Thermochimica Acta 638 (2016) 113–119

Contents lists available at ScienceDirect

Thermochimica Acta

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

Novel measurement of isobaric specific heat capacity for kerosene RP-3 at high temperature and high pressure

X.K. Gao[a], X. Wen[a], H. Zhou[a], Q. Zhu[a,*], J.L. Wang[b], X.Y. Li[a,*]

[a] College of Chemical Engineering, Sichuan University, Chengdu, Sichuan 610065, People's Republic of China
[b] Key Laboratory of Green Chemistry and Technology of the Ministry of Education, College of Chemistry, Sichuan University, Chengdu 610064, People's Republic of China

ARTICLE INFO

Article history:
Received 28 September 2015
Received in revised form 14 June 2016
Accepted 21 June 2016
Available online 22 June 2016

Keywords:
Measurement
Kerosene
Isobaric specific heat capacity
High temperature
High pressure

ABSTRACT

In this work, a novel and simple method was put forward to measure the isobaric specific heat capacity for the kerosene RP-3 with a flow-calorimeter at the conditions of high temperature and high pressure. Based on the energy conservation principle, the formula for heat capacity was derived and its measurement was realized by the convective mixing method between the hot and cold fuel. Taking the precision of the instrument and the error transfer into account, the relative expanded uncertainty of this method was acquired of about ±6.38% (coverage factor $k = 2$). Meanwhile, the accuracy and reliability were verified by the standard material of water and n-decane. In the temperature range from (296.2–719.0) K and under pressure range from (2.4–4.0) MPa, the measurement for the kerosene RP-3 was carried out and the experimental observations were compared and agreed well with the published data. At last, an empirical correlation relationship of heat capacity due to the temperature and pressure was presented by using Garg's model with the measured experimental data.

1. Introduction

Because of the great strategic significance in aerospace area, the hypersonic vehicles are becoming very popular research topic nowadays [1–4]. As the flight speed increases, the turbine components suffer more thermal stress and heat loads, which cause the waste of energy and reduce the turbine performance and lifetime [5]. In order to solve the cooling problem of the aircraft engine operating under high supersonic and hypersonic regime, a novel heat management project had been proposed, named as active regenerative cooling (ARC) technology [6–9], in which the fuel carried by the aircraft was adopted as the coolant to flow through the engine wall before injecting into the combustion chamber. As a result, the temperature of the fuel will rise by absorbing the heat when flowed through the cooling passage. Therefore, the obtaining of the reliable and precise data, e.g., the isobaric specific heat capacity (ISHC), will be the great help to the heat exchanger design in the new ARC technology.

Aiming at the ISHC of liquid, much work, not only the theoretical prediction but also the experimental determination, had been carried out in the literatures. In theoretical simulation, Jovanović et al. [10] put forward an improved four parameter equation to calculate the liquid heat capacity. Ceriani et al. [11] proposed the estimation method for the heat capacities of organic liquids as a function of temperature by group contribution methods [12], which investigated with pure material at constant pressure. Fan et al. [13] selected a three-species surrogate model to simulate the thermophysical and transport properties of Daqing RP-3 aviation kerosene by the extended corresponding states. However, for the complicated composition of aviation kerosene, theoretical models are very difficult to acquire the precise heat capacity values. In experimental measurement, Chorążewski et al. [14] measured the heat capacities of 1-C-hloroalkanes and 1-Bromoalkanes within the temperature range from 284.15 K to 353.1 K by a differential scanning calorimeter at constant pressure. The ISHC of rocket propellant (RP-1 fuel) was measured by Abdulagatov et al. [15] with a static vacuum adiabatic calorimeter immersed in a precision liquid thermostat. An automated flow calorimeter for the measurement of high accurate isobaric heat capacities for pure compounds and mixtures was developed by Segovia et al. [16]. However, the experiment measurement mentioned above are performed with a low temperature range, which can't meet the requirements of the aeroengine's design.

For the domestic kerosene RP-3 in China, Deng et al. [5] measured the ISHC by using a vacuum flow calorimeter in the near-

* Corresponding authors.
E-mail addresses: qzhu@scu.edu.cn, zhuquan552@hotmail.com (Q. Zhu), xyli@scu.edu.cn (X.Y. Li).

http://dx.doi.org/10.1016/j.tca.2016.06.015
0040-6031/

Nomenclature

C_p	Constant pressure heat capacity (kJ. kg^{-1}/K)
$\dot{m}$	Mass flow (g/s)
P	Pressure (MPa)
Q	The heat absorbed with the enhanced temperature by the unit mass of fuel (kJ. kg^{-1})
T	Temperature (K)
Greek	
Ψ	Heat loss at cooling part (kJ)
#1#	Heat loss at heating part (kJ)
Subscripts	
c	Constant
cal	Calculation
exp	Experiment
fit	Fitting
lit	Literature
m	Mixed

critical and supercritical regions. But the test section including the vacuum device is difficult to be assembled, which may hinder the extension of this method. Therefore, it is necessary to develop a simple and effective measurement method for on-line measuring the ISHC of the flowing fluid under real conditions.

In this work, the main objective was to develop a new and simple method to measure the heat capacity of aviation kerosene fuel RP-3 at high temperature and high pressure conditions. Therefore, a novel method was established and proposed based on the convective mixing technique of the hot and cold fluid. During the experiments, the pressure of the fuel was varied from (2.40–4.0) MPa, and the temperature was varied from (296.2–719.0) K.

2. Experimental

2.1. Apparatus

A schematic view of the experimental system and detail view of the mixing chamber are shown in Fig. 1. Two high pressure constant-flow pumps with dual floating pistons in series (P500 and P270, Dalian Elite Analytical instruments Co. ltd.) were used to deliver the fuel to the stainless tube, which have a maximum flow of 500 ml/min and 99 ml/min, respectively. The mass flow rate of the fuel was monitored by a mass flow meter (CMF010M323, Emerson) with an uncertainty of ± 0.1% of full scale 30 g/s. The pressure of the experiment system was controlled by a back pressure valve (0–15 MPa) and measured by the pressure transducer (3051S, Rosemount) with the uncertainty of 0.075% of full scale (10 MPa). Electrical power was supplied to the heating tube (16 kW maximum). The electric voltage and electric current were calibrated by the power calibration instrument (PW6001, HIOKI) with an uncertainty of ± 0.02 V and ± 0.02A respectively. Three K-type sheathed thermocouples (φ = 1 mm) were immersed into the bulk fuel through the tee joints for the measuring of temperature of the heated, cold, mixed fuel, respectively. In order to achieve the accurate temperature for the heated fuel, a K-type sheathed thermocouple was inserted into the entrance of the mixing chamber through the tee joints. The detail of the mixing chamber was marked in red circle and enlarged at the lower right corner of Fig. 1. The thermocouple had been calibrated by measuring the electromotive force at the fixed furnace temperature with a DC potentiometer (UJ52a, Raysting), which has a resolution of 0.1 μV. Compared with standard electromotive force published in NIST ITS-90 thermocouple database, an uncertainty of ± 0.22 K was obtained for the thermocouple in the temperature range (293.15 K–719.15 K).

After the convective mixing, the fuel were cooled by a water-cooled condenser, and then collected into the return tank. Finally, all the signals were monitored and collected by the data acquisition equipment (LR8400, HIOKI) which connects with a dedicated computer, including the mass flow, fluid temperature, pressure, electric voltage and current.

2.2. Materials

The domestic aviation fuel RP-3 was bought from the sixth oil depot in Chengdu of Sichuan province and analyzed by the GC–MS (Clarus SQ8, PerkinElmer), including 67.65% alkanes (mass percentage), 4.66% alkenes, 11.09% cyclanes, 15.63% aromatic hydrocarbons and 0.97% other. The detailed compositions are listed as follow Table 1.

In order to verify the accuracy and feasibility of this method, *n*-decane (purity ≥ 99%, Fushun Taiyangsheng Chemical Co. Ltd.) and the deionized water were used. The deionized water was bought from the Aladdin biochemical technology Co. Ltd. The electric conductivity of the deionized water is 0.5 μS/cm which was detected by the digital conductivity meter (DDB-303, Leici instrument factory). The detail information can see the Table 2.

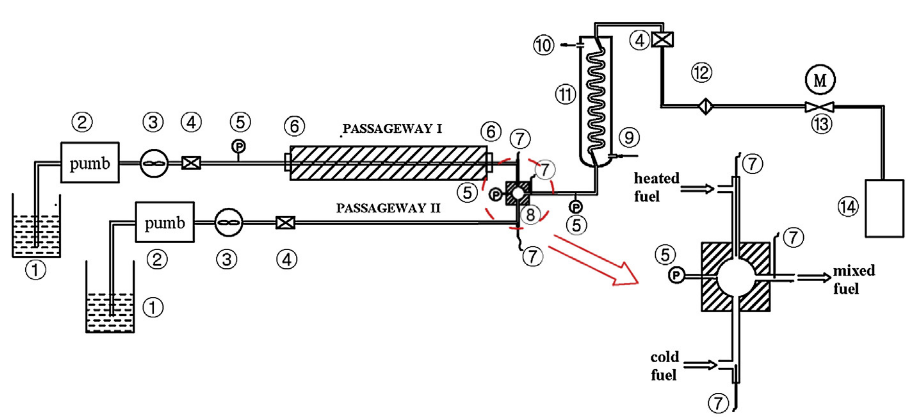

Fig. 1. Schematic of the experimental system and partial enlarged detail of the mixing chamber: (1) tank for fuel supply; (2) piston pump; (3) mass flowmeter; (4) insulation flange; (5) the pressure transducer; (6) electrical heating power connection; (7) thermoelectric couple; (8) the customized mixing chamber; (9) water inlet; (10) water outlet; (11) water-cooled condenser; (12) filter; (13) back pressure valve; (14) return tank.