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Critical Review of the Latest Thermodynamic and Transport Property Data and Models, and Equations of State for R-1234yf

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ABSTRACT

This paper critically reviews the best publically available data and property models for R-1234yf for the normal boiling point temperature, the critical state temperature, pressure, and density, vapor pressure, liquid density, specific heat at constant pressure, liquid dynamic viscosity, and surface tension. The paper presents new property correlations for vapor pressure, liquid density, and liquid dynamic viscosity, which provide better fits of the publically available data than any of the other available correlations. Finally, the paper reviews four publically available Equations of State, and shows that they each provide similar predictions for COP and Volumetric Cooling Capacities for several simulated ideal vapor compression refrigeration cycles.

1. INTRODUCTION

The European Union's F-Gas Regulations (Regulation (EC) No 842/2006 and Directive 2006/40/EC) specify that beginning on January 1, 2011 new models and on January 1, 2017 new vehicles fitted with air conditioning cannot be manufactured with fluorinated greenhouse gases having global warming potentials (GWP) greater than 150. Recently, R-1234yf (2,3,3,3-tetrafluoropropene; $CF_3CF=CH_2$), which has a 100-year time horizon GWP of four relative to carbon dioxide (Nielsen *et al.*, 2007) has been investigated (e.g., Minor and Spatz, 2008) as a possible replacement fluid for R-134a in automotive applications.

A considerable amount of R-1234yf development work has been underway in the automotive industry over the past few years [e.g., SAE CPR1234 (SAE, 2009)]; however, thermodynamic and transport property data, and associated Equations of State (EoS), have only begun appearing in the open literature since approximately midyear 2009.

The goals of the present paper are: (1) to critically review the thermodynamic and transport property data, property models, and EoS, which have been published in the open literature, (2) to present property correlations by the authors of this paper based on the best publically available thermodynamic property data at the time of writing, (3) to demonstrate the abilities of the various EoS to predict cycle performance [COP and Volumetric Cooling Capacity (VCC)], and (4) to argue for the validity of the simple–and thus easy to implement and use–methodologies presented by Brown *et al.* (2009a,b; 2010) to predict thermophysical properties and thus ultimately to predict cycle performance for not-so-well-described refrigerants (ones where little data has been published in the open literature, which is the case for the fluorinated propene isomers).

2. AVAILABLE EXPERIMENTAL DATA

While an unknown amount of proprietary thermodynamic property data exists for R-1234yf, it has only been within

the past year that experimental data, property correlations, and corresponding EoS have begun to appear in the open literature. This section will review the publicly available experimental data. Then, the following two sections will review the available property models and EoS, respectively.

2.1 Normal Boiling Point Temperature

Minor and Spatz (2008) give the normal boiling point temperature (NBP) as 244.15 K. Tanaka and Higashi (2009) report the NBP is 243.80 K (their source is a 2008 private communication with Leck and Yokozeki). While Di Nicola *et al*. (2009) do not provide the NBP, they present 34 vapor pressure measurements (Section 2.3) for pressures ranging from approximately 39 kPa to 3067 kPa. Of these, six are for pressures below atmospheric (ranging from approximately 39 kPa to 99 kPa). A curve-ft by this paper's authors of the data of Di Nicola *et al*. (2009) yields a NBP of 243.42 K. Therefore, we believe the most reliable NBP value at this time to be 243.42 K.

2.2 Critical State Properties

Minor and Spatz (2008) give the critical temperature (T_c) as 368.15 K and the critical pressure (P_c) as 3239 kPa. Tanaka and Higashi (2009) report T_c = 367.85 K, P_c = 3382 kPa, and the critical density (ρ_c) as 478 kg/m^3. We believe the critical state properties reported by Tanaka and Higashi (2009) are the most reliable ones in the open literature because they were measured using state-of-the-art techniques in a world-class laboratory, and described in Section 4 their values allow for better EoS fits than using the critical state values of Minor and Spatz (2008).

2.3 Vapor Pressure

Minor and Spatz (2008) provide the saturation pressures (P_{sat}) for two saturation temperatures (T_{sat}): P_{sat} = 0.673 MPa at T_{sat} = 298.15 K and P_{sat} = 2.47 MPa at T_{sat} = 353.15 K, though it is unclear if these are measured or predicted values. In addition to the values of Minor and Spatz (2008), there have been a total of 58 experimental values published to-date in the open literature by four research groups. (In actuality, there have been a few more data points; however, because of their nearness to the critical state the authors themselves did not consider them in their own data correlations, and thus we do not consider them in the correlations we develop in Section 3.3.) In particular, (1) Di Nicola *et al*. (2009) provide 34 data points for P_{sat} ranging from approximately 39 kPa to 3067 kPa and T_{sat} ranging from approximately 224 K to 363 K, (2) Hulse *et al*. (2009) provide 12 data points for P_{sat} ranging from approximately 88 kPa to 2448 kPa and T_{sat} ranging from approximately 241 K to 353 K, (3) Tanaka and Higashi (2009) provide 11 data points for P_{sat} ranging from approximately 940 kPa to 2894 kPa and T_{sat} ranging from approximately 310 K to 360 K, and (4) Leck and Yokozeki provide 1 data point indirectly [it is referenced as a private communication in Tanaka and Higashi (2009)].

2.4 Liquid Density

Minor and Spatz (2008) state that the saturated liquid density (ρ_f) is 1094 kg/m^3 at T_{sat} = 298.15 K, although again it is unclear if this is a measured or predicted value. In addition to the value of Minor and Spatz (2008), there have been a total of 16 experimental values for ρ_f and 23 experimental values for compressed liquid densities published to-date in the open literature by three research groups. (Similar to the case for vapor pressure, there are a few more density data points available in the open literature; however, because of their nearness to the critical state neither the authors themselves nor the authors of this paper use them in their correlations.) In particular, (1) Hulse *et al*. (2009) provide 9 data points for ρ_f ranging from approximately 265 K to 365 K, (2) Tanaka and Higashi provide 7 data points for ρ_f ranging from approximately 348 K to 368 K, and (3) Tanaka *et al*. (2009) provide 23 data points for compressed liquid densities for temperatures ranging from 310 K to 360 K for pressures up to 5000 kPa. In addition to these data, Yoshitake *et al*. (2009) provide a curve showing experimental data of liquid densities from 273 K to 323 K for pressures up to approximately 17 MPa. We do not include these data since manually reading them from the figures is too inaccurate and our attempt to request the numerical values from the authors was unsuccessful. We do note, however, that when we estimated their experimental ρ_f from their figures, they were within 2 % of the values predicted by our density correlation presented in Section 3.4.

2.5 Specific Heat at Constant Pressure

Tanaka *et al*. (2009) report the only publically available experimental data for specific heat at constant pressure (c_p). In particular, they provide 22 data points in the compressed liquid region for temperatures ranging from 310 K to 360 K for pressures up to 5000 kPa.

2.6 Other Properties

2.6.1 Surface Tension: Tanaka and Higashi (2009) report the only publically available experimental data for surface tension (σ). In particular, they provide 29 data points for temperatures ranging from 273 K to 334 K.

2.6.2 Liquid Dynamic Viscosity: Hulse *et al*. (2009) report the only publically available experimental data for liquid viscosity (μ). In particular, they provide 39 data points in the compressed liquid region for temperatures ranging from 257 K to 307 K for pressures up to 2100 kPa. In addition to these data, Yamaguchi *et al*. (2009) provide a curve showing experimental data of liquid viscosities from 263 K to 323 K for pressures up to approximately 20 MPa. We do not include these data since manually reading them from the figures is too inaccurate and our attempt to request the numerical values from the authors was unsuccessful. We do note, however, that when we estimated their experimental μ from their figures, they were within 2 % of the values predicted by our viscosity correlation presented in Section 3.6.2.

3. PROPERTY MODELS

3.1 Normal Boiling Point Temperature
Raabe and Maginn (2009) developed a force field for R-1234yf which allowed them to predict several thermodynamic properties through molecular simulations, yielding a NBP of 243.3 K. This value agrees quite well with the value of 243.42 K determined from a curve-fit by this paper's authors of the vapor pressure data of Di Nicola *et al*. (2009). Raabe and Maginn (2009) estimate the accuracy of their prediction of the NBP to be ±3.5 K.

3.2 Critical State Properties
Raabe and Maginn (2009) predict T_c = 366.4 K, P_c = 3376 kPa, and ρ_c = 469.8 kg/m^3, which differ from the measured values of Tanaka and Higashi (2009) by -0.4 %, -0.2 %, -1.7 %, respectively. Using a much simpler approach based on group contribution methods as outlined in Brown *et al*. (2009a) and using the NBP of 243.42 K, the present authors estimate that T_c = 368.2 K, P_c = 3425 kPa, and ρ_c = 472.6 kg/m^3, which differ from the measured values of Tanaka and Higashi (2009) by 0.1 %, 1.3 %, -1.2 %, respectively. Therefore, as long as the NBP of a refrigerant is accurately known one can quite easily (much more easily than detailed molecular simulations) and accurately predict the critical state properties. (Note: Brown *et al*. (2009b) demonstrated the robustness and accuracy of this approach for a group of 26 refrigerants.) However, if the NBP is not known, group contribution methods are much less accurate in predicting the NBP, which affects the ability of these same methods to accurately predict the critical state properties. In these cases, a more time-consuming and difficult approach for predicting the critical state properties such as that illustrated in Raabe and Maginn (2009) may be appropriate.

3.3 Vapor Pressure
Di Nicola *et al*. (2009) and Tanaka and Higashi (2009) provide Wagner-type vapor pressure correlations based on their 34 data points and 11 data points, respectively, and Hulse *et al*. (2009) provides an extended Antoine vapor pressure correlation based on their 12 data points. Leck (2009) provides an extended Antoine equation based on his company's unpublished data. In addition to the already published vapor pressure correlations, using the entire published data set of 58 points, we developed a Wagner-type vapor pressure correlation given in Equation (1):

$$T_r \ln\left(P_r\right) = A_1\tau + A_2\tau^{1.5} + A_3\tau^{2.5} + A_4\tau^5 \tag{1}$$

with the constants given in Table 1 and where the reduced temperature $T_r = T/T_c$, the reduced pressure $P_r = P/P_c$, and $\tau = 1 - T_r$. Table 2 shows relative ($e_r = \sum_{i=1}^{n} e_i / n$) and absolute ($e_a = \sum_{i=1}^{n} |e_i| / n$) mean percentage errors for data from the three publicly available data sets, where the relative error ($e = \left(y_p - y_k\right)/y_k \times 100$), y is a property value, and the subscripts p and k refer to predicted and known, respectively.

The first, and not at all surprising, thing to note is that each group of authors is able to most accurately predict their own data set. Secondly, the correlation we developed has the best accuracy when compared to the entire publically available data set since it is the only one based on all of the data. Thirdly, while Leck (2009) does not provide any data in his paper, his correlation is consistent with the data sets of Di Nicola *et al*. (2009) and Tanaka and Higashi (2009). Fourthly, the correlation and data set of Hulse *et al*. (2009) are inconsistent with those of Di Nicola *et al*. (2009) and Tanaka and Higashi (2009), and are inconsistent with the correlation of Leck (2009). Thus, we are led to believe the data of Hulse *et al*. (2009) to be less accurate than the others. Because of this, we once again correlated Equation (1) using only the 45 data points from Di Nicola *et al*. (2009) and Tanaka and Higashi (2009), with the

constants given in Table 3. Table 4 shows e_r and e_a for the five correlations compared to the 45 data points. Our correlation is the most accurate, and thus we believe it to be the best one available to-date in the open literature.

Table 1: Constants for Equation (1) derived from the published data sets consisting of 58 data points

$A_1 = -7.6060$	$A_2 = 2.3590$	$A_3 = -3.2795$	$A_4 = -1.0282$

Table 2: Relative and absolute mean percentage errors of five vapor pressure correlations for data from the three publicly available data sets

	Eq. (1)	Di Nicola *et al*. (2009)	Hulse *et al*. (2009)	Leck (2009)	Tanaka and Higashi (2009)
All 58 data points					
e_r (%)	0.0045	0.30	−1.17	0.077	0.22
e_a (%)	0.48	0.39	1.25	0.47	0.54
Data of Di Nicola *et al*. (2009)					
e_r (%)	−0.24	0.054	−1.31	−0.19	−0.031
e_a (%)	0.27	0.15	1.31	0.35	0.51
Data of Hulse *et al*. (2009)					
e_r (%)	1.10	1.35	0.10	1.09	1.14
e_a (%)	1.10	1.35	0.24	1.09	1.15
Data of Tanaka & Higashi (2009)					
e_r (%)	−0.46	−0.11	−2.22	−0.19	0.011
e_a (%)	0.46	0.11	2.22	0.19	0.035

Table 3: Constants for Equation (1) derived from the data sets of Di Nicola *et al*. (2009) and Tanaka and Higashi (2009) consisting of 45 data points

$A_1 = -7.3110$	$A_2 = 1.3841$	$A_3 = -1.5566$	$A_4 = -5.7037$

Table 4: Relative and absolute mean percentage errors of five vapor pressure correlations for data from Di Nicola *et al*. (2009) and Tanaka and Higashi (2009) consisting of 45 data points

	Eq. (1)	Di Nicola *et al*. (2009)	Hulse *et al*. (2009)	Leck (2009)	Tanaka and Higashi (2009)
Data of Di Nicola *et al*. (2009) and Tanaka & Higashi (2009)					
e_r (%)	0.0077	0.44	−1.53	−0.58	−0.021
e_a (%)	0.097	0.44	1.53	0.63	0.39

3.4 Density

Hulse *et al*. (2009) provides a Rackett-type saturated liquid density correlation based on their 9 data points and Leck (2009) provides a saturated liquid density correlation based on the non published data of his employer. Tanaka *et al*. (2009) instead provide a correlation for liquid densities up to $T_r = 0.98$, which when coupled with a vapor pressure correlation can be used to predict saturated liquid density. In addition to these two equations, using the entire published data set of 17 points, we developed VDNS-type [Equation (2)] and Rackett-type [Equation (3)] saturated liquid density correlations, with the constants given in Table 5. The VDNS-type correlation is part of NIST's ThermoData Engine (Frenkel *et al*., 2008). Table 6 shows e_r and e_r for the five correlations.

$$\rho_r = 1 + B_1 \tau^{0.35} + B_2 \tau^2 + B_3 \tau^3 + B_4 \tau^4 \qquad (2)$$

$$\rho_{\rm r} = {\rm C}_1 - \tau^{C_2} \tag{3}$$

where the reduced density $\rho_{\rm r} = \rho/\rho_{\rm c}$,

Each of the correlations predicts well, and with more or less the same level of accuracy, $\rho_{\rm f}$ up to $T_{\rm r}$ approximately 0.98, whereas the correlations of Leck (2009) and Tanaka *et al.* (2009) begin to deviate for $T_{\rm r} > 0.98$. Overall, the most accurate, and thus we believe to be the best one available to-date in the open literature, is our VDNS-type correlation given in Equation (2), with the constants given in Table 5.

Table 5: Constants for Equations (2)-(3) derived from the published data sets consisting of 17 data points

$B_1 = 2.0959$	$B_2 = 10.2667$	$B_3 = -55.8525$	$B_4 = 96.3091$
$C_1 = 0.2616$	$C_2 = 0.2914$	–	–

Table 6: Relative and absolute mean percentage errors of five saturated liquid density correlations for data from the two publicly available data sets

	Eq. (2)	Eq. (3)	Hulse *et al.* (2009)	Leck (2009)	Tanaka *et al.* (2009) coupled with Eq. (1)
For data points up to $T_{\rm r} = 0.98$ $e_{\rm r}$ (%) $e_{\rm a}$ (%)	−0.064 0.11	−0.15 0.27	−0.073 0.16	0.25 0.73	0.28 0.34
For all 16 data points $e_{\rm r}$ (%) $e_{\rm a}$ (%)	0.049 0.22	0.12 0.40	0.61 0.71	2.52 3.05	errors are extremely high

3.5 Specific Heat at Constant Pressure

Tanaka *et al.* (2009) provide a correlation for the liquid specific heat based on their 22 data points. This is the only correlation available in the open literature. There are, however, three correlations for the ideal gas specific heat at constant pressure ($c_p^{\rm o}$). In particular, Hulse *et al.* (2009) and Leck (2009) both provide correlations developed using statistical thermodynamics techniques, and the present authors have developed a correlation [Equation (4)] based on the much simpler Joback group contribution method (Poling *et al.*, 2001).

$$\frac{c_p^{\rm o}}{\rm R} = -0.316 + 19.543 T_{\rm r} - 6.543 T_{\rm r}^2 + 0.826 T_{\rm r}^3 \tag{4}$$

where R is the gas constant.

These three correlations provide similar results; however, when compared over a temperature range from 243.15 K to 573.15 K, Leck (2009) predicts values that are from 3.2 % to 4 % lower and Equation (4) predicts values that are from 7.4 % to 2 % lower than the predictions of Hulse *et al.* (2009). If these three correlations for $c_p^{\rm o}$ are used together with the Bondi method (Poling *et al.*, 2001) to predict saturated liquid c_p, the errors $e_{\rm r}$ and $e_{\rm a}$ compared to Tanaka *et al.* (2009) are: (1) Hulse *et al.* (2009): $e_{\rm r} = $ -0.8 % and $e_{\rm a} = $ 3.0 %, (2) Leck (2009): $e_{\rm r} = $ -2.8 % and $e_{\rm a} = $ 3.8 %, and (3) Equation (4): $e_{\rm r} = $ -3.5 % and $e_{\rm a} = $ 4.3 %. Therefore, the best correlation available in the open literature to-date for c_p is that of Tanaka *et al.* (2009) and the best correlation available in the open literature to-date for $c_p^{\rm o}$ is that of Hulse *et al.* (2009). However, we would like to note that the quite simple and straightforward group contribution method of Joback (Poling *et al.*, 2001) given in Equation (4) provides quite reasonable results that are consistent with those of Hulse *et al.* (2009) and Leck (2009).

3.6 Other Properties

3.6.1 Surface Tension: Tanaka and Higashi (2009) provide a correlation for σ based on their data, with errors $e_r = 0.29$ % and $e_a = 1.30$ %. Their correlation is given in Equation (5).

$$\sigma / \sigma_{\text{R-134a, T=273.15 K}} = 5.176\tau^{1.367} \tag{5}$$

3.6.2 Liquid Dynamic Viscosity: Hulse *et al*. (2009) provide a correlation for liquid viscosity based on their data, with errors $e_r = -1.12$ % and $e_a = 2.30$ %.. Their correlation is given in Equation (6).

$$\ln(\mu) = -4.9526 + \frac{922.43}{T} \tag{6}$$

The authors of this paper have developed–unpublished until now–a correlation based on the group contribution method of Sastri and Rao (2000). Our correlation given in Equation (7) has errors $e_r = 0.51$ % and $e_a = 2.37$ %. when compared to the data of Hulse *et al*. (2009).

$$\ln(\mu) = 4.326\left(1.3223^{2.97(1-T_r)}\right) - 6.9078 \tag{7}$$

In Equations (6) and (7), the units T are K and of μ are cP.

It is worth noting that while Equation (6) was developed from experimental data and Equation (7) was developed from group contribution methods, Equation (7) provides a marginally better estimate of the experimental data.

4. EQUATIONS OF STATE

To-date, only a few authors have presented EoS for R-1234yf in the open literature. In particular, (1) Akasaka *et al*. (2009) present both an Extended Corresponding States (ECS) EoS and a Patel-Teja (PT) EoS, (2) Brown *et al*. (2009a, 2010) present a Peng-Robinson (PR) EoS, (3) Hulse *et al*. (2009) present an ECS EoS, and (4) Leck (2009) presents a Martin-Hou (MH) EoS. The model of Akasaka *et al*. (2009) is based on the data of Tanaka and Higashi (2010) and Tanaka *et al*. (2010). The models of Hulse *et al*. (2009) and Leck (2009) are based on their own data. The model of Brown *et al*. (2009a, 2010) is based on group contribution estimations of the critical state properties, acentric factor, and c_p° from the known NBP. The model of Brown *et al*. implemented here is somewhat improved over previous versions since here we use a more accurate value for NBP.

The models of Akasaka *et al*. (2010), Hulse *et al*. (2009), and Leck (2009) are all based on differing amounts of experimental data; whereas, present paper's authors is based only on knowing an accurate value of the NBP. In fact, this is the power of the methodology: (1) it can be developed knowing only NBP, (2) it can be easily and quickly implemented in REFPROP 8.0 (Lemmon *et al*., 2007) without the user possessing any particular programming or EoS modeling skills, and (3) it provides reasonable accuracy for engineering analyses, for refrigerant screening, etc. The authors have used the methodology to predict the thermodynamic performance of several other fluorinated propene isomers (2009b, 2010) where little information is known about them, at least in the public domain.

While the model of the present authors is simple and based on very little experimental data (only NBP), Figure 1 shows, it provides quite reasonable predictions for P_{sat} and ρ_f for T_r from 0.65 to 0.90 vis-à-vis the more complex (in the sense of the need to have on hand much more experimental data) models of Akasaka *et al*. (2010), Hulse *et al*. (2009), and Leck (2009). The model of the present authors predicts P_{sat} with similar accuracy as the models of Akasaka *et al*. (2010) and Leck (2009) and somewhat better than the model of Hulse *et al*. (2009), and ρ_f with similar accuracy to the other three models up to $T_r = 0.85$. It is to be noted, however, that accurate ρ_f predictions do not greatly influence COP and VCC predictions, and moreover, for most comfort cooling applications, the reduced condenser temperature would have a maximum value on the order of 0.90 or thereabouts.

To demonstrate the power of the methodology of the present authors to provide very reasonable engineering estimates of thermodynamic performance, we simulated several ideal vapor compression refrigeration cycles (Table 7) using the models of Akaska *et al*. (2010), Hulse *et al*. (2009), Leck (2009), and the present authors. The results are presented in Figure 2. Figure 2a shows that COP predictions of all of the models are within ±1.2 % of one another. Figure 2b shows that VCC predictions of the present authors are within ±0.5 % of those of Akasaka *et al*.

Table 7. Various Ideal Vapor Compression Refrigeration Cycles Simulated

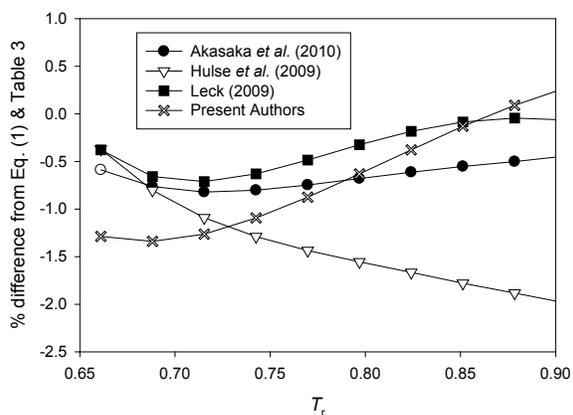| Cycle Number	Evaporator Saturation Temperature (ºC)	Evaporator Superheat (ºC)	Condenser Saturation Temperature (ºC)	Condenser Subcooling (ºC)	Compressor Isentropic Efficiency
1	0	5	40	5	75 %
2	-20	0	10	0	85 %
3	-30	5	0	5	75 %
4	10	2	50	2	80 %
5	0	10	50	10	70 %
6	15	0	45	0	80 %
7	15	5	55	5	75 %
8	0	0	40	0	100 %
9	0	5	40	5	100 %
10	-15	5	20	7.5	80 %
11	-5	5	30	5	80 %
12	-15	0	20	0	80 %
13	-5	0	30	0	80 %

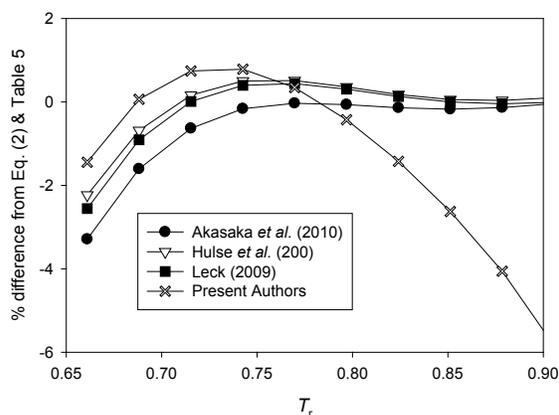Figure 1a. Saturation Pressure

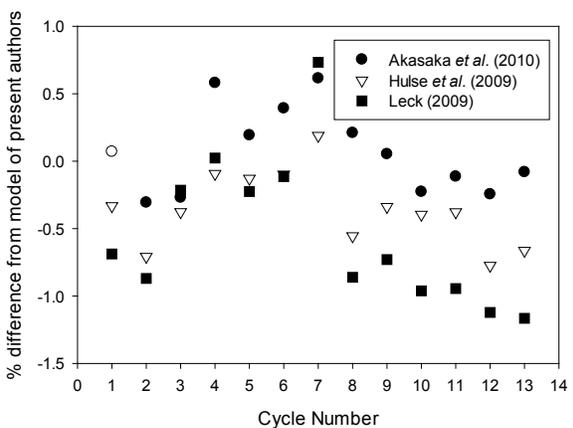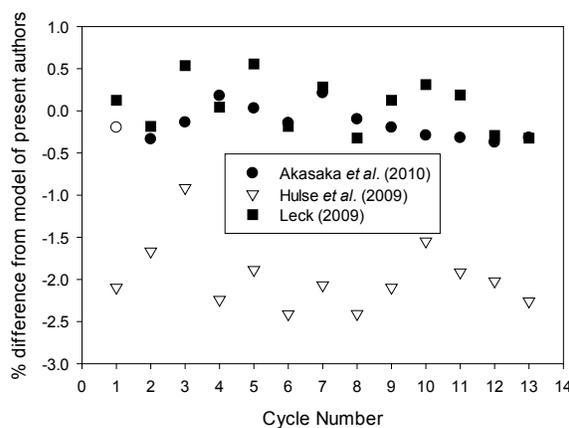Figure 1b. Saturated Liquid Density

Figure 2a. COP

Figure 2b. Volumetric Cooling Capacity

(2010) and Leck (2009); whereas, they differ by about 1.5 to 2.5 % from those of Hulse *et al.* (2009). We believe the model of Hulse *et al.* (2009) is less accurate than the other three since their estimations for the critical state properties are less accurate than the ones used by the other authors.

4. CONCLUSIONS

This paper critically reviews the best publically available data for R-1234yf for the normal boiling point temperature (NBP), the critical state temperature (T_c), pressure (P_c), and density (ρ_c), vapor pressure (P_{sat}), liquid density (ρ_f), specific heat at constant pressure (c_p), liquid dynamic viscosity (μ), and surface tension (σ). We believe the NBP value of 243.42 K by this paper's authors and the values of T_c = 367.85 K, P_c = 3382 kPa, and ρ_c = 478 kg/m^3 from Tanaka and Higashi (2009) to be the best ones available in the public domain.

In addition to reviewing experimental data, this paper presents correlations for the same properties and compares them with available data. We believe the best correlations (i) for P_{sat} to be Equation (1) with constants provided in Table 3, (ii) for ρ_f to be Equation (2) with constants provided in Table 5, (iii) for c_p to be the correlation of Tanaka *et al.* (2009), (iv) for μ to be Equation (7), and (v) for σ to be Equation (5), which is taken from Tanaka and Higashi (2009).

Finally, this paper reviews several Equations of State (EoS) and the uses them to simulate 13 different ideal vapor compression refrigeration cycles. While the Peng-Robinson model presented in this paper is based only on a known value of the NBP, it provides equally accurate and useful results for cycle performance simulations for engineering analyses as do the other publically available EoS, which are based on much more extensive experimental data sets. Therefore, this paper demonstrates the power of this paper's methodology to simulate the thermodynamic properties and cycle performance for not-so-well-described (ones with little or no experimental data) refrigerants. Moreover, if coupled with REPROP 8.0 (Lemmon *et al*, 2007), a user of this methodology does not need any programming or EoS modeling experience or knowledge (therefore, it is quick and easy to use).

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