



Isobaric specific heat capacity of natural gas as a function of specific gravity, pressure and temperature



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ABSTRACT

Natural gas engineering entails production, processing, storage and transportation of natural gas. A good handling of the gas requires a sophisticated understanding of how its density, compressibility, pseudo-pressure and specific heat capacity vary with the gas condition. A variety of methods have been presented in petroleum and gas journals and a host of scholastic materials to evaluate other properties over a wide range of temperatures, however, the available correlation for isobaric specific heat capacity is for only 150 °F. We generated 200 samples of natural gas mixture with methane component ranging from 0.74 to 0.9985 using normally distributed experimental design. The variations of the respective specific heat capacity of the components and the effect of composition on the specific gravity and overall specific heat capacity of the gas were taken into consideration. The developed correlation reads in the specific gravity and temperature to generate the ideal gas specific heat capacity of the sample. The result yielded 99.75% accuracy at 150 °F when compared to experimental data, as against the result from isentropic coefficient method which overestimated the ideal gas specific heat capacity by 25% at the same temperature. The ideal gas specific heat capacity developed compared to 6000 data points generated from mixing rule at different temperatures resulted in correlation regression coefficient of 0.9999. To account for the deviation from ideal gas behaviour, this work presents 99.7% *R* squared value for dimensionless residual specific heat capacity as a function of reduced temperature and pressure compared to that calculated from Starling Carnahan equation of state. This model is the first explicit correlation for the residual specific heat capacity of natural gas to be derived.

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1. Introduction

The specific heat capacity of natural gas is the quantity of heat required to raise the temperature of a kilo-mole of natural gas by 1 Kelvin or a Fahrenheit (in field unit). The specific heat capacity is required to calculate the amount of heat energy absorbed or evolved when the temperature of natural gas rises or falls. This requirement makes specific heat capacity vital in the design of intercoolers used between compressors when increasing the pressure of gathered gas to provide the needed energy for transmission through pipelines.

The heat energy accompanying an isobaric (constant pressure) temperature change (Abou-Kassem and Dranchuk, 1982) is given as:

$$\Delta H = n_G \bar{C}_p \Delta T \quad (1)$$

or

$$\Delta H = n_G \int_{T_1}^{T_2} C_p dT \quad (2)$$

where:

n_G = Number of kilomoles of natural gas

\bar{C}_p = Isochoric average specific heat capacity

ΔT = temperature change

If the temperature change is isochoric (constant volume), the expression becomes:

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$$\Delta H = n_G \bar{C}_v \Delta T \quad (3)$$

or

$$\Delta H = n_G \int_{T_1}^{T_2} C_v dT \quad (4)$$

The expression remains the same except for the isochoric specific heat capacity which replaces its isobaric counterpart. The majority of petroleum and gas journals and textbooks seem to have neglected the necessity of a correlation for specific heat capacity of natural gas. The only available correlation is for isentropic exponent k as a function of specific gravity γ_g at 150 °F from which the isobaric specific heat can be calculated as follows:

$$k^{150^\circ\text{F}} = \frac{2.738 - \log(\gamma_g)}{2.328}, \quad 0.55 < \gamma_g < 1 \quad (5)$$

But,

$$k = \frac{C_p}{C_v} \quad (6)$$

also,

$$C_p = C_v + R \quad (7)$$

Where R is the universal gas constant = 8134 J/kmol K

$$k = \frac{C_p}{C_p - R}$$

$$\frac{1}{k} = 1 - \frac{R}{C_p}$$

$$\frac{R}{C_p} = \frac{k - 1}{k}$$

so that,

$$C_p = \frac{kR}{(k - 1)} \quad (8)$$

For the fact that Eq. (8) only gives the value of the isobaric specific heat capacity when the temperature is 150 °F, it cannot be used to evaluate the parameter at elevated temperatures. Therefore, there is need for a correlation to that end (Trube, 1957).

2. Assumption

For simplification, it is assumed that natural gases having the same specific gravity have the same constituents in identical proportions. As would be seen later, this assumption simplifies the situation without impacting the result.

For instance, a mixture of 80% methane and 20% ethane has exactly the same specific gravity (0.651) as a mixture of 90% methane and 10% propane. We might expect the specific heat capacity to be different, but the specific heat capacity turned out to be the same at every temperature. Therefore, the specific gravity gives a good representation of the constituent and can be used along with temperature to express the specific heat capacity of an ideal natural gas.

To illustrate this point, data of isobaric specific heat coefficients extracted from Table 1 were used to construct a plot of the specific

Table 1

Constants of the degree three fit of C_p as a function of temperature (Cengel and Boles, 2002).

Compounds	a	b	c	d
Methane (C ₁)	19.89	5.024×10^{-2}	1.269×10^{-5}	-11.01×10^{-9}
Ethane (C ₂)	6.900	17.27×10^{-2}	-6.406×10^{-5}	7.285×10^{-9}
Propane (C ₃)	-4.04	30.48×10^{-2}	-15.72×10^{-5}	31.74×10^{-9}
n-Butane (C ₄)	3.96	37.15×10^{-2}	-18.34×10^{-5}	35.00×10^{-9}
i-Butane (C ₄)	-7.913	41.60×10^{-2}	-23.01×10^{-5}	49.91×10^{-9}
n-Pentane (C ₅)	6.774	45.43×10^{-2}	-22.46×10^{-5}	42.29×10^{-9}
i-Pentane (C ₅)	6.774	45.43×10^{-2}	-22.46×10^{-5}	42.29×10^{-9}
n-Hexane (C ₆)	6.938	55.22×10^{-2}	-28.65×10^{-5}	57.69×10^{-9}
Heptane+ (C ₇₊)	9.118	73.20×10^{-2}	-37.98×10^{-5}	76.47×10^{-9}
Carbon dioxide (CO ₂)	22.26	5.981×10^{-2}	-3.501×10^{-5}	7.469×10^{-9}
Nitrogen (N ₂)	28.90	0.1571×10^{-2}	0.8081×10^{-5}	-2.873×10^{-9}

heat capacities of the two mixtures over a temperature range of 50–1550 °C as shown in Fig. 1.

3. Methodology

Certain properties, including pseudo-critical temperature and pseudo-critical pressure, are calculated as the sum of partial pseudo-critical pressures and temperatures of the components of natural gas sample (Abou-kassem & Dranchuk, 1975; Farzaneh-Gord et al., 2010; George and Brown, 1944). These are elucidated in the following mathematical expressions:

$$P_{pc} = \sum_{i=1}^n y_i P_{pci} \quad (9)$$

$$T_{pc} = \sum_{i=1}^n y_i T_{pci} \quad (10)$$

Moreover, the specific gravity can be expressed in the same way. For instance, consider:

$$\gamma_g = \frac{MW_{\text{gas}}}{MW_{\text{air}}} = \frac{1}{MW_{\text{air}}} \sum_{i=1}^n y_i MW_i = \sum_{i=1}^n y_i \left(\frac{MW_i}{MW_{\text{air}}} \right)$$

Therefore,

$$\gamma_g = \sum_{i=1}^n y_i \gamma_{gi}$$

$$C_p = \sum_{i=1}^n y_i C_{pi} \quad (11)$$

where C_p is the heat capacity of the natural gas and C_{pi} is the heat capacity of each constituent gas.

The specific heat capacity of a gas at constant pressure is also expressed as degree-3-function of temperature so that:

$$C_p = a + bT + cT^2 + dT^3 \quad (12)$$

Combining Eqs. (11) and (12) results in:

$$C_p = \sum_{i=0}^n y_i a_i + T \left(\sum_{i=0}^n y_i b_i \right) + T^2 \left(\sum_{i=0}^n y_i c_i \right) + T^3 \left(\sum_{i=0}^n y_i d_i \right) \quad (13)$$

Since the mole fraction is used to calculate the specific gravity, the specific heat coefficients a , b , c , and d can be plotted against the

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