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Numerical investigation of Real gas effects on a two-stage pulse tube cryocooler performance

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Highlights

- A CFD code was developed to simulate a two-stage pulse tube cryocooler.
- The effect of real gas was investigated on cryocooler performance.
- Results based on four distinct equations of state including ideal gas, Van der Waals, Virial and Helium gas were compared.

Abstract

In this paper, a one-dimensional CFD code was developed to simulate a two-stage pulse tube cryocooler. The aim is to investigate real gas effects on cryocooler performance. Conservation equations were derived based on real gas equations of state in general form and then were discretized with control volume approach. Results based on four distinct equations of state including ideal gas, Van der Waals, Virial and Helium gas were compared. Results showed that at the first and second stage mean pressures of 25 and 12.5 bars, and the minimum no load attainable temperatures of almost 60 and 18 K, employing Helium equation of state, the deviation of almost 6.5 and 2.5 % relative to ideal gas equation of state was observed respectively. Meanwhile the ideal gas equation of state was fairly accurate and could be proposed to reduce the calculation cost.

Keywords: two-stage pulse tube cryocooler; one-dimensional CFD code; real gas effects; ideal gas

1. Introduction

The Basic Pulse tube Refrigerator (BPTR) was introduced by Gifford and Longsworth (Gifford and Longsworth, 1964) to the world in 1963. A great advantage was that it had no moving parts and so high reliability than other types of cryocoolers; but this invention could not reach below 120 K until in 1984. Mikulin et al. (Mikulin et al., 1984) made a modification to the basic pulse tube refrigerator by adding an orifice and a buffer after hot end of pulse tube. It controls phase angle between pressure and mass flow that causes more cooling capacity and lower temperature. This type was named Orifice Pulse tube Refrigerator (OPTR). Furthermore, many researchers modified it to get better cooling performance by changing geometrical parameters or number of stages.

Many investigations have been conducted through by thermodynamic and mathematical models to understand and improve pulse tube cryocoolers (Chen et al., 2000; Ju, 2001; Nika and Bailly, 2002; Razani et al., 2008, 2007; Shi, 2008). Xun et. al. investigated different mesh for regenerator. They have compared nylon and stainless steel mesh and have shown nylon mesh is better in cold temperature around 80 K (Xun et al., 2013). Zhi et al. studied the influence of phase angle on the gas parcels' heat transfer characteristics by using CFD. Kardgar and Jafarian simulated conjugate heat transfer in tube section of cryocooler. They concluded that the wall thickness should be considered in pulse tube heat transfer (Kargar and Jafarian, 2016). Cha et al. (Cha et al., 2006) made a two dimensional CFD model on a single-stage pulse tube refrigerator with inertance tube using Fluent software to optimize the system and investigate multi-dimensional flow effects. Numerical simulations were often done by using ideal gas assumption for prediction of gas behavior (Boroujerdi et al., 2011; Cha et al., 2006; Ghahramani, 2010; Lyulina et al., 2004; M.Arablu, 2012). However, some researchers such as De Waele et al. (De Waele et al., 1999)

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