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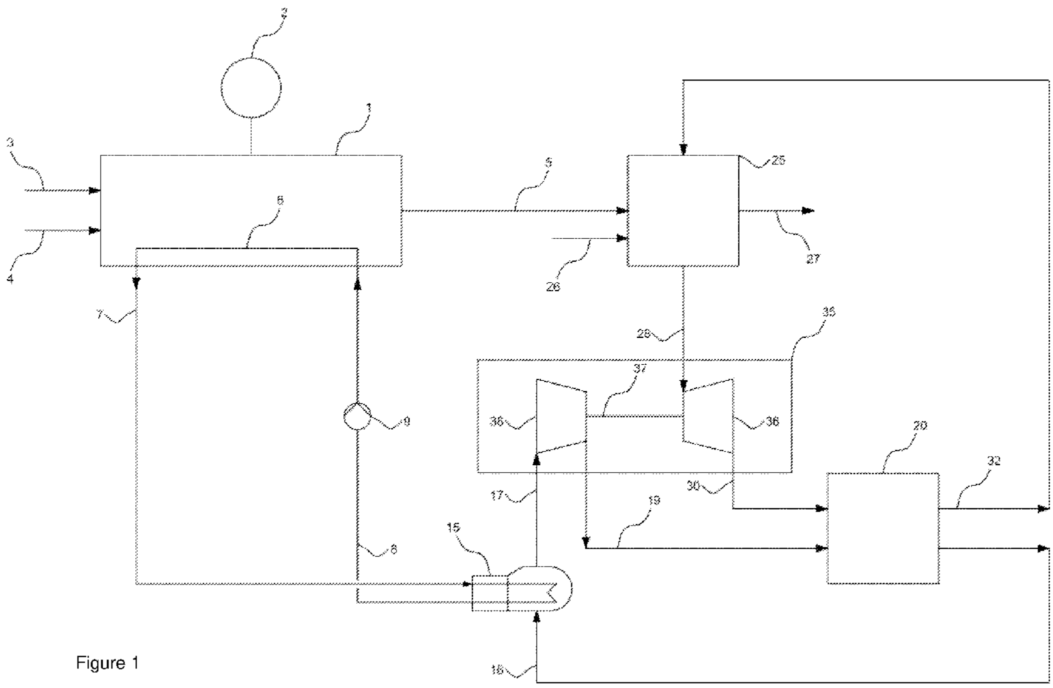

Figure 1

(57) Abstract: The invention relates to a system of generating steam at usable pressure level, in particular by compressing the low-pressure steam which is generated by recovering the low temperature waste heat rejected from an internal combustion engine, whereas the motive steam at high pressure required to compress the low- pressure steam is generated by the recovery of the high temperature exhaust waste heat of the same internal combustion engine. The amount of low temperature reject heat from the internal combustion engine is of significance when compared with total heat input to the internal combustion engine, and comparable to the high temperature exhaust waste heat. With the proposed system, utilization of the low temperature waste heat and generating steam at usable pressure level decreases the total fuel consumption when compared with generating the same amount of steam with conventional systems consuming fuel.

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A SYSTEM FOR GENERATION OF USABLE PRESSURE STEAM USING LOW TEMPERATURE WASTE HEAT FROM INTERNAL COMBUSTION ENGINES

Technical Field

The invention relates to a system of generating steam at usable pressure level, in particular by compressing the low-pressure steam which is generated by recovering the low temperature waste heat rejected from an internal combustion engine, whereas the motive steam at high pressure required to compress the low-pressure steam is generated by the recovery of the high temperature exhaust waste heat of the same internal combustion engine. The amount of low temperature reject heat from the internal combustion engine is of significance when compared with total heat input to the internal combustion engine, and comparable to the high temperature exhaust waste heat. With the proposed system, utilization of the low temperature waste heat and generating steam at usable pressure level decreases the total fuel consumption when compared with generating the same amount of steam with conventional systems consuming fuel.

Prior Art

Internal combustion engines are widely used for generation of electric power & heat in mostly land based applications and rarely in marine applications. They use fuel and combustion air to generate power. These types of engines are used as prime movers to drive electric generators to generate electricity. Extensive use of internal combustion engines is employed in industries where both generated power and the waste heat from the internal combustion engine are utilized, and utilization of heat which is a byproduct makes the localized use of the internal combustion engines further economical. Less than half of the fuel input to the internal combustion engine is converted into electricity whereas the rest of the energy input is rejected in several waste heat streams.

Primary heat rejection from the internal combustion engine is made with the exhaust gas stream. After extraction of thermal energy from combustion gases by the internal combustion engine, expanded combustion gas stream which is at a high temperature is moved away as an exhaust gas stream. This hot gas exhaust stream is mostly utilized in heat recovery steam generators to generate steam at pressure and temperature levels as required by heat consumers specific to that installation.

Secondary heat rejection from the internal combustion engine is mainly from engine lube oil, engine cylinders and combustion air charge, which are made into a cooling fluid stream circulating within the engine cooling circuits. This heat cannot be mostly utilized due to its low temperature characteristic, mostly below 100 °C.

Third heat rejection from the internal combustion engine is from the surface losses into the ambient, and in general not utilized for further use.

In installations where steam is consumed, the steam requirement of heat consumers may exceed the amount of available steam from the heat recovery steam generator downstream of the exhaust stream of the internal combustion engine. In such cases, to meet the increased steam demand, either steam generation of the heat recovery steam generator is increased by injecting supplementary fuel (and air as required) into the exhaust gas stream to cause supplementary combustion, or extra steam requirement is supplied by an auxiliary boiler where both systems consume fuel. Sometimes both systems are used as required. Combustion of extra fuel means increased amount fuel cost as well as increased amount of gaseous emissions.

Secondary heat rejection from internal combustion engine is for engine cooling purposes where the sources are mainly engine lube oil, engine block and combustion charge air. This heat is removed from the internal combustion engine by a cooling fluid stream which is in most cases an antifreeze & water solution, and mostly operating under 100 °C. Heated cooling fluid stream downstream of the internal combustion engine rejects the heat mainly into the atmosphere in air cooled radiators, and cooled fluid is circulated back into the internal combustion engine. The amount of heat in secondary heat rejection stream is significant and comparable with the usable amount of heat contained in high temperature exhaust gases in primary heat rejection of the internal combustion engine. Due to the low temperature of the cooling fluid, which is mostly under 100 °C, both pressure and temperature of the steam generated from this source is not sufficient for most of the heat consumers for direct use, and therefore this secondary heat is mostly wasted by dissipating into the atmosphere in most cases.

CN111441837B discloses a waste heat recovery device and a recovery method of an internal combustion engine, wherein the waste heat recovery device comprises: the waste heat recovery device of the internal combustion engine comprises an internal combustion engine cylinder body, a flue gas heat exchanger, an expander, a pressurized air preheater, a high-temperature heat regenerator, a low-temperature heat regenerator, a cooling unit, a pressurizing unit and a working medium tank, wherein the waste heat recovery device of the internal combustion engine uses supercritical/subcritical CO_2 as a circulating working medium. The invention utilizes supercritical/subcritical CO_2, fully recovers the waste heat of various heat sources with different qualities in the internal combustion engine, such as flue gas, cylinder liner water and pressurized air.

CN107542556A relates to generating power by waste heat of tail gas of automobile field, more particularly to a kind of self-adjusting for afterheat of IC engine recovery electricity generation system and its fitness-for-service assessment method.

Summary

An object of the invention to provide a system with the apparatus of prior art devices which overcomes the above-mentioned disadvantages, which reduces the total amount of fuel used to generate steam by recovering the low temperature heat source from the secondary heat rejection circuit of the internal combustion engine, generating low-pressure steam from this source and further compressing it to usable pressure levels as required by the heat consumers. Proposed systems for compressing low pressure steam are mechanical compression which uses expander compressor, and alternatively thermal compression which uses thermocompressor.

Internal combustion engine is a prior art used to generate power which consumes fuel and combustion air. Expanded combustion gases leaves the internal combustion engine at a fairly high temperature still containing high amount of energy and oxygen. Exhaust of internal combustion engine is connected to a waste heat boiler generating steam at a higher pressure and temperature level than as required by the heat consumers. The waste heat boiler is furnished with duct burner adding energy to the exhaust stream making it possible to generate higher amount of steam at higher temperatures and pressures as required.

In mechanical compression, an expander compressor machinery is used to compress the low-pressure steam while expanding the high-pressure steam. Mechanical power input to the compressor causes compression of the low-pressure steam, therefore this system is specified as mechanical compression. The generated high-pressure steam by the waste heat boiler after the internal combustion engine is forwarded into expander section of an expander compressor package and expansion of steam to the pressure level as required by heat consumers causes extraction of thermal energy and generation of work at rotating output shaft of the expander. The expanded steam is supplied to heat consumer. This work generated is transmitted by transmission into the inlet rotating shaft of the compressor. Compressor inlet low-pressure steam is generated in a low-pressure boiler generating steam at a fairly low pressure and temperature where the source to this boiler is the cooling fluid stream in which the secondary heat rejection of the internal combustion engine is made into, whereas this cooling fluid stream mostly operates under 100 °C. This low-pressure steam is then compressed in the compressor section of the expander compressor consuming work whereas the necessary work is supplied by the expander through the transmission. This compressed low-pressure steam is also supplied to heat consumer. Required heat for the generation of low-pressure steam is supplied from a waste source and no fuel is consumed to generate it. As a result, the suggested system for generating high pressure steam from the heat recovery steam generator and in addition low pressure steam from the low pressure boiler consumes less fuel in total when compared with generating the same amount steam with conventional systems using heat recovery steam generator or with an addition of an auxiliary boiler where both needs extra fuel combustion.

In thermal compression, a thermocompressor device is used to compress the low-pressure steam while expanding the high-pressure steam. Within the thermocompressor, conversion of high-pressure steam static pressure to dynamic pressure, heat transfer from high-pressure steam to low-pressure steam in direct contact and mixing, and conversion of dynamic pressure to static pressure of the mixture are thermal processes and therefore this system is specified as thermal compression. The generated high-pressure steam by the waste heat boiler after the internal combustion engine is forwarded into thermocompressor nozzle section which increases the velocity of the high-pressure inlet steam while decreasing its static pressure creating a low-pressure environment in suction chamber section of the thermocompressor. Low-pressure steam is generated in a low-pressure boiler generating steam at a fairly low pressure and temperature where the source to this boiler is the cooling fluid stream in which the secondary heat rejection of the internal combustion engine is made into, whereas this cooling fluid stream mostly operates under 100 °C. This low-pressure steam is connected to the suction chamber of the thermocompressor, and the lower pressure of the suction chamber causes suction of low-pressure steam into the thermocompressor. Both streams flow into the mixing chamber while transferring energy from waste heat boiler generated high pressure steam to low pressure boiler generated low pressure steam in direct contact and mixing. An expansion chamber with increased cross section follows the mixing chamber causing decrease in velocity and increase in static pressure of the mixture. Mixture leaving the thermocompressor is at a pressure level between two inlet streams to the thermocompressor: below high-pressure steam and above low-pressure steam. Thermocompressor outlet stream is supplied to heat consumer and or process user. Required heat for the generation of low-pressure steam is supplied from a waste source and no fuel is consumed to generate it. As a result, the suggested system for generating high pressure steam from the heat recovery steam generator and in addition low pressure steam from the low pressure boiler consumes less fuel in total when compared with generating the same amount steam with conventional systems using heat recovery steam generator or with an addition of an auxiliary boiler where both needs extra fuel combustion.

Brief Description of The Drawings

Figure 1 A block diagram of the process arranged with apparatus in accordance with and embodying the present invention with mechanical compression.

Figure 2 A schematic illustration, in greater detail of the single stage pressure casing expander compressor package given in Figure 1.

Figure 3 A schematic illustration, in greater detail of the multi stage pressure casing expander compressor package with multi transmission given in Figure 1.

Figure 4 A schematic illustration, in greater detail of the common transmission multi stage pressure casing of expander compressor package given in Figure 1.

Figure 5 A block diagram of the process arranged with apparatus in accordance with and embodying the present invention with thermal compression.

Figure 6 A schematic illustration, in greater detail of a single stage thermocompressor given in Figure 5.

Figure 7 A schematic illustration, in greater detail of a multiple stage thermocompressor given in Figure 5

Figure 8 A block diagram of a hybrid compressor package, a combination of mechanical compression and thermal compression.

Reference List

1 internal combustion engine

2	electric generator
3	combustion air
4	fuel
5	exhaust gas stream
6	engine cooling fluid stream
7	hot engine cooling fluid
8	cold engine cooling fluid
9	circulation pump
15	low-pressure boiler
16	low-pressure condensate
17	low-pressure steam
18	low-pressure compressor discharge stream
19	compressor discharge stream
20	heat consumer
25	waste heat recovery boiler
26	supplementary fuel
27	waste heat recovery boiler exhaust gas stream
28	high-pressure steam
29	high-pressure expander exhaust stream
30	expander exhaust stream
32	high-pressure condensate
35	expander compressor package
36	expander
37	transmission
38	compressor
40	low-pressure compressor
41	high-pressure compressor
43	high-pressure expander
44	low-pressure expander
45	first transmission
46	second transmission
48	common transmission
50	thermocompressor package
51	thermocompressor exhaust stream
55	thermocompressor
56	nozzle
57	suction chamber

58 mixing chamber
59 expansion chamber
64 multi-stage thermocompressor package
65 thermocompressor 1st stage
66 thermocompressor 2nd stage
67 motive steam
68 thermocompressor 1st stage outlet stream

Detailed Description of The Invention

Referring to Figure 1, an internal combustion engine (1) uses combustion air (3) and fuel (4) to create combustion. Increasing pressure and temperature by combustion is transformed into kinetic energy by expansion of hot combustion gasses causing movement and/or rotating internal components which is used to propel an electric generator (2). After completion of expansion, hot combustion gases are moved away from the internal combustion engine (1) with exhaust gas stream (5). The exhaust gas stream (5) comprises high levels of energy due to its high temperature. In order to utilize the energy in the exhaust gas stream (5), a waste heat recovery boiler (25) is used to cool down the exhaust gas stream (5) while generating high-pressure steam (28) by heating up, evaporating and superheating high pressure condensate (32) with heating surfaces of economizer, evaporator and superheater. The high-pressure condensate (32) fluid type used to generate high-pressure steam (28), is as per the requirement by heat consumer (20). Supplementary fuel (26) is supplied to the waste heat recovery boiler (25) for supplementary combustion causing increased steam generation. Air also can be supplied along with supplementary fuel (26), if required. A waste heat recovery boiler exhaust gas stream (27) is used to exhaust from the waste heat recovery boiler (25).

Engine cooling fluid stream (6) removes heat dissipated from several sources within the internal combustion engine (1) for cooling purposes. Cold engine cooling fluid (8) is forwarded by circulation pump (9) into the internal combustion engine (1) and forces engine cooling fluid stream (6) to pass through the cooling circuits where heat rejection is made from heating surfaces. Hot engine cooling fluid (7) flows into a low pressure boiler (15). The low-pressure boiler (15) is an evaporator where the hot engine cooling fluid (7) flows within one side of heating surface while transferring its heat into the low-pressure condensate (16) which is within the other side of the heating surface, causing evaporation of the condensate and generating low-pressure steam (17). The low-pressure condensate (16) fluid type used to generate the low-pressure steam (17) is as per the requirement of the heat consumer (20) and can be either the same type or other type of fluid than the high-pressure condensate (32).

Both the high-pressure steam (28) and the low-pressure steam (17) flows into expander compressor package (35) through separate streams. The expander compressor package (35) comprises compressor

(38), expander (36) and transmission (37). The high pressure steam (28) flows into the expander (36) whereas the low-pressure steam (17) flows into the compressor (38) of the expander compressor package (35).

The expander (36) is a machine which extracts thermal energy from the high-pressure steam (28) by expansion of it and uses it to do mechanical work on a rotating output shaft connected to the transmission (37), while the expanded high-pressure steam (28) leaves the expander (36) from expander exhaust stream (30) with lower pressure and temperature and consequently lower thermal energy compared with the inlet.

The compressor (38) is a machine that increases the pressure and consequently the thermal energy of the low-pressure steam (17) by reducing its volume or increasing its velocity or a mix of both, while consuming the required mechanical work from a rotating input shaft connected to the transmission (37), while the compressed low-pressure steam (17) leaves the compressor (38) from compressor discharge stream (19) with higher pressure and temperature and consequently higher thermal energy compared with the inlet.

The transmission (37) mechanically or hydraulically connects rotating output shaft of the expander (36) to rotating input shaft of the compressor (38). The energy extracted from the expander (36) by expansion of the high-pressure steam (28) is transmitted through the transmission (37) to the compressor (38) where the compression of the low-pressure steam (17) consumes the generated power by the expander (36). The compressor discharge stream (19) and the expander exhaust stream (30) are supplied to the heat consumer (20). The heat consumer (20) extracts internal energy of both the expander exhaust stream (30) and the compressor discharge stream (19) and causes condensation of them. The heat consumer (20) delivers the high-pressure condensate (32) into the waste heat recovery boiler (25) and the low-pressure condensate (16) into the low-pressure boiler (15).

For simplicity, single stage pressure casing type of the expander compressor package (35) is illustrated in the Figure 1 and further details of single stage pressure casing the expander compressor package (35) are given in Figure 2. The expander compressor package (35) can be of multi stage pressure casing type, and details of such configuration are given with Figure 3 and Figure 4.

Referring to the Figure 2, a single stage pressure casing type of the expander compressor package (35) given in the Figure 1 is further explained. The expander (36) can be of a single stage or multi stage axial type of turbine, single stage or multi stage radial type of turbine, multi stage a mix of axial and radial type of turbine or can be of single stage or multi-stage positive displacement type of expander. The expander (36) is packed into an individual pressure casing. The compressor (38) can be of a single stage or multi stage axial type of compressor, single stage or multi stage radial type of compressor, multi stage a mix of axial and radial type of compressor or can be of single stage or multi-stage positive displacement type of compressor. The compressor (38) is packed into an individual pressure casing. The transmission (37) can be mechanical shaft type, gearbox type, hydraulic type or continuous variable type.

Referring to the Figure 3, a multi stage pressure casing of the expander compressor package (35) with multi transmission referred in the Figure 1 is explained. For simplicity, only two stage pressure casing expander compressor is explained whereas number of pressure casings can increase for both the compressor and the expander sections. Function of each high-pressure expander (43) and low-pressure expander (44) given in the Figure 3 are the same with the function of the expander (36) given in the Figure 1 and the Figure 2. Function of each low-pressure compressor (40) and high-pressure compressor (41) given in the Figure 3 are the same with the function of the compressor (36) in the Figure 1 and the Figure 2. Function of each first transmission (45) and second transmission (46) given in the Figure 3 are the same in principle with the transmission (37) given in the Figure 1 and the Figure 2.

The high-pressure steam (28) is expanded within the high-pressure expander (43) to an intermediate pressure level and exits through high-pressure expander exhaust stream (29), flowing into the low-pressure expander (44) and further expanded within, and leaving through the expander exhaust stream (30) with a lower pressure. While the steam stream decreases in pressure, the temperature and the thermal energy decreases as well.

The total work by expanding the high-pressure steam (28) to the expander exhaust stream (30) is generated by two expanders connected in series on steam side where each high-pressure expander (43) and low-pressure expander (44) extracts some portion of the total extracted thermal energy and generates corresponding amount of work.

The low-pressure steam (17) is compressed within the low-pressure compressor (40) to an intermediate pressure level and exits through low-pressure compressor discharge stream (18), flowing into the high-pressure compressor (41) and further compressed within, and leaving through the compressor discharge stream (19) with a higher pressure. While the steam stream increases in pressure, the temperature and thermal energy increases as well.

The total work consumed by compressing the low-pressure steam (17) to the compressor discharge stream (19) is consumed by two compressors connected in series on steam side where each low-pressure compressor (40) and high-pressure compressor (41) transfers some portion of the energy to the steam stream and consumes corresponding amount of work.

The energy extracted from the high-pressure expander (43) by expansion of the high-pressure steam (28) to high-pressure expander exhaust stream (29) is transmitted through the first transmission (45) to the high-pressure compressor (41) where the compression of the low-pressure compressor discharge stream (18) to the compressor discharge stream (19) consumes the generated power by the expander high pressure (43).

The energy extracted from the low-pressure expander (44) by expansion of high-pressure expander exhaust stream (29) to the expander exhaust stream (30) is transmitted through the second transmission (46) to the low-pressure compressor (40) where the compression of low-pressure steam (17) to the low-pressure compressor discharge stream (18) consumes the generated power by the expander low pressure (44).

The high-pressure expander (43) and/or the low-pressure expander (44) can be of a single stage or multi stage axial type of turbine, single stage or multi stage radial type of turbine, multi stage a mix of axial and radial type of turbine or can be of single stage or multi stage positive displacement type of expander. Each of the high-pressure expander (43) and the low-pressure expander (44) are packed into individual pressure casings. The high-pressure compressor (41) and/or the low-pressure compressor (40) can be of a single stage or multi stage axial type of compressor, single stage or multi stage radial type of compressor, multi stage a mix of axial and radial type of compressor or can be of single stage or multi stage positive displacement type of compressor. Each of the high-pressure compressor (41) and the low-pressure compressor (40) are packed into individual pressure casings. The first transmission (45) and/or the second transmission (46) can be mechanical shaft type, gearbox type, hydraulic type, or continuous variable type.

For each compressor pressure casing, an expander pressure casing and an individual transmission interconnecting those are required in this type of configuration.

Requirement of going from a single stage pressure casing compressor expander given in the Figure 2 to multi stage pressure casing expander compressor given in the Figure 3 may arise due to several reasons. There might be cases where the expansion in expander or compression in compressor may require physical separation of compressor or expander stages into separate pressure casings due to requirements or limitations such as rotational speed, pressure ratio, volumetric flow increase or decrease, constructability and etc. In such cases, the compressor and the expander stages are physically separated into to pressure casings, expander pressure casings starting from high pressure casing to low pressure casing connected in series on the steam side, and compressor pressure casings starting from low pressure casing to high pressure casing connected in series on steam side. The number of pressure casings are calculated and optimized as per technical requirements, for the simplicity, only two pressure casings “high-pressure” and “low-pressure” are embodied in the Figure 3. As an example of a three stage pressure casing configuration, arrangement would comprise a high-pressure expander connected to a high-pressure compressor with transmission, an intermediate-pressure expander connected to an intermediate-pressure compressor with transmission, and a low-pressure expander connected to the low-pressure compressor with transmission, compressor pressure casings connected in series on the steam side and expander pressure casings connected in series on the steam side such as explained for the Figure 3 configuration above.

Referring to the Figure 4, a common transmission multi stage pressure casing type of the expander compressor package (35) given in the Figure 1 is explained. Descriptions for compressor and expander sections of the Figure 3 are valid for the Figure 4 while in the Figure 4, compressor input shafts and expander output shafts are connected to a common transmission (48).

Rotating output shaft of the high-pressure expander (43), rotating output shaft of the low-pressure expander (44), rotating input shaft of the high-pressure compressor (41) and rotating input shaft of the low-pressure compressor (40) are all connected to the common transmission (48). The common transmission (48) can be gearbox type, hydraulic type or continuous variable type or a mix of those for each connection.

The reason behind going from a multi-transmission multi stage pressure casing the expander compressor package (35) in the Figure 3 to common transmission multi stage pressure casing the expander compressor package (35) in the Figure 4 is to match total work generated by the expanders to total work consumed by the compressors while allowing each compressor pressure casing and expander pressure casing to operate at rotational speeds and duties not necessary to match each other.

For simplicity, only two pressure casing of expander and two pressure casing of compressor is illustrated where the number of both can increase due to reasons as explained in figure 3. Number of compressor pressure casings and expander pressure casings does not necessarily to match to each other.

Referring to Figure 5, the low-pressure condensate (16) fluid type fluid type used to generate low-pressure steam (17) is the same with the high-pressure condensate (32) which is used to generate the high-pressure steam (28). Both the high-pressure steam (28) and the low-pressure steam (17) flows into thermocompressor package (50) through separate streams. The thermocompressor package (50) comprises a single stage thermocompressor (55) or multiple of the thermocompressor (55) connected in series. For simplicity, in the Figure 5, the single stage thermocompressor (55) is illustrated. Details and operation of the thermocompressor (55) is given in Figure 6 whereas the arrangement and further description of the multistage thermocompressor (55) is given in Figure 7.

The thermocompressor (55) is a device using the high-pressure steam (28) to create a high velocity and decreased static pressure stream which causes suction of the low-pressure steam (17) and further mixing of both streams occurs in downstream section of the device while the outlet section of the thermocompressor (55) decrease the velocity of the mixture causing increase in static pressure, while thermocompressor exhaust stream (51) leaves the thermocompressor (55) at a pressure level between the high-pressure steam (28) and the low pressure steam (17). The thermocompressor exhaust stream (51) is supplied to the heat consumer (20). The heat consumer (20) extracts internal energy to the thermocompressor exhaust stream (51) and causes condensation of the stream. The heat consumer (20) delivers the high-pressure condensate (32) into the waste heat recovery boiler (25) and the low-pressure condensate (16) into the low-pressure boiler (15), which both are the same fluid at different pressure levels.

Referring to the Figure 6, operation of the thermocompressor (55) is explained. The high-pressure steam (28) flows into a nozzle (56). The high-pressure steam (28) supplied to nozzle (56) is referred as motive steam (67). The nozzle (56) causes velocity increase of the high-pressure steam (28) creating a jet flow while decreasing its static pressure to a point lower than the low-pressure steam (17). Outlet steam velocity of the nozzle (56) can be subsonic or supersonic, higher the velocity, higher the compression ratio of the low-pressure steam (17) can be achieved. Compression ratio is provided as thermocompressor exhaust stream (51) pressure divided by the low-pressure steam (17) pressure. Outlet stream of the nozzle (56) flows into the mixing chamber (58) while creating a lower pressure environment in a suction chamber (57) causing flow of the low-pressure steam (17) into the suction chamber (57) and subsequent mixing of streams in a mixing chamber (58). In an expansion chamber (59), velocity of the mixture is decreased due to the increase in cross section, while increasing the static pressure of the mixture. The thermocompressor exhaust stream (51) is at a pressure level between the high-pressure steam (28) and the low-pressure steam (17).

Referring to the Figure 7, the multi-stage thermocompressor package (64) is explained. For simplicity, only two stage thermocompressor (55) are embodied whereas number of the thermocompressor (55) connected in series can increase as required. Compression ratio of the thermocompressor (55) is limited, therefore when higher compression ratio is required, multiple of the thermocompressor (55) are connected in series to achieve higher compression ratios. Compression ratio is provided as the thermocompressor exhaust stream (51) pressure divided by the low-pressure steam (17) pressure. Motive steam (67), which can be supplied either from the high-pressure steam (28) or the thermocompressor exhaust stream (51) is supplied to the nozzle section of a thermocompressor 1st stage (65). The thermocompressor 1st stage (65) compresses the low-pressure steam (17) to an interim pressure level below the thermocompressor exhaust stream (51) and above the low-pressure steam (17). The high-pressure steam (28) is supplied to a thermocompressor 2nd stage (66) to compress the thermocompressor 1st stage outlet stream (68) and delivers the thermocompressor outlet stream (51) at a pressure point between the high-pressure steam (28) and a thermocompressor first stage outlet stream (68).

Referring to Figure 8, a hybrid compression system comprising the expander compressor package (35) and the thermocompressor package (50) is embodied. The expander compressor package (35) and the thermocompressor package (50) can be connected in series as required or when required. In a hybrid set-up, sequence, number of compression stages and compressor types can be arranged as required, for simplicity, the thermocompressor package (50) followed by the expander compressor package (35) is embodied. The high-pressure steam (28) flows into the thermocompressor (55) and compresses the low-pressure steam (17), and delivers the thermocompressor exhaust stream (51) to the compressor (38) suction. The compressor (38) compresses the inlet stream and delivers the compressor discharge stream (19). Required power for the compressor (38) is supplied by the expander (36) through the transmission (37) and generated by the expander (36) by the expansion of the high-pressure steam (28). The compressor discharge steam (19) and the expander exhaust stream (30) are supplied to the heat consumer (20), and the pressure level of these streams can be the same or different.

CLAIMS

1. A system for generation of usable pressure steam using low temperature waste heat from internal combustion engines (1) which uses combustion air (3) and fuel (4) to create combustion, wherein hot combustion gases are moved away from the internal combustion engine (1) with exhaust gas stream (5), and **characterized by comprising:**

- a waste heat recovery boiler (25) which is used to cool down the exhaust gas stream (5) while generating high-pressure steam (28) by heating up, evaporating, and superheating high pressure condensate (32) with heating surfaces of economizer, evaporator and superheater,
- a low pressure boiler (15) which is an evaporator where hot engine cooling fluid (7) flows within one side of heating surface while transferring its heat into the low-pressure condensate (16) which is within the other side of the heating surface, causing evaporation of the condensate and generating low-pressure steam (17),
- an expander compressor package (35),
    - o where both the high-pressure steam (28) and the low-pressure steam (17) flows into, and
    - o which comprises:
        - an expander (36) where the high pressure steam (28) flows into, and which extracts thermal energy from the high-pressure steam (28) by expansion of and using the thermal energy to do mechanical work on a rotating output shaft connected to a transmission (37), while the expanded high-pressure steam (28) leaves the expander (36) from expander exhaust stream (30) with lower pressure and temperature and consequently lower thermal energy compared with the inlet,
        - compressor (38) where the low-pressure steam (17) flows into, which increases the pressure and consequently thermal energy of the low-pressure steam (17) by reducing volume or increasing velocity or a mix of both, while consuming the required mechanical work from a rotating input shaft connected to the transmission (37), while the compressed low-pressure steam (17) leaves the compressor (38) from compressor discharge stream (19) with higher pressure and temperature and consequently higher thermal energy compared with the inlet, and
        - the transmission (37) which mechanically or hydraulically connects rotating output shaft of the expander (36) to rotating input shaft of the compressor (38), wherein the energy extracted from the expander (36) by expansion of the high-pressure steam (28) is transmitted through the transmission (37) to the compressor (38) where the compression of the low-pressure steam (17) consumes the generated power by the expander (36),

- a heat consumer (20),
    - where the compressor discharge stream (19) and the expander exhaust stream (30) are supplied to,
    - which extracts internal energy of both the expander exhaust stream (30) and the compressor discharge stream (19) and causes condensation of the expander exhaust stream (30) and the compressor discharge stream (19), and
    - which delivers the high-pressure condensate (32) into the waste heat recovery boiler (25) and the low-pressure condensate (16) into the low-pressure boiler (15).

2. The system according to claim 1, **characterized in that** the expander compressor package (35) is chosen as a multi stage pressure casing with multi transmission, wherein the multi stage pressure casing of the expander compressor package (35) comprises:

- high-pressure expander (43) and low-pressure expander (44),
    - wherein the high-pressure steam (28) is expanded within the high-pressure expander (43) to an intermediate pressure level and exits through high-pressure expander exhaust stream (29), flowing into the low-pressure expander (44) and further expanded within, and leaving through the expander exhaust stream (30) with a lower pressure,
- low-pressure compressor (40) and high-pressure compressor (41),
    - wherein the low-pressure steam (17) is compressed within the low-pressure compressor (40) to an intermediate pressure level and exits through low-pressure compressor discharge stream (18), flowing into the high-pressure compressor (41) and further compressed within, and leaving through the compressor discharge stream (19) with a higher pressure,
- first transmission (45) and second transmission (46),
    - wherein the energy extracted from the high-pressure expander (43) by expansion of the high-pressure steam (28) to high-pressure expander exhaust stream (29) is transmitted through the first transmission (45) to the high-pressure compressor (41) where the compression of the low-pressure compressor discharge stream (18) to the compressor discharge stream (19) consumes the generated power by the expander high pressure (43).

3. The system according to claim 2, **characterized in that** rotating output shaft of the high-pressure expander (43), rotating output shaft of the low-pressure expander (44), rotating input shaft of the high-pressure compressor (41) and rotating input shaft of the low-pressure compressor (40) are all connected to a common transmission (48).

4. The system according to claim 1, **characterized in that** the expander compressor package (35) is chosen as a thermocompressor package (50),

- where both the high-pressure steam (28) and the low-pressure steam (17) flows into,
- which is a device using the high-pressure steam (28) to create a high velocity and decreased static pressure stream which causes suction of the low-pressure steam (17) and further mixing of both streams occurs in downstream section of the device while the outlet section of the thermocompressor (55) decrease the velocity of the mixture causing increase in static pressure, while thermocompressor exhaust stream (51) leaves the thermocompressor (55) at a pressure level between the high-pressure steam (28) and the low pressure steam (17).

5. The system according to claim 4, **characterized in that** the thermocompressor package (50) is a single stage thermocompressor (55) or multi-stage thermocompressor package (64) connected in series.

6. The system according to claim 4 or 5, **characterized in that** the thermocompressor package (50) further comprising:

- a nozzle (56), where the high-pressure steam (28) flows into, and which causes velocity increase of the high-pressure steam (28) creating a jet flow while decreasing static pressure to a point lower than the low-pressure steam (17),
  - wherein outlet stream of the nozzle (56) flows into the mixing chamber (58) while creating a lower pressure environment in a suction chamber (57) causing flow of the low-pressure steam (17) into the suction chamber (57) and subsequent mixing of streams in a mixing chamber (58),
- an expansion chamber (59), where velocity of the mixture is decreased due to the increase in cross section while the static pressure increases.

7. The system according to claim 6, **characterized in that** the high-pressure steam (28) supplied to nozzle (56) is referred as motive steam (67).

8. The system according to claim 6 or 7, **characterized in that** the outlet steam velocity of the nozzle (56) can be subsonic or supersonic, higher the velocity so that higher the compression ratio of the low-pressure steam (17) can be achieved.

9. The system according to claim 5, **characterized in that** multi-stage thermocompressor package (64) comprising:

- a thermocompressor 1st stage (65),

  - where motive steam (67), which can be supplied either from the high-pressure steam (28) or the thermocompressor exhaust stream (51) is supplied to the nozzle section of,
  - which compresses the low-pressure steam (17) to an interim pressure level below the thermocompressor exhaust stream (51) and above the low-pressure steam (17),
- a thermocompressor 2nd stage (66),
  - where the high-pressure steam (28) is supplied to,
  - which compress the thermocompressor 1st stage outlet stream (68) and delivers the thermocompressor outlet stream (51) at a pressure point between the high-pressure steam (28) and a thermocompressor first stage outlet stream (68).

10. The system according to claim 4, **characterized in that** the expander compressor package (35) is chosen as a combination of the expander compressor package (35) and the thermocompressor package (50), wherein

- the expander compressor package (35) and the thermocompressor package (50) can be connected in series,
- the high-pressure steam (28) flows into the thermocompressor (55) and compresses the low-pressure steam (17), and delivers the thermocompressor exhaust stream (51) to the compressor (38) suction,
- the compressor (38) compresses the inlet stream and delivers the compressor discharge stream (19),
- required power for the compressor (38) is supplied by the expander (36) through the transmission (37) and generated by the expander (36) by the expansion of the high-pressure steam (28),
- the compressor discharge steam (19) and the expander exhaust stream (30) are supplied to the heat consumer (20).

11. The system according to claim 1, **characterized in that** the high-pressure condensate (32) fluid type used to generate high-pressure steam (28).

12. The system according to claim 1, **characterized in that** supplementary fuel (26) is supplied to the waste heat recovery boiler (25) for supplementary combustion causing increased steam generation.

13. The system according to claim 1, **characterized in that** in mechanical compression, the low-pressure condensate (16) fluid type fluid type used to generate the low-pressure steam (17) is as per the requirement of the heat consumer (20) and can be either the same type or other type of fluid than the high-pressure condensate (32).

14. The system according to claim 1, **characterized in that** in thermal compression, the low-pressure condensate (16) fluid type fluid type used to generate the low-pressure steam (17) is as per the requirement of the heat consumer (20) and is the same type of the high-pressure condensate (32).

15. The system according to claim 1, **characterized in that** the expander (36) is chosen as a single stage or multi stage axial type of turbine, single stage or multi stage radial type of turbine, multi stage mix of axial and radial type of turbine or can be of single stage or multi-stage positive displacement type of expander.

16. The system according to claim 1, **characterized in that** the compressor (38) is chosen as a single stage or multi stage axial type of compressor, single stage or multi stage radial type of compressor, multi stage a mix of axial and radial type of compressor or can be of single stage or multi-stage positive displacement type of compressor.

17. The system according to claim 1, **characterized in that** the transmission (37) is chosen as mechanical shaft type, gearbox type, hydraulic type, or continuous variable type.

18. The system according to claim 2, **characterized in that** the high-pressure expander (43) and/or the low-pressure expander (44) is chosen as a single stage or multi stage axial type of turbine, single stage or multi stage radial type of turbine, multi stage mix of axial and radial type of turbine or can be of single stage or multi stage positive displacement type of expander.

19. The system according to claim 2, **characterized in that** the high-pressure compressor (41) and/or the low-pressure compressor (40) is chosen as a single stage or multi stage axial type of compressor, single stage or multi stage radial type of compressor, multi stage a mix of axial and radial type of compressor or can be of single stage or multi stage positive displacement type of compressor.

20. The system according to claim 2, **characterized in that** the first transmission (45) and/or the second transmission (46) is chosen as mechanical shaft type, gearbox type, hydraulic type, or continuous variable type.

21. The system according to claim 3, **characterized in that** the common transmission (48) is chosen as gearbox type, hydraulic type or continuous variable type or a mix of those for each connection.

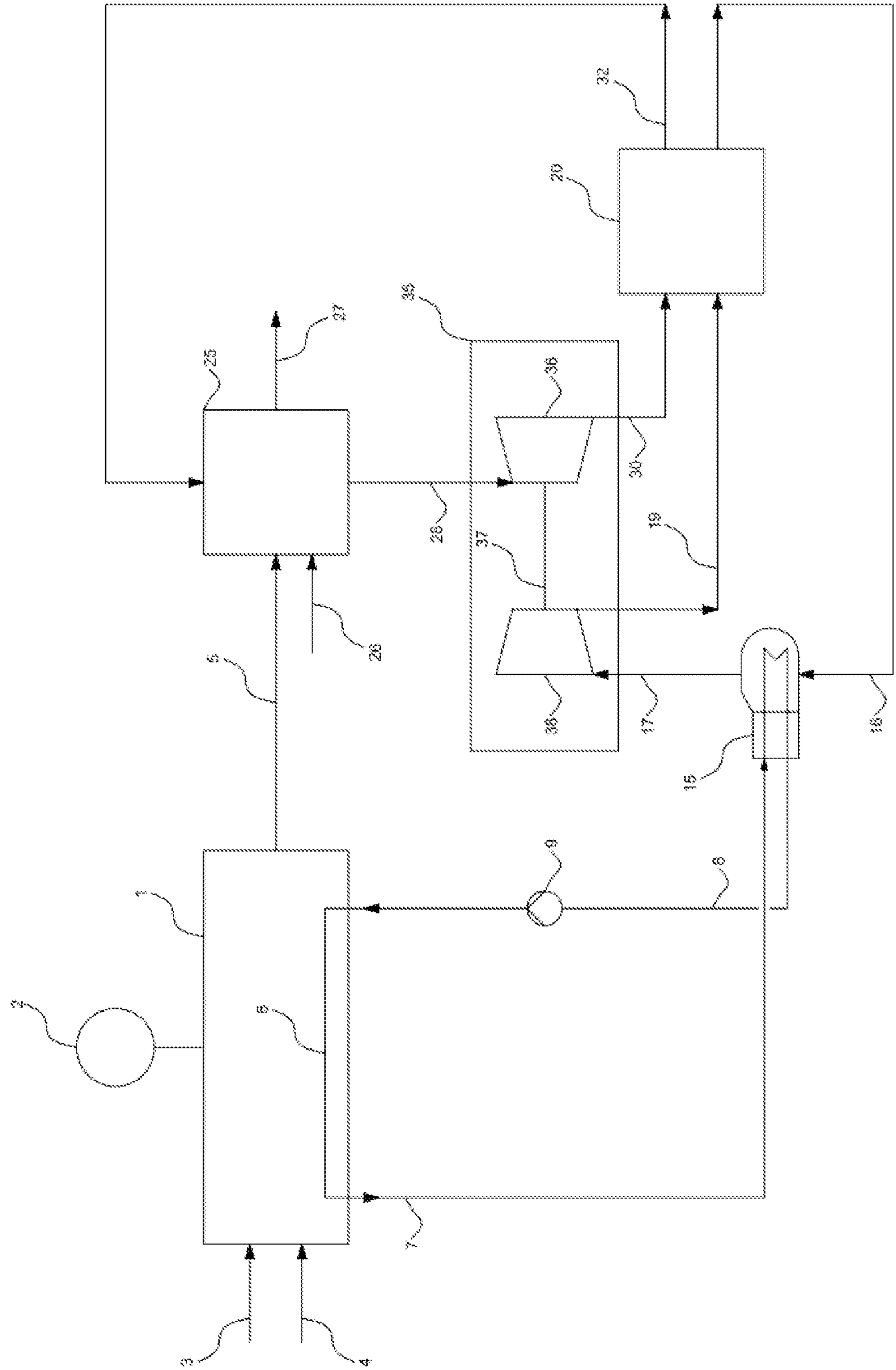

Figure 1

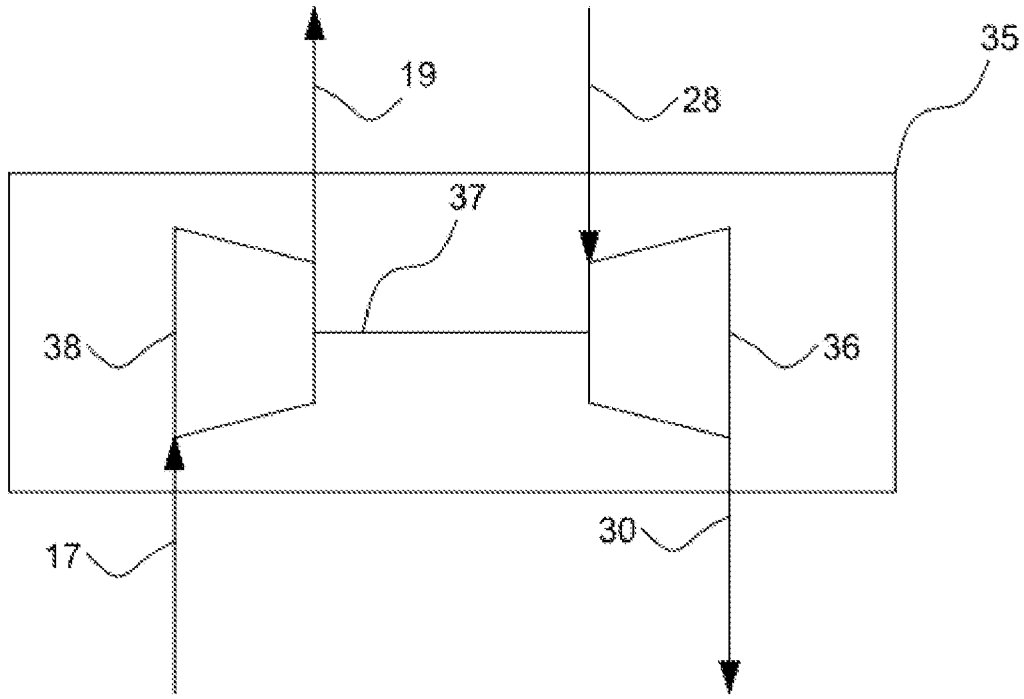

Figure 2

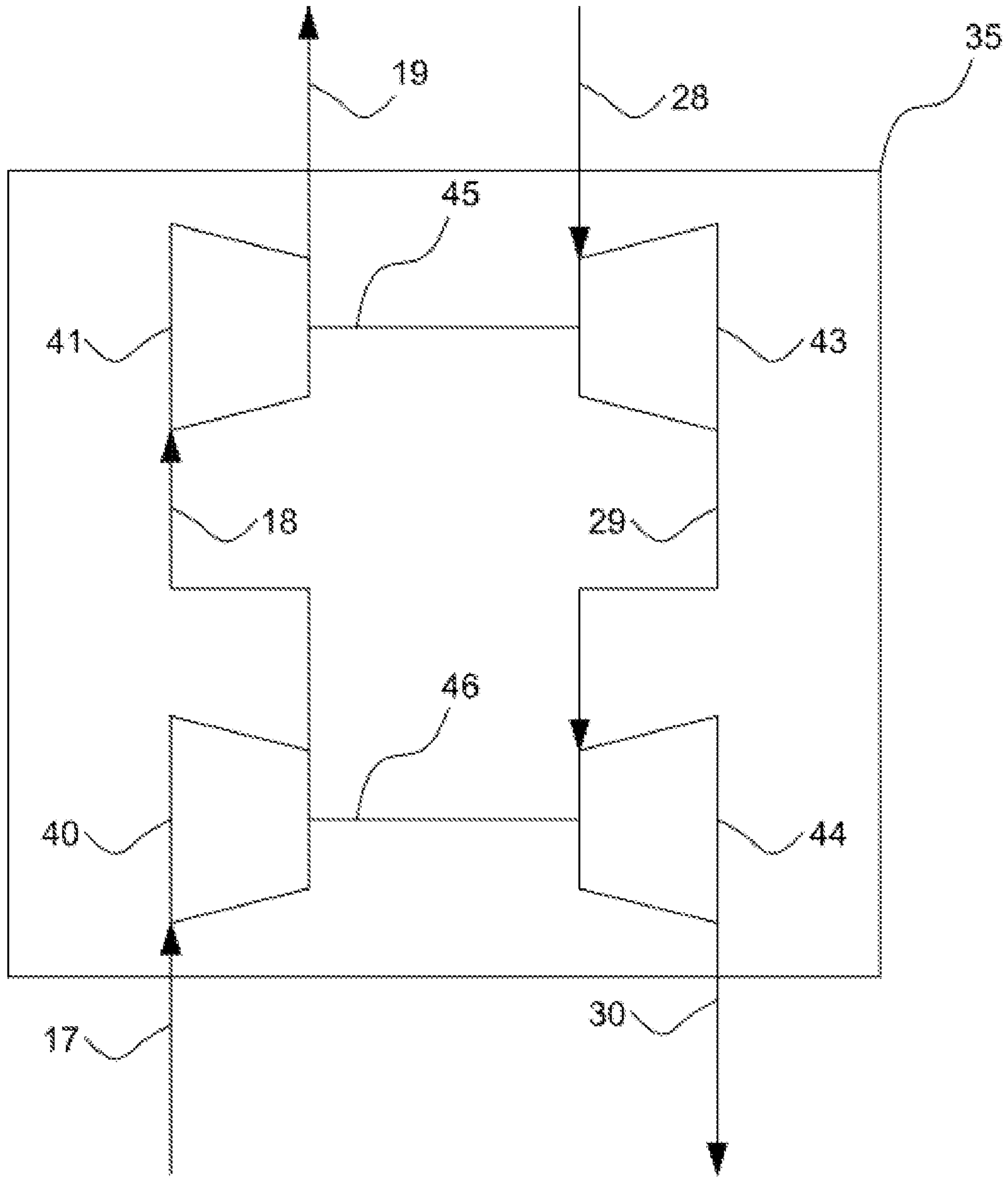

Figure 3

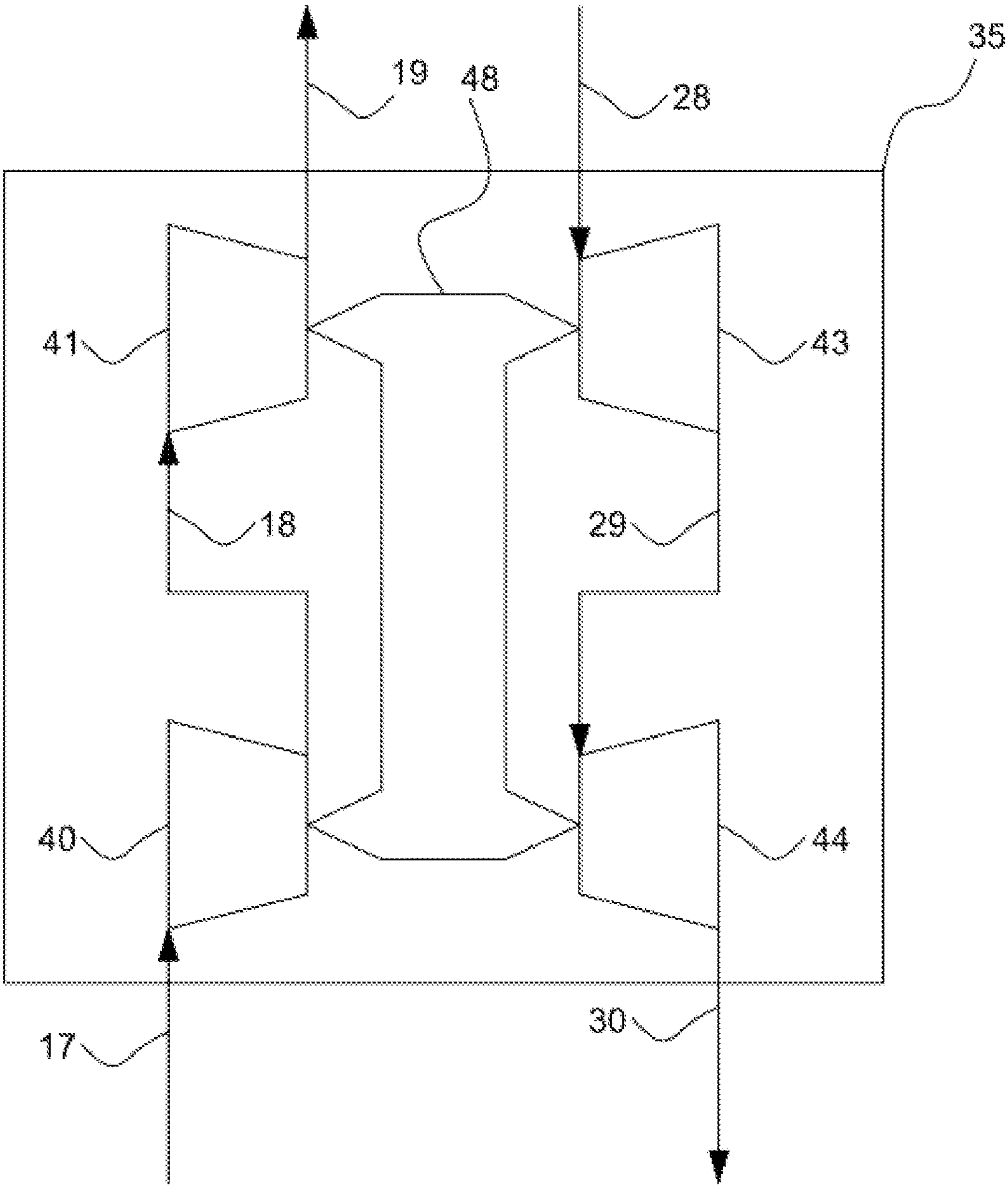

Figure 4

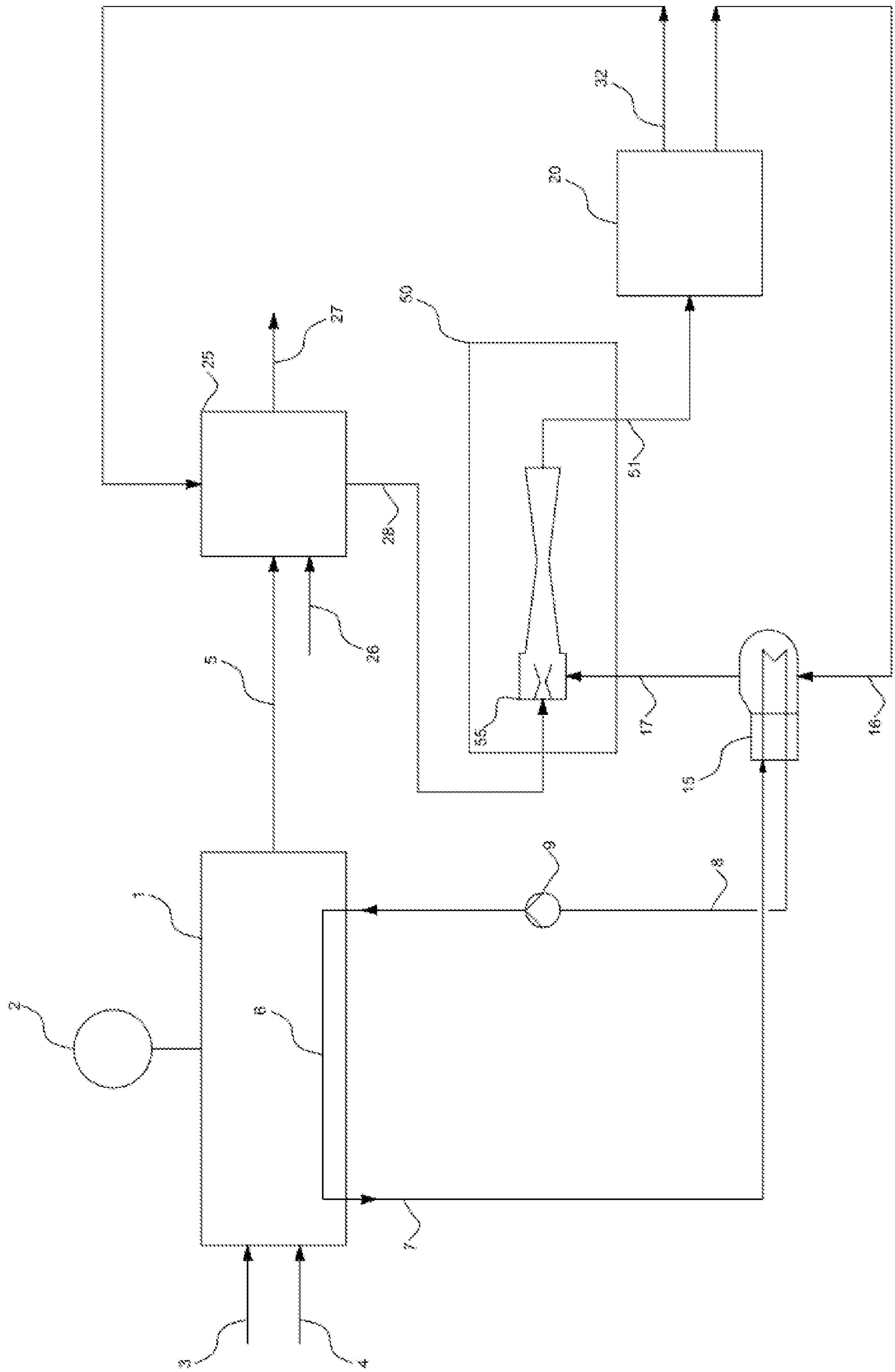

Figure 5

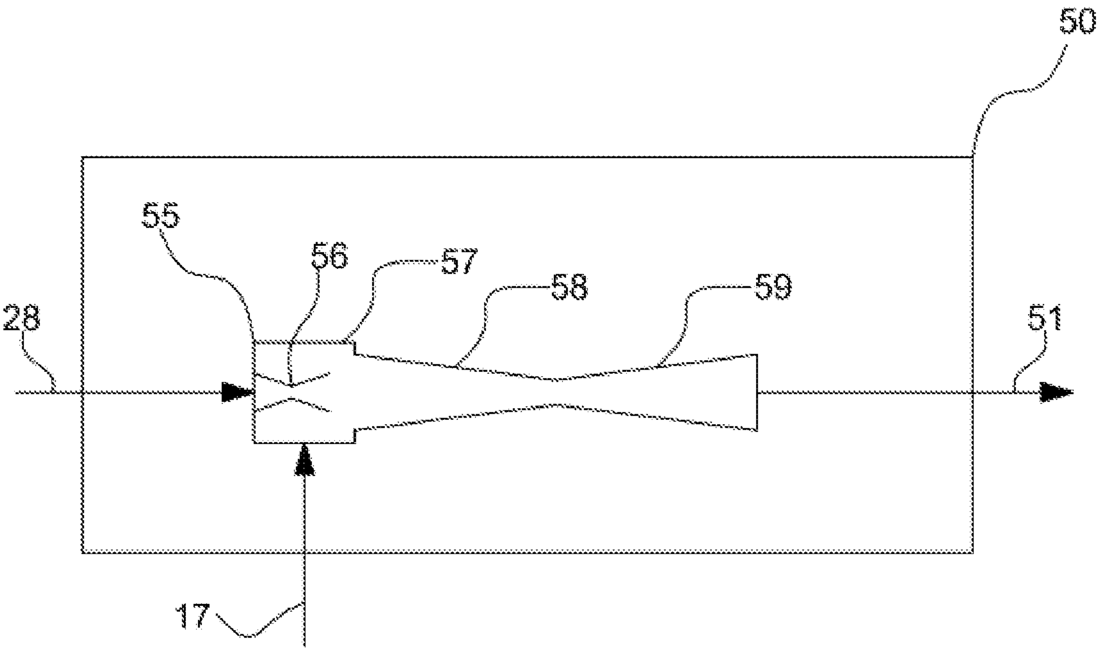

Figure 6

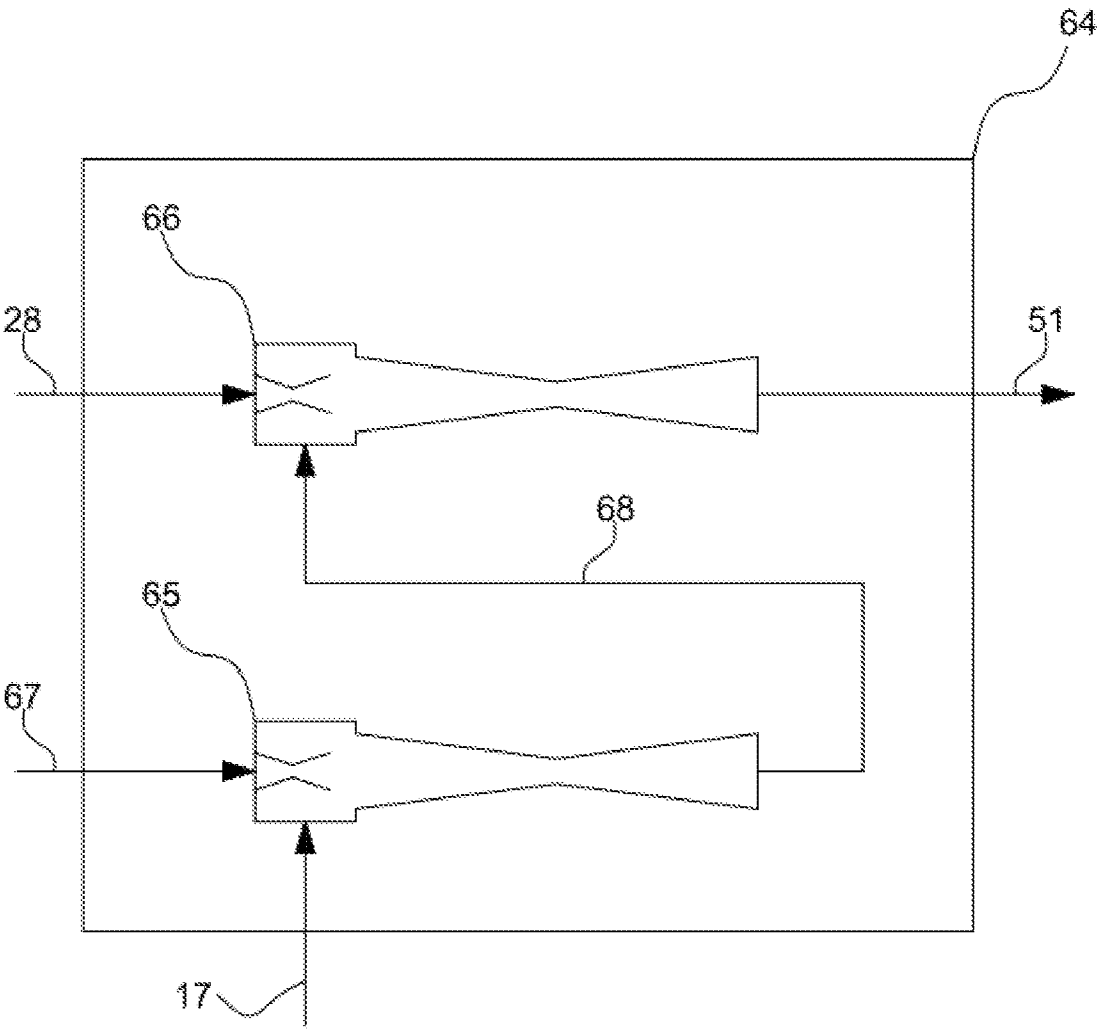

Figure 7

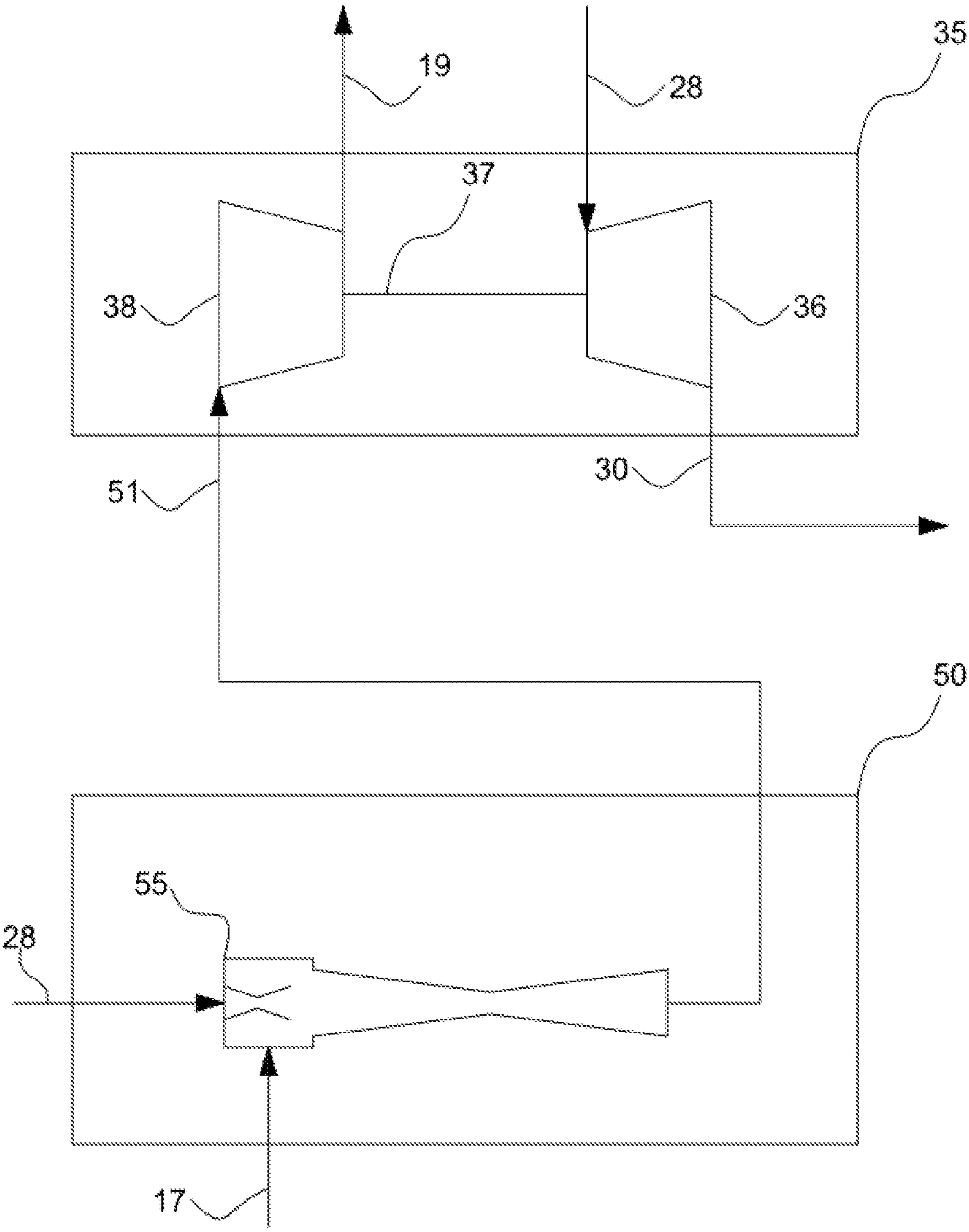

Figure 8

INTERNATIONAL SEARCH REPORT

International application No
PCT/TR2023/050528

A. CLASSIFICATION OF SUBJECT MATTER
INV. F01K17/00 F01K19/02 F01K23/06 F01K23/10
ADD.

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)
F01K

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

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

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	CN 110 905 619 A (UNIV TIANJIN) 24 March 2020 (2020-03-24) paragraphs [0054] - [0056]; figure 1	1-21
A	US 11 143 102 B2 (NUOVO PIGNONE TECNOLOGIE SRL [IT]) 12 October 2021 (2021-10-12) column 8, line 59 - column 9, line 40; figure 5	1-21

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"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)

"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

"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

"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

"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

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
1 December 2023	21/12/2023

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Röberg, Andreas

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No

PCT/TR2023/050528

Patent document cited in search report		Publication date	Patent family member(s)			Publication date
CN 110905619	A	24-03-2020	NONE			
US 11143102	B2	12-10-2021	EP	3420201	A1	02-01-2019
			RU	2018129741	A	24-03-2020
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