Available online at www.sciencedirect.com

SCIENCE DIRECT®

Energy Conversion and Management 47 (2006) 3224–3234

ENERGY CONVERSION & MANAGEMENT

www.elsevier.com/locate/enconman

Effects of heat transfer, friction and variable specific heats of working fluid on performance of an irreversible dual cycle

Lingen Chen [a,*], Yanlin Ge [a], Fengrui Sun [a], Chih Wu [b]

[a] *Postgraduate School, Naval University of Engineering, Wuhan 430033, PR China*
[b] *Mechanical Engineering Department, US Naval Academy, Anapolis, MD 21402, USA*

Received 3 July 2005; received in revised form 8 January 2006; accepted 15 February 2006
Available online 29 March 2006

Abstract

The thermodynamic performance of an air standard dual cycle with heat transfer loss, friction like term loss and variable specific heats of working fluid is analyzed. The relations between the power output and the compression ratio, between the thermal efficiency and the compression ratio, as well as the optimal relation between power output and the efficiency of the cycle, are derived by detailed numerical examples. Moreover, the effects of variable specific heats of the working fluid and the friction like term loss on the irreversible cycle performance are analyzed. The results show that the effects of variable specific heats of working fluid and friction like term loss on the cycle performance are obvious, and they should be considered in practical cycle analysis. The results obtained in this paper may provide guidance for the design of practical internal combustion engines.

Keywords: Thermodynamic optimization; Dual cycle; Heat resistance; Friction loss; Variable specific heat of working fluid

---

1. Introduction

Several authors have applied thermodynamic methods [1–7] to the analysis of the dual cycle [8–17]. Sahin et al. [8] studied the optimal power density characteristics of the dual cycle without any loss. Lin et al. [9] and Hou [10] derived the performance characteristics of the dual cycle with only the heat transfer loss and studied the effects of heat transfer loss on the performance of the cycle. Blank and Wu [11] analyzed the effect of combustion on the performance of an endoreversible dual cycle. Wang et al. [12] modeled the dual cycle with a friction like term loss and studied the effect of the friction like term loss on cycle performance. Chen et al. [13] derived the performance characteristics of the dual cycle with heat transfer and friction like term losses. Sahin et al. [14,15] optimized the performance of a new combined power cycle based on power density analysis of the dual cycle and made a comparative performance analysis of an endoreversible dual cycle under a maximum ecological function and maximum power conditions. Parlak et al. [16] optimized the performance of an

---

[*] Corresponding author. Tel.: +86 27 83615046; fax: +86 2783638709.
E-mail addresses: lingenchen@hotmail.com, lgchenna@yahoo.com (L. Chen).

0196-8904/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enconman.2006.02.016

irreversible dual cycle and gave experimental results. Ust et al. [17] analyzed and optimized the performance of an irreversible dual cycle based on an ecological coefficient of performance criterion. The works mentioned above were done without considering the variable specific heats of the working fluid, so Rocha-Martinez et al. [18] studied the effect of variable specific heats on Otto and Diesel cycle performances, but they only took the experiential expressions of the specific heats of the working fluid into the final expressions of cycle power output and efficiency without considering the effects of variable specific heats on the cycle process equations, while Ghatak and Chakraborty [19] analyzed the effect of variable specific heats and heat transfer loss on the performance of the dual cycle by considering the effect of variable specific heats on the cycle process equations. Ge et al. studied the effects of variable specific heats of the working fluid on the performances of an Otto cycle [20,21] with heat transfer loss [20] and with heat transfer and friction losses [21], respectively. Based on Refs. [13,19], this paper will study the effects of the variable specific heats of the working fluid on the performance of a dual cycle with heat transfer and friction like term losses.

2. Cycle model

An air standard dual cycle model is shown in Fig. 1. The compression process is an isentropic process 1 → 2; the heat additions are an isochoric process 2 → 3 and an isobaric process 3 → 4; the expansion process is an isentropic process 4 → 5 and the heat rejection is an isochoric process 5 → 1.

In practical cycles, the specific heats of the working fluid are variable, and these variations will have great influence on the performance of the cycle. According to Refs. [19–21], it can be supposed that the specific heats of the working fluid are functions of temperature alone, and over the temperature ranges generally encountered for gases in heat engines (300–2200 K), the specific heat curve is nearly a straight line, which may be closely approximated in the following forms:

$$C_{\mathrm{pm}} = a_{\mathrm{p}} + k_1 T \tag{1}$$

$$C_{\mathrm{vm}} = b_{\mathrm{v}} + k_1 T \tag{2}$$

where a_{p}, b_{v} and k_1 are constants, C_{pm} and C_{vm} are molar specific heats with constant pressure and volume, respectively. Accordingly, one has

$$R = C_{\mathrm{pm}} - C_{\mathrm{vm}} = a_{\mathrm{p}} - b_{\mathrm{v}} \tag{3}$$

where R is the molar gas constant of the working fluid.

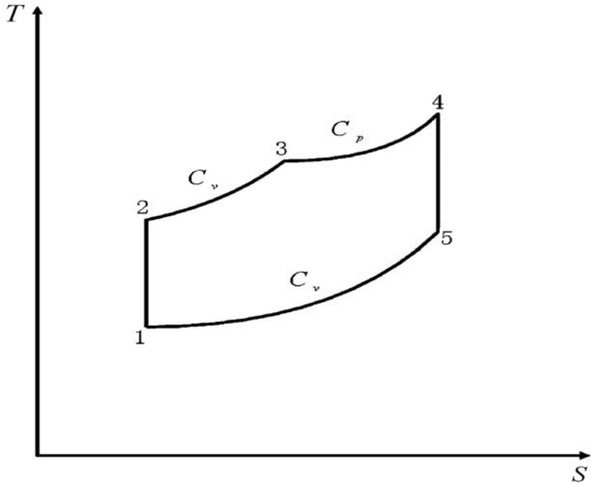

Fig. 1. T–S diagram for the cycle model.