Applied Thermal Engineering 39 (2012) 188–197

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Optimum design of limaçon gas expanders based on thermodynamic performance

Ibrahim A. Sultan*

School of Science, Information Technology and Engineering, The University of Ballarat, PO Box 663, Ballarat 3353 Victoria, Australia

ARTICLE INFO

Article history:
Received 6 January 2011
Accepted 17 January 2012
Available online 24 January 2012

Keywords:
Expander
Limacon
Isentropic
Energy
Thermodynamic
Positive displacement

ABSTRACT

Positive displacement expanders are acquiring popularity due to the current push to harvest energy from low-grade heat resources which have been previously overlooked. The limaçon technology does offer a simple and reliable design with a considerable potential for small-size ($\leq$4 kW) power plants. This paper presents a thermodynamic model for the limaçon design and goes on to utilise this model in an optimisation procedure adopted to calculate the expanders geometric parameters for specific power and operating constraints. The numerical method employed to solve the thermodynamic model is presented for the benefit of the reader. Two design case studies, for expanders with and without an inlet control valve, are offered at the end of the paper to prove the validity of the presented concepts and their suitability for the analysis.

1. Introduction

Like their turbo-machinery counterparts, positive displacement expanders are used to extract mechanical energy from pressurised gaseous fluids. However, unlike turbo-machines, Lemort et al. [1] point out that positive displacement expanders are suitable for low speed, low flow rate and high pressure ratio applications. Moreover, Smith and Stosic [2] argue that these expanders can handle two-phase flows better than conventional turbines.

Current interest in positive displacement gas expanders is fuelled by the need to capture sources of energy which may have been previously overlooked in two main areas; namely, refrigeration and power generation. Refrigeration plants based on CO_2 exhibit low COP values; and in order to increase their economic viability the pressure energy lost to the throttling process may be recovered by gas expanders as demonstrated by a number of authors, e.g. Nagata et al. [3] and Smith and Stosic [2]. The other application which requires the use of positive displacement expanders are the power production plants which are based on the Organic Rankine Cycle (ORC). These plants utilise organic fluids to extract energy from low-grade heat sources as detailed by Angelino et al. [4]. Organic fluids are most suitable for this application because of their low boiling temperatures as has been highlighted by Mago et al. [5] who report a very interesting observation that these plants perform best when the working fluid is at saturated conditions before it enters the expander. This underlines the need for positive displacement expanders which are naturally capable of handling two-phase flows expected to take place in these power production plants. Doty and Shevgoor [6], in the context of introducing the dual-source ORC, present an insightful discussion on organic fluids and their limitations as working media for Organic Rankine Cycles.

Most small ORC-based power plants utilise scroll-type positive displacement expanders which apply isentropic expansion on the working fluid without the need for an inlet valve. However, the modelling and experimental work, by Lemort et al. [1,7], underlines leakage as a problem which these expanders suffer even when special arrangements have been implemented to reduce this leakage mechanically. On the other hand, the results presented by Wang et al. [8] suggest that their method to suppress leakage by applying an external pressure on the mating surfaces does help to improve the expander volumetric performance. Due to the isentropic expansion that takes place inside the chamber, good efficiency figures have been reported for scroll expanders. These figures range from 63% reported by Saitoh et al. [9] to 83% reported by Mathias et al. [10]. Another expander design which does not require an inlet valve is the vane-type expander described by Yang et al. [11] who demonstrated a successful effort to improve its isentropic efficiency from 9% to 23%.

Expander designs which require inlet valve control to improve their efficiency have been reported by a number of authors. For example Baek et al. [12] report an effort to utilise a piston-cylinder arrangement for expanding CO_2 in refrigeration plants. The discussion presented by Baek et al. [12] on the workings and

* Tel.: +61 3 53279118.
E-mail address: i.sultan@ballarat.edu.au.

1359-4311/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.applthermaleng.2012.01.039