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HIGH TEMPERATURE HEAT PUMP – A NOVEL APPROACH TO INCREASE FLEXIBILITY AND EFFICIENCY OF CCGT AND CHP POWER PLANTS

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ABSTRACT

The increasing global energy demand together with the need for more sustainability and security of supply and competitive energy cost has led to considerable changes in energy policies all around the world. Over the past decade especially in Germany but also in the entire Europe the penetration of renewable energy sources (RES) became remarkably visible for the electric grid. The intermittent character of the RES and their massive introductions call for new measures for balancing the grid and reducing the consequent cost burden. Combined cycle power plants (CCGT) are obliged to operate more flexible to counteract the intermittent production of electricity by RES. At the same time, measures to decrease the environmental impact of CCGT, like co-generation to increase the energy efficiency are encouraged.

This paper presents a novel approach to increase the flexibility and efficiency of CCGT power plants and to increase flexibility of combined heat and power (CHP) generation systems. The high temperature heat pump (HTHP) uses “waste heat” to produce steam which can be used e.g. for industrial applications. Hence, the HTHP is operated above the temperature limits of conventional heat pumps. The paper offers the different integration options of the HTHP in the CCGT power plant or the CHP energy system including the district heating network (DHN). To give an example, waste heat from the moist flue gas of the CCGT including the condensation heat can be used as heat source for the HTHP which can produce steam for an industrial process plant which is located nearby. Alternatively, the HTHP can produce heat at an appropriate temperature level for the DHN. Therefore, the energy efficiency of the CCGT is increased. A second application option for the HTHP is to use heat from the DHN to produce steam at an industrial site which is connected to the DHN. In this way, the whole CHP energy system including CHP power plant, DHN, HTHP and steam consumer can be operated more flexible with regard to fluctuations of the electricity production from RES. In times of high RES production, the HTHP can utilise electricity from RES and heat from the DHN to produce steam. Simultaneously, the CHP power plant can increase heat production and decrease electricity production in case electricity prices are low at these times.

The presented work is part of the research project PUMP-HEAT which is funded by the EU within the Horizon 2020 framework programme. Besides Mitsubishi Hitachi Power Systems Europe GmbH (MHPSE), 13 industry and research partners participate in this project. The results refer to the milestone of “definition of layout options for HTHP”. Investigations about the improvement of flexibility and performance of CCGT power plants with HTHP will be performed by MHPSE until the next milestone which will be in September 2018. At the time of preparation of this paper, no final results concerning flexibility and performance of CCGT power plants are available.

INTRODUCTION

This paper deals with the potential applications of a high temperature heat pump (HTHP) for steam production. The HTHP is investigated by MHPSE in the PUMP-HEAT project. First, the motivation for developing the high temperature heat pump for steam production is described. Following, the most important thermodynamic fundamentals are explained to further describe the HTHP process and some key points for a potential implementation of the HTHP. Finally, the possible layout options of the HTHP in combination with combined cycle power plants are described in this paper.

Approximately one third of the yearly end use energy consumption in Germany is caused by the industrial sector. About 75 % of this amount is used for heating purposes, mostly in the form of process steam which is produced in combined heat and power (CHP) plants or in industrial boilers [1]. At the same time, in the industrial sector there is a high amount of waste heat which is released to the environment unused because technologies for waste heat recovery are too expensive for economic feasibility or not available.

To improve this situation in terms of energy efficiency, an innovative and cost-effective technology for heat recovery and simultaneous steam production is needed. The heat pump technology is predestined to utilize waste heat by increasing the temperature level to the specific requirements of the heat consuming process. However, commonly used heat pumps are limited to a maximum temperature of approx. 35 °C of the heat source and to a maximum temperature of approx. 90 °C at the heat sink side [2,3,4,5]. Hence, conventional heat pumps are not designed to produce process steam as the temperature level needs to be at least > 120 °C for process steam at an exemplary pressure level of 2 bar. The development of the HTHP which is able to produce process steam according to the requirements of the consumer can fill this gap and its application can increase the energy efficiency of industrial processes.

Furthermore, the HTHP can utilise heat from district heating networks (DHN) for a decentralised steam production at industrial sites which are connected to a DHN. In this way, the HTHP can increase the utilisation of DHN's which are usually operated with strong seasonal fluctuations due to high heating demand in winter and low heating demand in summer. As CHP plants, which are often realised as combined cycle (CC) power plants produce heat for such DHN, the HTHP can also increase utilisation of CC power plants with respect to the seasonal fluctuations. Finally, using electricity from renewable energy sources (RES) to run the HTHP reduces the carbon footprint of the industrial steam production and increases the flexibility of the electricity consumption which offers the possibility to efficiently use the electricity from RES during times of overproduction. In this respect, the HTHP can function as a device for demand side management (DSM).

In addition, the HTHP can be applied to increase the flexibility and efficiency of CC power plants by the integration in the thermal cycle of the power plant.

NOMENCLATURE

CC	combined cycle
CCGT	combined cycle gas turbine
CHP	combined heat and power
COP	coefficient of performance
DHN	district heating network
DSM	demand side management
GHG	green house gas
GT	gas turbine
GWP	global warming potential
HFC	hydrofluorocarbons
HRSG	heat recovery steam generator
HTHP	high temperature heat pump
LHV	lower heating value
OPD	ozone depletion potential
RES	renewable energy sources
ST	steam turbine
TES	thermal energy storage

HIGH TEMPERATURE HEAT PUMP FOR STEAM PRODUCTION

In general, heat pumps can be divided into three different kinds of main technical designs: absorption heat pumps, adsorption heat pumps and compression heat pumps. Absorption and adsorption heat pumps use an internal cycle of absorption respectively adsorption and desorption, which is driven by the heat source. In contrast, in compression heat pumps the temperature of the working fluid is raised by compression. According to the expected temperature ranges of the heat source and of the heat sink and to the expected power range, the high temperature heat pump is of type compression heat pump. The thermodynamic process of a compression heat pump can be described as reversed Carnot cycle. According to the working fluid the cycle is either a cold vapour process during which the state of aggregation changes (gaseous and liquid state) or a cold gas process during which the state of aggregation does not change (only gaseous state). The schematic thermodynamic processes are shown in Fig. 1a and Fig. 1b in T-s diagrams.

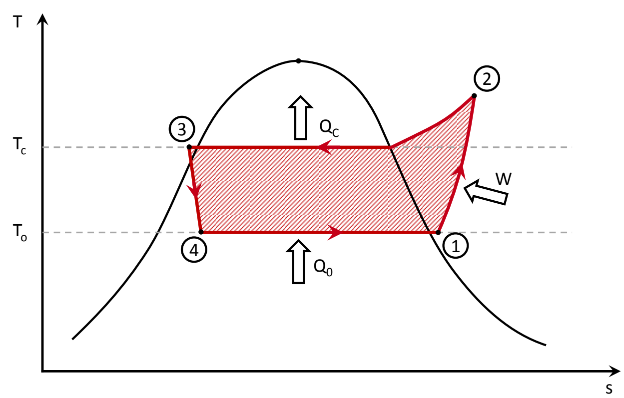

Fig. 1a: Cold vapour process of heat pumps

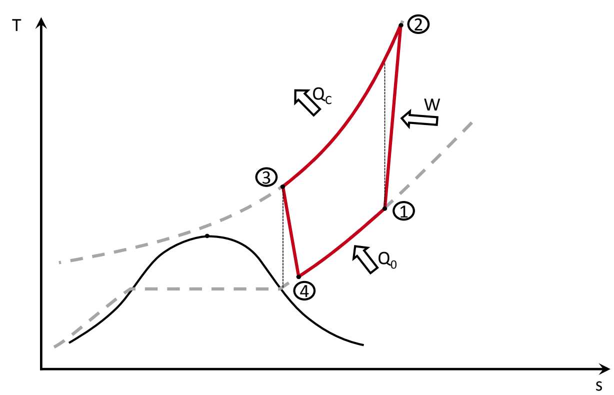

Fig. 1b: Cold gas process of heat pumps

The cold vapour process consists of the following changes of state of the working fluid [6]:

1→2: compression of the gaseous working fluid to condensation pressure

2→3: condensation of the working fluid, heat transfer to heat sink

3→4: throttling and cool down of working fluid in wet steam region to evaporation pressure

4→1: evaporation of the working fluid, heat transfer from heat source

To prevent the compressor from damage, it is important that the working fluid is at least slightly overheated after evaporation respectively at the compressor input (state 1) because liquid particles can damage the compressor blades. During compression of the working fluid, the work W is required. As the working fluid condenses (2→3), the heat Q_C is transferred from the working fluid to the heat sink at the temperature needed. During evaporation (4→1), the heat Q_0 is transferred from the heat sink to the working fluid.

The cold gas process consists of the following changes of state of the working fluid. The state of aggregation is gaseous in all states of the process [6]:

1→2: compression of the working fluid

2→3: cool down of the working fluid, heat transfer to heat sink

3→4: expansion in an expander and cool down of the working fluid

4→1: heating of the working fluid, heat transfer from heat source

Resulting from the gaseous state of aggregation during the complete cold gas process, the throttle valve can be replaced by an expander. Thus, a part of the mechanical energy, induced by the compressor, can be recovered.

The type of thermodynamic process depends on the chosen working fluid, on the temperature given at the heat source and on the temperature required at the heat sink. To limit the environmental impact, a working fluid with low global warming potential (GWP) and low ozone depletion potential (OPD) has to be chosen. Therefore, synthetic working fluids like fluorinated hydrocarbons (HFC) as they are commonly used as refrigerants in air conditioning systems are avoided. For the HTHP process natural working fluids with low GWP and an ODP of 0 like e.g. carbon dioxide (CO2), ammonia (NH3) or butane (C4H10) are more favourable.

The efficiency of the HTHP process is evaluated with the coefficient of performance (COP). In this case the COP is defined as ratio of the difference between the heat flow of the produced steam and the heat flow of the feed water to the total electrical consumption of the HTHP, as shown in the following equation:

$$\mathrm{COP} = \frac{\dot{\mathrm{H}}_{\mathrm{Steam}} - \dot{\mathrm{H}}_{\mathrm{Feed\ Water}}}{\mathrm{P_{el}}} \tag{1}$$

This value does not include the heat which is provided by the heat source, as it is assumed that the used heat is waste heat and otherwise will be released unused to the environment. For economic operation of the HTHP, the COP should be as high as possible. Therefore, the consumed electrical power should be minimized while the heat output is maximized.

According to the above described thermodynamic processes the following figure (Fig. 2) illustrates a schematic process flow diagram of the high temperature heat pump. The thermodynamic states of the working fluid are labelled with numbers 1 – 4 corresponding to the diagrams in Fig. 1a and 1b. The cold vapour process is illustrated with the dotted line and the expander at the change of state 3 – 4. The cold gas process is shown with the dashed and dotted line and the throttle valve at the change of state 3 – 4. The working fluid condenses (cold vapour process) or simply cools down (cold gas process) in a heat exchanger at the change of state 2 – 3. At the heat sink side of the heat pump cycle, the feed water is evaporated while heat is transferred from the working fluid to the water. With regard to the required steam parameters, the steam pressure and/or temperature after evaporation can be too low for the specific application. As a result, the produced steam has to be further treated which can be realized in different ways. The first option is to compress the steam in a single or multi-stage steam compressor. In Fig. 2 an exemplary 2-stage steam compressor with intermediate cooling by means of water injection is shown. The intermediate cooling is necessary to limit the temperature in accordance to the limits of the compressor materials. Alternatively, it can be designed as indirect cooling via heat exchangers and a cooling medium. Besides steam compression, the steam can alternatively be heated with an electrical heater which increases the temperature without increasing the pressure. A third alternative for steam treatment is to heat up the feed water without evaporation and to design a flash evaporation afterwards. The pressure of the hot water is decreased by a throttle valve into the two-phase region and the steam phase is separated. According to requirements, this steam has to be further heated and/or compressed. The benefit of the flash evaporation is a possibly lower power demand as the pressure is increased in the liquid state of the feed water which consumes less power compared to the compression of the gaseous steam. Another benefit of the flash evaporation is the avoidance of a phase change in the heat exchanger on the heat sink side. This can be beneficial in term of lower exergy losses during heat transfer if the heat pump process is designed as cold gas process which also works without a change of the state of aggregation of the working fluid. [7]

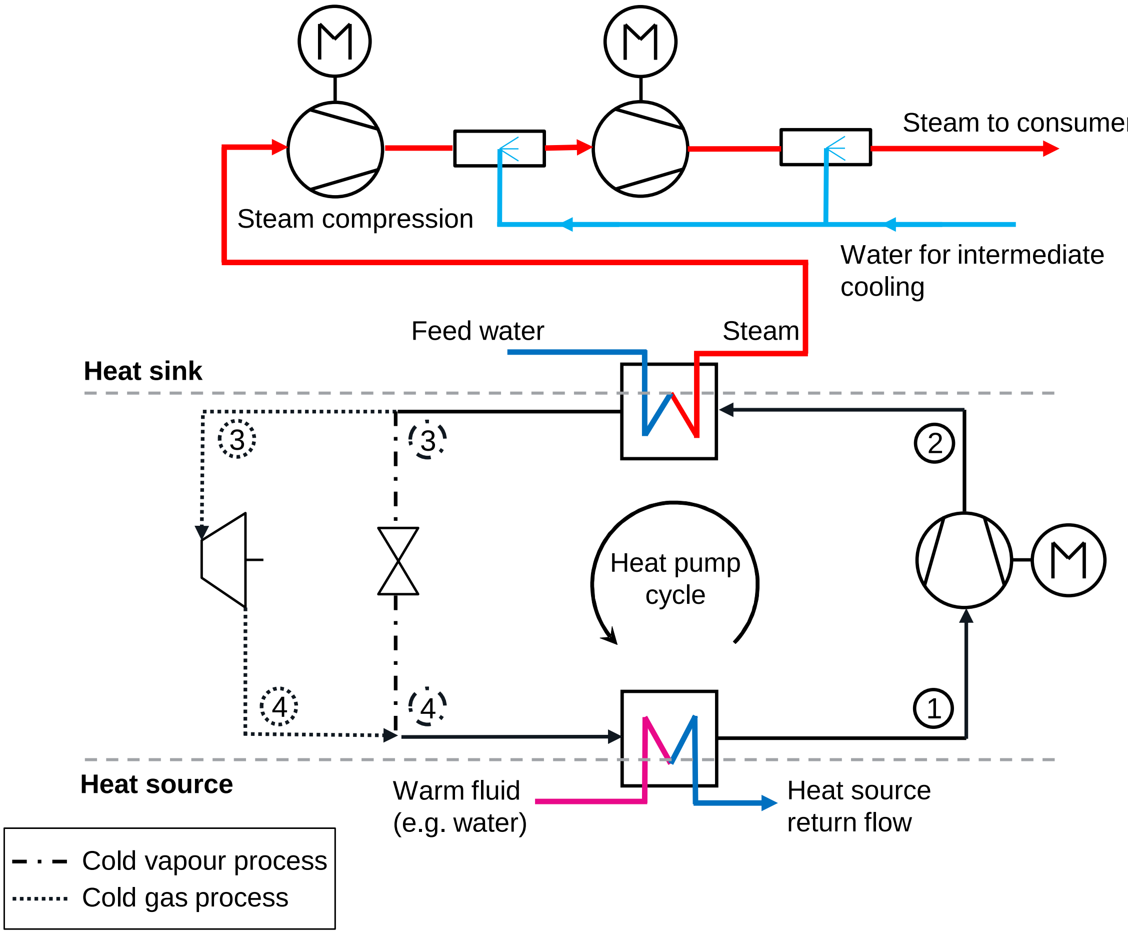

Fig. 2: Schematic process flow diagram of the HTHP

For a cost-effective implementation of the HTHP all compressors and expanders are built on one central gear, the so-called bull gear. Consequently, the HTHP can be realized as a compact machine with a single steel frame including the necessary piping and heat exchangers. The power of the electrical motor can vary between 1 and 40 MW_{el} but according to the availability of the turbomachinery equipment and to limit the size of the HTHP module, a range of 1 to 5 MW_{el} of electrical power is envisaged. [8]

A more detailed specification of the HTHP process including definition of the appropriate working fluid will be executed by MHPSE in the PUMP-HEAT project. Further, MHPSE plans to perform a conceptual design study of the heat exchangers used in the HTHP. The specification and simulation of the HTHP and the design of the heat exchangers will be performed in accordance to the specific application cases which will be defined after prioritizing the layout options which are described in the following.

LAYOUT OPTIONS FOR CCGT INTEGRATED HTHP

In the following section the different layout options for an integrated HTHP to increase the efficiency and flexibility of CCGT and CHP power plants are described. The investigations performed by MHPSE in the PUMP-HEAT project focus on layout option 1 ‘CC Performance Improvement with Flue Gas Cooler and HTHP’. Besides this layout three additional layout options are described in the following.

<u>Layout Option 1 – CC Performance Improvement with Flue Gas Cooler and HTHP</u>

In combined cycle power plants, the flue gas usually flows into the stack with a temperature of around 80 °C. The minimum temperature of the flue gas behind the heat recovery steam generator (HRSG) is often determined by local regulations. The draft which is caused by the stack effect ensures that the flue gas is removed to the atmosphere without the risk of falling down to the ground in high concentrations after cooling down and mixing with the ambient air which would cause negative environmental impact. Accordingly, a huge amount of thermal energy is released unused to the environment. To utilize not only the sensible heat but also the latent heat which is stored in the moist flue gas, offers the opportunity to increase the overall efficiency of CC power plants significantly. Usually, the fuel of CC power plants is natural gas which has a high share of hydrogen. Therefore, the flue gas has a high share of water in the form of steam which can be condensed if the flue gas is cooled down in a flue gas condenser. A temperature below 80 °C at the stack entry can be handled if the temperature difference between flue gas and ambient air is high enough to keep the stack effect working. In any case, the flue gas must have a temperature of approx. 50 °C to ensure that it is exhausted safely to the atmosphere.

Fig. 3 shows the schematic process flow diagram of the layout for CC power plants with heat recovery from flue gas and an integrated HTHP which uses the heat to produce steam. There are three options to utilise the produced steam, which are described in the following.

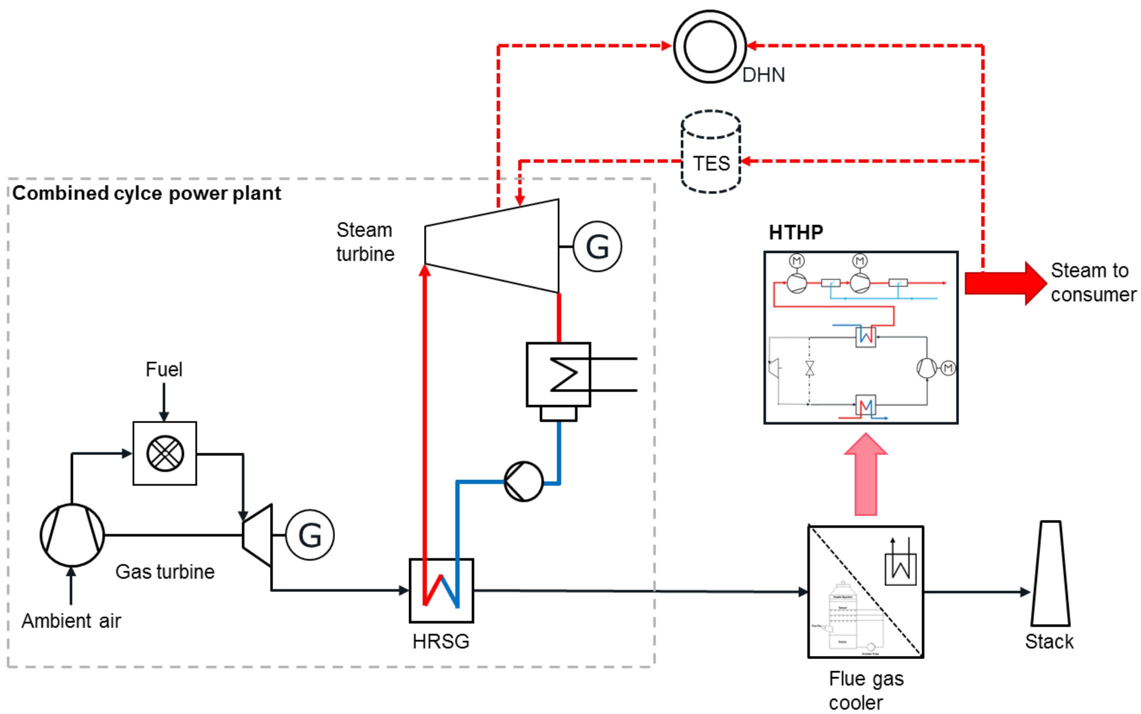

Fig. 3: Layout Option 1 with Flue Gas Cooler – Schematic process flow diagram

First, the steam which is produced by the HTHP can be utilised by a consumer which is located nearby the power plant, e.g. an industrial site like a refinery. This can increase the overall efficiency of the CC power plant in both, power oriented and CHP oriented operation. Alternatively, the produced steam can be used for the DHN if such infrastructure is available, i.e. if the plant is realised as CHP power plant. Hence, the efficiency of the CHP plant can be increased. Finally, the steam can be stored by means of a thermal energy storage (TES) which is applicable to store steam at the given temperature and pressure level. Such TES can be realized e.g. as a Ruths steam accumulator. A Ruths storage is a direct steam/hot water storage. During charging phase the steam condenses in the storage vessel and heat is released to the hot water inside the storage while the pressure rises. During discharging phase, the saturated steam is released at the top of the storage. Consequently, the pressure inside the storage drops and more steam evaporates [12]. The discharged steam can be used in the water steam cycle of the power plant which increases the power output of the CC power plant. The HTHP consumes electrical power. Therefore, it must be operated when electrical power demand and/or electricity prices are low. The power consumption of the HTHP decreases the overall power output of the system CC+HTHP. This can be beneficial if the lower operation limit of the CC power plant is already reached and a further reduction of the power output is required, e.g. caused by high RES production without shutting down the power plant. During times of high electrical power demand and high electricity prices, the steam from the TES helps to increase the power output of the CC power plant. The HTHP can be switched off in this case. This offers a higher flexibility for a power oriented operation of the CC.

The main benefits of this concept are the higher flexibility and the increased efficiency of the CC power plant in power oriented as well as in CHP oriented operation. Further, the power output can be decreased by the HTHP and at the same time steam for utilization in industrial applications or in the DHN can be produced by the HTHP which increases the overall efficiency. Another advantage is that the power output can be increased by using stored steam from the TES in the power plant.

There are 2 possible options to recover the sensible and latent heat from the flue gas. The first one is by means of a heat exchanger in which the flue gas cools down against a heat transfer medium, e.g. water while the steam content of the flue gas condenses. Due to the high volume flow of the flue gas this heat exchanger will become relatively large and expensive. Flue gas condensers in the form of heat exchangers are commercially available and the combination with heat pumps is described in the literature [10, 11]. Nevertheless, the commonly used heat pump technology is able to provide temperatures only up to approx. 90 °C. To use the produced heat in a DHN a temperature level of 110 – 180 °C is mandatory and for the production of process steam at a pressure of e.g. 2 bar a temperature above 120 °C is needed. In this regard, a process which combines a flue gas condenser with a HTHP which is able to provide temperatures above 90 °C and even steam, is a new approach to increase the overall efficiency of CC power plants. The second option is to use a spray tower derived from a flue gas scrubber (Fig. 4).

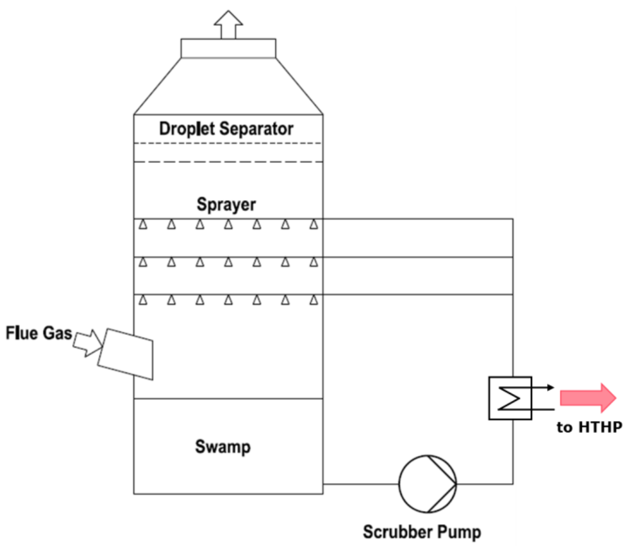

Fig. 4: Flue Gas Scrubber

In this device water is sprayed into the flue gas which cools down and the steam content condenses. At the bottom of the spray tower (swamp) the heated water accumulates. Next, a circulation pump carries the heated water through a heat exchanger in which the working fluid of the heat pump is heated and the water cools down before it enters the spray tower again. In both cases the flue gas has to be re-heated before entering the stack to reach an appropriate temperature for the stack effect. This is done by an internal flue gas re-heating. The option with spray tower is expected to have a significantly lower cost impact on the equipment costs compared to the option with flue gas condenser. Consequently this option is currently the preferred solution to recover heat from the flue gas based on the actual investigations.

<u>Case Study for Layout Option 1 with Flue Gas Scrubber</u>

A CC power plant with a 40 MW_{el} class gas turbine (GT) has an electrical gross power output of approx. 60 MW_{el} (1 GT on 1 ST) and has a flue gas mass flow of approx. 110 kg/s [9]. To cool down the moist flue gas from a temperature of 76 °C behind the HRSG to a temperature of 20 °C, a heat flow of approx. 25 MW_{th} must be removed from the flue gas. First, the flue gas is cooled in a regenerator to approx. 50 °C. Next, the flue gas is further cooled to approx. 20 °C in the spray tower. The condensate is removed in the swamp and the circulation pump transports it to the HTHP. Afterwards, the cold and dry flue gas is re-heated in the regenerator to a temperature of approx. 50 °C which consumes approx. 3 MW_{th} of thermal energy from the hot flue gas. Consequently, around 22 MW_{th} of thermal energy at a temperature of 20 – 50 °C can be recovered for utilization in the HTHP. The working fluid of the HTHP in this case study is NH3. The produced steam has a pressure of 4.2 bara and a temperature of 160 °C. The HTHP produces 70.5 t/h of steam with a COP of > 1.7. The overall net fuel utilisation factor of the CC power plant with integrated HTHP rises to approx. 102 % based on the LHV of the fuel. To limit the size of the HTHP it is split into 2 parallel devices with approx. 15 MW_{el} nominal electrical power each. For a cost-effective arrangement planning, the flue gas scrubber with spray tower should be placed in the middle of the 2 HTHP's (Fig. 5).

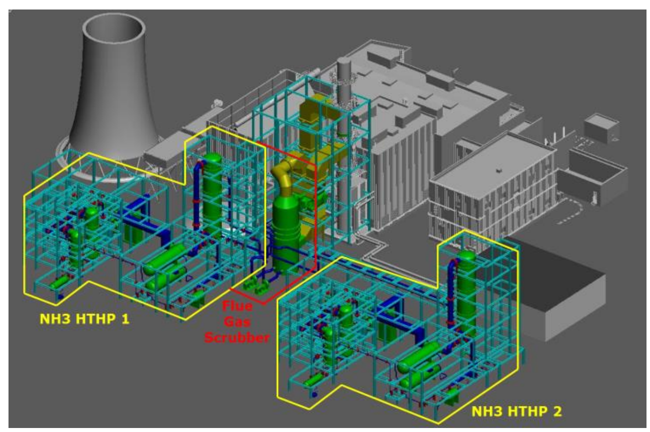

Fig. 5: Arrangement Planning of Layout Option 1

The financial impact of HTHP configuration in CCGT is still under investigation, but it can be already stated, that the specific investment cost (in € per MW used) of such a power plant will be higher in comparison with a standard CCGT. On the other side a significant specific fuel saving can be reached and first calculations show, that the overall business case can be better compared to the standard configuration. So we hope that within the following publications we can show a detailed economic evaluation showing that industrial GHG saving can be reached along with positive economic effects.

An important technical parameter which needs to be observed during design of the flue gas scrubber is the pressure drop on the flue gas side. The back pressure of the gas turbine significantly affects the produced power of the GT. As the GT usually produces around two-thirds of the overall electrical power output of a CC power plant, the back pressure of the GT influences the overall plant efficiency significantly. According to its design the HRSG causes a pressure loss of 20 – 35 mbar. The flue gas condenser must not increase the back pressure of the GT dramatically and the caused pressure loss should be as low as possible.

Layout Option 2 – CC Performance Improvement with Heat Recovery from Steam Condenser and HTHP

The second layout option with integration of a HTHP into CC power plant cycle is very similar to the first layout option described above. The main difference is the heat source of the HTHP which is the condenser of the CC power plant. Fig. 6 illustrates this layout in a schematic process flow diagram. Heat from the condenser is released to the HTHP which produces steam. For utilization of the produced steam, there are three options, in accordance to layout option 1: first, utilization of the steam by a consumer nearby the plant; second, using the steam for the DHN; third, storing it in a TES for a time independent utilization in the CC power plant cycle. The benefits of each of these three options are already described above. In contrast to the first layout option, the temperature level of the heat source of the HTHP is lower compared to the heat which is released from the flue gas cooler. Usually, power oriented CC power plants have condensation steam turbines with a low end pressure and consequently a low condensation temperature below 40 °C. If the HTHP uses this low temperature heat and produces steam at a temperature level of > 120 °C a huge temperature difference has to be realised by the HTHP which results in a relatively low COP. Therefore, a modification of the HTHP is likely needed. If the heat pump cycle is separated from the steam compression part of the HTHP the heat pump would be able to produce hot water. This hot water can be used for pre-heating of the hot water used within the DHN if the CC power plant has a connection to the DHN and therefore has also a CHP function besides power oriented operation. As the temperature of the DHN is usually in the range of 110 – 180 °C, further heating of the water from the DHN by the CC power plant is necessary.

Further, the HTHP can reduce the temperature of the condensate in the CC power plant cycle. As a result, the condensation pressure can be reduced which results in a higher power production of the low pressure steam turbine and a higher overall efficiency of the power plant. This is beneficial especially for power oriented operation of the CC power plant as these power plants usually have condensation steam turbines.

CHP oriented CC power plants are commonly realized with back pressure steam turbines. That means, the pressure behind the low pressure steam turbine is higher compared to condensation steam turbines and accordingly the temperature is higher. The low pressure steam behind the steam turbine is used to heat up the hot water for the DHN. If the heat from the steam is fully used for DHN purposes, the capabilities to integrate the HTHP on the water/steam cycle are limited because most of the heat is already efficiently used. This changes if only a part of the heat that is released with the steam behind the low pressure

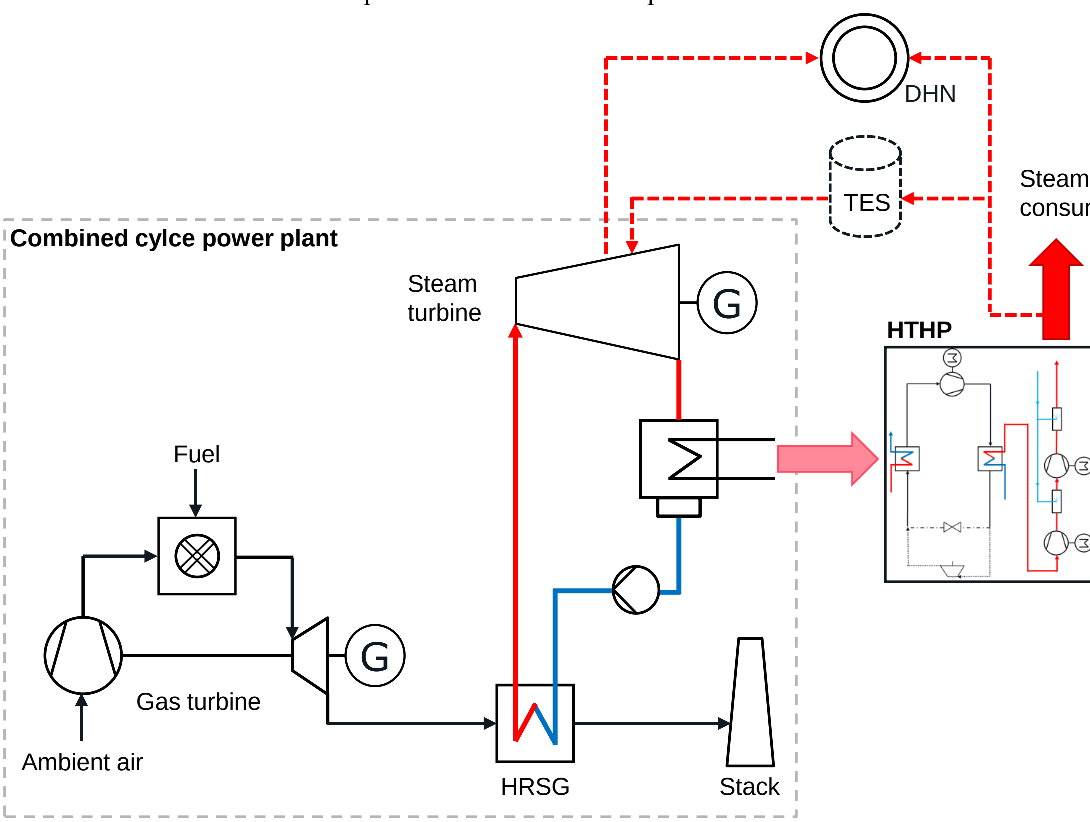

Fig. 6: Layout Option 2 – Schematic process flow diagram

steam turbine is needed for DHN purposes. In this case, the steam turbine has a high loss in produced electricity because the complete steam is expanded to a pressure which is higher as the minimum condensation pressure. To increase the overall efficiency, it can be beneficial to expand the steam to condensation pressure and use the heat from the condenser for production of hot water in the HTHP. In this way, the electricity production is increased and the heat demand is satisfied nevertheless. If steam needs to be produced with the HTHP, the temperature at the heat source side needs to be raised. To do so, bleed steam from the steam turbine at an appropriate temperature level can be used.

Layout Option 3 – Utilisation of DHN for decentralized Steam Production with HTHP

The third layout option focuses on CHP oriented CC power plants. It is a solution for decentralised steam production using the heat transfer capabilities of the DHN. Usually, industrial sites which have a certain steam demand have their own steam production. This is done either with industrial boilers which burn a fuel like e.g. natural gas or even with CHP power plants if they have a large steam demand. In contrast, the following layout option offers the opportunity to use heat from the DHN in a HTHP to produce steam. As a consequence, the fuel consumption of the industrial site can be reduced. If low carbon electricity from RES is used to drive the HTHP, the carbon footprint of the steam production can be reduced remarkably. In addition, if low electricity prices during times of RES overproduction are exploited, the specific cost impact of the steam can be reduced too.

Fig. 7 shows the schematic process flow diagram of this layout option. The DHN is fed by the CC power plant with heat at a temperature of 110 – 180 °C. To reach such temperatures, the back pressure steam turbine has a higher end pressure and hence, a lower electrical efficiency. To run the CC power plant also in times of low heat demand, a condenser is usually realized in parallel to the district heater. During transportation in the DHN pipelines, the pressure and temperature of the hot water is reduced slightly. An industrial site which is located elsewhere but with a connection to the DHN and a certain steam demand can use hot water from the DHN as heat source for the HTHP which produces steam to fully or partly cover the steam demand of the industrial site.

Especially in summer months, the utilisation of the DHN and therefore also of the CHP power plants is low. Because of the low demand, the prices for heat from the DHN are low too. At the same time, electricity prices are lower in summer months because of high penetration from photovoltaic energy. In this situation the steam production by means of the HTHP which uses cheap heat from DHN and cheap electricity from RES can be a cost-effective alternative to a fuel based steam production.

This concept can support initiatives to expand DHN's to increase the overall efficiency of a local energy system, like the initiative for the DHN in the Rhein-Ruhr area [13]. At the same time the annual utilization of the DHN and the CC power plant can be homogenized and seasonal fluctuations in the heat demand can be softened.

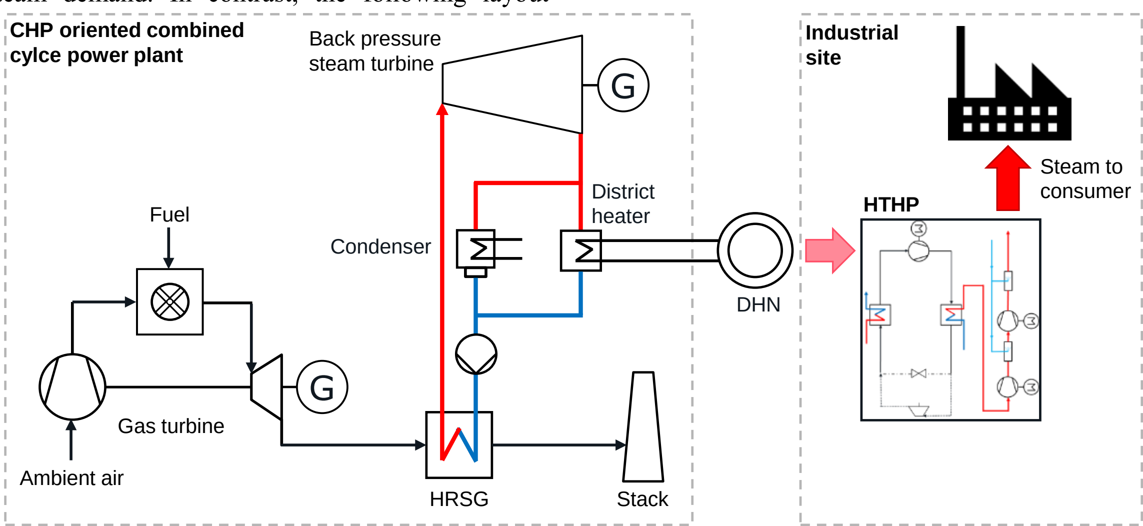

Fig. 7: Layout Option 3 – Schematic process flow diagram

Layout Option 4 – Utilisation of industrial Heat for Steam Production with HTHP

The fourth layout option, as it is illustrated in Fig. 8, is a solution to increase the energy efficiency of an industrial site with large steam demand and an on-site CHP oriented CC power plant. Usually, there are several steam extractions at the steam turbine to feed the steam grid at different pressure levels. A single steam extraction is shown in Fig. 8 with a dashed line.

In such a steam grid there occur high pressure and heat losses due to long transportation distances and therefore decreasing temperatures. The offered alternative is to replace the steam grid by a local hot water grid comparable to a DHN which causes less pressure and heat

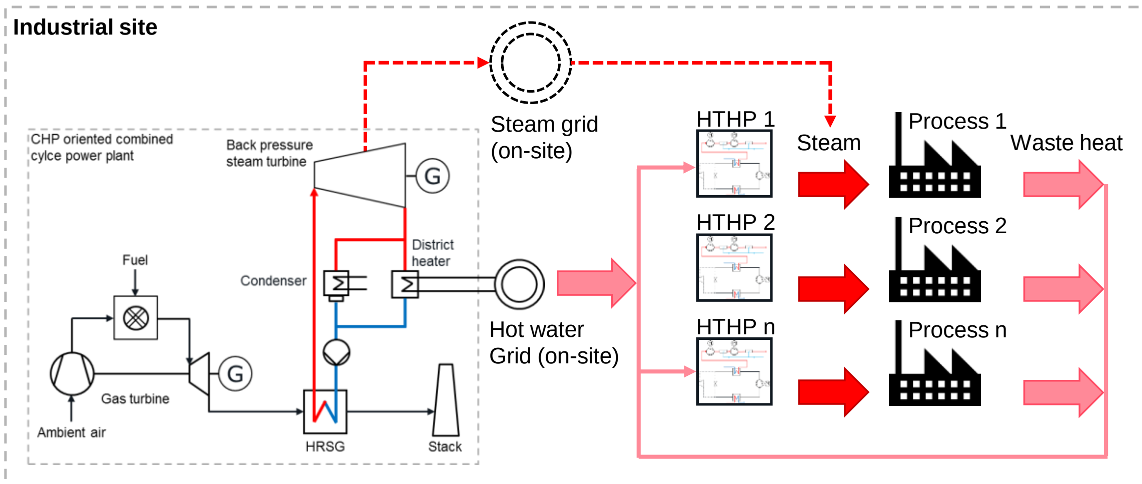

Fig. 8: Layout Option 4 – Schematic process flow diagram

losses. The electricity production of the CC would increase as more steam at higher pressure is expanded in the steam turbine. To produce steam, several HTHP's are located nearby the consuming processes. The HTHP uses the heat from the hot water grid as heat source. As a result, long transportation distances for the steam and therefore high pressure and temperature losses are avoided. Furthermore, waste heat which is produced by the processes can be integrated in the hot water grid. In this way, the overall efficiency of the energy system can be increased.

Moreover, this concept can be applied to establish an innovative energy management system for an industrial side based on the idea of a virtual power plant which combines the CC power plant and the HTHP's. Influences like the actual RES production, fast changing energy prices and changing demand of steam and electricity can be taken into account to optimise the electricity and steam production. In that way, the energy efficiency can be increased and the cost impact for energy production can be decreased.

OUTLOOK

The four different layout options for integration of the HTHP in the CC and CHP power plant cycle will further be investigated within the planned work in the PUMP-HEAT project. Investigations about the improvement of flexibility and performance of CCGT power plants with HTHP will be performed by MHPSE until the next milestone which will be in September 2018. The most promising layout options to increase flexibility and efficiency of the power plants will be identified. These layout options will be the basis for a detailed process and component analysis.

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