FROM TECHNOLOGY DEVELOPMENT TO (PRE-SERIES) PRODUCT – THE EPACK HYBRID

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ABSTRACT

Worldwide there is a potential resource of 4.300 GW_{th} of waste heat e.g. from engine power plants or industrial processes available that is nowadays left to dissipate naturally and equals the loss of 100 million litres of Diesel per hour, which show calculations based on data of DOE and Diesel & Gas Turbine World Wide.

The Organic Rankine Cycle (ORC) technology utilizes waste heat e.g. from biogas power, geothermal power and CHP plants or industrial processes and converts it CO_2-free into electrical energy. ORC plants and modules are commercially available and economically profitable only in large and medium scale applications with electric power outputs of 50 kW_{el} and larger. However, particularly large numbers of similar small scale waste heat sources, for example gas/diesel engine product families in CHP applications offer a huge potential for the implementation of standardized ORC modules. Especially in those applications part of the engine waste heat is often directly used e.g. in small heating networks or for fermentation and drying processes in biogas plants. This usually excludes the operation of an ORC module even if there is still a significant amount of waste heat that can be utilized only seasonally or is dissipated.

Considering such frequently found plant configurations the Orcan Energy GmbH has developed a flexible small scale "CHP-ready" ORC module – the ePack Hybrid – that can provide both, heat and power from the waste heat source by variable operation of an electricity-generation-only- and a CHP-mode. By the integration of a working fluid-to-water- and a fluid-to-air-condenser, the ePack Hybrid can provide hot water up to 80 °C if required or dissipate the condenser heat in the environment. According to the operational conditions (CHP share, required feed temperature, ambient air, etc.) the ePack Hybrid has a flexible net electric power output of 12 kW to 22 kW.

In order to take into account also further important market requirements as there are inter alia needs for excellent cost efficiency, high reliability, low maintenance effort and easy plug & play installation, the ePack design is based on standard off-the-shelf components and on innovative and patented system engineering. These technology features make the ePack Hybrid solution not only economically highly efficient but also outstandingly reliable.

With excellent results from extensive system tests and broad field experience with our ORC modules the ePack Hybrid is ready for commercialization and available as pre-series product.

The paper will explain the unique concept of the ePack Hybrid, and data from reference installations and operational experience of the installed ePack fleet will be presented.

1. THE EPACK HYBRID CONCEPT

The ePack Hybrid concept is based on technology experience gained during more than eight years of ORC development, and on specific requirements for small-scale ORC modules that are given by the market.

1.1 Market requirements

The focus market for the ePack Hybrid is the utilization of small-scale waste heat sources of internal combustion engines (ICE) in biogas plants, and of industry and heating processes. In these applications it is in many cases crucial to not just utilize the available waste heat for power production but to provide plant operators or process owners with the flexibility to still use part of the waste heat for heating purposes or as process heat,e.g. for fermenter heating, seasonal district heating or for drying processes (see Figure 1). The required temperature level for these heating purposes is between 50 °C (fermenter heating, drying processes) and 80 °C (district heating on cold winter days) while ICEs usually deliver hot water with a temperature level of 90 °C. In addition, the heat demand exists only seasonally and/or covers only a small part of the total available waste heat. Both, the seasonal character of heat demand and the requirement for temperature levels below typical ICE hot water temperature leaves a high potential for using ICE waste heat for power generation.

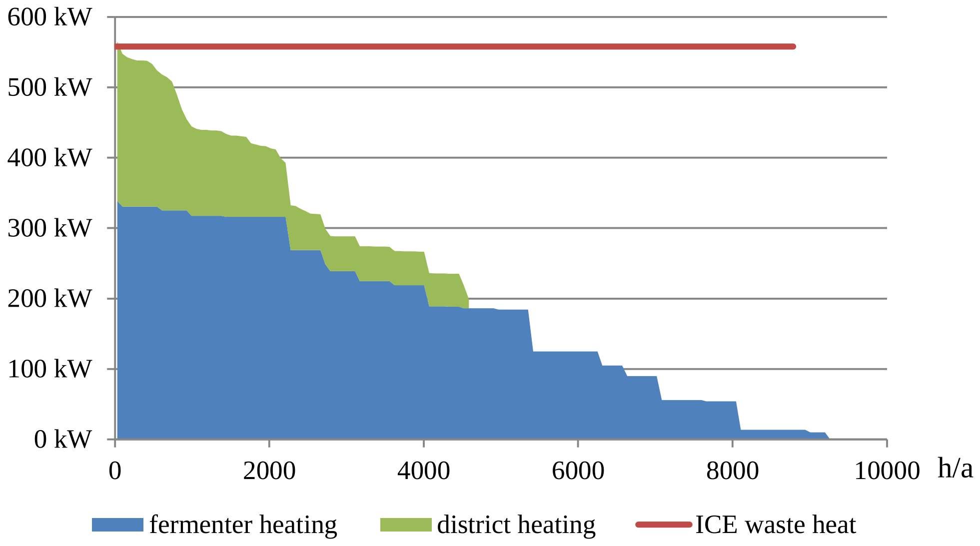

Figure 1: Typical annual heat demand for fermenter and district heating in a biogas plant

Besides this, further technical, operational and economical requirements are given for an ORC module. Amongst others, the most important ones are:

- Availability: firstly, the customer requires an ORC availability of more than 90 % and secondly it is mandatory for each ORC module not to influence the availability of the ICE it is coupled to. Thus, the ORC has to be operated and installed in such a way that it does not prevent the ICE from running in case of a shut down.
- Cost efficiency: an ORC module has to fulfil the typical requirements for return on invest (ROI) that are about three to four years in biogas applications but a maximum of two years in industrial applications. This includes all costs for the ORC module from investment to installation costs (CAPEX) and costs for service and maintenance over the ORC lifetime (OPEX).

- Plug & play installation: to ensure a fast and cost efficient installation, the ORC module has to be designed with a minimized number of simple interfaces. With a closed refrigerant cycle only interfaces for hot and cold water have to be connected to the existing ePack system. The electrical connection has to fulfil the requirements given by the transmission system operators for electricity. The engine shut down that is necessary for the ORC installation has to be as short as possible.

1.2 Product development – from market requirements to product

The development of the ePack Hybrid concept at Orcan Energy is based on long-term experience with the development of small scale, plug&play ORC products. The most important development principle thereby is to use off-the-shelf industrial standard components as basis for the ORC modules. This requires intensive tests for component qualification regarding application limits and reliability in order to fully rely on the given component's lifetime also in the ORC application.

The market driven product development at Orcan follows a stage gated product evolution process (PEP) which allows for a targeted and efficient development based on clear specifications and requirements. The stage-gate model not only improves the speed and performance of development but also reduces the risk of failure. It is based on testing prototypes at different levels of product maturity and immediately implementing the testing results in the following development steps. The PEP process also offers the possibility to quickly bring in modifications to the product in case the market requirements slightly change during the product development phase.

By such methodology, when launching the first ePack Hybrid Orcan Energy already had more than two years of field experience with in total more than 25 ePacks running more than 100.000 operating hours at a high availability level of nearly 95%, and generating more than 1 GWh_{el} of CO_2-free electricity.

1.3 Technology and operation concept of the ePack Hybrid

The ePack Hybrid converts waste heat in CO_2-free electric power and can provide heat at the same time in a CHP operational mode. If there is no heat demand, the heat can be dissipated into ambient air by the ePack Hybrid working in an electricity-generation-only mode. To enable both operational modes, two condensers – a water- and an air-cooled condenser – are incorporated in the ePack Hybrid. The water-cooled condenser is a usual plate heat exchanger, while the air-cooled condenser is constructed from micro-channel coils. The microchannel coils are directly integrated into the ePack casing, and the air volume flow which is needed for cooling of the coils is provided by two fans on top of the ePack.

Figure 2: The ePack Hybrid

According to the current heat demand the low pressure vapour flow after the expansion machine (screw expansion machine) is either directed into the water- (if heat is needed) or into the air-cooled condenser or it is split up between both condensers, if only part of the heat is needed. Instead of using valves or other mechanical devices to ensure the correct operation mode, thermodynamic effects are used and the amounts of heat in both condensers are controlled by the rotational speed of the fans. In all cases two important operation parameters have to be maintained:

- Suitable distribution of fluid in both condensers in order to ensure 100 % CHP operation, 100 % electricity-generation-only operation and all operating situations in between,
- Prevention from cavitation by sufficient sub-cooling of the working fluid in both condensers.

In order to control the ePack Hybrid condensation part only by thermodynamic effects, both condensers are connected in such a way that the pressure difference between them is equalized. The required filling level in both condensers for a sufficient sub-cooling of the fluid is ensured by a specifically calculated difference in height between the water and the air-cooled condenser. The gravitational pressure difference of the fluid due to the different heights of the two condensers than ensures the sufficient filling of the condensers. During operation the working fluid always flows into the "colder" condenser with the lower pressure level, which is at the same time always the condenser where the working fluid has to be. Thus the ePack Hybrid operation is in an intelligent way self-regulating.

- Electricity-generation-only and CHP-only mode: in this mode the heat cannot be used in the heating network and has to be dissipated into ambient air. Therefore the working fluid has to be condensed in the air-cooled condenser. This condenser is always the one with lower pressure level, because in this operation mode it's cooled by the air volume flow from the fans. The water-cooled condenser is not operating and has the temperature of the working fluid vapour after the expansion machine and thus a higher condensation pressure than the air-cooled condenser. In CHP-only mode the fans are not operating and vice versa the air-cooled condenser has the temperature of the working fluid after the expansion machine and therefor the higher condensation pressure. Thus all the working fluid is automatically directed into the water-cooled condenser.

- Operation modes with partial heat demand: these operation modes can be covered flexibly by operating the fans with a distinct rotational speed, such that both condensers have the same condensation pressure. The control parameter is the temperature of the return flow from the heating system. If this temperature is increasing, the heat demand of the heating system is lower; if it is decreasing the heat demand is higher. By increasing the rotational speed of the fans, more heat is dissipated into ambient air and less heat is feed into the heating system by the water-cooled condenser and vice versa.

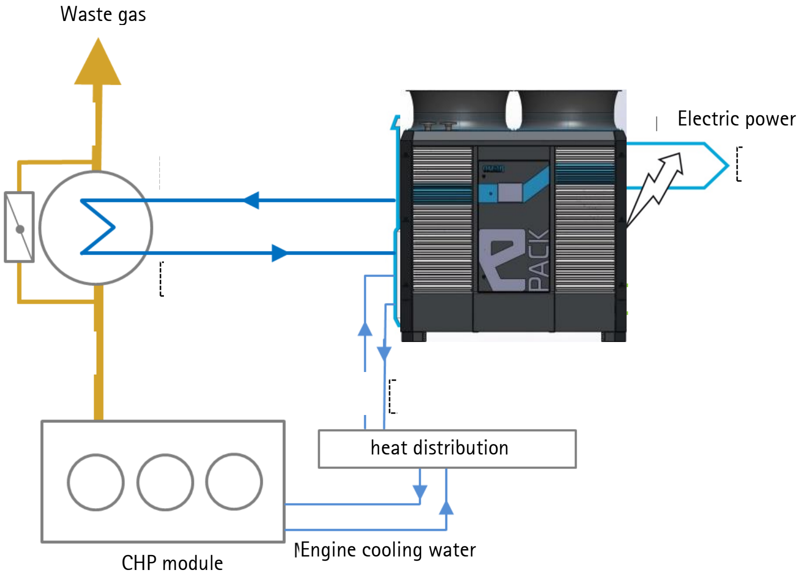

Figure 3: Integration of the ePack Hybrid into a ICE-CHP power plant with heating system

Figure 3 shows the integration of the ePack Hybrid in an ICE-CHP power plant with a heating system.

Based on performance measurements of several ePacks in operation and on well-known component parameters, the ePack Hybrid concept was firstly simulated and then completely designed, engineered and realized and tested in-house at the factory acceptance test bench. The simulation results are shown in Figure 4. They were calculated at a constant ambient temperature of 15 °C using the simulation software EES (Engineering Equation solver) with component models using the semi-hermetic modelling approach of the expansion machine as proposed by Quoilin and Lemort.

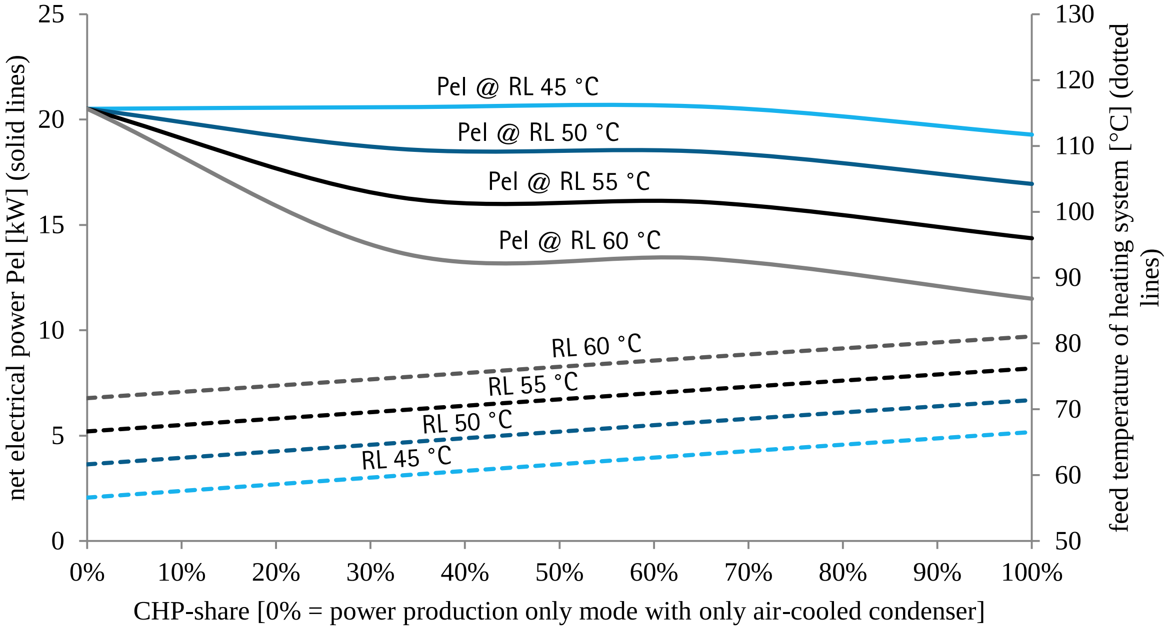

Figure 4: Simulation results for the ePack Hybrid in different operation modes

The net power output of the ePack Hybrid is mainly determined by three parameters: the CHP share, the return temperature of the heating system and the rotational speed of the fans. The maximum net power output can be gained in electricity-production-only mode with a CHP share of 0 %. In this mode lowest condensation pressures can be reached and therefore the enthalpy difference over the expansion machine is at its maximum. With increasing CHP share the net power output decreases due to increasing condensation pressures. Higher return temperatures from the heating system reinforce this effect. Between a CHP share of 40 % to 70 % the net power output has a plateau because the decreasing power output (due to higher condensation pressure levels) is partly compensated by lower power demand of the fans (due to lower rotational speed). Depending on the return temperature of the heating system, the ePack Hybrid can deliver feed temperatures of up to 80 °C, which is absolutely sufficient for most modern heating purposes.

By adjusting the feed temperature to the lowest level required for a specific application, the customer is able to maximise the power output of the ePack Hybrid.

2. OPERATIONAL EXPERIENCE

Orcan Energy has gained operational experience with small scale ORC modules since 2012. Up to now more than 20 ePack modules are installed in Germany in different applications, mainly in biogas power plants or as add-on to industry processes.

2.1 First operational experience with the ePack Hybrid at the factory acceptance test bench (FAT)

In order to check functionality, performance and quality of the ePack modules before installation and commissioning at a customer's site Orcan Energy has installed a test bench (factory acceptance test – FAT) where the ePacks are operated with hot water up to around 20 % of maximum load. This test bench was also used to verify the concept of the ePack Hybrid in real operation. Two different operation modes – electricity-generation-only, CHP-only and especially the switching process between these two modes – were tested in the FAT. Some exemplary results are given in Figure 5.

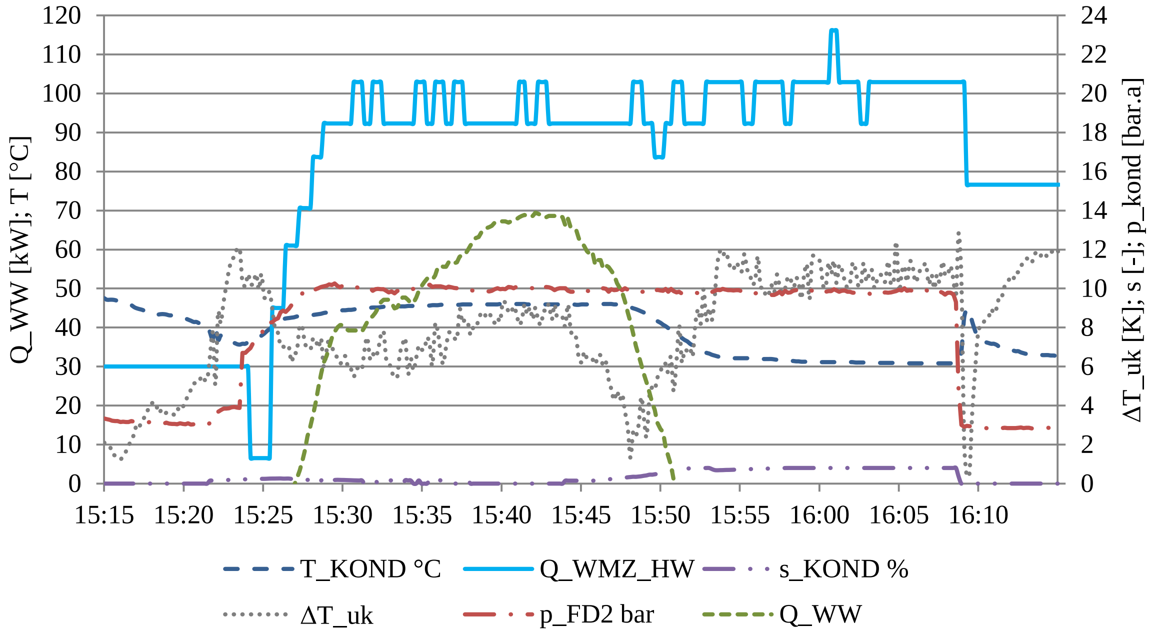

Figure 5: First test results of the ePack Hybrid operation in the FAT (electricity-generation-only mode, CHP-only mode and switching process)

Figure 5 shows that the ePack Hybrid steadily operates in both modes. The ePack Hybrid is starting in the CHP-mode with a heat input (Q_WMZ_HW) of around 100 kW. The fans are not running (s_KOND = 0 %) and the condensation heat is transferred to the heating system (Q_WW). At 15:45 the ventilators are starting and the condensing heat is transferred to the ambient by the integrated air cooled condenser. Therefore the heat transfer to the heating system (Q_WW) decreases to zero. The condensation temperature (T_KOND) is higher in the CHP-only mode. An indicator for the degree of operational stability is the subcooling (ΔT_uk) of the working fluid in the condensers. In an optimal operation mode the amount of subcooling should be the same in CHP-only and electricity-generation-only mode. The given test results reflect that the subcooling is around 8 K in CHP-only mode and 10 K in electricity-generation-only mode. During the switching process the subcooling slightly decreases but does not influence the cycle stability since it stays above zero and no cavitation problems of the feed pump are occurring.

Simulations and these tests in the FAT have shown that the ePack Hybrid is not only a sound concept but also working in a stable and reliable way even under changing conditions.

2.2 Field experience

The first ePack Hybrid is currently being installed at a customer's site in Germany. However, operational experience of the already installed fleet of Orcan ePacks with totally more than 100.000 operating hours already provides sufficient operational data with same or similar system components to answer the main questions regarding the ePack Hybrid's dynamic and part load operation at different ambient conditions. Especially the operation experience of three ePack sites can be transferred to the ePack Hybrid: two ePacks in biogas applications with an integrated condenser, which are basically the same ePack modules as the ePack Hybrid just without the water-cooled condenser, and one ePack which is integrated in an industrial heating system.

2.2.1 Dynamic and part load operation under different ambient conditions

Reliable operation of the ePack modules is crucial since the ePack has no influence on its heat source (the ICE) and has to follow the heat supply. It is also very important that the ePack is able to deliver electrical energy under different ambient conditions – at cold winter days as well as at hot summer days. The ePack is designed for a net electrical power output of 20 kW at an ambient temperature of 10 °C. Figure 6 shows an example of an ePack operating in the field under different conditions. If the heat source is stable, the ePack operates smoothly generating a stable net electrical output, if the heat source is fluctuating, the power output is fluctuating as well: the ePack operates reliably in a dynamic mode. At ambient temperatures below 10 °C the ePack delivers up to 22 kW of electrical power; at ambient temperatures up to 28 °C the ePack still generates around 15 kW with the air cooled condenser. The average net electrical power output over one year is 20 kW at an ePack-availability of 95 %.

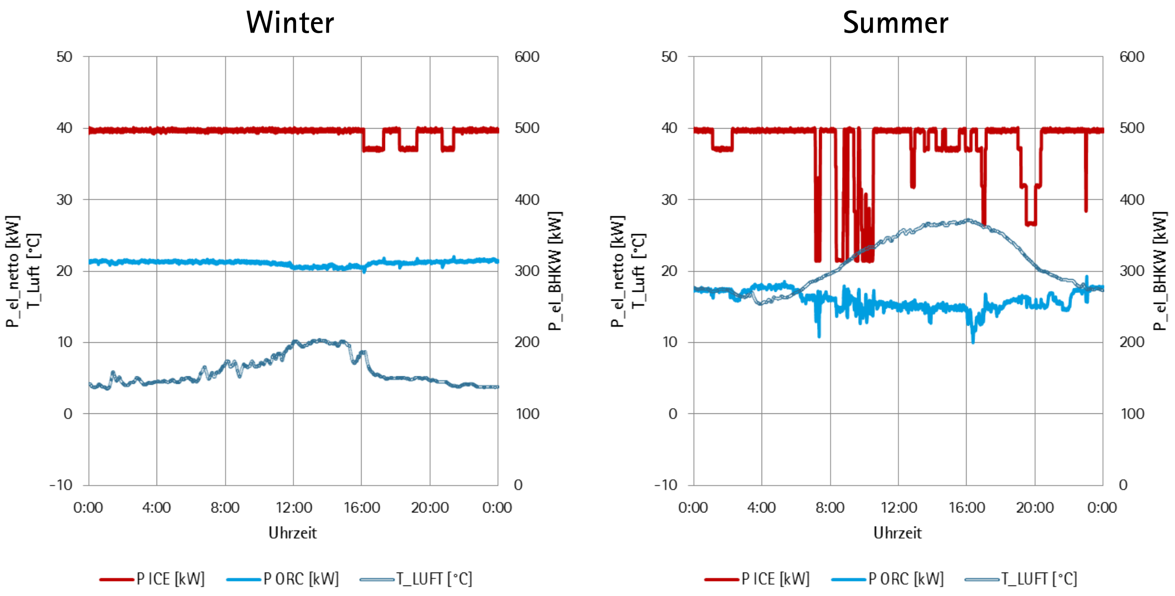

Figure 6: ePack operation in field under dynamic, part load and different ambient conditions

2.2.2 ePack operation as CHP module in an industrial heating system

When operating integrated into a heating system, the ePack performance is highly influenced by the return flow temperature of the heating system, which is the cooling temperature of the water-cooled condenser and therefore also determines the condensation temperature and pressure. In such configuration the ePack has to cope with highly fluctuating temperatures, and react to fast temperature changes, and has to deliver a maximum of electrical energy at the same time.

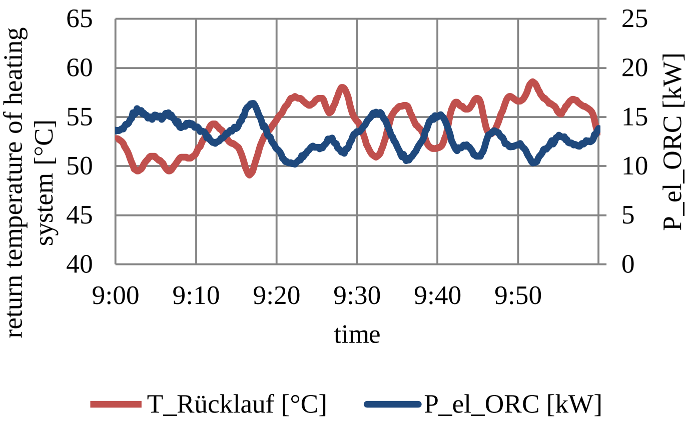

Figure 7: ePack operation as CHP module in an industrial heating system

Figure 7 shows data of an ePack operating as part of an industrial heating system. The ePack can respond very quickly to temperature changes of the heating system while still delivering a significant amount of net electrical energy of around 15 kW even at return flow temperatures (T_Rücklauf) of 50 °C to 55 °C.

3. CONCLUSIONS

The ePack Hybrid is a unique product which perfectly fits the waste heat market need of generating electricity and heat for downstream processes or district heating applications at the same time. Further significant customer requirements as in the first place high cost efficiency, but also quick and simple installation, compactness, and high reliability and availability are also fully met.

First tests of the ePack Hybrid have proven the functionality of the concept. The ePack Hybrid is reliably operating in the three different operation modes as there are: power-generation-only mode, CHP-only mode and the operational modes in between with a flexible share of CHP heat. The extensive operational experience with similar ORC modules that were sold in Germany by Orcan Energy since 2012 clearly demonstrates the reliable operation as power-generation units with an air-cooled condenser and as CHP unit with a water-cooled condenser even in highly dynamic or part load mode and at different ambient conditions. Therefore, it can be expected that also the ePack Hybrid – as it is based on same or similar components and system engineering – will operate in the same very stable and reliable way at customer sites.

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