Propulsion and Power Research 2013;2(2):119–130

http://ppr.buaa.edu.cn/

Propulsion and Power Research

www.sciencedirect.com

ORIGINAL ARTICLE

Investigation of flow resistance characteristics of endothermic hydrocarbon fuel under supercritical pressures

Chunben Zhang[a,b,*], Guoqiang Xu[a], Hongwu Deng[a], Kun Zhu[a]

[a]National Key Laboratory of Science and Technology on Aero-Engine Aero-Thermodynamics, School of Energy and Power Engineering, Beihang University, Beijing 100191, China
[b]Xi'an Aerospace Propulsion Institute, Xi'an 710100, China

Received 18 March 2012; accepted 22 January 2013
Available online 5 June 2013

KEYWORDS

Supercritical;
Hydrocarbon fuel;
Flow resistance;
Friction factor;
Pressure drop

Abstract The characteristics of flow resistance of a typical hydrocarbon fuel (RP-3) flow through adiabatic horizontal miniature tubes at supercritical pressures are experimentally investigated for both laminar and turbulent flow. The experiments are conducted by using a long tube measuring section and a short tube measuring section simultaneously in order to eliminate the effect of local pressure drop. In these experiments, the temperature of RP-3 changes from (295 to 789) K and the reduced pressure (P/P_c, $P_c=2.33$ MPa) ranges from 1 to 2.58, the mass flux is up to 1572.7 $kg/(m^2 \cdot s)$. Test results indicate that frictional pressure drops for various supercritical pressures at the same mass flux can be considered as equal with each other when the reduced temperature $T_b/T_{pc}<0.95$. When $T_b/T_{pc}>0.95$, difference appears and increases with the increase of T_b/T_{pc}. Additionally, the friction factor (f) of the supercritical fluid for turbulent flow has a critical value at $T_b/T_{pc}=1$, the values of f at this point for all pressures and mass fluxes are equal with each other. Moreover, at the same mass flux, there are two corresponding friction factors for the same Re, one is in the region

*Corresponding author: Tel.: +86 29 85206097.
E-mail address: zhang_cb@sjp.buaa.edu.cn (Chunben Zhang)

Peer review under responsibility of National Laboratory for Aeronautics and Astronautics, China.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jppr.2013.04.002

of $T_b/T_{pc} < 1$, the other is in the region of $T_b/T_{pc} > 1$. Finally, classical correlations of friction factor is inapplicable when $T_b/T_{pc} > 0.95$ at supercritical pressure and a new correlation has been obtained based on the experimental data.

1. Introduction

Engine fuel is usually used as the primary coolant for high temperature components cooling in aerospace. For liquid oxygen-kerosene rocket engine, the engine fuel is first used for thrust chamber cooling, and then injected into combustor; for advanced aircraft, flight speeds enter into high supersonic and hypersonic regime, and it will have more heat generating electronics, have more serious aerodynamic heating problem and operate with higher engine pressure compared to today's aircraft, all of which will increase the heat load of aircraft [1]. Thus, it is necessary to utilize the fuel as the primary coolant, and which will take a minimum weight penalty and technical risk [2]. With regard to the needs of the advanced gas turbine engines, the engine fuel is first pumped to an air/fuel heat exchanger to cool the cooling air (CCA) from compressor under supercritical pressure. At the same time, the fuel is heated up over its critical temperature. The supercritical fuel is then injected into the combustor while the cooled cooling air is led to the turbine for blade and disk cooling. Hence, the flow and heat transfer characteristics of supercritical hydrocarbon fuel play a key role in future CCA technology and active regenerative cooling technology development for advanced gas turbine engines, rocket engines and supersonic combustion ramjet (scramjet).

Brad and Michael [1,3] conducted experimental studies on the supercritical fluid flow and heat transfer of a hydrocarbon fuel, JP-7, in a vertical tube, intended for the technological development of the cooling strategies in future air-breathing propulsion systems. It was observed significant pressure and temperature oscillations along with declined local heat transfer coefficients when the reduced pressures (P/P_c) was below 1.5 and the tube wall temperatures was above its pseudo-critical temperature. Linne et al. [4] performed a series of heated tube experiments to investigate fluid instabilities that occur during heating of supercritical fluids. In these tests, JP-7 flowed vertically though small diameter tubes at supercritical pressures. All these tests were stable at the highest velocity, but there was no functional relationship observed between the instability and velocity, or a combination of velocity and temperature ratio. In addition, all of the unstable tests and most of the stable tests had significant buoyancy at the inlet of the test section. Li et al. [5] conducted a study on flow and heat transfer characteristics of China No. 3 aviation kerosene in a heated curved tube numerically under supercritical pressure. They concluded that heat transfer was enhanced after the wall temperature was over the pseudo-critical temperature, and the centrifugal force caused a strong secondary flow, which not only enhanced the heat transfer largely, but also increased the friction factors greatly throughout the flow process. Edwards and his team [6–9] investigated the mechanisms of hydrocarbon fuel decomposition at supercritical pressures and a series of additives have been developed to minimize cracking and coking in supercritical jet fuels.

Studies on hydrocarbon fuels in the open literature mainly focused on supercritical heat transfer and deposition, systematic investigations of the flow resistance were scarce compared to pure substance fluid such as carbon dioxide and water. Jiang et al. [10] experimentally investigated the heat transfer and the flow resistance of CO_2 in a vertical porous tube at supercritical pressures. Two new correlations were presented for upward and downward flows to predict the friction factors of supercritical pressure CO_2 in heated porous tubes. Pioro et al. [11] investigated the hydraulic resistance of water and carbon dioxide flows at supercritical pressures. It was illuminated that differences in pressure drop between supercritical and subcritical forced convection seemed to be related to significant variations in thermophysical properties near the critical and pseudo-critical points. And it was stated that the total pressure drop at supercritical pressures could be estimated using general correlations for pressure drop at subcritical pressures with correction factors for the effect of significant thermophysical properties variations and high heat fluxes. Petukhov [12], Kurganov [13,14] and many other researchers [15–17] also had outstanding contributions to the analysis of the characteristics of flow resistance of pure fluids.

Compared to pure fluids, due to the multi-components and chemical reaction in the heating process, there is no extensive data such as vapor pressure, specific heat, density, viscosity, surface tension, and critical parameters of hydrocarbon fuel which leads the theoretical research on hydrocarbon fuel is still not deep enough and many problems need to be solved. Based on the measured thermophysical properties of RP-3 in our previous works [18–21], both the laminar and turbulent characteristics of flow resistance of RP-3 flow through adiabatic horizontal miniature tubes at supercritical pressures are investigated experimentally in this paper, the paper is organized as follows: Firstly, the experimental apparatus and procedures are described in Section 2. Then the test results and the relative analysis are given in Section 3. Finally, a conclusion with some major findings of this paper is reached in Section 4.