Application of exergy balances for the optimization of non-adiabatic small turbomachines operation

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ABSTRACT

In the current context of global warming due to CO₂ (carbon dioxide) emissions, mainly produced by power plants and road transportation, it is imperative to optimize the operation of thermal engines in general and of gas turbines in particular. This requires accurate knowledge of their performance. In the case of turbomachines, performance is usually estimated by assuming an adiabatic flow. This assumption is inappropriate, however, for small-scale machines such as turbochargers and micro gas turbines. This study presents the influence of heat transfer on their performance. The concept of entropic temperature is developed and a general exergy analysis conducted in order to quantify accurately the available energy dissipation. Both a turbocharger and a gas turbine with internal heat transfer are investigated. Under the adiabatic assumption, the model results are overestimated. New gas turbine maps have therefore been generated and new operating points defined. The trends of the modeling results thus obtained are compared with the performance measured on a micro gas turbine with and without insulation. Fuel consumption is higher with internal heat transfer.

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1. Introduction

In the current context of global warming due to CO₂ (carbon dioxide) emissions, mainly produced by power plants and road transportation, it is imperative to optimize the operation of thermal engines (both reciprocating internal combustion engines and gas turbines). Achieving this goal requires an accurate knowledge of their performance. Two cases can be distinguished:

- firstly, the case of reciprocating internal combustion engines used for road transportation. The great majority of new cars are equipped with downsized engines, which usually implies using turbochargers. In Europe these cars run mainly under part load or even low load, particularly in urban conditions. This means that the turbocharger operates at low load and low speed. We are however poorly informed about turbocharger characteristics in this area.

- secondly, the case of gas turbines used for electricity generation. Electricity is primarily produced worldwide by means of fossil fuels, used in particular in combined cycles and cogeneration. In addition, the reorganization of the electricity market has favored the development of gas turbines, which can be rapidly implemented in decentralised applications. As these applications are smaller in scale, small gas turbines are thus of interest.

Usually heat transfer is neglected in turbomachinery studies. While this is appropriate for large machines due to their compactness (small exchange surface, high flows), in the two aforementioned cases, heat transfer is non-negligible. For instance, according to Podevin et al. [1], in some low load cases of turbochargers, as much energy is transferred to the air flow in the compressor by heat transfer as by compression. The same problem occurs for small gas turbines which can no longer be considered as adiabatic [2].

The assumption of an adiabatic evolution is inappropriate when using small-scale machines such as turbochargers and small gas turbines, operating under high temperatures (800 K and more). This has been underlined by a few studies such as [3–8], which have shown that during operation, heat is transferred from the