Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER International Communications in Heat and Mass Transfer 32 (2005) 1152–1164
International Communications in HEAT and MASS TRANSFER
www.elsevier.com/locate/ichmt

Piston effect in supercritical nitrogen around the pseudo-critical line☆

A. Nakano*, M. Shiraishi

National Institute of Advanced Industrial Science and Technology, 1-2-1 Namiki, Tsukuba East, Tsukuba, Ibaraki 305-8564, Japan

Available online 6 June 2005

Abstract

The combination of very high thermal compressibility and small thermal diffusion near the critical points of fluids affects thermal energy propagation, leading to the formation of weak acoustic waves as carriers of thermal energy. This heat transfer phenomenon is called the piston effect. It has been reported that the piston effect appears near the critical point. In this study, the piston effect in supercritical nitrogen was investigated by use of a laser holography interferometer. Since natural convection due to gravity interferes with the piston effect under terrestrial conditions, we attempted to suppress the generation of natural convection by adding heat from the top of the experimental cell and successfully observed the typical temperature profiles formed by the piston effect around the pseudo-critical line. The pressure and the temperature are relatively higher than the critical pressure and the critical temperature.

Keywords: Piston effect; Supercritical fluids; Laser holography; Nitrogen; Pseudo-critical line

1. Introduction

A fluid enters the supercritical state when its temperature and pressure exceed their respective critical points. In that state, the liquid–vapor interface no longer exists and the density takes an intermediate form between liquid and vapor. Near the critical point, the thermo-physical properties of fluids exhibit very strange behaviors; the specific heat and the isothermal compressibility show a strong divergence, causing the thermal diffusivity to become very small. It had been thought that thermal energy could be

☆ Communicated by K. Suzuki and S. Nishio.

* Corresponding author.
E-mail address: a.nakano@aist.go.jp (A. Nakano).

0735-1933/$ - see front matter
doi:10.1016/j.icheatmasstransfer.2005.05.009

hardly transferred near the critical point. However, fast dynamic temperature propagation was observed under micro-gravity conditions [1]. The fast heat transfer was verified by the German Spacelab Mission D-2 [2]. Onuki et al. [3] explained the fast heat transfer with adiabatic temperature propagation. This phenomenon was also analyzed from a thermodynamic point of view by Boukari et al. [4]. Zappoli et al. [5] accounted for the temperature propagation in the fluid by solving the complete set of hydrodynamic equations. They called the phenomenon the "piston effect". Since this effect in which thermal energy propagates as acoustic waves differs from conduction, convection, and radiation, it was considered the fourth mechanism of heat transfer [6]. The piston effect originates from the high compressibility and the low thermal diffusivity of supercritical fluids near the critical point. Maekawa and Ishii [7] analyzed the piston effect from both macroscopic and microscopic points of view. They also investigated the influence of gravitational acceleration on the piston effect [8]. Recently, the piston effect has been noticed in the chemical engineering field [9].

It has been reported that the piston effect appears near the critical point of fluids. However, we considered that the piston effect must appear in the region where the abnormality of the specific heat was observed. In the present study, the piston effect in supercritical nitrogen was investigated with a laser holography interferometer [10]. The piston effect has been detected experimentally under micro-gravity conditions because natural convection due to gravity hinders the piston effect. Here, we attempted to suppress the generation of natural convection and tried to detect the piston effect under terrestrial conditions as reported in a few previous studies [11,12]. Heat was added from the top of the experimental cell to suppress the generation of natural convection. We carried out the experiment around the pseudo-critical line of nitrogen and successfully obtained the typical temperature profiles formed by the piston effect.

2. Theoretical consideration

At first, we discuss about nitrogen using Fig. 1. Fig. 1a shows the phase diagram of nitrogen. The critical pressure and the critical temperature of nitrogen are 3.398 MPa and 126.2143 K, respectively.

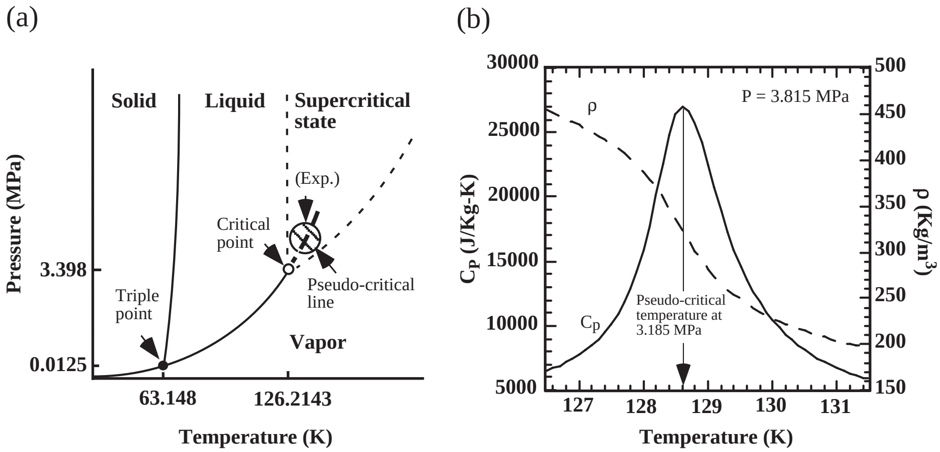

Fig. 1. Schematics about nitrogen. (a) The phase diagram. (b) Behavior of the specific heat at constant pressure, C_p, and the density, ρ, around the pseudo-critical temperature.