AERODYNAMIC AND HEAT TRANSFER INVESTIGATION OF METAL FOAM FOR TURBOCHARGER OPTIMIZATION

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ABSTRACT

This study presents the experimental investigation of aerodynamic and heat transfer performance of copper foam tubes. These tubes are interchangeable, in order to characterize various types and production methods of metal foams. They are designed to be used in a turbocharger turbine casing (volute), to exploit thermal losses.

Due to their ability to transfer heat, metal foams are ideal for this purpose, considering the thermal energy distribution within a turbine-compressor system. They are characterized by a high surface-to-volume ratio and the porous structure allows thermal storage and efficient heat exchange between solid phase of the foam and the liquid phase of the working medium.

The idea presented in this study is to combine the properties of metal foams with the heat fluxes exported from a turbocharger. Thus, a novel facility was created to evaluate the heat transfer mechanisms that occur from a heated metal foam to air passing through it. Therefore, the foam tubes inside a volute can potentially increase the thermal efficiency, achieving the optimization of the turbocharger.

INTRODUCTION

A considerable amount of thermal energy is lost when switching from gas turbines to micro gas turbines. As a result, efficiency could be reduced by up to 25%. The exploitation of thermal losses in micro gas turbines has been approached in many studies. Efstathiadis et al. [1], explored the use of a micro gas turbine for heat recovery through the Organic Rankine Cycle to generate electricity. Another possible approach is to optimize a component on the micro gas turbine. Optimization could be developed in many ways, some of which are modifying the design or introducing a new material.

A commonly used micro gas turbine in transportation is a turbocharger, characterized by thermal losses through conduction, convection & radiation. Due to temperature gradient between the inner and outer surface of the turbine casing, heat is conducted through the wall and dissipated by radiation and free convection to the surrounding environment [2]. The idea of optimizing the structure, is to insert metal foam into the volute (turbine casing). Initially, the approach is to insert copper foam tubes into the volute wall, parallel to the turbine's rotation axis. These tubes are designed to transfer heat from the wall to an external fluid.

Many researchers have proved the interesting heat transfer capabilities of open cell metal foams. The main parameters examined were porosity levels, cell size, heat transfer and temperature gradient. Zhao et al. [3], proved that the heat transfer coefficient of open cell foam tubes is up to three times higher than of plain tubes. As for the relationship between heat transfer and cell size, Zhao et al. [4], also proved that heat transfer is more sensitive to cell size than relative density. However, the density of the pores, as presented by Diani et al. [5], plays a significant role in increasing the pressure drop. Xia et al. [6], managed to calculate the heat transfer coefficient variations according to different porosity levels, by building a test rig. Although extensive research has been done on the ability of metal foams to exchange heat, there are no cases of experimental installations that aim to simulate the operation of foams in turbochargers.

RESULTS AND DISCUSSION

To investigate the ability of the foam to cause pressure drop and temperature difference to the passing fluid, for future optimization of a turbocharger volute, a test rig was constructed. It consists of connected Plexiglas tunnels, as shown in Fig.1. Initially it was designed with a Computer Aided Design software. Air flows inside the tunnels, from right to left. At the entrance, the flow is accelerated through the fans (1), followed by flow straightener (2) which removes residual twist. A Pitot - static tube is used for measuring axial speed (3). What follows is another straightener and the test section (4), where the foam specimen is located inside a copper tube. The tube is perpendicular to the axis of the flow. Thermochromic liquid crystals (TLC) are used encapsulated into a polymer sheet, which is wrapped around the copper tube. TLC are widely used in surface temperature measurements during heat transfer experiments. Each TLC has an active range and appear colorless before and after. The color change is reversible and repetitive, allowing the crystals to be used in a variety of applications [7]. A pump is used to circulate water through the foam sample. A rapid change in temperature can be achieved by using water as a working medium and consequently many colors of scale appear on the sheet. Temperature change data can be extracted by color change speed video recording. The rate of color change indicates the temperature difference and therefore the heat flow. Therefore, the effects of heat exchange from one liquid to another can be extracted. The process of heat exchange from the foam sample to the environment and vice versa represents the corresponding process occurring inside the turbocharger volute. Thus, a parametric system is created, where foam samples of different pore sizes can be imported, in order to finally find the optimum foam porosity regarding heat transfer capability.

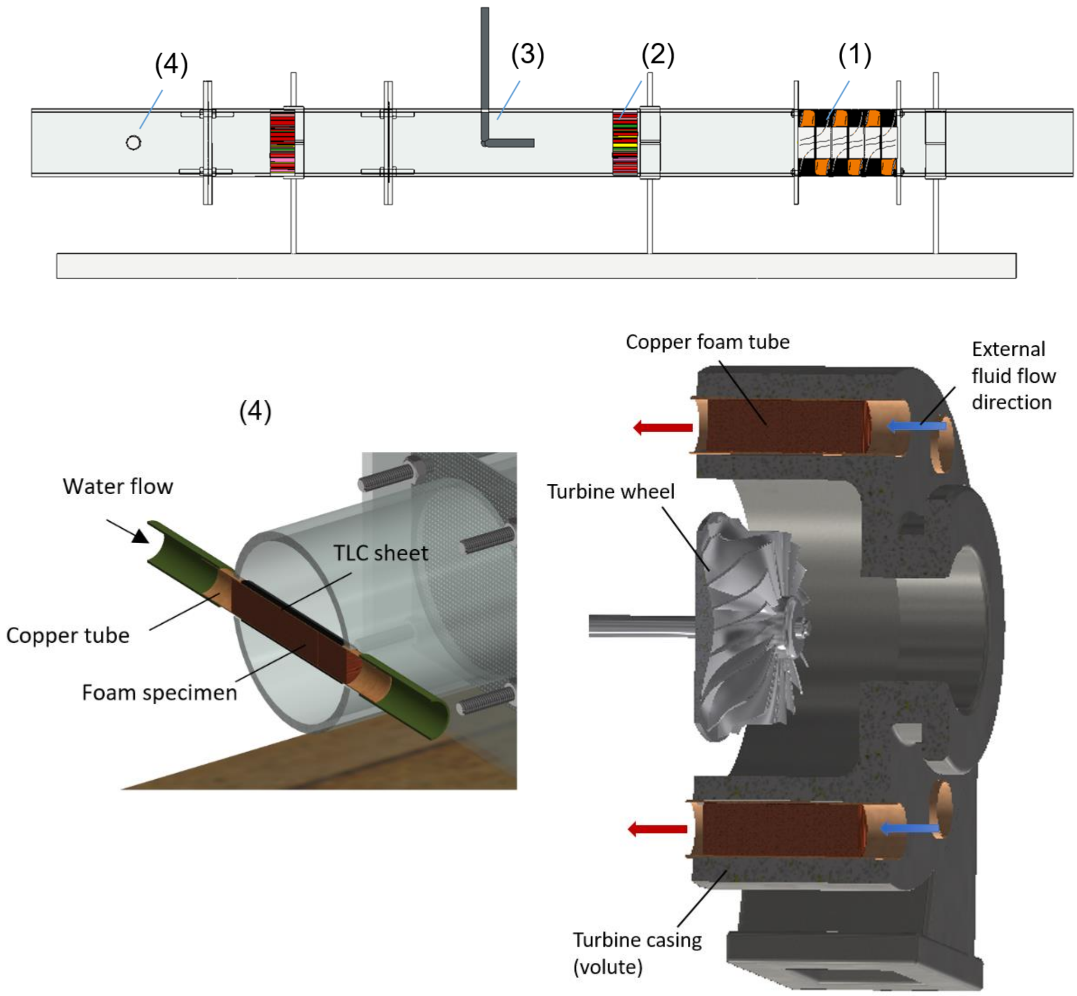

Figure 1: The experimental setup and section view of the foam tubes inside the turbocharger volute.

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