Theory and method for analysis of low temperature driven power cycles

Henrik Öhman*, Per Lundqvist

Department of Energy Technology, Royal Institute of Technology, Brinellvägen 68, Stockholm 10044, Sweden

ARTICLE INFO

ABSTRACT

A new method, using a combination of traditional first law and second law analysis, is developed to facilitate characterization and comparison of power cycles using low temperature heat sources. In trying to determine the best thermodynamic cycle and working media for a given application one must take the strongly non-linear effects of matching the pinch points of a particular cycle with a particular working media into account. The new method allows unbiased comparison of arbitrarily chosen power cycles, working fluids and component characteristics. The method also allows for operating conditions with finite capacity heat source and heat sink. The usefulness of the method is illustrated by the analysis of the effects of local temperature difference distribution for three different fully reversible power cycles using three different working media.

The driver for developing this method is to simplify comparison and communication among users and industrial professionals and thus enable a better understanding of characteristics and design criteria for low temperature heat driven power cycles.

1. Introduction

Given a global focus on energy efficiency Waste Heat Recovery (WHR) has become increasingly important in order to reduce environment load while increasing human standard of living. A substantial amount of work is thus performed; developing new technologies, products and theory making use of the vast amounts of waste heat available at low temperatures. However, the practical utilisation of the results obtained in technical and application design is still in its beginning. With globally only a handful industrial strength suppliers of Low Temperature Power Cycles (LTPC) and probably less than 5000 operating LTPC-units and an abundance of low temperature waste heat the assumption is made that utilization of LTPC's' in large numbers is hampered by lack of distributed knowledge among financiers and other professionals in the industry.

The use of first law thermal efficiency for evaluation purposes is common, but since both heat source and sink typically are finite this may provide simple but rather irrelevant conclusions. More elaborate efficiency terms, such as exergy analysis, provides more revealing analysis results but is difficult to communicate to professionals less knowledgeable in thermodynamics. Failing to take heat source and heat sink characteristics into consideration, or dismissing conclusions from exergy analysis, may lead to the understanding that systems converting low temperature waste heat to electric power are thermodynamically inefficient and therefore immature. (Apart from acting as a barrier to new technology this mechanism delays the utilization of energy efficient solutions causing unnecessary costs to process owners, product suppliers and the environment.)

A good example of a more elaborate analytic approach is taken by Feidt [1] analysing a Brayton engine operating with finite heat source and sink using a model specifically developed for the cycle. The method used is solid. However, the comparison with results for different thermodynamic cycles is compromised by the need to rebuild the thermodynamic model accordingly. Second law analysis such as entropy production minimization by Bejan [2] or exergy analysis such as Wei et al. [3] and Dai [4] offer powerful tools to perform analysis. However, a large amount of active professionals in the industry are unable to directly use the methods or the conclusions in their daily work.

Finite-time thermodynamics, as explained by Andresen [16] can be used to analyse the obvious contradiction between achieving a high thermal efficiency and large amount of produced power in a particular case. The elegant formulation of the Curzon–Ahlborn-efficiency in Curzon et al. [17] could in that perspective be used as an absolute reference. However this paper focuses on the

* Corresponding author. Tel.: +46706518085; fax: +4684664501.
E-mail addresses: henrik.ohman@rotor.se (H. Öhman), per.lundqvist@energy.kth.se (P. Lundqvist).