkyl being methyl, ethyl, propyl, butyl (not preferred due to toxicity), pentyl, hexyl, cyclohexyl, piperidines etc. Especially useful are water-free amines comprising tertiary and primary or secondary amine functions in one molecule, e.g. diethylamino-propylamine or aminopropyl-imidazole, or amines such as 1-Methylimidazole in combination with primary or secondary amines such as dibutyl- or dihexylamine. Said system offers the additional benefits of low viscosity at high CO₂ loading degree and low freezing point of the CO₂-loaded absorbent mix, and this system does not necessarily require a cosolvent.

The mixtures described here can also be used for gas separation purposes, e.g. for the removal of CO₂ from biogas, water-shift gas or other industrial gas streams from which CO₂

has to be removed. Most compositions are hardly water-absorbing, and if they absorb water (e.g. in the case of MDEA), water can be removed easily by heating / vacuum.

It will be appreciated that a range of parameters can be chosen quite freely for the operation of the C3 process for power generation, including amine chemistry, absorption enthalpy, pressure quote, pressure levels before and after the turbine or expansion device, CO₂ loading degree of the absorption liquid before and after the absorption section, total CO₂ content, all depending upon the available heat source and cooling source. In some embodiments, volatile tertiary amines can be used with the intention to cause an additional gas flow through the turbine (CO₂ plus tertiary amine, e.g. triethylamine). In general, however, less volatile components (amines, solvents) are preferred in order to prevent problems with condensing liquids downstream of the turbine. In general, the presence of water is not desired due to condensation / icing problems and due to the vapour pressure of water in the absorption section which has a negative impact on the pressure quote. However, in special cases (e.g. thermomorphic systems) the presence of water is acceptable.

Elaborating on the freedom to choose operation parameters, one important aspect of a power system is to adapt to varying sources of energy. Temperatures can vary between sites and over time. It is advantageous if the system is able to produce as much power as possible under varying circumstances without complete and costly redesign of the system itself.

The Carbon carrier cycle uses carbon dioxide, CO₂, that is absorbed in and is desorbed from a liquid medium. As explained in the a.m. disclosures, the loading level will vary

throughout the cycle centered around an average loading level. The amount of CO₂ then used in the expansion depends on the system configuration itself and also the flow rate of absorbent that is used in the cycle matched with the heating and cooling source.

The average loading level in the cycle combined with the absorption and desorption amount can be used to control the absolute pressures in the system and the flow rate of absorbent can be used to control the amount of CO₂. The reason for performing this adaption is to let the power producing expansion device operate at an optimal setpoint, thus producing a maximum amount of energy output.

In an example, a system designed for 90°C on the hot side and 20°C on the cold side is used in another application where the heat source is at 80°C and the cooling source is at 10°C. In this case, additional 10%-30% loading of CO₂ is added to the system in order to maintain exactly the same pressure ratio or the absolute pressure values as the expansion device was designed for. The CO₂ concentration can even be varied in a system within a few minutes if the heating and/or cooling source is variable, e.g. on a scale of hours.

Thus, according to the inventive method it is possible to adapt the average gas loading level in the C3 cycle between 20%-90 % of the maximum loading to the hot and cold source, in order to maximize the power output of the expansion device, and a decreasing of the average gas loading level in case the C3 cycle is operated at higher temperatures.

Example 9

Cold may be extracted from the closed loop thermodynamic cycle as disclosed in the references mentioned. The working medium CO₂ gas is expanded in the expansion device to very low pressure and very low temperature, such as minus 60°C. In the simplest embodiment, the gas is led through a heat exchanger allowing heating of the gas and transfer of cold, e.g. a stream of minus 20°C for any type of cooling requirement. The arrangement is simple, but will cause a back-pressure to the turbine thereby reducing the electricity production. A more advanced form of cold extraction is realized by pumping a liquid through the space through which the gas moves towards the absorption chamber. This liquid may be pumped in the form of a spray or a falling film or any other configuration which allows good contact between the cold CO₂ gas and the liquid. Preferably, liquids of high boiling point and low melting point are used. Silicone oils are suitable candidates. There is a risk that droplets of said heat transfer liquid enter the thermodynamic cycle. This may be controlled by elements such as demisters. A preferred way of operating the cold extraction is by using the same amine/solvent system which is used in the absorber, also for the cold extraction. A certain loss of the cold extraction medium can be compensated by pumping saturated amine/solvent from the absorption section to the cold extraction section. As the cold extraction medium is fully saturated, depending on the case a certain period after start-up, there will be no heat development in the cold extraction section due to additional CO₂ absorption. This liquid is preferably led through a heat exchanger, from which a second suitable liquid, such as glycol ethers or the like as known in the art, is carrying the cold energy to the point-of-use.

Claims

1. A method for improving the performance of thermodynamic cycles, particularly the performance of the C3 (Carbon Carrier Cycle) based on CO₂ gas absorbed in a liquid absorbent used as working fluid in a system comprising at least one CO₂ gas absorber, heat exchangers, at least one pump device and a pipe system for transport of said working fluid through the system, and an expansion device for converting gas expansion work to mechanical work, characterized by:

- feeding said working fluid to the expansion device for releasing said CO₂ gas under pressure by heat supplied from an external heating source operating at least at 70°C, preferably at 80 to 90°C or higher, wherein the expansion device being selected from the group consisting a modified 2-stroke engine, a turbocharger and a turbine.

2. The method according to claim 1, characterized by pre-heating the working fluid before feeding the same to the device.

3. The method according to claim 1, characterized by

- using said modified 2-stroke engine as device to absorb CO₂ in the absorption stage of the thermodynamic cycle, and
- using said modified 2-stroke engine as device to release CO₂ under pressure by heat supplied from an external heating source.

4. The method according to claim 1, characterized by coupling an outgoing rotating shaft from said device to a generator for generation of electricity.

5. The method according to claim 1, characterized by

- using a counter-current gas absorber to absorb the CO₂ gas in

which the liquid absorbent is sprayed into the incoming CO₂ gas stream,

- partially collecting said liquid absorbent, and
- re-spraying said partially collected liquid absorbent into the CO₂ gas stream, preferably at the upstream section of said absorber, i.e. so as to interacting with fresh gas, thus enabling a maximum loading level of the CO₂ gas into said liquid absorbent, and
- enabling intermediate cooling of the liquid absorbent.

6. The method according to claim 1, in case the device being a turbine,

- using a Venturi design for accelerating the gas flow to the turbine and for allowing high gas speed to disintegrate liquid absorbent droplets, and
- optimizing the flow of droplets and their residence time in the CO₂ gas absorber such that liquid absorbent droplets loaded with CO₂ can transfer the heat generated during the absorption of gas to a cooling wall in the CO₂ gas absorber.

7. The method according to claim 1, characterized by

- using said at least one heat exchanger as central heat exchanger for transferring heat from hot lean liquid absorber to cold rich liquid absorbent.

8. The method according to claim 1, characterized by

- supplying heat from a geothermal power unit by a hot water stream having a temperature from about 90 to 110°C,
- cooling the hot water stream to about 80 to 70°C, and
- using possible remaining hot water for district heating or heating an underground reservoir for heat storage.

9. The method according to claim 1, characterized by the liquid absorbent comprising cosolvents such as glycol ethers, preferably diethylene glycol mono-ethyl-ether, and amines such as dialkylamines, and preferably water-free amines comprising
5 tertiary and secondary amines, optionally combined in one molecule, or mixtures of strongly basic amines such as diaza-bicyclo-undecene or 1-Methylimidazole in combination with secondary or primary amines, in order to adjust the viscosity, provide lubrication, provide heat transfer, prevent foaming
10 and crystallization of the liquid absorbent.

10. The method according to claim 1, characterized by extracting cold from the thermodynamic cycle by leading cold CO₂ gas after having expanded in the device through a heat
15 exchanger.

11. The method according to claim 10, characterized by the heat exchanger being constructed without separation walls by using a liquid which is in direct contact with the CO₂ gas but
20 will not hinder the gas transport to the CO₂ gas absorber, whereby the liquid absorbent used in the CO₂ gas absorber is also used for cold extraction.

12. The method according to claim 1, characterized by
25 adaptation of the average gas loading level in the C3 cycle between 20%-90 % of the maximum loading to the hot and cold source, in order to maximize the power output of the expansion device, and a decreasing of the average gas loading level in case the C3 cycle is operated at higher temperatures.

30 13. The method according to claim 1, characterized by the use of a booster section or super-heater section in which preferably only the CO₂ gas is heated, prior to entering the

expansion device, to a higher temperature than the temperature provided by the primary heat source.

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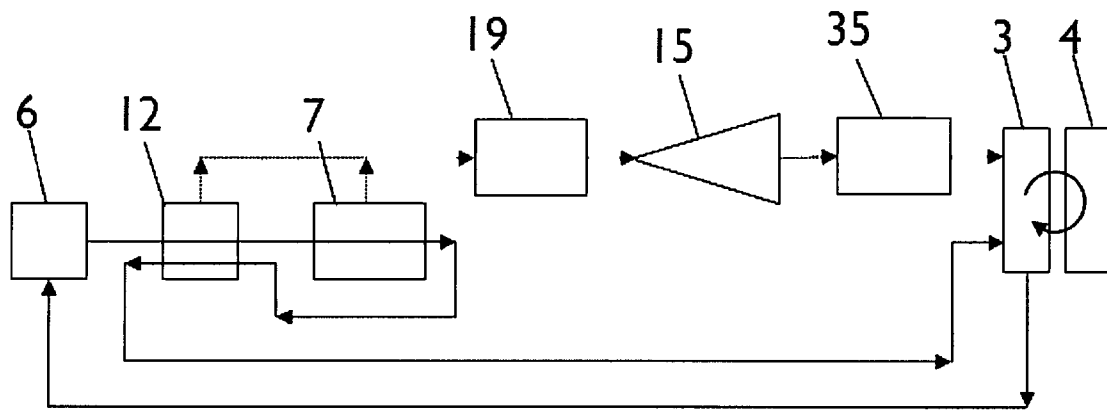


Fig. 1

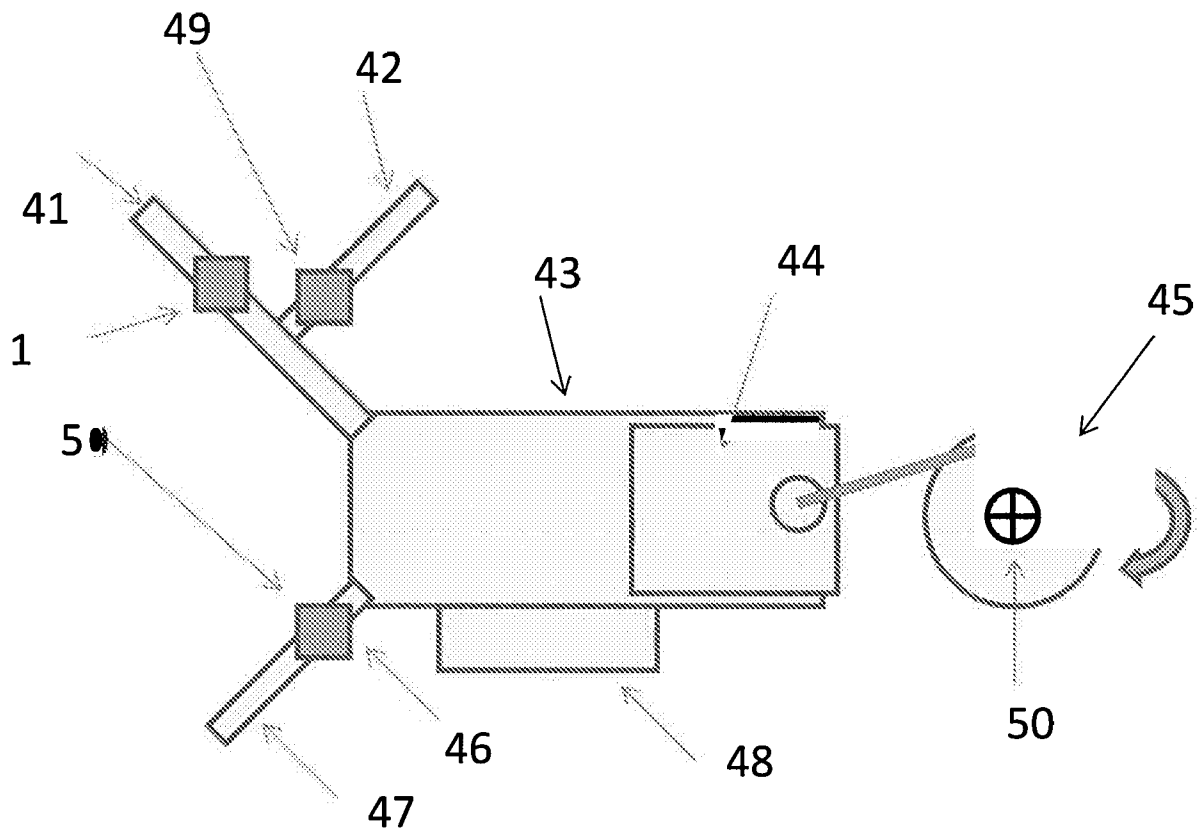


Fig. 2

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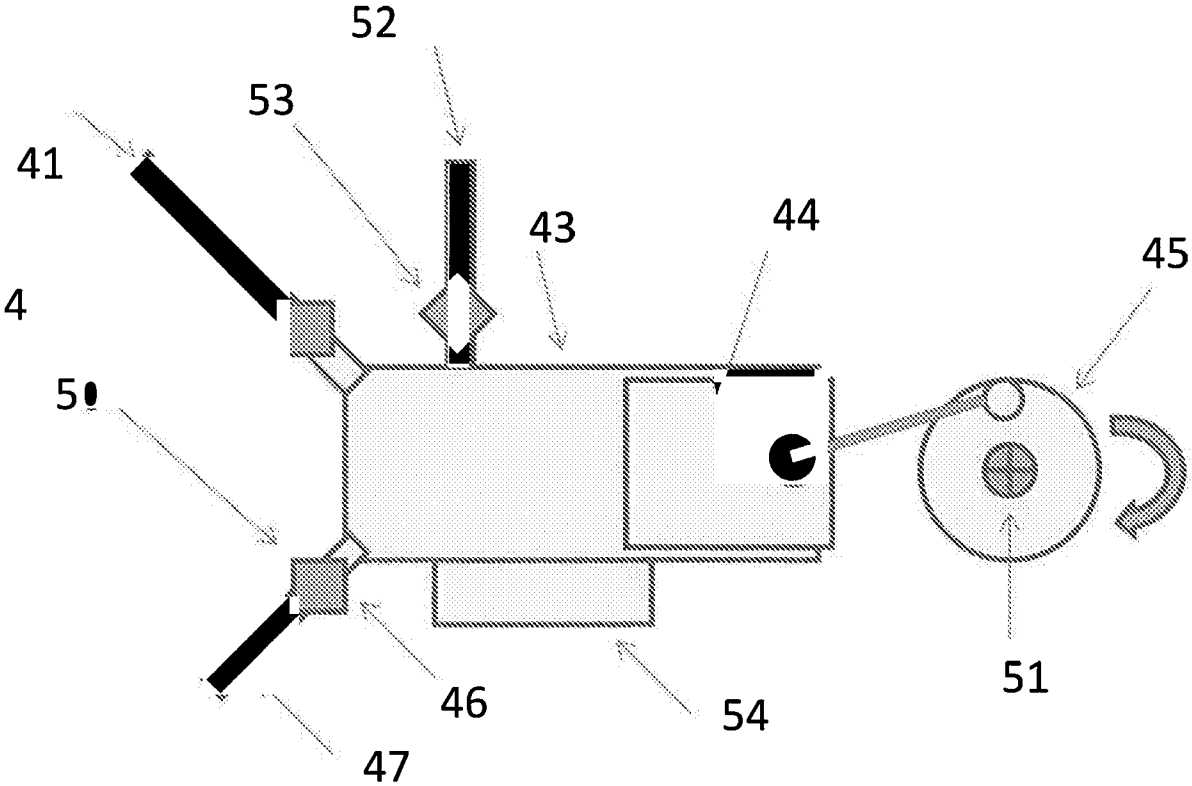


Fig. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2013/051059

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

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)

IPC: F01B, F01K, F03G, F04B, F25B

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

SE, DK, FI, NO classes as above

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

EPO-Internal, PAJ, WPI data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SE 9504683 A (NILSSON CARL EINAR ET AL), 29 June 1997 (1997-06-29); abstract; figure 3; claims --	1-2, 4, 7-8, 10-13
X	GB 2411699 A (TURNER MICHAEL PETER), 7 September 2005 (2005-09-07); abstract; figures 3.3 --	3
P, X	WO 2012128715 A1 (CLIMEON AB ET AL), 27 September 2012 (2012-09-27); abstract; page 21, line 22 - page 21, line 32 --	1-2, 4, 7-8, 10-13
A	GB 2461709 A (BAYIR HUSEYIN), 13 January 2010 (2010-01-13); abstract; page 8, line 11 - page 10, line 21; figures --	1-4, 7-8, 10-13



Further documents are listed in the continuation of Box C.



See patent family annex.

* Special categories of cited documents:	"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
"A" document defining the general state of the art which is not considered to be of particular relevance	"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
"E" earlier application or patent but published on or after the international filing date	"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
"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)	"&" document member of the same patent family
"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	

Date of the actual completion of the international search

28-02-2014

Date of mailing of the international search report

03-03-2014

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INTERNATIONAL SEARCH REPORT

 International application No.
 PCT/SE2013/051059

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	WO 9807962 A (HAGEMAN BRIAN C), 26 February 1998 (1998-02-26); abstract; page 17, line 25 - page 18, line 15; page 49, line 15 - page 57, line 11; figures --	1-4, 7-8, 10-13
A	WO 9717585 A1 (UNIV NOTTINGHAM ET AL), 15 May 1997 (1997-05-15); abstract; pages 29-32; figures --	1-4, 7-8, 10-13
A	US 20090071153 A1 (BOYAPATI CHENNA KRISHNA RAO ET AL), 19 March 2009 (2009-03-19); abstract; paragraphs [0048], [0063]; figures --	1-4, 7-8, 10-13
X	US 20110314844 A1 (GU JUNJIE ET AL), 29 December 2011 (2011-12-29); paragraphs [0001], [0005]-[0006], [0016], [0032]; figure 2	1
Y	--	5
Y	GB 1478429 A (METALLGESELLSCHAFT AG ET AL), 29 June 1977 (1977-06-29); page 1, line 15 - page 1, line 28; page 3, line 104 - page 3, line 129; figure 1 --	5
A	WO 0066887 A1 (FPL ENERGY INC), 9 November 2000 (2000-11-09); abstract; figures --	1-2, 4-5, 7-8, 10-13
A	US 20030116018 A1 (ECHIZEN HIROSHI ET AL), 26 June 2003 (2003-06-26); abstract; paragraph [0081]; figure 1 --	5
A	US 4023938 A (GUTH HANS ET AL), 17 May 1977 (1977-05-17); page 1, column 2, line 42 - page 1, column 2, line 65; figures -- -----	5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE2013/051059

Box 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:

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

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

The following separate inventions were identified:

1: Claims 1-4, 7-8 and 10-13 directed to a method for improving the performance of thermodynamic cycles by using a modified two stroke engine.

2: Claim 5 directed to a method for improving the performance of thermodynamic cycles by using a counter-current gas absorber.

.../...

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. ☒ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.: 1-5, 7-8, 10-13
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- ☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- ☒ No protest accompanied the payment of additional search fees.

Continuation of: Box No. III

3: Claim 6 directed to a method for improving the performance of thermodynamic cycles by using a turbine with a venturi design.

4: Claim 9 directed to a method for improving the performance of thermodynamic cycles by using a liquid absorbent comprising co-solvents and amines.

Continuation of: second sheet

International Patent Classification (IPC)

F01K 25/06 (2006.01)

F01K 25/10 (2006.01)

F25B 15/00 (2006.01)

F01B 23/00 (2006.01)

F03G 7/06 (2006.01)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

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International application No.

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