**Introduction and Motivation**

A truck powertrain can be improved with the integration of an efficient waste heat recovery system, see Figure 1. Final product results will have a beneficial impact on the environment.

**Mini ORCHID Test Rig**

**Background**

A mini Organic Rankine Cycle Hybrid Integrated Device a.k.a. ORCHID test laboratory is being designed and is due for construction in the 1st quarter of 2015, see Figure 2. The set-up will be used to study the performance of expanders and gasdynamics of organic vapours. A balance of plant ensures that the integration of three primary sections (the auxiliary loop, the supersonic de laval nozzle and turbine) together with a non-intrusive optical measurement system are compatible as an integrated system. The flexibility of the set-up allows the nozzle and turbine, which are the primary test sections, to be interchanged.

**Purpose**

The purpose of the ORCHID test rig is to realize an "experimental tool" to validate numerical codes which will be used to design small innovative turbines.

1. To study real gas behaviour of dense vapours over simple and complicated geometrical shapes in order to validate numerical codes.
2. To test various innovative mini-turbine designs. it is believed that innovative design methodologies, keeping in mind the development of measurement campaigns targeting the expanders.

**Outcomes**

- Improved Fluid dynamic knowledge of dense vapours or supercritical fluids. It must be developed if small turbine technology is to operate with these fluids.
- Optimization of the design (thrust efficiency) of turbo-technology and other components used in the power industry utilizing dense gases with small geometries.

**Test Bench Design and Layout**

Investigations are directed at fluids appropriate for WHR in the mobile sector but also for stationary applications such as solar heat collectors. The set-up is designed to study gasdynamics of fluid flow at temperatures as high as 325 degrees Celsius. The design constraints are derived from allowable heating power and the ceiling has been set at 100 kW. Expander design (nozzle and various turbines) as well as preliminary dimensioning of auxiliary components such as diaphragm feed pump, evaporator and condensers, plate heat exchanger etc. As well as the measurement system and the control strategy will be considered. A Process flow diagram of the set-up, displayed in Figure 5, provides an overview of the plant configuration. The turbine or nozzle can be inserted on the empty nodes.

**Figure 1:** Heavy duty truck utilizing the ORCHID-Powertrain concept, Figure adapted from [1].

**Figure 2:** Preliminary overview/design of the ORCHID plant.

**Figure 3:** Temperature-entropy diagram showing expansion regions of interest for D6 (supercritical).

**Figure 4:** Representations of the test sections for the ORCHID test rig.

**Figure 5:** The auxiliary loop which contains the pump, condenser, regenerator, evaporator, filter and valves.

**Figure 6:** Cutaway section of a shroud and blade row; a pressure tap blade configuration.

**Figure 7:** Exploded view of a radial outflow turbine being utilized in a truck powertrain.

**Objectives and Requirements**

A test bench orientated at the design, evaluation and optimization of mini-ORC expanders will answer questions concerning dense vapour behaviour. The set-up will be equipped with two different test sections and thus embodies different objectives.

1. The performance evaluation of various mini-ORC turbine configurations suitable for systems at the 10 kW power level. The minimum net conversion efficiency of the setup with the turbine as the test section is 20%.

2. The identification of qualitative flow field phenomenon for example flow field features using the Schlieren technique. A further step in the research attempts to generate quantitative data on the velocity field using PIV. Pressure transducers and temperature probes will be used to confirm visual data gathered during the process.

**Results and Applications**

- Will assist in the development of a new combined-cycle powertrain for heavy duty vehicles which aim to increase efficiency beyond 50 % and reduce emissions.
- Further development concerning new highly efficient mini-ORC turbogenerator technology for decentralized solar power generation.

**Deliverables**

In the last quarter of 2014 the balance of plant will be commissioned and ready for construction with a planned completion in the last quarter of 2015. The initial measurements will be Schlieren images of normal and oblique shock waves within the diverging part of the nozzle. These and subsequent PIV measurements are planned to take place in 2016.

**Future Work**

The next stages of the research will focus on flow measurements on a test/turbine with optical access.

**References**