

A COMPARATIVE STUDY OF MECHANISTIC PARACHOR MODEL OVER PARACHOR MODEL IN A MULTI-COMPONENT HYDROCARBON SYSTEM

Mohammad Marufuzzaman¹, Amr Henni¹, Azizur Rahman²

¹Industrial Systems Engineering (ISE), University of Regina, Canada

²Industrial Engineering and Management (IEM), Khulna University of Engineering and Technology (KUET), Khulna, Bangladesh

ABSTRACT

Interfacial tension is an important property for many processes such as enhanced oil recovery by gas injection and flow through porous media, and in mass and heat transfer applications. The objective of this study is to study four prevalent interfacial tension models along with their governing mechanisms. Also, Mechanistic Parachor model has been studied in comparison with Parachor Model. The trait of the Mechanistic Parachor model is that it considers the mass transfer mechanism responsible for attaining the thermodynamic fluid phase equilibria in multi component hydrocarbon systems, while the other three IFT models doesn't consider the effect. The Mechanistic Parachor model has been tested on Rainbow Keg River (RKR) crude oil-gas systems and showed better IFT prediction over the conventional Parachor model.

Key words: Interfacial Tension, Parachor Model, Mechanistic Parachor Model, Gradient Theory.

1. INTRODUCTION

Interfacial tension is a physical parameter which plays an important role in many processes in a number of industrial applications, such as heat transfer under boiling conditions, mass transfer during extraction etc. In the petroleum industry, processes such as gas condensate recovery, near critical fluid recovery and secondary and tertiary crude oil recovery, in particular, by gas injection, bring very low surface tension to into play. These surface tensions (i.e liquid/vapour interfacial tensions) must be known because of their dominating influence on capillary pressures, relative permeabilities, one needs reliable theoretical estimates.

While most of the thermodynamic properties refer to individual fluid phases, interfacial tension (IFT) is unique in the sense that it is a property of the interface between the phases. Several models have been proposed for the calculation of interfacial tensions of simple fluids and mixtures in the past few decades. The most important among these models are the Parachor model [1,2], Mechanistic Parachor model [3], Gradient Theory [4], and the linear gradient theory [5,6]. The IFT, being a property of interface, is strongly dependent on the compositions of fluid phases in contact, which in turn depend on the mass transfer interactions between the phases. The commonly occurring mass transfer mechanisms between the fluid phases to attain equilibrium are vaporization, condensation, or a combination of the two. In the vaporizing drive mechanism, the vaporization of lighter components

(C1–C3) from the liquid (crude oil) to hydrocarbon vapor phase promotes the attainment of miscibility of the two phases. In condensing drive mechanism, the condensation of intermediate and heavy components (C4–C8) from hydrocarbon gas to the crude oil is responsible for attaining miscibility between fluid phases. In combined condensation and vaporization drive mechanism, the simultaneous counter-directional mass transfer mechanisms, that is, vaporization of lighter components from crude oil to gas and condensation of intermediate and heavy components from gas to crude oil, are responsible for attaining miscibility of the phases. These mass transfer interactions affect the compositions of both phases and hence their interfacial tension. Therefore, the dynamic changes in IFT can be used to infer information on mass transfer interactions taking place prior to the attainment of thermodynamic fluid phase equilibrium and miscibility.

2. OBJECTIVES OF THIS STUDY

The objectives of this study are to (1) study the different existing interfacial theory (2) study of Mechanistic Parachor Model in comparison with Parachor Model which considers the mass transfer interactions occurring prior to attaining fluid phase equilibria. This paper use data from Subash and Rao [3] and Rao [7] to compare Mechanistic Parachor Model with Parachor Model. Subash and Rao [3] proposed the Mechanistic Parachor model where the authors used

Rainbow Keg River (RKR) as a reservoir crude oil-gas system since the fluid compositions and the phase behavior data needed for IFT calculations and the experimental IFT measurements are readily available from Rao [7]. These gas-oil interfacial tension measurements are made using the axisymmetric drop shape analysis (ADSA) technique by fitting the images of the captured pendent drops of crude oil in gas phase with the drop profile calculated using the Laplace capillary equation. An aging period of about 2 h was allowed between the fluid phases to reach equilibrium during these experiments. Flash calculations needed for gas-oil interfacial tension calculations are carried out using QNSS/Newton algorithm and Peng–Robinson equation of state, with CMG Winprop module (Version 2008.10.3118.22139).

3. EQUILIBRIUM IFT PREDICTION MODELS

3.1 Parachor Model

This model is the oldest among all the IFT prediction models and because of simplicity is still most widely used in petroleum industry to estimate the interfacial tension between fluids. Empirical density correlations are used in this model to predict the interfacial tension.

The Macleod [1] and Sudgen [2] related surface tension of a pure compound to the density difference between two phases, as

$$\sigma^{1/4} = P(\rho_M^L - \rho_M^V) \quad (1)$$

where σ is the surface tension (dyne/cm), ρ_M^L and ρ_M^V are the molar densities of the liquid and vapor phases, respectively (g mol/cm^3), and the proportionality constant P, is known as the Parachor. The Parachor values of different pure compounds are reported in the literature by J.K.Ali [8]. Also one can use the value from the library component of CMG Winprop module (Version 2008.10.3118.22139) on the component selection/ properties option.

The equation proposed by Macleod-Sudgen [1,2] was later extended to multi component hydrocarbon mixtures by Weinaug and Katz [9] using the simple molar average technique for the mixture Parachor,

$$\sigma^{1/4} = \rho_M^L \sum x_i P_i - \rho_M^V \sum y_i P_i \quad (2)$$

where x_i and y_i are the mole fractions of the component i in the liquid and vapor phases, respectively, and P_i is the Parachor of the component i . Parachor values of pure compounds are used in Eq. (2) to calculate the interfacial tension of the mixtures, considering the Parachor value of a component in a mixture is the same as that when pure [10]. This model has been extensively used for prediction of surface tension of pure compounds and binary mixtures.

Fanchi [11] proposed the following correlation for calculating the parachor of a hydrocarbon mixture:

$$P = 176.05005 - 7472.9807 v_c - 0.87458088 T_c + 1560.4793 H + 19.309439 H^2 + 0.05013801 H^3 - \frac{25.691718}{H} \quad (3)$$

where,

$$H = v_c^{5/6} T_c^{0.25}$$

Here v_c is the molar specific critical volume in L/mol and T_c is the critical temperature in K.

In addition, Firozabadi et al. [12] calculated the parachors of several crude cuts of various crude oils from their surface tensions. They found a quadric relation between the parachor and the molecular weight of each crude cut and proposed the following empirical correlations:

$$P = -11.4 + 3.23 M - 0.0022 M^2 \quad (4)$$

where M is the molecular weight of each crude cut.

Furthermore, Ahmad [13] correlated the parachor of a hydrocarbon mixture with its molecular weight M by

$$P = -4.614873 + 2.558855 M + (3.4004065 \times 10^{-4}) M^2 + \frac{3767.396}{M} \quad (5)$$

3.2 Mechanistic Parachor Model

In the application of the conventional Parachor model to multi component mixtures, Parachor values of pure components are used in IFT prediction, considering each component of the mixtures as if all the others were absent. Significant interactions take place between the various components in a multi component mixture and hence the inability of pure component Parachor values to account for these interactions of each component with the others in a multi component mixture appears to be the main reason for poor IFT predictions from the Parachor model in multi component hydrocarbon systems.

In the Mechanistic Parachor model proposed by Subhash and Rao [3] introduces a ratio of diffusivity coefficients raised to an exponent into the Parachor model to account for mass transfer effects. The mass transfer interactions for phase equilibria between any two fluid phases take place by diffusion due to concentration gradient and by dispersion. Hence diffusivities are used in the Mechanistic Parachor model to account for mass transfer interactions. Furthermore, only diffusivities can reasonably represent mass transfer interactions in complex multi component systems like crude oil-hydrocarbon gas mixtures involving multi components in both the phases. The ratio of diffusivities in both the directions (vaporising and condensing) between the fluid phases raised to an exponent used in the mechanistic model enables the relation of the same dimensions of the original Parachor model. The mechanistic model is given by:

$$\sigma^{1/4} = \left(\frac{D_{os}}{D_{so}}\right)^n (\rho_M^L \sum x_i P_i - \rho_M^V \sum y_i P_i) \quad (6)$$

where D_{os} is the diffusivity of the oil in gas (solvent), D_{so} is the diffusivity of the gas (solvent) in oil, and n is the exponent, whose sign and value characterize the type and extent of governing mass transfer mechanism for fluid phase equilibria. If $n > 0$, the governing mechanism is vaporization of lighter components from the oil to the gas phase. If $n < 0$, the governing mechanism is condensation of intermediate to heavy components from the gas to the crude oil. The value of n equal to zero ($n \approx 0$) indicates equal proportions of vaporizing and condensing mass transfer mechanisms to be responsible for fluid phase equilibria. This condition of equal mass transfer in both the directions of vaporization and condensation appear to be most common in binary mixtures where the conventional Parachor model has shown to result in reasonably accurate interfacial tension predictions ($n = 0$ in the mechanistic Parachor model). The higher the numerical value of n (irrespective of its sign) the greater the extent of that governing mass transfer mechanism.

Lee [14] compared the diffusivity data of multi component systems at reservoir conditions obtained from various correlations with experiments and concluded that Wilke-Chang equation [15] is the best available empirical correlation to compute the diffusivities in multi component hydrocarbon systems. Hence, equation (7) is used in equation (6) to calculate the interfacial tension in a crude oil-solvent system:

$$D_{AB} = \frac{(117.3 \times 10^{-18})(\varphi M_B)^{0.5} T}{\mu \nu_A^{0.6}} \quad (7)$$

where D_{AB} is the diffusivity of solute A in very dilute solution in solvent B (m^2/s), M_B is the molecular weight of the solvent (kg/kmol), T is the temperature (K), μ is the solution viscosity (kg/ms), ν_A is the solute molar volume at normal boiling point ($m^3/kmol$), φ is the associated factor for solvent, set equal to unity if the solvent used are unassociated.

Equation (7) is extended to multi component hydrocarbon mixtures, using

$$M_B = \sum x_{Bi} M_{Bi} \quad (8)$$

$$\nu_A = \sum x_{Ai} \nu_{Ai} \quad (9)$$

where x_i is the mole fraction of the component i in the mixture, M_{Bi} is the molecular weight of the component i , and ν_{Ai} is the molar volume of the component i at normal boiling point.

3.3 Gradient Theory

The gradient theory [4] states that the surface tension of the planar interface of a mixture is given by

$$\sigma = \int_{-\infty}^{+\infty} \sum_i \sum_j c_{ij} \frac{dn_i}{dz} \frac{dn_j}{dz} dz \quad (10)$$

where dn_i/dz represents the local gradient in the density of component i . By analogy with the bulk energy

parameters, $a_{ij} = (1 - k_{ij})\sqrt{a_i a_j}$, the crossed influenced parameter c_{ij} are related to the geometric mean of the pure component influence parameters c_i and c_j by

$$c_{ij} = (1 - \beta_{ij})\sqrt{c_i c_j} \quad (11)$$

where β_{ij} is binary interaction coefficients. Stability of the interface requires β_{ij} to be included between 0 and 1. When $\beta_{ij} = 0$, the mixing rule is reduced to the geometric mean.

Computation of surface tension with equation (10) also requires knowledge of the gradients in density through the interface. This can be obtained by minimizing the Helmholtz free energy of the planer interface.

$$F = \int_{-\infty}^{+\infty} [f_o(n) + \sum_i \sum_j \frac{1}{2} c_{ij} \frac{dn_i}{dz} \frac{dn_j}{dz}] dV \quad (12)$$

So in the absence of an external potential, the Helmholtz free energy density of an inhomogeneous fluid, given by the gradient theory, is the sum of two contributions: the Helmholtz free energy density $f_o(n)$ of the homogeneous fluid at the local composition n ; and a corrective term, which is a function of the local density gradients.

Surface Tension from Equation (10) can be written as:

$$\sigma = \int_{n_{ref}}^{n_{ref}} \sqrt{2 \Delta \Omega(n_1, \dots, n_N) \sum_i \sum_j c_{ij} \frac{dn_i}{dn_{ref}} \frac{dn_j}{dn_{ref}} dn_{ref}} \quad (13)$$

where,

$$\sum_i \sum_j c_{ij} \frac{dn_i}{dz} \frac{dn_j}{dz} = \Delta \Omega(n) = \Omega(n) - \Omega_B$$

and from the chain rule of differentiation,

$$\frac{dn_i}{dz} = \frac{dn_i}{dn_{ref}} \frac{dn_{ref}}{dz}$$

one obtains

$$dz = \sqrt{\frac{\sum_i \sum_j c_{ij} \frac{dn_i}{dz} \frac{dn_j}{dz}}{\Delta \Omega(n_1, \dots, n_N)}} dn_{ref}$$

Thus, the only inputs necessary to use the gradient theory, once the vapor-liquid equilibrium (VLE) has been computed, are the Helmholtz free energy density of the homogeneous fluid $f_o(n_1, \dots, n_N)$ (that can be derived from the equation of states) and the influence parameters of the various components.

The Helmholtz free energy can be obtained from Peng-Robinson equation of states [16], which is expressed as:

$$P = \frac{RT}{v-b} - \frac{a(T)}{v(v+b) + b(v-b)} \quad (14)$$

where b is the covolume and $a(T)$ is the energy parameter. For a mixture, these parameters are related to the ones of the pure fluids by mixing rules.

The parameters of the pure fluid are given by

$$b_i = 0.07780 \frac{RT_{ci}}{P_{ci}} \quad (15)$$

$$a_i(T) = 0.45724 \frac{R^2 T_{ci}^2}{P_{ci}} \alpha(T_{ri}) \quad (16)$$

with,

$$\alpha(T_{ri}) = \{1 + m_i(1 - \sqrt{T_{ri}})\}^2 \quad (17)$$

The coefficient m_i is function of the acentric factor as

$$m_i = 0.37464 + 1.54226 \omega_i - 0.26992 \omega_i^2 \quad (18)$$

In 1978, Robinson and Peng [17] proposed the following modification of Equation (18) for components heavier than n-decane:

$$m_i = 0.379642 + 1.485030 \omega_i - 0.164423 \omega_i^2 + 0.016666 \omega_i^3 \quad (19)$$

And the influence Parameter is calculated as:

$$\frac{c_i}{a_i b_i^{2/3}} = A_i t_i + B \quad (20)$$

where b_i is the covolume, and $a_i(T)$ in the energy parameters in the PR-EOS. The coefficients A_i and B are merely correlated with the acentric factor to the component i by the relations

$$A_i = \frac{-10^{-16}}{1.2326 + 1.3757 \omega_i} \quad (21)$$

$$B_i = \frac{-10^{-16}}{0.9051 + 1.5410 \omega_i} \quad (22)$$

3.4 Linear Gradient Theory (Lgt) Model

In the linear gradient theory (LGT), a planer interface is assumed between the bulk liquid and vapor phases. In addition it is assumed that the molar density of each component at the VLE stste is linerly distributed across the liquid-vapor interface [5, 6]. Similar to GT, the LGT calculates the IFT between the bulk liquid and vapor phases by using

$$\gamma_{eq} = \int_{\rho_{r1}^v}^{\rho_{r1}^l} \sqrt{2c[P + \omega(\rho)]} d\rho_1 \quad (23)$$

where c is the influence parameter, P is the equilibrium pressure, $\omega(\rho)$ is the grand canonical free energy density, and ρ_1 represents the integral variable. The subscript “1” denotes a component that has a maximum

molar density difference between its bulk liquid and vapor phases at the VLE state:

$$\Delta\rho_1 = \{\max|\rho_i^L - \rho_i^V|; i = 1, 2, \dots, r\} \quad (24)$$

Here ρ_i^L and ρ_i^V are the molar densities of the i th component in the bulk liquid and vapor phases, respectively, $i = 1, 2, \dots, r$.

The influence parameter c in equation (23) can be calculated by applying the following mixing rule [5]

$$c = \sum_{i=1}^r \sum_{j=1}^r z_i z_j c_{ij} \quad (25)$$

Where z_i is the mole percentage of the i th component in the mixture, $i = 1, 2, \dots, r$. The influence parameter on the basis of SRK EOS [18] can be calculated as

$$\frac{c_{ij}}{a_i b_i^{2/3}} = (1.403 \times 10^{-16}) A_i (1 - T_{r,i})^{B_i}; i = 1, 2, \dots, r \quad (26)$$

where a_i and b_i are the SRK EOS constants of the i th component; $T_{r,i}$ is its reduced temperature by its critical temperature; A_i and B_i are constant and can be calculated from the following equations respectively:

$$A_i = 0.28367 - 0.05164 \omega_i \quad (27)$$

$$B_i = -0.81594 + 1.06810 \omega_i - 1.11470 \omega_i^2 \quad (28)$$

where ω_i is the Pitzer acentric factor of the i th component. The grand canonical free energy density is defined as

$$\omega(\rho) = f(\rho) - \sum_{i=1}^r \rho_i \mu_i \quad (29)$$

Here, $f(\rho)$ is the Helmholtz free energy density of a homogeneous mixture with the molar density ρ . Also,

$$f(\rho) = \rho RT \left[\int_0^\rho \left(\frac{P}{RT \rho^2} - \frac{1}{\rho} \right) d\rho + \frac{1}{\rho} \sum_{i=1}^r \rho_i \ln \rho_i \right] \quad (30)$$

$$\mu_i = \left[\frac{\partial f(\rho)}{\partial \rho_i} \right]_{T, V} \quad (31)$$

4. PREDICTED IFT FROM THE MECHANISTIC PARACHOR MODEL

The crude oil and hydrocarbon gas compositions and the reservoir temperature from Rao [7] are used in IFT computations for this reservoir. The IFT measurements at various C_{2+} enrichments in hydrocarbon gas phase and at various pressures reported by Rao [7] are used for comparison with model predictions. A mixture consisting of 10 mol% of crude oil and 90 mol% of hydrocarbon gas is used as the feed composition in the computations to match the composition used in the reported experiments.

Enrichment (mol% C ₂₊ + CO ₂)	IFT (mN/m)			Weighted squared deviation	
	Experimental (Rao, 1997)	Parachor model	Mechanistic Parachor model	Parachor model	Mechanistic Parachor model
32.86	2.86	1.88	2.37	0.1167	0.0290
37.55	1.89	1.46	1.84	0.0518	0.0007
41.45	1.51	1.14	1.43	0.0610	0.0026
42.61	1.39	1.04	1.32	0.0620	0.0029
47.48	0.70	0.68	0.86	0.0007	0.0518
Objective function (Δ) =				0.2921	0.0871

The comparison of IFT predictions by the original Parachor model with experiments at various C₂₊ enrichments in gas phase is given in Tables 1 and 2, respectively for pressures 14.8 and 14.0 MPa. These results are also shown in Figs. 1 and 2, respectively at these pressures. As can be seen, similar trends in IFT are observed for both the pressures. The match between the experiments and the model predictions is not good and IFT under predictions are obtained with the Parachor model.

The disagreement between the experiments and the model predictions, as seen in Figs. 1 and 2, are attributed mainly to the absence of mass transfer effects in the original Parachor model.

Table 1: Comparison of IFT measurements with Parachor and mechanistic Parachor models for RKR fluids at 87 °C and 14.8 MPa

Enrichment (mol% C ₂₊ + CO ₂)	IFT (mN/m)			Weighted-squared deviation	
	Experimental (Rao, 1997)	Parachor model	Mechanistic Parachor model	Parachor model	Mechanistic Parachor model
17.79	4.26	2.91	3.79	0.1000	0.0123
21.64	3.89	2.59	3.36	0.1124	0.0184
25.85	3.27	2.21	2.88	0.1043	0.0144
30.57	2.69	1.81	2.36	0.1065	0.0155
33.86	2.13	1.54	2.00	0.0762	0.0035
37.70	1.52	1.24	1.61	0.0347	0.0034
43.07	0.97	0.85	1.10	0.0166	0.0175
48.39	0.53	0.50	0.65	0.0028	0.0535
49.28	0.27	0.48	0.63	0.0061	0.0173
Objective function (Δ) =				0.5595	0.1558

The computed diffusivities between the fluid phases at various C₂₊ enrichments in hydrocarbon gas phase for RKR fluids at pressures 14.8 and 14.0 MPa are given in Table 3. The mass transfer interactions between the fluid phases declined slightly as the C₂₊ enrichment in hydrocarbon gas phase is increased for both the pressures. However, the ratio of diffusivities in both directions (oil to gas and gas to oil) remains almost the same at all C₂₊ enrichments in gas phase. The average ratios of diffusivities between the fluids at all C₂₊

enrichments are 3.70 and 3.92, respectively for pressures 14.8 and 14.0 MPa. From the mass transfer enhancement parameters and the average ratios of diffusivities between the fluid phases, the exponents (n) characterizing the governing mass transfer mechanism are found to be 0.20 and 0.17, respectively for pressures

Table 2: Comparison of IFT measurements with Parachor and mechanistic Parachor models for RKR fluids at 87 °C and 14.0 MPa

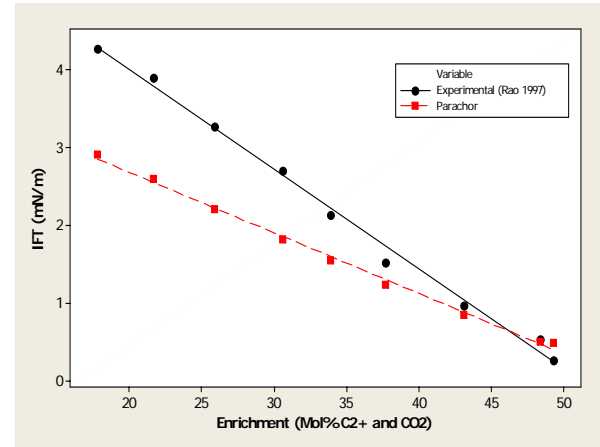


Fig 1. Comparison between IFT measurements and Parachor model for RKR fluids at 87 °C and 14.8 MPa.

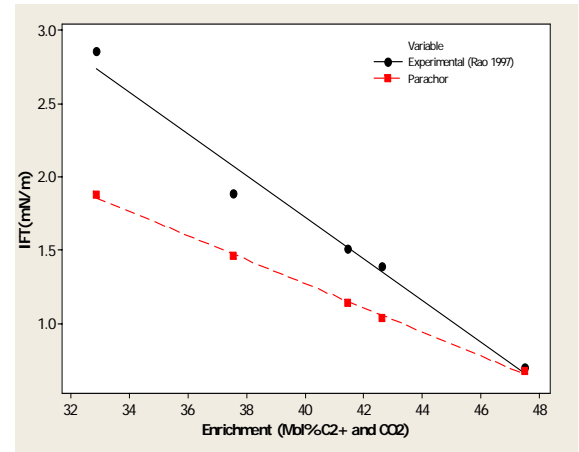


Fig 2. Comparison between IFT measurements and Parachor model for RKR fluids at 87 °C and 14.0 MPa.

14.8 and 14.0 MPa. These values of n being greater than zero, indicate that the vaporization of light components from the crude oil into the gas phase is the mass transfer mechanism that governs the fluid phase equilibria of these reservoir fluids. This can be attributed to the presence of significant amounts of lighter components (52 mol% C₁-C₃) in the crude oil of this reservoir.

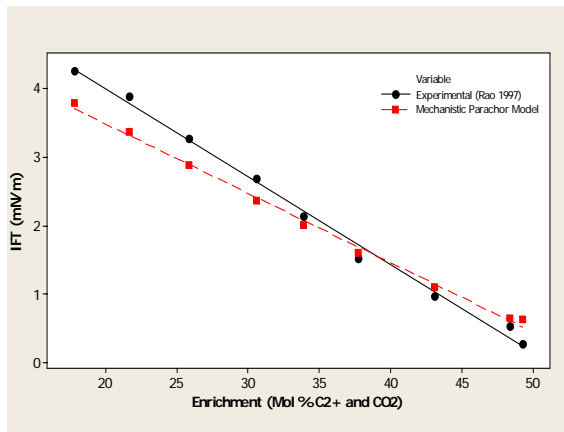


Fig 3. Comparison between IFT measurements and mechanistic Parachor model for RKR fluids at 87 °C and 14.8 MPa.

The comparison between the IFT predictions of mass transfer enhanced mechanistic Parachor model with experiments at various C_{2+} enrichments in gas phase is given in Tables 1 and 2, respectively for pressures 14.8 and 14.0 MPa. These results are also shown in Figs. 3 and 4, respectively at these pressures. Since the optimization of the mass transfer enhancement parameter (k) is based on minimizing the sum of squared deviations between the experimental and calculated values, the mechanistic model prediction matched well with the experiments for both pressures (14.8 and 14.0 MPa)

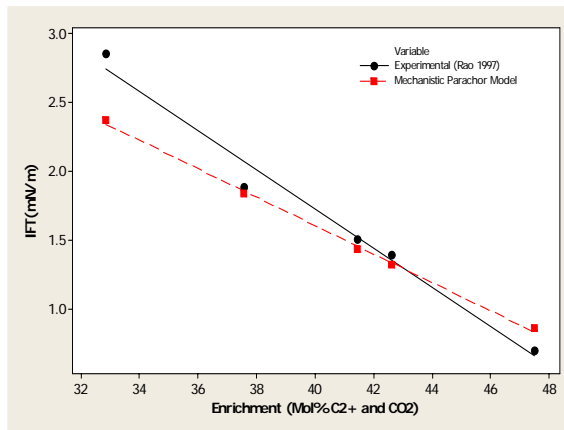


Fig 4. Comparison between IFT measurements and mechanistic Parachor model for RKR fluids at 87 °C and 14.0 MPa.

Table 3: Diffusivities between oil and gas at various C_{2+} enrichments for RKR fluids

Table 4. Model exponent of different single experimental IFT measurements points in the Mechanistic Parachor Model for RKS fluids at 14.8 MPa.

14.8 MPa				14.0 MPa			
(mol % C_{2+} + CO_2)	Dos (m ² /s)	Dso (m ² /s)	Dos/Dso	(mol% C_{2+} + CO_2)	Dos (m ² /s)	Dso (m ² /s)	Dos/Dso
17.79	3.45	9.69	3.56	32.68	3.44	8.67	3.97
	E-08	E-09			E-08	E-09	
21.64	3.45	9.40	3.68	37.55	3.34	8.39	3.98
	E-08	E-09			E-08	E-09	
25.85	3.42	9.11	3.75	41.45	3.21	8.18	3.93
	E-08	E-09			E-08	E-09	
30.57	3.36	8.81	3.81	42.61	3.17	8.12	3.91
	E-08	E-09			E-08	E-09	
33.86	3.29	8.62	3.82	47.48	2.99	7.89	3.79
	E-08	E-09			E-08	E-09	
37.70	3.19	8.41	3.80				
	E-08	E-09					
43.07	3.03	8.14	3.73				
	E-08	E-09					
48.39	2.85	7.89	3.61				
	E-08	E-09					
49.28	2.83	7.88	3.59				
	E-08	E-09					

Enrichment (mol% C_{2+} + CO_2)	Average= 3.70			Average= 3.92		
	IFT (mN/m)			k	Dos/Dso	N
	Experimental (Rao, 1997)	Parachor	Mechanistic Parachor Model			
17.79	4.26	2.190	4.26	1.46	3.56	0.30
21.64	3.89	2.590	3.89	1.50	3.68	0.30
25.85	3.27	2.210	3.27	1.47	3.75	0.29
30.57	2.26	1.180	2.69	1.48	3.81	0.29
33.86	2.13	1.540	2.13	1.39	3.82	0.25
37.70	1.52	1.240	1.52	1.23	3.80	0.16
43.07	0.97	0.850	0.97	1.15	3.73	0.11
48.39	0.53	0.500	0.53	1.10	3.61	0.07

5. CONCLUSION

In this paper four different IFT models along with their governing equations have been discussed. Then among them the most recent IFT model known as Mechanistic Parachor model has been compared with Parachor model in Rainbow Keg River (RKR) crude oil system. The ratio of diffusivities between the fluid phases raised to an exponent is introduced into the Parachor model for mass transfer effects. The sign and value of the exponent in the mechanistic model characterize the type and the extent of governing mass transfer mechanism for fluid phase equilibria and miscibility. The Mechanistic Parachor Model can be utilized to identify the predominating mass transfer mechanism in the combined vaporizing/condensing mode and to determine dynamic interfacial tension and the miscibility in multi component hydrocarbon system by using the compositional data of the fluid phases.

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7. NOMENCLATURE

Symbol	Meaning	Unit
P	Pressure	(Pa)
T _c	Critical Temperature	(K)
V _c	Molar specific volume	(L/mol)
M	Molecular Weight	(kg/kmol)
σ	Surface Tension	(dyne/cm)
ρ_M^L	Molar Density of Liquid	(g mol/cm ³)
ρ_M^V	Molar Density of Vapour	(g mol/cm ³)
D _{AB}	Diffusivity	(m ² /s)

8. MAILING ADDRESS

Mohammad Marufuzzaman
 Industrial Systems Engineering (ISE),
 University of Regina, Canada
 E-mail: marufuzm@uregina.ca