

International Journal of Engineering Sciences & Research Technology

(A Peer Reviewed Online Journal)

Impact Factor: 5.164



Chief Editor

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**INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH
TECHNOLOGY**

**DEVIATION OF GASEOUS HELIUM PROPERTIES FROM AN IDEAL GAS
EQUATION**

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DOI: 10.5281/zenodo.1488721

ABSTRACT

For the purpose to develop industry, from new potential mineral or substances, Indonesia needs the equation of state or the ideal gas formulation to simplify the thermodynamic design problem solving analytically or computationally to produce newly advanced, superior products. To build up P-V-T data, many references and experimental data are needed, such as specific heat, the speed of sound, and many others. An approximate mathematical model is required to produce analytical results, analytically, computationally. In most concept, the use of simplified equations, such as an ideal gas, is preferable, especially during the employment of the perturbation method, numerical techniques to produce new superior products. In this paper some results of ideal gas model deviation would be presented, especially helium for a wide range of pressure up to 108 Pa and a wide range of temperature, 2 K to 1500 K. In this extensive region, gaseous helium behaves as an ideal gas, one can expect that the specific heat of constant volume is $C_v = 3/2 R = 3.118 \text{ J/g K}$. There are vast regions in space where ideal gas and constant Prandtl number assumptions can be used to approximate the thermophysical properties of gaseous helium.

KEYWORDS: -V-T data; helium properties; ideal gas formulation; Prandtl number assumptions; physical properties.

1. INTRODUCTION

Product development competition in the global market would rely significantly on innovation and the new smart material, gas and liquid development. Indonesia has a lot of new potential mineral or substances that would become the core of the concentrating element in developing new important Indonesia technology in the future. Some of them in the form of gas and liquid. This unique secret substance or mineral would require serious studies to formulate the equation of state of this matter to provide tools during the thermodynamic design to produce new superior products. In this study, the development of a complete equation of state for Helium 4 from 2 to 1500 K at Pressures to 108 Pa would be used as a reference model [1].

Helium is a colorless, odorless, tasteless, non-toxic, inert, monatomic gas that heads the noble gas. Its boiling and melting points are the lowest amongst all the members. Liquid helium is used in cryogenics, particularly in the cooling of superconducting magnets, with the main commercial application being in MRI scanners. Helium's other industrial uses as a pressing and elimination vapors, as a shielding gas for arc soldering and in procedures such as growing crystals to make silicon crackers account for half of the gas produced.

Several investigations on the helium industry process have been completed. Liemberger et al. [2] have investigated a hybrid of two membrane separation step and a pressure swing adsorption; they were investigated via process simulation. A sensitivity analysis reveals that the required amount of specific energy depends on several parameters like total helium recovery, feed concentration, feed pressure, membrane selectivity, PSA recovery and compression efficiency. Anderson [3] found that, in general, modern replicas of helium whichever



do not count for an oligopoly regulating source, or they do not estimate resource helium removal and storing agendas based on an intertemporal enlargement of the value of the source. Such mockups could be of very restricted use to decision makers. This evaluation creates only a few papers with a helium market place typical that has combined these critical thoughts. That and other financial studies sideways similar lines could be precious in serving inform current helium rule debates and conclusions. Boreham [4] have

explored helium in the Australian liquefied natural gas (LNG) accumulations potentially have a higher untapped value in helium extraction (i.e., resulting from current and future LNG production) compared with Australia's sole commercial onshore helium extraction facility in Darwin natural gas.

Lie et al. have conducted preliminary design and performance analysis of a radial inflow turbine for a large-scale helium cryogenic system [5]. Smith has completed helium substitution of natural gas hydrocarbons in the report of their hydrate [6]. Kim et al. have done cryogenic thermal studies on terminations for helium gas cooled superconducting cables [7]. Alden has introduced helium recovery using membrane processes [8]. Some scientists have initiated an advanced exergoeconomic evaluation of a new cryogenic helium recovery process from natural gas based on the flash separation-APCI modified [9].

Transient convection heat transfer for helium gas at various flow decay times has been thoroughly studied [10]. Shafaei & Mehrpooya have performed process development and sensitivity analysis of novel integrated helium recovery from natural gas processes [11]. Two experts have examined hydrogen and LNG production from coke oven gas with multi-stage helium expansion refrigeration [12]. Eggenberger et al. have studied the temperature dependence of the leak rate and permeability of helium gas through Kapton foils [13]. Felkai et al. have introduced Helium-Xenon mixtures to improve the topological signature in high-pressure gas xenon TPCs [14]. Numerical study on the elimination vapor stream and heat transmission physiognomies in helium chilled rock-hard breeder blanket of CFETR [15]. As with any gas whose density differs from that of air, inhaling a small volume of helium momentarily varies the quality and power of the human voice. In systematic investigation, the performance of the two fluid stages of Helium-4 (Helium I and Helium II) is imperative to investigate learning quantum mechanism, in particular, the possessions of superfluidity, and to those observing at the wonders, such as superconductivity, formed in substance close to total zero.

McCarty [15] collected all sources available around the world to build up P-V-T data. In addition to these P-V-T data, there were many references in the literature which contain other useful experimental data such as specific heat, the speed of sound, and many others. All of the articles which included appropriate experimental data were considered for possible contribution to the correlation of the thermodynamic properties of helium. Over the past few years, some other correlations of properties of helium had been published. Most of these had been of limited scope, and only one had included the two-phase region. In the last ten years or so, the high-speed digital computer had made the equation of state approach to thermodynamic properties more and more attractive.

When the task of correlating the thermodynamic properties of helium was undertaken, one of the ultimate goals was the production of a single equation of state which would adequately predict the current experimental data from 2 to 1500 K with pressures as high as possible. As is always the case when trying to fit a large surface such as a P-V-T surface, part of the surface is compromised to allow even a reasonable fit of another portion of the surface. It was therefore decided after a long and tedious period of experimentation with, and development of, various mathematical models for the equation of state of helium that further efforts along the single equation of state approach would likely be fruitless.

2. METHOD

Two-dimensional compressible system for deposited boundary power

The following is the example, where the ideal gas assumption is significantly useful to develop an exact precise solution, the governing equations for the two-dimensional compressible system for boundary power deposited on a planar 2-dimensional box with height ratio δ [16].

$$\rho_t + (\rho u)_x + \delta(\rho v)_y = 0, \exp(-\phi\gamma y) + p = \rho T, \quad (1)$$

$$\rho(u_t + uu_x + \delta v u_y) = -\frac{1}{\gamma} p_x + \epsilon \left(\frac{3}{4}\right) \left\{ \mu(u_x - \frac{\delta}{2} v_y) \right\}_x + \epsilon \left\{ \mu(\delta^2 u_y + \delta v_x) \right\}_y, \quad (2)$$



$$\rho(v_t + uv_x + \delta v v_y) = -\frac{\delta}{\gamma} p_y + \xi \{ \exp(-\varphi \gamma y) - \rho \} + \epsilon \left(\frac{4}{3} \right) \{ \mu(\delta^2 v_y - \frac{\delta}{2} u_z) \}_y + \epsilon \{ \mu(\delta u_y + v_x) \}_x \tag{3}$$

$$\rho \frac{C_v}{(\gamma-1)} (T_t - u T_x + \delta v T_y) = - \{ \exp(-\varphi \gamma y) + p \} (u_z + \delta v_y) + \epsilon \frac{\gamma}{(\gamma-1) Pr} \{ (k T_x)_x + \delta^2 (k T_y)_y \} + \epsilon \gamma \mu \left(\frac{4}{3} \right) (u_x^2 + \delta^2 v_y^2 - \delta u_x v_y) + (\delta u_y + v_x)_x \tag{4}$$

Where subscripts t, x, y denote partial derivatives. The non-dimensional variables are defined by

$$\rho = \rho' / \rho'_{s0}, p = p'_{tr} / p'_{s0}, T = T' / T'_0, t = t' / t'_0, \chi = \chi' / L', y = y' / H', u = u' / c'_0, v = v' / c'_0, \delta = L' / H' \tag{5}$$

$$\mu = \mu' / \mu'_0, k = k' / k'_0, Pr = \mu'_0 C'_{po} / k'_0, C_v = C'_v / C'_{vo} \text{ and } \epsilon = Pr'_a t'_c, \xi = g' L' / c'^2_0, \varphi = g' H' / c'^2_0 = \xi / \delta. \tag{6}$$

$$\text{the acoustic and conduction time scale } t'_a = \frac{L'}{c'_0}, t'_c = \frac{L'^2}{\kappa'_0} \tag{7}$$

The equilibrium initial conditions are given by

$$\left. \begin{aligned} t = 0, T = 1, p = \{ \exp(-\varphi \gamma y) \} \\ |k T_w| = q_w(t; \epsilon) \\ u = v = p = 0 \end{aligned} \right\} t > 0$$

and the boundary conditions for the system can be described as

$$\begin{aligned} x = 0, 1; u = v = 0 \\ y = \pm 1; T_y = 0 \\ q_w = q'_w / \left(\frac{k'_0 T'_0}{L'} \right) \end{aligned}$$

Where $-k' T'_y; Z' = 0$ is the prescribed heat addition at the wall.

This paper currently under finishing step to come up to the conduction time solution. It is unfortunate that the work of McCarty [15] has not been completed with the working range where the ideal gas assumption would be valid.

The purpose of this study, after serious studies to formulate the equation of state, it is necessary to have basic knowledge of the medium involved, especially the thermodynamic and physical properties of this helium. An approximate mathematical model to produce analytical results is needed which would reveal the physical details of processes in the system. In the current concept, the use of simplified equations, an ideal gas, is limited to regimes in which they describe realistic physics. In this ideal gas assumption would simplify the analytical, high accuracy thermodynamic design, especially during the employment of the perturbation method to produce new superior products.

Helium as a working fluid

The purpose of this work is to conduct a theoretical investigation of a confined helium system subjected to thermal boundary heating. To carry out this effort, it is necessary to have basic knowledge of the medium involved, especially the thermodynamic and physical properties of helium. A simplified approach employed is based on representing the equation of state and the transport properties of helium by simple analytical formulae. These simple relations can be used in an approximate mathematical model to produce analytical results which reveal the physical details of processes in the system. The use of simplified equations is limited to regimes in which they describe realistic physics. In this chapter, a study is made of the deviation of the real equation of state from that for an ideal gas. Also, the Prandtl number variation in state space is examined.



Helium, at temperatures substantially above the standard boiling point, behaves nearly as an ideal gas. This is due to its weak interactive potential and the spherically symmetric molecular configuration. From this basic idea, several empirical equations, describing the relationship between the thermodynamic properties, have been developed in terms of extensions from the ideal gas model in the form of a virial expansion. In this study, the equation of state formulated by [1] is used because it covers an extensive range of temperatures and pressures.

$$p = \rho RT [1 + B(b_i, T) \rho] + \sum_{i=1}^8 n_{1i} \rho^3 T^{(1.5-\frac{i}{2})} + \sum_{i=1}^4 n_{2i} \rho^4 T^{(1.5-i)} + \sum_{i=1}^6 n_{3i} \rho^5 T^{(0.75-\frac{i}{4})} + \sum_{i=1}^4 n_{4i} \rho^3 e^{\gamma \rho^2} T^{(1.0-i)} + \sum_{i=1}^3 n_{5i} \rho^5 e^{\gamma \rho^2} T^{(1.0-i)} + \sum_{i=1}^2 n_{6i} \rho^6 T^{(1.0-i)} \quad (8)$$

where the second virial coefficient B can be written as

$$B(b_i, T) = \sum_{i=1}^9 b_i T^{(1.5-\frac{i}{2})} \quad (9)$$

The coefficients n_{ji} and b_i in (8) and (9) are tabulated in Table 1.

In these equations all variables and coefficients are in dimensional form, the pressure p is in atmospheres, the density ρ is in moles per liter, the temperature T is in degrees Kelvin and the second virial coefficient B is in liters/mole. This single equation, with three different sets of adjustable parameters each of which are used in a specified region on the p - V - T surface, is valid from 2 K to 1500 K at pressures up to 108 Pa.

Helium as an ideal gas

Using (8) and (9), one can determine the deviations of gaseous helium from an ideal gas at any thermodynamic state point in the form of $p/\rho RT - 1$. Fig. 1 shows the lines of constant fractional deviation of the gaseous helium equation of state from the ideal equation $p = \rho RT$, where p , ρ , T are the dimensional pressure, density and temperature respectively and R is the gas constant.

The temperature varies from 15K to 1500 K and density from 0.04 to 80.0 kg/m³. It should be noted that the constant pressure lines in Fig.1 are calculated from (8), formulated by [1]. The standard condition $T_{st} = 300K$, $p_{st} = 1 \text{ atm}$, is denoted by an asterisk while the critical point $T_{cr} = 5.2014 \text{ K}$, $p_{cr} = 2.2449 \text{ atm}$, is located below the region plotted in Fig. 1. It is seen in Fig. 1 that there is a vast region where the ideal gas assumption can be applied with reasonable accuracy. The deviation increases toward the near-critical area and the region of high density. The deviation is still less than 5 percent as long as the gas temperature $T > 15 \text{ K}$ and the density $\rho < 5 \text{ kg/m}^3$.

Table 1 Coefficients n_{ji} and b_i used in (8) and (9) from [1].

$n_{11} = -3.6027735292 \times 10^{-5}$	$n_{32} = 4.0855110880 \times 10^{-7}$	$b_1 = -5.0815710041 \times 10^{-7}$
$n_{12} = 1.6079946555 \times 10^{-3}$	$n_{33} = 1.0900567964 \times 10^{-5}$	$b_5 = -5.3143174768 \times 10^{-1}$
$n_{13} = -2.7441763615 \times 10^{-2}$	$n_{34} = -5.0060952775 \times 10^{-5}$	$b_9 = 2.0804456338$
$n_{14} = 1.4739506957 \times 10^{-1}$	$n_{35} = 1.1312765043 \times 10^{-4}$	$b_2 = -1.1168680862 \times 10^{-4}$
$n_{15} = -4.3559344838 \times 10^{-1}$	$n_{36} = -1.2539843287 \times 10^{-4}$	$b_6 = -9.5759219306 \times 10^{-1}$

$n_{16} = 1.3447956078$	$n_{41} = 5.6875644111 \times 10^{-3}$	$b_3 = 1.1652480354 \times 10^{-2}$
$n_{17} = -1.7040375125$	$n_{42} = -1.4438146625 \times 10^{-1}$	$b_7 = 3.9374414843$
$n_{18} = 9.0262674040 \times 10^{-1}$	$n_{43} = 3.3768874851 \times 10^{-3}$	$b_4 = 7.447458998 \times 10^{-2}$
$n_{21} = 1.9661380688 \times 10^{-6}$	$n_{51} = 1.0754201218 \times 10^{-6}$	$b_8 = -5.1370239224$
$n_{22} = 1.7122932666 \times 10^{-4}$	$n_{52} = -4.52646223089 \times 10^{-5}$	$\gamma = -5.000 \times 10^{-4}$
$n_{23} = 2.3051000563 \times 10^{-4}$	$n_{53} = 3.85973888864 \times 10^{-5}$	
$n_{24} = -9.6564739100 \times 10^{-4}$	$n_{61} = -1.4802195348 \times 10^{-8}$	
$n_{31} = -2.3326553271 \times 10^{-7}$	$n_{62} = 4.1721791119 \times 10^{-7}$	

The equation of state (8) can be used to calculate the specific heat at constant volume [1]

$$C_v = C_{v0} - \int_{\rho_0}^{\rho} \frac{T}{\rho^2} \left(\frac{\partial^2 p}{\partial T^2} \right)_{\rho} d\rho \tag{10}$$

Where in the integrand, the second derivative of p with respect to T is evaluated keeping ρ fixed, and the whole integrand is then integrated over a required density range isothermally. In (10), C_{v0} is the specific heat of constant volume for a given thermodynamic state. This reference value can be found from a table of the thermodynamic properties of helium, for example, that reported by [1]. In the region where gaseous helium behaves as an ideal gas, one can expect that the specific heat of this monatomic gas at constant volume is $C_v = \frac{3}{2} R = 3.118 \text{ J/g K}$. Fig. 2 shows the deviation of specific heat at constant volume C_v from a constant C_v approximation.

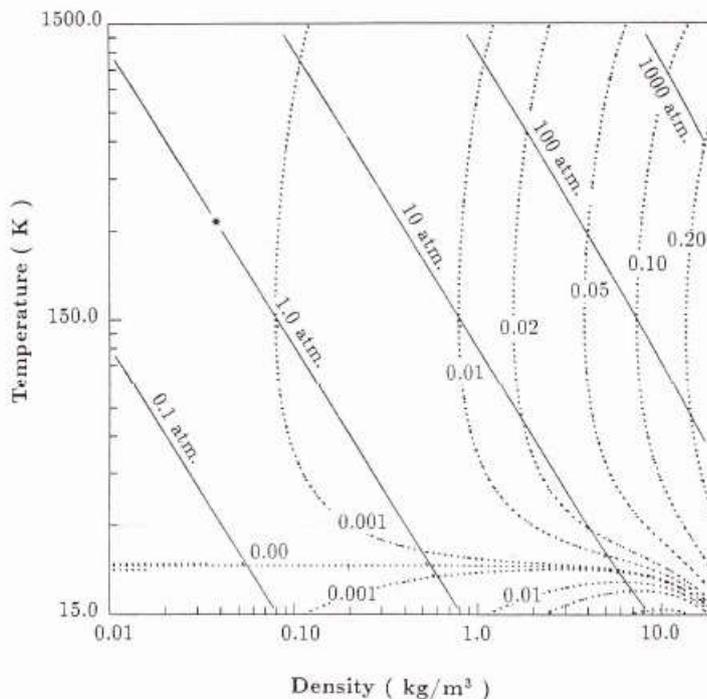


Figure 1 Fractional deviations (dotted lines) of the gaseous helium equation of state from the equation of state $p' = \rho'RT'$. The solid lines represent constant pressure states for the real equation of state.

The deviation is relatively small over the region considered. The deviation of the specific heat, C_v , increases very weakly toward the area of high density. For a system with a density $\rho < 10 \text{ kg/m}^3$, the deviation of C_v from the given constant is less than 5 percent.

Subsequently, the specific heat at constant pressure C_p can be calculated as [1]

$$C_p = C_v + \frac{T}{\rho^2} \left(\frac{\partial p}{\partial T} \right)_\rho^2 \left(\frac{\partial \rho}{\partial p} \right)_T \tag{11}$$

and from which the deviation of C_p from a constant value $C_p = \frac{5}{2} R$ can be evaluated.

As soon as these specific heats are found from (8) – (11), the speed of sound c_0 of the gaseous helium for any thermodynamic state can be determined[1],

$$c_0 = \sqrt{\frac{C_p}{C_v} \left(\frac{\partial p}{\partial \rho} \right)_T} \tag{12}$$

with these equations, one can quickly generate the thermodynamic table for p , C_v , C_p and c_0 for gaseous helium at different thermodynamic states and at the same time analyze the deviation of gaseous helium from an ideal gas. Equations describing transport properties of helium over a wide range of conditions have also been developed. Along with the thermodynamic properties derived above, the correlation for thermal conductivity of helium formulated by Hands and Arp[17] and the viscosity equation given by McCarty [18] can be used to find the deviation of Prandtl number of the gaseous helium from a constant value. The result is plotted in Fig. 3. Once again it is seen that the deviation increases toward the region of high density and temperature.

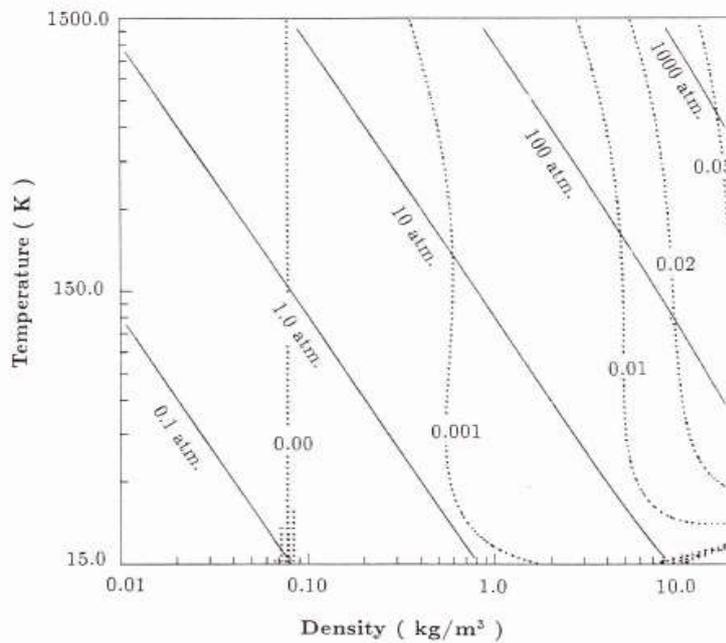


Figure 2 Fractional deviations (dotted lines) for C_v of the gaseous helium from $C_v = 3.118 \text{ J/b K}$. The solid lines represent constant pressure states for the real equation of state.

These results show that there is a region in space where ideal gas and constant Prandtl number assumptions can be used to approximate the thermophysical properties of gaseous helium.

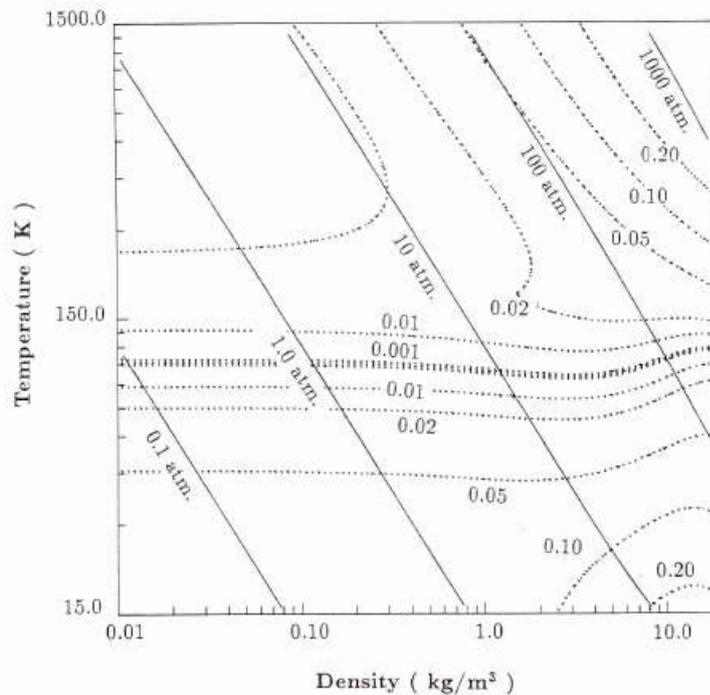


Figure 3 Fractional deviations for Pr of the gaseous helium from $Pr = 0.669$. The solid lines represent constant pressure states for the real equation of state.

3. DISCUSSION

In this study, after discovering the equation state for helium in a specified region on the p - V - T surface, from 2 K to 1500 K at pressures up to 108 Pa, one could justify where gaseous helium behaves as an ideal gas. The results show that the standard condition $T_{st} = 300\text{K}$, $p_{st} = 1\text{ atm}$, is denoted by an asterisk while the critical point $T_{cr} = 5.2014\text{ K}$, $p_{cr} = 2.2449\text{ atm}$. A broad region has been found valid for ideal gas assumption with reasonable accuracy. The deviation increases toward the near-critical area and the region of high density. The deviation is still less than 5 percent as long as the gas temperature $T > 15\text{ K}$ and the density $\rho < 5\text{ kg/m}^3$. In the region where gaseous helium behaves as an ideal gas, which is significantly wide, one can expect that the specific heat of constant volume is $C_v = \frac{3}{2}R = 3.118\text{ J/g K}$. The solid lines represent constant pressure states for the real equation of state.

The correlation for thermal conductivity of helium formulated by [17] and the viscosity equation can be used to find the deviation of Prandtl number of the gaseous helium from a constant value. It is seen that the deviation increases toward the region of high density and temperature. These results show that there is a region in space where ideal gas and constant Prandtl number assumptions can be used to approximate the thermophysical properties of gaseous helium.

4. CONCLUSION

A lot of new potential mineral or substances could become the core of valuable material, in the form of gas and liquid, to develop future technology. This substance or mineral would require the equation of state formulation for the thermodynamic design to produce new advanced products.

To build up P - V - T data, many references in the literature and experimental data are needed, such as specific heat, the speed of sound, and many others. An approximate mathematical model to produce analytical results, analytically, computationally, is required which would reveal the physical details of processes in the system. In most concepts, the use of simplified equations, an ideal gas is preferable. In this ideal gas assumption would simplify the analytical, high accuracy thermodynamic design, especially during the employment of the perturbation method to produce new superior products.

In this paper, several results were presented, especially for a wide range of pressure up to 108 Pa and a wide range of temperature, 2 K to 1500 K. In this vast region, gaseous helium behaves as an ideal gas; one can expect that the specific heat of constant volume is $C_v = \frac{3}{2}R = 3.118 \text{ J/g K}$. There are wide region in space where ideal gas and constant Prandtl number assumptions can be used to approximate the thermo physical properties of gaseous helium.

5. ACKNOWLEDGEMENTS

The authors would like to express heartfelt gratitude to Prajitno for a productive session, useful suggestions, and collaboration. We appreciate the help of our students Farhan, Fadhil, and Hasan, and the lab staff members, Ponimin and Wajiono, for giving their advice in construction work and conducting data management, which we gratefully acknowledge.

NOMENCLATURE

c'_o	speed of sound at the reference state
C'_p	specific heat at constant pressure
C'_{po}	specific heat at constant pressure at the reference state
C'_v	specific heat at constant volume
C'_{vo}	specific heat at constant volume at the reference state
C_v	dimensionless specific heat at constant volume
g'	gravity
k'_o	thermal conductivity
k	dimensionless thermal conductivity
L'	the width of the container
p'_{so}	pressure at reference state at the reference height
p'_{tr}	pressure perturbation
p	dimensional pressure
P_r	the Prandtl number
R	dimensional gas constant
t'	time
t'_a	acoustic time
t'_c	conduction time
t	dimensionless acoustic time
t_o	dimensionless acoustic cut-off time
u'	horizontal gas velocity
u'_e	horizontal gas velocity at the boundary layer edge
u	dimensionless horizontal gas velocity
v'	vertical gas velocity
v	dimensionless vertical gas velocity
x'	horizontal coordinate
x	dimensionless horizontal coordinate
y'	vertical coordinate
y	dimensionless vertical coordinate

Greek letters

γ	the ratio of specific heats
δ	aspect ratio
ε	Knudsen number – like parameter
κ'_o	thermal diffusivity at reference state
μ'_o	dynamic viscosity at reference state
μ	dimensionless dynamic viscosity
ν'_o	kinematic viscosity at reference state
ν	dimensionless kinematic viscosity
ρ'	density



ρ dimensionless density
 φ small parameter

REFERENCES

- [1] R. D. McCarty, "Thermodynamic Properties of Helium - 4 from 2 to 1500 K at Pressures to 10 Pa," *J. Phys. Chem. Ref. Data*, vol. 2, pp. 923–1024, 1973.
- [2] W. Liemberger, M. Miltner, and M. Harasek, "Efficient Extraction of Helium from Natural Gas by Using Hydrogen Extraction Technology," *Chem. Eng. Trans.*, vol. 70, pp. 865–870, 2018.
- [3] S. T. Anderson, "Economics , Helium , and the U . S . Federal Helium Reserve : Summary and Outlook," *Nat. Resour. Res.*, vol. 27, no. 4, pp. 455–477, 2018.
- [4] C. J. Boreham *et al.*, "Helium in the Australian liquefied natural gas economy," *APPEA J.*, vol. 58, no. Daly 2005, pp. 209–237, 2018.
- [5] X. Li, C. Lv, S. Yang, J. Li, B. Deng, and Q. Li, "Preliminary design and performance analysis of a radial inflow turbine for a large-scale helium cryogenic system," *Energy*, vol. 10, p. 179, 2018.
- [6] C. Smith, A. Barifcani, and D. Pack, "Helium substitution of natural gas hydrocarbons in the analysis of their hydrate," *J. Nat. Gas Sci. Eng.*, vol. 35, pp. 1293–1300, 2016.
- [7] C. H. Kim, S. K. Kim, L. Graber, and S. V. Pamidi, "Cryogenic thermal studies on terminations for helium gas cooled superconducting cables," *Phys. Procedia*, vol. 67, pp. 201–207, 2015.
- [8] M. Alders, D. Winterhalder, and M. Wessling, "Helium recovery using membrane processes," *Sep. Purif. Technol.*, vol. 189, no. July, pp. 433–440, 2017.
- [9] H. Ansarinassab, M. Mehrpooya, and M. Pouriman, "Advanced exergoeconomic evaluation of a new cryogenic helium recovery process from natural gas based on the flash separation–APCI modified process," *Appl. Therm. Eng.*, vol. 132, pp. 368–380, 2018.
- [10] Q. Liu, L. Wang, and K. Fukuda, "Transient convection heat transfer for helium gas at various flow decay times," *Appl. Therm. Eng.*, vol. 116, pp. 355–363, 2017.
- [11] A. Shafaei and M. Mehrpooya, "Process development and sensitivity analysis of novel integrated helium recovery from natural gas processes," *Energy*, vol. 154, pp. 52–67, 2018.
- [12] J. Xu, W. Lin, and S. Xu, "Hydrogen and LNG production from coke oven gas with multi-stage helium expansion refrigeration," *Int. J. Hydrogen Energy*, vol. 43, no. 28, pp. 12680–12687, 2018.
- [13] A. Eggenberger, I. Belosevic, A. Antognini, K. Kirch, and F. M. Piegsa, "Temperature dependence of the leak rate and permeability of helium gas through Kapton foils," *Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip.*, vol. 798, pp. 140–143, 2015.
- [14] R. Felkai *et al.*, "Helium–Xenon mixtures to improve the topological signature in high pressure gas xenon TPCs," *Nucl. Instruments Methods Phys. Res. Sect. A Accel. Spectrometers, Detect. Assoc. Equip.*, vol. 905, no. May, pp. 82–90, 2018.
- [15] M. Wang *et al.*, "Numerical study on the purge gas flow and heat transfer characteristics in helium cooled solid breeder blanket of CFETR," *Prog. Nucl. Energy*, vol. 105, no. November 2017, pp. 114–123, 2018.
- [16] Sutrisno, *Conduction time scale solution for two dimensional slender box subjected to fast heating at the vertical boundary*. unpublished.
- [17] B. A. Hands and V. D. Arp, "A Correlation of Thermal Conductivity Data for Helium," *Cryogenics (Guildf.)*, vol. 21, no. 12, pp. 697–703, 1981.
- [18] R. D. McCarty, "Thermo physical Properties of Helium - 4 from 2 to 1500 K with Pressures to 1000 atmospheres," 1972.

CITE AN ARTICLE

Sutrisno, Iswahyudi, S., & Wibowo, S. B. (2018). DEVIATION OF GASEOUS HELIUM PROPERTIES FROM AN IDEAL GAS EQUATION. *INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY*, 7(11), 63-71.

