Irreversible chemical-engines and their optimal performance analysis

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Received 25 June 2003; accepted 15 July 2003

Abstract

A new cyclic model of a class of chemical engines is set up, in which not only finite-rate mass transfer and mass leakage but also the internal irreversibility resulting from friction, eddy currents and other irreversible effects inside the cyclic working fluid are taken into account. The influences of these irreversibilities on the performance of the cycle are revealed. The optimal relation between the power output and the efficiency of the cycle is derived. On the basis of the optimal relation, some optimal performances and important performance bounds of the cycle are determined and evaluated. For example, the maximum power-output and the corresponding efficiency, the maximum efficiency and the corresponding power output, the optimal mass-transfer time, the minimum rate of energy loss and so on are calculated and analyzed. The results obtained here cannot only enrich the application of thermodynamic theory but also provide some theoretical guidance for the effective application of energy resources and for the optimal design and development of a class of chemical engines. Moreover, some important conclusions relative to the isothermal endoreversible chemical engines, which have been investigated previously, can be directly deduced from the results in this paper.

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1. Introduction

It is well known that modern thermodynamics can be used to place not only upper but also lower bounds for some important performance parameters of various
Nomenclature

\( h_1, h_2 \) coefficients of mass transfer between the working fluid and the reservoirs \( \mu_H, \mu_L \)

\( h_I = h_1 / \left(1 + \sqrt{h_1/h_2}\right) \)

\( h_L \) mass-leakage coefficient

\( I \) internal irreversibility parameter

\( P \) power output

\( P_m \) power output at the maximum efficiency

\( P_{\text{max}} \) maximum power output

\( P^*_{\text{max}} \) maximum power output of the endo-reversible chemical engine

\( r = h_2/h_1 \)

\( t_1, t_2 \) times of mass transfer in the two mass-exchange processes

\( W \) work output

\( \beta = \mu_1 - I \mu_2 \)

\( \eta \) efficiency

\( \eta_I = 1 - I \mu_L / \mu_H \)

\( \eta_m \) efficiency at maximum power output

\( \eta_r \) reversible efficiency

\( \eta_{\text{max}} \) maximum efficiency

\( \Delta N_1, \Delta N_2 \) transferred masses in the branches \( \mu_1 \) and \( \mu_2 \)

\( \Delta N_L \) quantity of mass leakage per cycle between the reservoirs \( \mu_H \) and \( \mu_L \)

\( \Delta P \) rate of energy loss

\( \Delta P^* \) dimensionless rate of energy loss

\( \Delta U_1 \) internal energy flow into the iso-chemical-potential \( \mu_1 \) process

\( \Delta U_2 \) internal energy flow out from the iso-chemical-potential \( \mu_2 \) process

\( \mu_H, \mu_L \) chemical potentials of high and low chemical potential reservoirs

\( \mu_1, \mu_2 \) chemical potentials of the working fluid which exchanges mass with the reservoirs \( \mu_H \) and \( \mu_L \)

\( \mu_{1, \min}, \mu_{1, \max} \) minimum, maximum bounds of the chemical potential \( \mu_1 \)

\( \mu_{2, \min}, \mu_{2, \max} \) minimum, maximum bounds of the chemical potential \( \mu_2 \)

\( \tau \) cyclic period

\( \lambda = t_2/t_1 \)

energy-conversion devices. Reversible limits are rigorous, but often far from a realistic situation. All energy transformation processes occurring in reality are irreversible and in many cases these irreversibilities must be included in a realistic description of such processes. Analysis of energy converters, operated in finite time, can yield more realistic bounds for interesting practical systems. Since 1975, most of
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