Numerical Design of a Test Plant for Dynamic Analysis of High Temperature Thermoelectric Generators

Marcus Rohne[1], André Schlott[1], Vicente Pacheco[1], Jens Meinert[1]

[1] Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Branch Lab Dresden, Department Energy and Thermal Management, Winterbergstraße 28, Dresden, Germany

Introduction: Thermoelectric generators (TEG) use Seebeck's effect to directly convert heat into electricity. TEG represent, therefore, a promising option for energy harvesting of waste heat, for example in car exhaust systems. To investigate the dynamic behaviour, especially the mechanical stability, of high temperature TEG made of Mg- and Mn-silicides [1], a test facility was numerically designed and finally constructed. The aim of the simulations was to design a special heat exchanger that allows to realize high heating and cooling rates of at least 13 K/min at the hot side of the TEG. Furthermore, the system behaviour was simulated in order to predict heat losses, temperature distribution and the pressure drop of the cooling air flow. Figure 1 shows the principle construction of the test facility.

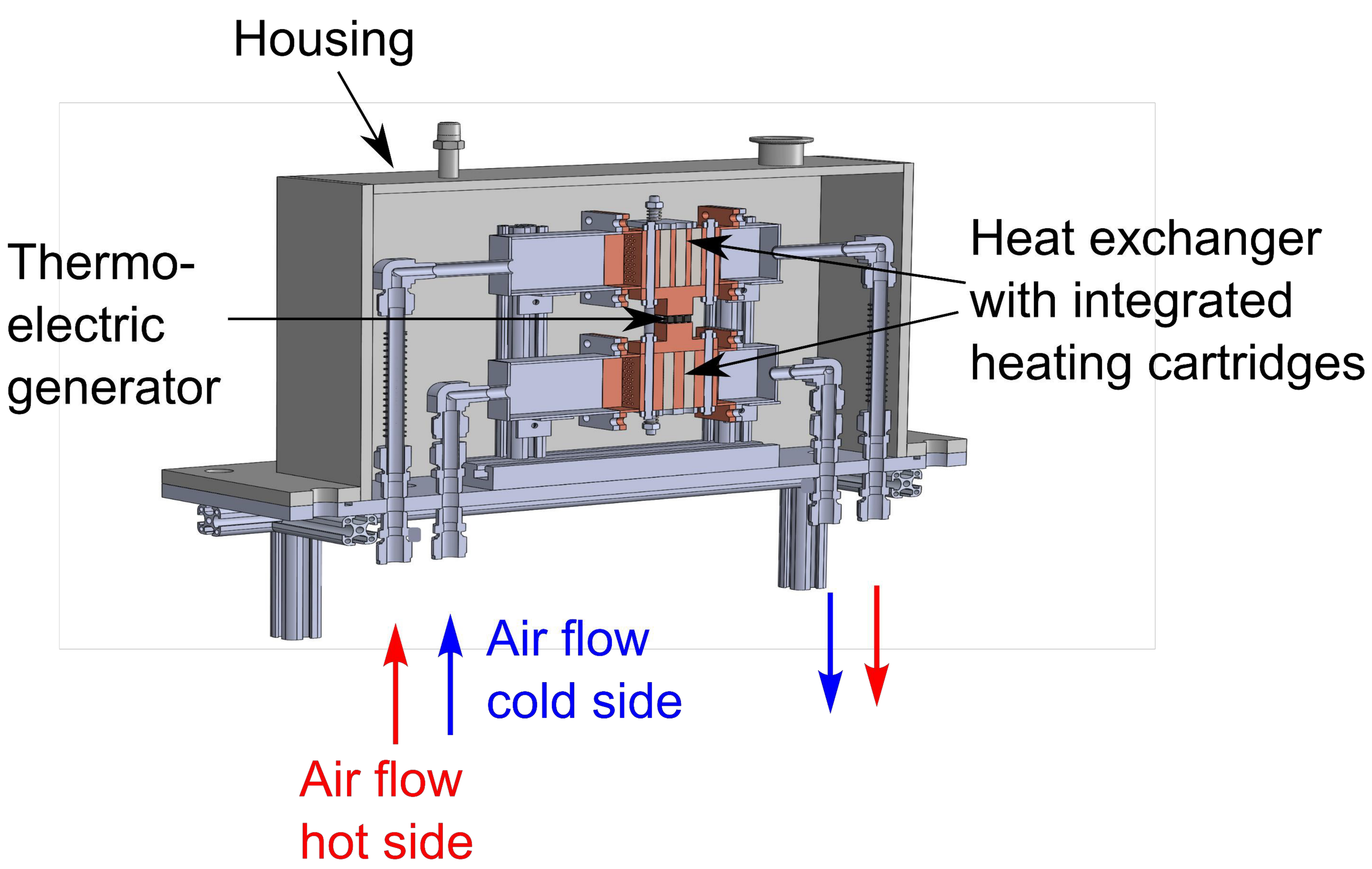

Figure 1. Principle construction of the test facility.

Computational Methods: Transient thermal simulations were performed using the "heat transfer in solids" module. The temperature at the contact surface to the TEG was calculated as a function of various heat fluxes to evaluate the system's heating behaviour. The cooling rate was determined for different geometries and heat transfer coefficients as a function of fluid flow rates. In this way, three different types of heat exchangers were simulated and compared with each other. Heat losses were calculated by defining convective cooling conditions at the outer surfaces of the heat exchangers and the flow channels. The geometry for the heat transfer simulation is shown in figure 2 (above). Furthermore, a turbulent single phase flow simulation was made in order to estimate the pressure drop of the cooling air flow (figure 2, below).

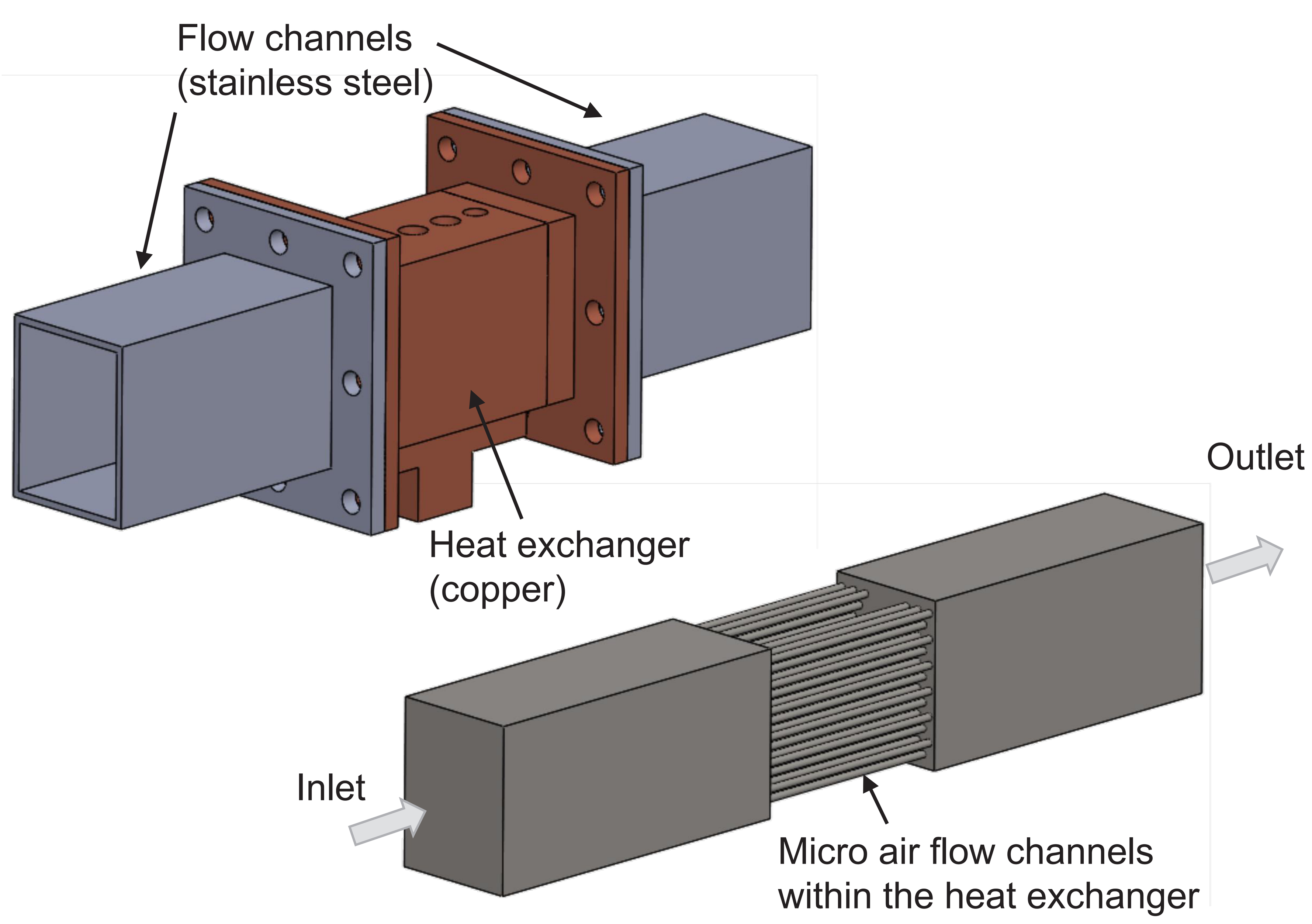

Figure 2. Geometries of the solid model for heat transfer simulation (above) and fluid model for single phase flow simulation (below).

Results: Figure 3 presents the temperature distribution at the surface of the heat exchanger and the flow channels for a hot side temperature of 600 °C. In figure 4, the streamlines of the air flow for a given flow rate of 150 Nl/min are shown.

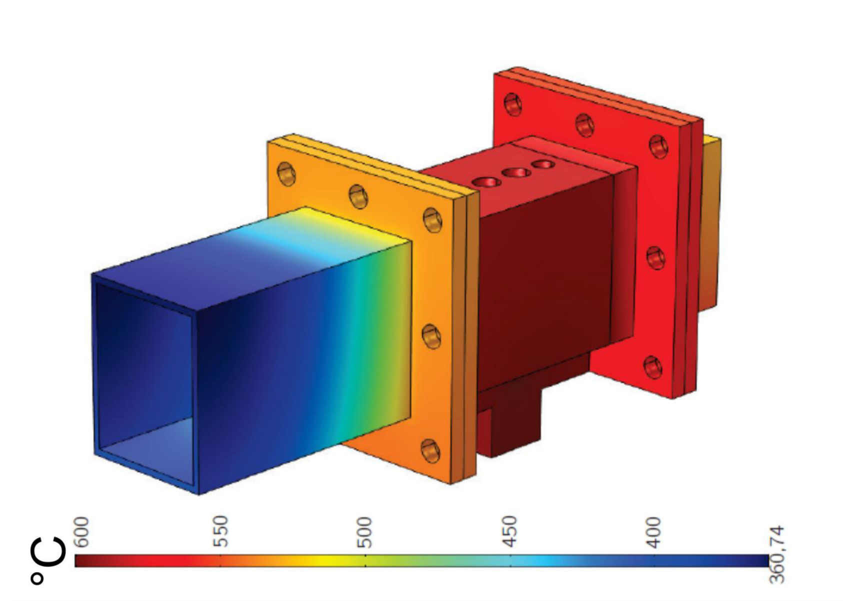

Figure 3. Temperature distribution of the hot side heat exchanger.

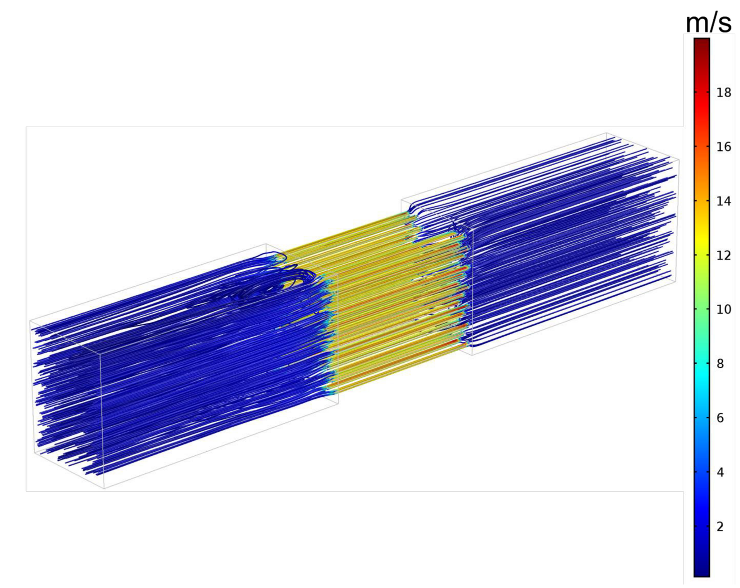

Figure 4. Streamlines of the air flow.

Based on the simulation results, the operating parameters of the test facility have been calculated (summarized in table 1). The heat exchangers finally built are shown in figure 5. They consist of sixty small flow channels and three (hot side), respectively two (cold side) heating cartridges, each with 315 W heating power. Figure 4 compares the simulation results with validation measurements and shows an excellent agreement.

Parameter	Value
Heating Power Heating rate	945 W Up to 50 K/min
Cooling Power Cooling rate	600…950 W Up to 30 K/min
Heat losses	160 W at 600 °C
Cycle time	8…14 min
Pressure drop	200 Pa

Table 1. Calculated parameters of the test facility.

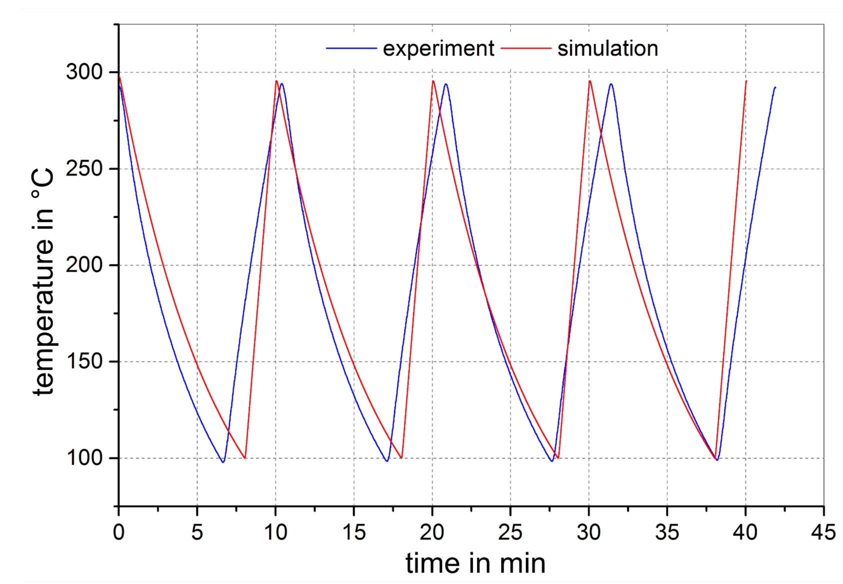

Figure 4. Comparison between measured and calculated thermal cycles.

Conclusions: Using Comsol Multiphysics a test section was designed that allows the dynamic characterization of high temperature thermoelectric generators. The simulations are in very good agreement with the behaviour of the real system. The finally constructed test facility, which is shown in figure 6, exceeds the requirements clearly. In further investigations, the Comsol model could possibly be extended to consider the behaviour of the thermoelectric material and to simulate the TEG´s efficiency under transient conditions.

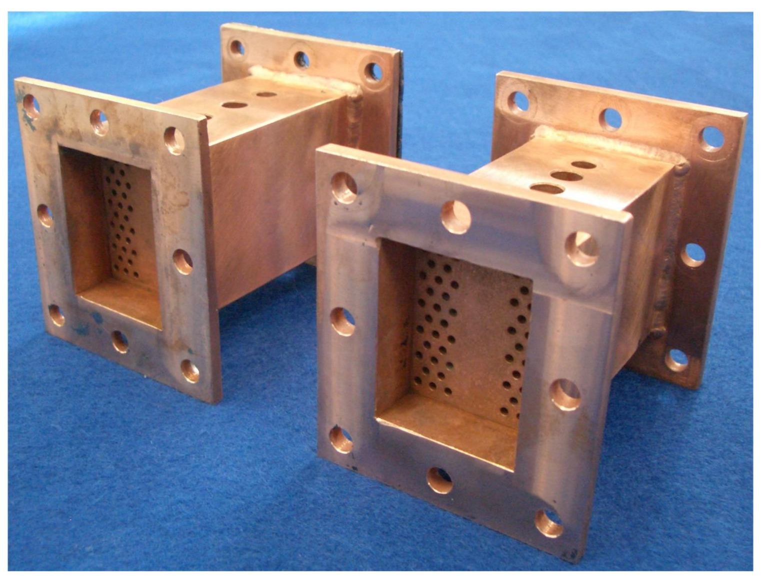

Figure 5. Constructed heat exchangers.

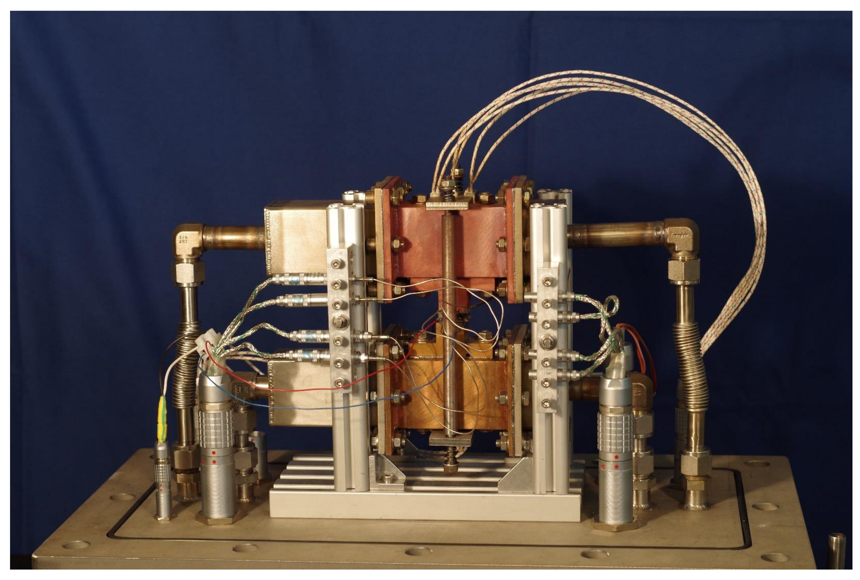

Figure 6. Finally constructed test facility (without housing).

References:

1. Weißgärber, Advanced PM technologies to manufacture thermoelectric materials and supercapacitors, World Congress on Powder Metallurgy & Particulate Materials (PM 2014), 18.-22. May, Orlando, Florida, USA.

Excerpt from the Proceedings of the 2016 COMSOL Conference in Munich