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(54) **WASTE HEAT RECOVERY AND CONVERSION SYSTEM AND RELATED HEAT EXCHANGER**

ABWÄRMERÜCKFÜHRUNGS- UND UMWANDLUNGSSYSTEM UND DAZUGEHÖRIGER WÄRMETAUSCHER

SYSTÈME DE RÉCUPÉRATION ET DE CONVERSION DE CHALEUR PERDUE ET ÉCHANGEUR DE CHALEUR APPARENTÉ

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Description

FIELD OF THE INVENTION

[0001] Various embodiments of the present invention generally relate to a waste heat recovery system and related methods. In particular, certain exemplary embodiments relate to a waste heat recovery and/or power conversion system that can be integrated with a waste heat source.

DESCRIPTION OF RELATED ART

[0002] A variety of industrial processes and/or thermodynamic engines discharge waste heat into the environment. For example, a typical combustion engine used for propulsion of a moving vessel (e.g., a locomotive, automotive, or marine vessel) or power production (e.g., diesel-electric generators) has the thermodynamic efficiency of generally less than 40%. Lower efficiencies may result when these engines are operated outside of their optimal operational conditions, such as, for example, idling, acceleration transients, and low- and high-power engine operations. The efficiency can be further decreased for engines with purely mechanical or unsophisticated fuel metering controls.

[0003] For most combustion engine applications, and under most operating conditions, 22% to 46% of the total energy of fuel used by a combustion engine is normally lost through exhaust gases and engine cooling, which represent waste heat discharged into the environment. EP 884550 discloses a heat exchanger according to the preamble of claim 1.

SUMMARY

[0004] Thus, there may be a need for developing a heat recovery system and method for recovering and/or converting waste heat into useable energy. Recovering such waste heat and/or converting it into usable energy may increase efficiency, which results in fuel savings as well as reduction in pollutant emission and thermal discharge into the environment.

[0005] A waste heat recovery heat exchanger according to the invention is defined in independent claim 1. A corresponding waste heat recovery system is defined in claim 12.

[0006] Accordingly, various exemplary embodiments of the present disclosure may provide an integral waste heat recovery and conversion system and related methods capable of reliably and cost-effectively recovering and converting waste heat energy. For example, certain exemplary embodiments provide modular high-pressure heat exchanger for extracting waste heat energy from various thermodynamic systems and an integral conversion system for ultimately transforming the extracted waste heat energy into electricity and/or other forms of usable energy.

[0007] One exemplary aspect may provide a scalable, modular waste heat energy recovery and integral conversion system configured to convert waste heat energy produced by any source that rejects thermal energy into the environment, to heat a working fluid circulating within modular high-pressure heat exchangers thermally and hydraulically coupled and integrated with power conversion unit (PCU) for efficient waste heat conversion into usable energy.

[0008] The working fluid can be a suitable fluid with thermal-physical properties that favor phase changes from sub-cooled liquid to superheated vapor when exposed to low-grade heat transfer from any heat source fluid to the working fluid. The working fluid can also be a gas. In this case, the waste heat recovery and conversion system may be simplified as components dedicated to condensation of the working fluid would no longer be required.

[0009] The modular heat exchangers, all together with the integrated waste heat conversion system, may be configured to match the ever changing thermodynamic parameters characterizing variable waste heat production sources, especially when these sources are represented by internal combustion engines.

[0010] Another aspect may utilize scalable and modular heat exchangers configured to pre-heat and superheat the working fluid for expansion within the integral waste heat conversion system as non-invasive retrofit for internal combustion engines. In this case, the waste heat recovery and conversion system may be formed by universal pre-heating interfaces coupling the waste heat source thermal-hydraulic system (i.e., pipes, stuck, ducts transporting waste heat fluid) to at least one turbine expander to a fast alternator and to a high-pressure pump dedicated to pressurize the working fluid, for the conversion of waste heat energy into electricity and other usable energy forms. As an example of usable energy forms, a compressor system may be coupled to the fast rotating components forming the integral power conversion system so as to provide compressed intake air to a combustion engine and increase its performance while reducing Particulate Matter formation at idling and intermediate power settings.

[0011] Although bottom cycle technologies dedicated to combustion engines generally show low efficiencies, high manufacturing cost, high maintenance costs, and low reliability, the present invention is intended to provide a solution to the low-reliability, and high-costs represented by similar technologies by relatively simple to manufacture high-pressure heat exchangers with geometries and materials that withstand the harsh conditions in which this equipment operates and that can be assembled as clusters of heat exchangers, or multiple modules, to match the waste heat source availability. The scalable, modular, and integral thermal-hydraulic connectivity feature of the waste heat recovery and conversion system characterizing the present invention allows retrofitting schemes that do not require heavy financing. Individual

modules can be installed gradually and in a sequence wherein savings attained by the operation of each module over time can result in "self-financing" for the installation of additional modules up to matching the total waste heat source energy availability.

[0012] Waste heat energy transported, for example, by the fluid circulating in the cooling system and exhaust gas tubing of an industrial process or a combustion system heats up a suitable working fluid inside a modular heat exchanger in thermal contact with the fluid transporting waste heat energy without mixing with these fluid. By the modular heat exchanger, the working fluid expands by changing thermodynamic state from liquid to superheated vapor (for working fluid characterized by a system of liquid and vapor, or containing two-phases) within fluid-dynamically optimized channels derived internally the high-pressure heat exchanger.

[0013] The channels are formed by surfaces within the modular heat exchanger configured so as to increase the working fluid residence time and to enhance the working fluid thermal coupling with the fluid transporting waste heat energy. The residence time is increased by utilizing channel geometries that force the working fluid through pathways that increase turbulence while the working fluid accelerates as a result of its expansion through the channels and as a result of heat energy transfer from the high-pressure heat exchanger internal surfaces.

[0014] Furthermore, residence time is enhanced by configuring the working fluid and the fluid transporting waste heat energy so as to essentially swirl or rotate the working fluid and the fluid transporting waste heat energy while wetting and surrounding the surfaces forming the waste heat source system.

[0015] The thermal coupling between the working fluid and the fluid transporting waste heat energy occurs without mixing and is enhanced by utilizing suitable high thermal conductivity materials that form the support structures of the channels so as to make them capable of withstanding high-pressure, thermal stresses and mechanical deformation on all axes. As the working fluid travels through the modular heat exchanger, it becomes superheated and, depending on the selected working fluid, it may change phase from liquid to super heated vapor. At this point, the superheated working fluid exiting the modular heat exchanger may enter a series of modular pre-heating and modular heat exchangers so as to increase the waste heat energy transfer to the working fluid, for direct or indirect expansion of the superheated working fluid vapors within at least one set of turbine-alternator systems for the conversion of the working fluid energy into mechanical and electrical energy respectively.

[0016] As mentioned, depending on the application, the modular heat exchanger and waste heat conversion system formed by a turbine and alternator may be mechanically or thermal-hydraulically coupled to an air compressor system for the generation of compressed air. When compressed air is provided to the intake manifold of a combustion engine, the results are pollutant emission reductions and engine performance enhancement.

[0017] Finally, the working fluid exhausting from the turbine system is either cooled by heat exchangers thermally coupled with environmental fluid (i.e., gaseous single phase working fluid), or made to condense within a sudden-condensation chamber (i.e., liquid-vapor phase working fluid), thereby causing a vacuum at the turbine outlet and resulting in increased waste heat recovery and conversion system efficiency.

[0018] Certain exemplary embodiments of the present disclosure focus on bottom cycle applications and make its utilization commercially viable in the context of, for example, internal combustion engine applications. Also, various exemplary embodiments may provide the ability of the waste heat recovery and conversion system to be minimally invasive, with the high-pressure heat exchangers sufficiently rugged to withstand full flame immersion for operation in highly corrosive environments for a high-reliability over prolonged periods of time. Overall, the waste heat recovery and conversion system may efficiently transform low- and high-grade waste heat energy into re-usable energy without significantly interfering with the fluid-dynamic conditions characterizing the fluid transporting waste heat energy from the waste heat sources into the environment as the high-pressure preheating heat exchangers, and the superheating high-pressure heat exchangers are designed to reduce back pressure normally generated by drag forming between the heat source fluid and the surfaces of the high-pressure heat exchangers.

[0019] Additional objects and advantages of the invention will be set forth in part in the description which follows, and in part will be obvious from the description, or may be learned by practice of the invention. The objects and advantages of the invention will be realized and attained by the elements and combinations particularly pointed out in the appended claims.

[0020] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0021] The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate several embodiments of the invention and together with the description, serve to explain the principles of the invention.

Fig. 1 is a schematic diagram illustrating an application of a heat recovery and conversion system according to one exemplary embodiment.

Fig. 2 is a schematic diagram illustrating exemplary applications of a universal thermal and hydraulic coupler forming an interface between the high-pressure heat exchanger and the heat source while comprising a nozzle to direct waste heat fluid and fea-

tures allowing the high-pressure heat exchanger to mechanically expand/contract freely while providing hydraulic sealing with the waste heat source.

Fig. 3 is a perspective view of the universal thermal and hydraulic coupler forming a high-pressure heat exchanger of Fig. 2.

Fig. 4 is a perspective view of a retrofittable conduit for transporting fluid that carry waste heat energy from a waste heat source into a modular high-pressure heat exchanger integrally coupled to the conduit and showing the exterior walls of a high-pressure heat exchanger featuring geometries that allow redirecting of the heat source fluid while executing the functions of a nozzle.

Fig. 5 is a perspective view of a retrofittable conduit for transporting fluid that carry waste heat energy from a waste heat source into a modular high-pressure heat exchanger of Fig. 4 showing the coupling of the high-pressure heat exchanger with a sealing flexible member.

Fig. 6 is a schematic diagram illustrating exemplary applications of a high pressure heat exchanger positioned internally a heat source fluid duct.

Fig. 7 is a perspective view of high-pressure heat exchanger for retrofitting configurations in which the high pressure heat exchanger may be positioned within heat source fluid conduits with minimum drag and maximum heat transfer between the waste heat source and the working fluid.

Fig. 8 is a perspective view of a waste heat source conduit or manifold retrofitted with baffles to increase waste heat fluid mixing and turbulence.

Fig. 9 is a perspective view of modular high-pressure heat exchangers grouped to form a thermal-hydraulically coupled cluster of high-pressure heat exchangers submerged within the heat source fluid.

Fig. 10 is a perspective view of multiple modular high-pressure heat exchangers clustered and thermal-hydraulically connected to universal high-pressure heat exchangers with vibrational and structural decouplers thermal-hydraulically and mechanically coupled to an exemplary waste heat source represented by the exhaust gases of a combustion engine.

Fig. 11 is a schematic diagram illustrating exemplary applications of a power conversion unit (PCU) for the conversion of recovered waste heat energy into electricity and other usable energy forms. The schematic illustrates coupling between the expander, a fast generator/motor, a high-pressure pump wherein the expander provides features for utilization of compressed air.

Fig. 12 is a perspective view of an exemplary compact power conversion unit with features shown in the schematic of Fig. 11 and offering universal thermal-hydraulic and electrical couplings.

DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

[0022] Reference will now be made in detail to the exemplary embodiments of the invention, examples of which are illustrated in the accompanying drawings. Wherever possible, the same reference numbers or letters will be used throughout the drawings to refer to the same or like parts.

[0023] Various exemplary embodiments of the present disclosure provide a system and method for recovering waste heat from a heat source and converting it into useable energy. In some exemplary embodiments, the heat recovery system may be formed as a single modular system, where various components of the system are integrated into a single modular unit. For example, as will be described in more detail later, the waste heat recovery and conversion system utilizes a waste heat energy to heat a working fluid circulating within heat exchangers thermally and hydraulically coupled to an integrated power conversion system formed by one or more turbine expanders housed in a power conversion unit and coupled to energy conversion systems (e.g., an electric generator, a high-pressure pump, a clutch or direct mechanical coupler providing torque to drive a compressor or as a torque generator).

[0024] The working fluid may be any fluid having thermal-physical properties that favor phase changes from liquid to superheated vapor when exposed to a waste heat source. Alternatively, the waste heat recovery and conversion system may utilize a gaseous working fluid. In this case the integral power conversion unit may be configured to recirculate the gas after expansion in the expander turbine by substituting the high-pressure pump with a compressor/blower and by eliminating the condenser.

[0025] The heat exchangers of the present invention may be utilized to pre-heating and superheating the working fluid and as a mechanical and thermal hydraulic interface to decouple the vibrational and structural environment represented by the heat source from the structures of the heat exchangers. The heat exchangers may be formed by compact high-pressure heat exchanging surfaces containing channels for the circulation of the working fluid and provided with universal flanges for thermal-hydraulic coupling with the waste heat source. The heat exchangers may be modular and configured as stand-alone or clusters of heat exchanger systems all together with the power conversion system forming the integrated waste heat conversion system of the present invention and may be configured to tolerate the stressors generated by ever changing thermodynamic parameters characterizing variable waste heat production sources, especially when these sources are represented by internal combustion engines. To attain the advantages and in accordance with the purpose of the invention, as embodied and broadly described herein, one aspect of the invention provides means to utilize the scalable modular

heat exchanger and integral waste heat conversion systems for internal combustion engine applications, wherein the waste heat recovery and conversion system may be formed by coupling at least one turbine expander to an electric generator/motor and to an air compressor for the conversion of waste heat energy into electricity and compressed air respectively through a configuration that can be non-invasively retrofitted on existing combustion engine platforms, as well as to new combustion engines utilized for direct propulsion or for hybrid applications (e.g., diesel-electric vehicles, gas-electric vehicles, and stationary combustion-engine driven electric generator platforms).

[0026] As waste heat sources may be represented by different configurations utilizing various fluid for the rejection of waste heat energy into the environment, an objective of the present invention is to provide a universal, scalable, modular, waste heat recovery and integral conversion system for the conversion of various forms of waste heat energy into useful energy easily, with minimally invasively configurations highly adaptable to various waste heat sources requiring minimum maintenance. Depending on the application, the grade, or temperature, of the waste heat source (e.g., high-, intermediate-, low-grade) and mass-flow-rate of the fluid transporting waste heat energy for final rejection into the environment, the scalable modular heat exchanger and integral conversion system of the present invention may be coupled in parallel, in series, or any hybrid configuration (e.g., series and parallel). Similarly, the modules forming the embodiment of the invention may be scaled to directly match the waste heat source availability rating by employing a large single module, or clusters of smaller modules that all together match the total waste heat energy outputted from the waste heat source.

[0027] Fig. 1 is a schematic diagram illustrating various industrial applications of a heat recovery and conversion system according to one exemplary embodiment of the present disclosure. As shown in Fig. 1, the conversion of waste heat energy from a heat source 1 into usable energy may result in a lower heat release 44 into the environment as a portion of the waste heat energy normally discharged to the environment is converted into usable forms of energy. Heat source 1 can be any waste or residual heat from an industrial process, a combustion engine, or any other thermal source. By way of examples only, heat source 1 may comprise exhaust gases from combustion engines, steam or hot gases from various industrial processes, and waste liquids released into the environment or cooled down by closed-loop cooling system prior to being discharged into the environment.

[0028] Heat source fluid 2 may be in the form of gas or liquid. Heat source fluid 2, transporting waste heat energy from heat source 1, is made to exchange its thermal energy with 1st Heat Exchanger 3 configured to preheat working fluid 4 prior to entering into the 2nd Heat exchanger 5 configured to superheat working fluid 4 while transiting within its channels. Working fluid 4 circulates in a closed-loop and does not mix with heat source fluid 2. 1st heat exchanger 3 and 2nd heat exchanger 5 may be configured with a flexible thermal-hydraulic and mechanical coupling to attenuate vibrational stressors induced by coupling of the heat exchangers with heat source 1, thereby providing an interface between the heat exchangers and the heat source to mitigate vibrational and thermal stressors. As heat source fluid 2 transfers its thermal energy to working fluid 4, heat source fluid 2 lowers its energy content for final discharge into the environment at lower temperatures.

[0029] The heat exchangers in pre-heating interface 3 may have sufficiently large heat transfer surfaces to directly obtain superheating of working fluid 4. If working fluid 4 is a liquid-vapor phase fluid, working fluid 4 may be in a sub-cooled state at the inlet of pre-heating interface 3. Depending on the thermodynamic state of heat source fluid 2, working fluid 4 may exit pre-heating interface 3 in a sub-cooled liquid, a mixed vapor-liquid, or superheated thermodynamic state.

[0030] Working fluid 4 exiting 1st heat exchanger 3 enters the 2nd heat exchanger 5 configured as a stand alone high pressure heat exchanger or as a cluster of modular heat exchangers, to provide additional thermal energy exchange between heat source fluid 2 and working fluid 4 through its extended heat transfer surfaces. Superheated working fluid 4 exiting 2nd heat exchanger 5 then enters a power conversion unit (PCU) 6 for expansion within a set of turbines or expander for conversion of heat source 1 into electricity, compressed air, and/or any other usable energy forms while providing pumping power for working fluid 4 to circulate through the closed-loop formed by coupling 1st heat exchanger, 2nd heat exchanger and the PCU 6. PCU 6 may be integral as its expander, pump, alternator/motor, torque coupler and condenser may be configured as a single piece within the same housing. This configuration is particularly suitable for applications dedicated to internal combustion engines coupled to electric generators as the waste heat recovery and conversion system of the present disclosure converts a portion of the recovered waste heat energy into electricity for ready electrical voltage and phase coupling with the electrical generators and equipment driven by the internal combustion engine.

[0031] The conversion of a portion of the waste heat energy into compressed air may be required to satisfy pollutant reduction features of the waste heat recovery and conversion system. Converting a portion of the recovered heat source 1, when applied to combustion engines, into compressed air provides the combustion engine with excess oxygen (air) when the engine operates at low Revolution per Minute (RpM) and/or at high transient loads. Most internal combustion engines operating in these conditions manifest high pollutant emissions. Therefore, providing compressed air as a result of waste heat recovery and conversion results in pollutant emission reductions, while enhancing the combustion engine performance at low RpM and during transients in which

the combustion engine duty cycle is changed from low- to high-loads.

[0032] As a result of thermal energy transfer with working fluid 4, heat source fluid 2, exiting the 2nd heat exchanger 5, may be characterized by lower temperatures, thereby allowing for Emission Gas Recirculation methodologies and further decrease pollutant emissions.

[0033] For waste heat sources characterized by non air-breathing processes (e.g., requiring compressed air to improve their pollutant emissions), the modular heat exchangers forming 1st and 2nd heat exchangers 3 and 5 respectively may be configured to increase working fluid 4 energy content for expansion within an expander, for example, formed by a turbine-generator system for electricity production only. For applications requiring conversion of waste heat energy into mechanical torque, working fluid 4 may be expanded through an expander (i.e. turbines) coupled, for example, via gear-box or through a magnetic or hydraulic clutch, to provide shaft work. As working fluid 4 exits the expander system it enters a condenser 7 integrated with the volumes and surfaces formed by the power conversion unit housing so as to provide compact thermal-coupling and a vacuum or a low-pressure state at the exit of the expander. This low-pressure thermodynamic state may be induced by condensation caused by thermal exchange with the compressor fluid (e.g., air). Additionally, auxiliary cooling may be provided by external cooling sources as it will be shown in Fig. 11 and Fig. 12. High-pressure working fluid 4 circulates by means of a pump driven by the torque generated by the expander forming the integral power conversion unit.

[0034] To summarize the exemplary embodiments shown in Fig. 1, the waste heat recovery and conversion system may comprise a waste heat source 1 characterizing by thermal-hydraulic systems (i.e., pipes, ducts, venting stuck etc.) transporting waste heat energy from heat source 1 to the environment, one or more high-pressure heat exchangers (e.g. 1st and 2nd heat exchangers 3 and 5) wherein a suitable working fluid 4 circulates at high pressure by means of a pump, integrated with and driven by the power conversion unit 6, for the transfer of waste heat energy 1 transported by heat source fluid 2 and transferred into working fluid 4, thereby superheating it, for expansion and conversion into electricity and other suitable energy forms, wherein the working fluid condenses after exiting the expander through a condensing system 7 so as to re-set the closed-loop thermodynamic cycle. 1st and 2nd heat exchangers 3 and 5 respectively all together with the components forming the PCU 6 may be made integral and modular as these components may be housed as a single piece.

[0035] The working fluid may be represented by water which may be used to describe the exemplary embodiments of the invention. It should be understood, however, that any other fluid having suitable thermodynamic properties may be used alternatively or additionally. For example, for configurations wherein working fluid is in a gaseous form, condenser 7 may be configured to function as an intercooler while the high-pressure pump integrated with the power conversion unit may be configured to operate as a re-circulator or blower.

[0036] With reference to Fig. 2 and Fig. 3, the operational processes occurring within the high-pressure heat exchanger forming a thermal and hydraulic coupler are described in detail. As shown in this figures, flange 13 allows for thermal-hydraulic and mechanical coupling with heat source 1. This provides a thermal-hydraulic and mechanical interface between heat source 1 and 1st heat exchanger 3 so as to minimize or eliminate thermal and vibrational stressors potentially transferred from the heat source to the heat exchanger and power conversion unit systems. 1st heat exchanger 3 may be characterized by channels 10 formed by inner jacket walls 18 and outer jacket walls 17. Channels 10 may be configured to form internal pathways by channel fins 11 for working fluid 4 to increase its residence time and enhance heat transfer while transiting within the 1st heat exchanger. All together, heat channel 10 and fins 11 form a structure allowing high-pressure operation.

[0037] As heat source fluid 2 transfers energy to channels 10 by thermal transfer via channel fins 11 and/or via outer and inner jacket walls 17 and 18 respectively, without mixing with working fluid 4, the thermodynamic state of working fluid changes from inlet 8 to outlet 9 as it expands and accelerates within channel 10. Depending on the thermodynamic state and mass-flow-rate of heat source fluid 2, and on the dimensions and materials forming the high-pressure heat exchanger of 1st heat exchanger 3, working fluid 4 may exit outlet 9 as sub-cooled liquid single phase, as liquid-vapor two-phase, or as superheated vapor single phase. Superheated fluid 21 denotes a single-phase superheated fluid. If working fluid 4 is gaseous, the gas or mixed gases increase their energy content from inlet 8 to outlet 9. As the heat source may be formed by a system inducing vibrational stressors, flexible member flange 14 allows for mechanical coupling with flexible member 12 whose vibrational decoupling of flange 15 allows for mechanical and thermal-hydraulic coupling with modular 2nd heat exchanger(s) 5 without transferring structural loads and vibrational stresses associated with the system representing heat source 1.

[0038] Fig. 4 and 5 show exemplary geometries of the 1st heat exchanger 3 wherein heat source fluid 2 may enter through flange 13 configured to thermal-hydraulically and mechanically couple the 1st heat exchanger 3 to heat source 1. As for the embodiments described in Fig. 2 and 3, the outer jacket walls 17 and inner jacket walls 18 comprise channels 10 and fins 11 (shown in Fig. 2) not shown in Fig. 4 and 5 for simplicity. 1st heat exchanger 3 high-pressure inlet 9 and outlet 8 are interchangeable so as to allow for execution of series, parallel, counter- and parallel-flow configurations according to heat source 1 waste energy availability and PCU 6 ratings. Fig. 4 shows a method to direct heat source fluid 2

flow so as to enable retrofitting with a variety of waste heat sources and configurations. In these exemplary representations, nozzle 16 accelerates waste heat fluid 2 while re-directing the flow. While flange 14 is mechanically directly coupled to flange 13 (e.g., it may be part of the same body), flexible member 12 and flexible member flange 15 allows thermal-hydraulic coupling with 2nd heat exchanger 5 while providing a vibration damping system to minimize vibrational and thermal stresses.

[0039] With reference to Fig. 6 and Fig. 7, the operational processes occurring within the 2nd heat exchanger 5 are described in detail. As shown in these figures, channels 22 are formed by the jacket-like structure comprising the superheating inner and outer surfaces 26 and 28 respectively, and by internal pathways formed by superheating inner and outer fins 23 and 27.

[0040] To minimize drag and reduce backpressure 2nd heat exchanger 5 may be configured to feature aerodynamically optimized drag reducing entrance 24 and end 25. Additionally, to further reduce aerodynamic drag, 2nd heat exchanger 5 may be configured to be "floating" within a heat source duct 20 by providing hydraulic and mechanical connections through flexible hydraulic couplers 19. The heat source duct 20 may be provided with the heat source equipment (i.e., exhaust gas manifolds for applications involving waste heat recovery and conversion from combustion engines). Alternatively, a heat source 1 hydraulic conduit may be formed by configuring hydraulic conduit 20 with flanges 29 for modular coupling with clusters of 2nd heat exchangers 5 thermal-hydraulically connected in series, parallel or mixed series-parallel configurations. As working fluid 4 enters 2nd heat exchanger 5 at inlet 8, its energy content increases due to thermal exchange with heat source fluid 2 and becomes superheated while transiting through channels 22. Outlet 9 and inlet 8 are interchangeable, thus allowing for various counter-flow, parallel-flow, or hybrid parallel-counter-flow configurations.

[0041] Fig. 7 illustrates an exemplary embodiment of the 2nd heat exchanger 5 without heat source duct 20 for simplicity. In this exemplary representation, fins 23 may be represented by sealed pins extruding through channel 22 and wetted by heat source fluid 2. In Fig. 7 outer fins 27 are not shown for simplicity. In this representation, super heated fluid 21 exits at outlet 9, while working fluid 4 entering at interchangeable inlet/outlet 8 is not shown.

[0042] With reference to Fig. 8 the exemplary waste heat source duct 20 may be formed by one or multiple conduit, or manifolds with various shapes, for transport of heat source fluid 2 to the environment. To increase heat source fluid 2 turbulence and heat transfer the heat source duct 20 may be retrofitted with mixing baffles 30. For exemplary purposes the heat source duct 20 may be configured with multiple heat source fluid inlets and outlets that can be coupled to modular heat source ducts via heat source duct coupling flanges 29.

[0043] Fig. 9 is an exemplary representation in perspective view of modular 2nd heat exchangers 5 grouped to form a thermal-hydraulically-coupled and mechanically supported cluster of 2nd heat exchangers 5 submerged within heat source fluid 2. This figure is not to scale with respect to the heat source duct 20 represented in Fig 8. As shown in Fig. 9, heat source fluid 2 may wet all surfaces of each individual 2nd heat exchangers 5, grouped in the cluster formed by supporting 2nd heat exchangers 5 though cartridge flanges 32. By wetting 2nd heat exchanger 5 outer surfaces 28 and inner surfaces 26 (shown in Fig. 9 only for one of the multiple superheating heat exchangers forming the cluster) heat transfer from heat source fluid 2 to working fluid 4 may be enhanced. Hydraulic connections among each individual high-pressure heat exchanger and those providing one or multiple inlets 8 to working fluid 4 and outlets 9 to transport superheated fluid 21 may be configured with flexible hydraulic couplers 19 shown in Fig. 6, not shown in Fig. 9.

[0044] Fig. 10 shows an exemplary embodiment of thermally-hydraulically and mechanically coupled 1st and 2nd heat exchangers 3 and 5 respectively, thermal-hydraulically and mechanically interfaced with the heat source 1, supported within modular heat source ducts 20, and submerged within heat source fluid 2 resulting from operation of a combustion engine representing, as an example, waste heat source 1. As shown in this figure while 1st heat exchanger 3 is mechanically forming a single piece with the cylinders blocks of the combustion engine, representing as an example waste heat source 1, each heat source duct 20 is mechanically linked to waste heat source 1 through flexible members 12, thereby minimizing the impact of vibrations, and that of expansion and contractions exerted the materials forming the 2nd heat exchangers 5.

[0045] Fig. 11 shows a schematic diagram illustrating exemplary applications of the power conversion unit (PCU) 6 for the conversion of recovered waste heat energy from a heat source 1 into electricity 42 and other usable energy forms. The power conversion unit 6 may include at least one expander 34, mechanically coupled to at least one electric generator/motor 36. The electric generator motor 36 may be configured as a fast and compact electrical machine equipped with a coupling shaft. Alternatively all of the rotary components forming the electrical generator motor 36, the pump 37, the expander 34, the shaft coupler and the compressor 40 may mechanically coupled to a single shaft 35. The expander 36 may be configured to expand superheated fluid 21 by one or multiple turbines or positive displacement components. The fast electric generator/motor 36 may be configured to produce electrical power when driven by expander 34 or deliver torque to shaft 35 when operated as an electric motor. The high-pressure pump may be configured to provide a variable mass-flow-rate (i.e. proportional to shaft 35 revolutions per minute) for example via external control system. The power conversion unit 6 may also be configured to provide mechanical torque resulting from recovered waste heat source 1 energy, for example, to drive an air compressor 40 for combustion

engine applications as part of a pollutant reduction system. All of the components comprised in Fig. 11 and 12 may be integral and housed to form a single unit.

[0046] By hydraulically coupling the power conversion unit 6 to the 1st and 2nd heat exchangers the thermodynamic loop shown in Fig. 1 is closed. Working fluid 4 may be configured to be stored within a reservoir integrally formed within the housing of condenser 7 wherein it is suctioned by pump 37 and compressed for utilization by the 1st and/or 2nd heat exchangers 3 and 5 respectively. Superheated fluid 21 produced by 1st and 2nd heat exchangers 3 and 5 respectively may be hydraulically coupled to the power conversion unit 6 by insulated high-pressure tubing (not shown). As superheated fluid 21 expands in expander 34 it exhausts in the condenser 7. Condensing working fluid 33 exiting the expander 34 may undergo condensation by means of active and passive cooling via thermal exchange with the surfaces forming the housing of condenser 7 integrated with power conversion unit 6 and transferring thermal energy to the environment passively via natural convection, and/or actively by forced convection through active recirculation of cooling fluids.

[0047] Thermal transfer between the condensing working fluid 33 and the thermodynamic environment represented by condenser 7 may be induced by circulating the working fluid via condenser auxiliary cooling 49 (e.g., radiator system), and/or by thermal transfer with a second fluid 41 (e.g., air) circulating, for example, via compressor 40 in combination or independently of the cooling impact induced by enhancing condenser cooling fins 48. In this configuration, prior to entering compressor 40, secondary fluid 41 provides cooling to condenser 7 through fins 48.

[0048] The electric generator/motor 36 may be configured to mechanically couple expander 34 through shaft 35. When the integral power conversion unit 6 is configured to recover and convert waste heat source 1 energy from combustion engines, the compressor 40 may provide features to reduce pollutant emissions while increasing engine efficiency. In this configurations there are combustion engine operating conditions (e.g., low thermal loads) that may reduce waste heat source 1 ability to provide sufficient waste heat energy to drive expander 34. To ensure compressor 40 maintains the function of compressing secondary fluid 41, the electric generator/motor may be actively configured to switch from "generator mode" to "motor mode", thereby electrically driving compressor 40. Compressor 40 represents a usable form of converted waste heat source. Shaft 35 may be coupled to compressor 40 or any other torque requiring auxiliary system by shaft coupler 39 which may involve various types of clutch systems (e.g., electrical, hydraulic, magnetic, friction and/or centrifugally driven).

[0049] Cooling of the electric generator/motor 36 may be accomplished by means comprising the generator/motor cooling system 38. These cooling means may be particularly required for high compact "fast RpM" generator/motors and may independently or jointly include a third cooling fluid 47 to transfer thermal energy with the electric generator/motor 36 and its electric interface 43 by electric interface cooling fins 45, and/or thermal transfer to cooling fluid circulating in the condenser 7 (i.e., via condenser cooling auxiliary 49), and/or thermal transfer with secondary fluid 41 by electric interface cooling fins 46.

[0050] Fig. 12 shows a perspective view of an exemplary power conversion unit integrating the features shown in the schematic of Fig. 11. As shown in this Figure, motive and control electric power may be distributed from and provided to the power conversion unit 6 through electric bus inlet/outlet 42. Superheated fluid 21 is provided to the integral power conversion unit 6 through inlet 50, the third cooling fluid 47 may be circulated through inlet/outlet set 51, high-pressure working fluid 4 is provided at pump 37 outlet 52, condenser auxiliary cooling may be circulated via inlet outlet set 53, and secondary fluid 41 enter compressor 40 suction inlet 54 and exits at compressor 40 discharge 55. The power conversion unit 6 external surfaces may be thermally insulated. Thermal-hydraulic and mechanical coupling of the power conversion unit 6 with 1st and/or 2nd heat exchangers may be provided through flexible hydraulic couplers 19 and 12 to decouple vibrational and mechanical stresses produced by the heat source 1.

[0051] Other embodiments of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed herein. It is intended that the specification and examples be considered as exemplary only, with the scope of the invention being indicated by the following claims.

Claims

1. A heat exchanger (5) comprising:

an outer duct (20) defining an inlet and an outlet through which a first fluid (2) flows in and out, respectively, of the outer duct (20); and
at least one inner duct disposed inside the outer duct (20) and defining at least one inner channel (22) inside the inner duct and an outer channel between an outer surface (28) of the inner duct and an inner surface of the outer duct (20);
wherein the inner duct defines the inner channel (22) through which a second fluid (4) flows to exchange heat energy with the first fluid (2);
wherein said inner channel (22) is arranged between said outer surface (28) of the inner duct and an inner surface (26) of the inner duct; and
wherein the inner surface (26) of the inner duct defines a central channel distinct from said outer channel and in fluid communication therewith so that said first fluid (2) flowing in through said inlet and flowing out through said outlet of the outer

duct (20) can exchange heat energy with the second fluid (4) through the inner surface (26) and the outer surface (28) of the inner duct; and **characterized in that** the inner duct is hydraulically and mechanically connected to the inner surface of the outer duct (20) through at least one inlet (8) and at least one outlet (9) for the second fluid (4), which are configured with flexible hydraulic couplers (19).

2. The heat exchanger of claim 1, wherein the first fluid (2) flows in a first direction inside the outer duct (20), and the second fluid (4) flows in a second direction substantially opposite to the first direction.

3. The heat exchanger of claim 1 or 2, wherein both the outer duct (20) and inner duct are substantially cylindrical.

4. The heat exchanger of any one of claims 1-3, wherein the outer duct and inner duct are substantially concentric.

5. The heat exchanger of any one of claims 1-3, wherein a plurality of inner ducts are disposed inside the outer duct (20).

6. The heat exchanger of any one of claims 1-5, further comprising a plurality of fins (23, 27) extending from the inner channel (22) to the central channel and/or the outer channel to enhance heat transfer between the first fluid (2) and the second fluid (4).

7. The heat exchanger of any one of claims 1-6, wherein the second fluid (4) enters the inner channel (22) of the inner duct in a subcooled state and exits the inner channel (22) in a superheated state.

8. The heat exchanger of any one of claims from 1-7, wherein the inner surface of the outer duct (20) is provided with mixing baffles (30) increasing mixing and turbulence of the first fluid (2).

9. The heat exchanger of any one of claims from 1-8, wherein said inlet (8) and outlet (9) for the second fluid (4) lead to the outside of the outer duct (20).

10. The heat exchanger of any one of claims 1-9, wherein the outer duct (20) is provided with a flexible thermal-hydraulic and mechanical coupling (12) suitable to attenuate vibrational stresses induced by coupling the heat exchanger (5) with a heat source (1).

11. The heat exchanger of any one of claims 1-10, wherein said inlet and outlet of the outer duct (20) are provided with respective coupling flanges (29) coupling the heat exchanger to a further heat exchanger (5) of any one of claims 1-10.

12. A waste heat recovery system comprising:

the heat exchanger (5) of any one of claims 1-11;
a power conversion unit (6) configured to convert the energy transferred from the first fluid (2) to the second fluid (4) into usable energy (42).

13. The system of claim 12, further comprising a condenser (7) configured to condense the second fluid (4).

14. The system of claim 12 or 13, further comprising a preheating interface (3) disposed between a heat source (1) and the heat exchanger (5), wherein the preheating interface (3) is configured to preheat the second fluid (4) prior to entering the heat exchanger (5).

15. The system of claim 14, wherein the preheating interface (3) comprises a preheating heat exchanger comprising:

an inlet through which the first fluid (2) enters to the preheating heat exchanger from the heat source (1);
an outlet through which the first fluid (2) exits the preheating heat exchanger and enters the heat exchanger (5); and
a preheating channel (10) through which the second fluid (4) flows to preheat the second fluid (4) prior to entering the heat exchanger (5).

16. The system of claim 14 or 15, wherein the preheating interface (3) comprises a flange (13) configured to fix the preheating heat exchanger to the heat source (1).

17. The system of any of claims 14-16, wherein the preheating interface (3) comprises a flexible member (12) configured to reduce vibration stress between the heat source (1) and the heat exchanger (5).

18. The system of any of claims 12-17, wherein the power conversion unit (6) includes at least one expander (34) mechanically coupled to at least one electric generator/motor (36) through a shaft (35).

19. The system of claim 18, wherein the electric generator/motor (36), a pump (37) suitable for pumping the second fluid (4), a shaft coupler (39) and a torque requiring auxiliary system (40) are mechanically coupled to said shaft (35).

20. The system of claim 19, wherein said torque requiring system (40) is a compressor suitable for compressing a secondary fluid (41) for cooling said condenser (7).

Patentansprüche

1. Ein Wärmetauscher (5), umfassend:

- ein äußeres Rohr (20), welches einen Einlass und einen Auslass abgrenzt, wodurch ein erstes Fluid (2) in das äußere Rohr (20) zu- bzw. aus diesem abfließt; und
- wenigstens ein inneres Rohr, der innerhalb des äußeren Rohrs (20) angeordnet ist und wenigstens einen inneren Kanal (22) innerhalb des inneren Rohrs abgrenzt sowie einen äußeren Kanal zwischen einer äußeren Oberfläche (28) des inneren Rohrs und einer inneren Oberfläche des äußeren Rohrs (20);
- wobei das innere Rohr den inneren Kanal (22) abgrenzt, durch welchen ein zweites Fluid (4) fließt, um Wärmeenergie mit dem ersten Fluid (2) auszutauschen;
- wobei das besagte, innere Rohr (22) zwischen der besagten, äußeren Oberfläche (28) des inneren Rohrs und einer inneren Oberfläche (26) des inneren Rohrs angeordnet ist;
- und wobei die innere Oberfläche (26) des inneren Rohrs einen zentralen Kanal definiert, der von dem besagten äußeren Kanal getrennt ist und mit jenem in Strömungsverbindung steht, so dass das besagte, erste Fluid (2), welches durch den besagten Einlass zu- und durch den besagten Auslass des äußeren Rohrs (20) abfließt, Wärmeenergie mit dem zweiten Fluid (4) durch die innere Oberfläche (26) und die äußere Oberfläche (28) des inneren Rohrs austauschen kann; und

dadurch gekennzeichnet, dass

- das innere Rohr hydraulisch und mechanisch mit der inneren Oberfläche des äußeren Rohrs (20) verbunden ist durch wenigstens einen Einlass (8) und wenigstens einen Auslass (9) für das zweite Fluid (4), welche mit biegsamen, hydraulischen Koppelelementen (19) konfiguriert sind.

2. Der Wärmetauscher nach Anspruch 1, wobei das erste Fluid (2) in einer ersten Richtung innerhalb des äußeren Rohrs (20) fließt, während das zweite Fluid (4) in einer zweiten Richtung substantiell entgegen der ersten Richtung fließt.

3. Der Wärmetauscher nach Anspruch 1 oder 2, wobei sowohl das äußere Rohr (20) als auch das innere Rohr substantiell zylindrisch ist.

4. Der Wärmetauscher nach einem der Ansprüche 1-3, wobei das äußere Rohr (20) und das innere Rohr substantiell konzentrisch sind.

5. Der Wärmetauscher nach einem der Ansprüche 1-3, wobei eine Mehrzahl von inneren Rohren innerhalb des äußeren Rohrs (20) angeordnet sind.

6. Der Wärmetauscher nach einem der Ansprüche 1-5, ferner umfassend eine Mehrzahl von Finnen (23, 27), welche sich von dem inneren Kanal (22) zu dem zentralen Kanal und/oder zu dem äußeren Kanal erstrecken, um die Wärmeübertragung zwischen dem ersten Fluid (2) und dem zweiten Fluid (4) zu verbesssern.

7. Der Wärmetauscher nach einem der Ansprüche 1-6, wobei das zweite Fluid (4) in den inneren Kanal (22) des inneren Rohrs in unterkühltem Zustand hineingelangt und den inneren Kanal (22) in überhitztem Zustand verlässt.

8. Der Wärmetauscher nach einem der Ansprüche 1-7, wobei die innere Oberfläche des äußeren Rohrs (20) mit Misch-Leitblechen (30) versehen ist, um die Vermischung und Turbulenz in dem ersten Fluid (2) zu steigern.

9. Der Wärmetauscher nach einem der Ansprüche 1-8, wobei der besagte Einlass (8) und Auslass (9) für das zweite Fluid (4) zu der Außenseite des äußeren Rohrs (20) führen.

10. Der Wärmetauscher nach einem der Ansprüche 1-9, wobei das äußere Rohr (20) mit einer biegsamen, thermal-hydraulischen und mechanischen Kupplung (12) versehen ist, die in der Lage ist, durch die Kopplung des Wärmetauschers (5) mit einer Wärmequelle (1) induzierte Vibrationsbeanspruchungen abzuschwächen.

11. Der Wärmetauscher nach einem der Ansprüche 1-10, wobei die besagten Ein- und Auslässe des äußeren Rohrs (20) mit jeweiligen Koppelflanschen (29) versehen sind, um den Wärmetauscher mit einem weiteren Wärmetauscher (5) nach einem der Ansprüche 1-10 zu koppeln.

12. Ein Abwärmerückführungssystem, umfassend:

- den Wärmetauscher (5) nach einem der Ansprüche 1-11;
- eine Energieumwandlungseinheit (6), welche dazu konfiguriert ist, um die von dem ersten Fluid (2) auf das zweite Fluid (4) übertragene Energie in nutzbare Energie (42) umzuwandeln.

13. Das System nach Anspruch 12, ferner umfassend einen Kondensator (7), der dazu konfiguriert ist, um das zweite Fluid (4) zu kondensieren.

14. Das System nach Anspruch 12 oder 13, ferner um-

fassend eine Vorheiz-Anschlussstelle (3), die zwischen einer Wärmequelle (1) und dem Wärmetauscher (5) angeordnet ist, wobei die Vorheiz-Anschlussstelle (3) dazu konfiguriert ist, um das zweite Fluid (4) vor dem Einströmen in den Wärmetauscher (5) vorzuheizen.

15. Das System nach Anspruch 14, wobei die Vorheiz-Anschlussstelle (3) einen Vorheiz-Wärmetauscher aufweist, umfassend:

- einen Einlass, durch welchen das erste Fluid (2) von der Wärmequelle (1) in den Vorheiz-Wärmetauscher (5) hineingelangt;
- einen Auslass, durch welchen das erste Fluid (2) den Vorheiz-Wärmetauscher (5) verlässt und in den Wärmetauscher (5) hineingelangt; und
- einen Vorheiz-Kanal (10), durch welchen das zweite Fluid (4) fließt, um das zweite Fluid (4) vorzuheizen, bevor dieses in den Wärmetauscher (5) hineingelangt.

16. Das System nach Anspruch 14 oder 15, wobei die Vorheiz-Anschlussstelle (3) einen Flansch (13) aufweist, welcher dazu konfiguriert ist, um den Vorheiz-Wärmetauscher an der Wärmequelle (1) festzulegen.

17. Das System nach einem der Ansprüche 14-16, wobei die Vorheiz-Anschlussstelle (3) ein biegsames Element (12) aufweist, welches dazu konfiguriert ist, um die Vibrationsbeanspruchung zwischen der Wärmequelle (1) und dem Wärmetauscher (5) zu reduzieren.

18. Das System nach einem der Ansprüche 12-17, wobei die Energieumwandlungseinheit (6) wenigstens einen Expander (34) umfasst, der mechanisch über eine Welle (35) mit wenigstens einem elektrischen Generator / Motor gekoppelt ist.

19. Das System nach Anspruch 18, wobei der elektrische Generator / Motor (36), eine zum Pumpen des zweiten Fluids (4) geegnete Pumpe (37), eine Wellenkupplung (39) und ein Drehmoment erforderndes Hilfssystem (40) mechanisch an die besagte Welle (35) gekoppelt sind.

20. Das System nach Anspruch 19, wobei das Drehmoment erfordernde System (40) ein Kompressor ist, der dazu in der Lage ist, ein sekundäres Fluid (41) zu komprimieren, um den besagten Kondensator zu kühlen.

Revendications

1. Echangeur de chaleur (5) comprenant :

un conduit de sortie (20) définissant une entrée et une sortie à travers lesquelles un premier fluide (2) entre et sort en s'écoulant respectivement du conduit externe (20) ; et
au moins un conduit interne disposé à l'intérieur du conduit externe (20) et définissant au moins un canal interne (22) à l'intérieur du conduit interne et un canal externe entre une sortie externe (28) du conduit interne et une surface interne du conduit externe (20) ;
dans lequel le conduit interne définit le canal interne (22) à travers lequel un second fluide (4) s'écoule pour échanger l'énergie thermique avec le premier fluide (2) ;
dans lequel :

ledit canal interne (22) est agencé entre ladite surface externe (28) du conduit interne et une surface interne (26) du conduit interne ;
et dans lequel :

la surface interne (26) du conduit interne définit un canal central distinct dudit canal externe et en communication de fluide avec ce dernier, de sorte que ledit premier fluide (2) s'écoulant à travers ladite entrée et sortant par ladite sortie du conduit externe (20) peut échanger l'énergie thermique avec le second fluide (4) à travers la surface interne (26) et la surface externe (28) du conduit interne ; et
caractérisé en ce que :

le conduit interne est raccordé de manière hydraulique et mécanique à la surface interne du conduit externe (20) par le biais d'au moins une entrée (8) et au moins une sortie (9) pour le second fluide (4), qui sont configurées avec des coupleurs hydrauliques (19) flexibles.

2. Echangeur de chaleur selon la revendication 1, dans lequel le premier fluide (2) s'écoule dans une première direction à l'intérieur du conduit externe (20) et le second fluide (4) s'écoule dans une seconde direction sensiblement opposée à la première direction.

3. Echangeur de chaleur selon la revendication 1 ou 2, dans lequel à la fois le conduit externe (20) et le conduit interne sont sensiblement cylindriques.

4. Echangeur de chaleur selon l'une quelconque des revendications 1 à 3, dans lequel le conduit externe et le conduit interne sont sensiblement concentriques.

5. Echangeur de chaleur selon l'une quelconque des revendications 1 à 3, dans lequel une pluralité de conduits internes est disposée à l'intérieur du conduit externe (20).

6. Echangeur de chaleur selon l'une quelconque des revendications 1 à 5, comprenant en outre une pluralité d'ailettes (23, 27) s'étendant à partir du canal interne (22) jusqu'au canal central et/ou au canal externe pour améliorer le transfert de chaleur entre le premier fluide (2) et le second fluide (4).

7. Echangeur de chaleur selon l'une quelconque des revendications 1 à 6, dans lequel le second fluide (4) pénètre dans le canal interne (22) du conduit interne dans un état sous-refroidi et sort du canal interne (22) dans un état surchauffé.

8. Echangeur de chaleur selon l'une quelconque des revendications 1 à 7, dans lequel la surface interne du conduit externe (20) est prévue avec des déflecteurs de mélange (30) augmentant le mélange et la turbulence du premier fluide (2).

9. Echangeur de chaleur selon l'une quelconque des revendications 1 à 8, dans lequel ladite entrée (8) et la sortie (9) pour le second fluide (4) mènent à l'extérieur du conduit externe (20).

10. Echangeur de chaleur selon l'une quelconque des revendications 1 à 9, dans lequel le conduit externe (20) est prévu avec un couplage thermo-hydraulique et mécanique (12) flexible approprié pour atténuer les efforts vibratoires induits en couplant l'échangeur de chaleur (5) avec une source de chaleur (1).

11. Echangeur de chaleur selon l'une quelconque des revendications 1 à 10, dans lequel lesdites entrée et sortie du conduit externe (20) sont prévues avec des brides de couplage (29) respectives couplant l'échangeur de chaleur à un autre échangeur de chaleur (5) selon l'une quelconque des revendications 1 à 10.

12. Système de récupération de chaleur perdue comprenant :

    l'échangeur de chaleur (5) selon l'une quelconque des revendications 1 à 11 ;
    une unité de conversion de puissance (6) configurée pour convertir l'énergie transférée du premier fluide (2) au second fluide (4) en énergie utilisable (42).

13. Système selon la revendication 12, comprenant en outre un condenseur (7) configuré pour condenser le second fluide (4).

14. Système selon la revendication 12 ou 13, comprenant en outre une interface de préchauffage (3) disposée entre une source de chaleur (1) et l'échangeur de chaleur (5), dans lequel l'interface de préchauffage (3) est configurée pour préchauffer le second fluide (4) avant d'entrer dans l'échangeur de chaleur (5).

15. Système selon la revendication 14, dans lequel l'interface de préchauffage (3) comprend un échangeur de chaleur de préchauffage comprenant :

    une entrée à travers laquelle le premier fluide (2) pénètre dans l'échangeur de chaleur de préchauffage à partir de la source de chaleur (1) ;
    une sortie à travers laquelle le premier fluide (2) sort de l'échangeur de chaleur de préchauffage et pénètre dans l'échangeur de chaleur (5) ; et
    un canal de préchauffage (10) à travers lequel le second fluide (4) s'écoule pour préchauffer le second fluide (4) avant d'entrer dans l'échangeur de chaleur (5).

16. Système selon la revendication 14 ou 15, dans lequel l'interface de préchauffage (3) comprend une bride (13) configurée pour fixer l'échangeur de chaleur de préchauffage à la source de chaleur (1).

17. Système selon l'une quelconque des revendications 14 à 16, dans lequel l'interface de préchauffage (3) comprend un élément flexible (12) configuré pour réduire l'effort vibratoire entre la source de chaleur (1) et l'échangeur de chaleur (5).

18. Système selon l'une quelconque des revendications 12 à 17, dans lequel l'unité de conversion de puissance (6) comprend au moins un dispositif d'expansion (34) mécaniquement couplé à au moins un générateur/moteur électrique (36) par le biais d'un arbre (35).

19. Système selon la revendication 18, dans lequel le générateur/moteur électrique (36), une pompe (37) appropriée pour pomper le second fluide (4), un coupleur d'arbre (39) et un système auxiliaire nécessitant un couple (40) sont mécaniquement couplés audit arbre (35).

20. Système selon la revendication 19, dans lequel ledit système nécessitant un couple (40) est un compresseur approprié pour comprimer un fluide secondaire (41) afin de faire refroidir ledit condenseur (7).

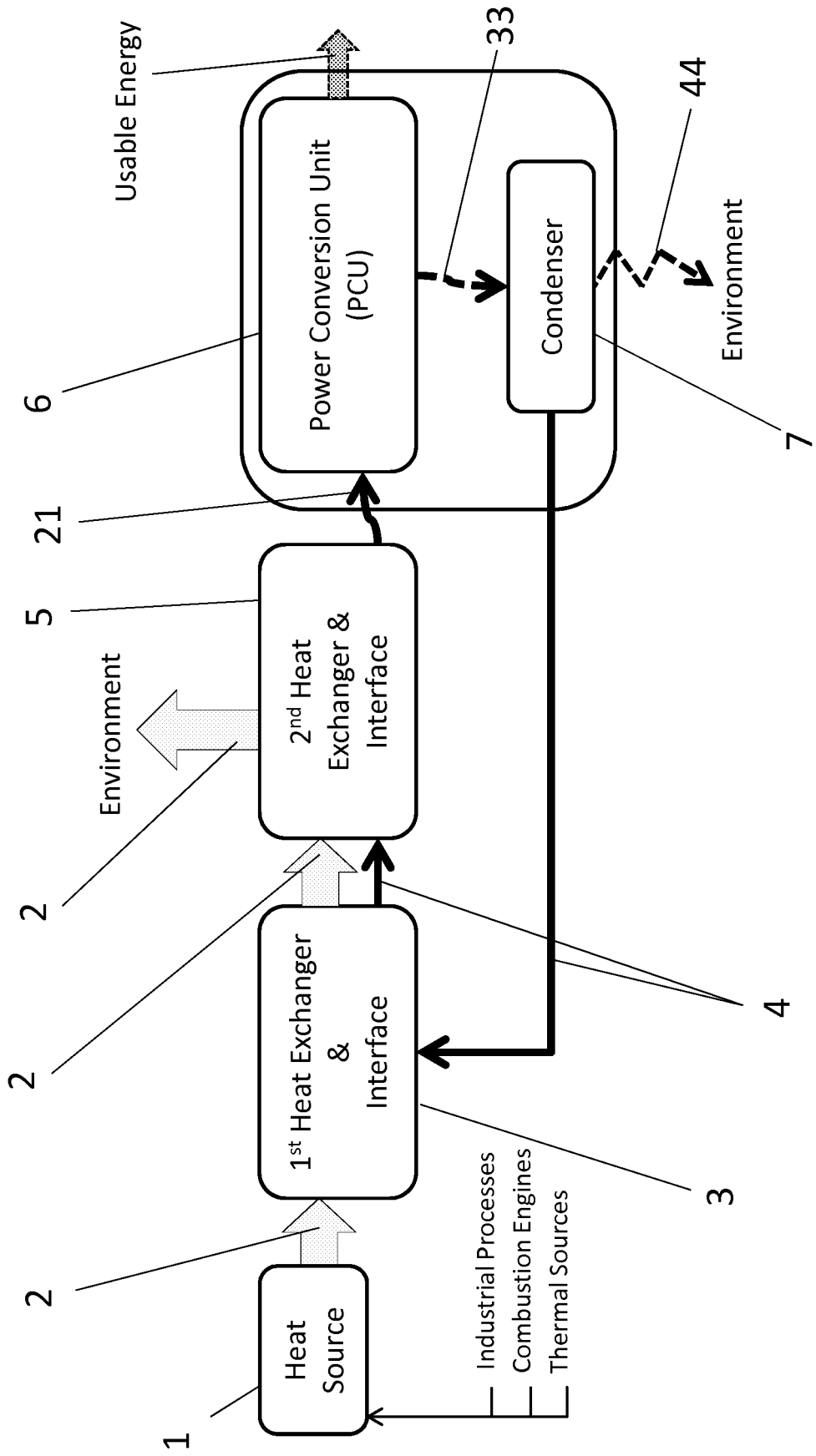

Usable Energy
33
44
Power Conversion Unit (PCU)
Condenser
Environment
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7
21
5
2nd Heat Exchanger & Interface
Environment
2
2
1st Heat Exchanger & Interface
4
2
3
Heat Source
Industrial Processes
Combustion Engines
Thermal Sources
1

Fig. 1

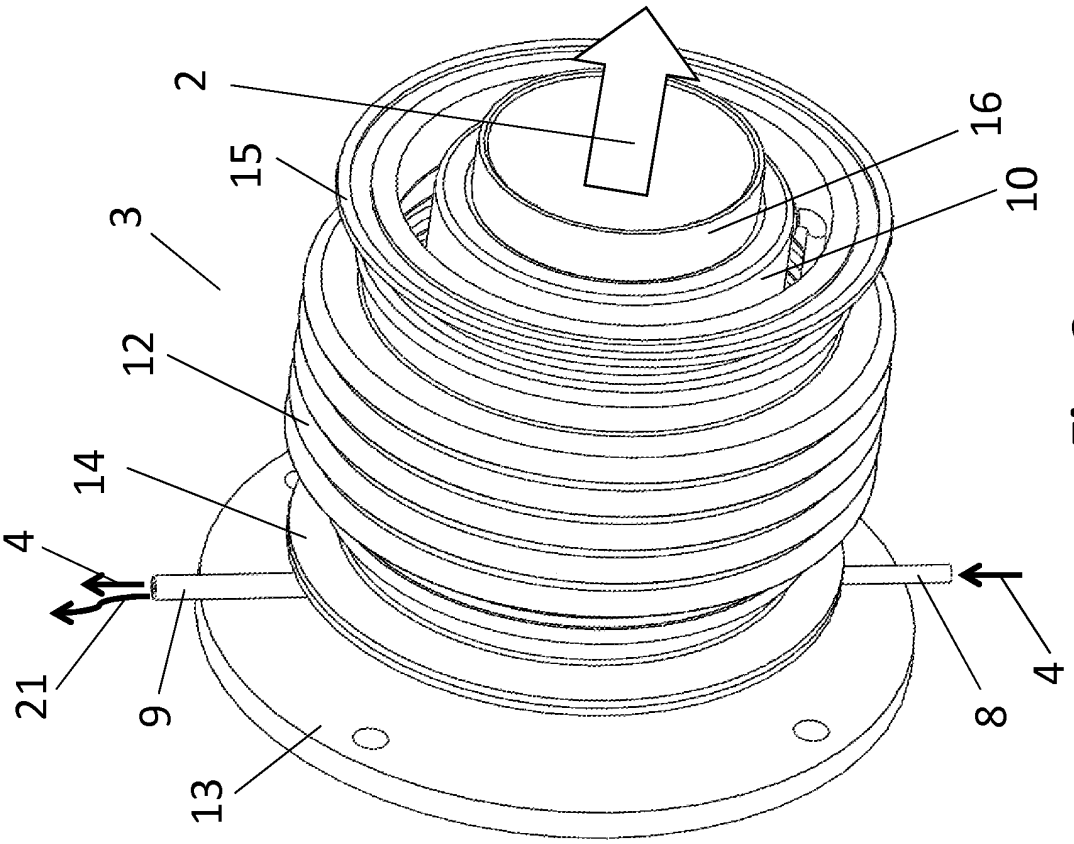

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Fig. 3

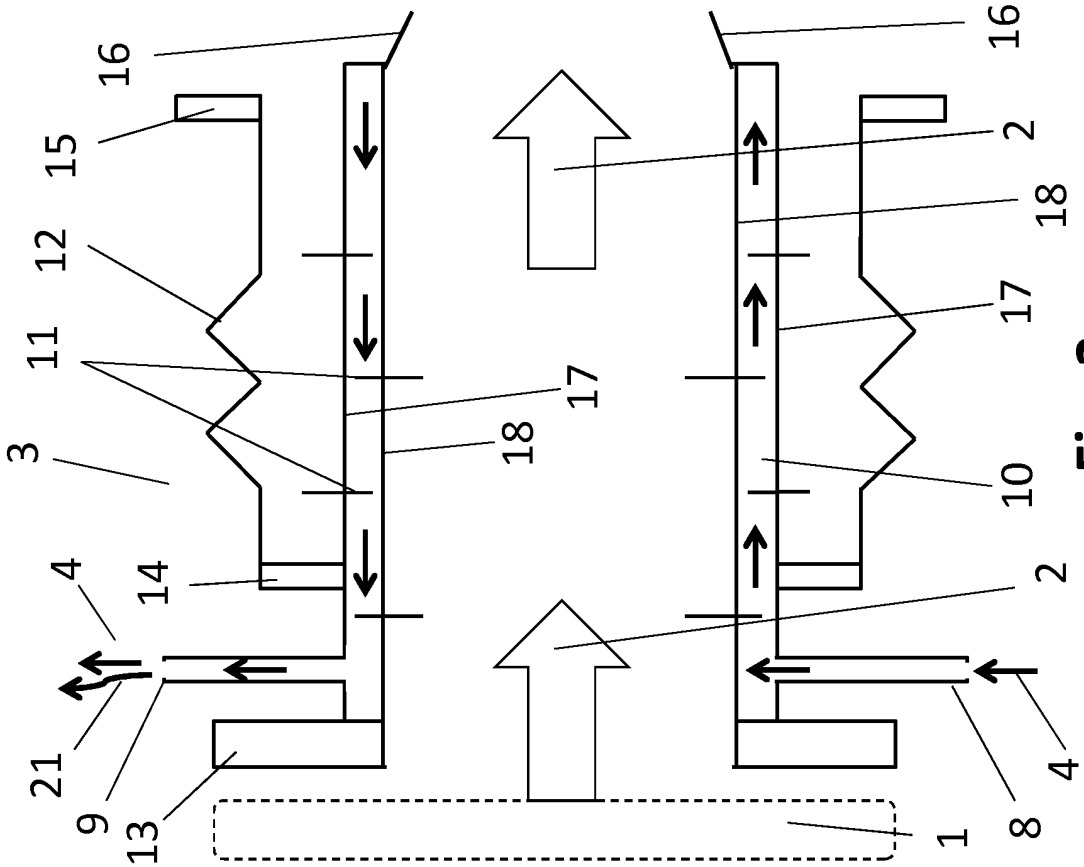

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Fig. 2

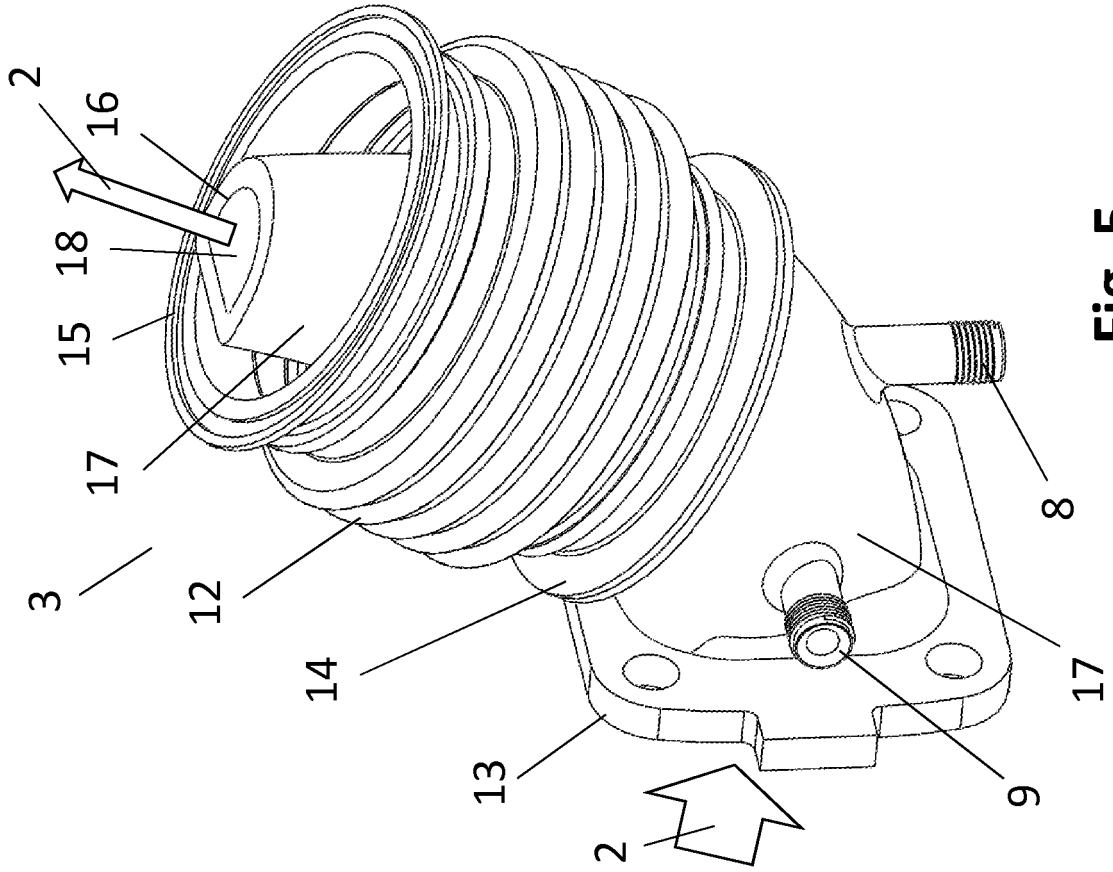


Fig. 5

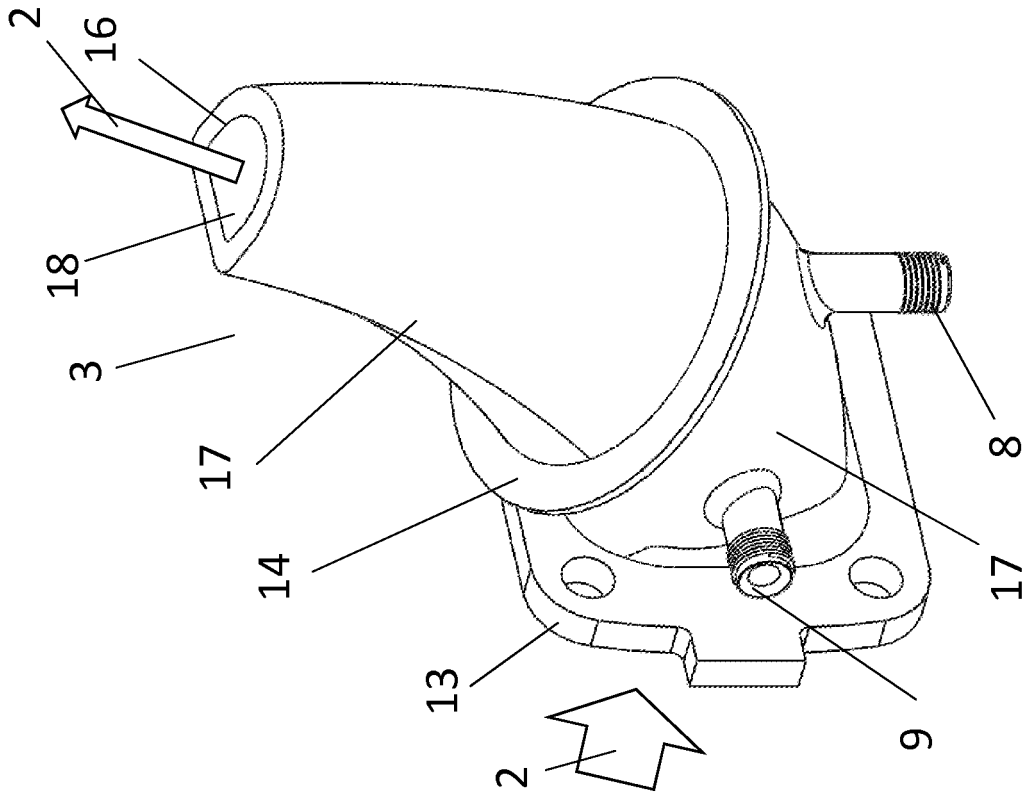


Fig. 4

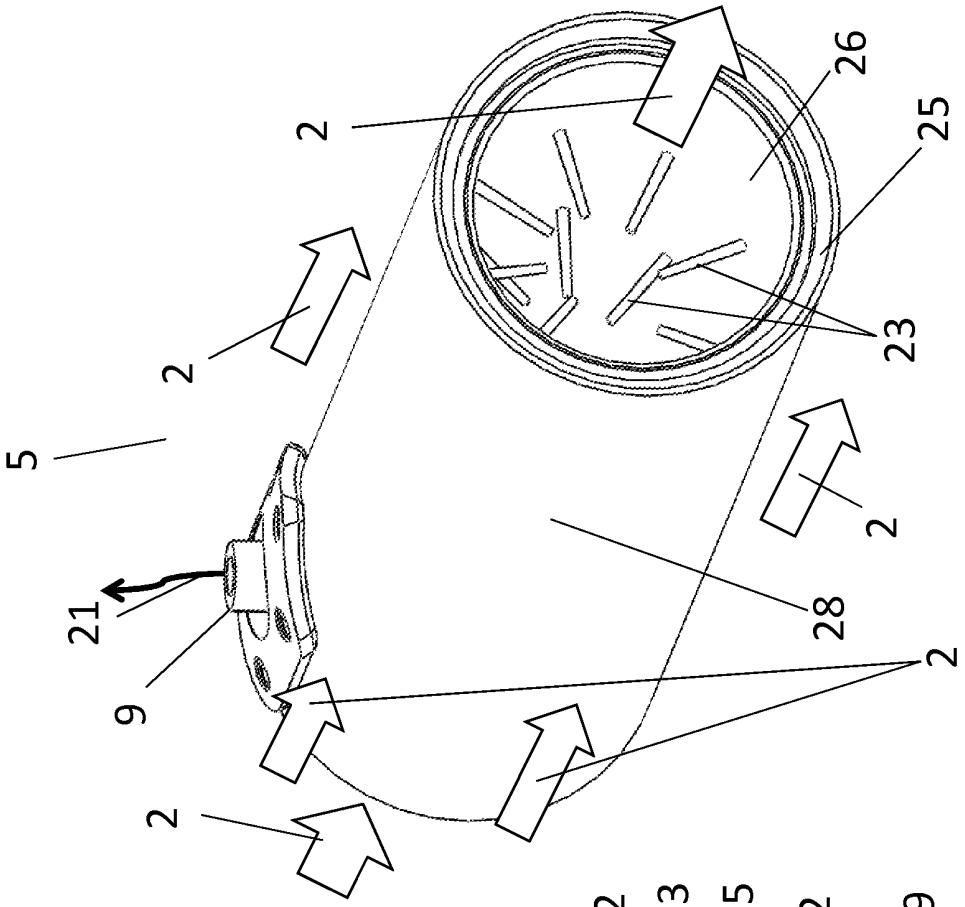

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Fig. 7

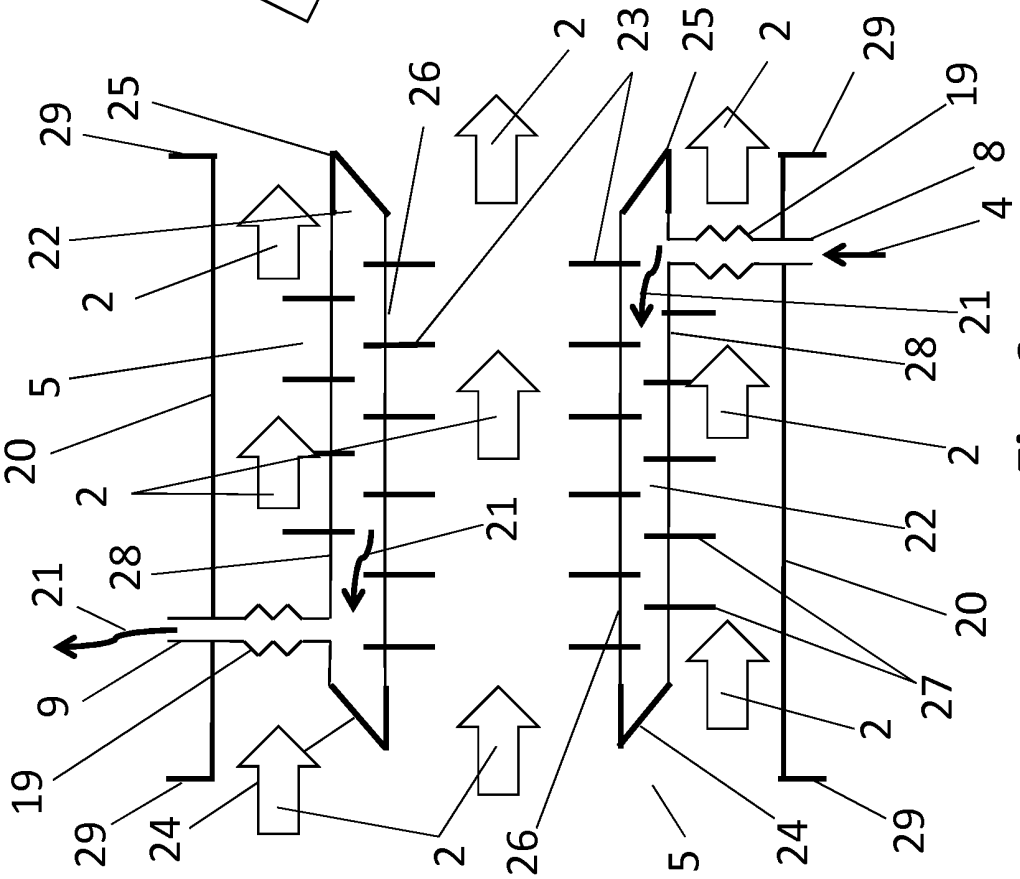

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Fig. 6

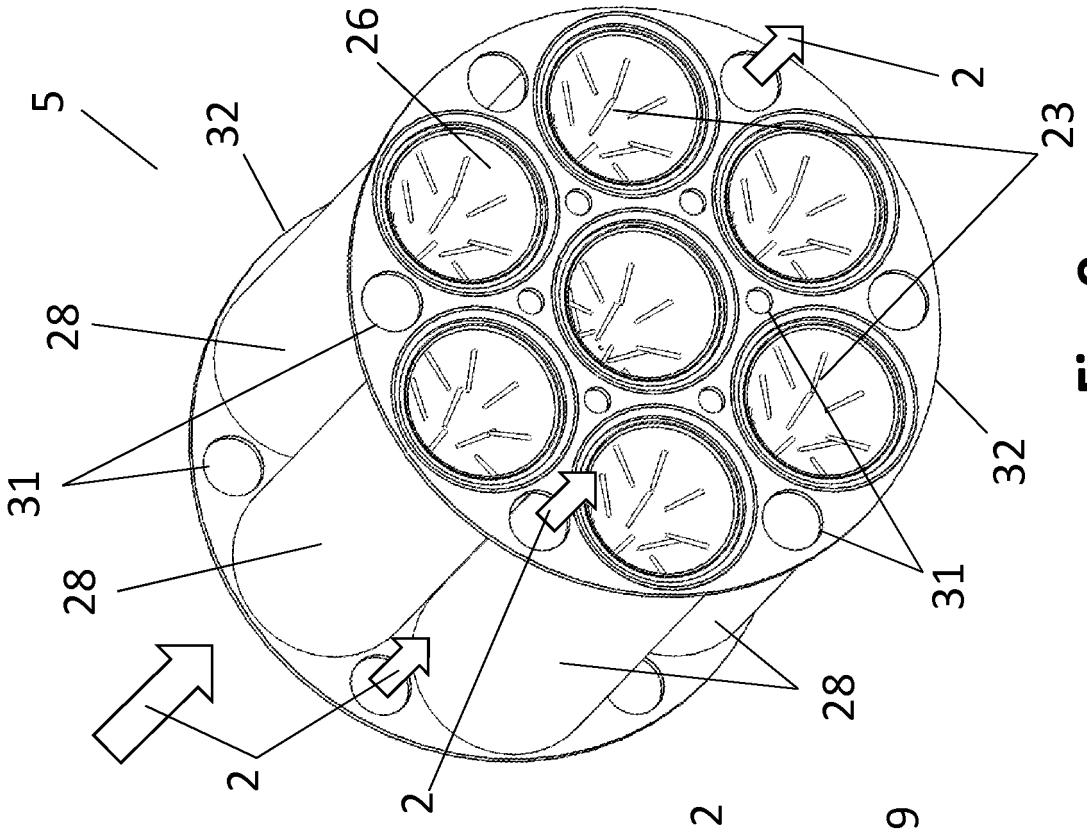


Fig. 9

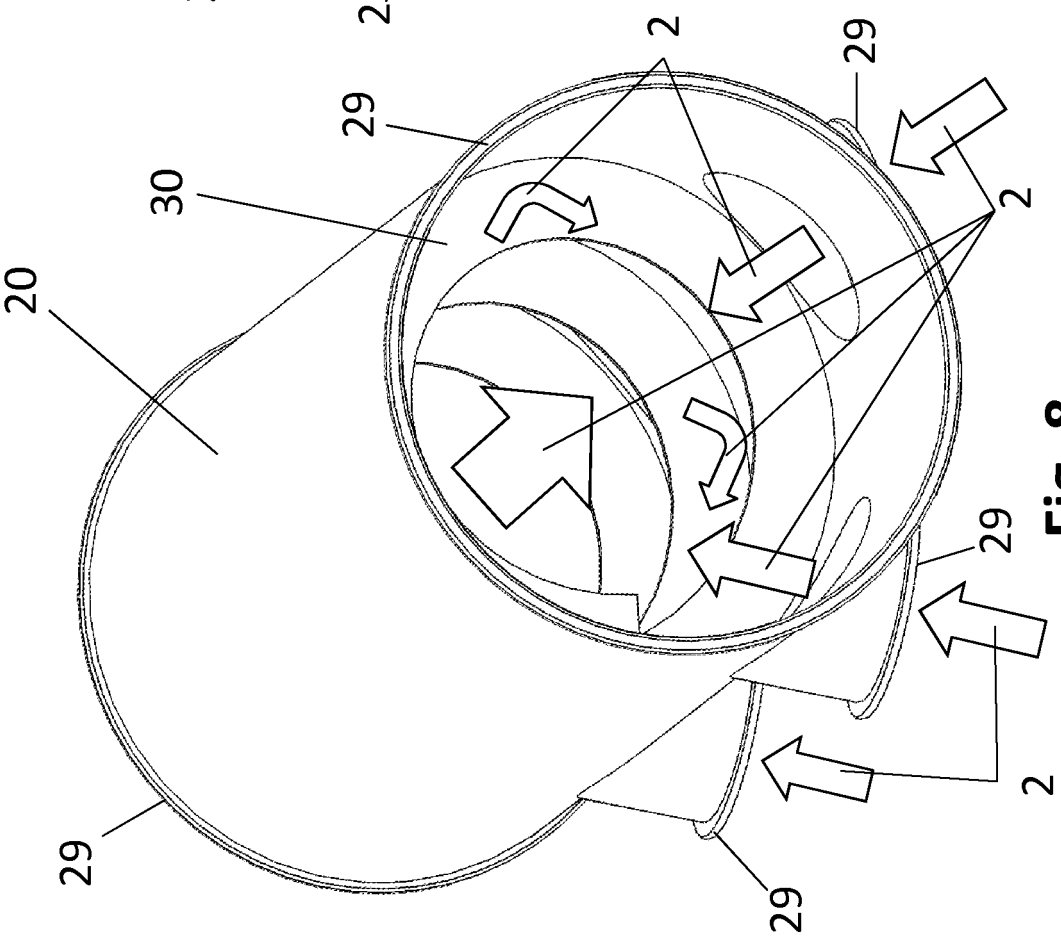


Fig. 8

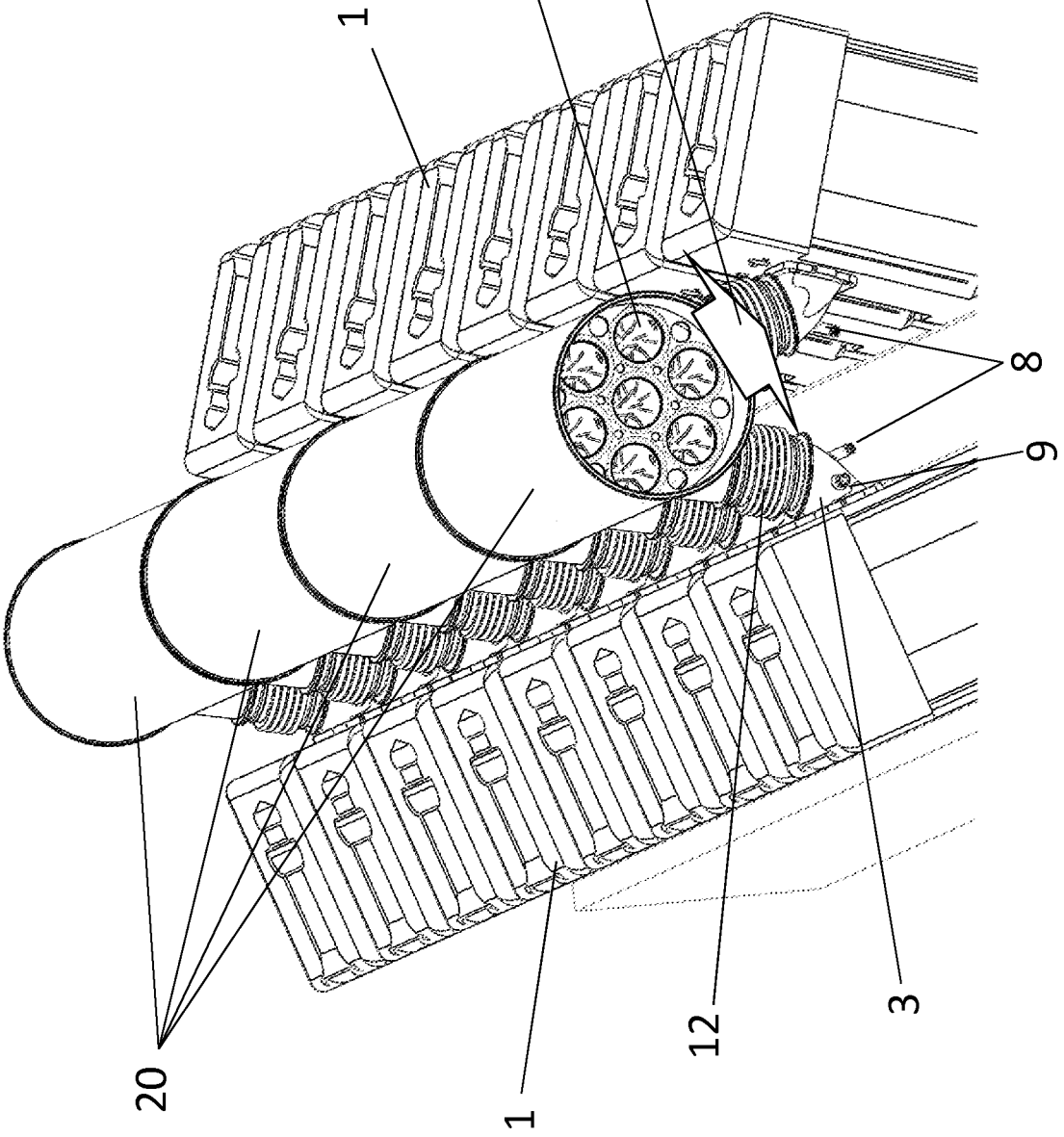


Fig. 10

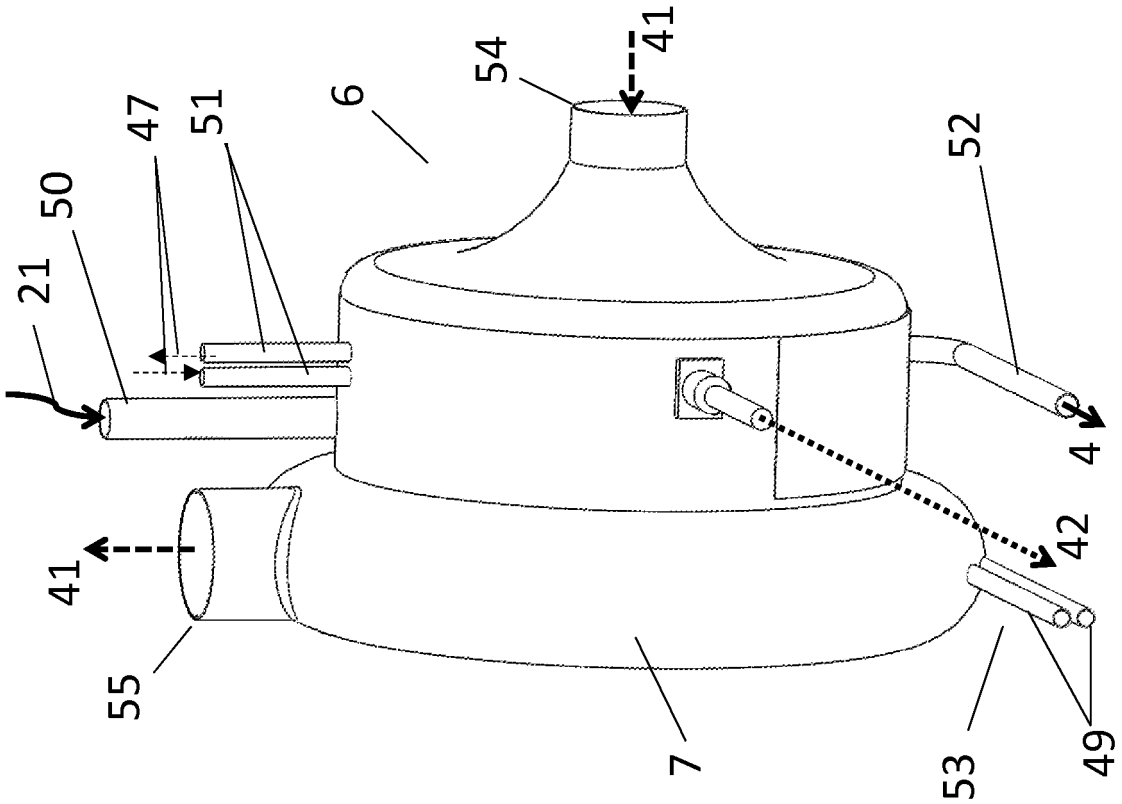

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Fig. 12

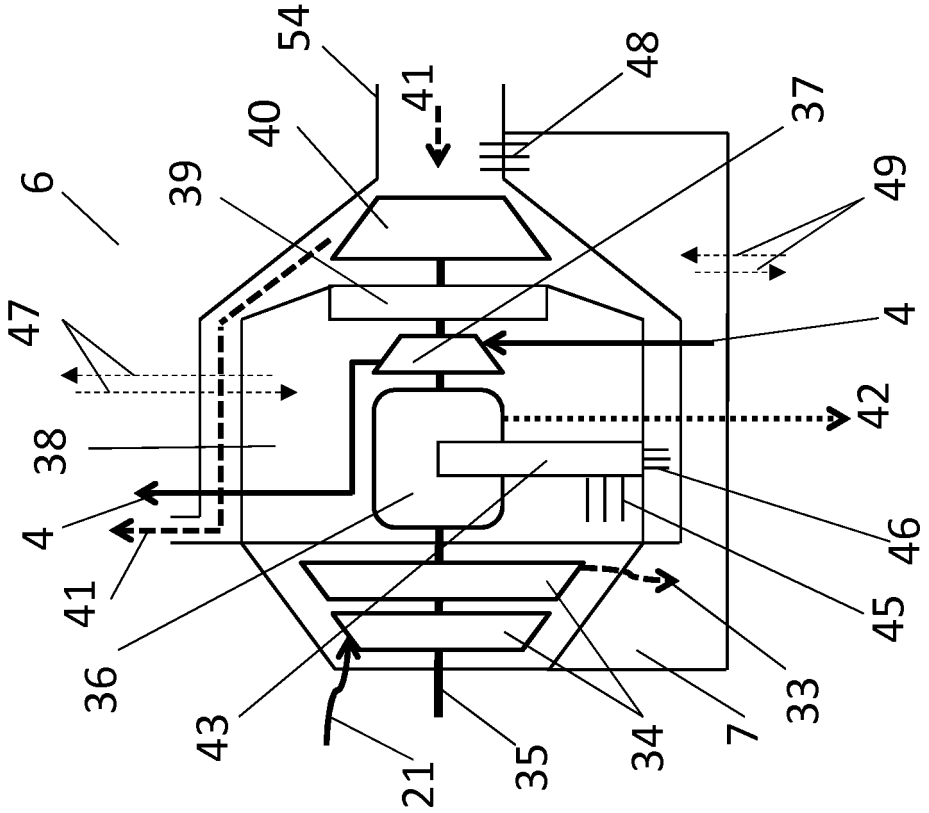

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Fig. 11

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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