Available online at www.worldscientificnews.com

World Scientific News

An International Scientific Journal

WSN 178 (2023) 12-22 EISSN 2392-2192

Correlation Study between "Structure and Commencement Temperature" of Nematogenic Mesomorphs having Azo-Ester Linkage

Neha K. Baku[1], Archana Y. Cholera[1], J. J. Travadi[2,*]

[1]Department of Chemistry, Faculty of Science, Atmiya University, Rajkot, 360005, Gujarat, India

[2]Department of Chemistry, Kamani Science College and Prataprai Arts College, Amreli, 365601, Gujarat, India

*E-mail: address: j.travadi72@gmail.com

ABSTRACT

Correlation study between 'commencement of Nematic Transition Temperature (NTT)' and their 'structural property data set' is carry out. Stepwise backward regression analysis method is applied to find out good correlation between 'transition temperature data set' and 'physical descriptors. Physical descriptors are selected on the basis of good r^2-value and P-values with their respective NTTs. Data set of randomly selected 32 compounds is used as training set to obtain "Quantitative Structure and Property Relationship (QSPR) model". Validation of derived QSPR equation is carried out on trial series as well as on test series. Average standard deviation of 5.93 for 32 compounds of trial set, and 7.09 for 11 compounds of test series is observed; between predicted NTTs and experimentally measured NTTs. Thus, it holds well on the data set of trial series and test series with comparative good degree of accuracy. Hence, derived QSPR equation can utilize to design new similar type mesomorphs having comparative low NTTs, so that they can be use at desired temperature.

***Keywords*:** azo-ester, physical descriptors, nematic, regression analysis, prediction

(Received 05 February 2023; Accepted 26 February 2023; Date of Publication 02 March 2023)

1. INTRODUCTION

Most of the solid substances melt at definite temperatures into isotropic liquid, but a thermotropic mesomorph gets first loosened into a cloudy but flowing liquid at some lower temperature before it turn into a clear isotropic liquid at the higher temperature. A thermotropic mesomorph possesses the degree of molecular order, lies between true crystalline state and that of isotropic liquid.

This intermediate state of substances possesses the flow property like liquids and optical properties like birefringence associated with crystalline solids. This characteristic behaviour is called mesomorphism [1]. Mesomorphs show several degrees of orientational and positional order, based on which liquid crystals are classified into Nematic, Smectic or Cholesteric types of liquid crystals [2].

Diversify applications of Liquid Crystals (mesomorphs) [3-14] attract and collaborate researchers of various fields of science viz. Chemistry, Physics, Electronics, Medicinal Science, Biochemical Science, Polymer Science etc. and become an interdisciplinary research subject.

In present work of "Quantitative structure and property relationship", words "Quantitative structure" deals with physical properties of compounds, which are based on the structures of the compounds; those are to be correlated with their Liquid Crystalline property data. Here, Liquid Crystalline property data are taken in terms of Nematic Transition Temperatures (NTTs); which represent the temperature on which Nematic mesophase commences during heating process of compound and the structure of the compounds are represent in terms of their physical properties.

With the help of a liable QSPR equation one can predict Liquid Crystalline property of any projected/designed compound which is to be synthesized. A systematic use of QSPR study in the Liquid Crystal's research field may not only save our time, but it may also save unnecessary labour, waste of chemicals etc. Moreover these, we can also prepare new mesomorphs with better and desired liquid crystalline properties may having a good mesophase length and expected low transition temperatures; so that they can be utilize at sufficient low temperatures. To do this, one should calculate same physical descriptors for the projected compound having similar type structure to that of the compounds of trial (training) set (series) i.e. which are used to derive QSPR equation.

Then, by introducing these values of calculated physical descriptors of projected compound, in derived QSPR equation, liquid crystalline property (NTT) of projected compound can be predicted. Following this exercise repeatedly, expected liquid crystalline property (e.g. low NTT) can obtain by changing functional group/s, their positions and geometry of projected compounds. Thus, one can designed new similar type of compound having expected NTT, so that they can be use at desired low temperature.

Thus, detail study and understanding of QSPR analysis gives statistical path to synthesize new liquid crystalline compounds. In this way, QSPR study may support the research in the recent age of "GREEN CHEMISTRY" [15].

In present study, I have tried to correlate Nematic Transition Temperatures as liquid crystalline property of azo-ester linked substances with their structure-dependent physical properties. As per my knowledge; this is only second time that "Quantitative Structure and Property Relationship (QSPR)" method is applied to establish structure-property relationship, using physical descriptors derived from quantum mechanics calculations to predict Nematic Transition Temperatures (NTTs) of mesomorphic compounds [16].

2. METHODOLOGY

2. 1. Selection of series of mesomorphic compounds

Usually researchers made efforts to synthesize novel thermotropic LCs and to correlate effects of molecular structure on liquid crystal properties, by varying molecular aromaticity, central groups, terminal groups, positions of same or different functional groups on phenyl ring or rings, geometrical shape, size, polarity and polarizability, etc [17-19]. Mainly three major factors viz. Steric, electronic and geometric influences the actual mesomorphic properties of LCs. Hence, with keeping focus on these criteria a humble effort is taken on hand to correlate effects of molecular structure on liquid crystal property (Nematic Transition Temperature) through QSPR study.

In present data analysis, all selected data are taken from registered thesis [20]. Total four azo-ester linkage homologous series; 1 to 4 (Figure-1) are selected for present study. These all four series are structurally similar with respect to basic skeleton. These all four series are identical with respect to two phenyl rings and one napthyl ring, central bridges of ester linkage (-COO-) and azo linkage (-N=N-) and left hand side changing alkoxy terminal groups, but they are differ with respect to presence and absence of right hand side terminal substituent group of *ortho*-NO_2, *meta*-NO_2, *para*-CH_3 respectively.

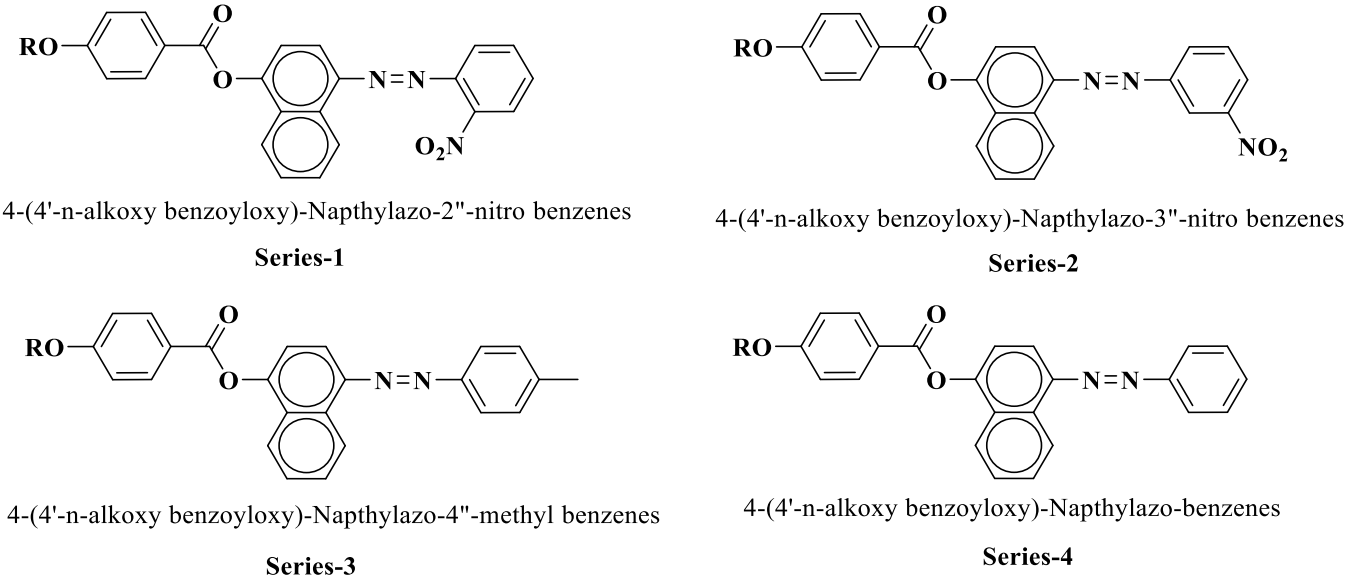


Figure 1. Azo-ester linkage homologous series

2. 2. Selection of data set

From these four series, total 43 compounds and their Nematic Transition Temperatures in °C (NTTs) are chosen for the QSPR study. Among this data set, randomly 8 compounds and their NTTs of each individual series (1 to 4) are selected as trial series for statistical work, to generate QSPR model. Thus, total 32 compounds and their NTTs are set as trial series.

Test series of eleven compounds construct from the rest of other homologues of each series (1 to 4) to check validity of the derived QSPR equation.

Experimental NTTs are chosen as dependent variables, while structural (physical) descriptors of selected compounds are chosen as independent variables for the statistical analysis.

2. 3. Computational work

Minimum structural energy optimization having no symmetrical restriction is obtained for each compound before calculating different physical descriptors with following semi-empirical PM3 level of theory [21]. Once the lowest energy level is obtained for each compound, maximum physical properties were calculated for each compound. All physical parameters (descriptors) are taken as independent variables in present correlation study, which are calculated from ChemDraw Ultra 3D (version 8.0) software.

Statistical analysis is carried out using "KYplot (5.0)" statistical software on "HP 15 Notebook PC-Model number; G8D31PA#ACJ"; to derive QSPR equation. Correlation study and multiple linear regression analysis are performed one by one, to find out good r^2 and P-values among all calculated physical descriptors with NTTs of trial series. Here, P-value and r^2-value represents that; up to which extent dependent variables (here NTTs) are in correlation with independent variables (here structural/physical descriptors). For example, P-value should be less than 0.005 and r^2-value should be greater than 0.65 to indicate good and liable internal correlationship among variables. Derived QSPR equation represents correlation between calculated physical descriptors with observed Nematic Transition Temperatures (NTTs) for training data set as well as testing data set.

3. RESULTS AND DISCUSSION

Selection of the proper physical descriptors requires a careful statistical process. At initial stage, individual correlation between each physical descriptor with NTTs of trial series has been checked out. Internal correlation matrix (Table 1) of selected physical descriptors is generated, which lies between 0.004 (minimum) to 0.97 (maximum) showing minimum correlation between HOMO and non-VDW descriptors while, maximum correlation between Radius and CMA (Connolly Molecular Area). Some of the higher internal correlation neglected to acquire good QSPR equation.

Table 1. Correlation matrix of selected physical descriptors

	WI	**Radius**	**HOMO**	**CMA**	**HOF**	**DL**	**Non-VDW**	**NTT**
WI	1							0.52
Radius	0.92	1						0.44
HOMO	0.72	0.73	1					0.44

CMA	0.96	0.97	0.75	1				0.46
HOF	0.73	0.54	0.33	0.59	1			0.33
DL	0.16	0.25	0.43	0.24	0.004	1		0.17
Non-VDW	0.27	0.1	0.05	0.18	0.73	0.144	1	0.15
NTT	0.52	0.44	0.44	0.46	0.33	0.17	0.15	1

Abbreviations: - WI = Winner Index, HOMO = Highest Occupied Molecular Orbital, CMA = Connolly Molecular Area, HOF = Heat of Formation in K Cal./ mole at 25 °C, DL = Dipole Length in eV, Non-VDW = Non-1,4 van der Waals energy in K Cal./ mole

On the basis of good r^2-value and p-value, elimination and selection of appropriate independent variables is carried out. The computed physical descriptors along with their observed NTTs for each molecule of trial series are presented in Table 2.

Using generated data set of Table 1 and Table 2 of the trial set, following most appropriate QSPR equation (QSPR model)* is derived by performing multiple regression analysis following by stepwise beck-ward regression method.

***Y = 86.77497 – (0.020900858*b1) – (5.719471765*b2) + (0.004255914*b3) + (0.342941793*b4) – (0.23802*b5) – (0.247708585*b6) + (5.80634*b7)**

where, Y is Nematic Transition Temperature (NTT), while b1, b2, b3, b4, b5, b6 and b7 are values of physical descriptors WI, Radius, HOMO, CMA, HOF, DL and non-VDW respectively of each homologue of trial set.

The statistically computed correlation coefficient r^2 is observed 0.6747, with average standard deviation of 5.93 for 32 compounds of trial set. R^2 is resultant correlation coefficient between dependent variables (NTTs) and independent variables (physical descriptors). These values show comparative good agreement for the best possible prediction of the Nematic

Transition Temperature (NTT) for similar type of compounds. Obtained QSPR equation is tried to justify here by validation of derived QSPR equation on trial series (Table 3), as well as on test series (Table 4).

Deviation and correlation between predicted activity and experimental measured NTTs presented here with graphical presentation in Graph 1 and Graph 2 for trial and test series respectively. Average standard deviation of 5.93 for 32 compounds of trial set, and 7.09 for 11 compounds of test series is observed; between predicted NTTs and experimentally measured NTTs. For test series, results show that only 18.18% of the compounds show absolute error more than 20% while, 54.55% compounds of the test series have absolute error of less than 10% only.

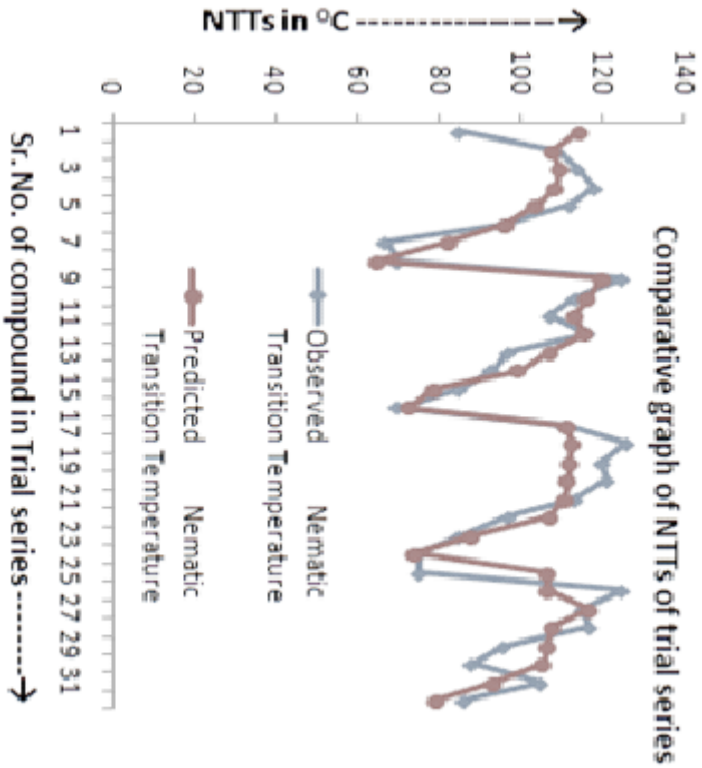
These results put confidence on comparative good reliability of derived QSPR equation. Results might give us an idea about the way to synthesize new similar type of mesomorphic substances by needful structural changes in basic skeleton of trial series having expected liquid crystalline property (low NTT).

Table 2. Physical descriptors along with the molecules of trial series and the observed NTTs

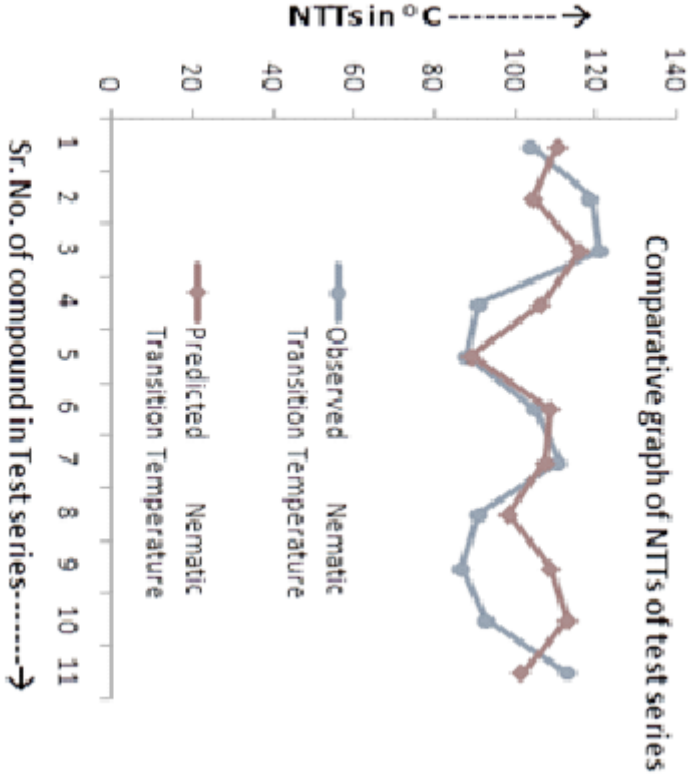
Sr. No.	Trial (Training) Set Series number	Number of "C" in n alkoxy group (-R) in Training Series	Wiener Index	Radius	HOMO	Connolly Molecular Area	Heat of Formation	Dipole Length	Non-VDW	Nematic Transition Temperature
1	1	1	3241	9	-8.66	380.78	-247.3	4.5	-7.17	85
2	1	3	3960	10	-8.7	412.82	-288.6	7.67	-8.19	109
3	1	4	4370	10	-8.7	431.17	-309.22	7.77	-8.27	114
4	1	5	4815	1.10E+01	-8.63	452.46	-329.86	5.64	-8.05	118
5	1	7	5814	1.20E+01	-8.67	488.63	-371.14	4.44	-8.19	112
6	1	8	6370	12	-8.72	504.76	-391.78	9.22	-9.07	96
7	1	12	8994	14	0	612.49	-473.34	0	-10.18	67
8	1	14	10560	15	0	651.03	-515.62	0	-10.58	70
9	2	1	3310	9	-8.76	383.56	-247.3	7.26	-5.98	125
10	2	3	4035	10	-8.76	423.14	-288.58	7.86	-6.98	113
11	2	4	4448	11	-8.77	441.6	-309.22	7.63	-7.04	107
12	2	5	4896	11	-8.76	456.5	-329.86	7.85	-6.73	116
13	2	7	5901	12	-8.77	493.25	-371.14	7.93	-7.46	97
14	2	8	6460	13	-8.76	515.74	-391.78	7.79	-7.91	93
15	2	12	9096	15	0	590.18	-474.34	0	-8.16	85
16	2	14	10668	16	0	654	-515.62	0	-8.05	70
17	3	1	2767	9	-8.49	380.84	-106.83	1.77	-3.75	111
18	3	3	3416	10	-8.47	420.18	-148.11	2.11	-4.17	126
19	3	4	3788	11	-8.51	444.36	-168.75	1.46	-4.31	120
20	3	5	4193	11	-8.43	454.25	-189.39	2.19	-4.27	121
21	3	7	5106	12	-8.45	501.05	-230.67	1.54	-4.61	113
22	3	8	5616	13	0	512.86	-251.31	0	-4.08	97
23	3	12	8036	15	0	604.19	-333.87	0	-5.43	85
24	3	14	9488	16	0	641.21	-375.15	0	-5.54	75
25	4	1	2492	9	-8.54	366.41	-74.72	1.06	-3.39	75
26	4	3	3102	10	-8.52	401.08	-116	2.55	-3.92	125
27	4	4	3453	10	-8.59	425.2	-136.64	1.91	-3.2	115
28	4	5	3836	11	-8.65	440.89	-157.28	1.38	-4.15	117
29	4	7	4702	12	-8.52	481.99	-198.56	1.412	-4.38	96
30	4	8	5187	12	-8.59	498.94	-219.2	1.98	-4.62	88
31	4	12	7497	14	0	583.85	-301.76	0	-4.94	105
32	4	14	8888	15	0	621.61	-343.04	0	-5.27	86
r^2 with NTT	NA	NA	0.52	0.44	0.44	0.46	0.33	0.17	0.15	NA
p-value with NTT	NA	NA	3.66E-06	3.62E-05	3.90E-05	1.74E-05	0.00059	0.02	0.03	NA

Table 3. Validation of QSPR equation on trial series

Sr. No.	Trial (Training) Set Series number	Number of "C" in n-alkoxy group (-R) in Training Series	Observed Nematic Transition Temperature	Predicted Nematic Transition Temperature	Difference	Standard Deviation	Abs.% error
1	1	1	85	114.2247626	29.22476263	20.665028	34.382074
2	1	3	109	107.5877818	-1.412218242	0.9985891	1.66143
3	1	4	114	109.7301062	-4.269893779	3.0192708	5.0234
4	1	5	118	108.7290282	-9.270971781	6.555567	10.907
5	1	7	112	103.843462	-8.15653797	5.7675433	9.5959
6	1	8	96	96.37312987	0.373129871	0.2638427	0.4389763
7	1	12	67	82.32431283	15.32431283	10.835926	18.028603
8	1	14	70	64.83202374	-5.167976258	3.6543111	6.079
9	2	1	125	119.9614249	-5.038575076	3.5628106	5.928
10	2	3	113	116.5329677	3.532967725	2.4981854	4.1564326
11	2	4	107	113.1334299	6.13342992	4.3369899	7.2157999
12	2	5	116	115.5379231	-0.462076877	0.3267377	0.5436
13	2	7	97	106.9831781	9.983178114	7.0591729	11.744915
14	2	8	93	99.62748921	6.627489213	4.6863426	7.7970461
15	2	12	85	78.78874895	-6.21125105	4.3920177	7.3074
16	2	14	70	72.56383664	2.563836638	1.8129063	3.0162784
17	3	1	111	111.2523272	0.25232717	0.1784223	0.2968555
18	3	3	126	112.7621957	-13.2378043	9.3605412	15.5739
19	3	4	120	111.8206229	-8.179377144	5.783693	9.623
20	3	5	121	111.7119693	-9.288030695	6.5676295	10.93
21	3	7	113	110.9719256	-2.02807444	1.4340652	2.386
22	3	8	97	107.0506855	10.05068548	7.1069079	11.824336
23	3	12	85	88.16491175	3.16491175	2.2379306	3.7234256
24	3	14	75	73.97986755	-1.020132454	0.7213426	1.2
25	4	1	75	106.6745335	31.67453355	22.397277	37.264157
26	4	3	125	106.4744351	-18.52556491	13.099553	21.79
27	4	4	115	116.6615232	1.661523161	1.1748743	1.9547331
28	4	5	117	107.8455195	-9.154480491	6.4731952	10.77
29	4	7	96	106.6034464	10.6034464	7.4977689	12.474643
30	4	8	88	105.6576085	17.65760847	12.485815	20.773657
31	4	12	105	93.37679431	-11.62320569	8.2188476	13.67
32	4	14	86	79.44308457	-6.556915432	4.6364394	7.71



Graph-1



Graph-2

Table 4. Validation of QSPR equation on test series.

Sr. No.	Test Series number	Number of "C" in n-alkoxy group (-R) in Test Series	Observed Nematic Transition Temperature	Predicted Nematic Transition Temperature	Difference	Standard Deviation	Abs.% error
1	1	2	104	110.59	6.59	4.659834	7.752941
2	1	6	119	104.71	-14.29	10.10456	16.81
3	2	2	121	116.23	-4.77	3.372899	5.61
4	2	6	91	106.78	15.78	11.15815	18.56471
5	2	10	88	89.33	1.33	0.940452	1.564706
6	3	2	105	108.77	3.77	2.665793	4.435294
7	3	6	111	107.81	-3.19	2.255671	3.75
8	3	10	91	98.46	7.46	5.275017	8.776471
9	4	2	87	109.02	22.02	15.57049	25.90588
10	4	6	93	112.94	19.94	14.09971	23.45882
11	4	10	113	101.82	-11.18	7.905454	13.15

4. CONCLUSIONS

1) From this statistical exercise satisfactory good QSPR model is obtained. But it may be possible to construct more significant QSPR model to reduce percentage error in prediction, with increase data set of compounds and calculating more numbers of physical descriptors following by establish better correlation between them.
2) Table 2 reveals the effect of selected parameters on NTTs of compounds. It shows that Winner Index (The sum of the chemical bonds existing between all pairs of heavy atoms in the molecule), HOMO (Quantum chemical descriptor), Connolly Molecular Area (Steric Parameter), Heat of Formation (Which is a measure of the relative thermal stability of a molecule), Dipole Length (Steric length parameter) and non-VDW (Nonbonding Vander Waals energy between molecules) influence predominantly on the commencement of nematic phase. These results support the fact that prediction of NTTs of azo-ester linkage compounds mainly dictated by molecular properties associated with steric and electronic characteristics.
3) Percentage errors of prediction are shown high in compounds of series-4 compare to that of the other series. These results lead to good prediction in right hand side substituted azo-ester linkage compounds compare to that of the non-substituted homologues.
4) There is lot of scope of QSPR study in the field of Liquid Crystals (LCs). It surprises that QSPR subject is almost untouched in the research field of LCs, though it might gives planned statistical track to researchers to synthesize new mesomorphic substances with better and desired liquid crystalline properties.
5) QSPR analysis may be useful to the theoretical and computational design of molecules that would lead to synthesize liquid crystalline compounds which can work at desired temperature range.

6) QSPR analysis also may be useful to predict Latent Transition Temperatures (LTTs) of similar type non-mesomorphic compounds, which are predict in present era by executing study of binary series and extrapolation method [22-23].

Acknowledgement

We are especially thankful to Dr. Annasaheb Suryawanshi (Dept. of Statistics, Saurashtra University, Rajkot, India), Dr. K. D. Ladva (Chemistry Department, Shree M. & N. Virani Science College, Rajkot, Gujarat, India) and Dr. Devinder Tullysir (Sr. Scientist, TRC, Bhat, Gujarat, India) for giving me help and valuable suggestions regarding to property calculations and regression analysis.

References

[1] Friedel G. In Colloid Chemistry; Edited by Alexander. J. The Chemical Catalog Company. (Inc. New York). 1926; 1: 102.

[2] Friedel, G. (1922) Annales de Physique, 18, 273

[3] Dave JS, Dewar MJS. Mixed Liquid Crystals. *J Chem Soc.* 1954; 4617

[4] Dave JS, Dewar MJS. Mixed Liquid Crystals. Part II. The Effect of Structure on the Transition Temperatures of Mixed Liquid Crystals. *J Chem Soc.* 1955; 4305.

[5] Dewar MJS, Goldberg RS. Role of p-Phenylene Groups in Nematic Liquid Crystals. *J Am Chem Soc.* 1970; 92 (6), 1582–1586

[6] Eidenschink R. Liquid Crystals-New Compounds, New Applications. Wiley Online Library. https://doi.org/10.1002/anie.198914241

[7] Kurmeier HA, Scheuble B, Poetsch E, Finkenzeller E. Substituted Phenyltrifluormethylethers. European Patent. 0334911B1. 1988.

[8] Pauluth D, Tarumi K. Advanced Liquid Crystals for Television. *Jour Mater Chem.* 2004; vol. 14: p. 1219-1227

[9] Meier G, Sackmann E, Grabmaier JG. Applications of Liquid Crystals. Springer, Berlin, Heidelberg 1975; p. 21-160

[10] Owsik J, Aleksander BS, and Elzbieta S. Use of Chiral Liquid Crystals in Laser Engineering. *Society of Photo-Optical Instrumentation Engineers (SPIE) Digital Library*. 1st March 1995, Vol. 2202: 185

[11] Samus S, Owan PW, Hossack WJ. An Iterative Algorithm for Connected Structure Computer Generated Holograms. *Optics Communications* 1994; 104: 266-270

[12] Benbow SJ, Chan AW, Bowsher DR, et al. The Prediction of Diabetic Neuropathic Plantar Foot Ulceration by Liquid-Crystal Contact Thermography. *Diabetes Care.* 1994; 17: 835-839.

[13] Selawry OS, Selawry HS, Holland JF. Use of Liquid Cholesteric Crystals for Thermographic Measurment of Skin Temperature in Man. *Molecular Cryst.* 1966; 1: 495

[14] Eidenschink R, Krause G, Pohl L. DE-B 26366844. 1976.

[15] Travadi JJ, Ladva KD, Vadodaria MS, et al. The Effect of Laterally Substituted Methoxy Group on Mesomorphicity. *PRAJÑĀ - Journal of Pure and Applied Sciences.* 2017; Vol. 24-25: 106-109

[16] Manuel VG, Rosa NG, Antonio MR, et al. Quantitative Structure-Property Relationships to Estimate Nematic Transition Temperatures in Thermotropic Liquid Crystals. *Journal of Molecular Structure: THEOCHEM* 2005; 727: 63-69. https://doi.org/10.1016/j.theochem.2005.02.033

[17] Vadodaria MS, Ladva KD, Doshi AV, et al. Synthesis of Novel Ester Series and Study of Its Mesomorphism Dependence on Terminal End Group with Lateral –OCH_3 group. *Mole Cryst and Liq Cryst.* 2016; Vol. 624: No.1: 59-68

[18] Travadi JJ Vadodaria MS, Ladva KD, et al. Study of the Effect of Lateral Substitution on Mesogenic Behavior with Reference to -CH=CH- Unit. *Mole Cryst and Liq Cryst.* 2016; Vol. 626: 90-99

[19] Bhoya UC, Vyas NN, Doshi AV. Determination of Latent Mesogenic Behavior in Nonmesogenic Compounds by Extrapolation Method. *Mole Cryst and Liq Cryst.* 2012; 552: 104–110

[20] Prajapati HR. Study of Mesomorphic State of Matter Through New Homologous Series and Binary Mixtures. Ph.D. Thesis, Saurashtra University, Rajkot, India. 2005.

[21] Girone´s X, Carbo´-Dorca R. Using Molecular Quantum Similarity Measures under Stochastic Transformation to Describe Physical Properties of Molecular Systems. *J Chem Inf Comput Sci.* 2002; 42: 317-325

[22] Doshi AV, Bhoya UC, Travadi JJ. Determination of Latent Transition Temperatures of Nonmesomorphs by Extrapolation Method in Binary Systems. *Mole Cryst and Liq Cryst.* 2012; 552: 10-15

[23] Doshi AV. and Prajapati HR. Mixed Mesomorphism-I: Determination of Latent Transition Temperatures (LTTs). *Der Pharma Chemica* 2011; 3(1): 123-133