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TES.POD® with Combined Heat & Power (CHP) production

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Azelio TES.POD with Combined Heat & Power (CHP) production

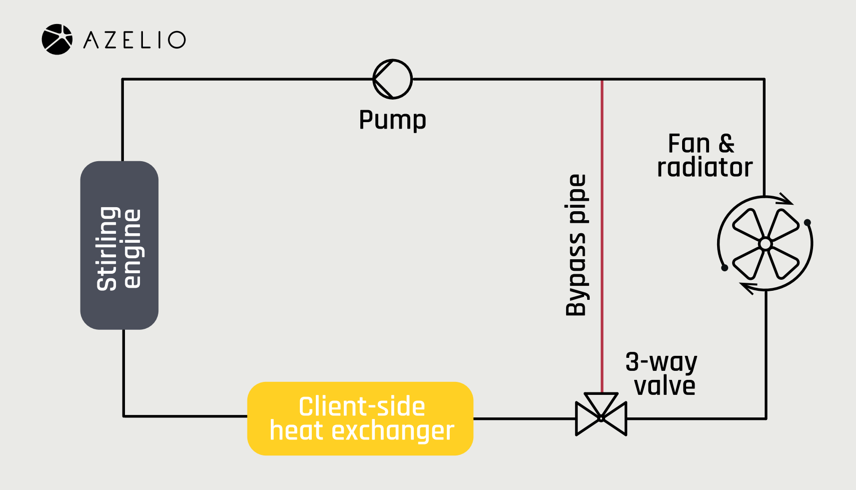
The Azelio TES.POD system is now available with Combined Heat and Power (CHP) production. This system has been successfully demonstrated at Haneberg farm in Sweden. This paper provides a description of the system and outlines its economic benefits to the LCOE.

INTRODUCTION

The long-duration energy storage system that Azelio has developed for electricity production on demand now also features heat production. This is commonly known as Combined Heat and Power, or CHP. The residual heat from the system, when the TES.POD is in operation for electricity generation, is currently available at temperatures up to 60°C and is planned to meet 75°C in 2028. This low-temperature heat can be utilised in many customer applications such as agriculture, communities, and industries. In CHP mode, one TES.POD unit produces around 11 kW electricity and 25 kW thermal power throughout the 13 hour discharge cycle.

The Stirling engine is powered by heat from the thermal energy storage and cooled by air in a radiator, in normal electricity production mode. The utilisation of residual heat from the TES.POD is realised through the addition of a client-side heat exchanger in the engine cooling circuit, as shown in Figure 1. This enables the client to extract all low-temperature heat necessary to cool the Stirling engine without engaging the radiator. If the heat demand is lower than the engine cooling demand, the radiator is engaged by the 3-way mixing valve to control temperature levels in the system. The algorithms in the control system of the TES.POD automatically actuate the mixing valve for optimal operation. The algorithms ensure quick start-up and fast response to changes in the client-side heat demand. Furthermore, the control system is designed to minimise power consumption of the cooling fan during hybrid operation.

Figure 1 PI&D for the CHP cooling circuit



PROOF OF CONCEPT

The first commercial TES.POD with CHP was installed and operated at Haneberg farm, located in eastern Sweden on the Näshulta lake (Figure 2). One of the activities at this agricultural farm is to produce grain, which is dried to improve preservation after the harvest in August and September. The grain is currently being dried using a fossil fuel-fired dryer. The CHP proof of concept aimed to replace part of the fossil fuel consumed during the drying process with clean residual heat from the TES.POD.

The drying process requires hot air at 73°C. Normal ambient temperatures in August are around 15°C, hence the heater needed to heat ambient air through the dryer by 58°C. Azelio's CHP system reduced the required temperature rise in the fossil-fired heater by preheating the air, while also providing electricity to the farm. A single TES.POD saved approximately 10% of the fossil fuel used in the dryer. Adding more TES.POD units would allow substitution of up to 60% of the fossil fuel with renewable heat.

Haneberg was the first TES.POD unit in CHP operation and was established as a research project, together with the Swedish Energy Agency.

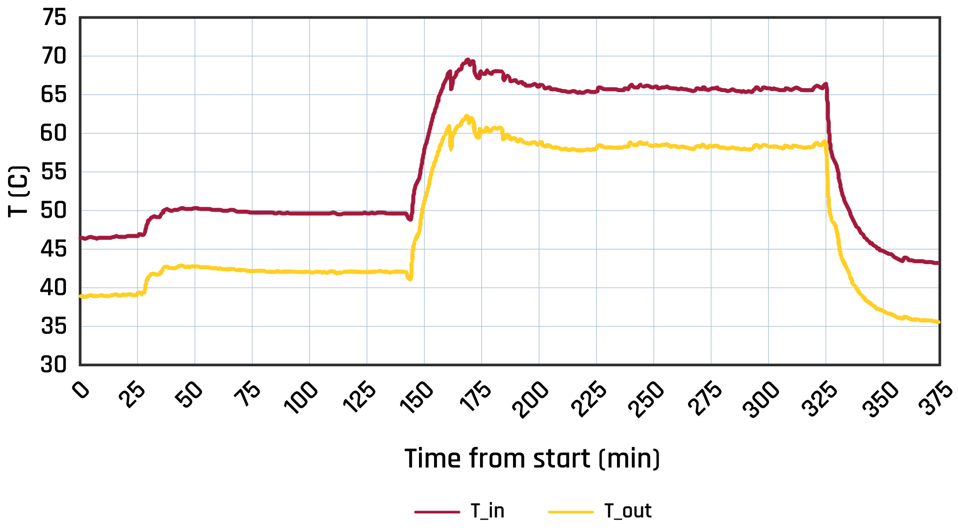
Figure 2 The Haneberg proof of concept installation

The graph in Figure 3 shows results from an operational test performed at the Haneberg project site in September.

The scope was to demonstrate that heat from the engine could be extracted at different temperatures, namely 50°C and 65°C. Lower temperatures are also possible if required.

Figure 3 shows the engine coolant before (T_in) and after the heat exchanger (T_out), where heat transfer to the client-side heat exchanger medium takes place. As shown below, the test was successful, as the engine coolant at heat exchanger inlet held a constant profile at both 50°C and 65°C. Having transferred heat to another medium, the engine coolant exits the heat exchanger at a lower temperature. The final temperature reached by the other medium depends on the mass flow, inlet temperature, heat exchange area and characteristics, as well as the heat extraction temperature on the engine side. For example, a heat exchanger with a 5K pinch-point would supply air at 60°C when the engine coolant is at 65°C, if provided the proper mass flow. The heat delivered by the engine during the test run was approximately 25 kW at nominal power.

Figure 3 CHP operating temperatures from Haneberg



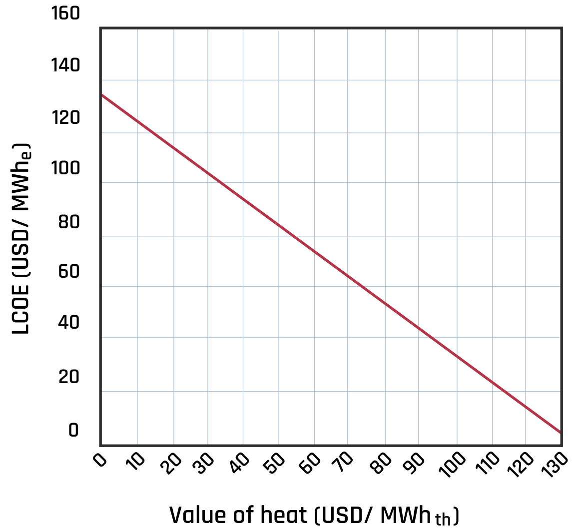
ECONOMICS

Operating the TES.POD in CHP mode offers significant economic advantages, depending on the value assigned to heat. Simulations of a PV array and CHP TES.POD clusters, operating to supply both heat and electric power, were used to analyse the impact of different values of heat (USD/MWh$_{th}$) on the Levelised Cost Of Electricity (LCOE, USD/MWh$_e$).

The results of this analysis, as seen in Figure 4, show the strong and linear decrease of the LCOE with increased value of the heat. Next generation TES.POD with new engine concept, combined with adopted storage to enable a significantly more energy-efficient system with lower cost base, will even further reduce the LCOE compared to the numbers provided here.

More details regarding this study are available in the Azelio prospectus published in September 2022 (www.azelio.com/investors/rights-issue-2022).

Figure 4 LCOE as a function of value of heat

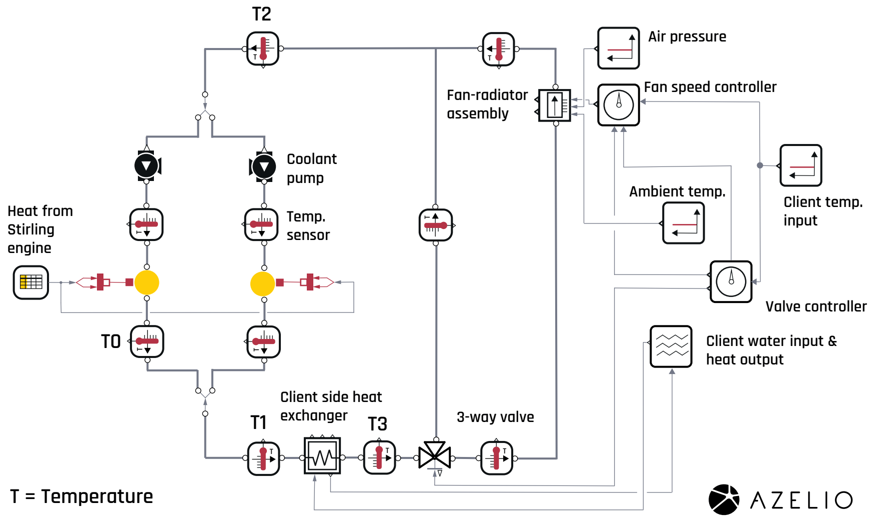


Compared to a standard TES.POD supplying only electricity, the CHP variant requires a marginally higher initial investment per unit per disacharge, as additional components are needed, for example, mixing valve, piping, and heat exchanger. However, the energy output per unit per discharge, in the form of both electric and thermal energy, increases significantly compared to the standard design. As a result, the CAPEX per unit per kWh energy supplied per discharge decreases by more than 60%.

VIRTUAL DEVELOPMENT & CONTROL STRATEGY

Advanced systems modelling has been utilised to design the residual heat water circuit, and to design and virtually test the control algorithms, as shown in Figure 5.

Figure 5 System model of the cooling system of TES.POD CHP



For the TES.POD CHP variant, a new controller has been developed. The control logic guarantees optimal cooling of TES.POD's Stirling engine at any time; independently if the heat sink is ambient air or cooling water from the client, or a combination of both. The controller manages both the coolant mass flow through the mixing valve, and the speed of the radiator-fan that determines the level of cooling. The mixing valve controls how much cooling water should be passed through the bypass pipe.

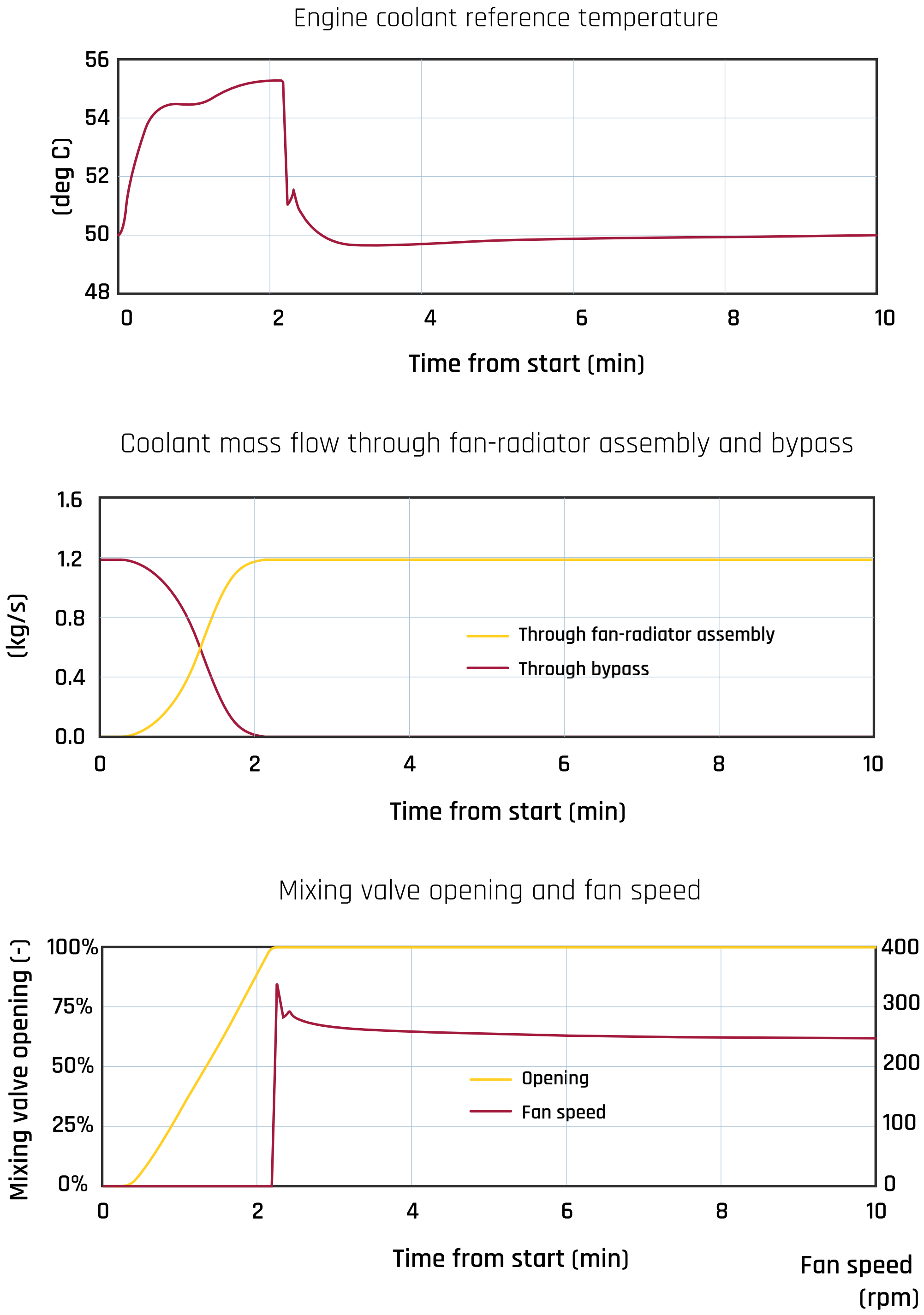
Both the mixing valve setting, and the fan speed, are dependent on the difference between the engine coolant temperature at the inlet to the Stirling engine, and the setpoint value for the coolant. A positive temperature difference indicates the engine coolant is overheated, and the valve opens in order for more coolant to flow to the fan-radiator. A negative temperature difference represents an excessively cooled engine, in which case the fan slows down, and the mixing valve closes to reroute the coolant flow to the bypass pipe. In this way, the parasitic power consumption required to operate and control the fan decreases, improving the TES.POD net efficiency.

The mixing valve is closed towards the fan-radiator assembly whenever the TES.POD is operated in CHP mode, and sufficient heat is removed in the client heat exchanger. Note the fan-radiator assembly is not used in this instance. The opposite operating condition occurs whenever the TES.POD is supplying electric power only, as there is no useful water mass flow though the client heat exchanger. In this case, the mixing valve is completely open towards the fan-radiator assembly, the coolant flows exclusively in this direction, and the fan is operated. A hybrid operational mode is also possible. In this scenario, the TES.POD is cooled by both the client heat exchanger and the fan-radiator assembly. This configuration can arise when the water-coolant heat exchanger cannot provide the required heat sink capacity, and the support of the fan-radiator assembly is needed to avoid overheating of the engine coolant.

Plots in Figure 6 illustrate an example of the cooling system control logic. Here a single TES.POD unit is operated in CHP mode, delivering both electric power and heat. Ambient conditions are constant at 20°C. The TES.POD is initially cooled, only through the client heat exchanger. More specifically, cooling water on the client side enters the heat exchanger with a constant mass flow and a constant temperature, 0.8 kg/s and 40°C respectively. The coolant flow on the TES.POD side of the heat exchanger remains constant at 1.2 kg/s. At start-up, the mixing valve is fully open towards the bypass pipe, and the coolant flows exclusively through the bypass pipe. The water mass flow is, however, insufficient to cool the Stirling engine, and the engine coolant temperature quickly increases from the initial value of 50°C to around 54°C.

The objective of the controller is to keep the engine coolant temperature at its setpoint value of 50°C, and it becomes necessary to open the mixing valve and start the fan. This operational change of the cooling system takes place in less than one minute, with the coolant flow quickly rerouted from the bypass to the fan-radiator assembly. This process slows the temperature increase of the engine coolant without starting the fan, due to natural convection through the radiator. The coolant remains too hot, however, and the controller starts the fan, quickly adjusting its rotational speed to 250 rpm by means of a PI-controller. The coolant temperature decreases below the setpoint in less than one minute, and the system reaches steady-state operation eight minutes from the start.

Figure 6 Example of cooling system control logic in operation



Engine coolant reference temperature

Coolant mass flow through fan-radiator assembly and bypass

Mixing valve opening and fan speed

CONCLUSIONS

Azelio has developed a variant of its TES.POD that now also features heat as a product, in addition to electricity production, and this solution has been demonstrated for the first time at Haneberg farm in Sweden.

Heat can be extracted up to 60°C, and each TES.POD simultaneously produces 11kW of electricity and 25 kW heat at that temperature. The electrical power output is slightly lower when heat is co-produced at 60°C than when operating in electricity mode only, at standard atmospheric conditions. Including heat as a product with an additional revenue stream significantly reduces the LCOE, and a bespoke control system has been developed which enables the client to extract the heat from the TES.POD at any temperature and any heat load, while maintaining stable operation of the TES.POD.