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Parametric optimization of a new combined refrigeration cycle – active thermal potentiostatting system

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Abstract

The active thermal potentiostatting system proposed by Martinovskii and Tsirlin is directly generalized to a more practical case, in which one intermediate chamber, besides a thermal potentiostatting chamber, and two irreversible refrigeration cycles are included and the influence of the thermal resistance between the working fluid and the reservoirs, the heat leakages from the environment to the intermediate chamber and from the intermediate chamber to the potentiostatting chamber are taken into account. Expressions for the main parameters of the system are derived. By using the optimal control theory, the minimum total power input of the system with non-zero cooling rates is calculated and the temperatures of the working fluid in the isothermal processes of the refrigeration cycles are optimized. The optimal allocation of the heat-transfer areas of the heat-exchangers in the refrigeration cycles is discussed in detail. The results obtained here are more general and useful than the relevant results in literature and can provide some valuable guidance for the optimal design and operation of real active thermal potentiostatting systems.
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Keywords: Refrigeration; Cold room; Optimization; Thermodynamic cycle; Capacity; Irreversible

Optimisation des paramètres d'un nouveau cycle frigorifique polyvalent muni d'un dispositif potentiostatique

Mots clés : Réfrigération ; Chambre froide ; Optimisation ; Cycle thermodynamique ; Puissance ; Irréversibilité

1. Introduction

Single-stage refrigeration systems are adequate for most refrigeration applications and have been widely used in many fields. However, when the span of temperature between the cooled space and the heat sink is considerable and the heat

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Nomenclature

A	total heat-transfer area (m^2)
A_1	heat-transfer area between the first refrigeration cycle and the intermediate chamber (m^2)
A_2	heat-transfer area between the first refrigeration cycle and the environment (m^2)
A_3	heat-transfer area between the second refrigeration cycle and the internal chamber (m^2)
A_4	heat-transfer area between the second refrigeration cycle and the environment (m^2)
A_{L1}	heat-transfer area between the intermediate chamber and the environment (m^2)
A_{L2}	heat-transfer area between the two chambers (m^2)
A_I	heat-transfer area of the first refrigeration cycle (m^2)
A_{II}	heat-transfer area of the second refrigeration cycle (m^2)
P_1	power input of the first refrigeration cycle (W)
P_2	power input of the second refrigeration cycle (W)
P	total power input of the refrigeration system (W)
q_1	heat-transfer rate between the first refrigeration cycle and the intermediate chamber (W)
q_2	heat-transfer rate between the first refrigeration cycle and the environment (W)
q_3	heat-transfer rate between the second refrigeration cycle and the internal chamber (W)
q_4	heat-transfer rate between the second refrigeration cycle and the environment (W)
R_1	cooling rate of the first refrigeration cycle (W)
R_2	cooling rate of the second refrigeration cycle (W)
T_1, T_2	temperatures of the working fluid in the two isothermal processes of the first refrigeration cycle, respectively (K)
T_3, T_4	temperatures of the working fluid in the two isothermal processes of the second refrigeration cycle, respectively (K)
T_c	temperature of the internal chamber (K)
T_h	temperature of the environment (K)
T_i	temperature of the intermediate chamber (K)
U_1	heat-transfer coefficient between the first refrigeration cycle and the intermediate chamber ($W\,K^{-1}\,m^{-2}$)
U_2	heat-transfer coefficient between the first refrigeration cycle and the environment ($W\,K^{-1}\,m^{-2}$)
U_3	heat-transfer coefficient between the second refrigeration cycle and the internal chamber ($W\,K^{-1}\,m^{-2}$)
U_4	heat-transfer coefficient between the second refrigeration cycle and the environment ($W\,K^{-1}\,m^{-2}$)
U_{L1}	heat-transfer coefficient between the intermediate chamber and the environment ($W\,K^{-1}\,m^{-2}$)
U_{L2}	heat-transfer coefficient between the two chambers ($W\,K^{-1}\,m^{-2}$)
x	ratio of the heat-transfer area of the first refrigeration cycle to the total heat-transfer area
y	ratio of the temperature of the internal chamber to the temperature of the environment
τ	ratio of the temperature of the environment to the temperature of the intermediate chamber

Subscripts and superscript

min	minimum
P	at minimum power input
*	dimensionless

leakage is inevitable, two- or multi-stage combined refrigeration systems have to be used. In recent years, the theory of thermodynamic optimization or entropy generation minimization [1] has been extended to combined refrigeration cycle systems [2–15]. In general, multi-stage combined refrigeration systems may be grouped into two classes. One is the multi-stage combined refrigeration systems in series, and the other is the multi-stage combined refrigeration systems in parallel connection. Some scholars have successfully used the optimal control theory to investigate the two-stage or multi-stage combined refrigeration systems in series and some important results have been obtained. For example, Chen and Yan [2], Chen and Wu [3] modeled a two-stage combined refrigeration cycle in series and derived the relation expressions between the optimal coefficient of performance and the rate of refrigeration and between the optimal coefficient of performance and the specific cooling rate, respectively. Chen et al. [4] set up a two-stage refrigeration cycle connected in series for both a piston type and a steady flow model and derived the fundamental equation between the optimal specific rate of refrigeration and the coefficient of performance. Chen et al. [5] explored the influence of a bypass heat leak on the optimum performance of a two-stage refrigeration cycle in series. Chen [6,7] investigated the performances of two-stage and n-stage combined refrigeration system in series which included the influence of the heat leak, finite rate heat-transfer and internal dissipation of the working fluid. Goktun [8] derived an improved equation of COP of a two-stage irreversible refrigeration cycle in series in which the effects of the thermal resistance and internal irreversibilities were taken into account. Furthermore, Chen et al. [9] established a model of a generalized irreversible two-stage combined refrigeration cycle with heat resistance, heat leakage and internal irreversibility, and the

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