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Research Paper

Comparison of air-standard rectangular cycles with different specific heat models

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HIGHLIGHTS

- Air-standard rectangular cycle models are built and investigated.
- Finite-time thermodynamics is applied.
- Different dissipation models and variable specific heats models are adopted.
- Performance characteristics of different cycle models are compared.

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ABSTRACT

In this paper, performance comparison of air-standard rectangular cycles with constant specific heat (SH), linear variable SH and non-linear variable SH are conducted by using finite time thermodynamics. The power output and efficiency of each cycle model and the characteristic curves of power output versus compression ratio, efficiency versus compression ratio, as well as power output versus efficiency are obtained by taking heat transfer loss (HTL) and friction loss (FL) into account. The influences of HTL, FL and SH on cycle performance are analyzed by detailed numerical examples.

1. Introduction

The development of finite-time thermodynamics [1–13] helps scholars to find the extreme of different objective function and the relation between objective functions of various thermodynamic cycles. Chen et al. [14] obtained the relations between optimal efficiency and power output of Carnot engines with different heat transfer laws. Zhang et al. [15] optimized the power and efficiency of combined Brayton and inverse Brayton cycles. Chen et al. [16] studied the maximum power output of multistage irreversible heat engines with a generalized heat transfer law. Liu et al. [17] optimized the sintering proportioning based on energy value. Performance analyses and optimizations for various internal combustion engine cycles have been also performed [18–38]. Previous studies of thermodynamic cycles [39–44] were based on constant specific heats (SH) model. Chen et al. [39,40] investigated the influence of heat transfer loss (HTL) on the performances of Otto cycle [39] and Diesel cycle [40], and further studied the performance characteristics of the Otto cycle with heat transfer loss (HTL) and friction loss (FL) [41]. Ge et al. [42] established an irreversible Miller cycle model with HTL and FL. Zhao and Chen [43] studied the influence of HTL and internal irreversibility loss on the performance of the irreversible Miller cycle. Descieux and Feidt [44] investigated the influence of working parameters on the simulation results of the ignition engine cycles with HTL and FL. But actually the variable SH cannot be ignored in real thermodynamic cycles, so some precise models of variable SH were built. Ghatak and Chakraborty [45] first built the linear variable SH model of working fluid. Considering this model, Chen et al. [46] investigated the irreversible Dual cycle with FL and Ge et al. [47] studied the endoreversible Diesel cycle. Abu-Nada et al. [48–51] built the non-linear variable SH model of working fluid. Ge et al. [52]

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Nomenclature

a_p	constant to calculate linear variable specific heats at constant pressure, J/(mol · K)
b_v	constants to calculate linear variable specific heats at constant volume, J/(mol · K)
C_{pm}	specific heats at constant pressure, J/(mol · K)
C_{vm}	specific heats at constant volume, J/(mol · K)
k	coefficient of linear variable specific heats, J/(mol · K^2)
L	total distance the piston travels per cycle, m
M	moles of working fluid, mol
N	numbers of cycles operating in a second
P_R	reversible power output, W
P_μ	power lost, W
$P_{const,0,1,2,3}$	power output of different cycle models, W
Q_{in}	heat added to the working fluid, W
Q_{out}	heat rejected by the working fluid, W
R	molar gas constant, J/(mol · K)
$T_{1,2,3,4}$	temperature at different states 1, 2, 3 and 4, K
$V_{2,3}$	volume at different states 2 and 3, m^3

Greek symbol

α	heating value, J/mol
β	coefficient of heat transfer loss, J/(mol · K)
γ	compression ratio
μ	coefficient of friction, N · s/m
$\eta_{const,0,1,2,3}$	efficiency of different cycle models, %

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max	maximum value

studied the irreversible Otto cycle with FL, and Liu et al. [53] modeled endoreversible Meletis- Georgiou (MG) cycle by considering non-linear variable SH model of working fluid.

Rectangular cycle is a thermodynamic cycle which has no isothermal process or adiabatic process. It is safer and easier to implement in practice. Ferreira Da Silva [54] studied the cycle performance by using classical thermodynamics. Considering constant SH model, Liu et al. [55] obtained the performance characteristics of endoreversible rectangular cycle with HTL, and Liu et al. [56] investigated the irreversible rectangular cycle with FL and HTL. Wang et al. [57] studied the endoreversible rectangular cycle with HTL by considering linear variable SH model of working fluid. Based on Refs. [54–57], this paper will study the performance of rectangular cycle with HTL and FL by considering different SH models of working fluid. The endoreversible rectangular cycle with nonlinear variable SH model and the irreversible rectangular cycle with linear and nonlinear variable SH model will be studied. Performance comparison with those of endoreversible rectangular cycle with constant SH [55] and linear variable SH [57] of working fluid will be performed.

2. Models of variable SH and rectangular cycle

2.1. Variable SH models

The performance of practical cycles is affected greatly by the variable SH of working fluid. According to Refs. [19,45–53,57], over the temperature ranges 300–2200 K, the SH are supposed to be only related to the temperature.

2.1.1. The linear variable SH model

The change of SH is approximately linear with temperature in linear variable SH model [45–47]:

$$C_{pm} = a_p + kT \tag{1}$$

$$C_{vm} = b_v + kT \tag{2}$$

2.1.2. The nonlinear model of variable SH

The nonlinear variable SH model was defined as follows [48–53]:

$$\begin{aligned} C_{pm} = {} & 7.2674 \times 10^{-10}T^2 + 4.2166 \times 10^{-6}T^{1.5} - 1.23134 \\ & \times 10^{-5}T + 9.1698 \times 10^{-4}T^{0.5} + 38.5787 - 4.3848 \\ & \times 10^{5}T^{-1.5} + 8.8827 \times 10^{6}T^{-2} - 6.4148 \times 10^{8}T^{-3} \end{aligned} \tag{3}$$

$$\begin{aligned} C_{vm} = {} & 7.2674 \times 10^{-10}T^2 + 4.2166 \times 10^{-6}T^{1.5} - 1.23134 \\ & \times 10^{-5}T + 9.1698 \times 10^{-4}T^{0.5} + 30.2647 - 4.3848 \\ & \times 10^{5}T^{-1.5} + 8.8827 \times 10^{6}T^{-2} - 6.4148 \times 10^{8}T^{-3} \end{aligned} \tag{4}$$

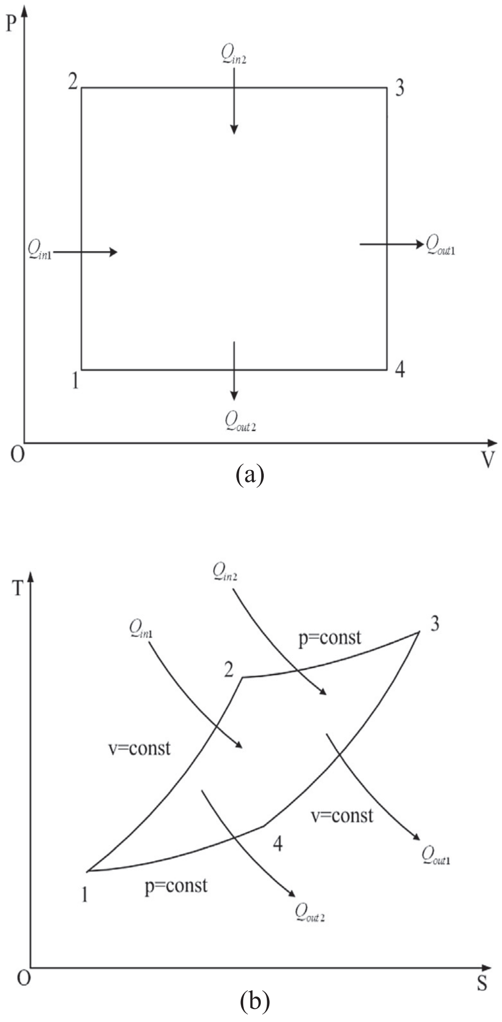

Fig. 1. The air-standard rectangular cycle model. (a)P-V diagram of the cycle model. (b) T-S diagram of the cycle model.