On the isobaric specific heat capacity of natural gas

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A R T I C L E   I N F O

A B S T R A C T

A colorimeter equipped with a gas booster in conjunction with a PVT cell was used to measure the heat capacity of natural gas with different amounts of impurities. Based on new experimental and literature data, a general investigation of the isobaric specific heat capacity was carried out using the Jarrahian–Heidaryan equation of state (J–H-EOS). A model was obtained that is valid in wide ranges of pressures (0.1–40 MPa) and temperatures (250–414 K). The arithmetic average of the model's absolute error is acceptable in engineering calculations and has superiority over other methods in its class.

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1. Introduction

Natural gas is comparatively environmentally sound, and due to its longer estimated future availability compared to oil it is gaining importance, even though it, too, is a fossil fuel. Accounting for almost one-fourth of the world's primary energy consumption, natural gas is one of the most important primary energy sources [1].

Natural gas treatment requires an understanding of how its thermophysical properties vary with conditions. In dealing with natural gas flow with heat transfer, accurate estimates of its isobaric heat capacity must be made, if enthalpy changes are to be calculated. The heat capacity is required to calculate the amount of heat energy transferred when the temperature of natural gas changes.

In general, heat capacity (C) is defined as the ratio of the amount of heat energy transferred (Q) to a given change in temperature (ΔT):

$$C \equiv \frac{Q}{\Delta T} \tag{1}$$

More generally, because heat capacity is dependent on temperature, it could be written as:

$$C(T) = \frac{dQ}{dT} \tag{2}$$

At constant pressure, isobaric specific heat capacity is related to the change in enthalpy (H) accompanying a change in temperature. It can also be expressed as the slope of an isobar on the enthalpy versus temperature, so it could be written as:

$$C_p = \left(\frac{dQ}{dT}\right)_p = \left(\frac{\partial H}{\partial T}\right)_p \tag{3}$$

where enthalpy is a mathematical function of temperature.

Estimating the isobaric heat capacity (C_p) of natural gas has been extensively studied. Numerous researchers have presented correlations for estimating the ideal gas heat capacity (C_p^0) of pure compounds. Kobe et al. [2] and Thinh et al. [3] developed some relationships for ideal isobaric heat capacities of pure gases as third-order polynomials of temperature. Using a dimensional analysis, Kothari and Doraiswamy [4] demonstrated that ideal isobaric heat capacities of pure gases could be expressed as functions of molecular weight and reduced temperature. Hankinson et al. [5] obtained a correlation for ideal heat capacity of sweet natural gases. Their correlation is a surface fit that involves gas gravity and temperature as variables.

At high pressures, (C_p) deviates form the ideal state. Since, it is a critical matter, it has been addressed by many investigators [6–17].

Expressing heat capacity based on an equation of state (EOS) for natural gases is the general method in industry. Dranchuk and Abou-Kassem [18] presented a method using the EOS of Dranchuk et al. [19] to calculate heat capacity. Through the relationships from Thinh et al. [3], their method uses the ideal gas heat capacity defined for a range of hydrocarbon gas gravities. Sutton and Hamman [20] provided changes with regard to impurities and developed correlations for natural gas and gas condensate.

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Table 1
Composition of the natural gas mixture used in this study.

Component	Mole (%)
Methane	71.5
Ethane	11.0
Propane	6.5
n-Butane	1.9
iso-Butane	0.9
n-Pentane	0.4
iso-Pentane	0.4
Carbon dioxide	4.0
Nitrogen	1.8
Hydrogen sulfide	1.6
Total	100

Kareem et al. [21] generated C_p^0 for 200 samples of natural gas mixtures with a verity of methane mole fraction from 0.74 to 0.9985 using a normally distributed experimental design. Based on specific gravity and temperature, they generated an ideal gas specific heat capacity correlation, as well as a correlation to account for the deviation from ideal gas behavior by a dimensionless residual specific heat capacity as a function of reduced temperature and reduced pressure based on the EOS of Hall and Yarborough [22].

This study consists of two parts. In the first part, an experimental investigation was carried out by a colorimeter equipped with a gas booster in conjunction with a PVT cell to measure the heat capacity of a natural gas with different amounts of impurities. In the second part, based on new experimental and literature data and using the equation of state of Jarrahian–Heidaryan [23] (J–H-EOS), a general investigation of isobaric specific heat capacity was carried out.

2. Experimental

2.1. Materials and method

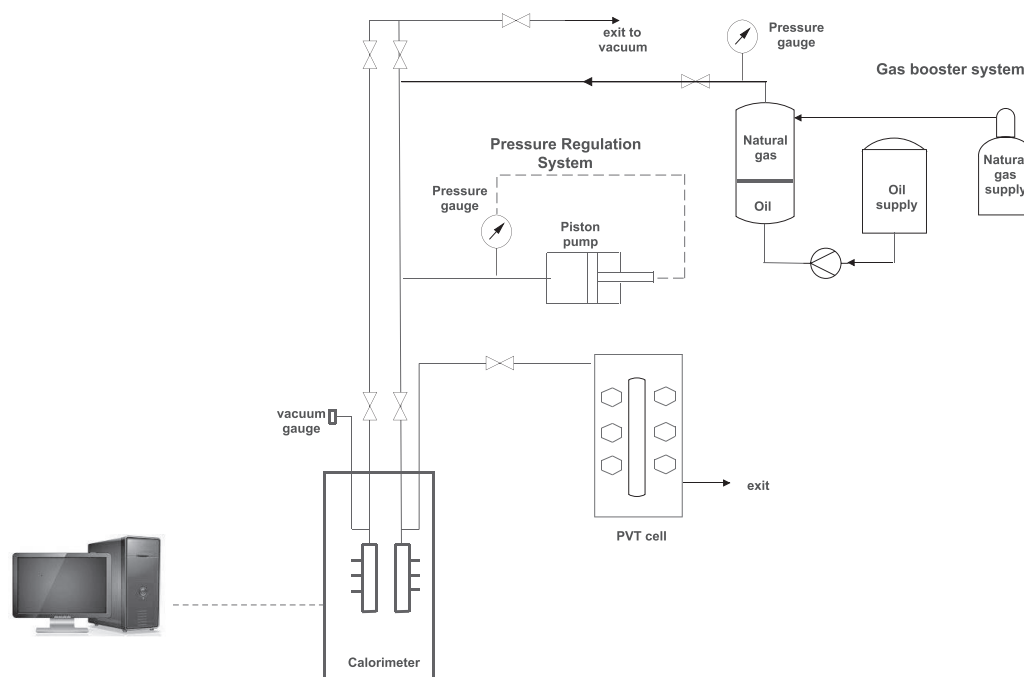The composition of the natural gas used in the experiments is presented in Table 1.

The schematic diagram of the experimental set-up is shown in Fig. 1.

A gas booster system was used to compress natural gas to the required pressures [24]. The major drawback of the system was that the rate of release of high-pressure gas from the system had to be carefully regulated. To keep the pressure constant, it was necessary to let the cell open and continuously increase the volume of the whole system. This was done by connecting the line from the measuring cell to a cylinder with a piston (pressure-regulation system) [25].

The calorimeter was composed of two identical and independent thermopiles constituted of several series of thermocouples. An electrical signal representative of heat exchanges was produced due to temperature differences between the cell and the calorimeter. Two steel cells were located inside the calorimeter: the measurement cell, which contains the mixture, and the reference cell, which was empty. These cells were placed inside a cylinder surrounded by a heating element. The difference between the heat needed to raise the temperature of the measuring cell and that needed to raise the temperature of the reference cell by the same temperature increment was obtained by continuously measuring the difference in the power received by the two cells and integrating over time [26].

The density was measured to calculate the heat capacity of the fluid. A high-pressure, high-temperature visual laboratory PVT cell [27] was used to study the volumetric properties of the natural gas. The PVT cell had a 100 MPa maximum working pressure, a working temperature from 266 to 422 K and a 100 cm^3 total volume.

Apparatus calibration results (for pure methane) are given in Fig. 2.

Fig. 1. Experimental apparatus.