

## **Production of process gas by heat recovery from low-temperature waste heat**

**[0001]** The invention relates to a process for the steam reforming of hydrocarbonaceous feedstocks, focussing in particular on the production of process gas by heat recovery from low-temperature waste heat. The invention aims at a greater efficiency in exploiting the energy of a hydrogen- and steam-containing process gas produced in a steam reforming process. In addition, the invention relates to an apparatus for running the process according to the invention.

**[0002]** The steam reforming process serves to convert a reaction mixture of steam and hydrocarbonaceous feedstocks into a hydrogen-enriched process gas. This process gas is obtained from the steam reforming process at a temperature above 100 °C. In most cases, this temperature ranges between 700 and 1000 °C.

**[0003]** To allow subsequent processing of the process gas, which, for example, may consist in a treatment and/or an increase of the hydrogen portion by pressure-swing adsorption or a membrane process, it is to be cooled. In most cases, the temperature required for subsequent processing ranges between 20° and 50°C. Between the individual cooling steps, further reaction steps may be provided which, for example, may include the reaction of carbon monoxide with water to give carbon dioxide and hydrogen.

**[0004]** From the patent literature various different approaches are known to exploit the amount of heat contained in the process gas for heating substances involved in and/or outside the process. Frequently the amount of heat contained is specifically used to preheat the boiler feed water for the steam reforming process by way of heat exchange.

**[0005]** In a typical conventional heat recovery process integrated into a syngas production plant, the amount of heat in the process gas is normally used by generating a high-pressure steam in a waste-heat boiler in a first step and converting the process gas in a CO conversion unit into carbon dioxide and hydrogen. Subsequently passage through various different heat exchangers is provided in order to heat, for example, the hydrocarbonaceous feedstock, the boiler feed water and/or the make-up water. In most cases, the residual heat of the process gas is dissipated to the atmosphere via a cooling section. The condensate obtained in the cooling section is fed to a water treatment unit, where the make-up water is added, and then directed to the boiler feed water preheater, from where the heated flow is conveyed to the steam generation system.

**[0006]** The disadvantage involved in this conventional heat recovery method is that the major part of the heat of the process gas which leaves the CO conversion unit is the heat from a moist condensation. This condensation is subject to a pinch effect resulting from further cooling, which makes it very difficult to recover the contained heat and a significant portion is dissipated to the atmosphere via the cooling section. Here, the pinch effect is defined by the approximation of the temperatures of two streams, by which the temperature difference between the two streams is reduced, thus also minimising the driving force for the heat exchange. In this way, a lot of energy from the process gas gets lost unexploited.

**[0007]** A proposal to avoid this problem is disclosed in US 2006/0231463 A1. Here, water is heated and fed to a water treatment unit. A first water stream from this unit is directed to a low-pressure steam generator and a second water stream to a first boiler feed water preheater. Process gas for heat exchange is passed through both units. The water stream obtained from the first boiler feed water preheater is subdivided into two partial streams and sent to two additional boiler feed water preheaters, the first of the two, hereinafter referred to as boiler feed water preheater 1, also being passed by process gas for heat exchange, and the second, hereinafter referred to as boiler feed water preheater 2, being passed by flue gas for heat exchange. The two water streams obtained from the two before-mentioned boiler feed water preheaters are then conveyed to the steam generation unit.

**[0008]** The disadvantage involved in this system is that the heat exchange in boiler feed water preheater 1 through which process gas is passed is subject to a pinch effect, thus restricting the desired heat transfer to a very limited degree. The general rule applies that the larger the amount of boiler feed water passing through this unit, the higher the useful heat yield. The subdivision of the water stream before passing through boiler feed water preheater 1, however, results in a limited amount of boiler feed water passing through the unit so that a notable portion of the heat contained in the process gas is dissipated to the atmosphere via the cooling section - usually in the form of air coolers – and thus gets lost unexploited. In addition, part of the heat of the flue gas is used to heat the boiler feed water. This heat portion of the flue gas is thus no longer available for the actual steam generation.

**[0009]** A further disadvantage involved in the interconnection of the individual units in US 2006/0231463 A1 is that the water to be heated and then sent to the water treatment unit is to be heated via the amount of heat contained in the process gas. The water treatment unit usually consists in a degasifier, which is mostly operated at approximately atmospheric pressure or slight overpressure, typically below 5 bar

(abs.), in order to remove as much oxygen and other gases from the water as possible. Conceptually, the temperature of the water supply stream of this water treatment unit is typically limited to between 80° and 95°C. Technically, the water supply stream could, however, be heated by the heat contained in the process gas to a temperature above 100°C. Therefore an additional control device must be provided to ensure that the temperature of the supply stream to the water treatment unit does not exceed the limit of 95°C. In this way, the heat of the process gas cannot be exploited completely and the contained residual heat is finally dissipated unexploited into the atmosphere.

**[0010]** The present invention has been developed against the background of the above-described state of the art, with the aim to make available a process for the production of process gas which does not involve the afore-mentioned problems related to the heat recovery from the amount of heat contained in the process gas and in which the heat recovery is designed even more efficiently. It is also the subject matter of the invention to disclose an apparatus to run the process according to the invention.

**[0011]** This is achieved by employing a heat recovery process in the steam reforming of hydrocarbonaceous feedstocks by means of steam, in which a steam reformer generates a process gas which contains a first amount of heat, and a flue gas which contains a second amount of heat, comprising at least six heat exchangers, a water treatment unit, a cooling section, a high-temperature conversion unit, at least two pressure boosting units, at least one consumer and at least one unit for subsequent processing of the resulting process gas. The generated process gas containing the first amount of heat passes the high-temperature conversion unit, where it is, for the most part, converted into carbon dioxide and hydrogen, after which the resulting heat-containing process gas is directed into a first heat exchanger for subsequent heat transfer, and afterwards into at least two more heat exchangers which are operated as boiler feed water preheaters, product condensate heat exchangers or low-pressure evaporators, and are connected in series in any sequence desired, the process gas resulting from the low-pressure evaporator being first fed into a further boiler feed water preheater, where heat energy is transferred to a partial stream of the boiler feed water from the water treatment unit, after which the process gas obtained passes the cooling section, where it is further cooled generating a condensate flow, and finally fed into at least one unit for subsequent processing of the resulting process gas.

**[0012]** Furthermore, a deionised water stream is sent to a second heat exchanger for being heated. The deionised water stream from the second heat exchanger is directed for degassing into the water treatment unit, the boiler feed water stream from

the water treatment unit passes a pressure boosting unit and is subdivided, a first part of the boiler feed water stream being sent to the low-pressure evaporator, where a low-pressure steam is generated, and the generated low-pressure steam is subdivided and a first partial low-pressure stream is directed for heat transfer to the water treatment unit and a second partial low-pressure stream is sent to at least one consumer. This second partial stream of low-pressure steam may also be used for preheating other process media such as liquid feedstock or may be transferred for a use outside battery limit. A second part of the boiler feed water stream is passed through the second heat exchanger for the purpose of energy transfer and subsequently through one or more boiler feed water preheaters for being heated by the heat amount contained in the process gas and finally conveyed to the steam generation unit.

**[0013]** In the deaerator of the water treatment unit, the deionised water is degassed from a major part of the oxygen. Subsequently other dosing fluids may be added as, for example, ammonia for adjusting the pH value. The product resulting from this treatment is referred to as boiler feed water.

**[0014]** Via a pressure boosting unit, the condensate flow from the cooling section is passed to the product condensate heat exchanger for being heated by the heat amount contained in the process gas, after which the condensate flow is heated again.

**[0015]** The process gas from the first heat exchanger first runs preferably through a first boiler feed water preheater, in which heat energy is transferred to a boiler feed water stream, subsequently a product condensate heat exchanger, where heat energy is transferred to a condensate flow, and from there the resulting process gas is directed to the low-pressure evaporator, in which low-pressure steam is generated from a boiler feed water stream by means of the heat amount contained, from where it is sent to the subsequent steps of the defined process chain.

**[0016]** In another embodiment of the invention the process gas from the first heat exchanger first runs through a first boiler feed water preheater, in which heat energy is transferred to a boiler feed water stream, subsequently it is sent to a low-pressure evaporator, in which low-pressure steam is generated from a boiler feed water stream by means of the heat amount contained, and from there the resulting process gas is directed into the product condensate heat exchanger, where heat energy is transferred to a condensate flow, from where it is sent to the subsequent steps of the defined process chain.

**[0017]** Advantageously the process gas from the first heat exchanger first runs through a product condensate heat exchanger, in which the heat energy is transferred to a condensate flow, from there it runs through the first boiler feed water preheater, in which heat energy is transferred to a boiler feed water stream, and then it is passed to a low-pressure evaporator, where low-pressure steam is generated from a boiler feed water stream by means of the amount of heat contained, and subsequently the resulting process gas is passed to the subsequent steps of the defined process chain as described above. In a further embodiment of the invention the process gas from the product condensate heat exchanger runs first through the first boiler feed water preheater, where heat energy is transferred to a boiler feed water stream, and then through another product condensate heat exchanger, before it is directed into the low-pressure evaporator, from where it is passed through the subsequent steps of the defined process chain.

**[0018]** Another possible embodiment of the invention is that the process gas from the first heat exchanger runs first through a product condensate heat exchanger, where heat energy is transferred to a condensate flow and to a partial stream of the boiler feed water stream, from where it is passed to the low-pressure evaporator, where low-pressure steam is generated from a boiler feed water stream by means of the heat energy contained, and the resulting process gas is then passed to the subsequent steps of the defined process chain.

**[0019]** Optionally, the process gas leaving the first heat exchanger is sent for subsequent heat transfer to a further boiler feed water preheater, which is fed with another partial stream resulting from a further subdivision of the second part of the boiler feed water stream which has passed the water treatment unit, the pressure boosting unit and the second boiler feed water preheater, and is thus further heated.

**[0020]** The process gas leaving the first heat exchanger and/or the further boiler feed water preheater is preferably fed into a low-temperature conversion unit, in which carbon dioxide and hydrogen are formed, from where it is passed to one of the downstream heat exchangers of the defined process chain.

**[0021]** In a further embodiment of the invention the process gas which has run through a heat exchanger is subsequently passed to a separator, and a resulting liquid stream is separated from the heat-containing process gas and united with the condensate flow from the cooling section and from other separators, and this mixture is passed via the pressure boosting unit and afterwards through a product condensate heat exchanger for being heated by the heat contained in the process gas.

**[0022]** Optionally it is further advisable to pass the process gas for subsequent heat transfer through additional heat exchangers which are integrated into the process upstream and downstream of the low-pressure evaporator.

**[0023]** The related apparatus for steam reforming of hydrocarbonaceous feedstocks by means of steam is suited to run a process according to claim 1, consisting of a sequence of equipment items for the passage of process gas, comprising a high-temperature conversion unit, at least four heat exchangers, a cooling section and at least one unit for subsequent processing of the resulting process gas, wherein conveying lines are provided to interconnect the individual devices via their gas outlets and gas inlets to convey the process gas.

**[0024]** The apparatus for steam reforming further comprises another heat exchanger, a water treatment unit, at least two pressure boosting units, at least one consumer, a device for the inlet of a deionised water stream into the subsequent heat exchanger, a device for transferring the deionised water stream from the before-mentioned heat exchanger into the water treatment unit, a device for transferring the boiler feed water stream leaving the water treatment unit into the pressure boosting unit, a device for subdividing the boiler feed water stream leaving the pressure boosting unit, a first feed line being provided to transport a first part of the boiler feed water stream to the low-pressure evaporator and a discharge line for removing the generated low-pressure steam from the low-pressure evaporator, comprising a device for transferring a first partial stream of the generated low-pressure steam to the water treatment unit and a further device for transferring a second partial stream of the generated low-pressure steam into the subsequent consumers, and providing a second feed line for the transport of the second part of the boiler feed water stream to a subsequent heat exchanger, and from there discharging a feed to the second boiler feed water preheater and from there providing a discharge line to the first boiler feed water preheater or to a product condensate heat exchanger and/or directly to the subsequent steam generation, and providing a device for transferring the condensate flow from the cooling section via a pressure boosting unit into one or more product condensate heat exchangers.

**[0025]** It is of advantage to arrange the sequence of equipment items for the passage of process gas in a series connection of a high-temperature conversion unit, a first heat exchanger, a first boiler feed water preheater, a product condensate heat exchanger, a low-pressure evaporator, a second boiler feed water preheater, a cooling section and at least one unit for processing the resulting process gas, in the given sequence.

**[0026]** In a further advantageous embodiment of the apparatus, the sequence of equipment items for the passage of process gas consists in a series connection of a high-temperature conversion unit, a first heat exchanger, a first boiler feed water preheater, a low-pressure evaporator, a product condensate preheater, a second boiler feed water preheater, a cooling section and at least one unit for processing the resulting process gas, in the given sequence.

**[0027]** Optionally the sequence of equipment items for the passage of process gas consists in a series connection of a high-temperature conversion unit, a first heat exchanger, a product condensate heat exchanger, a first boiler feed water preheater, a low-pressure evaporator, a second boiler feed water preheater, a cooling section and at least one unit for processing the resulting process gas, in the given sequence.

**[0028]** Preferably the sequence of equipment items for the passage of process gas consists in a series connection of a high-temperature conversion unit, a first heat exchanger, a product condensate heat exchanger, a low-pressure evaporator, a second boiler feed water preheater, a cooling section and at least one unit for processing the resulting process gas, in the given sequence, wherein a device for transferring a first partial stream of boiler feed water stream from the second boiler feed water preheater into a product condensate heat exchanger is provided as well as a further device for transferring the second partial stream of boiler feed water stream from the second boiler feed water preheater directly to the steam generation.

**[0029]** Another possible embodiment of the invention provides for an additional third boiler feed water preheater in the sequence of equipment items for the passage of process gas, the gas inlet of which is connected to the gas outlet of the first heat exchanger and the gas outlet of which is connected to the gas inlet of an optional low-temperature conversion unit or a subsequent heat exchanger, and where a device for transferring another partial stream of boiler feed water from the water treatment unit and the second boiler feed water preheater ends.

**[0030]** In a further embodiment of the apparatus, a low-temperature conversion unit is integrated into the sequence of equipment items for the passage of process gas, the gas inlet of which is connected to the gas outlet of the first heat exchanger or the additional third boiler feed water preheater and the gas outlet of which is connected to a subsequent heat exchanger.

**[0031]** It is of advantage that additional separators are integrated into the sequence of equipment items for the passage of process gas, the gas inlets of which

are connected to the gas outlets of the respective upstream heat exchanger and the gas outlets of which are connected to the respective heat exchanger downstream in the process chain, and which are each provided with a discharge line for the produced liquid, which ends into the device for transferring the condensate flow from the cooling section into a product condensate heat exchanger and is passed via a pressure boosting unit.

**[0032]** In a further embodiment of the invention a second boiler feed water preheater is integrated into a separator which is optionally equipped with additional internals and/or packings and which is provided with a discharge line for conveying the obtained process condensate into the device for transferring the condensate flow from the cooling section into a product condensate heat exchanger.

**[0033]** A further embodiment of the apparatus according to the invention is to integrate further additional heat exchangers into the sequence of equipment items for the passage of process gas.

**[0034]** It is of advantage to use an air preheating unit as a consumer which is designed for the passage of low-pressure steam in order to preheat ambient air.

**[0035]** In addition, it is recommended to provide a pressure-swing adsorption unit or a cooling box as a unit for subsequent processing of the resulting process gas.

**[0036]** Optionally, another device for subdividing the second stream of low-pressure steam may be provided in addition so to establish a feed line for air-preheating and a feed line to further consumers.

**[0037]** The invention is illustrated below in more detail in an exemplary fashion by means of seven figures, i.e.:

Fig. 1: shows a process diagram of the process according to the invention for the recovery of heat from the steam reforming of hydrocarbonaceous feedstocks by means of steam.

Fig. 2: shows an alternative integration of the heat exchangers represented in Fig. 1 into the process for the recovery of heat from the steam reforming of hydrocarbonaceous feedstocks by means of steam.

Fig. 3: shows another advantageous process variant for the recovery of heat in the steam reforming of hydrocarbonaceous feedstocks by means of

steam, in which process gas passes through the product condensate heat exchanger upstream of the first boiler feed water preheater.

Fig. 4: shows another exemplary variant of an interconnection of the heat exchangers used. Here, the major difference as compared to Figs. 1 to 3 is that there is no first boiler feed water preheater.

Fig. 5: supplements the representation of Fig. 1, in which various optional elements are integrated into the process such as a third boiler feed water preheater, a low-temperature conversion unit, an additional optional separator and a heat exchanger.

Fig. 6: shows the additional integration of a further product condensate heat exchanger into the process chain according to Fig. 1.

Figs. 7A to D: show the graphic representation of the temperature decrease of the process gas (dashed line) and the heating behaviour of the individual media (solid line) by the energy transfer involved in the process according to the invention.

**[0038]** Fig. 1 shows a process diagram for the recovery of heat from the steam reforming of hydrocarbonaceous feedstocks by means of steam, in which the produced heat-containing process gas 1a first passes through a high-temperature conversion unit 2 where part of the carbon monoxide is converted to give carbon dioxide and hydrogen. The resulting heat-containing process gas 1b is then directed to a first heat exchanger 3 for subsequent heat transfer. Subsequently, heat-containing process gas 1c passes through a first boiler feed water preheater 4, where the heat contained in the process gas is transferred to preheated boiler feed water 14e which is discharged from water treatment unit 13 and has passed through pressure boosting unit 25, heat exchanger 16 and boiler feed water preheater 8. Deionised water 12a is heated in heat exchanger 16 and the heated deionised water 12b is sent to water treatment unit 13 for degassing. If the deionised water is preheated, this involves the advantage that one side of the heat exchanger need to be designed for low pressures only and part of the heat exchanger may therefore be fabricated of low-alloy steel, which will save cost. This results in boiler feed water 14a which is then preheated as described above. The resulting boiler feed water stream 14f is then conveyed to the steam generation for subsequent processing.

**[0039]** The heat-containing process gas 1d discharged from boiler feed water preheater 4 is subsequently passed to product condensate heat exchanger 5 where it transfers heat to process condensate 15a which has passed pressure boosting unit 27 and been obtained from cooling section 10. Preheated process condensate 15b is then used for subsequent heating.

**[0040]** Process condensate 15a is collected by separators of cooling section 10, which, in this example, comprises an air cooler and a water cooler, and is reheated in a product condensate heat exchanger 5. This process could be carried out in a reaction vessel supplied with water, in which at least part of the steam to be separated from the process gas condenses by direct cooling and is discharged with the water used for cooling. If such a vessel is used, it will be possible to preheat the process condensate even further, which would be an advantage, as the higher the preheating degree of the process condensate the higher the amount of heat in the flue gas used for other media and the steam generation.

**[0041]** Heat-containing process gas 1e resulting from product condensate heat exchanger 5 is subsequently passed to low-pressure evaporator 6 where the heat is transferred to part of the boiler feed water stream 14c generated in water treatment unit 13 and has been pressurised. Low-pressure steam 19a thus obtained is recycled in a first partial stream 19b to water treatment unit 13, whereas a second partial stream of heated boiler feed water 19c is fed into a consumer, in this example an air preheater 18 which serves to heat ambient air 17 which is subsequently used as combustion air 20.

**[0042]** Heat-containing process gas 1f resulting from low-pressure evaporator 6 is subsequently fed into boiler feed water preheater 8 where partial stream 14d of the boiler feed water generated in water treatment unit 13 is further preheated before it is transferred to boiler feed water preheater 4. Process gas 1g resulting from boiler feed water preheater 8 then passes cooling section 10 where the process gas is further cooled and a condensate flow produced, and condensate flow 15a is passed into product condensate heat exchanger 5. Finally the condensed heat-containing process gas 1h passes through the unit for subsequent processing of the resulting process gas 11, which may, for example, be a pressure-swing adsorption unit, where the generated hydrogen is separated from the process gas.

**[0043]** Fig. 2 represents a process variant of Fig. 1. The difference between Fig. 2 and Fig. 1 is that heat-containing process gas 1d which leaves boiler feed water preheater 4 passes first through low-pressure evaporator 6 and subsequently product condensate heat exchanger 5. The interconnection of the individual equipment items

remains unaffected. The energy recovery of the variant shown in Fig. 1, however, should be expected to be higher.

**[0044]** A further embodiment is shown in Fig. 3. The difference to Fig. 1 is that heat-containing process gas 1c resulting from heat exchanger 3 passes through product condensate heat exchanger 5 first and then through boiler feed water preheater 4. The interconnection of the individual equipment items remains unaffected and is analogous to the sequence of equipment shown in Fig. 1.

**[0045]** In Fig. 4 boiler feed water preheater 4 is completely omitted. Here, heat-containing process gas 1c obtained from heat exchanger 3 is directed to product condensate heat exchanger 5, from where the resulting heat-containing process gas 1d passes through low-pressure evaporator 6 and subsequently boiler feed water preheater 8. Preheated boiler feed water stream 14e generated in boiler feed water preheater 8 is subdivided in this example and a partial stream 14f is passed via product condensate heat exchanger 5 together with product condensate 15a, where it is submitted to further preheating. The second partial stream 14g of the preheated boiler feed water is conveyed to the steam generation.

**[0046]** The interconnection shown in Fig. 5 includes further optional equipment items of positive effect on the process. Basis for the description and the specification of differences is Fig. 1. Heat-containing process gas 1c from heat exchanger 3 is passed to an additional boiler feed water preheater 21 which is fed from a further partial stream 14g of the boiler feed water stream, which has been preheated in boiler feed water preheater 8. The resulting heated boiler feed water 14h is also conveyed to the steam generation and hence further used. According to the embodiment shown in this figure, the process water resulting from boiler feed water preheater 21 is subsequently passed to a low-temperature conversion unit 22 where carbon dioxide and hydrogen are formed. The resulting heat-containing process gas 1e subsequently passes boiler feed water preheater 4 and product condensate preheater 5 as shown in Fig. 1. Process gas 1g resulting from product condensate preheater 5 is subsequently passed into separator 23, where the obtained process condensate 15c is separated from the process gas and - with the other process condensate flows - directed as process condensate 15d via a pressure boosting unit 27 to product condensate heat exchanger 5. Furthermore, the resulting heat-containing process gas 1h passes through low-pressure evaporator 6 and separator 7. Condensate flow 15e from separator 7 is also sent to product condensate heat exchanger 5 together with the other condensate flows 15d resulting from the overall process. Low-pressure steam 19a resulting from low-pressure evaporator 6 is subdivided into three partial streams. Partial stream 19b of the

low-pressure steam is directed to water treatment unit 13, 19c to air preheater 18 and 19d to subsequent consumers 26. Downstream of separator 7 a further heat exchanger 24 is connected and serves for additional energy transfer. The process continues according to the process chain as shown in Fig. 1, consisting of boiler feed water preheater 8, cooling section 10 and pressure-swing adsorption unit 11. In this embodiment, however, an additional heat exchanger 9 is provided between boiler feed water preheater 8 and cooling section 10.

**[0047]** Fig. 6 shows another variant of Fig. 1. Process condensate flow 15a from cooling section 10 is sent via a pressure boosting unit 27 and a further additional product condensate heat exchanger 28 before it is passed through product condensate heat exchanger 5. This involves the advantage that the product condensate absorbs even more heat, which can be used for heating other media in the subsequent course of the process.

**[0048]** The equipment items additionally integrated in Fig. 5 may be used in a combination as shown in Fig. 5 but may also be integrated as individual components into the respective process chains. In addition, not only Fig. 1 may serve as a basis for such equipment integration but all figures can be used as a basis for the integration. This shows that the process involves many options to adapt the respective process to the individual requirements of a plant operator and also to integrate the appurtenant plant sections into existing plants. Furthermore, it is possible to implement these process variants in new plants.

**[0049]** In the case of favourable dimensions, the low-pressure evaporator could be provided with a safety reserve and, in the event of a shutdown, cool the process gas by generating and blowing off low-pressure steam. In addition to air-preheating and water treatment as described above, the generated low-pressure steam may just as well be used to boil out CO<sub>2</sub> in a CO<sub>2</sub> process-gas scrubbing process. The maximum temperature of the generated low-pressure steam in such case is 200 °C.

**[0050]** Some calculation examples below are used to illustrate the improvement of energy recovery represented as a total from low-pressure steam, boiler feed water and condensate flows. They are based on a typical interconnection according to the state of the art, using a minimum number of equipment items employed in conventional processes according to the state of the art. Based on Fig. 1, low-pressure evaporator 6 is omitted as well as boiler feed water preheater 8 so that boiler feed water stream 14d is directly sent into boiler feed water preheater 4. The below tables serve to show how drastically the present invention positively influences the energy recovery in

comparison to this typical interconnection. Some of the before-described figures have been used as a basis for the calculation. It is assumed that there is a separator downstream of the first four series-connected heat exchangers of the sequence of equipment items for the passage of process gas. The exemplary calculations are based on a plant capacity of 33,455 Nm<sup>3</sup>/h of hydrogen.

| <b>Interconnection variant</b>                                            | <b>Energy recovery:</b>                                                   |
|---------------------------------------------------------------------------|---------------------------------------------------------------------------|
|                                                                           | <b>Total from:<br/>steam + boiler feed water +<br/>product condensate</b> |
|                                                                           | <b>[kW]</b>                                                               |
| <b>Typical interconnection</b>                                            | 10,480                                                                    |
| <b>Fig. 2</b>                                                             | 12,670                                                                    |
| <b>Fig. 3</b>                                                             | 13,760                                                                    |
| <b>Fig. 6</b>                                                             | 13,760                                                                    |
| <b>As Fig. 3; + integral boiler feed<br/>water preheater in separator</b> | 13,760                                                                    |

From this results that the interconnection variant of the invention reflected by Fig. 3 and Fig. 6 involves a very high level of energy recovery as compared to the typical interconnection according to the state of the art. Consequently, an increase in the total of heat recovery of approx. 3270 kW can be expected, which would be unused and lost in the typical interconnection variant according to the state of the art.

The basic conditions for the calculations are shown in Figs. 7A to D as a graphic function of temperature and energy recovery. The dashed line represents the temperature decrease of the process gas depending on the energy contained, whereas the solid line represents the heating behaviour of the individual media used in the process. The individual process steps represented in the graphs are reflected by the inserted reference numbers which are also used in the other figures 1 to 6.

**[0051]** Advantages resulting from the invention:

- Improved energy recovery from the amount of heat contained in the process gas.
- Additional preheating of the process condensate in a product condensate heat exchanger effects that more energy from the flue gas is available for heating other media and can be used for steam generation.
- According to the state of the art the process condensate in the flue gas duct is preheated until boiling. By preheating the process condensate by process gas as provided by the invention, it is possible to do without conventional heating in the flue gas duct, which will contribute to a simplification of the process concept.
- The process according to the invention involves the advantage that it can be integrated into already existing plants which are without access to low-pressure steam and must generate it from valuable high-pressure steam.
- The temperature and pressure conditions in heat exchanger 16 exclude the risk of steam hammers which contribute to the improvement of the operational safety.

### List of references used

|                                                           |                                   |
|-----------------------------------------------------------|-----------------------------------|
| 1a, 1b, 1c, 1d, 1e, 1f, 1g,<br>1h, 1i, 1j, 1k, 1l, 1m, 1n | Heat-containing process gas       |
| 2                                                         | High-temperature conversion unit  |
| 3                                                         | Heat exchanger                    |
| 4                                                         | Boiler feed water preheater       |
| 5                                                         | Product condensate heat exchanger |
| 6                                                         | Low-pressure evaporator           |
| 7                                                         | Separator                         |
| 8                                                         | Boiler feed water preheater       |
| 9                                                         | Heat exchanger                    |
| 10                                                        | Cooling section                   |
| 11                                                        | Pressure-swing adsorption unit    |
| 12a, 12b                                                  | Deionised water                   |
| 13                                                        | Water treatment unit              |
| 14a, 14b, 14c, 14d, 14e,<br>14f, 14g, 14h, 14i            | Boiler feed water stream          |
| 15a, 15b, 15c, 15d, 15e                                   | Process condensate                |
| 16                                                        | Heat exchanger                    |
| 17                                                        | Ambient air                       |
| 18                                                        | Air preheater                     |
| 19a, 19b, 19c, 19d                                        | Low-pressure steam                |
| 20                                                        | Combustion air                    |
| 21                                                        | Boiler feed water preheater       |
| 22                                                        | Low-temperature conversion unit   |
| 23                                                        | Separator                         |
| 24                                                        | Heat exchanger                    |
| 25                                                        | Pressure boosting unit            |
| 26                                                        | Subsequent consumers              |
| 27                                                        | Pressure boosting unit            |
| 28                                                        | Product condensate heat exchanger |

## Patent claims

1. Heat recovery process in the steam reforming of hydrocarbonaceous feedstocks by means of steam, in which a steam reformer generates a process gas which contains a first amount of heat and a flue gas which contains a second amount of heat, comprising
  - at least six heat exchangers, a water treatment unit, a cooling section, a high-temperature conversion unit, at least two pressure boosting units, at least one consumer and at least one unit for subsequent processing of the resulting process gas, in which
  - the generated process gas containing the first amount of heat passes the high-temperature conversion unit, where it is, for the most part, converted into carbon dioxide and hydrogen, after which the resulting heat-containing process gas is directed into a first heat exchanger for subsequent heat transfer, and afterwards at least two more heat exchangers which are operated as boiler feed water preheaters, product condensate heat exchangers or low-pressure evaporators, and are connected in series in any sequence desired, the process gas resulting from the low-pressure evaporator being first fed into a further boiler feed water preheater, where heat energy is transferred to a partial stream of the boiler feed water from the water treatment unit, after which the process gas obtained passes the cooling section, where it is further cooled generating a condensate flow, and finally fed into at least one unit for subsequent processing of the resulting process gas,
  - a deionised water stream is sent to a second heat exchanger for being heated, the deionised water stream from the second heat exchanger is directed for degassing into the water treatment unit, the boiler feed water stream from the water treatment unit passes a pressure boosting unit and is subdivided,
    - a first part of the boiler feed water stream being sent to the low-pressure evaporator, where a low-pressure steam is generated, and the generated low-pressure steam is subdivided and a first partial low-pressure stream is directed for heat transfer to the water treatment unit and a second partial low-pressure stream is sent to at least one consumer, and
    - a second part of the boiler feed water stream being passed through the second heat exchanger for the purpose of energy transfer and subsequently through one or more boiler feed water preheaters for being

heated by the heat amount contained in the process gas and finally conveyed to the steam generation,

- the condensate flow from the cooling section is passed via a pressure boosting unit to the product condensate heat exchanger for being heated by the heat amount contained in the process gas, after which the condensate flow is heated again.
2. Process according to claim 1, **characterised in that** the process gas from the first heat exchanger first runs preferably through a first boiler feed water preheater, in which heat energy is transferred to a boiler feed water stream, subsequently a product condensate heat exchanger, where heat energy is transferred to a condensate flow, and from there the resulting process gas is directed to the low-pressure evaporator, in which low-pressure steam is generated from a boiler feed water stream by means of the heat amount contained, from where it is passed through the subsequent steps of the defined process chain.
  3. Process according to claim 1, **characterised in that** the process gas from the first heat exchanger first runs through a first boiler feed water preheater, in which heat energy is transferred to a boiler feed water stream, subsequently it is sent to a low-pressure evaporator, in which low-pressure steam is generated from a boiler feed water stream by means of the heat amount contained, and from there the resulting process gas is directed into the product condensate heat exchanger, where heat energy is transferred to a condensate flow, from where it is passed through the subsequent steps of the defined process chain.
  4. Process according to claim 1, **characterised in that** the process gas from the first heat exchanger first runs through a product condensate heat exchanger, in which the heat energy is transferred to a condensate flow, from there it runs through the first boiler feed water preheater, in which heat energy is transferred to a boiler feed water stream, and then it is passed to a low-pressure evaporator, where low-pressure steam is generated from a boiler feed water stream by means of the amount of heat contained, and subsequently the resulting process gas is passed through the subsequent steps of the defined process chain.
  5. Process according to claim 4, **characterised in that** the process gas from the product condensate heat exchanger runs first through the first boiler feed water

preheater, where heat energy is transferred to a boiler feed water stream, and then through another product condensate heat exchanger, before it is directed into the low-pressure evaporator, from where it is passed through the subsequent steps of the defined process chain.

6. Process according to claim 1, **characterised in that** the process gas from the first heat exchanger runs first through a product condensate heat exchanger, where heat energy is transferred to a condensate flow and to a partial stream of the boiler feed water stream, from where it is passed to the low-pressure evaporator, where low-pressure steam is generated from a boiler feed water stream by means of the heat energy contained, and the resulting process gas is then passed through the subsequent steps of the defined process chain.
7. Process according to one of claims 1 to 6, **characterised in that** the process gas leaving the first heat exchanger is sent for subsequent heat transfer to a further boiler feed water preheater, which is fed with another partial stream resulting from a further subdivision of the second part of the boiler feed water stream which has passed the water treatment unit, the pressure boosting unit and the second boiler feed water preheater, and is thus further heated.
8. Process according to one of claims 1 to 7, **characterised in that** the process gas leaving the first heat exchanger and/or the further boiler feed water preheater is fed into a low-temperature conversion unit, in which carbon dioxide and hydrogen are formed, from where it is passed to one of the downstream heat exchangers of the defined process chain.
9. Process according to one of claims 1 to 8, **characterised in that** the process gas which has run through a heat exchanger is subsequently passed to a separator, and a resulting liquid stream is separated from the heat-containing process gas and united with the condensate flow from the cooling section and from other separators, and this mixture is passed via the pressure boosting unit and afterwards through a product condensate heat exchanger for being heated by the heat contained in the process gas.
10. Process according to one of claims 1 to 9, **characterised in that** the process gas for subsequent heat transfer is passed through additional heat exchangers which

are integrated into the process upstream and downstream of the low-pressure evaporator.

11. Apparatus for steam reforming of hydrocarbonaceous feedstocks by means of steam, suited to run a process according to claim 1, consisting of a sequence of equipment items for the passage of process gas, comprising
  - a high-temperature conversion unit,
  - at least four heat exchangers,
  - a cooling section, and
  - at least one unit for subsequent processing of the resulting process gas,
 conveying lines being provided to interconnect the individual devices via their gas outlets and gas inlets,
 and further comprising
  - another heat exchanger,
  - a water treatment unit,
  - at least two pressure boosting units,
  - at least one more consumer,
  - a device for the inlet of a deionised water stream into the subsequent heat exchanger,
  - a device for transferring the deionised water stream from the heat exchanger into the water treatment unit,
  - a device for transferring the boiler feed water stream leaving the water treatment unit into the pressure boosting unit,
  - a device for subdividing the boiler feed water stream leaving the pressure boosting unit,
    - a first feed line being provided to transport a first part of the boiler feed water stream to the low-pressure evaporator and a discharge line for removing the generated low-pressure steam from the low-pressure evaporator, comprising a device for transferring a first partial stream of the generated low-pressure steam to the water treatment unit and a further device for transferring a second partial stream of the generated low-pressure steam into the subsequent consumers, and
    - a second feed line being provided for the transport of the second part of the boiler feed water stream to a subsequent heat exchanger, and from there discharging a feed to the second boiler feed water preheater and from there providing a discharge line to the first boiler feed water preheater or to one

or more product condensate heat exchanger/s and/or directly to the subsequent steam generation, and

- a device for transferring the condensate flow from the cooling section via a pressure boosting unit into one or more product condensate heat exchangers.
12. Apparatus according to claim 11, **characterised in that** the sequence of equipment items for the passage of process gas consists in a series connection of a high-temperature conversion unit, a first heat exchanger, a first boiler feed water preheater, a product condensate heat exchanger, a low-pressure evaporator, a second boiler feed water preheater, a cooling section and at least one unit for processing the resulting process gas, in the given sequence.
  13. Apparatus according to claim 11, **characterised in that** the sequence of equipment items for the passage of process gas consists in a series connection of a high-temperature conversion unit, a first heat exchanger, a first boiler feed water preheater, a low-pressure evaporator, a product condensate preheater, a second boiler feed water preheater, a cooling section and at least one unit for processing the resulting process gas, in the given sequence.
  14. Apparatus according to claim 11, **characterised in that** the sequence of equipment items for the passage of process gas consists in a series connection of a high-temperature conversion unit, a first heat exchanger, a product condensate heat exchanger, a first boiler feed water preheater, a low-pressure evaporator, a second boiler feed water preheater, a cooling section and at least one unit for processing the resulting process gas, in the given sequence.
  15. Apparatus according to claim 11, **characterised in that** the sequence of equipment items for the passage of process gas consists in a series connection of a high-temperature conversion unit, a first heat exchanger, a product condensate heat exchanger, a low-pressure evaporator, a second boiler feed water preheater, a second heat exchanger, a cooling section and at least one unit for processing the resulting process gas, in the given sequence, wherein a device for transferring a first partial stream of boiler feed water stream from the second boiler feed water preheater into a product condensate heat exchanger is provided as well as a further device for transferring the second partial stream of boiler feed water stream from the second boiler feed water preheater directly to the subsequent steam generation.

16. Apparatus according to one of claims 11 to 15, **characterised in that** an additional third boiler feed water preheater in the sequence of equipment items for the passage of process gas is provided, the gas inlet of which is connected to the gas outlet of the first heat exchanger and the gas outlet of which is connected to the gas inlet of an optional low-temperature conversion unit or a subsequent heat exchanger, and where a device for transferring another partial stream of boiler feed water from the water treatment unit and the second boiler feed water preheater ends.
17. Apparatus according to one of claims 11 to 16, **characterised in that** a low-temperature conversion unit is integrated into the sequence of equipment items for the passage of process gas, the gas inlet of which is connected to the gas outlet of the first heat exchanger or the additional third boiler feed water preheater and the gas outlet of which is connected to a subsequent heat exchanger.
18. Apparatus according to one of claims 11 to 17, **characterised in that** additional separators are integrated into the sequence of equipment items for the passage of process gas, the gas inlets of which are connected to the gas outlets of the respective upstream heat exchanger and the gas outlets of which are connected to the respective heat exchanger downstream in the process chain, and which are each provided with a discharge line for the produced liquid, which ends into the device for transferring the condensate flow from the cooling section into a product condensate heat exchanger and is passed via a pressure boosting unit.
19. Apparatus according to one of claims 11 to 18, **characterised in that** the second boiler feed water preheater is integrated into a separator which is optionally equipped with additional internals and/or packings and which is provided with a discharge line for conveying the obtained process condensate into the device for transferring the condensate flow from the cooling section into a product condensate heat exchanger.
20. Apparatus according to one of claims 11 to 19, **characterised in that** further additional heat exchangers are integrated into the sequence of equipment items for the passage of process gas.

21. Apparatus according to one of claims 11 to 20, **characterised in that** an air preheating unit is used as a consumer designed for the passage of low-pressure steam in order to preheat ambient air.
22. Apparatus according to one of claims 11 to 21, **characterised in that** a pressure-swing adsorption unit or a cooling box is provided as a unit for subsequent processing of the resulting process gas.

## Abstract

### Production of process gas by heat recovery from low-temperature waste heat

The invention relates to a heat recovery process in the steam reforming of hydrocarbonaceous feedstocks by means of steam, in which a steam reformer  
5 generates a process gas which contains a first amount of heat and a flue gas which contains a second amount of heat, comprising at least six heat exchangers, a water treatment unit, a cooling section, a high-temperature conversion unit, at least two pressure boosting units, at least one consumer and at least one unit for subsequent processing of the resulting process gas. The generated process gas containing the first  
10 amount of heat first passes the high-temperature conversion unit, where it is, for the most part, converted into carbon dioxide and hydrogen, after which the resulting heat-containing process gas is directed into a first heat exchanger for subsequent heat transfer, and afterwards into at least two more heat exchangers which are operated as boiler feed water preheaters, product condensate heat exchangers or low-pressure  
15 evaporators, and are connected in series in any sequence desired, the process gas resulting from the low-pressure evaporator being first fed into a further boiler feed water preheater, where heat energy is transferred to a partial stream of the boiler feed water from the water treatment unit, after which the process gas obtained passes the cooling section, where it is further cooled generating a condensate flow, and finally fed into at  
20 least one unit for subsequent processing of the resulting process gas. Furthermore, a deionised water stream is sent to a second heat exchanger for being heated. The deionised water stream from the second heat exchanger is directed for degassing into the water treatment unit, the boiler feed water stream from the water treatment unit passes a pressure boosting unit and is subdivided, a first part of the boiler feed water stream being sent to the low-pressure evaporator, where a low-pressure steam is  
25 generated, and the generated low-pressure steam is subdivided and a first partial low-pressure stream is directed for heat transfer to the water treatment unit and a second partial low-pressure stream is sent to at least one consumer. A second part of the boiler feed water stream is passed through the second heat exchanger for the purpose of energy transfer and subsequently through one or more boiler feed water preheaters for being heated by the heat amount contained in the process gas and finally conveyed to the steam generation. Via a pressure boosting unit, the condensate flow from the cooling section is passed to the product condensate heat exchanger for being heated by the heat amount contained in the process gas, after which the condensate flow is  
30 heated again.  
35

Fig. 1

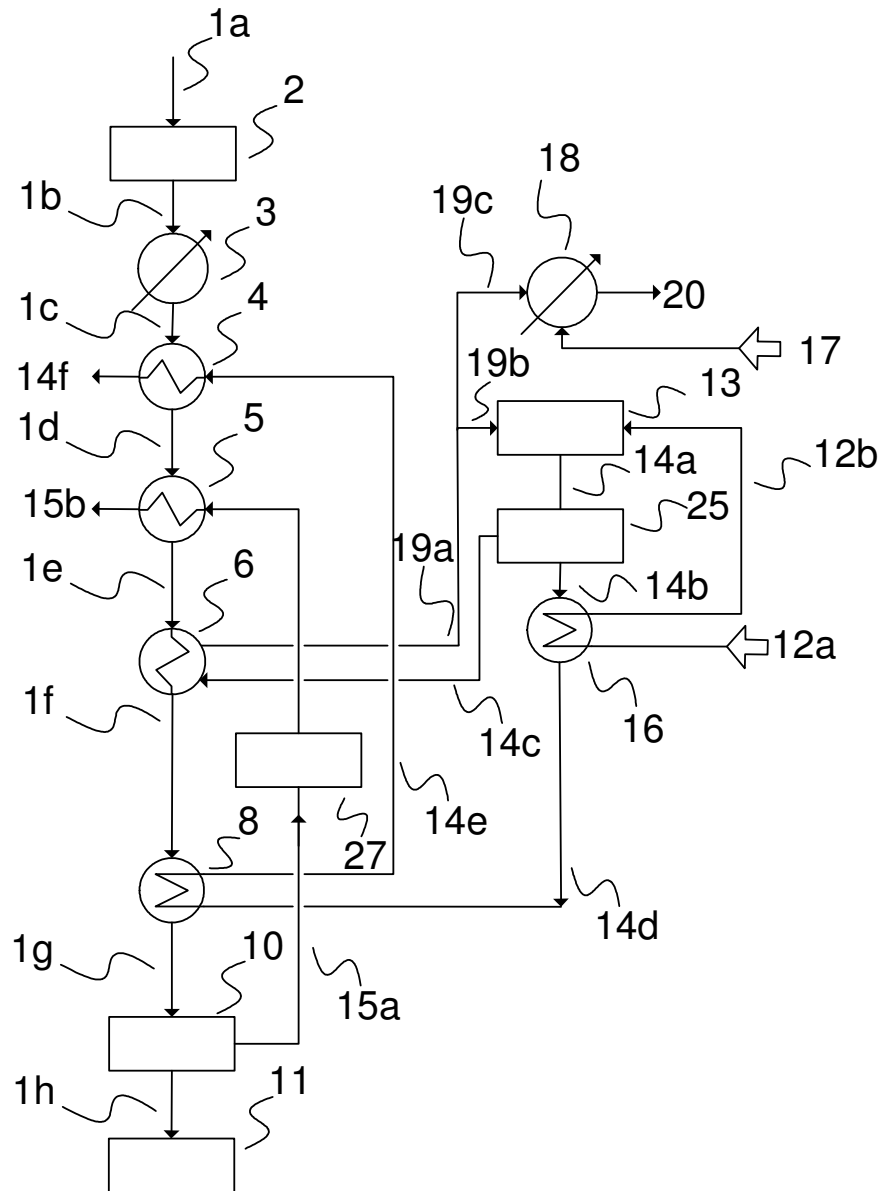


Fig. 2

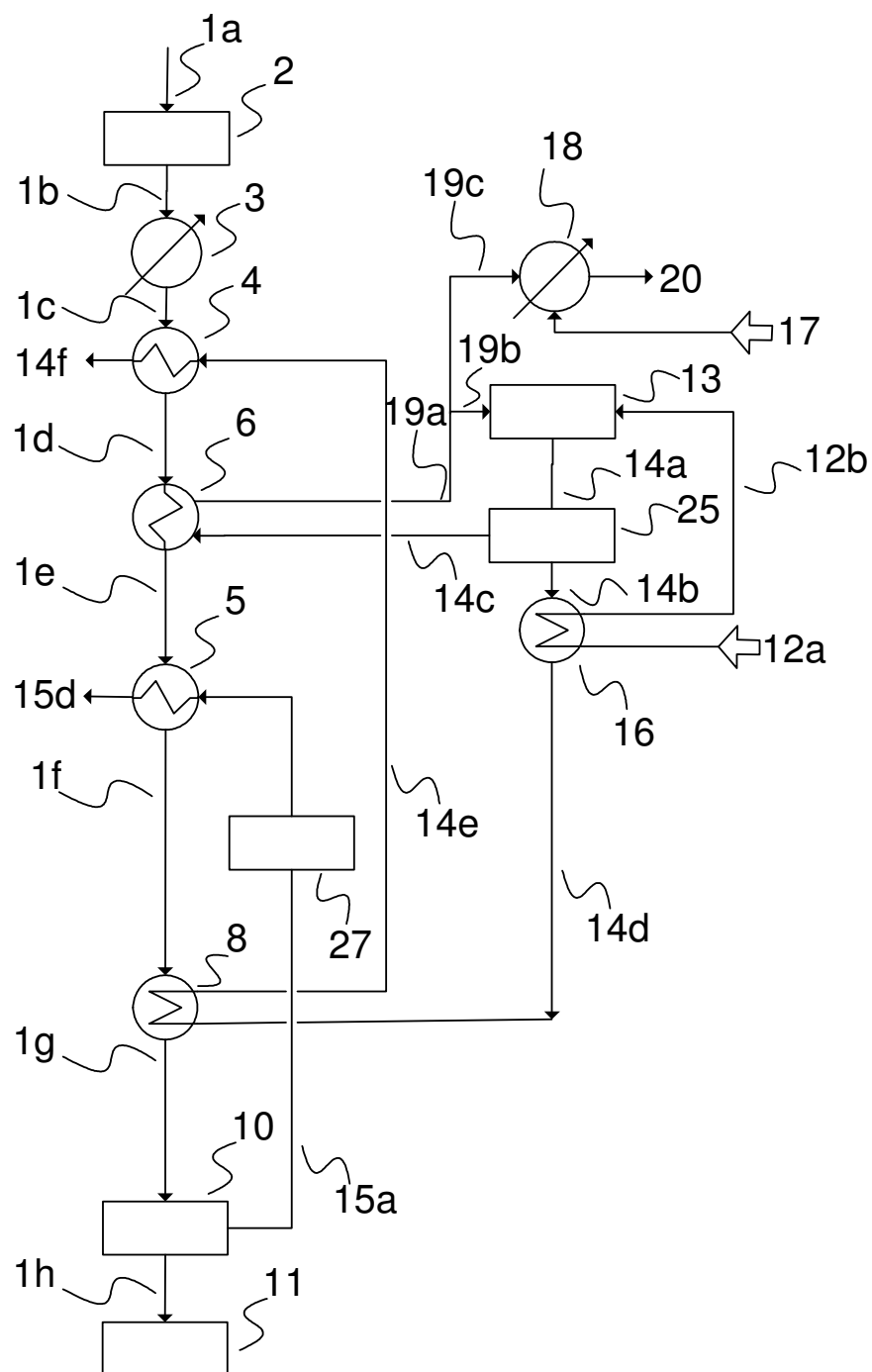


Fig. 3

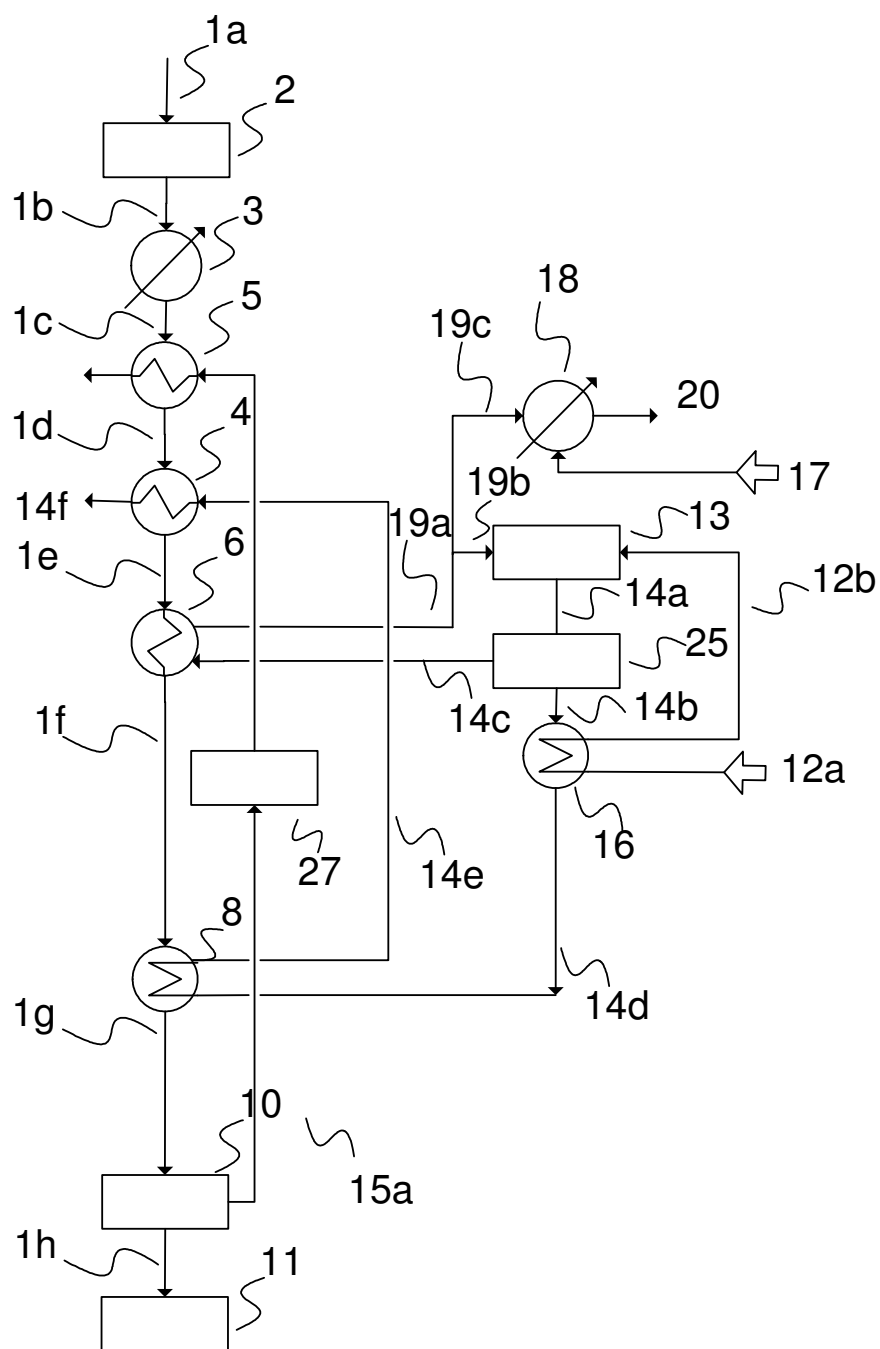




Fig. 5

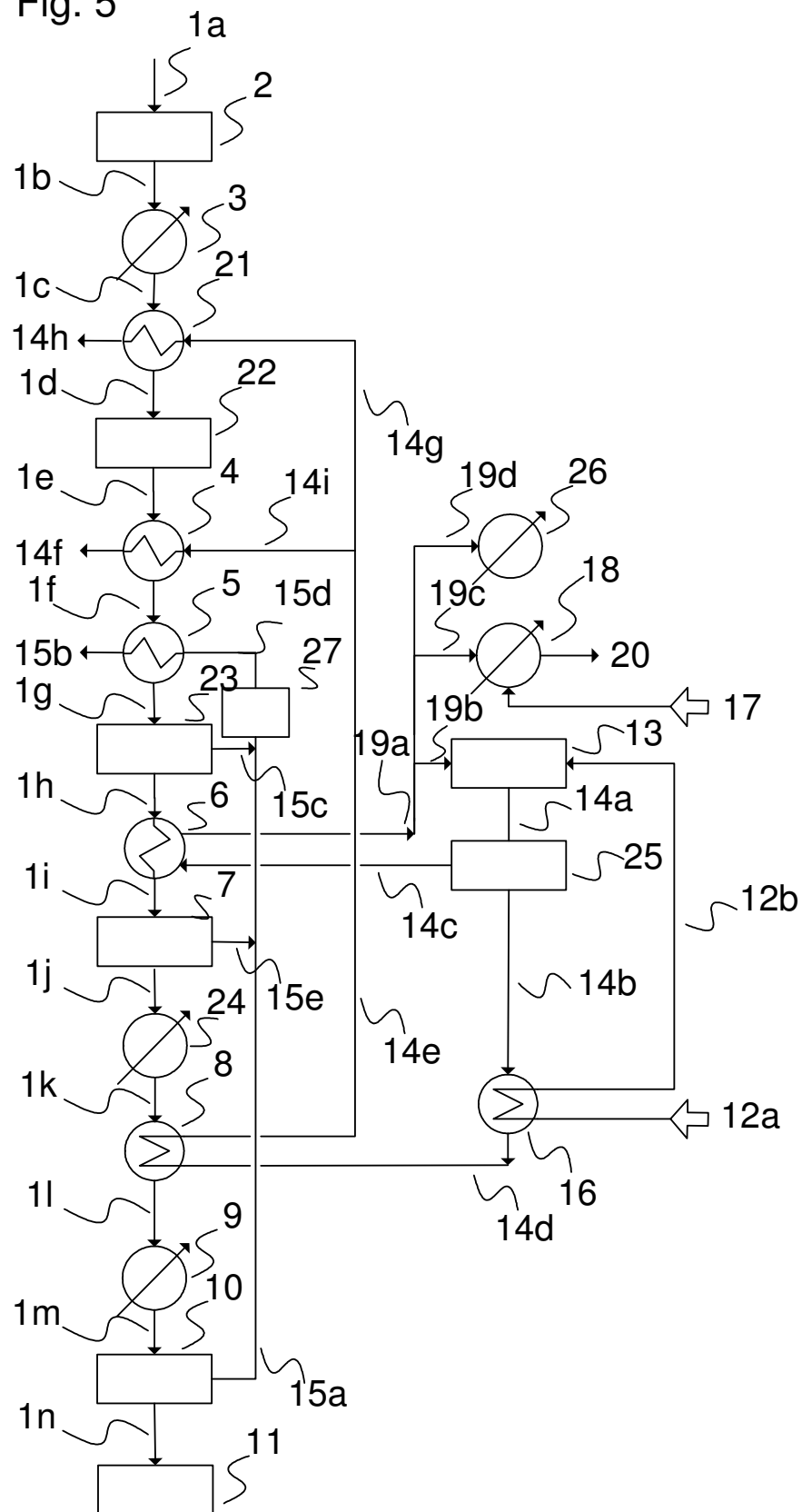


Fig. 6

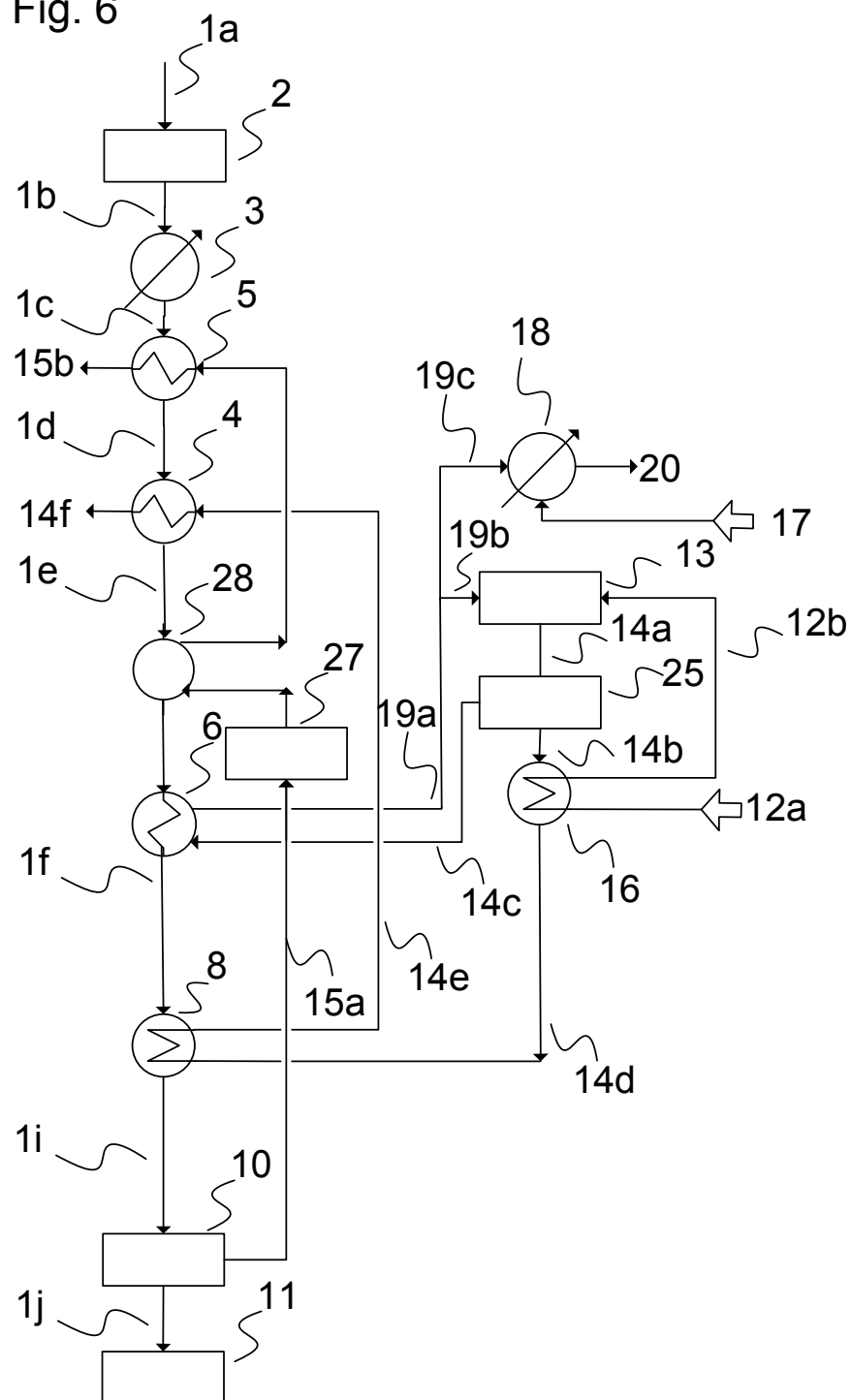
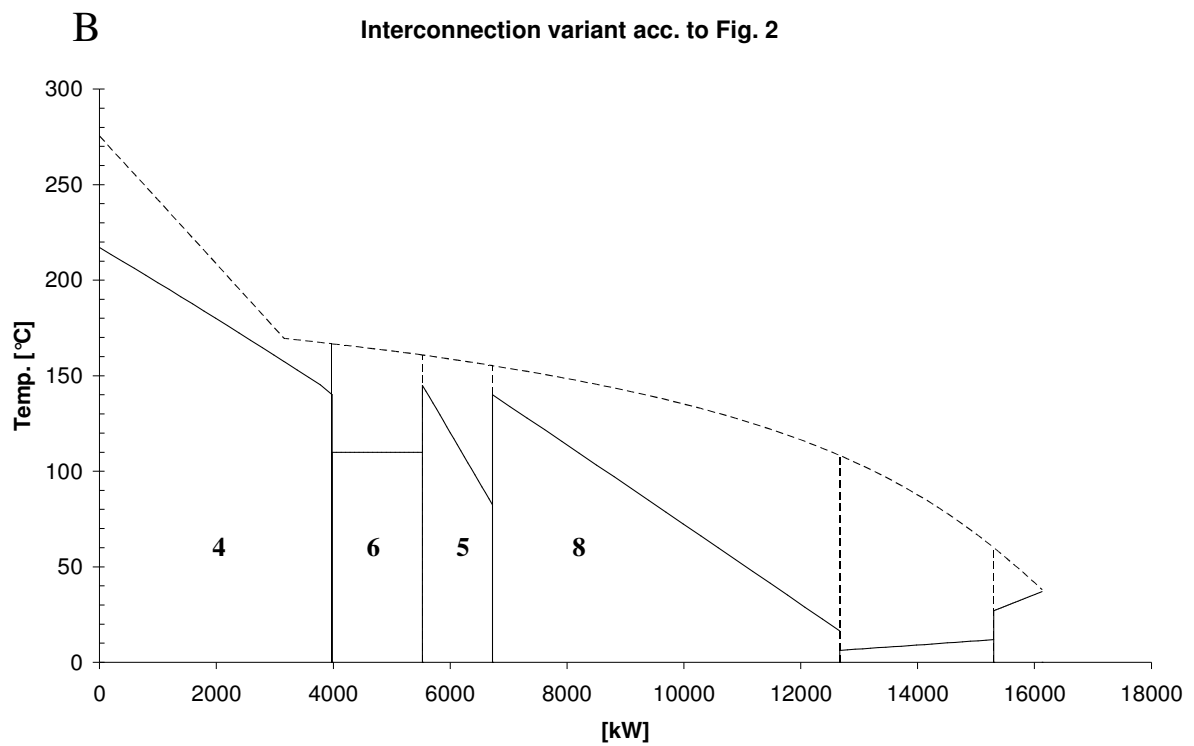
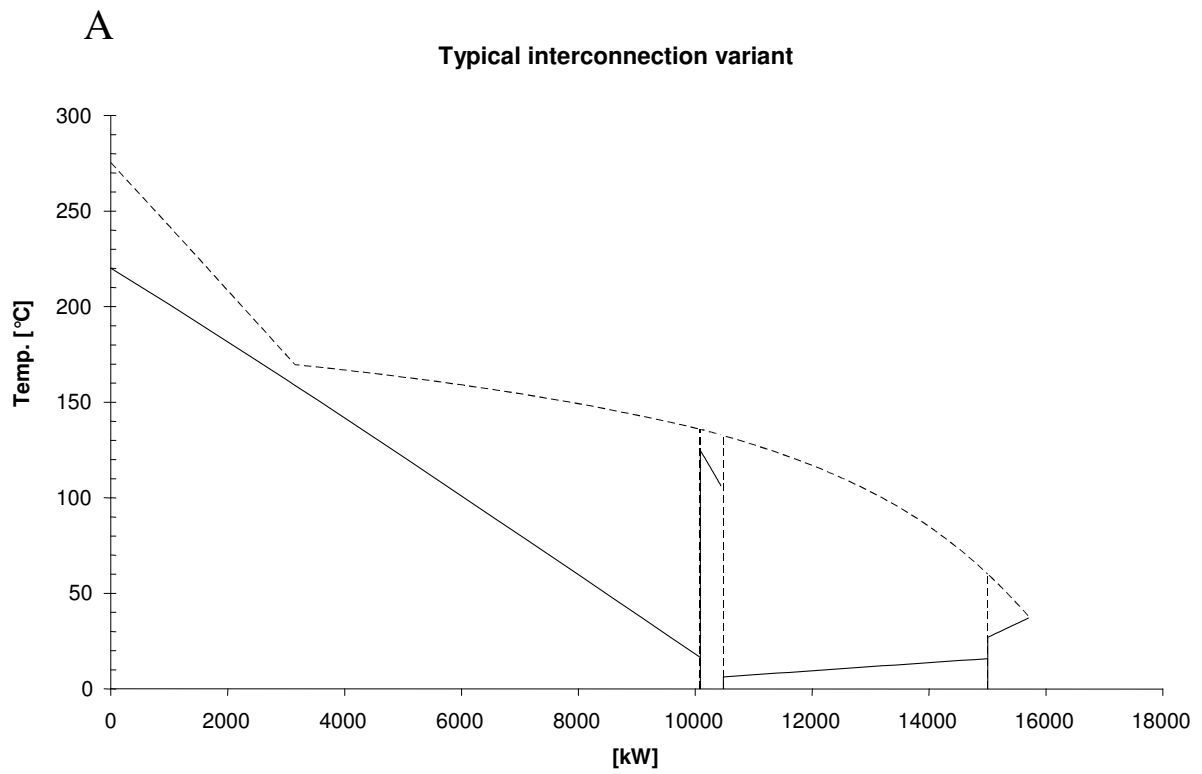
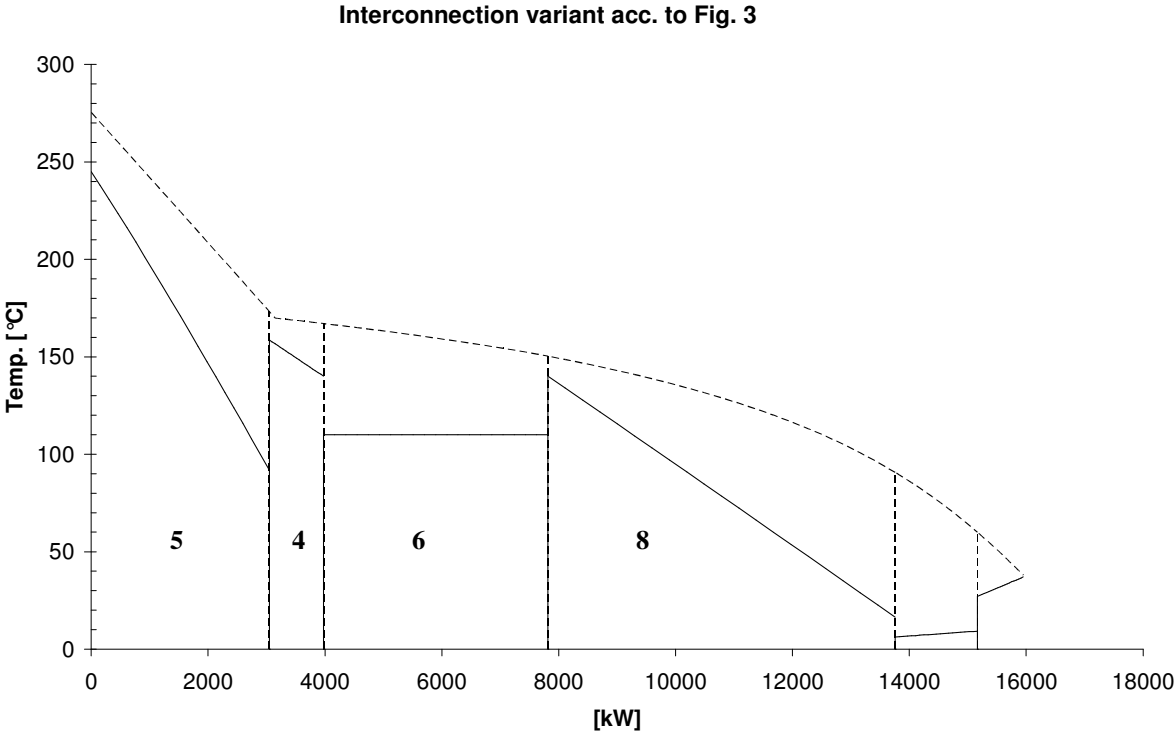


Fig. 7



C



D

