

Process and apparatus for transferring heat from a first medium to a second medium

The invention relates to a process and an apparatus for transferring heat from a first, relatively cold medium to a second, relatively hot medium.

In current power plants, work is typically
5 generated by means of a Carnot cycle or "steam cycle", employing a high temperature source and a low temperature source (heat sink). In practice, a high temperature medium, typically superheated steam, is fed to a turbine, which generates work, and is subsequently condensed,
10 (super)heated and once more fed to the turbine. I.e., the difference between the amount of heat contained in the high temperature medium and the amount of heat sunk to the low temperature source is converted into work, in accordance with the first law of thermodynamics.

15 At higher temperature differences between the high and low temperature sources, more heat can be converted into work and the efficiency of the process improves. Typically, the environment (earth) serves as the low temperature source (heat sink) and the high temperature
20 medium is generated by burning fossil fuels or by nuclear fission.

DE 32 38 567 relates to a device for generating temperature differences for heating and cooling. Under the influence of an external force, a temperature difference is
25 established in a gas. By using centrifugal forces and with gases of high molecular weight, this effect is increased to such an extent that it is of interest for technical use.

WO 03/095920 relates to a method for transmitting heat energy, wherein the heat energy is transmitted into an
30 inner chamber (3) of a rotating centrifuge via a first heat exchanger (4, 4a, 4b), in which inner chamber (3) a gaseous energy transfer medium is provided, and wherein the heat is discharged from the centrifuge (2) via a second heat

exchanger (5; 5a, 5b). The amount of energy used can be reduced substantially by providing the gaseous energy transmission medium inside the rotor (12) in a state of equilibrium and by radially orienting the heat flow in an outward direction. It is essential to the invention underlying WO 03/095920 that convection be prevented (page 2, last sentence).

US 3,902,549 relates to a rotor mounted for high-speed rotation. At its center is located a source of thermal energy whereas at its periphery there is located a heat exchanger. Chambers are provided, accommodating a gaseous material which, depending upon its position in the chambers, can receive heat from the source of thermal energy or yield heat to the heat exchanger.

Embodiments of the present invention seek to provide a process for efficiently generating a high temperature medium.

According to the first aspect of the present invention, there is provided a process of transferring heat from a first relatively cold medium to a second relatively hot medium, comprising the steps of

rotating a contained amount of a compressible fluid about an axis of rotation, thus generating a radial temperature gradient in the fluid, and

heating the second medium by means of the fluid in a section of the fluid relatively far from the axis of rotation, wherein the compressible fluid is at a pressure in excess of 2 bar.

An embodiment of the present invention further comprises the step of extracting heat from, i.e. cooling, the first medium by means of the fluid in a section at or relatively close to the axis of rotation.

The hot and cold media thus obtained in turn can be employed e.g. to heat or cool buildings or to generate electricity by means of e.g. a Carnot cycle or "steam cycle".

The efficiency of the process according to an embodiment of the present invention can be further increased if segments,

defined in radial direction, of the fluid are thoroughly mixed to obtain an at least substantially constant entropy in these segments and thus improved heat conduction within the fluid.

Also, heat conduction and hence efficiency increases with the pressure and density of the fluid. Thus, pressure is preferably in excess of 2 bar (at the axis of rotation), more preferably in excess of 10 bar (at the axis of rotation). The ratio of pressure at the circumference and pressure at the axis of rotation is preferably in excess of 5, more preferably in excess of 8.

According to the second aspect of the present invention, there is provided an apparatus for transferring heat from a first relatively cold medium to a second relatively hot medium, comprising a gastight drum rotatably mounted in a frame, and

a first heat exchanger mounted inside the drum relatively far from the axis of rotation of the drum, for instance in the inner wall of the drum, wherein the drum contains a compressible fluid and the apparatus is arranged to operate at a pressure, in the fluid, in excess of 2 bar.

In an embodiment of the present invention, the apparatus comprises a second heat exchanger positioned at or relatively close to the axis of rotation.

In another embodiment, the apparatus comprises one or more at least substantially cylindrical and co-axial walls, separating, in radial direction, the inside of the drum into a plurality of compartments.

In a further embodiment, at least one of the heat exchangers is coupled to a cycle for generating work. The further cycle can comprise an evaporator or super-heater, which is thermally coupled to the high temperature heat exchanger, a condenser, thermally coupled to the low temperature heat exchanger, and a heat engine. The environment will typically serve as a heat sink, but may also serve a high temperature source, if the operating temperature of the cycle is sufficiently low.

In yet a further embodiment, the compressible fluid is a gas and preferably contains or consists essentially of a mono-atomic element having an atomic number $(Z) \geq 18$, such as Argon, preferably ≥ 36 , such as Krypton and Xenon.

The invention is based on the insight that, although heat normally flows from a higher to a lower entropy and hence from higher to a lower temperature, in a column of an isentropic, compressible fluid positioned in a field of gravity heat also flows from a lower to a higher entropy. In the atmosphere of the earth, this effect reduces the vertical temperature gradient from a calculated 10 °C/km to an actual 6,5 °C/km. Hydropower is based on the same principle.

A reduced heat resistance further enhances heat flow from a lower to a higher temperature.

In accordance with at least some embodiments of the present invention, artificial gravity is employed to reduce the length of the column of the compressible fluid, in comparison with a column subjected merely to the gravity of the earth, and the atmosphere is replaced by a gas allowing a much higher temperature gradient in the fluid. Mixing is employed to improve heat conduction within the fluid.

Within the framework of the present invention the term "gradient" is defined as a continuous or stepwise increase or decrease in the magnitude of a property observed in passing from one point to another, e.g. along a radius of a cylinder.

For the sake of completeness, it is noted that US 4,107,944 relates to a method and apparatus for generating heating and cooling by circulating a working fluid within passageways carried by rotors, compressing said working fluid therewithin and removing heat from said working fluid in a heat removal heat exchanger and adding heat into said working fluid in a heat addition heat exchanger, all carried by said rotors. The working fluid is sealed within,

and may be a suitable gas, such as nitrogen. A working fluid heat exchanger is also provided to exchange heat within the rotor between two streams of said working fluid.

US 4,005,587 relates to a method and apparatus for transport of heat from a low temperature heat source into a higher temperature heated sink, using a compressible working fluid compressed by centrifugal force within a rotating rotor with an accompanying temperature increase. Heat is transferred from the heated working fluid into the heat sink at higher temperature, and heat is added into the working fluid after expansion and cooling from a colder heat source. Cooling is provided within the rotor to control the working fluid density, to assist working fluid circulation.

Similar methods and apparatuses are known from US 3,828,573, US 3,933,008, US 4,060,989, and US 3,931,713.

WO 2006/119946 relates to device (70) and method for transferring heat from a first zone (71) to a second zone (72) using mobile (often gaseous or vaporous) atoms or molecules (4) in which in one embodiment, the chaotic motion of the atoms/molecules which usually frustrates the transfer of heat by simple molecular motion is overcome by using preferably elongated nanosized constraints (33) (such as a carbon nanotube) to align the atoms/molecules and then subjecting them to an accelerating force in the direction in which the heat is to be transferred. The accelerating force is preferably centripetal. In an alternative embodiment, molecules (4c) in a nanosized constraint may be arranged to transfer heat by means of an oscillation transverse of the elongation of an elongated constraint (40).

JP 61165590 and JP 58035388 relate to rotary-type heat pipes. US 4,285,202 relates to industrial processes for energy conversion involving at least one step which consists in acting on the presence of a working fluid in

such a manner as to produce either compression or expansion.

The invention will now be explained in more detail with reference to the drawings, which schematically show a presently preferred embodiment.

Figures 1 and 2 are a perspective view and a side view of a first embodiment of the apparatus according to the present invention.

Figure 3 is a cross-section of a drum used in the embodiment of Figures 1 and 2.

Figure 4 is a cross-section of a second embodiment of the apparatus according to the present invention.

Figure 5 is a schematic layout of a power plant comprising the embodiment of Figure 4.

Identical parts and parts performing the same or substantially the same function will be denoted by same numeral.

Figure 1 shows an experimental setup of an artificial gravity apparatus 1, in accordance with the present invention. The apparatus 1 comprises a static base frame 2, firmly positioned on a floor, and a rotary table 3, mounted on the base frame 2. Driving means, e.g. an electromotor 4 are mounted in the base frame 2 and are coupled to the rotary table 3. To reduce drag, an annular wall 5 is fastened to the rotary table 3, along its circumference. Further, a cylinder 6 is fastened to the rotary table 3 and extends along a radius thereof.

As shown in Figure 3, the cylinder 6 comprises a centre ring 7, two (Perspex™) outer cylinders 8, two (Perspex™) inner cylinders 9 mounted coaxially inside the outer cylinders 8, two end plates 10, and a plurality of studs 11, with which the end plates 10 are pulled onto the cylinders 8, 9, and the cylinders 8, 9, in turn, onto the centre ring 7. The cylinder 6 has a total length of 1,0 meter. Figure 3 is to scale.

The lumen defined by the centre ring 7, the inner cylinders 9, and the end plates 10, is filled with Xenon, at ambient temperature and a pressure of 1,5 bar, and further contains a plurality of mixers or ventilators 13.

5 Finally, a Peltier element (not shown) is mounted on the inner wall of the ring 7 and temperature sensors and pressure gauges (also not shown) are present in both the ring 7 and the end plates 10.

During operation, the rotary table 3 and hence the
10 cylinder 6 is rotated at a speed of approximately 1000 RPM. Radial segments of the fluid are thoroughly mixed by means of the ventilators 12, to obtain an at least substantially constant entropy in these segments. In view of the fact
15 that the process is reversible and in view of the thermal isolation provided by the inner and outer cylinders 8, 9, which isolation enables conducting substantially adiabatic processes, heat transfer within the cylinder 6, from the axis of rotation to the circumference and vice versa, is substantially isentropic.

20 Upon rotation, the temperature and the pressure of the Xenon at the end plates 10 increase and the temperature and pressure at the ring 7 drop. When, upon reaching equilibrium, a stepped heat pulse is fed to the gas at the ring 7 by means of the Peltier element, temperature and
25 pressure at the ring 7 increase and, subsequently, temperature and pressure at the end plates 10 increase, i.e. heat flows from a source having a relatively low temperature (the gas at the ring) to a source having a relatively high temperature (the gas at the end plates).

30 Figure 4 is a cross-section of a second artificial gravity apparatus 1 in accordance with the present invention. The apparatus 1 comprises a static base frame 2, firmly positioned on a floor, and a rotary drum 6, mounted, rotatable about its longitudinal axis, in the base frame 2,
35 e.g. by means of suitable bearings, such as ball bearings

20. The drum 6 suitably has a diameter in a range from 2 to 10 meters, in this example 4 meters. The wall of the drum is thermally isolated in a manner known in itself. The apparatus 1 further comprises a driving means (not shown)
5 to spin the drum at rates in a range from 50 to 500 RPM.

The drum 7 contains (at least) two heat exchangers, a first heat exchanger 22 mounted inside the drum relatively far from the axis of rotation of the drum 7 and a second heat exchanger 23 positioned at or relatively
10 close to said axis. In this example, both heat exchangers 22, 23 comprise a coiled tube coaxial with the axis of rotation and connected, via a first rotatable fluid coupling 24, to a supply and, via a second rotatable fluid coupling 25, to an outlet.

15 The embodiment shown in Figure 4 further comprises an tube 26, coaxial with the longitudinal axis of the drum 7 and containing an axial ventilator 27 to forcedly circulate the contents of the drum. In this example, the drum is filled with Xenon at a pressure of 5 bar (at
20 ambient temperature), whereas the heat exchangers 22, 23 are filled with water.

Figure 5 is a schematic layout of a power plant comprising the embodiment of Figure 4, coupled to a cycle for generating work, in this example a so-called "steam
25 cycle". The cycle comprises an super-heater 30, coupled to the high temperature heat exchanger 22 of the apparatus 1, a heat engine, known in itself and comprising, in this example, a turbine 31, a condenser 32 coupled to the first heat exchanger 23 of the apparatus 1, a pump 33, and an
30 evaporator 34. The steam cycle is also filled with water. Other suitable media are known in the art.

Rotating the drum will generate a radial temperature gradient in the Xenon, with a temperature difference (ΔT) between the heat exchangers in a range from
35 100°C to 600°C, depending on the angular velocity of the

drum. In this example, the drum is rotated at 350 RPM resulting in a temperature difference (ΔT) of approximately 300°C. Water at 20°C is fed to both heat exchangers 22, 23. Heated steam (320°C) from the high temperature heat
5 exchanger 22 is fed to the super-heater 30, whereas cooled water (10°C) from the low temperature heat exchanger 23 is fed to the condenser 32. The steam cycle generates work in a manner known in itself.

In another embodiment, the apparatus comprises two
10 or more drums coupled in series or in parallel. For instance, in configurations comprising two drums in series, the heated medium from the first drum is fed to the low temperature heat exchanger of the second drum. As a result, heat transfer to the high temperature heat exchanger in the
15 second drum is increased considerably, when compared to heat transfer in the first drum. The cooled medium from the first drum can be used as a coolant, e.g. in a condenser.

In another embodiment, and as an alternative or addition to the aforementioned tube (26), the apparatus
20 comprises a plurality of at least substantially cylindrical and co-axial walls, separating the inside of the drum into a plurality of compartments. The fluid in each of the compartments is thoroughly mixed, e.g. by means of ventilators or static elements, so as to establish a
25 substantially constant entropy within each of the compartments and thus enhance mass transport within each of the compartments. As a result, an entropy gradient, stepwise and negative in outward radial direction, is achieved which enables heat transfer from the axis of
30 rotation of the drum to the circumference of the drum.

The walls mutually separating the compartments may be solid, thus preventing mass transfer from one compartment to the next, or may be open, e.g. gauze- or mesh-like, thus allowing limited mass transfer. The walls
35 may also be provided with protrusions and/or other features

that increase surface area and thus heat transfer between compartments.

In yet another embodiment, an additional liquid flows, e.g. inside radially extending tubes, from the
5 centre towards the circumference of the drum, thus gaining potential energy and pressure. The high pressure liquid drives a generator, e.g. a (hydro)turbine, and is subsequently evaporated by means of the relatively hot compressible fluid (e.g., Xenon) at or near the inner wall
10 of the drum. Vapour thus obtained is transported back to the centre of the drum, at least partially by employing its own expansion, and condensed by means of the relatively cold compressible fluid. This embodiment can be used to directly drive a generator.

15 The invention is not restricted to the above-described embodiments, which can be varied in a number of ways within the scope of the claims. For instance, other media, such as carbon dioxide, hydrogen, and CF_4 , can be used in the heat exchangers in the drum.

CLAIMS

1. Process of transferring heat from a first relatively cold medium to a second relatively hot medium, comprising the steps of

rotating a contained amount of a compressible fluid about an axis of rotation, thus generating a radial temperature gradient in the fluid, and

heating the second medium by means of the fluid in a section of the fluid relatively far from the axis of rotation, wherein the compressible fluid is at a pressure in excess of 2 bar.

2. Process according to claim 1, comprising the step of extracting heat from the first medium by means of the fluid in a section at or relatively close to the axis of rotation.

3. Process according to claim 1 or 2, wherein segments of the fluid are thoroughly mixed.

4. Process according to any one of the preceding claims, wherein the compressible fluid is at a pressure in excess of 10 bar.

5. Process according to any one of the preceding claims, wherein the compressible fluid is contained in a drum having a diameter of at least 1,5 meter and is rotated at at least 50 RPM, preferably at at least 100 RPM.

6. Process according to any one of the preceding claims, wherein work is generated by means of at least the first medium, preferably by means of both the first and second media, and preferably by means of a Carnot or steam cycle.

7. Process according to any one of the preceding claims, comprising two or more steps, in series or in parallel, of rotating a contained amount of the compressible fluid about an axis of rotation.

8. Process according to any one of the preceding claims, comprising the further steps of

allowing an additional liquid to flow away from the axis of rotation,

driving a generator with the liquid,

evaporating the liquid by means of the fluid in a section of the fluid relatively far from the axis of rotation,

pumping the vapour towards the axis of rotation, and,

condensing the vapour by means of the fluid in a section at or relatively close to the axis of rotation.

9. Process according to any one of the preceding claims, wherein the compressible fluid contains or consists essentially of a mono-atomic element having an atomic number $(Z) \geq 18$, preferably ≥ 36 .

10. Apparatus for transferring heat from a first relatively cold medium to a second relatively hot medium, comprising a gastight drum rotatably mounted in a frame, and a first heat exchanger mounted inside the drum relatively far from the axis of rotation of the drum, wherein the drum contains a compressible fluid and the apparatus is arranged to operate at a pressure, in the fluid, in excess of 2 bar.

11. Apparatus according to claim 10, comprising a second heat exchanger positioned at or relatively close to the axis of rotation.

12. Apparatus according to claim 10 or 11, comprising one or more at least substantially cylindrical and co-axial walls, separating the inside of the drum into a plurality of compartments.

13. Apparatus according to any one of the claims 10-12, wherein at least one of the heat exchangers comprises a coiled tube coaxial with the axis of rotation.

14. Apparatus according to any one of the claims 10-13, wherein at least one of the heat exchangers is coupled to a cycle for generating work.

15. Apparatus according to claim 14, wherein the cycle comprises an evaporator or super-heater, which is thermally coupled to the high temperature heat exchanger, a condenser, thermally coupled to the low temperature heat exchanger, and a heat engine.