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THERMAL ENGINE

Technical area

The present invention relates to a heat engine.

State of the art

Currently available heat engines (WKM) consist at their core of an evaporator, an expansion machine, a condenser and a liquid pump. In addition, an WKM includes a heat source, a heat sink, valves, pipes and control elements.

In the evaporator, supplied heat is used to evaporate a working fluid, often water, at elevated pressure. In the process, the liquid working fluid is first preheated in one or more heat exchangers, evaporated and in most cases superheated.

The steam generated in heat exchangers is fed to the expansion machine (feed steam) and expanded in it. The mechanical energy generated by the expansion machine is usually converted into electrical energy and fed into the power grid. The expanded steam is usually fed to a condenser and condensed there. The completely condensed working fluid is brought to an increased pressure by means of the liquid pump and fed back to the evaporator. This closes the circuit of the working fluid. The process is called a cycle process.

Turbines are predominantly used as expansion machines. However, piston machines, screw machines and vane machines (rotary piston machines) are for example also possible. Continuously operating expansion machines such as turbines work particularly effectively at a certain (expansion) pressure ratio π. If one deviates from this pressure ratio π, the exergetic quality of the expansion rapidly decreases. Discontinuously operating expansion machines, such as piston machines and screw machines, have high exergetic qualities even with a strongly varying pressure ratio π. In piston machines and screw machines, this follows from the variability of the degree of filling of the cylinder. If the cylinder is only filled in a low ratio (e.g. 10 %) during loading, a high pressure ratio π is achieved (e.g. $\pi = 20$ with adiabatic exponent $\kappa = 1.3$). If the cylinder is filled to a high degree (e.g. 50 %), a low pressure ratio π is obtained (e.g. $\pi = 2.5$ at $\kappa = 1.3$). This relationship will play a role in later explanations.

In the case of water as the working fluid, the heat engine process described above is called the Clasusius-Rankine process (CRC). If other working fluids are used, the process is called Organic Rankine Process (ORC). Both types of process roughly describe a rectangle in the T-S diagram. For this reason, CRC and ORC belong to the carnot-like processes. The effectiveness of the processes can be increased by multi-stage evaporation, internal heat exchangers and the use of working fluid mixtures (Kalina process).

Heat sources for sensitive low-temperature heat can be, for example, geothermal plants, solar plants or waste heat flows from industrial processes. When using sensitive low-temperature heat, an ideal WKM process has the shape of a triangle in the T-s diagram. This process form is called a triangular process or triangle cycle or trilateral cycle [1] in the literature. If a triangular process is feasible, the triangular process can generate, for example, 30% more mechanical power from the available heat compared to ORC or CRC, which represent the state of the art [2, 3]. However, it has not yet been possible to realise a triangular process

Document DE102012007210A1 describes a heat engine with energy storage, which is the closest prior art to the present invention. Documents WO2016/124709A1 and EP2703764A2 also describe heat engines with energy storage.

Problems to be solved

It is an object of the invention to present a structure and the function of a heat engine, wherein the heat engine permits the extensive implementation of a triangular process. The core of the invention is the provision of heat transfer medium from one or more containers in batch operation. The heat engine according to the invention is defined by all the features of the attached independent claim 1. The thermal energy for the evaporation is thereby transferred from a container filled with heat transfer medium (1a or 1b) to the evaporator 40. The following problems are solved:

1. continuous operation of the heat engine is achieved by using two containers, both of which can be alternately connected to the heat source or to the evaporator via valves 19, 20, 21, 22.
2. harmful condensation of steam in the expansion machine EM, 10, is avoided by superheating the working medium after evaporation.
3. superheating and preheating of the working medium is done by heat transfer medium from the heat source 21 and not from the containers 1a, 1b. In this way, the working medium is preheated and always superheated to approximately the maximum temperature of the heat source 21.

4. The heat still present in the working medium after expansion is removed from the expanded steam by heat exchangers (desuperheaters) 32 and returned to the process in a further batch process with containers 50a and 50b and the preheater 45 at low dissipation.

Description of the invention

The invention is based on the realisation of batch processes in the field of thermodynamic circular processes. There are essentially two forms of cyclic processes: Heat pumps and heat engines. Batch processes have already been successfully implemented in the field of heat pumps (see for example EP2470850 A2). The technique of batch processes is transferred to heat engines by the present invention as defined exclusively by the appended independent claim 1.

Heat engines usually operate with constant evaporation pressure. The heat source provides essentially sensible heat via a heat transfer medium. The heat transfer medium is, for example, water or thermal oil. If the heat source is exhaust gas or thermal water, the heat must first be transferred from the heat source to water or thermal oil (not shown). The heat is used in heat exchangers for preheating, evaporation and superheating of working medium. In batch processes, the heat transfer medium is temporarily stored in a container 1a. This container can be connected via valves either to the heat source 21 for charging or to the evaporator 40 for discharging. During charging, warmer working fluid flows from the heat source 21 into the top of the container 1a or 1b and colder working fluid flows out of the bottom of the container. During unloading, warmer heat transfer medium flows out of the top of container 1a and into evaporator 40, and heat transfer medium cooled by a few Kelvin flows out of the bottom of evaporator 40 and into the bottom of container 1a via pump 41. In this way, the container 1a is successively cooled, whereby the vapour pressure of the working medium successively decreases. The cooling is continued until a minimum temperature of the heat transfer medium is reached. The time from the beginning of the cooling of the container 1a until the minimum temperature is reached is called a cycle.

According to EP2470850 A2 for heat pumps, two containers 1a and 1b are also used in the heat engine so that the heat engine can be kept in operation without interruption. The containers are constructed in such a way that they can be connected to the heat source 21, or to the evaporator 40, and hot and cold heat transfer medium mix as little as possible during this process.

When cooling of one of the containers 1a or 1b with cold heat transfer medium through the evaporator 40 is completed, the evaporator 40 can be connected to the heat source 21 in an intermediate cycle by means of a valve 60. This causes warm heat transfer medium to flow from the heat source to the evaporator 40 and to heat it up, then to flow through the pumps 41 and 17 and the check valves 27, 18. The evaporator is thus preheated before it is connected to the second, heated container. This prevents warm heat transfer medium from the container from mixing with cold heat transfer medium from the evaporator 40. Valves 19, 20, 21 and 22 are closed during the intermediate cycle.

In heat engines, it is important that the working fluid in the expansion machine 10 does not condense. To avoid condensation, the working fluid is usually superheated after evaporation. In addition, friction in the expansion machines (e.g. piston friction) and conversion of the vortex energy in the working fluid into heat counteract condensation. In heat engines with a batch process, the evaporation temperature of the working fluid drops sharply in the course of the process and the risk of the expansion machine 10 cooling down and the working fluid condensing in the expansion machine increases. For this reason, the measures according to the invention against condensation are of particular importance in batch processes. On the one hand, heat transfer medium is fed directly from the heat source to the superheater, thereby achieving the highest possible superheat. The heat transfer medium should have the same capacity flow (specific heat capacity times mass flow) as the gaseous working fluid. After the superheater, the heat transfer medium flows into the preheater. Here, the working fluid is liquid and thus has a higher specific heat capacity and consequently a higher capacity flow, which leads to dissipation in the preheater. To reduce dissipation, heat transfer medium is pumped from the desuperheater heat exchanger into the preheater, as will be shown later.

In a further embodiment of the invention, the expansion machine is heated and insulated to prevent condensation in the expansion machine.

In many realised continuous processes, the working fluid leaves the WKM in a superheated state. According to the state of the art, the superheat can be removed from the process via a heat exchanger 32, called desuperheater, and used e.g. for preheating the liquid working fluid. It can be easily explained by means of a T-s diagram that the degree of superheating at the end of expansion is, as a first approximation, proportional to the superheating before entering the expansion machine. In the batch process, the superheat of the working medium before the expansion machine is low at the beginning of the cycle and high at the end of the cycle. The same is true for the superheating after the expansion. According to the invention, the superheat after expansion in the batch process is decoupled by a heat exchanger at the outlet of the expansion machine and stored in another pair of containers, called desuperheater containers. Each of these two containers can be connected in cycles either to the desuperheater 32 or to the preheater 45. In this way, the superheat can be used to reduce the imbalance of the capacity currents in the preheater.

According to the increasing temperature of the working medium at the outlet of the expansion machine 10, the respective connected desuperheater container 50a or 50b is filled from above with increasingly warmer heat transfer medium. At the end of a cycle, the desuperheater container is warmest at the top and the temperature decreases linearly with the container height as a first approximation. When discharging into the preheater 45, warm heat transfer medium is taken from the top of the superheater container 50a or 50b and fed to the preheater 45 according to the temperature present at the heat transfer medium outlet of the superheater 9. The falling temperature at the upper outlet of the desuperheater container 50a or 50b coincides with the likewise falling temperature at the heat transfer medium outlet of the superheater 9 if the mass flow of the pump 15 is suitable.

When the desuperheater 32 has finished filling one of the containers 50a or 50b with warm heat transfer fluid, the container can be connected to the preheater 45 in an intermediate cycle by means of a valve 61. This allows cold heat transfer medium to flow from the preheater 45 via pumps 59 and 51 and check valves 57, 58 to the desuperheater 32 and cool it down before it is connected to the second, cool container. This prevents warm heat transfer medium from the desuperheater from mixing with cold heat transfer medium from the container. Valves 53, 54, 55 and 56 are closed during the intermediate cycle.

The heat engines with batch process according to the invention enable the implementation of triangular processes according to claim 1 and the subclaims. The increase of the electrical efficiency of the heat engine by about 30% to 50% and the use of low-cost and durable components such as containers, valves, check valves and pumps promises a very good marketability of the invention with low payback times for the additional investment.

- Figure 1 shows the structure of a heat engine according to the state of the art for stationary operation. From a heat source 21, heated heat transfer medium passes into the superheater 9, from there into the evaporator 40, from there into the preheater 45 and from there via a pump 17 back to the heat source 21. In the superheater 9, evaporator 40 and preheater 45, the heat transfer medium gives off heat to the evaporable working medium. The liquid working medium passes from the working medium pump 15 to the preheater 45, from there to the evaporator 40 and from there in a gaseous state to the superheater 9 and from there to the expansion machine 10, EM in which the working medium expands and performs work which is delivered by the EM 10 to a generator 11 and converted into electrical energy and passed on to el. consumers. The steam 32 expanded in the EM 10 is led to a condenser 12, where it is liquefied and collected in a collecting container 13, SB. From the collection container 13, liquid working fluid is delivered to the pump 15 as required, thus closing the working fluid circuit.

- Figure 2 shows batch operation in a heat engine with only one container and thus outside the scope of the present invention. The working fluid circuit is shown dashed in this figure to distinguish it from the circuit of the heat transfer medium. The heat exchanger 40 combines preheater, evaporator and superheater. Compared to figure 1, a container 1a is inserted between the heat source 21 and the heat exchanger 40. The container can be hydraulically connected to the heat source 21 or the heat exchanger 40 depending on the valve opening of the valves 19 or 20, so that an exchange of heat transfer medium is then possible. When the valve 19 is open, warm heat transfer medium flows from the heat source 21 via the valve 19 at the top into the container 1a. From the lower connection of the container 1a, colder heat transfer medium returns to the heat source 21 via the pump 17. When the valve 20 is open, heat transfer medium passes from the heat exchanger 40 via the pump 41 to the lower connection of the container 1a. From the upper connection of the container 1a, heat transfer medium returns via the valve 20 to the heat exchanger 40. A control device 44 detects the level of the liquid working medium in the heat exchanger 40 (dotted lines) and controls the mass flow of the working medium in the pump 15 using the setpoint deviation of the level as an example. With this set-up, the temperature of the working medium at the inlet of the expansion machine 10 can drop sharply, which can lead to cooling of the EM 10 and condensation of working medium in the EM 10.
- Figure 3 shows a set-up for implementing batch operation with a separate preheater 45 and superheater 9. Similar to Figure 2, Figure 3 also shows a heat engine with only one container and is thus outside the scope of the present invention. Here, a partial flow 33 of the hot heat transfer medium is directed from the heat source 21 into the superheater 9, from there into the preheater 45 and via a pump 46 back to the heat source 21. The working fluid is directed from the pump 15 via the preheater 45, the evaporator 40 and the superheater 9 to the expansion machine EM 10 as in the prior art. In the process, the working fluid is brought to high temperatures before entering the EM 10, which reliably prevents cooling of the EM 10 and condensation in the EM 10.

- Figure 4 shows the batch operation of a heat engine with a pair of containers 1a and 1b. In addition to Figure 3, a second container 1b, two valves 21 and 22 and two check valves 18 and 27 have been added. Valves 21 and 22, in analogy to the design of container 1a, allow container 1b to be hydraulically coupled to heat source 21 or evaporator 40. For example, while container 1a is connected to heat source 21, container 1b is connected to evaporator 40. I.e. valves 19 and 22 are open, valves 20 and 21 are closed. After container 1a is filled with warm heat transfer medium and container 1b has transferred its heat to the evaporator, the valves are switched so that container 1a is coupled to evaporator 40 and 1b to heat source 21. I.e. valves 20 and 21 are open, valves 19 and 22 are closed. Check valves 18 and 27 prevent the flows from mixing. The disadvantage of this design is that superheat that is still present in the working fluid after expansion in the expansion machine EM 10 is not used.
- Figure 5 shows batch operation with a second pair of containers 50a and 50b, which absorb the superheat after the working fluid has been depressurised in the expansion machine 10 and discharge it to the preheater 45. For this purpose, the containers 50a and 50b are coupled to the desuperheater 32 and the preheater 45 by means of the valves 53, 54, 55 and 56 in an analogous manner to containers 1a and 1b, but here alternately. The pump 51 provides the required mass flow through the desuperheater, the pump 59 provides the required mass flow through the preheater 45 and the check valves 57 and 58 provide a separation of the circuits through the desuperheater 32 and through the preheater 45. In this set-up, with a suitable design of the containers and the mass flows in the heat exchangers preheater, evaporator, superheater and desuperheater, there is only little dissipation. Assuming an ideal expansion machine, the set-up can convert approximately the entire exergy contained in the heat source 21 into mechanical energy. The triangular process can be achieved to a large extent.
- Figure 5 shows an optimisation of batch operation with flush valves 60 and 61. If, for example, container 1a has transferred its heat to evaporator 40, the evaporator has cooled down. If the second, heated container 1b is now directly connected to the evaporator 40, the cold heat transfer medium in the evaporator 40 mixes with the warm one from container 1b, which is detrimental to the process. To avoid the mixing, the cold evaporator 40 is first connected to the heat source via valve 60 and heated. The valves 19 to 22 are closed. When the evaporator 40 is heated, valve 60 is closed and valves 19 and 22 are opened. Each cooling of container 1a or 1b is thus followed by a flushing phase via valve

60. The same procedure applies to flush valve 61. Here, each heating phase of the desuperheater 32 is followed by a cooling phase via valve 61, so that a renewed input of superheat from the working medium into the desuperheater 32 can begin in the new cycle.

PATENTKRAV

1. Varmekraftmaskine med en varmekilde (21), en ekspansionsmaskine (10), en kondensator (12), en kondensatopsamlebeholder (13), en arbejdsmiddelpumpe (15), en fordamper (40), en første beholder (1a) til et varmebærende medium, en anden beholder (1b) til et varmebærende medium, en første pumpe til et varmebærende medium (17), en anden pumpe (41) til et varmebærende medium, en første ventil (19), en anden ventil (20), en tredje ventil (21) og en fjerde ventil (22),
hvor varmekraftmaskinen er indrettet således, at, under driften af varmekraftmaskinen, den første beholder (1a), i en første funktionsmåde for varmekraftmaskinen, er sluttet hydraulisk til varmekilden (21) via den første ventil (19) og den første pumpe (17) og, i en anden funktionsmåde for varmekraftmaskinen, er sluttet til fordamperen (40) via den anden ventil (20) og den anden pumpe (41),
hvor, i den første funktionsmåde for varmekraftmaskinen, et varmere varmebærende medium fra varmekilden (21) i forbindelse med en tilslutning af den første beholder (1a) til varmekilden (21) fyldes på den første beholder (1a) foroven, og et koldere varmebærende medium udtages i det nederste område af den første beholder (1a) og føres tilbage til varmekilden (21), og, i den anden funktionsmåde for varmekraftmaskinen, et varmere varmebærende medium i forbindelse med en tilslutning af den første beholder (1a) til fordamperen (40) udtages fra det øverste område af den første beholder (1a), ledes ind i fordamperen (40), og fra fordamperen (40) ved hjælp af den anden pumpe (41) pumpes ned i det nederste område af den første beholder (1a),
hvor den anden beholder (1b), i den anden funktionsmåde for varmekraftmaskinen, er sluttet

hydraulisk til varmekilden (21) via den tredje ventil (21) og den første pumpe (17), og, i den første funktionsmåde for varmekraftmaskinen, er sluttet til fordamperen (40) via den fjerde ventil (22) og den anden pumpe (41),

hvor, i den anden funktionsmåde for varmekraftmaskinen, et varmere varmebærende medium fra varmekilden (21) i forbindelse med en tilslutning af den anden beholder (1b) til varmekilden (21) fyldes på den anden beholder (1b) foroven, og et koldere varmebærende medium udtages i det nederste område af den anden beholder (1b) og føres tilbage til varmekilden (21),

og, i den første funktionsmåde for varmekraftmaskinen, et varmere varmebærende medium i forbindelse med en tilslutning af den anden beholder (1b) til fordamperen (40) udtages fra det øverste område af den beholder (1b), ledes ind i fordamperen (40), og fra fordamperen (40) ved hjælp af den anden pumpe (41) pumpes ned i det nederste område af den anden beholder (1b),

hvor varmekraftmaskinen er indrettet således, at under driften af varmekraftmaskinen én af den første og den anden beholder (1a, 1b) er sluttet til varmekilden (21) og den anden af den første og den anden beholder (1b, 1a) er sluttet til fordamperen (40), således, at fordampningsenergi enten overføres fra den ene eller den anden af den første og den anden beholder til fordamperen (40), og ekspansionsmaskinen (10) under driften af varmekraftmaskinen kontinuerligt forsynes med damp, og beholderens tilslutning til varmekilden (21) og fordamperen (40), under driften af varmekraftmaskinen, efter et stykke tid kan ombyttes ved hjælp af ventilerne (19, 20, 21, 22).

2. Varmekraftmaskine ifølge krav 1, med en forvarmer (45), en overheder (9) og en yderligere pumpe (46) til det varmebærende medium,

hvor arbejdsmidlet under driften af varmekraftmaskinen forvarmes af forvarmeren (45), derefter strømmer ind i fordamperen (40), derefter strømmer ind i overhederen (9) og derefter ind i ekspansionsmaskinen (10), og det varmebærende medium ved hjælp af den yderligere pumpe (46) til det varmebærende medium pumpes direkte fra varmekilden (21) ind i overhederen (9) og derefter ind i forvarmeren (45) og derefter ved hjælp af pumpen (46) tilbage til varmekilden (21).

3. Varmekraftmaskine ifølge krav 1 eller 2, med en køler (32), et andet par af beholdere (50a, 50b) til et varmebærende medium, ventiler (53, 54, 55, 56), to pumper (51, 59) til det varmebærende medium,

hvor de to beholdere (50a, 50b) med ventiler enten kan sluttes til køleren (32) eller til forvarmeren (45),
hvor en første beholder (50a, 50b) er sluttet til forvarmeren (45) og en anden beholder (50b, 50a) til køleren (32) skiftevist,
hvor køleren (32) under driften af varmekraftmaskinen gennemstrømmes med et arbejdsmiddel fra ekspansionsmaskinen (10), og resterende varme fra arbejdsmidlet i køleren (32) afgives til det varmebærende medium, det varmebærende medium derefter pumpes ind i den første beholder foroven og fra det nederste område af den første beholder tilbage til køleren (32) igen ved hjælp af pumpen, mens det varmebærende medium fra forvarmeren (45) pumpes ind i den anden beholder forneden ved hjælp af den anden pumpe for at blive pumpet tilbage til forvarmeren (45) igen fra den øverste tilslutning på den anden beholder,
og hvor den hydrauliske tilslutning af den første og den anden beholder til køleren (32) og forvarmeren (45) kan ombyttes.

4. Varmekraftmaskine ifølge krav 1 til 3, med en ventil (60) mellem varmekilden (21) og fordamperen (40), hvor ventilen (60) muliggør en opvarmning af fordamperen (40) med det varmebærende medium direkte fra varmekilden (21), hvor opvarmningen under driften af varmekraftmaskinen foregår efter afsluttet afkøling af det varmebærende medium i en af de to beholdere (1a, 1b), der var forbundet med fordamperen (40).

5. Varmekraftmaskine ifølge krav 1 til 4, med en ventil (61) mellem køleren (32) og forvarmeren (45), hvor ventilen muliggør afkølingen af køleren (32) med det varmebærende medium direkte fra forvarmeren (45), hvor opvarmningen under driften af varmekraftmaskinen foregår efter afsluttet opvarmning af det varmebærende medium i en af de to beholdere, der var forbundet med forvarmeren (45).

6. Varmekraftmaskine ifølge krav 1 til 5, hvor ekspansionsmaskinen (10) er udført opvarmet og isoleret.

7. Varmekraftmaskine ifølge krav 1 til 6, hvor den første og den anden beholder (1a, 1b) er udført tilspidset foroven og forneden, idet tilspidsningen muliggør en hvirvelfri tilførsel af det varmebærende medium til beholderen.

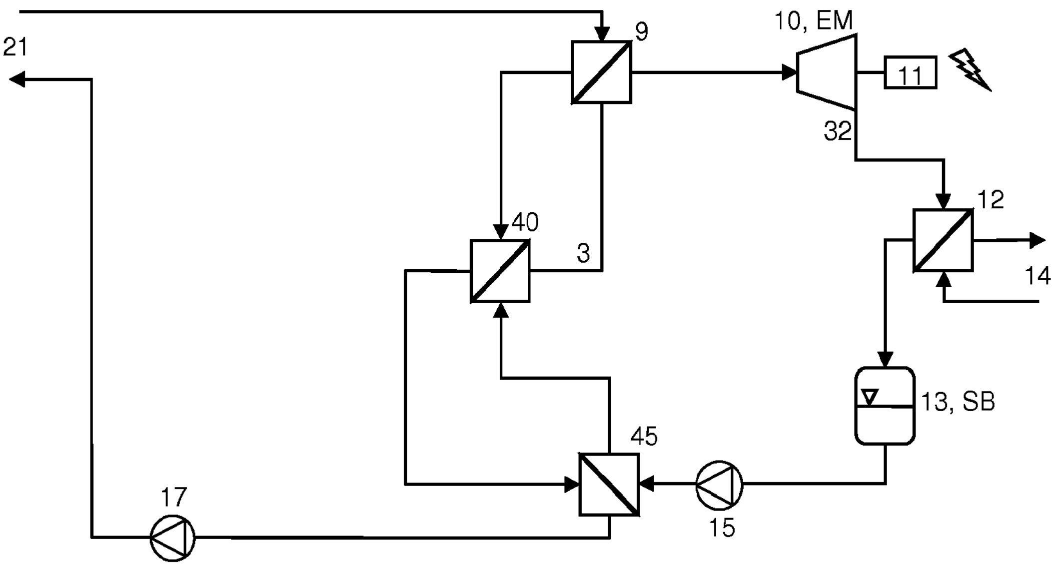

Figure 1: Heat engine, stationary operation, state of the art

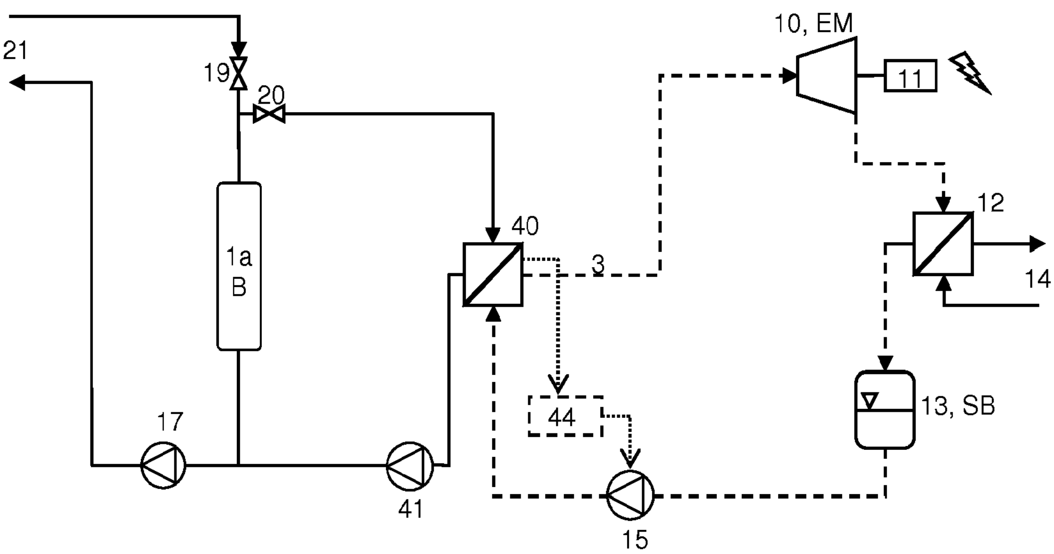

Figure 2: Batch operation in a heat engine with only one container

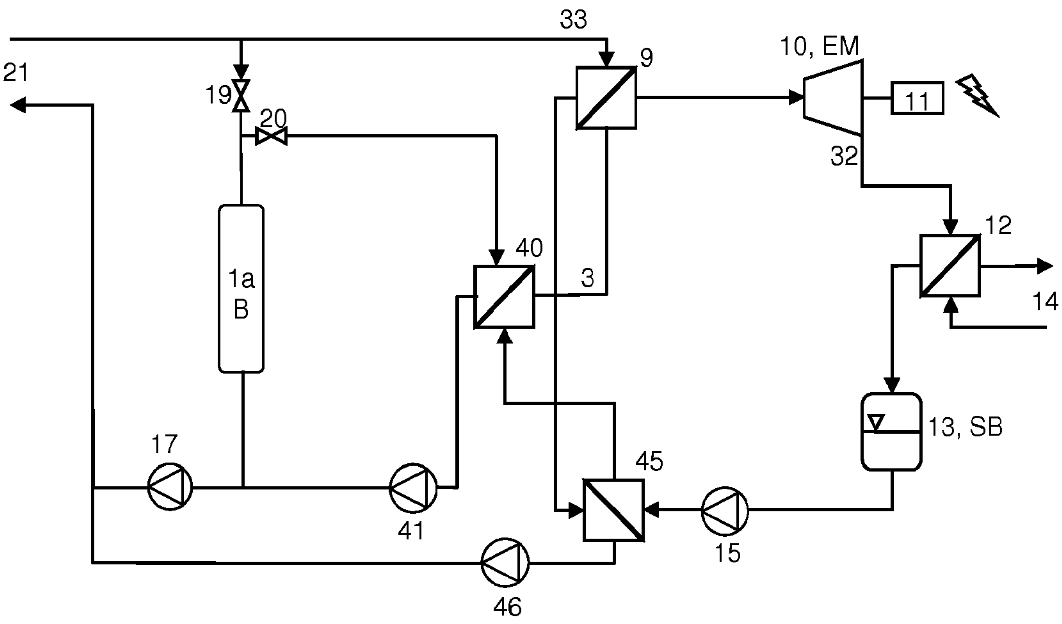

Figure 3: Batch operation of a heat engine with a preheater and superheater

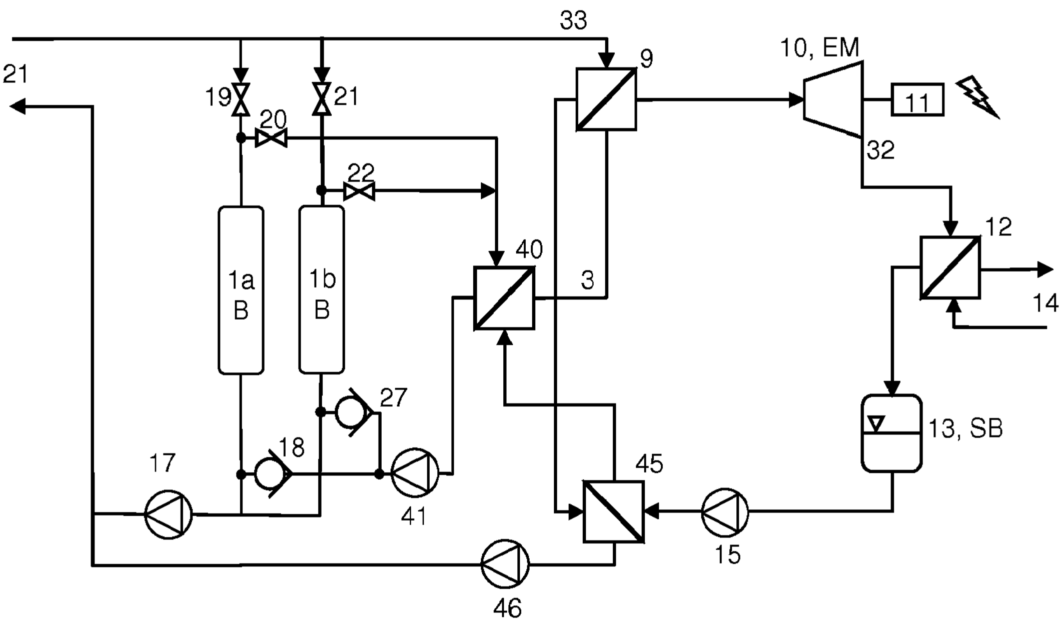

Figure 4: Batch operation of a heat engine with a pair of containers, a preheater and superheater

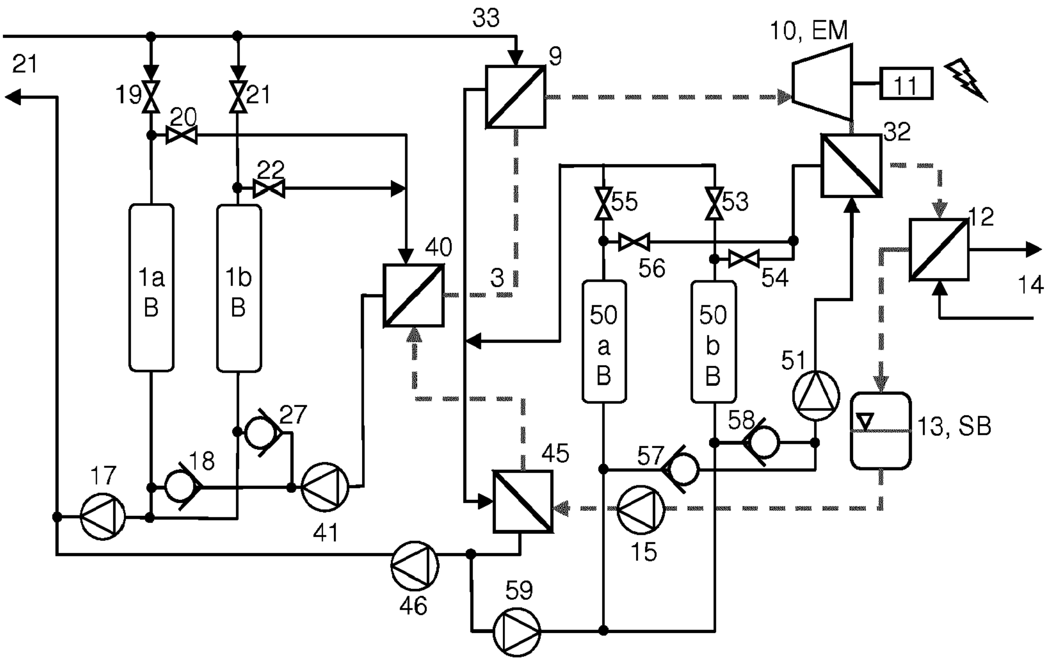

Figure 5: Batch operation of a heat engine with a pair of containers, a preheater and superheater, and a superheater pair of containers

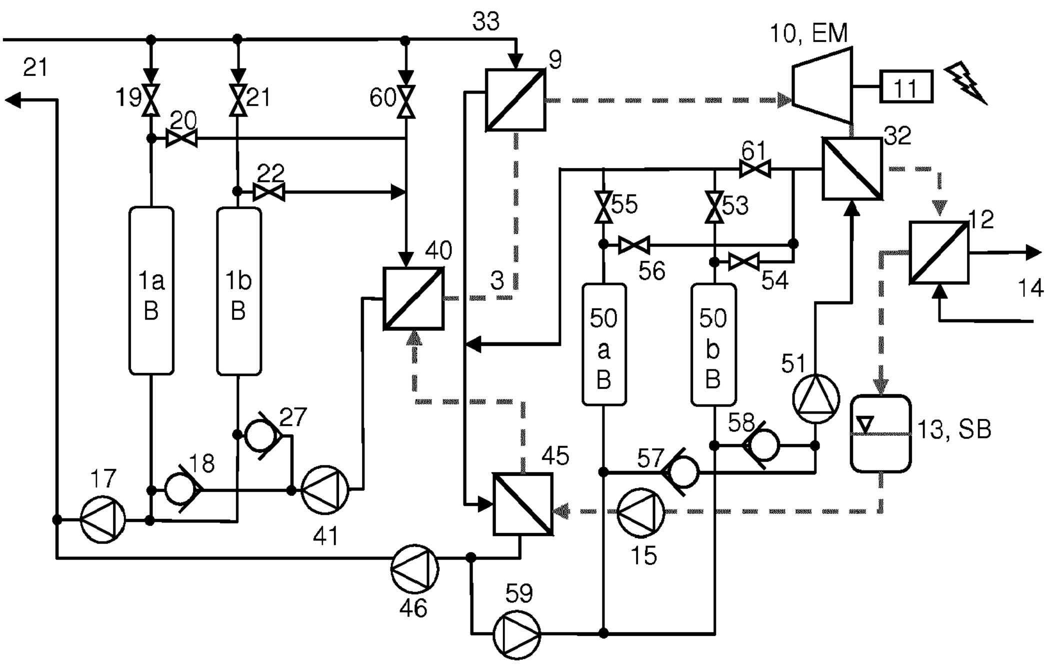

Figure 6: Batch operation of a heat engine with flush valves 60 and 61