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Irreversible chemical-engines and their optimal performance analysis

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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

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Nomenclature

h_1,h_2	coefficients of mass transfer between the working fluid and the reservoirs μ_H, μ_L
h_I	$= h_1/\left(1+\sqrt{Ih_1/h_2}\right)$
h_L	mass-leakage coefficient
I	internal irreversibility parameter
P	power output
P_m	power output at the maximum efficiency
$P_{\max}$	maximum power-output
$P^0_{\max}$	maximum power output of the endo-reversible chemical engine
P'	$= P/(h_1\mu_H^2)$
r	$= h_2/h_1$
t_1, t_2	times of mass transfer in the two mass-exchange processes
W	work output
β	$= \mu_1 - I\mu_2$
η	efficiency
η_I	$= (1 - I\mu_L/\mu_H)$
η_m	efficiency at maximum power output
η_r	reversible efficiency
$\eta_{\max}$	maximum efficiency
ΔN_1,ΔN_2	transferred masses in the branches μ_1 and μ_2
ΔN_L	quantity of mass leakage per cycle between the reservoirs μ_H and μ_L
ΔP	rate of energy loss
ΔP^*	dimensionless rate of energy loss
ΔU_1	internal energy flow into the iso-chemical-potential μ_1 process
ΔU_2	internal energy flow out from the iso-chemical-potential μ_2 process
μ_H,μ_L	chemical potentials of high and low chemical potential reservoirs
μ_1, μ_2	chemical potentials of the working fluid which exchanges mass with the reservoirsμ_H and μ_L
$\mu_{1,\min}$, $\mu_{1,\max}$	minimum, maximum bounds of the chemical potential μ_1
$\mu_{2,\min}$, $\mu_{2,\max}$	minimum, maximum bounds of the chemical potential μ_2
τ	cyclic period
λ	$= t_2/t_1$

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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