Investigation of Similarity of Performance of the Equations of State Available in CFTurbo For H_2, N_2, O_2, CH_4, CO_2, and Air

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Abstract: In this publication, a qualitative study is conducted to investigate how different equations of state perform for different gases at different temperatures and pressures. Perfect Gas, Redlich-Kwong, Aungier/Redlich-Kwong, Soave/Redlich-Kwong, Peng-Robinson, and Cool Prop are used to calculate the properties of H_2, N_2, O_2, CH_4, CO_2, and air at a reduced temperature between 1.89 and 6.04 and reduced pressure between 0.027 and 6.661. Initially, we delved into the existing literature to locate experimental data for the specified gases. Due to a lack of experimental data, Cool Prop calculations are used as a reference due to its high accuracy (error $\leq 1\%$). Then, the performance of each equation for each gas is estimated. Finally, the similarity of the accuracy of each equation independently of the gas is estimated and general rules of their performance are indicated.

Keywords: Thermodynamics, Hydrogen, Nitrogen, Oxygen, Methane, Carbon Dioxide, Air, Equation of State, Perfect Gas, Redlich-Kwong, Aungier/Redlich-Kwong, Soave/Redlich-Kwong, Peng-Robinson, Cool Prop.

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1 Introduction

During the lifetime of a fluid dynamics analyst, they would face many times the challenge of choosing a gas equation of state (EOS) for their analysis. There are indeed a lot of EOS and new ones are being developed. Each one has its advantages and disadvantages.

We also found ourselves in the same position. Specifically, we were designing a high-pressure air compressor using the turbomachinery designing software CFTurbo. CFTurbo gives the option of using the following six EOS: Perfect Gas (PG), Redlich-Kwong (RK), Aungier/Redlich-Kwong (ARK), Soave/Redlich-Kwong (SRK), Peng-Robinson (PR), and Cool Prop (CP). We must note that Cool Prop is a library with several equations that are chosen based on the gas under analysis to achieve high accuracy. The question is which of the above EOS is more suitable for each gas and under what conditions.

To answer to the above question, we conducted a study evaluating the performance of these equations and concluded that for air CP is the best choice and the next best options are the ARK equation for low temperature, and the SRK equation for high temperature.

That study has been published, [1], and the current study is its continuation by studying more substances. Specifically, it is a qualitative analysis to study the performance of the above EOS for different gases at different temperatures and pressures. The aim is to indicate general rules (independent of gas) for the performance of these EOS based on the similarities in their performance. H_2, N_2, O_2, CH_4, and CO_2 were chosen for this analysis. This analysis may work as a guide for choosing between the above EOS for the mentioned gases. Despite that there are many specifically developed EOS for each gas, the above EOS are easy to recreate and be used. For this reason, they are usually utilized by industrial software such as CFTurbo, Ansys, and Unisim.

It must be noted that this need is for high pressure conditions, where PG performs poorly. For close to room conditions, the EOS choice is usually solved with PG. In these cases, the use of PG can even be omitted, e.g., in studies [2], [3], [4], [5] and [6].

Firstly, the available literature was studied to find out if there are similar analyses. No similar analysis was found that compares the stated EOS for the mentioned gases in the conditions of this analysis, as described below.

For H_2, publications [7] and [8] provide specifically developed EOS. Literature [9], [10], and [11] compare different EOS for H_2, among them RK, SRK, and PR, but their performance was not investigated in terms of similarity. Also, it was very interesting to observe the existence of publications studying EOS for H_2 under stellar conditions. These sources were not involved as the interest of this study

is earth conditions.

For N_2, the publications [7], [12], [13] and [14] provide specifically developed EOS. We also found [15] that compares different EOS (ideal gas equation, Van Deer Waals, Beattie-Bridgeman, Benedict-Webb-Rubin, and Martin-Hou) for predicting N_2.

For O_2, publications [7], [16] and [17] provide specifically developed EOS.

For CH_4 most literature proposes EOS created to predict specifically methane properties, [12], [18], [19], [20].

Finally, for CO_2 we found a publication [21], that compares PG and PR with other EOS. In [22] SRK is compared with more advanced EOS. We also find studies with developed EOS for high accuracy calculations, [23], [24].

It is worth mentioning that EOS are also used for calculating supercritical fluid solubility [25].

2 Problem Formulation

To investigate the similarity of performance of the EOS at predicting the state of the mentioned gases we applied the following procedure.

Reduced temperature, T_r, and reduced pressure, P_r, are used as calculation points. The definition and calculation of these two values are presented in Equations (1) and (2). This is a conventional way to compare the tendency of an EOS for different gases, this method has been applied by [26]. The ranges of the analysis are T_r between 1.89 and 6.04 and P_r between 0.027 and 6.661. These are the ranges investigated in the previous publication [1].

The error of each EOS for each gas is calculated with the same method as in [1]. Firstly, the density in the required ranges is found and together with the corresponding temperature is used in the EOS to calculate the pressure. The calculated pressure is compared with the experimental/reference pressure of the corresponding (density, temperature) point, and the error between them is calculated. The errors between EOS for each gas are compared and their similarity is estimated.

The results of air are drawn from [1] and are not calculated in this study.

2.1 Density of the gases

To find the pressure and temperature that correspond to these ranges, the critical temperature and critical pressure of each gas are used in equations (1) and (2):

$$T_r = \frac{T}{T_c} \tag{1}$$

$$P_r = \frac{P}{P_c} \tag{2}$$

Where T_r – reduced temperature, T – temperature [K], T_c – critical temperature [K], P_r – reduced pressure, P – pressure [Pa], and P_c – critical pressure [Pa].

The critical temperature and pressure of the gases under consideration are presented in Table 1. The limits of the ranges of each gas are presented in Table 2.

	H_2	N_2	O_2	CH_4	CO_2
M_w (gr/mol)	2.016	28.02	32.00	16.04	44.01
T_c (K)	33.2	126.2	154.6	190.56	304.15
P_c (bar)	13	33.90	50.40	45.992	73.97
V_c (dm^3/kg)	33	3.18	2.50	6.15	2.14
ω	-0.216	0.040	0.025	0.011	0.228

Table 1. Properties of the gases in this analysis

	T_{min} (K)	T_{max} (K)	P_{min} (bar)	P_{max} (bar)
H_2	62.7	200.5	0.35	86.6
N_2	238.2	762.3	0.90	225.8
O_2	291.7	933.5	1.34	335.7
CH_4	359.7	1151.0	1.23	306.4
CO_2	574.8	1836.9	1.97	492.7

Table 2. Ranges of the gases in this analysis

Available experimental data of the density of each gas in the required ranges was investigated. The found sources provide almost the same values for each substance. It must be noted that contemporary sources with free access were limited. Due to limited financial sources, the study was based on the most recent and suitable data, as presented below.

For H_2, almost the same experimental data was found in [27] (1982) and [28] (1981), which cover all the ranges of the analysis. Their difference in the provided properties is a maximum of 0.2% in the desired range. [28] was selected as it provides data closer to the points of the analysis. More experimental data was found, but no better option was found [29], [30].

For N_2, [27] (1982) is used. Other sources provided data on different units, [31], [32], so they were avoided to prevent unit conversion errors. Reference [33] has limited data.

For O_2, sufficient data was not found. [27] provides data up to 400 K covering 25% of the points of interest, and [34] provides data up to 100 atm covering 54% of the points of interest. Sources [32], [35], [36], and [37] provide even more limited data.

[34] (1953) is used as it covers the largest range.

For CH_4, experimental data was derived from [38] (1974). [38] covers all the pressure range but the temperature range is only up to 620 K. More literature was investigated but no better option was found, [39], [40], [41]. It must be noted that the decomposition temperature of CH_4 ranges from 880 K to 1103 K which is within the range of the analysis. This area is noted in the tables with the results. The term "area" is used a lot in the following paragraphs, but it must be clarified that it refers to a set of points.

For CO_2, [42] (2008) provides a table with all the published papers with experimental data on CO_2. All these papers provide data for a temperature lower than the lowest limit of our interest except [43](1995), which provides data up to 698 K and 340 bar. This data was used for this study. More contemporary sources also provide data out of temperature range, [44], [45], [46]. The decomposition minimum temperature of CO_2 is 2400 K, which is above the maximum temperature of this analysis, so all the points are included.

It is worth noting that the website of the National Institute of Standards and Technology (NIST), U.S. Department of Commerce, provides thermodynamic properties for all the gases in this analysis but a subscription is required. Its website is the following: *webbook.nist.gov*. One more interesting thing about this site is that it provides a calculator of thermodynamic properties: *https://webbook.nist.gov/chemistry/fluid/*. The advantage of this tool over Cool Prop is that it is more user-friendly and provides the sources used for the calculation together with the results.

By using interpolation or regression for two independent variables we acquire the values at the conditions of this study, Table 3. However, the available experimental data on O_2, CH_4, and CO_2 do not cover the required range. To overcome this problem, it was decided to use CP for the calculation of the density of the gases instead of the experimental points. The performance of CP was evaluated using all the experimental data presented. The maximum error is less than 1% for all the gases, for any pressure and temperature combination inside the required range, and by using all the available experimental data for all the substances. Specifically, the maximum error is 0.2% for H_2, 0.1% for N_2, 0.5% for O_2, 0.5% for CH_4, 0.2% for CO_2, and 1.0% for air. For air, the maximum error was derived from [1]. Also, the results of the NIST calculator have less than 0.01% deviation from the results of CP, strengthening validity.

Another solution would be to calculate the error on the available data and then interpolate them. However, this approach would limit the range of this study. So, we preferred to accept less accurate results in exchange for a wider range.

2.2 Equations of State

In this subsection, the used EOS are briefly presented. An Excel calculator with Perfect Gas (PG), Redlich-Kwong (RK), Aungier/Redlich-Kwong (ARK), Soave/Redlich-Kwong (SRK) and Peng-Robinson (PR) models were created and verified in [1]. The same Excel calculator is used for the current analysis. Please advise [1]for more details on the EOS and their verification. As it was stated, Cool Prop (CP) is used to calculate the density of the gases in this analysis, which is used instead of the experimental values. The CP calculations were realized using a Python script provided by the Coop Prop website.

Perfect Gas:

$$P = \rho \cdot R \cdot T \tag{3}$$

Redlich-Kwong:

$$P = \frac{R_u \cdot T}{V_m - b_{RK}} - \frac{a_{RK}}{\sqrt{T} \cdot V_m \cdot (V_m + b_{RK})} \tag{4}$$

Aungier/Redlich-Kwong:

$$P = \frac{R \cdot T}{V - b_{ARK} + c_{ARK}} - \frac{a_{ARK} \cdot T_r^{-n}}{V \cdot (V + b_{ARK})} \tag{5}$$

Soave/Redlich-Kwong:

$$P = \frac{R_u \cdot T}{V_m - b_{RK}} - \frac{a_{SRK} \cdot A_{SRK}}{\sqrt{T} \cdot V_m \cdot (V_m + b_{RK})} \tag{6}$$

Peng-Robinson:

$$P = \frac{R_u \cdot T}{V_m - b_{PR}} - \frac{a_{PR} \cdot A_{PR}}{V_m \cdot (V_m + b_{PR}) + b_{PR} \cdot (V_m - b_{PR})} \tag{7}$$

Where:

P – pressure [Pa]

P_c – critical pressure provided in Table 1

ρ – density calculated by CoolProp [kg/m^3]

R – specific gas constant [J/kg/K]:

$$R = \frac{R_u}{M_w} \tag{8}$$

R_u – universal gas constant [J/mol/K]:

$$R_u = 8.31447 \ \frac{J}{\text{mol} \cdot K} \tag{9}$$

T – temperature [K]

T_c – critical temperature provided in Table 1

T_r – reduced temperature calculated with Equation 1
V – specific volume [m^3/kg]:

$$V = \frac{1}{\rho} \tag{10}$$

V_c – critical volume provided in Table 1
V_m – molar volume [m^3/mol]:

$$V_m = \frac{1}{\rho} \cdot M_w \tag{11}$$

M_w – molar mass provided in Table 1 [gr/mol]
a_{RK} – is a constant that corrects for the attractive potential of molecules of RK [Pa·$K^{1/2}$·$m^{3\cdot2}$/mol^2]:

$$a_{RK} = \frac{1}{9 \cdot (\sqrt[3]{2} - 1)} \cdot \frac{{R_u}^2 \cdot T_c^{2.5}}{P_c} \tag{12}$$

a_{ARK} -is a constant that corrects for the attractive potential of molecules of ARK [Pa·$m^{3\cdot2}$/kg^2]:

$$a_{ARK} = 0.42747 \cdot \frac{R^2 \cdot T_c^{2.5}}{P_c} \tag{13}$$

a_{SRK} – is a constant that corrects for the attractive potential of molecules of SRK [Pa·$K^{1/2}$·$m^{3\cdot2}$/mol^2]:

$$a_{SRK} = \frac{1}{9 \cdot (\sqrt[3]{2} - 1)} \cdot \frac{{R_u}^2 \cdot T_c^2}{P_c} \tag{14}$$

a_{PR} – is a constant that corrects for the attractive potential of molecules of PR [Pa·$m^{3\cdot2}$/mol^2]:

$$a_{PR} = 0.457235 \cdot \frac{{R_u}^2 \cdot T_c^2}{P_c} \tag{15}$$

b_{RK} -is a constant that corrects for the volume of RK and SRK [m^3/mol]:

$$b_{RK} = \frac{\sqrt[3]{2} - 1}{3} \cdot \frac{R_u \cdot T_c}{P_c} \tag{16}$$

b_{ARK} – is a constant that corrects for the volume of ARK [m^3/kg]:

$$b_{ARK} = 0.08664 \cdot \frac{R \cdot T_c}{P_c} \tag{17}$$

b_{PR} – is a constant that corrects for the volume of PR [m^3/mol]:

$$b_{PR} = 0.077796 \cdot \frac{R_u \cdot T_c}{P_c} \tag{18}$$

c_{ARK} – is a constant that corrects for the volume of ARK [m^3/kg]:

$$c_{ARK} = \frac{R \cdot T_c}{P_c + \frac{a_{ARK}}{V_c \cdot (V_c + b_{ARK})}} + b_{ARK} - V_c \tag{19}$$

n – is calculated using the following equation:

$$n = 0.4986 + 1.1735 \cdot \omega + 0.4754 \cdot \omega^2 \tag{20}$$

A_{SRK} – is a modification to the attractive term of SPK:

$$A_{SRK} = (1 + (0.480 + 1.574 \cdot \omega - 0.176 \cdot \cdot \omega^2) \cdot (1 - \sqrt{T_r}))^2 \tag{21}$$

A_{PR} – is a modification to the attractive term of PR:

$$A_{PR} = (1 + (0.37464 + 1.5226 \cdot \omega - 0.26992 \cdot \cdot \omega^2) \cdot (1 - \sqrt{T_r}))^2 \tag{22}$$

ω – the acentric factor provided in Table 1

3 Problem Solution

In this section, we present the calculations performed and the results to investigate the similarity of performance of the EOS presented in Section 2.

As we described in Section 2, we use pressure values to evaluate the performance of each equation of state to avoid computational errors as all the equations are solved to pressure. The points $P_{r,i}$ and $T_{r,j}$ of the analysis are the same as the $P_{r,i}$ and $T_{r,j}$ of [1] and are presented in Table 3.

Reduced Pressure-P_r analysis points	Reduced Temperature T_r analysis points
0.0266	1.8875
0.1332	2.2650
0.2664	2.6425
0.5329	3.0200
1.0658	3.3975
1.5987	3.7750
2.1316	4.5300
2.6645	6.0400
3.9967	
5.3289	
6.6612	

Table 3. P_r and T_r points of the analysis

The error of each point $P_{r,i}$ and $T_{r,j}$ is calculated using the following equation:

$$Error_{ij} = = \frac{\left|(Calculated\ Pressure)_{ij} - (P_i\ corresponding\ to\ P_{r,i})\right|}{(P_i\ corresponding\ to\ P_{r,i})} \tag{23}$$

For each point $P_{r,i}$ and $T_{r,j}$ we calculate the P_i and T_j using equations (1) and (2). P_i and T_j are used to calculate their corresponding density ρ_{ij} by using the Cool Prop Python script. Then both T_j and ρ_{ij} are inserted in the EOS of Section 2 to calculate the pressure $(Calculated\ Pressure)_{ij}$, which is used together with the $(P_i\ corresponding\ to\ P_{r,i})$ in equation (21) to calculate the $Error_{ij}$.

For example, we want to calculate the error of the equations for CO_2 at P_r=2.6645 and T_r=3.7750 which corresponds to P=1970 bar and T=1148 K. At this point the density is calculated using CP to be ρ=86.55

kg/m^3. The calculated pressure at this point using the Soave/Redlich-Kwong equation is 198.7 bar. By using equation (21) we find that the error is 0.82%.

The results are presented in the following pages. Each page presents tables with the prediction error of one equation of state for all the gases in this analysis. P_r and T_r are used for the points of calculations so the errors of different gases can be compared. To facilitate the evaluation, error values equal to or smaller than 0.1 are colored with blue, error values between 0.1 and 1% and equal to 1% are colored with green, error values between 1% and 2% and equal to 2% are colored with orange, and error values bigger than 2% are colored with red. A 1% error is considered the maximum target error for this analysis.

The similarity of the Perfect Gas (PG) equation is investigated in Tables 4 to 9. It is observed that PG performs well at low P_r among the gases of this study. Specifically, a maximum 1% error appears up to P_r=0.1332 for all the gases, while for O_2, CH_4, CO_2, and air this applies up to P_r=0.2664. The error patterns formed on the tables can be considered similar among the different gases if some minor details are ignored.

The similarity of the Redlich-Kwong (RK) equation is investigated in Tables 10 to 15. It is observed that RK performs better than PG. A maximum 1% error appears up to P_r=0.2664 for all the gases, while for H_2 this applies up to P_r=0.5329, for N_2, O_2, and CH_4 up to P_r=2.1316, and air up to P_r=1.5987. Error patterns can be considered similar between N_2, O_2, CH_4, and air with lower error values at low T_r. H_2 and CO_2 have similar tendencies, but there are many differences in the error partner between them and between the other gases.

The similarity of the Aungier/Redlich-Kwong (ARK) equation is investigated in Tables 16 to 21. It is observed that ARK performs a lot better than RK and PG. More than 1% error appears in trapezoidal/orthogonal areas at high P_r. The limits of this area are different for each gas varying between P_r=2.1316-3.9967 and T_r=2.2650-2.6425. Another observation is that ARK performs well at low T_r for all gases except H_2 for which it performs well at high T_r. By accepting small deviations, error patterns can be considered similar among the gases, except the pattern of H_2 which has a reverse tendency with high errors at low T_r instead of high T_r like the other gases.

The similarity of the Soave/Redlich-Kwong (SRK) equation is investigated in Tables 22 to 27. It is observed that SRK performs a little bit poorer than ARK. More than 1% error appears in triangular/trapezoidal areas at high P_r. The limits of this area are different for each gas varying between P_r=1.0658-2.1316 and T_r=3.3975-6.040. For H_2 and CO_2 these areas are not homogenous, meaning that points with less than 1% error appear in them. Again, by accepting small deviations, error patterns can be considered similar among the gases. A considerable size deviation between them is observed.

The similarity of the Peng–Robinson (PR) equation is investigated in Tables 28 to 33. It is observed that PR performs poorer for H_2 than ARK and SRK, better for CO_2, and almost the same for the other gases. For H_2, more than a maximum 1% error appears in a trapezoidal area with limits P_r=0.5329-1.5987. For CO_2, more than a maximum 1% error appears in a small triangular area with limits P_r=2.6654-6.6612 and T_r=4.5300-6.0400, and two points at T_r=1.8875 and P_r=3.9667 and P_r=5.3289. For the other gases, this area is trapezoidal and its limits are different for each one varying between P_r=1.0658-5.3289. In the majority, it can be said that PR performs well at low P_r and high T_r. A similarity can be observed only among N_2, O_2, CH_4, and air. H_2 can also be included in this category but it has a much larger area with more than a 1% error. CO_2 has an inverse performance by performing mostly better at low temperatures rather than high as the other gases. Also, PR has the best performance for CO_2.

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.12	0.65	1.32	2.66	5.34	7.91	10.2	12.1	14.6	13.4	9.29
2.2650	0.06	0.31	0.62	1.24	2.41	3.45	4.32	4.97	5.55	4.60	2.36
2.6425	0.02	0.13	0.26	0.52	0.97	1.32	1.56	1.67	1.36	0.24	1.55
3.0200	0.00	0.03	0.06	0.11	0.17	0.17	0.09	0.07	0.83	2.07	3.71
3.3975	0.01	0.03	0.06	0.13	0.29	0.49	0.75	1.06	2.06	3.37	4.92
3.7750	0.02	0.07	0.13	0.27	0.56	0.89	1.24	1.64	2.77	4.10	5.60
4.5300	0.03	0.11	0.21	0.41	0.83	1.27	1.72	2.18	3.42	4.75	6.15
6.0400	0.03	0.12	0.24	0.47	0.94	1.41	1.88	2.36	3.56	4.78	6.01

Table 4. The Error (%) of the Perfect Gas equation from CP values for H_2

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.10	0.48	0.94	1.85	3.54	4.98	6.10	6.82	6.71	4.08	0.19
2.2650	0.03	0.15	0.30	0.56	0.97	1.20	1.26	1.12	0.07	2.31	5.32
2.6425	0.00	0.01	0.02	0.07	0.24	0.52	0.90	1.39	3.04	5.23	7.81
3.0200	0.02	0.09	0.19	0.40	0.86	1.38	1.97	2.62	4.49	6.64	9.00
3.3975	0.03	0.14	0.28	0.57	1.19	1.84	2.53	3.25	5.20	7.31	9.52
3.7750	0.03	0.16	0.33	0.67	1.36	2.07	2.81	3.57	5.53	7.59	9.69
4.5300	0.04	0.18	0.37	0.73	1.48	2.23	2.98	3.74	5.66	7.59	9.53
6.0400	0.03	0.18	0.35	0.70	1.41	2.11	2.80	3.50	5.21	6.90	8.57

Table 5. The Error (%) of the Perfect Gas equation from CP values for O_2

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.16	0.11	0.45	1.06	2.12	2.92	3.42	3.59	2.53	0.39	4.46
2.2650	0.22	0.18	0.15	0.11	0.15	0.35	0.70	1.20	3.08	5.72	8.88
2.6425	0.25	0.33	0.43	0.65	1.17	1.77	2.46	3.22	5.41	7.94	10.7
3.0200	0.26	0.40	0.57	0.92	1.67	2.45	3.28	4.15	6.44	8.89	11.4
3.3975	0.27	0.43	0.64	1.06	1.91	2.78	3.67	4.58	6.89	9.25	11.6
3.7750	0.27	0.45	0.67	1.12	2.02	2.92	3.83	4.74	7.02	9.30	11.5
4.5300	0.28	0.46	0.69	1.15	2.05	2.96	3.85	4.73	6.89	9.00	11.0
6.0400	0.27	0.44	0.65	1.07	1.89	2.70	3.49	4.27	6.17	7.98	9.73

Table 6. The Error (%) of the Perfect Gas equation from CP values for CO_2

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.40	0.77	1.22	2.08	3.66	4.96	5.94	6.52	6.13	3.34	1.02
2.2650	0.34	0.45	0.58	0.80	1.12	1.26	1.21	0.97	0.44	2.85	5.96
2.6425	0.31	0.29	0.26	0.18	0.06	0.42	0.88	1.45	3.29	5.62	8.30
3.0200	0.29	0.21	0.10	0.14	0.66	1.25	1.91	2.62	4.64	6.92	9.38
3.3975	0.28	0.16	0.01	0.31	0.97	1.68	2.43	3.21	5.29	7.51	9.81
3.7750	0.28	0.14	0.04	0.40	1.14	1.90	2.69	3.49	5.57	7.72	9.90
4.5300	0.27	0.12	0.07	0.46	1.24	2.03	2.82	3.62	5.62	7.62	9.60
6.0400	0.27	0.13	0.05	0.42	1.14	1.87	2.58	3.30	5.06	6.78	8.47

Table 7. The Error (%) of the Perfect Gas equation from CP values for N_2

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.12	0.51	0.99	1.93	3.67	5.16	6.34	7.14	7.22	4.76	0.57
2.2650	0.05	0.18	0.34	0.63	1.09	1.37	1.46	1.37	0.30	1.84	4.76
2.6425	0.02	0.02	0.02	0.00	0.13	0.37	0.72	1.18	2.75	4.86	7.35
3.0200	0.00	0.07	0.15	0.34	0.77	1.26	1.82	2.44	4.24	6.32	8.61
3.3975	0.01	0.11	0.25	0.52	1.11	1.73	2.40	3.10	4.99	7.04	9.19
3.7750	0.01	0.14	0.30	0.63	1.29	1.99	2.70	3.44	5.36	7.35	9.40
4.5300	0.02	0.16	0.34	0.71	1.44	2.18	2.92	3.67	5.54	7.43	9.30
6.0400	Decomposed CH_4										

Table 8. The Error (%) of the Perfect Gas equation from CP values for CH_4

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.08	0.45	0.90	1.77	3.34	4.65	5.63	6.23	5.83	2.97	1.45
2.2650	0.01	0.13	0.27	0.50	0.82	0.96	0.91	0.68	0.72	3.13	6.26
2.6425	0.02	0.03	0.05	0.12	0.35	0.70	1.17	1.73	3.56	5.88	8.56
3.0200	0.04	0.11	0.21	0.43	0.94	1.53	2.18	2.90	4.91	7.17	9.62
3.3975	0.05	0.16	0.30	0.61	1.25	1.95	2.70	3.47	5.55	7.75	10.0
3.7750	0.05	0.18	0.35	0.70	1.41	2.17	2.95	3.75	5.82	7.96	10.1
4.5300	0.06	0.20	0.39	0.76	1.52	2.29	3.07	3.86	5.86	7.85	9.83
6.0400	0.05	0.19	0.37	0.72	1.43	2.13	2.84	3.54	5.29	7.01	8.69

Table 9. The Error (%) of the Perfect Gas equation from CP values for Air

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.01	0.10	0.23	0.52	1.24	2.12	3.14	4.26	7.31	10.1	12.0
2.2650	0.01	0.09	0.19	0.41	0.93	1.53	2.18	2.86	4.63	6.34	7.83
2.6425	0.01	0.07	0.15	0.32	0.71	1.13	1.59	2.05	3.23	4.36	5.40
3.0200	0.01	0.05	0.12	0.25	0.54	0.86	1.19	1.53	2.37	3.18	3.93
3.3975	0.00	0.04	0.09	0.19	0.42	0.66	0.91	1.16	1.80	2.41	2.97
3.7750	0.00	0.03	0.07	0.15	0.33	0.52	0.71	0.91	1.39	1.87	2.31
4.5300	0.00	0.02	0.04	0.10	0.21	0.33	0.45	0.57	0.88	1.18	1.47
6.0400	0.00	0.01	0.02	0.04	0.09	0.14	0.20	0.26	0.40	0.55	0.69

Table 10. The Error (%) of the Redlich-Kwong equation from CP values for H_2

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.01	0.07	0.14	0.25	0.43	0.54	0.60	0.61	0.56	0.55	0.76
2.2650	0.01	0.07	0.14	0.26	0.48	0.66	0.81	0.94	1.22	1.51	1.85
2.6425	0.01	0.07	0.14	0.26	0.50	0.71	0.90	1.08	1.49	1.89	2.31
3.0200	0.01	0.07	0.13	0.26	0.50	0.72	0.93	1.13	1.60	2.06	2.51
3.3975	0.01	0.06	0.13	0.26	0.50	0.72	0.94	1.14	1.64	2.12	2.59
3.7750	0.01	0.06	0.12	0.25	0.48	0.71	0.92	1.13	1.64	2.12	2.60
4.5300	0.01	0.06	0.12	0.23	0.45	0.67	0.88	1.08	1.58	2.05	2.52
6.0400	0.01	0.05	0.10	0.19	0.39	0.57	0.76	0.94	1.39	1.83	2.26

Table 11. The Error (%) of the Redlich-Kwong equation from CP values for O_2

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.27	0.43	0.62	1.01	1.75	2.42	3.02	3.54	4.60	5.43	6.13
2.2650	0.27	0.40	0.58	0.92	1.56	2.16	2.71	3.22	4.32	5.29	6.18
2.6425	0.26	0.39	0.54	0.84	1.42	1.97	2.47	2.94	4.00	4.95	5.83
3.0200	0.26	0.37	0.51	0.79	1.32	1.81	2.28	2.72	3.72	4.62	5.46
3.3975	0.26	0.36	0.49	0.74	1.23	1.69	2.12	2.54	3.48	4.33	5.12
3.7750	0.25	0.35	0.47	0.70	1.16	1.59	1.99	2.38	3.27	4.08	4.82
4.5300	0.25	0.34	0.44	0.64	1.04	1.42	1.78	2.12	2.92	3.65	4.32
6.0400	0.25	0.31	0.40	0.56	0.88	1.18	1.48	1.76	2.42	3.03	3.59

Table 12. The Error (%) of the Redlich-Kwong equation from CP values for CO_2

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.29	0.22	0.13	0.03	0.32	0.56	0.74	0.88	1.12	1.38	1.82
2.2650	0.29	0.22	0.14	0.02	0.33	0.60	0.85	1.08	1.60	2.11	2.64
2.6425	0.29	0.23	0.15	0.01	0.32	0.61	0.88	1.14	1.75	2.33	2.91
3.0200	0.30	0.23	0.15	0.00	0.30	0.59	0.87	1.14	1.77	2.38	2.97
3.3975	0.30	0.24	0.16	0.01	0.28	0.56	0.84	1.10	1.74	2.35	2.93
3.7750	0.30	0.24	0.17	0.02	0.26	0.53	0.80	1.06	1.68	2.27	2.84
4.5300	0.30	0.25	0.18	0.05	0.21	0.46	0.70	0.95	1.53	2.08	2.62
6.0400	0.30	0.26	0.20	0.10	0.12	0.32	0.53	0.73	1.22	1.69	2.14

Table 13. The Error (%) of the Redlich-Kwong equation from CP values for N_2

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.01	0.04	0.09	0.18	0.31	0.38	0.38	0.32	0.06	0.19	0.22
2.2650	0.01	0.04	0.09	0.19	0.36	0.50	0.61	0.69	0.84	0.97	1.16
2.6425	0.01	0.04	0.09	0.20	0.39	0.56	0.72	0.86	1.17	1.46	1.76
3.0200	0.01	0.04	0.10	0.20	0.41	0.60	0.78	0.95	1.33	1.69	2.04
3.3975	0.01	0.04	0.10	0.21	0.42	0.61	0.80	0.99	1.41	1.81	2.18
3.7750	0.01	0.04	0.10	0.21	0.42	0.62	0.82	1.00	1.45	1.86	2.25
4.5300	0.01	0.04	0.09	0.20	0.41	0.61	0.81	1.00	1.45	1.87	2.26
6.0400	Decomposed CH_4										

Table 14. The Error (%) of the Redlich-Kwong equation from CP values for CH_4

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.03	0.10	0.17	0.33	0.60	0.80	0.93	1.01	1.11	1.29	1.66
2.2650	0.03	0.09	0.16	0.31	0.59	0.85	1.07	1.27	1.69	2.10	2.56
2.6425	0.03	0.09	0.16	0.30	0.58	0.85	1.10	1.34	1.88	2.38	2.90
3.0200	0.03	0.08	0.15	0.29	0.56	0.83	1.09	1.34	1.92	2.47	3.00
3.3975	0.03	0.08	0.15	0.28	0.54	0.80	1.06	1.31	1.90	2.46	2.99
3.7750	0.03	0.08	0.14	0.26	0.52	0.77	1.02	1.26	1.84	2.40	2.93
4.5300	0.03	0.07	0.13	0.24	0.47	0.70	0.92	1.15	1.70	2.22	2.72
6.0400	0.03	0.06	0.11	0.20	0.39	0.57	0.76	0.94	1.40	1.85	2.28

Table 15. The Error (%) of the Redlich-Kwong equation from CP values for Air

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.02	0.08	0.15	0.25	0.33	0.28	0.11	0.16	1.26	2.64	3.75
2.2650	0.02	0.07	0.12	0.21	0.31	0.34	0.30	0.22	0.18	0.75	1.40
2.6425	0.02	0.06	0.11	0.19	0.30	0.36	0.38	0.37	0.24	0.00	0.32
3.0200	0.02	0.05	0.09	0.17	0.28	0.36	0.40	0.43	0.42	0.34	0.20
3.3975	0.01	0.05	0.08	0.15	0.26	0.35	0.41	0.45	0.51	0.51	0.46
3.7750	0.01	0.04	0.08	0.14	0.25	0.33	0.40	0.46	0.55	0.59	0.60
4.5300	0.01	0.04	0.06	0.12	0.22	0.30	0.37	0.43	0.55	0.64	0.69
6.0400	0.01	0.03	0.05	0.09	0.16	0.23	0.29	0.35	0.47	0.57	0.65

Table 16. The Error (%) of the Aungier/Redlich-Kwong equation from CP values for H_2

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.01	0.05	0.10	0.17	0.26	0.29	0.26	0.20	0.03	0.15	0.02
2.2650	0.01	0.05	0.10	0.19	0.35	0.46	0.55	0.63	0.78	0.98	1.25
2.6425	0.01	0.06	0.11	0.21	0.39	0.56	0.70	0.83	1.15	1.48	1.84
3.0200	0.01	0.06	0.11	0.22	0.42	0.60	0.77	0.94	1.33	1.72	2.13
3.3975	0.01	0.06	0.11	0.22	0.43	0.62	0.81	0.99	1.42	1.84	2.27
3.7750	0.01	0.06	0.11	0.22	0.43	0.62	0.82	1.00	1.45	1.89	2.33
4.5300	0.01	0.05	0.10	0.21	0.41	0.61	0.80	0.99	1.44	1.89	2.33
6.0400	0.01	0.05	0.09	0.18	0.36	0.54	0.71	0.89	1.31	1.73	2.14

Table 17. The Error (%) of the Aungier/Redlich-Kwong equation from CP values for O_2

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.23	0.24	0.24	0.24	0.22	0.14	0.02	0.13	0.49	0.65	0.57
2.2650	0.24	0.25	0.27	0.31	0.39	0.44	0.48	0.50	0.57	0.75	1.07
2.6425	0.24	0.27	0.30	0.37	0.51	0.63	0.74	0.85	1.12	1.43	1.83
3.0200	0.24	0.28	0.32	0.41	0.59	0.75	0.91	1.07	1.43	1.82	2.24
3.3975	0.24	0.28	0.34	0.44	0.64	0.83	1.02	1.20	1.62	2.04	2.48
3.7750	0.24	0.29	0.34	0.45	0.67	0.88	1.08	1.28	1.74	2.18	2.62
4.5300	0.24	0.29	0.35	0.47	0.70	0.92	1.14	1.34	1.83	2.29	2.73
6.0400	0.24	0.29	0.35	0.46	0.69	0.91	1.12	1.32	1.80	2.24	2.66

Table 18. The Error (%) of the Aungier/Redlich-Kwong equation from CP values for CO_2

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.30	0.25	0.20	0.10	0.06	0.16	0.22	0.24	0.23	0.33	0.67
2.2650	0.30	0.25	0.19	0.08	0.12	0.30	0.46	0.60	0.94	1.30	1.74
2.6425	0.30	0.25	0.19	0.07	0.15	0.37	0.57	0.77	1.23	1.71	2.20
3.0200	0.30	0.25	0.19	0.07	0.17	0.40	0.62	0.84	1.36	1.87	2.39
3.3975	0.30	0.25	0.19	0.07	0.17	0.41	0.64	0.86	1.40	1.93	2.45
3.7750	0.30	0.25	0.19	0.07	0.17	0.40	0.63	0.85	1.40	1.93	2.44
4.5300	0.30	0.25	0.20	0.08	0.14	0.37	0.59	0.80	1.33	1.83	2.32
6.0400	0.30	0.26	0.21	0.11	0.08	0.27	0.46	0.65	1.10	1.54	1.97

Table 19. The Error (%) of the Aungier/Redlich-Kwong equation from CP values for N_2

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.01	0.03	0.08	0.15	0.26	0.29	0.27	0.19	0.12	0.38	0.40
2.2650	0.01	0.03	0.08	0.17	0.32	0.43	0.52	0.59	0.71	0.82	1.00
2.6425	0.01	0.03	0.08	0.18	0.36	0.51	0.65	0.78	1.07	1.34	1.62
3.0200	0.01	0.04	0.09	0.19	0.38	0.56	0.73	0.88	1.25	1.60	1.94
3.3975	0.01	0.04	0.09	0.19	0.39	0.58	0.76	0.94	1.34	1.73	2.09
3.7750	0.01	0.04	0.09	0.20	0.40	0.59	0.78	0.96	1.39	1.79	2.17
4.5300	0.01	0.04	0.09	0.19	0.40	0.60	0.79	0.97	1.41	1.82	2.21
6.0400	Decomposed CH_4										

Table 20. The Error (%) of the Aungier/Redlich-Kwong equation from CP values for CH_4

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.03	0.07	0.11	0.20	0.33	0.38	0.35	0.26	0.09	0.35	0.36
2.2650	0.03	0.06	0.11	0.20	0.37	0.50	0.61	0.68	0.80	0.92	1.12
2.6425	0.03	0.06	0.11	0.20	0.39	0.56	0.72	0.87	1.18	1.46	1.77
3.0200	0.03	0.06	0.11	0.21	0.40	0.59	0.77	0.94	1.34	1.71	2.08
3.3975	0.03	0.06	0.11	0.21	0.40	0.60	0.79	0.97	1.41	1.82	2.22
3.7750	0.03	0.06	0.11	0.20	0.40	0.59	0.78	0.97	1.42	1.85	2.26
4.5300	0.03	0.06	0.11	0.20	0.38	0.56	0.74	0.93	1.37	1.80	2.21
6.0400	0.03	0.06	0.09	0.17	0.32	0.48	0.64	0.79	1.18	1.56	1.93

Table 21. The Error (%) of the Aungier/Redlich-Kwong equation from CP values for Air

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.04	0.18	0.34	0.64	1.14	1.52	1.80	1.96	1.86	1.22	0.53
2.2650	0.03	0.14	0.27	0.51	0.92	1.24	1.50	1.71	1.98	1.95	1.71
2.6425	0.03	0.12	0.22	0.41	0.75	1.03	1.26	1.46	1.80	1.96	1.97
3.0200	0.02	0.10	0.18	0.34	0.62	0.86	1.07	1.25	1.59	1.81	1.92
3.3975	0.02	0.08	0.15	0.29	0.53	0.73	0.92	1.08	1.40	1.63	1.78
3.7750	0.02	0.07	0.13	0.24	0.45	0.63	0.79	0.93	1.23	1.45	1.62
4.5300	0.02	0.05	0.10	0.18	0.34	0.48	0.60	0.72	0.96	1.16	1.31
6.0400	0.01	0.03	0.06	0.11	0.21	0.29	0.37	0.45	0.61	0.75	0.86

Table 22. The Error (%) of the Soave/Redlich-Kwong equation from CP values for H_2

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.01	0.06	0.12	0.25	0.59	1.00	1.45	1.92	3.03	3.78	4.03
2.2650	0.01	0.06	0.13	0.27	0.57	0.89	1.21	1.54	2.25	2.74	2.96
2.6425	0.01	0.06	0.12	0.25	0.50	0.76	1.01	1.25	1.76	2.11	2.28
3.0200	0.01	0.05	0.11	0.21	0.43	0.63	0.83	1.02	1.40	1.66	1.78
3.3975	0.01	0.05	0.09	0.18	0.35	0.52	0.68	0.82	1.11	1.29	1.37
3.7750	0.01	0.04	0.08	0.15	0.29	0.42	0.54	0.65	0.87	0.99	1.04
4.5300	0.01	0.02	0.05	0.09	0.18	0.26	0.32	0.38	0.49	0.53	0.52
6.0400	0.00	0.01	0.01	0.02	0.03	0.04	0.04	0.03	0.00	0.07	0.17

Table 23. The Error (%) of the Soave/Redlich-Kwong equation from CP values for O_2

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.19	0.03	0.18	0.59	1.45	2.34	3.24	4.13	6.09	7.42	8.10
2.2650	0.19	0.04	0.14	0.50	1.22	1.91	2.58	3.22	4.59	5.54	6.05
2.6425	0.20	0.08	0.07	0.37	0.94	1.48	1.99	2.46	3.47	4.19	4.61
3.0200	0.21	0.11	0.01	0.24	0.68	1.09	1.47	1.82	2.57	3.11	3.44
3.3975	0.21	0.14	0.05	0.12	0.44	0.75	1.02	1.28	1.82	2.21	2.45
3.7750	0.22	0.17	0.10	0.02	0.24	0.45	0.65	0.82	1.19	1.46	1.61
4.5300	0.23	0.21	0.19	0.14	0.07	0.00	0.06	0.11	0.21	0.27	0.27
6.0400	0.24	0.26	0.29	0.34	0.45	0.55	0.66	0.76	1.00	1.24	1.46

Table 24. The Error (%) of the Soave/Redlich-Kwong equation from CP values for CO_2

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.32	0.37	0.43	0.57	0.88	1.26	1.66	2.09	3.06	3.66	3.74
2.2650	0.32	0.38	0.45	0.59	0.87	1.17	1.46	1.74	2.33	2.70	2.80
2.6425	0.32	0.37	0.44	0.56	0.81	1.04	1.27	1.47	1.88	2.13	2.20
3.0200	0.32	0.37	0.42	0.53	0.73	0.92	1.09	1.24	1.54	1.71	1.75
3.3975	0.32	0.36	0.40	0.49	0.66	0.80	0.94	1.05	1.27	1.38	1.39
3.7750	0.32	0.35	0.39	0.46	0.59	0.70	0.80	0.89	1.04	1.10	1.09
4.5300	0.32	0.33	0.36	0.40	0.47	0.53	0.58	0.62	0.68	0.68	0.63
6.0400	0.31	0.31	0.32	0.32	0.32	0.32	0.31	0.29	0.23	0.15	0.04

Table 25. The Error (%) of the Soave/Redlich-Kwong equation from CP values for N_2

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.03	0.07	0.12	0.24	0.54	0.91	1.33	1.79	2.95	3.83	4.25
2.2650	0.03	0.08	0.14	0.27	0.54	0.84	1.14	1.45	2.17	2.72	3.04
2.6425	0.03	0.08	0.13	0.25	0.49	0.73	0.97	1.20	1.71	2.10	2.34
3.0200	0.03	0.07	0.12	0.22	0.43	0.62	0.81	0.99	1.37	1.65	1.83
3.3975	0.03	0.06	0.10	0.19	0.36	0.51	0.66	0.80	1.09	1.30	1.44
3.7750	0.02	0.05	0.09	0.16	0.29	0.41	0.53	0.63	0.85	1.01	1.11
4.5300	0.02	0.04	0.06	0.10	0.17	0.24	0.31	0.36	0.47	0.54	0.58
6.0400	Decomposed CH_4										

Table 26. The Error (%) of the Soave/Redlich-Kwong equation from CP values for CH_4

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.01	0.05	0.11	0.25	0.56	0.94	1.37	1.83	2.88	3.52	3.63
2.2650	0.00	0.06	0.13	0.28	0.57	0.86	1.16	1.45	2.11	2.54	2.67
2.6425	0.00	0.05	0.13	0.26	0.51	0.75	0.98	1.19	1.64	1.94	2.05
3.0200	0.01	0.05	0.11	0.23	0.45	0.64	0.82	0.98	1.31	1.51	1.59
3.3975	0.01	0.04	0.09	0.19	0.38	0.53	0.67	0.80	1.04	1.18	1.23
3.7750	0.01	0.03	0.07	0.16	0.31	0.44	0.55	0.64	0.82	0.91	0.93
4.5300	0.01	0.01	0.04	0.10	0.20	0.28	0.34	0.39	0.47	0.50	0.47
6.0400	0.02	0.01	0.00	0.02	0.05	0.06	0.07	0.07	0.04	0.03	0.12

Table 27. The Error (%) of the Soave/Redlich-Kwong equation from CP values for Air

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.10	0.47	0.91	1.73	3.17	4.39	5.41	6.26	7.79	8.88	10.0
2.2650	0.08	0.38	0.73	1.41	2.61	3.65	4.56	5.35	6.94	8.12	9.07
2.6425	0.07	0.31	0.61	1.17	2.19	3.09	3.88	4.60	6.09	7.26	8.22
3.0200	0.06	0.26	0.51	0.99	1.86	2.65	3.35	3.99	5.37	6.48	7.41
3.3975	0.05	0.23	0.44	0.85	1.61	2.30	2.93	3.50	4.76	5.80	6.69
3.7750	0.04	0.20	0.38	0.74	1.41	2.02	2.58	3.10	4.25	5.22	6.06
4.5300	0.04	0.15	0.30	0.58	1.11	1.60	2.06	2.49	3.45	4.29	5.03
6.0400	0.03	0.10	0.20	0.39	0.75	1.09	1.41	1.72	2.42	3.05	3.62

Table 28. The Error (%) of the Peng–Robinson equation from CP values for H_2

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.04	0.19	0.36	0.67	1.15	1.48	1.69	1.84	2.15	2.78	3.86
2.2650	0.02	0.13	0.24	0.46	0.81	1.09	1.31	1.50	1.93	2.46	3.19
2.6425	0.02	0.09	0.18	0.34	0.62	0.85	1.06	1.24	1.69	2.20	2.81
3.0200	0.01	0.07	0.14	0.26	0.49	0.70	0.89	1.07	1.51	1.99	2.54
3.3975	0.01	0.06	0.11	0.22	0.42	0.60	0.78	0.95	1.38	1.83	2.34
3.7750	0.01	0.05	0.09	0.19	0.36	0.53	0.70	0.86	1.27	1.71	2.19
4.5300	0.01	0.04	0.08	0.15	0.30	0.45	0.60	0.75	1.14	1.54	1.98
6.0400	0.01	0.03	0.06	0.13	0.26	0.39	0.52	0.65	1.00	1.37	1.75

Table 29. The Error (%) of the Peng–Robinson equation from CP values for O_2

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.23	0.24	0.25	0.24	0.14	0.06	0.33	0.63	1.19	1.22	0.65
2.2650	0.23	0.21	0.18	0.12	0.02	0.18	0.35	0.52	0.81	0.78	0.41
2.6425	0.22	0.20	0.17	0.11	0.02	0.14	0.25	0.35	0.49	0.43	0.13
3.0200	0.23	0.20	0.18	0.13	0.04	0.04	0.10	0.15	0.19	0.09	0.18
3.3975	0.23	0.21	0.20	0.17	0.12	0.09	0.06	0.05	0.09	0.24	0.50
3.7750	0.23	0.22	0.22	0.21	0.20	0.21	0.22	0.25	0.36	0.54	0.81
4.5300	0.23	0.24	0.26	0.29	0.35	0.42	0.50	0.58	0.80	1.06	1.36
6.0400	0.24	0.27	0.31	0.39	0.55	0.71	0.87	1.03	1.41	1.78	2.16

Table 30. The Error (%) of the Peng–Robinson equation from CP values for CO_2

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.27	0.13	0.05	0.36	0.85	1.21	1.46	1.64	2.07	2.81	4.01
2.2650	0.29	0.19	0.08	0.14	0.50	0.80	1.05	1.27	1.80	2.43	3.25
2.6425	0.29	0.23	0.14	0.01	0.30	0.55	0.78	1.00	1.53	2.13	2.81
3.0200	0.30	0.25	0.18	0.06	0.18	0.40	0.61	0.81	1.33	1.88	2.50
3.3975	0.30	0.26	0.20	0.10	0.10	0.30	0.49	0.68	1.18	1.70	2.26
3.7750	0.30	0.26	0.22	0.13	0.05	0.23	0.41	0.59	1.06	1.55	2.07
4.5300	0.30	0.27	0.23	0.16	0.00	0.16	0.32	0.48	0.90	1.34	1.80
6.0400	0.30	0.28	0.25	0.18	0.05	0.09	0.23	0.37	0.73	1.10	1.48

Table 31. The Error (%) of the Peng–Robinson equation from CP values for N_2

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.02	0.18	0.36	0.69	1.22	1.59	1.83	1.99	2.28	2.80	3.76
2.2650	0.01	0.11	0.24	0.47	0.85	1.16	1.41	1.61	2.05	2.54	3.19
2.6425	0.00	0.08	0.17	0.34	0.64	0.90	1.12	1.33	1.79	2.27	2.82
3.0200	0.00	0.06	0.13	0.26	0.51	0.73	0.94	1.13	1.59	2.05	2.55
3.3975	0.00	0.04	0.10	0.22	0.43	0.63	0.82	1.00	1.44	1.88	2.35
3.7750	0.01	0.04	0.09	0.19	0.38	0.56	0.74	0.91	1.33	1.75	2.19
4.5300	0.01	0.03	0.07	0.16	0.32	0.49	0.65	0.80	1.20	1.59	1.98
6.0400	Decomposed CH_4										

Table 32. The Error (%) of the Peng–Robinson equation from CP values for CH_4

	Error (%)										
	P_r ↴										
T_r ↴	0.0266	0.1332	0.2664	0.5329	1.0658	1.5987	2.1316	2.6645	3.9967	5.3289	6.6612
1.8875	0.06	0.20	0.37	0.68	1.18	1.53	1.76	1.91	2.28	2.99	4.18
2.2650	0.04	0.13	0.24	0.45	0.81	1.11	1.36	1.56	2.04	2.63	3.42
2.6425	0.03	0.10	0.17	0.32	0.60	0.85	1.08	1.29	1.79	2.34	2.99
3.0200	0.03	0.08	0.13	0.25	0.47	0.69	0.89	1.09	1.59	2.11	2.69
3.3975	0.03	0.06	0.11	0.20	0.39	0.58	0.77	0.95	1.43	1.92	2.45
3.7750	0.03	0.06	0.09	0.17	0.34	0.51	0.68	0.85	1.30	1.77	2.27
4.5300	0.03	0.05	0.08	0.14	0.28	0.42	0.57	0.72	1.13	1.55	1.99
6.0400	0.02	0.04	0.07	0.12	0.23	0.35	0.47	0.60	0.94	1.29	1.66

Table 33. The Error (%) of the Peng–Robinson equation from CP values for Air

4 Conclusion

Based on the above calculations and the observations on the error areas, the following conclusions are made.

Foremost, it is obvious that Cool Prop is the best among the options of this study achieving a maximum of 0.5% for the pure gases and a maximum of 1% for air which is a mixture. However, similarity was not studied due to the lack of data for O_2, CH_4, and CO_2.

Similarity was not observed for all the gases with the used equations of state. Similarity was observed for Perfect Gas and Soave/Redlich-Kwong if some minor deviations were ignored. Aungier/Redlich-Kwong has similar patterns for all the gases except H_2, which has an inverse to horizontal axis pattern. Similarity of Redlich-Kwong and Peng–Robinson was observed for N_2, O_2, CH_4, and air. In the case of Redlich-Kwong, H_2, and CO_2 have a similar error tendency but a different pattern with each other and from the other gases. In the case of Peng-Robison, H_2 has a similar pattern to the other substances if the considerable size deviation is ignored. CO_2 has an inverse to horizontal axis pattern.

So, the similarity assumption of predicting gas properties between the used equations is supported only by Perfect Gas and Soave/Redlich-Kwong, while the other equations show a similarity to most of the gases but not for all. Based on that, a user can consult Tables 4 to 33 for choosing one of the above models, but they should verify the performance of the model using available experimental data or at least a high-accuracy calculator such as Coop Prop.

In terms of which is the most efficient equation of state, except of course Coop Prop, Aungier/Redlich-Kwong is the next best as it provides a maximum 1% error on larger areas. Combined with Redlich-Kwong, it provides a maximum of 1% error for H_2 in almost all the ranges. Aungier/Redlich-Kwong combined with Soave/Redlich-Kwong achieves the best calculations for N_2, O_2, CH_4, and air. The best combination for CO_2 is Soave/Redlich-Kwong and Peng–Robinson.

The dependence of error pattern similarity may be related to gas properties such as molar mass and/or acentric factor. A further study on this matter may not be of value as the present EOS are used mainly for preliminary analysis, while for accuracy, specifically developed equations can be used.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

Vasileos Moutsios performed research on literature, formal analysis, and the writing-original draft.
P. Dionissios Margaris performed supervision, review, and validation.
Mike Gongolidis conducted thermodynamic property calculations using the CoolProp library via Python, followed by a comprehensive review of the results.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.