

*Full Length Research*

# Analysis of solvent effects on the reactivity of carboxylic acids with diazodiphenylmethane using Catalan's and Krygowski-Fawcett's approaches

L.K. Akinola

Department of Chemistry, Bauchi State University, Gadau, Nigeria. Email: [lukman.akinola@yahoo.com](mailto:lukman.akinola@yahoo.com).

Accepted June 20, 2015

---

Solvent effects on the reactivity of eight carboxylic acids with diazodiphenylmethane in some pure organic solvents were examined in the light of Catalan's three-parameter and Krygowski-Fawcett's two-parameter equations using multiple linear regression analysis. Findings reveal that the results from the two different approaches are in good agreement in explaining the specific solute-solvent interaction. It was also shown that the nonspecific dipolarity/polarizability term in the Catalan equation contributes small but significant impact on the observed solvent effects. The fitness of models based on Krygowski-Fawcett's equation is adjudged to be relatively poor due to the neglect of nonspecific solute-solvent interaction in the models. Better insight into the mechanism of how solvents affect the reactivity of carboxylic acids was provided by Catalan's approach.

**Keywords:** Carboxylic acids, Diazodiphenylmethane, Multiple Regression, Reactivity, Solvent Effects.

---

## INTRODUCTION

The observation that solvents have influence on chemical reactivity was first noticed over a century ago by Berthelot, Pean de Saint-Gilles, Menshutkin, Claisen, Knorr, and Wilslicenus (Reichardt, 1994). Nowadays, it is generally known to all chemists that the rates and equilibrium positions of chemical reactions, as well as the position and intensity of absorption bands in ultraviolet/visible, infrared, nuclear magnetic resonance, and electron spin resonance spectroscopy, are solvent-dependent (Whetsel and Kagarise, 1962; Amis and Hinton, 1973; Huisgen, 1980; Reichardt, 1982; Diakovitch *et al*, 1984; Blandamer and Burgess, 1990; Burgess, 1991; Engberts *et al*, 1998; Reichardt, 2003; Homocianu *et al*, 2011). As pointed out by Abraham *et al* (1988), there are two main reasons for studying solvent effects on reaction rates and other processes. The first objective is the prediction of rate constants in other solvents while the second objective is to reach some understanding of

the various influences that might affect reaction rate.

In order to take two or more aspects of solvation into account, several multiparameter equations have been proposed by different scholars (Taft *et al*, 1985; Katrizky *et al*, 2003). According to Reichardt (2003), these equations generally take the form of equation 1(a) and are based on the assumption that solvent-dependent processes can be represented as a linear combination of two or more independent but complementary solvent empirical parameters or/and bulk solvent physical properties. In equation 1(a),  $A$  is the value of a solvent-dependent physicochemical property ( $\log K$ ,  $\log k$ ,  $h\nu$ , etc.) in a given solvent and  $A_0$  is the statistical quantity corresponding to the value of this solvent-dependent property in the gas phase or in an inert solvent; B, C and D represent independent but complementary solvent parameters, which account for the different solute-solvent interaction mechanisms; b, c and d are the regression

coefficients describing the sensitivity of the solvent-dependent properties.

Catalan's three-parameter approach and Krygowski-Fawcett's two-parameter approach are among the numerous multiparameter approaches that have so far been proposed. In the Catalan's equation shown in equation 1(b),  $k$  and  $k_0$  represent the reaction rate constants in a given solvent and in a gas phase (or inert solvent) respectively; SPP corresponds to the solvent dipolarity/polarizability; SA corresponds to the solvent hydrogen bond donor (HBD) acidity; SB corresponds to the solvent hydrogen bond acceptor (HBA) basicity;  $a$ ,  $b$  and  $c$  are the regression coefficients describing the sensitivity of  $\log k$  to SPP, SA and SB respectively (Reichardt, 2003). Similarly, in the Krygowski-Fawcett's equation shown in equation 1(c),  $k$  and  $k_0$  represent the reaction rate constants in a given solvent and gas phase (or inert solvent) respectively;  $E_T(30)$  and DN are the Dimroth-Reichardt solvent polarity parameter and the Gutmann's donor number, representing a measure of Lewis acidity of the solvent and a measure solvent basicity respectively;  $\alpha$  and  $\beta$  are the regression coefficients describing the sensitivity of  $\log k$  to electrophilic and nucleophilic solvent properties respectively (Reichardt, 2003).

Reactions of carboxylic acids with diazodiphenylmethane have been studied extensively by many investigators and the mechanisms of these reactions are fairly understood (Chapman *et al*, 1968; Jovanovic *et al*, 2000; Nikolic *et al*, 2000; Uscumlic *et al*, 2005; Nikolic and Uscumlic, 2007; Drmanic *et al*, 2009). It is for this reason that chemists generally choose the reaction, as well as other model reactions, for testing the validity of newly proposed multiparameter equations. The main thrust of the current paper therefore is to carry out multiple regression analysis on the second-order rate constants for the reactions of eight carboxylic acids with diazodiphenylmethane in some pure organic solvents, in the light of Catalan's three-parameter and Krygowski-Fawcett's two-parameter equations, with a view to unravel the influence of solvents on the reactivity of these reactions.

$$A = A_0 + b.B + c.C + d.D + \dots \quad \dots\dots 1(a)$$

$$\log k = \log k_0 + a.SPP + b.SA + c.SB \quad \dots\dots 1(b)$$

$$\log k = \log k_0 + \alpha.E_T(30) + \beta.DN \quad \dots\dots 1(c)$$

## METHODOLOGY

Second-order rate constants for the reactions of benzoic acid, cyclopent-1-ene-carboxylic acid, cyclohex-1-ene-carboxylic acid, cyclohept-1-ene-carboxylic acid, phenylacetic acid, cyclopent-1-ene-acetic acid, cyclohex-1-ene-acetic acid and cyclohept-1-ene-acetic acid with

diazodiphenylmethane in fifteen organic solvents were obtained from literature (Uscumlic and Nicolich, 2009). Catalan's solvatochromic parameters (SPP, SA and SB) were taken from the compilation of Catalan (2001) while Dimroth-Reichardt solvent polarity parameter ( $E_T(30)$ ) and Gutmann donor number (DN) were taken from the compilation of Marcus (1998). Multiple linear regression analyses, in line with Catalan's three-parameter approach and Krygowski-Fawcett's two-parameter approach, were carried out with these data using Microsoft Excel. The goodness of fit of the models derived from these analyses was evaluated using coefficient of determination,  $R^2$  (the closer to 1 the better), standard error of the estimate,  $s$  (the smaller the better) and Fisher index of reliability,  $F$  (the larger the better). Shown in Tables 1 and 2 are the Catalan's parameters and Krygowski-Fawcett's parameters for some selected organic solvents used in this investigation. The second-order rate constants for the reactions under study were presented in Tables 3 and 4.

## RESULTS AND DISCUSSION

The results of multiple regression analyses of  $\log k_2$  for the reactions of benzoic acid, cyclopent-1-ene-carboxylic acid, cyclohex-1-ene-carboxylic acid, cyclohept-1-ene-carboxylic acid, phenylacetic acid, cyclopent-1-ene-acetic acid, cyclohex-1-ene-acetic acid and cyclohept-1-ene-acetic acid with diazodiphenylmethane in fifteen organic solvents, by means of Catalan's three-parameter equation, are presented in equations 2(a) – 2(h). As shown in the equations, the rates of reaction between the eight carboxylic acids and diazodiphenylmethane are satisfactorily described by solvent dipolarity/polarizability, solvent HBD acidity, and solvent HBA basicity as indicated by the values of coefficients of determination ( $R^2 \geq 0.909$ ). On the basis of the standard errors of the regression coefficients, the sensitivity of the rates of these reactions is adequately precise to both solvent HBD acidity and solvent HBA basicity but somewhat imprecise to the solvent dipolarity/polarizability. Although the fitness of the correlations obtained in the present study is adjudged to be fairly satisfactory on the basis of the multiple correlation coefficients presented in equations 2(a) – 2(h), more excellent correlations with  $R^2$  values as high as 0.992 have been reported in the literature using Kamlet-Taft three-parameter approach (Uscumlic and Nicolich, 2009).

Judging by the signs of the coefficients of the last three terms in equations 2(a) – 2(h), it can be inferred that the solvents influence the rates of reactions between carboxylic acids and diazodiphenylmethane by two opposing effects. The positive signs of the coefficients of the terms SPP and SA indicate that the rates of these reactions increase with increasing solvent dipolarity/polarizability and solvent HBD acidity. Hence,

**Table 1.** Catalan's parameters for some selected solvents

Solvent	SPP	SA	SB
Methyl acetate	0.785	0.000	0.527
Cyclohexanone	0.874	0.000	0.482
Diethyl ketone	0.883	0.000	0.557
Carbon tetrachloride	0.632	0.000	0.044
Chloroform	0.786	0.047	0.071
Ethyl acetate	0.795	0.000	0.542
Cyclopentanone	0.908	0.000	0.465
Dioxane	0.701	0.000	0.444
Acetonitrile	0.895	0.044	0.286
Acetone	0.881	0.000	0.475
Methanol	0.857	0.605	0.545
Ethanol	0.853	0.400	0.658
Ethylene glycol	0.932	0.565	0.534
Dimethyl sulfoxide	1.000	0.072	0.647
Tetrahydrofuran	0.838	0.000	0.591

**Table 2.** Krygowski-Fawcett's parameters for some selected solvents

Solvent	$E_T(30)$	DN
Methyl acetate	38.9	16.3
Diethyl ketone	39.3	15.0
Carbon tetrachloride	32.4	0.0
Chloroform	39.1	4.0
Ethyl acetate	38.1	17.1
Dioxane	36.0	14.8
Acetonitrile	45.6	14.1
Acetone	42.2	17.0
Methanol	55.4	30.0
Ethanol	51.9	32.0
Ethylene glycol	56.3	20.0
Dimethyl sulfoxide	45.1	29.8
Tetrahydrofuran	37.4	20.0

solvation of the transition states is dominated by the dipolarity/polarizability and HBD acidity of the solvents. The negative sign of the coefficient of the term SB however, indicate that the rates of these reactions decrease with increasing HBA basicity of the solvents. This implies that the solvent HBA basicity stabilizes the initial states before the commencement of the reactions and is therefore responsible for the decrease in the reaction rates. From the magnitudes of the regression coefficients, the percentage contributions of Catalan's parameters (SPP, SA and SB) were calculated and the results are given in Table 5. Except for the reaction of benzoic acid, substantial contributions of solvent effects to the reactivity of the carboxylic acids were due mainly to

the specific solute-solvent interactions, with the solvent HBA basicity playing the greatest role (more than 50% in all but one case). Table 5 also show that with the exception of the reaction of benzoic acid, only small proportions of the observed solvent effects can be ascribed to the nonspecific solute-solvent interaction as less than 15% of the observed solvent effects are due to the solvent dipolarity/polarizability term in the equations. The results just presented agree with the findings reported by Uscumlic and Nicolic (2009) for the analysis of solvent effects on the reactivity of carboxylic acids with diazodiphenylmethane using Kamlet-Taft approach.

The results of multiple regression analyses of  $\log k_2$  for the reactions of benzoic acid, cyclopent-1-ene-carboxylic

**Table 3.** Second-order rate constants for the reaction of benzoic acid and cycloalkene-carboxylic acids with diazodiphenylmethane in various solvents ( $\text{dm}^3 \text{mol}^{-1} \text{min}^{-1}$ )

Solvent	Benzoic acid	Cyclopent-1-ene-carboxylic acid	Cyclohex-1-ene-carboxylic acid	Cyclohept-1-ene-carboxylic acid
Methyl acetate	0.260	0.044	0.032	0.031
Cyclohexanone	0.220	0.028	0.020	0.019
Diethyl ketone	0.265	0.073	0.053	0.051
Carbon tetrachloride	0.638	0.399	0.329	0.286
Chloroform	12.30	5.373	4.335	3.378
Ethyl acetate	0.180	0.038	0.025	0.016
Cyclopentanone	0.293	0.036	0.025	0.025
Dioxane	0.058	0.088	0.065	0.062
Acetonitrile	3.730	0.430	0.318	0.199
Acetone	0.350	0.059	0.048	0.039
Methanol	2.470	1.106	0.818	0.654
Ethanol	0.995	0.534	0.417	0.332
Ethylene glycol	4.020	2.452	1.962	1.570
Dimethyl sulfoxide	0.141	0.012	0.008	0.007
Tetrahydrofuran	0.105	0.027	0.019	0.016

**Table 4.** Second-order rate constants for the reaction of phenylacetic acid and cycloalkene-acetic acids with azodiphenylmethane in various solvents ( $\text{dm}^3 \text{mol}^{-1} \text{min}^{-1}$ )

Solvent	Phenylacetic acid	Cyclopent-1-ene-acetic acid	Cyclohex-1-ene-acetic acid	Cyclohept-1-ene-acetic acid
Methyl acetate	0.132	0.181	0.144	0.098
Cyclohexanone	0.153	0.187	0.149	0.102
Diethyl ketone	0.279	0.268	0.214	0.148
Carbon tetrachloride	6.628	2.161	1.759	1.299
Chloroform	613.0	46.06	37.84	29.02
Ethyl acetate	0.210	0.036	0.028	0.017
Cyclopentanone	0.117	0.139	0.110	0.074
Dioxane	0.169	0.319	0.255	0.177
Acetonitrile	8.919	1.535	1.294	0.972
Acetone	0.233	0.246	0.194	0.146
Methanol	2.539	2.237	1.652	1.299
Ethanol	1.139	0.828	0.659	0.614
Ethylene glycol	5.049	4.080	3.020	2.237
Dimethyl sulfoxide	0.014	0.031	0.024	0.016
Tetrahydrofuran	0.057	0.071	0.056	0.039

acid, cyclohex-1-ene-carboxylic acid, cyclohept-1-ene-carboxylic acid, phenylacetic acid, cyclopent-1-ene-acetic acid, cyclohex-1-ene-acetic acid and cyclohept-1-ene-acetic acid with diazodiphenylmethane in thirteen organic solvents, by means of Krygowski-Fawcett's two-parameter equation, are presented in equations 3(a) – 3(h). As shown in the equations, the rates of reaction

between the eight carboxylic acids and diazodiphenylmethane poorly correlated with Dimroth-Reichardt solvent polarity parameter ( $E_T(30)$ ) and Gutmann donor number (DN) as indicated by the values of the coefficients of determination ( $R^2 \leq 0.896$ ). Comparing the standard errors of the estimate and the Fisher indices of reliability in equations 3(a) – 3(h) with

**Table 5.** Percentage contributions of Catalan's parameters to the reactivity of the studied reactions

Solvent	%SSP	%SA	%SB
Benzoic acid	38	24	39
Cyclopent-1-ene-carboxylic acid	3	47	50
Cyclohex-1-ene-carboxylic acid	2	47	51
Cyclohept-1-ene-carboxylic acid	0	48	51
Phenylacetic acid	14	28	58
Cyclopent-1-ene-acetic acid	11	34	55
Cyclohex-1-ene-acetic acid	11	34	55
Cyclohept-1-ene-acetic acid	11	34	55

their corresponding values in equations 2(a) – 2(h) also revealed that the quality of the linear equations obtained by means of Catalan's approach is better than the quality of the linear equations obtained by means of Krygowski-Fawcett's approach. The poor correlation observed in the models derived from Krygowski-Fawcett's approach can be ascribed to the supposition that nonspecific solute-solvent interactions are negligible (Reichardt, 2003).

However, in spite of this drawback, some qualitative information about the reactivity of the reactions under investigation can be deduced from the models derived from Krygowski-Fawcett's approach. The positive sign on the coefficients of  $E_T(30)$  term in equations 3(a) – 3(h) indicated that the rates of reactions between carboxylic

acids and diazodiphenylmethane increase with increasing electrophilic solvent property. Conversely, the negative sign on the coefficients of DN term in equations 3(a) – 3(h) indicated that the rates of reactions between carboxylic acids and diazodiphenylmethane decrease with increasing nucleophilic solvent property. It can be interpreted from these findings that while solvation of the transition state is dominated by the Lewis acidity of the solvents, the Lewis basicity of the solvents is responsible for the solvation of the initial state. The result just presented for Krygowski-Fawcett's approach is in good agreement with the result presented in the preceding paragraph for Catalan's approach in explaining the specific solute-solvent interaction.

#### Benzoic acid

$$\log k_2 = -1.79 + (3.36 \pm 1.08).SPP + (2.10 \pm 0.39).SA - (3.40 \pm 0.53).SB \quad \dots\dots\dots 2(a)$$

$$R^2 = 0.920, s = 0.30, n = 15, F = 20.25$$

#### Cyclopent-1-ene-carboxylic acid

$$\log k_2 = 0.14 + (0.18 \pm 1.22).SPP + (3.03 \pm 0.44).SA - (3.22 \pm 0.60).SB \quad \dots\dots\dots 2(b)$$

$$R^2 = 0.929, s = 0.33, n = 15, F = 22.98$$

#### Cyclohex-1-ene-carboxylic acid

$$\log k_2 = 0.08 + (0.14 \pm 1.25).SPP + (3.10 \pm 0.45).SA - (3.33 \pm 0.62).SB \quad \dots\dots\dots 2(c)$$

$$R^2 = 0.929, s = 0.34, n = 15, F = 23.09$$

#### Cyclohept-1-ene-carboxylic acid

$$\log k_2 = 0.07 + (0.00 \pm 1.21).SPP + (3.03 \pm 0.44).SA - (3.21 \pm 0.61).SB \quad \dots\dots\dots 2(d)$$

$$R^2 = 0.929, s = 0.33, n = 15, F = 23.11$$

#### Phenylacetic acid

$$\log k_2 = 1.01 + (1.45 \pm 1.97).SPP + (2.86 \pm 0.71).SA - (5.97 \pm 0.98).SB \quad \dots\dots\dots 2(e)$$

$$R^2 = 0.909, s = 0.54, n = 15, F = 17.45$$

#### Cyclopent-1-ene-acetic acid

$$\log k_2 = 0.54 + (0.84 \pm 1.38).SPP + (2.59 \pm 0.49).SA - (4.15 \pm 0.68).SB \quad \dots\dots\dots 2(f)$$

$$R^2 = 0.919, s = 0.38, n = 15, F = 19.96$$

Cyclohex-1-ene-acetic acid $\log k_2 = 0.45 + (0.87 \pm 1.39).SPP + (2.55 \pm 0.50).SA - (4.18 \pm 0.69).SB$ $R^2 = 0.917, s = 0.38, n = 15, F = 19.51$	.....2(g)
Cyclohept-1-ene-carboxylic acid $\log k_2 = 0.34 + (0.85 \pm 1.46).SPP + (2.68 \pm 0.52).SA - (4.24 \pm 0.73).SB$ $R^2 = 0.914, s = 0.40, n = 15, F = 18.59$	.....2(h)
Enzoic acid $\log k_2 = -3.82 + (0.12 \pm 0.02).E_T(30) - (0.08 \pm 0.02).DN$ $R^2 = 0.896, s = 0.34, n = 13, F = 20.33$	.....3(a)
Cyclopent-1-ene-carboxylic acid $\log k_2 = -4.61 + (0.13 \pm 0.02).E_T(30) - (0.09 \pm 0.02).DN$ $R^2 = 0.882, s = 0.42, n = 13, F = 17.65$	.....3(b)
Cyclohex-1-ene-carboxylic acid $\log k_2 = -4.83 + (0.13 \pm 0.02).E_T(30) - (0.10 \pm 0.02).DN$ $R^2 = 0.884, s = 0.43, n = 13, F = 17.99$	.....3(c)
Cyclohept-1-ene-carboxylic acid $\log k_2 = -4.78 + (0.13 \pm 0.02).E_T(30) - (0.09 \pm 0.02).DN$ $R^2 = 0.875, s = 0.44, n = 13, F = 16.40$	.....3(d)
Phenylacetic acid $\log k_2 = -4.07 + (0.16 \pm 0.04).E_T(30) - (0.15 \pm 0.03).DN$ $R^2 = 0.862, s = 0.67, n = 13, F = 14.57$	.....3(e)
Cyclopent-1-ene-acetic acid $\log k_2 = -3.78 + (0.13 \pm 0.03).E_T(30) - (0.11 \pm 0.02).DN$ $R^2 = 0.864, s = 0.49, n = 13, F = 14.77$	.....3(f)
Cyclohex-1-ene-acetic acid $\log k_2 = -3.84 + (0.13 \pm 0.03).E_T(30) - (0.11 \pm 0.02).DN$ $R^2 = 0.862, s = 0.50, n = 13, F = 14.55$	.....3(g)
Cyclohept-1-ene-acetic acid $\log k_2 = -4.13 + (0.13 \pm 0.03).E_T(30) - (0.11 \pm 0.02).DN$ $R^2 = 0.854, s = 0.53, n = 13, F = 13.45$	.....3(h)

## CONCLUSION

Multiple linear regression analyses were carried out on the second-order rate constants for the reactions of eight carboxylic acids with diazodiphenylmethane using Catalan's three-parameter and Krygowski-Fawcett's two-parameter equations. The results from the two different approaches are in good agreement in explaining the specific solute-solvent interaction on the reactivity of these carboxylic acids. The nonspecific dipolarity/

polarizability term in the Catalan equation was found to play a small but significant role in the observed solvent effects. The relatively poor fitness of Krygowski-Fawcett's models was attributed to the neglect of nonspecific solute-solvent interaction in the models. Catalan's three-parameter approach, like Kamlet-Taff's three-parameter approach reported in the literature, is therefore capable of providing insight into the mechanism by which solvents affect the reactivity of carboxylic acids with diazodiphenylmethane.

## REFERENCES

- Abraham MH (1985). Solvent Effects on Reaction Rates. *Pure Appl. Chem.* 57(8):1055-1064.
- Abraham MH, Grellier PL, Abboud, JM, Doherty, R.M. and Taft, R.W, (1988): Solvent Effects in Organic Chemistry: Recent Developments. *Canadian Journal of chemistry* 66, 2673 – 2686.
- Amis, E.S and Hinton, J.F. (1973): *Solvent Effects on Chemical Phenomena*. Academic Press, New York. Pp. 207 – 449.
- Blandamer, M.J. and Burgess, J. (1990): Solute-Solute Interactions and the Kinetics of Chemical Reactions in Aqueous Solutions. *Pure & Applied Chemistry* 62(1): 9 – 16.
- Burgess, J. (1991): Solvation and Reactivity of Inorganic Complexes. *Pure & Applied Chemistry* 63(12): 1677 – 1686.
- Catalan, J. (2001): Solvent Effects Based on Pure Solvent Scales. In Wypych, G. (Ed): *Handbook of Solvents*. Chem Tec Publishing, Toronto. Pp. 583 – 616.
- Chapman, N.B.; Ehsan, A.; Shorter, J. and Toyne, K.J. (1968): A New Interpretation of the Kinetics of the Reaction between Carboxylic Acids and Diazodiphenylmethane in Toluene. *Tetrahedron Letters* 9(9): 1049 – 1054.
- Diakovitch, V.A.; Arnaudov, M.G.; Shishkova, L.M. and Ilieva, M.B. (1984): Correlation between IR-Characteristics Vibrations and Solvent Parameters: Koppel-Palm's Multiparameter Equation. *Journal of Molecular Liquids* 28(2): 115 – 118.
- Drmanic, S.Z.; Marinkovic, A.D. and Jovanovic, B.Z. (2009): Effects of Solvent and Structure on the Reactivity of 6-Substituted Nicotinic Acids with Diazodiphenylmethane in Aprotic Solvents. *Journal of Serbian Chemical Society* 74(12): 1359 – 1370.
- Engberts, J.B.F.N.; Famini, G.R.; Perjessy, A. and Wilson, L.Y. (1998): Solvent Effects on C=O Stretching Frequencies of Some 1-Substituted 2-Pyrrolidinones. *Journal of Physical Organic Chemistry* 11, 261 – 272.
- Fawcett, W.R. (1994): *Solvent Acidity and Basicity in Polar Media and their Roles in Solvation*. Technical Report No. 8, Office of Naval Research, USA.
- Homocianu, M.; Airinei, A. and Dorohoi, D.O. (2011): Solvent Effects on the Electronic Absorption and Fluorescence Spectra. *Journal of Advanced Research in Physics* 21(1): 1 – 9.
- Huisgen, R. (1980): Cycloaddition Mechanism and the Solvent Dependence of Rate. *Pure & Applied Chemistry* 52, 2283 – 2302.
- Jovanovic, B.; Juranic, I.; Mistic-Vukovic, M.; Brkic, D. and Vitnik, Z. (2000): Kinetics and Mechanism of the Reaction of Substituted 4-Pyrimidine Carboxylic Acids with Diazodiphenylmethane in Dimethylformamide. *Journal of Chemical Research (S)*, 506 – 507.
- Katritzky, A.R.; Fara, D.C.; Yang, H. and Tamm, K. (2003): Quantitative Measures of Solvent Polarity. *Chemical Review* 104, 175 – 198.
- Marcus, Y. (1998): *The Properties of Solvents*. John Wiley & Sons, New York. Pp. 145 – 152.
- Nikolic, J.B. and Uscumlic, G.S. (2007): A Linear Solvation Energy Relationship Study for the Reactivity of 2-Substituted Cyclohex-1-enecarboxylic and 2-Substituted Benzoic Acids with Diazodiphenylmethane in Aprotic and Protic Solvents. *Journal of Serbian Chemical Society* 72(12): 1335 – 1357.
- Nikolic, J.B.; Uscumlic, G.S. and Krstic, V.V. (2000): Reactivity of Cyclohex-1-enylcarboxylic and 2-Methylcyclohex-1-enylcarboxylic Acids with Diazodiphenylmethane in Aprotic Solvents. *Journal of Serbian Chemical Society* 65(12): 839 – 846.
- Reichardt, C. (1982): Solvent Effects on Chemical Reactivity. *Pure & Applied Chemistry* 54(10): 1217 – 1227.
- Reichardt, C. (1994): Solvatochromic Dyes as Solvent Polarity Indicators. *Chemical Reviews* 94, 2319 – 2358.
- Reichardt, C. (2003): *Solvents and Solvent Effects in Organic Chemistry*. Wiley-VCH Verlag, Weinheim. Pp. 389 – 469.
- Taft, R.W.; Abboud, J.M.; Kamlet, M.J. and Abraham, M.H. (1985): Linear Solvation Energy Relationship. *J. Solution Chem.*, 14(3): 153 - 186.
- Uscumlic, G.S. and Nikolic, J.B. (2009): The Study of Linear Solvation Energy Relationship for the Reactivity of Carboxylic Acids with Diazodiphenylmethane in Protic and Aprotic Solvents. *J. Serbian Chemical Society* 74(12): 1335 – 1357.
- Uscumlic, G.S.; Nikolic, J.B. and Krstic, V.V. (2005): Hydroxylic Solvent Effects on the Reaction Rates of Diazodiphenylmethane with 2-Substituted Cyclohex-1-enylcarboxylic and 2-Substituted Benzoic Acids: Part II. *Indian Journal of Chemistry* 44B, 1283 – 1287.
- Whetsel, K.B. and Kagarise, R.E. (1962): Solvents Effects on Infrared Frequencies II: The Effects of Chloroform and Carbon Tetrachloride on the Carbonyl Bands of Ketones. *Spectrochimica Acta*, 18(3): 329 – 339.