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ANNEX 57

Flexibility by implementation of heat pumps in multi-vector energy systems and thermal networks

Demo No.: D-001	**Location/City:** Hallein	**Country:** Austria
Project name (short and full title): Salzburg Absorption Heat Pump		
Quotation: "Investigate and demonstrate the integration of an absorption heat in a biomass cogeneration plant for waste heat utilization"		
Schedule of the demo project (research study): 2018-2020		**Year of realisation:** 2020
Leader organisation (owner, constructor, solution developer, research inst., etc.): Owner: Salzburg AG Research Institution: Graz University of Technology - Institute of Thermal Engineering		
Participating organisations – demonstration project part (involved other organisations): No further organisation than the above-mentioned are involved		
Budget of the demo (invest/monitoring etc.): unknown		
Summary of the project: The project shows the integration of an absorption heat pump (AHP) in a biomass cogeneration plant to utilize the unusable waste heat of the flue gas. Within this project the operation of the AHP was monitored through the commissioning phase and the first year of operation. The monitoring data was evaluated and potential for optimization has been identified and realized.		
Expected results • Reduction of the unused waste heat of the biomass cogeneration plant and therefore increasing the efficiency of the biomass cogeneration plant • Supplying the district heating network with renewable energy and increasing the share of renewables • Achieving a stable operation of ≈8500 h per year		
Published articles (paper, article etc.): • Wagner, P., Astl, C., Rieberer, R., 2022. Absorptionswärmepumpe zur Abwärmenutzung: Modellierung einer Anlage zur Rauchgaskondensation in einem Biomasseheizkraftwerk [Absorption heat pump - Modelling of an AHP for waste heat utilization in a biomass cogeneration plant]. Proc. Deutsche Kälte-Klima-Tagung 2022, Magdeburg.		
Contact information: René Rieberer, Graz University of Technology – Institute of Thermal Engineering, +43 316 873 7303, rene.rieberer@tugraz.at		
Country: Austria	**Participating Organisation:** Graz University of Technology – Institute of Thermal Engineering	**Contact/name:** Philipp Wagner

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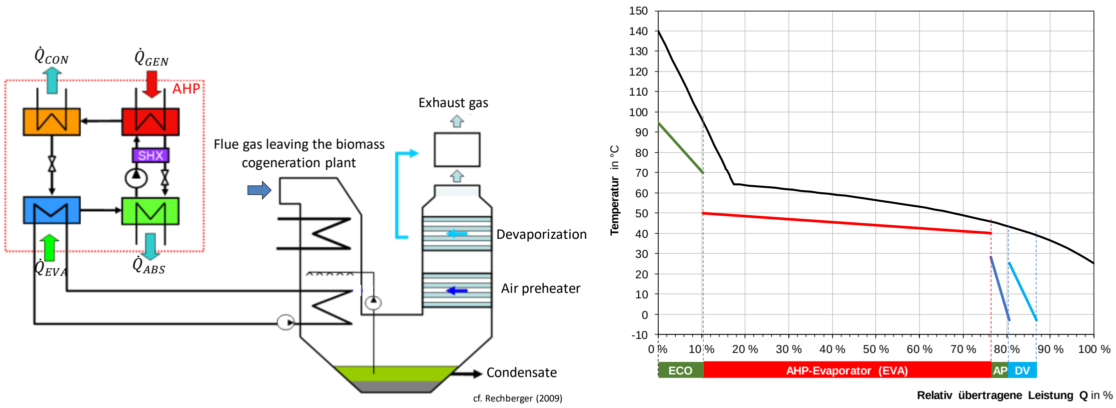

Figure 1: Scheme of the integration of an absorption heat pump in a biomass power plant

Figure 2: Installed absorption heat pump

Project classes:

RD&D status

Large-scale demonstration	Small-scale demonstration	Lab scale (results based on measurements)	Design study (results based on simulation)
☒	☐	☐	☒

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Type of heat pump

Decentralized HP (cold district heating)	Centralized HP with a district heating system
☐	☒
Heating	Cooling
☒	☐

Heat source of HP: Waste heat (flue gas) from a biomass cogeneration plant

Power supply for HP (electricity grid, PV, wind turbine etc.): Thermally-driven by steam from a biomass cogeneration plant

Buildings

New buildings	Existing buildings	Mix of new and existing buildings
☐	☐	☒
Residential	Non-residential	Mixed use
☐	☐	☒

Energy storage

Battery storage		Thermal energy storage	
Centralized	Decentralized	Centralized	Decentralized
☐	☐	☒	☐

Control for the flexible heat pump operation

Heat driven control[1]	Predictive control[2]	Rule based control[3]
☐	☐	☒

[1] Operation of heat pumps to the cover heat demand depending on ambient temperatures
[2] Operation of heat pump using a model-based heat demand prediction
[3] Heat pumps are controlled by a set of predefined rules (e.g. heat pump operation with blocking time)

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1. General description of the project

Salzburg AG operates district heating networks (DHNs) in Hallein and Salzburg. The city centres of Hallein and Salzurg are ≈20km away from each other. Since the capacity of the heat generation plats and the waste heat potential in Hallein is higher, than the demand, the two DHNs were connected in Elsbethen (between Hallein and Salzburg). Therefore, it is possible to transfer heat from Hallein to Salzburg to reduce the load on the plants supplying Salzburg and to increase the flexibility of the heat supply.

One of the flexibility measures in the district heating network in Hallein covers the implementation of an absorption heat pump (AHP) to increase the waste heat utilisation of unusable waste heat of a largescale waste heat source at the cellulose manufacturer AustroCel. As the low-temperature heat source for the AHP the flue gas of a biomass cogeneration plant is used.

The AHP integrated, is manufactured by the company Thermax Limited. The AHP uses H_2O as refrigerant and LiBr as solvent and reaches a heating capacity of about 8 MW and a COPH of about 1.68 at a driving temperature of ≈162 °C (hot steam), a heat sink in-/outlet temperature of 63/90 °C and a heat source in-/outlet temperature of 60/30 °C. Figure 3 shows a simplified schematic diagram of the AHP cycle.

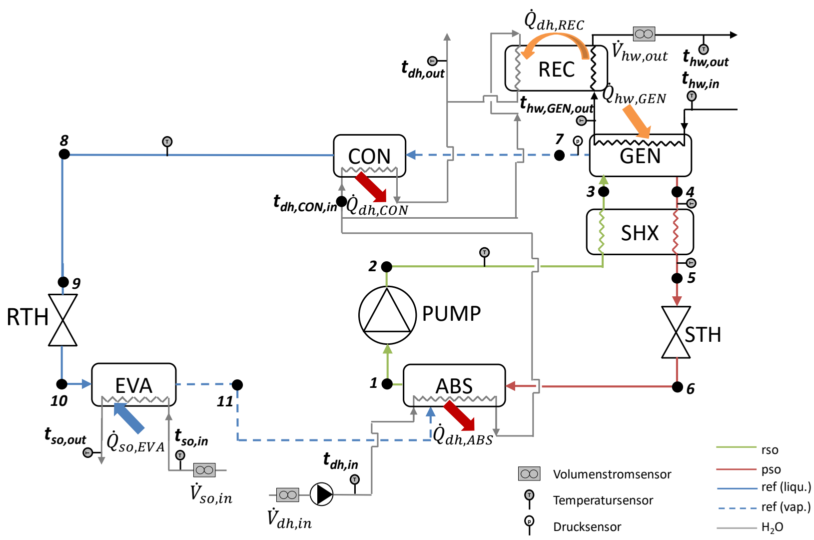

Figure 3: Simplified scheme of the absorption heat pump cycle

The installation of the AHP was started in October 2019 and finalised during November 2019 and January 2020. After the commissioning phase the AHP started it's trail operation in February 2020. Final adjustments and parameter settings at the AHP were carried out at the end of 2020. Furthermore, there were some challenges with the operation of the AHP, which were finally solved during the first half of 2021.

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2. Building and system description of the project

Based on the schematic diagram of the AHP (see Figure 3) a detailed monitoring concept was developed. Besides the external temperatures and mass and volume flow rates also the internal state points were considered. Especially additional temperature sensors at each state point as well as pressure sensors and internal mass/volume flow sensors are necessary for a detailed investigation. Since it's quite a risky for the manufacturer to integrated lots of temperature sensors into the AHP as it is a source for leakages and/or air intake, it was not possible to integrate a temperature sensor at each state point. For the evaluation available volume flow meters as well as temperature and pressure sensors are shown in Figure 3.

Data for the monitoring was collected from July 2020 until March 2022. Due to some challenges during the trail operation the monitoring of the AHP was performed for a full year between January 2021 and December 2022. In this phase external volume flows and temperatures at the absorber, condenser, desorber and evaporator were measured. The corresponding external energy flows as well as the Coefficient of Performance (COP) of the AHP were derived from the measured temperatures and volume flow rates. The supplied heat flow rate to the district heating network (dh) was calculated according to Eq. (1), the recovered heat flow rate from the flue gas (so,EVA) according to Eq. (2) and the driving heat flow rate at the generator (high temperature heat source, hw) according to Eq. (3). The Coefficient of Performance (COP) was calculated according to Eq. (4), the Seasonal Performance Factor (SPF) according to Eq. (4).

$$\dot{Q}_{dh} = \dot{V}_{dh} \cdot \rho_{H_2O,dh} \cdot c_{p,H_2O} \cdot (t_{dh,out} - t_{dh,in}) \quad (1)$$

$$\dot{Q}_{so,EVA} = \dot{V}_{so} \cdot \rho_{H_2O,so} \cdot c_{p,H_2O} \cdot (t_{so,in} - t_{so,out}) \quad (2)$$

$$\dot{Q}_{hw} = \dot{V}_{hw} \cdot \rho_{H_2O,hw} \cdot (h_{hw,in} - t_{hw,out}) \quad (3)$$

$$COP = \frac{\dot{Q}_{dh}}{\dot{Q}_{hw}} \quad (4)$$

$$SPF = \frac{\int_{\tau=0}^{\tau end} \dot{Q}_{dh} \cdot d\tau}{\int_{\tau=0}^{\tau end} \dot{Q}_{hw} \cdot d\tau} = \frac{Q_{dh}}{Q_{hw}} \quad (5)$$

Figure 4 shows exemplarily the the monitored data of week number 15 in 2021. In the first diagram the energy flows are shown. The energy output (energy of absorber, condenser and heat recovery, red line) which was delivered to the heat distribution system ($\dot{Q}_{dh}$) was rather constant at around 7.5 MW, while the input energy at the desorber ($\dot{Q}_{hw}$, green line) was at approximately 4.5 MW. The blue line which shows the recovered heat flow from the flue gas ($\dot{Q}_{so,EVA}$) can be seen as "free energy" and was at approximetlly 3 MW. In the second diagram the COP is shown, which was between 1.7-1.8. Furthermore, in the third and fourth diagramm the corresponding measured volume flow rates and temperatures are shown.

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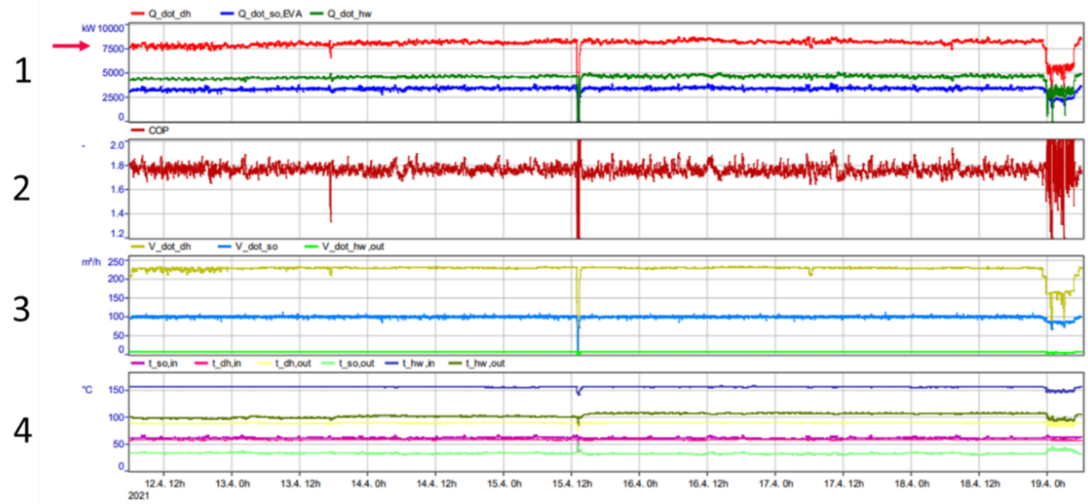

Figure 4: Energy flows (1), COP (2), volume flows (3), temperatures (4) of the AHP in week number 15, 2021

It can also be seen that the performance of the AHP was quite stable and only deviated a few times from the (nominal) operating point. On the 15th of April the AHP was shut down and restarted and on the 19th of April the operating point was changed to partial load for a few hours. Nevertheless, these deviations mainly happened in the startup phase.

Figure 5 shows the monthly energy in- and outputs of the AHP from January 2021 to December 2021. It should be noticed, that there is some missing data in March, April and May 2021. To account for the missing measurement data, the monthly values had been extrapolated (shaded bars) based on a monthly average. However, in the monthly comparison it is shown that the operation of the AHP is rather constant since August 2021. Due to external factors (limited input energy from the biomass plant of the cellulose manufacturer due to a reduced production), the AHP was mainly operated in a partial load mode at around 6 MW and therefore produced less energy than expected. Within 2021 the AHP supplied ≈51.5 GWh (including extrapolation) to the district heating network. For the winter season 2022/2023 it is planned that the AHP will be operated at nominal load of about 8 MW.

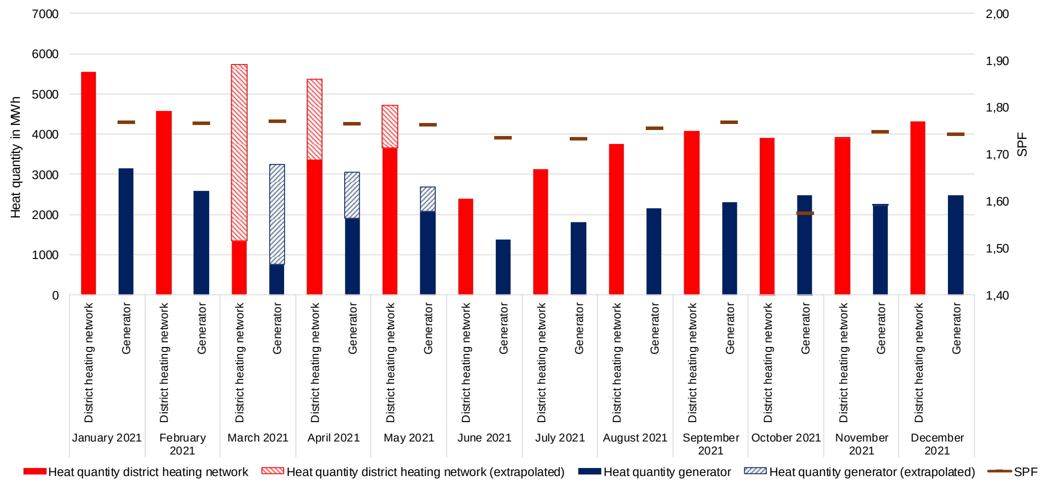

Figure 5: Energy in- (red bars) and output (blue bars) of the AHP

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3. Energy supply – scheme of the heat supply system:

The heat supply in the district heating network in Salzburg is supplied by 9 cogeneration plants which are powered by natural gas, oil and biomass. In the last years the amount of natural gas an oil was reduced and of biomass increased. Furthermore, waste heat potentials are located and if possible integrated into the district heating network. Therefore, the share of renewable sources should be significantly increased in the coming years.

4. Flexibility – scheme and control strategy of the system:

Various heat generation plants, which are partially cogeneration plants, supply the DHNs of Hallein and Salzburg. Biomass, waste heat, natural gas and fuel oil are used as energy sources. Due to optimisations in the last years, the use of fuel oil has been reduced to a minimum. The plants are selected for operation are chosen based on a superordinate operation strategy. This strategy includes, among others, the operating costs of the plant and the fuel, the current load and the expected load profile as well as the CO_2-emissions related to the operation of the plant.

Due to the fact that the AHP uses waste heat and is driven by biomass, the heat supplied to the DHN can be considered as CO_2 neutral, thus reducing the average CO_2 emissions of the DHN. Furthermore, the flue gas of the biomass cogeneration plant should be cooled as much as possible in order to condensate water vapour of the flue gas and reduce steam clouds to an absolute minimum. Finally, the ramp-up and ramp-down of the AHP takes some time, which also leads to losses. For these reasons the AHP is in general operated at its highest possible capacity and as much as possible, preferring the operation of the AHP over other heat generation plants.

5. Description of the business model with a flexible HP-operation

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6. Results of the project[4]

After a few challenges during the implementation phase, the AHP has proven its functionality. To compare the CO_2-emissions of the waste heat utilization with an AHP integrated in a biomass cogeneration plant a life-cycle-analysis was carried out. For the reference system a standard district heating network in Austria with an average CO_2-emission of 200 g CO_2/kWh was taken. For an annually delivered heat of ≈51.5 GWh (2021) to the heat distribution network ≈10300 $tCO_{2,äq}$ would have been caused by assuming a standard CO_2-emission of the average Austria district heating networks. By integrating an AHP for waste heat utilization in a biomass cogeneration plant the annually CO_2-emissions can be reduced to ≈200 $tCO_{2,äq}$ which is basically caused by providing the driving heat (steam from the biomass plant) for the AHP.

[4] Data partially from:

- Beermann, M., 2022. Lebenszyklusanalysen Demonstratoren ThermaFLEX. ThermaFLEX – Final Meeting, 18th October 2022, Wien.

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7. Challenges / socio economical barriers and opportunities

The most vulnerable part of the AHP is the generator due to high temperatures and the corrosiveness of the H2O/LiBr solution together with air entering the AHP via leakages. As the pressure in AHPs is below the atmospheric pressure an air intake can occur. To reduce the amount of air in the AHP vacuum pumps are always in operation.

During the desorption process the concentration of LiBr increases in the solution which also increases the corrosiveness of the solution. Therefore, it is necessary to choose a material for the generator heat exchanger which withstands high temperature and is resistant against corrosion. Operating the AHP at its operating limit accelerates the corrosion and therefore possibly leads to a reduced life time of the AHP. In a predecessor of the current AHP damages at the generator occurred which increased the maintenance and repair effort. Therefore, for the current AHP in operation a different generator design was chosen in order to reduce the corrosion rate in the generator.

8. Additional information: Flexibility options

Contents: district heat pump

Share of heat sources (in %)	1. Heat source: Waste heat (flue gas)	100 %
Share of power supply (power grid, PV-units at site, wind turbine at site etc.)	1. Power supply: Steam from the biomass cogeneration plant 2. Power supply: Electricity to drive the solution pump (negligible: <1 % of the heat output)	100 %
System boundary by calculation of the SPF	Nominal operating conditions: District heat network in-/outlet temperature Heat source in/outlet temperature Driving temperature	63 °C / 90 °C 60 °C / 30 °C 162 °C
Seasonal performance factor in design and measured (SPF)		1.73 (measured, 2021)
COP of HeatPump at the design condition (point in °C or traverse as function in °C), independent of site boundaries	Design / nominal operating conditions: District heat network in-/outlet temperature Heat source in/outlet temperature Driving temperature COP	63 °C / 90 °C 60 °C / 30 °C 162 °C 1.68
COP incl. all peripheral devices at source and sink side		unknown
Location of heat pump (e.g. heating centre (centralized heating installation), using existing infrastructure etc.)		Heating centre at AustroCel in Hallein

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Contents: district heating network[5]

Land area for buildings served by heat distribution network	≈27 (Hallein) ≈66 (Salzburg, if network connection is active)	km²
Total heated floor area in buildings connected	≈22.000 (Salzburg)	connections
Trench length for heat distribution network	≈27 (Hallein) ≈230 (Salzburg, if network connection is active)	km
Heating capacity	380 (Salzburg)	MW
Heat annually supplied into the heat distribution network	unknown	MWh/a
Heat annually delivered from the heat distribution network	≈810.000 (Salzburg)	MWh/a
Annual average supply temperature in the heat distribution network	unknown	°C
Annual average return temperature in the heat distribution network	unknown	°C
Heat generation based on renewable sources	≈250.000 (Salzburg)	MWh/a
Share of renewable sources	30	%

Contents: description of energy storage system

Energy storage type:	Energy storage in the heat distribution network
Storage size (capacity):	30.000 m³ (Salzburg)
Term of flexibility:	unknown
Storage temperature (thermal energy storage)	unknown

[5] Data partially from:

- Schuller, S., 2018. Demonstratoren der Salzburg AG in ThermaFLEX. ThermaFLEX - Kick-off Meeting, 17th December 2018, Graz.
- Salzburg AG, 2020. Fernwärmeerzeugung Salzburg: Wo unsere Energie und Wärme herkommen.https://www.salzburg-ag.at/content/dam/web18/dokumente/unternehmen/erzeugung/Kraft-Waerme-Kopplung.pdf (23.11.2022).

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Contents: indicators for flexible heat pump operations

Cost (potential cost saving)		
Thermal level (losses of thermal comfort)		
Load matching factors (load supply & load cover factors)		