**Micro Gas Turbine**

**Technology**

Research and

Development

for European

Collaboration

**Recuperator**



# Acknowledgments

This document was produced by the European Turbine Network (ETN) in order to identify a number of key areas that require substantial R&D efforts for micro turbines from the European community to become competitive in the energy sector worldwide.

The manuscript was produced by Andreas Huber from Deutsches Zentrum für Luft- und Raumfahrt (DLR) and co-authored by Hamidreza Darabkhani from Cranfield University.

The European industry involved or interested in the development of micro turbine technology has identified a number of key areas that require substantial R&D efforts for micro turbines to become competitive in the energy industry. These include recuperator technology, turbomachinery, system integration, multi-fuel combustion technology and material technology. These areas correspond to the working groups defined in the minutes of the ETN meeting on MGT technology held in Brussels 8 October 2015. This document presents potential work areas and proposed project outlines for European collaboration to improve MGT technology, based on the input of the member of the MGT Recuperator working group.

Contributions to this document were provided by the organisations listed below:

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# Introduction

Microturbines are small gas turbines used for small-scale power generation at one point in a distributed network or at a remote location. These power sources typically have rated power outputs between 25 kW and 500 kW. Relative to other technologies for small-scale power generation, microturbines offer a number of advantages, including: a small number of moving parts, compact size, light weight, low emissions, low electricity costs, potential for low cost mass production, and opportunities to utilize waste fuels. They have been commonly used in many engineering fields.

The current challenging performance targets for microturbines include fuel-to-electricity efficiencies of 40% or higher, capital costs less than $500/kW, NOx emissions reduced to single parts per million, several years of operation between overhauls, lives of 40,000 hours and fuel flexibility [1-2].

A schematic diagram of the TURBEC T100 Micro turbine is shown in following figure 1 [3], where the different components are:

1. Electric Generator
2. Air inlet
3. Combustion chamber
4. Recuperator air by-pass
5. Compressor
6. Turbine
7. Regenerator
8. Heat exchanger



Figure 1 – Schematic draw of the TURBEC T100 Micro turbine system [3]

Typical operating conditions are:

* Combustion chamber pressure = 4.5 bar
* Turbine Inlet Temperature = 950°C
* Turbine exit gas temperature = 620-650°C
* Exhaust gases temperature = 80°C
* Rotation speed = 70000 rpm

# State of the Art

State of the art: primary surface recuperators, see literature from R.K. Shah

# Necessary Technology Developments

A gas turbine recuperator is a gas to gas heat exchanger for recovering gas turbine exhaust heat for pre-heating combustor entry air in order to save fuel. In terms of (usually counter flow) heat exchanger design, the combination of requirements imposed by the gas turbine cycle makes successful development of a recuperator an extraordinary tough challenge. These requirements include:

1) High effectiveness (typically >80%).

2) Low pressure losses (typically not more than a few % (<2-4...%) for both hot and cold flow paths (pressure loss and effectiveness can be often exchanged: high effectiveness can often only be obtained with relatively high pressure loss for the same volume).

3) Resistance to high temperatures (steady state: creep life and corrosion resistance). Depending on the turbine inlet temperature and turbine efficiencies, general trends for the hot inlet max temperatures are:

a) With high cycle pressure ratios (>5) usually 650-700 C (stainless steels)

b) Low cycle pressure ratios (<4) >750 C (advanced/nickel based high temperature alloys)

4) Resistance to thermal shock and large temperature gradients in the structure (low cycle fatigue life)

5) Large pressure difference between hot and cold flow. For example, with a cycle pressure ratio of 7 it would be 6 bar, meaning significant structural loads in the heat exchanger matrix

6) Compact / low weight design

7) Minimal heat loss (insulation)

8) Affordable costs

a) Minimal use of expensive materials

b) Low manufacturing costs

9) Recuperator operation in mobile systems

In order to improve the know-how associated to recuperators in Europe, different work areas have been identified. Those are

* Thermodynamic optimization
* Gas composition and fouling

## Thermodynamic optimization

The recuperator parameters that mainly affect the overall efficiency of the MGT are the effectiveness and the pressure losses. If the effectiveness increases (maintaining that same heat transfer coefficient), the exchange surface is higher, so the recuperator is larger. With the same exchange area, the heat transfer coefficient is higher with more turbulent flows (and/or with secondary flow structures), but the pressure losses increase too.

This means that geometry of the exchange surfaces must be optimized in order to find the best compromise (in term of overall efficiency of the machine) between heat transfer, compactness and pressure losses.

3D-trade-off regarding recuperator effectiveness, backpressure and cost.

1. Task 1: Literature: collection of gas-to-gas heat transfer coefficient and pressure drops laws

2. Task 2: Micro-channel CFD analysis to validate the laws in the recuperator conditions

3. Task 3: Local optima - What could be local optima within this 3D-space?.

4. Task 4: Global optima - Is there a global optimum feasible? Can a perpetuum mobile be reached?

5. Task 5: Matching Recuperator systems to the application

## Gas composition and anti-fouling channels geometries

Compatibility of the recuperator with the turbine fuel flexibility.

1. Task 1 : Exhaust gases characterization - Physical properties of the gas : Cp values, viscosity, particles characterization, condensation behavior, …

2. Task 2: sensitivity of the recuperator regarding contamination and performance loss (effectiveness and pressure drop) due to exhaust impurities. Fouling : state-of-the art correlations…, anti-fouling methods (description, test : pyrolysis, vapor,…,)

3. Task 3: CFD analysis to validate fouling

4. Task 4: Possibility of Cleaning of recuperator systems

## Cost minimization

Another issue related to the surfaces is the manufacturing process: the geometry of the heat exchanger and the assembly process of its parts, must be compatible with automatic machining/assembling techniques. The primary surface type appears today the best solution from the point of view of cost and reliability.

Cost reduction of recuperator

1. Task 1: Determine possibilities of cost reduction potential by high volume effects

a. Based on modularity

b. Based on standardization

c. Based on compactness

d. Based on automation in serial production

e. Based on others

2. Task 2: Determine possibilities of cost reduction potential by process and material selection

3. Task 3: Identify total value cost reduction possibilities by advanced integration with a specific engine,…

4. Task 4: Integration of recuperator systems in the process

5. Task 5: Determination of influence factors of emission reduction

# Working group members contributions

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| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Task | DLR | Cranfield | KIT | UNIGE (TPG) |  |  |  |  |
| Literature Review |  |  |  | X |  |  |  |  |
| Micro-channel CFD |  |  |  |  |  |  |  |  |
| Local Optima |  |  |  | X |  |  |  |  |
| Global Optima |  |  |  | X |  |  |  |  |
| Matching Recuperator systems to the application |  |  |  | X |  |  |  |  |
| Exhaust gases characterization |  |  |  |  |  |  |  |  |
| Fouling sensitivity |  |  |  |  |  |  |  |  |
| CFD analysis of fouling |  |  |  |  |  |  |  |  |
| Possibility of Cleaning of recuperator systems |  |  |  |  |  |  |  |  |
| Exhaust impurities attack |  |  |  |  |  |  |  |  |
| Manufacturing ability |  |  | x |  |  |  |  |  |
| High volume effect |  |  |  | X |  |  |  |  |
| Integration effect |  |  |  | X |  |  |  |  |
| Determination of influence factors of emission reduction |  |  |  |  |  |  |  |  |
| Completely innovative design solutions for recuperators |  |  |  | X |  |  |  |  |

## ACTE (ACT)

## BOSAL (BOS)

## BTU Cottbus-Senftenberg (BTU)

At the “Department of Internal Combustion Engines and Flight Propulsion” at the BTU Cottbus-Senftenberg, in the development of highly efficient micro turbines, also suitable recuperator systems are projected. First, a system for the micro turbine system, called MGT100, was designed. As part of the investigations, a heat exchanger system of high temperature resistant metal foils was created with a spacer made of woven grids.

Objective of further investigation is the production lighter and cost efficient Recuperator systems for turbomachinery with pressure ratios of up to 5 and with high degrees of exchange. Simple heat ex-changer foils were taken to combine surfaces with effective turbulators in order to use cost-effective surfaces. Next work carried out for the optimization of structural weight and stability of innovative recuperative systems. Through an improved heat transfer the total size of recuperator systems are reduced and thus a cost reduction can be achieved.

In addition to calculations and simulations of heat-technical issues for recuperator systems we car-ried out to continue stress analysis and stability studies for changing load cases. Especially for thin heat transfer surfaces, support and turbulator structures would be developed to optimize heat ex-changer surfaces, which then can be used wisely. With further investigation heat exchanger surfaces are optimized with respect to cost-benefit ratios. Overall Objectives are compact, lightweight and efficient appliances that solve the heat transfer task cost efficient and compatible with mass production. Precise attention is placed on the pressure loss of each system, as this has a direct impact on the potential of the entire system.

The use of innovative hydroforming surfaces also should be minimized the requirement of transfer surface and the manufacturing cost. In this context, material analyses for the use of the most suitable material for each recuperator-application are performed. In particular adjustments, which are needed to increase the turbine inlet temperature of a micro gas turbine, are in the focus of scientific analyses.

Further the developed equipment would be tested on a self-developed 100kW micro turbine in heat transfer capacity, pressure drop, expansion potential and strength in use. These tests take place also for individual recuperator components with hot gas to a temperature level of 600 °C.

As part of the arrangement of recuperative systems in the entire machine flow guidance and inflow / outflow would be further optimized. An arrangement around the combustion chamber would be preferred. In this context, the gas collector and gas distribution structure, as well as the entire system were also simulated and analyzed with CFD methods.

## University of Genoa (TPG)

The Thermochemical Power Group (TPG) of the University of Genoa has a wide experience on recuperators from both theoretical and experimental points of view. In details, TPG worked in design activities related to this component (an apt design software operating in the W-TEMP tool was developed) and in laboratory tests on the recuperator of the T100 microturbine. Using an experimental facility based on a fully instrumented T100, several tests were carried out at the University of Genoa producing a large number of results related to both steady-state and transient performance of this component (including unbalanced conditions). The recuperator performance was analyzed during the start-up phase, producing significant experimental results related to this type of operation, usually not fully investigated by manufacturers and researchers.

The TPG of the University of Genoa is interested to collaborate with the ETN partners on the following topics related to recuperators for mGTs:

* analysis of non-uniform flow and temperature distribution;
* thermoeconomic analysis and optimisation;
* design improvement of standard technology using simulation software or performing experimental tests in reduced-scale rigs;
* development of completely innovative recuperator concepts considering less expensive materials and layouts;
* diagnostic aspects of reuperators including the development of apt tools for data validation, fault detection and other topics (e.g. development of GUIs);
* recuperator issues in advanced mGT based cycles (e.g. CSP or mHAT plants).

## University of Leeds, UK (UOL) (Prof. Gordon E. Andrews)

## DIME, University of Genova, Italy (Prof. Pietro Zunino)

Competences and possible contribution

Relating to this activity, the research group of the DIME, Department of Mechanical, Energy, Management and Transportation Engineering, University of Genova is developing an in house computer code which is able to take into account the main recuperator parameters, simulate the main thermo-fluid dynamic features and is suitable to be employed within the optimization process. The code output provides the data necessary to interact our cycle optimization program giving the optimized overall cycle efficiency.

The University of Leeds has a 30 years long experience on heat transfer aspects of gas turbine low NOx combustor wall cooling using the techniques of impingement and effusion cooling and their combination. Moreover enhanced heat transfer in impingement geometries using obstacles in the gap and related work on simple parallel plate cooling with obstacles in the gap have been investigated.

A compact heat exchanger using a combination of the impingement effusion geometry with crossflow in the effusion wall, where the effusion holes act as obstacles in the crossflow, can be developed and has demonstrated to be a promising solution due to its high compactness leading to lower total surface area, for the same pumping power (W/m3) and heat transfer (W/m3K), with respect to the best compact heat exchanger in literature (strip fin - plate fin).

Designs of this type might be worth considering as it would be a new type of recuperator rather than using the same system as in competitor machines.

The main drawback of these enhanced technological solutions concerns the high manufacturing costs that have to be properly assessed for MGT applications.

## Institute of Micro Process Engineering, Karlsruhe Institute of Technology, Germany (Prof. Jürgen Brandner)

At KIT, Karlsruhe Institute of Technology, a long experience in design and manufacturing of mini and micro heat exchanger exists at the Institute of Micro Process Engineering. The adoption of micro structured surfaces, such as micro head exchanger is perfectly suitable for both requirement of a micro gas turbine. On one hand, it increases the ratio of the heat exchange surface area to the volume of the heat exchanger of it; on the other hand, ITT results in a very compact form of the heat exchanger. The Institute of Micro Process Engineering at KIT has developed a highly accurate and robust micro milling for copper as well as wet chemical etching manufacturing of miniaturist heat exchanger. There competence is also the design of this micro heat exchanger.

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|  |  |  |
| Micro milling of copper | Wet chemical etching of stainless steel |

## Mitis

Mitis is currently developing a 1kWe microturbine based microCHP system for residential applications. Mitis initial R&D activities have focused on the development of a compact high efficiency and low cost recuperator integrated with a flameless combustor for natural gas. Current work is now targeting the turbomachinery components development.

Mitis recuperator has been designed using extensive CFD analysis using Conjugate Heat Transfer. We have already investigated the optimization of microchannels heat exchanger with channels in the 100 microns size. We have also developed an optimization system to optimize the efficiency of the cycle with respect to the channel geometry and the manufacturing constraints. Therefore Mitis is interested in contributing to WP1 and WP2 by applying its design technologies to come up with innovative designs.

In our R&D work, we have tested several assembly processes for welding our heat exchanger including diffusion bonding, micro laser welding and brazing. We plan to conduct experimental campaigns to investigate and characterize base materials and welds with respect to hot gas corrosion resistance and are therefore interested to contribute to WP3.

We are optimizing our recuperator with respect to cost by designing the matrix structure accounting for efficiency but also the most appropriate ‘cost-wise’ manufacturing process, and are therefore interested to contribute to WP4.

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