DETERMINATION OF SOLUTE DESCRIPTORS FOR ILLICIT DRUGS USING GAS CHROMATOGRAPHIC RETENTION DATA AND ABRAHAM SOLVATION MODEL

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Thesis Prepared for the Degree of
MASTER OF SCIENCE

UNIVERSITY OF NORTH TEXAS

August 2015

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Mitheo, Yannick K. *Determination of solute descriptors for illicit drugs using gas chromatographic retention data and Abraham solvation model*. Master of Science (Analytical Chemistry), August 2015, 88 pp., 36 tables, 14 figures, references, 62 titles.

In this experiment, more than one hundred volatile organic compounds were analyzed with the gas chromatograph. Six capillary columns ZB wax plus, ZB 35, TR1MS, TR5, TG5MS and TG1301MS with different polarities have been used for separation of compounds and illicit drugs. The Abraham solvation model has five solute descriptors. The solute descriptors are E, S, A, B, L (or V). Based on the six stationary phases, six equations were constructed as a training set for each of the six columns. The six equations served to calculate the solute descriptors for a set of illicit drugs. Drugs studied are nicotine (S= 0.870, A= 0.000, B= 1.073), oxycodone(S= 2.564. A= 0.286, B= 1.706), methamphetamine (S= 0.297, A= 1.570, B= 1.009), heroin (S=2.224, A= 0.000, B= 2.136) and ketamine (S= 1.005, A= 0.000, B= 1.126). The solute property of Abraham solvation model is represented as a logarithm of retention time, thus the logarithm of experimental and calculated retention times is compared.

ACKNOWLEDGEMENTS

I am very thankful and glad to have Dr. Teresa D. Golden as my mentor and advisor. There are no better or proper words to express my deep, sincere gratitude and respect for my research advisor than saying thank you. She has encouraged, supported and provided me with every need possible in order to do my research. I am happy and humble for the opportunity she offered me to work with her and the rest of the group to pursuit my future and become a better learner. My sincere thank goes also to my committee members, Dr. William Acree and Dr. Shushama Dandekar. Dr. Acree did provide some of the sample used for my thesis; with his expertise, I was able to understand the chemistry behind this project.

I would like to thank Syeda Sabrina for training me on how to use the gas chromatograph and Michel Stovall for her encouragement on how to be an independent person. I would like to thank Dr. Golden research group members, Michael Kahl, Dylan Harbour, Casey Thurber, Ryan Daugherty, Dr. Jeerapang Tientong, Dr. Heidi Conrad, Viviane Huynh, Teresa Allen, Stephen Sanders, Ting Zhou, and Johnathan Bishop for the great time we spent together and for their support. I appreciate the support and help from Benjamin Starr, Dylan Harbour and Timothy Stephens who helped me throughout the whole process. I also wanted to thank the department of chemistry at the University of North Texas for their financial assistance that motivated me to work hard.

I want to take this opportunity to thank my family, my parents, my cousins, nieces, nephews, uncles and closest friends for their encouragements, support, love and prayers through the ups and downs. I want to thank my wife Dr. Chantal Tshikaya and her family for their support, motivation and love.

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CHAPTER 1

DESCRIBING ABRAHAM SOLVATION PARAMETER MODEL AND GAS CHROMATOGRAPHY

1.1 Introduction

Drug permeability across membranes is predicted by partition coefficients between an aqueous or a gas phase and lipid phase. To better predict the effect of various functional groups on partitioning, similar drug like molecules need to be studied.

The Abraham solvation model is used to predict the adsorption, distribution, metabolism, elimination and toxicity (ADMET) properties of the drug molecules. It is a good approach for studying and predicting biological activities and partition co-efficient. The introduction of early ADME is important because it decreased the proportion of compounds failing in clinical trials. The main goal of preclinical ADME is to remove weak drug candidates in the early stages of drug development and allow the resources to be used on potential drug candidates.

Drug candidate's ADMET (Adsorption, distribution, metabolism, elimination and toxicity) properties of drugs discovery can be predicted computationally or experimentally. Only 20% of developed drug candidates proceed to clinical trial stage testing, and among those compounds that enter clinical development less than 10% receive government approval. Drugs failures occur because of poor bioavailability, poor solubility, toxicity concerns, drug-drug interactions, degradation and poor shelf –life stability, and unfavorable pharmacokinetic properties [1-3].

In general, most newly discovered drugs have higher molecular weights and have more complicated molecular structures than previously discovered drugs; this explain the reasons why most drug candidates fail in the early development stage. Drug permeability across membranes is

predicted by partition coefficients between an aqueous or a gas phase and lipid phase [4]. To better predict the effect of various functional groups on partitioning, similar drug like molecules need to be studied. Gas chromatography method is ideal for studying a large set of compounds.

Gas chromatography is one of the techniques to consider for studying the distribution of drug compounds between different organic phases. The retention times obtained from the GC are used to model biological activities that involve the transfer of a drug molecule from gas phase to the biological phase. From the retention time; the solute descriptor are calculated, then the solutes descriptors are correlated to the biological routes [5].

In order for drug to penetrate the central nervous system (CNS); it must cross through blood brain barrier (BBB). The Abraham solvation model is used to predict the ADMET properties of the drug molecules.

The Abraham solvation model is two linear free energy relationships (LFER) where one equation described transfer process of the drug between two condenses phases.

$$SP = \mathbf{c} + e\mathbf{E} + s\mathbf{S} + a\mathbf{A} + b\mathbf{B} + v\mathbf{V} \quad (1)$$

and the second describe gas to condense phase transfer

$$SP = \mathbf{c} + \mathbf{eE} + \mathbf{sS} + \mathbf{aA} + \mathbf{bB} + \mathbf{lL} \quad (2)$$

The solute property (SP) is the dependent variable. The SP represents the properties of a series of analytes in a fixed phase. The independent known solutes descriptors (**E, S, A, B, L, V**) are solute properties, they reflect the ability of the solute-solvent interaction. The process coefficients or regression coefficients **c, e, s, a, b, l, v** describe the solvation properties which can be obtained through multiple linear regression analysis (MLRA) [6].). **c** is a regression constant**,** **a** and **b** are measure of solvent's base properties and acid properties; **e** is the measure of solvent dispersion interaction; **s** is the ability of the solvent phase to go through dipole –dipole induce interaction with solute; **l** and **v** measure of size needed to form solvent cavity and dispersion

forces for a gas. The **E** is the excess molar refraction [($cm^3mol^{-1}/10$]; **S** is solute dipolarity/polarizability. The **A** and **B** are the effective hydrogen bond acidity and hydrogen bond basicity, The **V** is the McGowan characteristic volume [(cm^3mol^{-1})/100]. **V** can always be calculated from the solute molecular formula, or known atomic size and number of chemical bonds in the molecule. **L** is the logarithm of the solute gas phase dimensionless Ostwald partition coefficient into hexadecane at 298 K. The **V** and **L** descriptors both measure size and are viewed as measure of the solvent cavity term that will accommodate the dissolved solute.

There are more than 4000 organic, organometallic and inorganic solute descriptors available or published. A large list of solute descriptors is available in one of the published review articles [7], and in several other published papers [8-9]. Solute descriptors can be obtained through regression analysis using different types of experimental data, gas to-solvent partitions, solubility data and chromatographic retention data. The A, B and S descriptors need to be determined experimentally. Once the retention time of any solute is obtained, it can be used to calculate the natural log of retention time to solve equations (1) or (2). The process coefficients can then be determined through multiple linear regression analysis of experimental logarithm of retention time depending on the column used [10-12].

The use of molecular descriptors in the Abraham solvation model become very helpful to understand which barriers the drug can cross and also the descriptors provide some information about the molecule's acidity, basicity and polarity. The Abraham solvation model can be applied to both chemical and biological process (e.g. blood brain partition [13], human and rat intestinal absorption [14], solubility [15-16]). The Abraham solvation model gives us some indication of the solute properties in terms of the molecular solute descriptors. The literature search shows that either the gas chromatography or high pressure liquid chromatography can be used for separation

of compounds depending on the goal of the project. For partitioning of a solute between two condense phases, a high pressure liquid gas chromatography is preferred while for partitioning of a solute from a gas to a condensed phase gas chromatography is needed. From the retention data, the gas-liquid partition coefficient and other thermodynamic properties of mixing can be easily created. Using the thermodynamic properties and appropriate models allows understanding of the intermolecular interactions responsible for the solvation in the stationary phase [17-19]. Now, the solvation parameter model makes a valuable tool for obtaining quantitative structure- property relationship for biomedical, chemical and environmental processes. The model correlates a free energy related property of a system to a six free energy descriptors describing the molecular properties. The main goal is to create a suitable quantitative structure property relationship (QSPR) to enable the prediction of further system properties for compounds lacking experimental values. In QSPR studied, two approaches are used; the first is based on theoretical descriptors. All needed parameters for prediction can be calculated simply from the three dimensional representation of the molecular structure of each of the solutes of the mixtures, as well as mixtures of chemically diverse compounds [20-21]. The disadvantage of the approach is that the particular descriptors may be challenging to understand and the model may lack chemical meaning. The second approach on review papers is based on descriptors determined using the experimental technique such as gas chromatography. Abraham and co- workers have published several papers and reviews showing the correlation of different models system for the prediction of solute descriptors and the interpretation of data using chromatography technique for separation of mixture[22-25]. Taft and Kamlet have established in the 1980, the simple concept of linear solvation energy relationships (LERs). They have shown for several chemical systems that some property which linearly correlated to a either a free energy of reaction, or a free energy

of transfer, or a activation energy can be correlated with several molecular property of the solvents or solutes involved[26-30]. Chromatographic retention and logarithmic partition coefficients ($LogK_L$) are linear free energy parameters, thus one can correlate these data with the molecular properties of the solutes using the LSER model [31-34]

In the experiment, we are developing an Abraham solvation model correlation equation that can predict and provide molecular descriptors for illicit drugs. More than one hundred known compounds have been collected from published literature with known descriptors [35-38]. Out of the five descriptors in equation (1) and (2), E and L or V descriptors can be found in the literature for a known target drug compound. To calculate the other three descriptors(S, A, B), equations (1) and (2) can be assigned the log of retention time (LogtR) with the calculated process coefficients, thus the unknown descriptors can be predicted. Before obtaining the process coefficients, the retention time of different compounds are needed from the gas chromatography experiment. The prediction values of target drug compound can be achieved through multiple linear regression analysis. The advantage of using the Abraham solvation model resides in the newly developed column equation. Once retention times of unknown illicit drugs or compounds are determined, it is a matter of plugging them in the developed stationary equation to get the molecular descriptors. In order to use the Abraham model to predict the ADMET properties, one must have a prior knowledge of the desired compound's solute descriptors.

1.2 Abraham Solvation Parameter Model

1.2.1 E: Excess Molar refractivity

Solute molar refractivity, E, is the difference between the molar refractivity and the alkane molar refractivity with the same McGowan volume V. E expresses the ability of the polarizable electrons in the molecule to be involved in the solute-solvent interaction.

$$E = MR_x \text{ (observed)} - MR_x \text{ (alkane of same } V_x) \quad [39]$$

(3)

Where E unit is in $cm^3mol^{-1}/10$. E can be calculated from the molecular structure of the compound. The McGowan volume in the molar refraction, MR_x can be calculated as

$$MRx = V*[(\eta^2-1)/ (\eta^2+2)]$$

(4)

Where V in equation 4 is the McGowan volume (unit is $(cm^3/mol)/10$), and η is the pure liquid solute refractive index at 25° C.

1.2.2 S: Dipolarity/Polarizability

S is the solute dipolarity or polarizability. It represents the tendency of a solute to participate in dipole-dipole and induce dipole-dipole interactions. The S represents or reflects the interactions that involve both induced and stable polarity of a solute. A large mass of data from gas liquid chromatography (GLC) can determine the polarity.

1.2.3 A: Solute's Hydrogen Bond Acidity and B: Solute Hydrogen Bond Basicity

A is the solute effective or summation hydrogen-bond acidity. This descriptor was originally obtained from hydrogen complexation constants for mono –acid. Now, it's obtained by chromatographic or partition measurements. B is the effective or summation hydrogen-bond basicity. For mono-bases, this descriptor was obtained from hydrogen complexation constants, now poly bases can be found by partition measurements [40]. Both solute hydrogen bond acidity and basicity descriptors describe the hydrogen donor and acceptor solute ability. The Hydrogen bond acidity and basicity were developed by Abraham model solvation using the equilibrium constant for the 1:1 reaction in carbon tetrachloride, CCl_4 at 298 K. When carbon tetrachloride, acid and base are present in a solution at low concentration, both will undergo

1.2.4 V: McGowan Volume

The McGowan volume is calculated from the atom and the numbers of bonds in the solute molecule in partition system with two condense phases. All type of bonds is treated equally in the solute, whether it is a single bond, double or triple bond. The number of bond can be solve by this equation

$$B = N-1+ R \quad (7)$$

Here B is the total number of bonds, N is the total number of atoms and R is the total number of ring structures. **V** is related to the size of the molecule as well as the size of the solvent cavity. The McGowan volume can be calculated as follow

$$V = [\sum \text{atom contributions} – (6.56*B)]/100 \quad (8)$$

1.2.5 L: Ostwald Solubility

The **L** is defined as gas-to-hexadecane partition coefficient at 25° C. The Ostwald solubility can be measured experimentally from solute's retention volume by gas liquid chromatography. It does include the cavity effect and the London dispersion effect of process. The process can be follow as

$$\text{Solute (gas phase)} \rightleftharpoons \text{solute (hexadecane)}. \quad (9)$$

1.2.6 Process Coefficients

The process coefficients shown on equation (1) and equation (2) reflect particular solute –solvent interactions that correspond to chemical properties of the solvent phase. Process coefficient e, is the measure of solvent dispersion interactions. It describes how the solvent or phase interacts with the solute through π and n-electron pairs. We anticipate e to be positive, but an electronegative atom in phase might change it to negative. s is the ability of the solvent phase to go through dipole –dipole induce interactions with a solute. When s is positive, the molecule polarity increase and it will prefer the condense phase. The a process coefficient reflects the

acid-base interactions. An illustration of hydrogen-bond complexation reactions is shown in Figure 1.1[41]

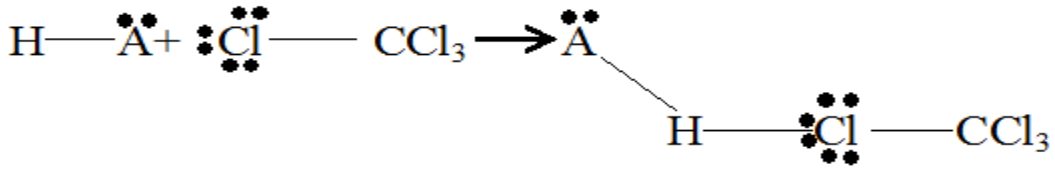

Figure 1.1. Hydrogen-bond complexation reaction. Adapted from ref. 41

H-A is the acidic solute, the reference base solvent is CCl_4 and the hydrogen bond complex created is A-H-Cl-CCl_3. The solute descriptor A is created by applying the following equation.

$$\mathbf{A} = \frac{(\text{Log}K_A^H + 1.1)}{4.636} \quad (5)$$

Log K_A^H is the average hydrogen bond acidity for solutes in CCl_4, 1.1 is the scale factor that enable the **A** descriptor to go through the origin and 4.636 is the empirical factor that maintains the acidity scale within a suitable range.

For the hydrogen bond basicity, the equation is represented by

$$\mathbf{B} = \frac{(\text{Log}K_B^H + 1.1)}{4.636} \quad (6)$$

LogK_B^H is the average hydrogen bond basicity for solute in CCl_4, 1.1 is the scale factor that enable the **B** descriptor to go through the origin and 4.636 is the empirical factor that so that **B**= 1.00 for the hydrogen bond base hexamethylphosphortriamide which allows a suitable working range for the B values. Solute can form more than one hydrogen bond with neighboring molecules in bulk solvent, making the 1:1 complexation assumption inaccurate for certain solutes [40].

complementary solvent hydrogen bond acidity. The b coefficient will be a measure of the solvent phase hydrogen bond basicity. The l and v coefficients will include not only an endorgonic cavity effect, but exergonic solute- solvent effects rising through solute polarizability. The c coefficient is an independent constant generated by multi regression linear analysis (MLRA). The c coefficient does contribute to the cavity formation and it is related to the nonpolar interaction of the retention time [41-43]. This is direct for the gas-to-condensed phase partition since there is no interaction in the gas phase. Equation (1) refers to difference between the properties of two phases. Thus the positive values reflect that the solute will favor the condense phase while the negative values will show a tendency to favor a gas phase. The Abraham solvation model is a useful model that can predict and illustrate the solute-solvent interaction in a system. Once the predicting equations are established in the system, one can just insert any new solute or drug compound values for certain gas-phase to derive the new solute descriptor.

Table 1.1 Summation of the Abraham solvation parameter model.

Solute descriptor	Process Coefficient
	c: Linear regression constant
E : Excess molar refractivity (cm^3/mol)/100	e: interaction of the solvent or phase with the solute through π and n-electron pairs
S: dipolarity/Polarizability	s: ability of the solvent phase to go through dipole-dipole induce interaction with a solute
A: Hydrogen bond acidity	a:measure of solvent's base properties
B: Hydrogen bond basicity	b: measure of solvent's acid properties
L:Ostwald solubility	l:measure of size needed to form solvent cavity and dispersion forces for a gas
V: McGowan volume(cm^3/mol)/10	v: measure of size needed to form solvent cavity and dispersion forces

1.3 Gas Chromatography

1.3.1 Beginning of Gas Chromatography (GC)

The discovery of the actual GC is generally attributed to A.T. James and Archer.J. P Martin in their 1952 paper. They did report a separation of volatile fatty acids by partition chromatography with nitrogen gas as a mobile phase and a stationary phase of silicone oil/stearic acid supported on diatomaceous earth. But the origin of the GC lies in the 1941 publication in which Martin, with R.L.M Synge, first described liquid phase partition chromatography [59-60]. The term chromatography was used by Mikhail Tswett based on the fact that it separated the components of solution by color (liquid chromatography). The term Chroma means color, graphein means writing.

1.3.2 Instrumentation of Gas Chromatography

Gas chromatography is an analytical technique that can be used to separate volatile organic compounds based on partition or distribution of analyte between two phases in a system. The two phases are the mobile and stationary phase. The GC contains partitioning between a solid or liquid stationary phase kept on the column wall or on a solid sorbent and the gaseous mobile phase. The organic volatile samples are separated due to differences in their partitioning behavior between the mobile gas phase and the stationary phase in column. Since the partitioning behavior depends on temperature, the central part of the GC which is the oven contains the column. The distribution coefficient or partition coefficient measure the tendency of an analyte to be attracted to the stationary phase

$$K = Cs/Cm \quad (10)$$

K is the partition coefficient or distribution coefficient, Cs is the molar concentration of analyte in the stationary phase, Cm is molar the concentration of analyte in mobile phase. Larger

K values lead to larger retention analyte time. K can be controlled by the stationary phase chemical nature and the column temperature.

1.3.3 Advantage and Disadvantage of Gas Chromatography

The advantage of using gas chromatography is fast analysis, high efficiency which implies high resolution. Gas chromatography is a non-destructive method, high quantitative accuracy. GC is good for quantitative analysis of volatile compounds.

The disadvantage of gas chromatography resides in the limitation of sample to be volatized. It's not suitable for sample that degraded at high temperature (thermally labile).

The main components of the gas chromatography are the oven (where the column is and where separation takes place), the detector, the inlet and other factors need to be considered for better separation. A schematic representation of the gas chromatography in Figure 1.2[a]

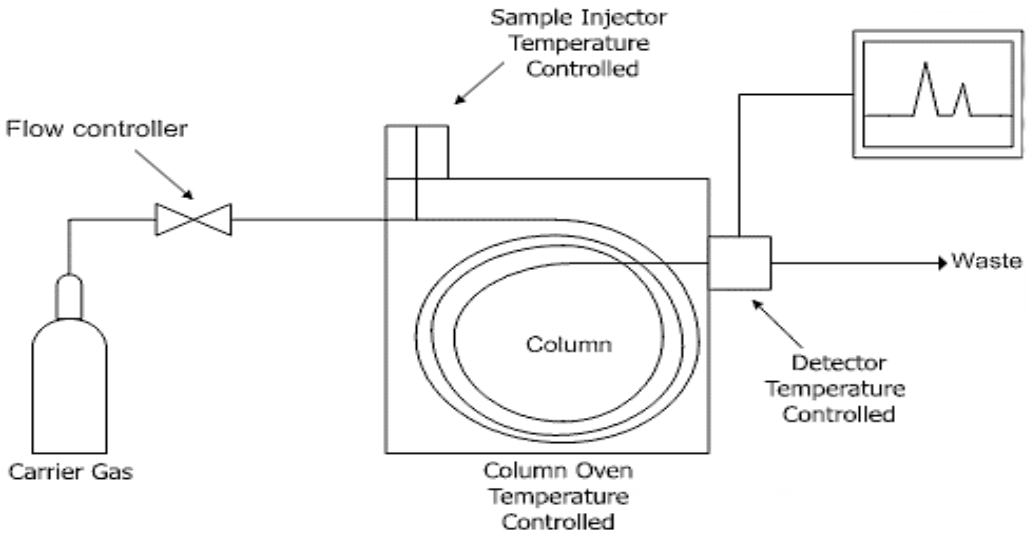

Figure 1.2. Schematic diagram of the components of a typical gas chromatograph. Adapted from http://en.wikipedia.org/wiki/gas_chromatography

The sample is introduced to the instrument through the inlet part (vaporized) with the help of carrier gas or mobile phase (usually helium gas, nitrogen or argon), then the carrier gas is forced through the stationary phase (column).The stationary phase needs to be something that does not react with the mobile phase. Then the sample has a chance to interact with the stationary phase as it moves past it. Because of the differences in rates, samples can be separated into their components. Sample that interact greatly, appear to move more slowly, those that have weak interaction appear to move more quickly. Then the detector records the signal which is called a peak. The peak is proportional to the amount of analyte injected. Other factors that need to be considered are the sample type, the column oven, type of detector, the injection system and carrier gas.

1.3.4 Column Oven

The column oven is the central part of the gas chromatography, the separation of mixture or components take place in the column. The oven temperature is programed at different rate with isothermal set as chosen. The GC separation is based on temperature, the higher the temperature, the faster the sample will elute. Higher temperature can lead to poor separation because of less interaction between the solute and the stationary phase. The temperature can be programmed or isothermally controlled. If a sample has a high boiling point (100 $^{\circ}$C and above); the temperature needs to be programmed, the separation required increasing the temperature during the run. A good separation occurs when the temperature is ramped and increased at slow rate. Isothermal temperature is advantages for optimal resolution.

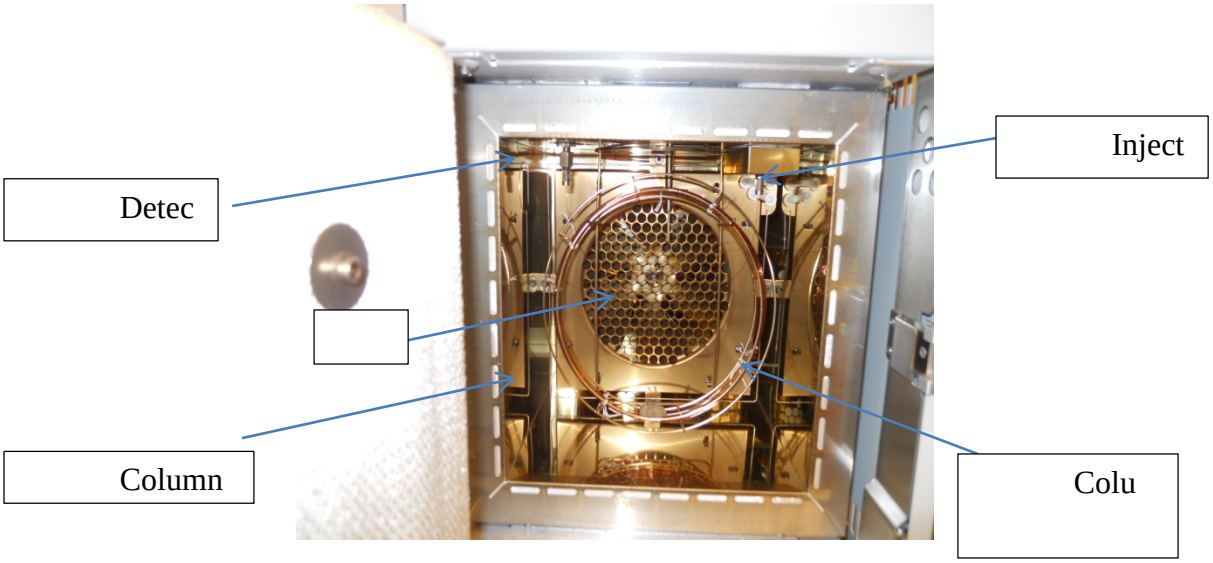

Figure 1.3. Picture of GC column oven and column from our la.b

A measure of the separation column efficiency is the number of theoretical plates which is defined by:

$$N = 16(t_R/W)^2 \quad (11)$$

Where N is the number of theoretical plates, t_R is the total retention time and W is width of the peak at the base

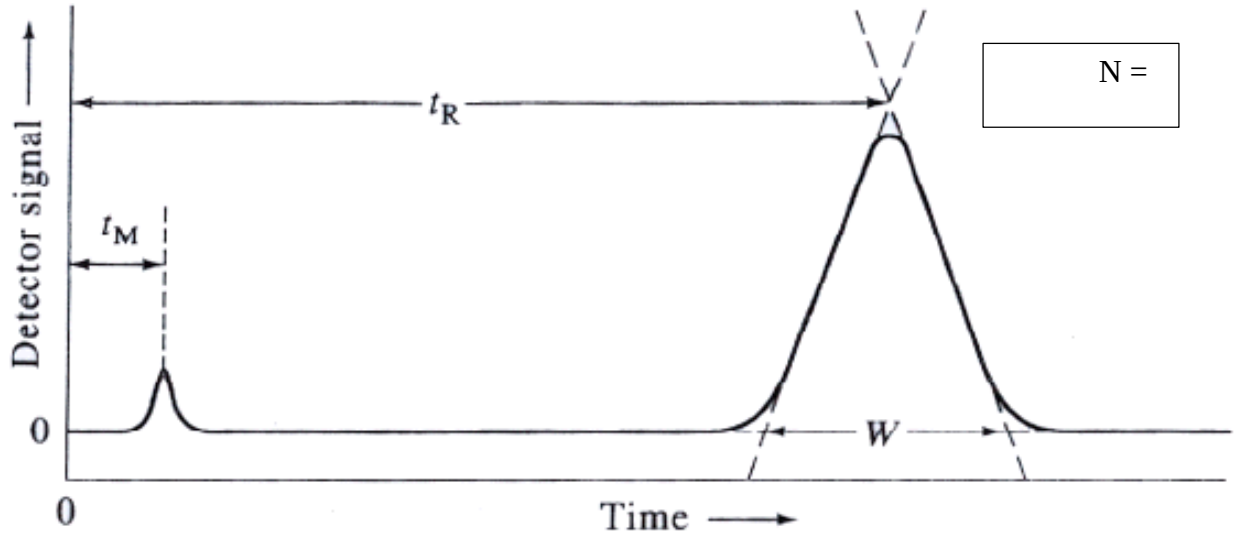

Figure 1.4. Column efficiency. clu-in.org/characterization/technologies/images/theoreticalz.gif

The resolution of the peak is how well the peak are separated

$$R = 2(t_{R2} - t_{R1})/ (W_1 + W_2) \quad (12)$$

Where R is the resolution, t_{R1} and t_{R2} are the total retention times for component 1 and 2, W_1 and W_2 are peak widths for substance 1 and 2 respectively.

There are two types of columns used for the GC, a capillary (mostly used) and the packed column. Here is a table that distinguished both types of columns.

Table 1.2. GC column packed vs capillary.

GC column packed vs capillary	
Packed columns	Capillary columns
Usually a glass or stainless steel coil	Thin fused-silica
filled with a packing coated material	
0.5-3 m long	typically 1-100m in length
5 mm internal diameter	0.1-1 mm internal diameter
6 mm outside diameter	film thickness 0.1-0.5 µm

The factors that affect the column performance are the column diameter, column length, and the chemical inside the stationary phase [61, 44-45]

Table 1.3. Available recommended stationary phases for different columns.

Type of compounds	Polarity of compound	Preferred stationary phase
Alcohols, Ketones, esters, carboxylic acid diols, amine	Polar compounds containing Cl, F, Br, O, P, N, S other than C and H atom	20% diphenyl/ 80% dimethyl siloxane, 6% cyanopropylphenyl/94% dimethylsiloxane, 35%diphenyl/65% dimethylsiloxane, 50% diphenyl/50% dimethyl siloxane, ethylene glycol, alkylene glycol
Alkanes	Non Polar C and H atom only C-C bond	5% diphenyl/95% dimethylsiloxane, methyl silicone,50% n-octyl/50% methylsiloxane
Alkenes, Arenes, alkynes aromatic hydrocarbon bonds.	Polarizable C and H atom only, C=C or C=C	80%biscyanopropyl/20% cyapropylphenyl siloxane, 90%biscyanoprophyl/10% cyanopropylphenyl siloxane

Table 1.4. Stationary phase interactions.

Functional group	Dispersion	Dipole	Hydrogen bonding
Methyl	strong	none	none
Phenyl	strong	none to weak	weak
Cyanopropyl	strong	very strong	moderate
Trifluoropropyl	strong	moderate	weak
PEG	strong	strong	moderate

Table 1.4 shows the dispersion, dipole and hydrogen bonding of different functional group for the stationary phase interactions [47].

1.3.5 Inlet System

The amount of analyte to be injected to the column must be controlled so that the inlet system does not deliver a huge amount of sample to the column. The sample must be vaporized prior to get into the column. The injector should not be too hot; otherwise the sample will be decomposed. The set of temperature is 50 °C above the boiling of the highest boiling sample. The peak shape will be poor if the temperature is too low. The inlet system has a microsyringe through which the simple is introduce to the inlet port. The syringe must be a gas-tight type to avoid loss of sample. Inside the inlet, there is an inlet liner that provides proper mixing of sample vapor with carrier gas and prevents non-volatile material to get in contact with the column. There are two types of injection system.

1 split/splitless

2 On column

1.3.5.1 Split/Splitless

In split/splitless mode the sample is injected after mixing with the carrier gas, then it splits into two unequal portions. One part goes to the column; the other portion goes to waste. The disadvantage of split mode is that the rest of sample that did not go to the column is wasted. With the splitless option, the whole amount of sample is injected through the column. The

splitless mode is usually applied for trace analysis. The issue with splitless mode is that it puts high solvent load on the column.

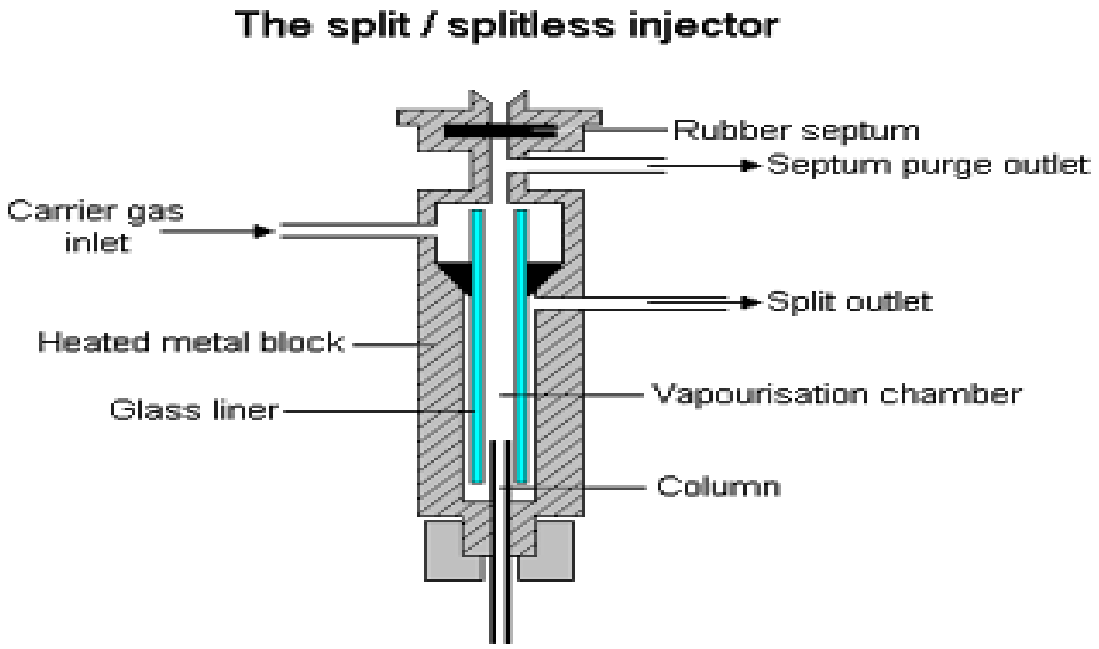

Figure 1.5. Split/splitless injector.

1.3.5.2 On-column

It's a mode of injection that avoids the hot injection liner all together is suitable for thermally unstable (labile) analyte or GC analyte with a boiling point differences that undergo discrimination in flash vaporization. It is widely use in packed column. It's the cold on-column injector. On column injector, a tall, low thermal –mass extension is attached to the top of the injector. It keeps the needle cool from the heat coming from the GC oven at the top of its temperature program [46].

1.3.6 Type of Analyte

The sample to be analyzed must be volatile enough in order to go through the column with the help of carrier gas such as helium or nitrogen. Derivatization of compounds can be done for analyte that is not volatile enough before separation. Careful precaution needs to be taken

when running a mixture of volatile and non-volatile compounds to avoid the interference of non-volatile to the compound of interest.

1.3.7 Mobile Phase or Carrier Gas

The role of the carrier gas is to help transport the analyte through the column.

The GC carrier gas needs to be inert with the analyte, dry and free of oxygen to prevent column deterioration. The helium gas or nitrogen (carrier gas) needs to be pure (99.999% or more), otherwise the quantitative analysis will be of noisy baseline, poor sensitivities. Maintaining a constant flow is necessary to avoid change in the retention time.

1.3.8 Detector

There are several types of detector for different purposes. The universal detector used in our GC is the flame ionization detector (FID). An FID normally uses hydrogen/air flame into which the analyte is passed to oxidize organic molecules and produces electrically charged particles (ions). The ions are collected and thus produce an electrical signal which is then measured. The detector role is to produce an electrical response proportional to the sample concentration. Flame ionization detectors are subjects to two broad trouble categories which are contamination and electronics. Contamination is by far the most common problem. Everything that passes through a FID is burned in the hydrogen flame. Large amounts of chlorinated compound or carbon disulfide however are not burned as well as hydrocarbons. Carbon particle tends to aggregate between the jet and the collector forming an electrical leakage path, and the result is high, noisy baseline. Another type of problem is stationary phase bleed from the column into the detector. To check the detector contamination, the GC power must be turn off and shut off the combustion gas flow. The FID is a mass sensitive detector; it depends on the mass of analyte entering the detector per unit time. The disadvantage of flame ionization detector is that

it destroys everything coming out of the column. The main part of the flame ionization detector is the ion chamber which is made of stainless steel, including the gas inlet, flame nozzle, a pair of electrodes and housing. The column flow rate has an impact on the detector's response. Current is detected when eluent burns and generates ions; there is a change between the jet and the collector electrode. The current is amplified by the electrometer, producing a response. The information can be recorder as peak area, retention time and peak height. The retention time is the time taken for a particular compound to travel through the column to the detector. Qualitative and Quantitative analysis can be observed through the computer program recorder [48]

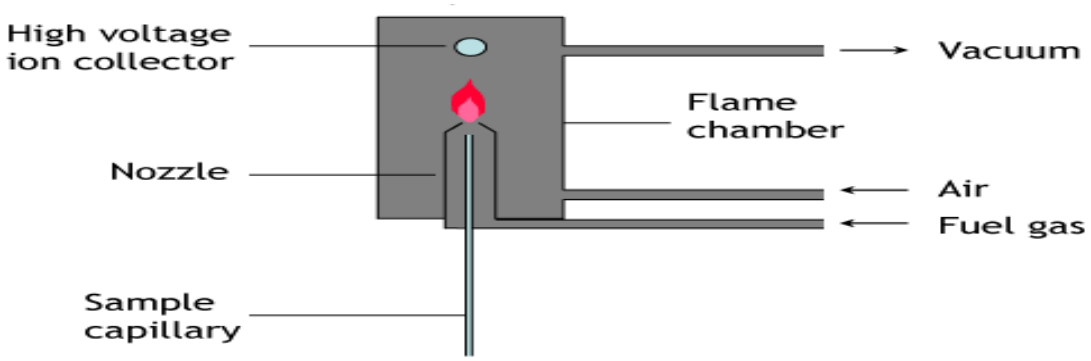

Figure 1.6. Flame ionization detector.

Table 1.5. Summary of common gas chromatography detector

Detector	Type	Detectability	Selectivity	Dynamic Range
Flame ionisation detector (FID)	Mass flow	100 pg	most organic compounds/universal	10^7
Thermal conductivity (TCD)	concentration	1 ng	universal	10^7
Photo-ionization (PID)	concentration	2pg	Aliphatics, aromatics,ketones	10^7
			Esters,aldehydes, amines,	
			heterocyclics, organosulfurs	
Electron capture (ECD)	concentration	50 fg	Halides, nitrates,nitriles	10^5
			anhydrides, organometallics	

Flame photometric (FPD)	mass flow	100 pg	sulfur, tin, boron,	10^3
			phosphorus, arsenic,	
			selenium, chromium	
			Halides, nitrates,nitriles	
			anhydrides, organometallics	
Nitrogen phosphorus (NPD)	mass flow	10 pg	Nitrogen, phosphorus	10^6

The type of detector to use depends on the goals of the experiment and the type of analyte to be studied. Each detector will give different type of selectivity. In our case we are using the FID universal detector. Most of these detectors use helium or nitrogen as carrier gases. Most detectors use hydrogen and air or make up gases and other may use hydrogen and air possibly oxygen as support gases.

1.4 Summary

Gas chromatography is a method for separating substance in a mixture and measuring the relative quantities of substance. The result in gas chromatography provides the peak area or peak height and the retention time. In this experiment the retention time of different solutes are used in the Abraham solvation model equation to predict solute descriptors. The experimental retention time data can be applied through the Abraham solvation model to predict various and significant chemical and biological properties of pharmaceutical importance. The retention time is a reflection of the substance's affinity for the stationary phase. The retention time can be used as property to characterize the compound. We can rely on the retention time only when measuring reference or sample under identical conditions and shorty after each other.

Once the drug's descriptors are determined, they can be used to predict the partitioning behavior of molecule through different biological barriers. In this experiment, the partitioning coefficients are determined by measuring the retention time and using them in the appropriate

equation. The partitioning coefficient tells us whether or not the chemical will cross the biological membranes. These partitioning coefficients also relate to the effects of solvent phase on solute-solvent phase. Right now, we are adding more solutes to develop the equation for gas chromatography stationary phase to predict solutes descriptors for illicit drugs from the GC retention time and structural information.

CHAPTER 2

RESEARCH PROCEDURE

2.1 The Aim of this Research

The goal of this research is to experimentally determine solute descriptors for certain drug compounds. First the gas chromatography is used to obtain the retention time of drug compounds, then the chromatography data (retention time) is applied to calculate the molecular descriptors with the use of Abraham solvation model equation (2). After obtaining the molecular or solute descriptors, they are used to predict some chemical or biological properties as mentioned in chapter one. More than one hundred compounds were used in this experiment. The advantage of using the Abraham solvation model resides in the newly developed column equation. Once the retention times of unknown illicit drugs or compounds are determined, it is a matter of plugging them in the developed stationary equation to get the solute descriptors.

2.2 Gas Chromatography Instrument

In this study, a gas chromatograph with flame ionization detector (FID) (Thermo Fisher Scientific, Model GC FOCUS) is used to obtain the retention times. Chromquest software was used to analyze the data. The helium carrier gas flow rate was set to 1.5 ml/min.

Six different chromatographic columns were used for separations. Column TR-5, TR1-MS, TG-1301MS, TG- 5MS all bought from Fisher Scientific, and column ZB-Wax, Zb-35 purchased from Zebron. All 6 columns had the same length (30m), same internal diameter (0.32mm) and film thickness (.25µm). A summary of the columns stationary phase is shown in Table 2.

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purchased from Zebron. All 6 columns had the same length (30m), same internal diameter (0.32mm) and film thickness (.25µm). A summary of the columns stationary phase is shown in Table 2.1.

Table 2.1. Summary of all 6 columns stationary phase used in this experiment.

Column	Stationary Phase	Polarity	Max. Temp.	Recommended
ZB-wax plus	Polyethylene glycol	Polar	250 °C	Glycols, aromatic isomers, esters, Alcohol ketones
ZB-35	35% phenyl 65% dimethyl polysiloxane	mid-polarity	340 °C	Pharmaceutical steroids, semi volatile amines
TR 1MS	100% dimethyl polysiloxane	Non polar	360 °C	Chlorinated and nitro aromatic compounds
TR 5	5% phenyl methyl	Low polarity	350 °C	Alcohols, low pesticides, free fatty acids, aromatic flavors
TG5 MS	5% diphenyl 95% dimethyl polysiloxane	low-polarity	350 °C	Semi volatile, phenol, amines
TG 1301MS	6% cyanopropyl phenyl 94% dimethyl polysiloxane	Mid polarity	280 °C	Oxygenate residuals, solvent, alcohols, volatile organics

The chemical compounds and the illicit drugs were all dissolved in methanol, dichloromethane, dimethylsulfoxide (DMSO) or acetonitrile to make solution for injection. Both liquid and solid concentration is 1 mg/ml. Low boiling point compounds like ethanol, ethyl acetate, methyl acetate, acetone, and butanone are diluted with dichloromethane or DMSO because the methanol solvent peak can co-elutes with the peak of interest.

The run starts at initial oven low temperature of 50 degree Celsius, with a hold time of 2 minutes. Then the temperature is raised at the rate of 15°C per minute with 5 minutes hold time to the final temperature depending on the maximum temperature of the column inside the oven. The maximum temperature of the oven on average is 260-330°C, prep-run timeout is 10.00 minute and equilibrium time is 0.50 minute. The FID detector temperature is 200°C. The inlet temperature is 240°C. The injection volume of sample is 1µl, but can vary depending on the peak

area of the sample. The split ration of the analyte can vary too. Methanol is used to wash the needle for pre and post injection of the sample for three cycles. The needle itself is rinsed with the sample three times before injection. Each sample was tested three times to reproduce accurate and precise data. The column is conditioned twice in between each run to make sure there is no carry over or no interference with the retention time of the desire sample. Below is a summary of method development.

Table 2.2. Summary of method development

Sample concentration	1 mg/ml
Injection volume	1.0µl
Split ratio	50:1
Split mode	Split
Column Dimension	30 m x 0.32 mmID x 0.25µm film thickness
Carrier flow rate	1.5 ml/min
Carrier gas	Helium
Initial oven temperature	50°C (hold for 2 min)
Final oven temperature	330°C (depending on the column max temp(hold for 5 min)
Injector temperature	240°C
Pre run time	10 min
Equilibrium time	0.5 min
Ramp	15°C/min
Detector	FID
Detector temperature	200°C
Solvents	Methanol, DCM. DMSO

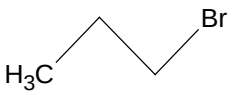
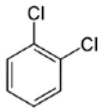
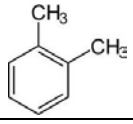
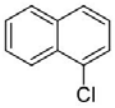
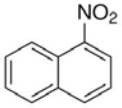
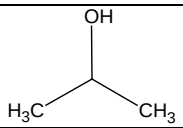
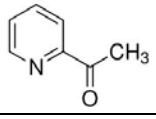
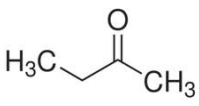
2.3 Nature of Chemical Compounds

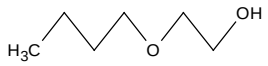
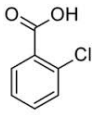
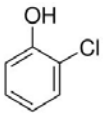
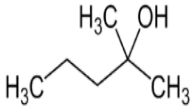
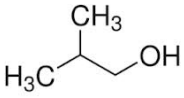
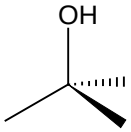
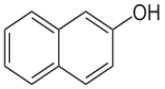
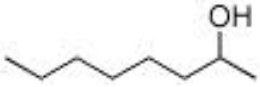
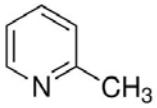
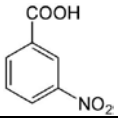
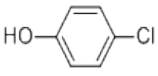
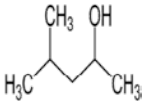
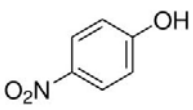
There are several type of compounds selected with a wide range of boiling point and size. The compounds to be run need to have similar functional group with the drug sample. Compounds need to be volatile in order to be run in the gas chromatograph.

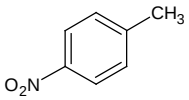
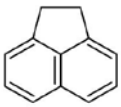
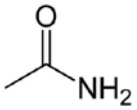
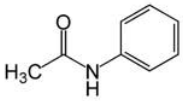
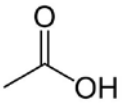
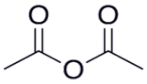
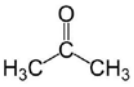
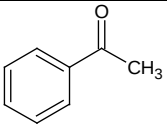
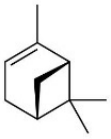
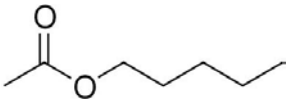
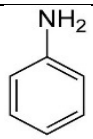
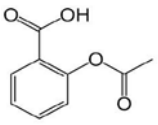
Below is the list of more than one hundred compounds run in Table 2.2

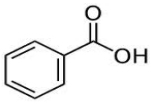
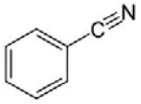
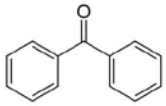
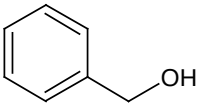
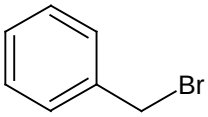
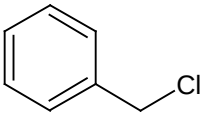
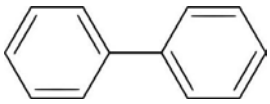
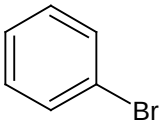
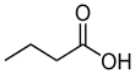
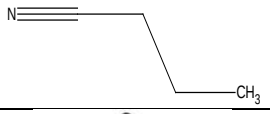
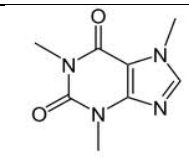
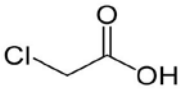
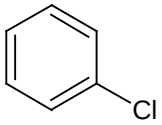
Table 2.3 .Structure of Compounds and their boiling point

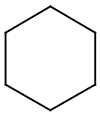
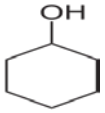
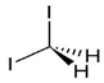
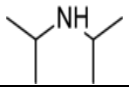
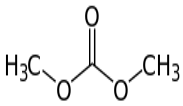
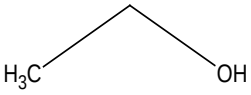
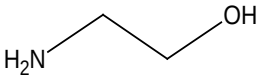
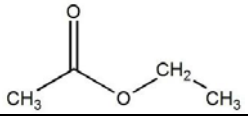
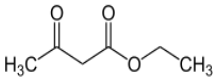
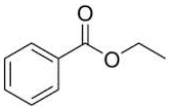
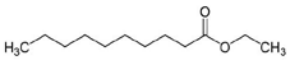
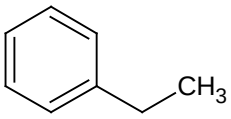
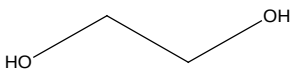
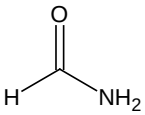
Solute	Structure	Boiling point(°C)

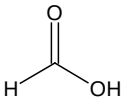
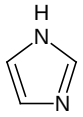
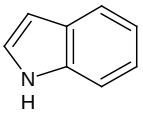
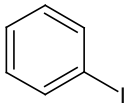
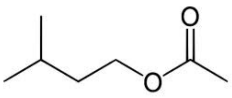
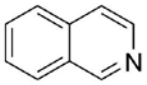
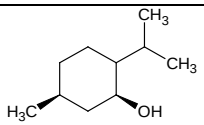
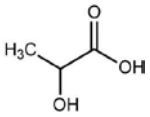
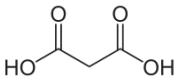
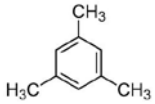
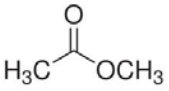
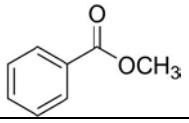
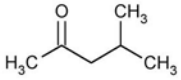
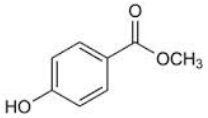
1- Bromopropane		71
1,2- Dibromoethane		131
1,2-Dichlorobenzene		180
1,2-Dimethylbenzene		144
1-Bromohexane		158
1-Butanol		117.4
1-Chloronaphthalene		263
1-Nitronaphthalene		304
1-Nonene		146
1-Octanol		195
1-Octene		121
2 Propanol		82
2-Acetylpyridine		189
2-Butanone		79.6

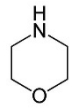
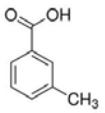
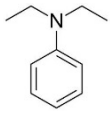
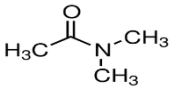
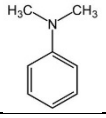
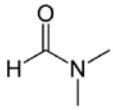
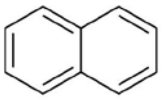
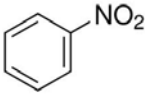
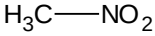
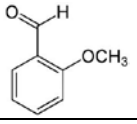
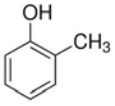
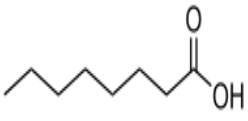
2-Butoxyethanol		171
2-Chlorobenzoic acid		285
2-Chlorophenol		175
2-Methyl -2-pentanol		121
2-Methyl-1-propanol		108
2-Methyl-2-propanol		82
2-Naphthol		286
2-Octanol		195
2-Picoline		129
3-Amino-1-propanol		188
3-Nitrobenzoic acid		341
4-Chlorophenol		220
4-Methyl-2 pentanol		132
4-Nitrophenol		279

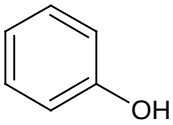
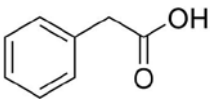
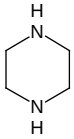
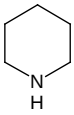
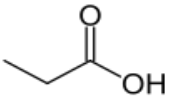
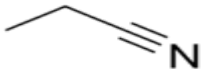
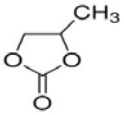
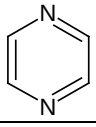
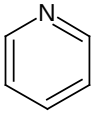
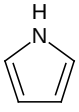
4-Nitrotoluene		238
Acenaphthene		280
Acetamide		222
Acetanilide		304
Acetic Acid		118
Acetic anhydride		139
Acetone		56.5
Acetophenone		202
Alpha pinene		155
Amyl acetate		148
Aniline		186
Aspirin		140
Benzene		80.1

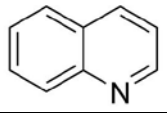
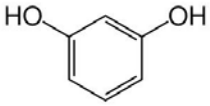
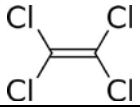
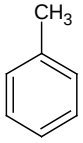
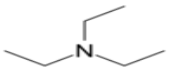
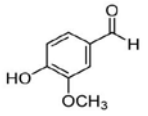
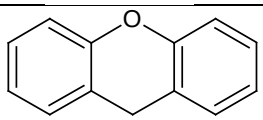
Benzoic Acid		249
Benzonitrile		191
Benzophenone		305.4
Benzyl Alcohol		205
Benzyl bromide		198
Benzyl chloride		179
Biphenyl		255
Bromobenzene		156
Butyric acid		163.5
Butyronitrile		117
Caffeine		178
Chloroacetic acid		189
Chlorobenzene		132

Cyclohexane		80.7
Cyclohexanol		161
Diiodomethane		181
Diisopropylamine		84
Dimethyl carbonate		90
Ethanol		78.5
Ethanolamine		170
Ethyl Acetate		77
Ethyl Acetoacetate		180.8
Ethyl benzoate		213
Ethyl decanoate		245
Ethyl benzene		136
Ethylene glycol		195
Formamide		210

Formic acid		107.3
Imidazole		256
Indole		254
Iodobenzene		189
Iso-pentyl acetate		287.6
Isoquinoline		242
L Menthol		212
Lactic acid		122
Malonic acid		140
Mesitylene		164.7
Methyl Acetate		56.9
Methyl Benzoate		199.6
Methyl isobutyl ketone		115.9
Methyl-4-hydroxybenzoate		298.6

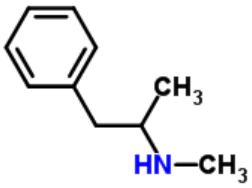
Morpholine		129
m-Toluic acid		263
N,N-Diethylaniline		217
N,N-Dimethylacetamide		165
N,N-Dimethylaniline		194
N,N-Dimethylformamide		153
Naphthalene		218
nitrobenzene		210.9
Nitromethane		100
Nonylamine		201
N,propyl alcohol		97.2
o-anisaldehyde		238
o-cresol		191
Octanoic acid		237

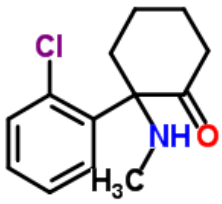
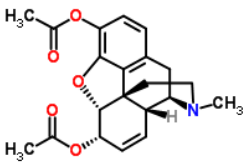
Octylamine		176
Pentan-1-ol		139
Phenanthrene		332
Phenol		181.7
Phenylacetic Acid		265.5
Piperazine		146
Piperidine		106
Propanoic Acid		141
Propionitrile		97
Propylene Carbonate		240
Pyrazine		115
Pyridine		115.2
Pyrrole		129

Quinoline		237
Resorcinol		277
Tetrachloroethylene		121.1
Tetrahydrofuran		66
Toluene		110.6
Triethyl amine		89.7
Vanillin		285
Xanthene		312

Illicit and prescription drugs to be studies are methamphetamine, oxycodone, nicotine, heroin and ketamine. The drugs chemical formula and other information are listed below in Table 2.3

Table 2.4. Chemical and physical properties of drugs to be studied

Compound	**Chemical Structure**	**Molecular Formula**	**Molecular Weight (g/mol)**	**Boiling Point (°C)**
Methamphetamine		$C_{10}H_{15}N$	149.23	212

Oxycodone		$C_{18}H_{21}NO_4$	315.36	501
Ketamine		$C_{13}H_{16}ClNO$	237.72	262
Heroin(diacetyl morphine)		$C_{21}H_{23}NO_5$	369.41	273
Nicotine		$C_{10}H_{14}N_2$	162.23	247

Chemical compounds in Table 2.2 have some similar functional groups to the drug compounds in Table 2.3. HPLC grade (Spectrum chemical Mfg.Corp.), analytical grade dichloromethane (Spectrum chemical Mfg.Corp.), DMSO, ACN are solvents used to dissolved drug samples and compounds. Once the retention time of each compound is obtained, equation (2) is used to solve Abraham solvation parameter model with the retention time of each compound using the experimental gas-to liquid partition coefficients data(E,S,A,B,L,V) from literature [49-52]. The software utilized to calculate the process coefficients by multiple linear regression analysis (MLRA) is the statistical package for social science (SPSS). The SPSS is software for managing data and calculate a wide variety of statistics. With the use of SPSS, the processes coefficients are obtained, then the log of calculated retention time are found. Multiple

linear regression analysis is a technique that correlates two or more independent variable (x) and a dependent variable(y) to produce equation coefficients. MLRA is used to construct linear free energy relationships with the Abraham solvation parameter model. The method of MLRA can be used with Microsoft excel or SPSS. In order to produce a good quality regression for five variables, one needs to have at least thirty samples.

2.4 Statistical Analysis

The data analyses are examined with the use of SPSS software and Microsoft excel. First, each compound is run three times, and then the average of the three run is obtained. Next the standard deviation is calculated. Standard deviation shows how much variation or dispersion from the average exists. A large standard deviation indicates that data points are spread out over a large range of values, therefore poor relationships among data. A low standard deviation indicates that data points tend to be very close to the mean, thus a good relationship among data. A low standard deviation is preferable because it shows a good relationship among data. After the standard deviation, the logs of experimental retention times are calculated. Once the calculated log and experimental log of retention time are acquired, excel or origin program can be used to graph the experiment log of retention time on x axis versus the calculated log of retention time on y axis. The correlation coefficient, r reflects the linear relationship between the two variables. A positive sign (+1) on the correlation coefficient indicates a positive or direct correlation between two variables. A negative sign (-1) indicates an indirect correlation between two variables. The correlation coefficient denoted by r^2 or R^2 is a measure of the strength of the straight line or linear relationship between two variables.

2.5 Training Sets

Since there are five unknowns (E, S, A, B, L or V) to be solved in the Abraham solvation model, there is a need of at least five equations to be established in order to determine the solute descriptors of illicit drugs. The known process coefficients (e, s, a, b, l or v) are used through the system equations to generate the solute descriptors or molecular descriptors. The process coefficients for each column are calculated with the help of the SPSS software by multiple linear regression analysis. The overall sums of squares are set at a minimum to fit the aimed cells of S, A, and B in excel where A and B are set as unconstrained variable with a values of greater than or equal to zero since acidity and basicity cannot be negative. The S is set as unrestrained variable. The method used is the Microsoft excel solver that uses the generalized reduced gradient (GRG2) algorithm for optimizing nonlinear problems. This algorithm was developed by Leon Lasdon, of the University of Texas at Austin, and Allan Warren, of Cleveland State University

CHAPTER 3

RESULT AND DISCUSSION

3.1 Result from Each Column Used

In this experiment, more than one hundred compounds were run. Below is the list of the three runs, the mean values, the standard deviation and percent relative standard deviation of each solute on all six columns used. Compounds that are not listed on the table means they did not elute or their boiling point exceeded the maximum temperature of the column used. Not all illicit drugs ran on each column. The data for each column are shown in Table 3.1-3.6.

Table 3.1. Retention time (min) for column ZB Wax plus max temperature 250 °C (polyethylene glycol) column

Solute	**Run1**	**Run2**	**Run3**	**Avg**	**Stdev**	**%RSD**
1,2-Dibromoethane	6.643	6.647	6.648	6.646	0.003	0.040
1,2-Dichlorobenzene	9.343	9.340	9.340	9.341	0.002	0.019
1,2-Dimethylbenzene	6.492	6.480	6.485	6.486	0.006	0.093
1-Bromohexane	6.100	6.113	6.110	6.108	0.007	0.111
1-Bromopropane	2.888	2.887	2.888	2.888	0.001	0.020
1-Butanol	5.552	5.562	5.555	5.556	0.005	0.092
1-Nonene	3.497	3.492	3.497	3.495	0.003	0.083
1-Octanol	9.348	9.350	9.355	9.351	0.004	0.039
1-Octene	2.613	2.615	2.615	2.614	0.001	0.044
2- Propanol	3.423	3.428	3.420	3.424	0.004	0.118
2-Acetylpyridine	10.290	10.283	10.285	10.286	0.004	0.035
2-Butanone	3.925	3.913	3.915	3.918	0.006	0.164
2-Butoxyethanol	8.110	8.108	8.112	8.110	0.002	0.025
2-Chlorophenol	12.135	12.138	12.140	12.138	0.003	0.021
2-Methyl -2-Pentanol	5.108	5.103	5.115	5.109	0.006	0.118
2-Picoline	6.827	6.822	6.815	6.821	0.006	0.088
3-Amino-1-propanol	9.682	9.668	9.663	9.671	0.010	0.102
4-Chlorophenol	15.358	15.363	15.365	15.362	0.004	0.023
4-Methyl-2 pentanol	5.813	5.815	5.813	5.814	0.001	0.020
4-Nitrotoluene	11.897	11.898	11.898	11.898	0.001	0.005
Acetamide	11.358	11.357	11.362	11.359	0.003	0.023
Acetic Acid	9.142	9.137	9.102	9.127	0.022	0.239
Acetic anhydride	6.598	6.620	6.612	6.610	0.011	0.168

Acetone	3.195	3.195	3.195	3.195	0.000	0.000
Acetophenone	10.635	10.645	10.648	10.643	0.007	0.064
Alpha pinene	4.823	4.815	4.812	4.817	0.006	0.118
Amyl acetate	6.310	6.310	6.302	6.307	0.005	0.073
Aniline	11.377	11.378	11.382	11.379	0.003	0.023
Benzene	4.013	4.010	4.007	4.010	0.003	0.075
Benzoic Acid	15.733	15.755	15.748	15.745	0.011	0.071
Benzonitrile	10.305	10.307	10.307	10.306	0.001	0.011
Benzyl bromide	10.122	10.115	10.122	10.120	0.004	0.040
Benzyl chloride	9.538	9.537	9.532	9.536	0.003	0.034
Biphenyl	12.667	12.663	12.663	12.664	0.002	0.018
Bromobenzene	8.053	8.053	8.057	8.054	0.002	0.029
Butyric acid	9.707	9.712	9.718	9.712	0.006	0.057
Butyronitrile	5.130	5.135	5.135	5.133	0.003	0.056
Chlorobenzene	6.755	6.755	6.755	6.755	0.000	0.000
Cyclohexane	3.328	3.348	3.362	3.346	0.017	0.511
Cyclohexanol	8.167	8.170	8.168	8.168	0.002	0.019
Diiodomethane	7.037	7.048	7.032	7.039	0.008	0.116
Diisopropylamine	3.273	3.270	3.277	3.273	0.004	0.107
Dimethyl carbonate	4.018	4.035	4.043	4.032	0.013	0.317
Ethanol	3.975	3.977	3.977	3.976	0.001	0.029
Ethanolamine	8.040	8.008	8.100	8.049	0.047	0.580
Ethyl Acetate	3.592	3.593	3.590	3.592	0.002	0.043
Ethyl Acetoacetate	8.538	8.610	8.593	8.580	0.038	0.439
Ethyl benzoate	10.733	10.733	10.737	10.734	0.002	0.022
Ethyl decanoate	10.402	10.417	10.413	10.411	0.008	0.075
Ethylbenzene	5.402	5.398	5.399	5.400	0.002	0.039
Ethylene glycol	10.095	10.095	10.047	10.079	0.028	0.275
Formamide	10.085	10.087	10.085	10.086	0.001	0.011
Formic acid	3.342	3.280	3.398	3.340	0.059	1.767
Iodobenzene	9.135	9.128	9.133	9.132	0.004	0.039
Isoquinoline	13.078	13.092	13.090	13.087	0.008	0.058
Lactic acid	7.715	7.708	7.715	7.713	0.004	0.052
L-menthol	9.993	9.995	9.993	9.994	0.001	0.012
Malonic acid	8.425	8.430	8.428	8.428	0.003	0.030
Mesitylene	7.082	7.083	7.082	7.082	0.001	0.008
Methyl Acetate	3.252	3.255	3.252	3.253	0.002	0.053
Methyl Benzoate	10.413	10.410	10.407	10.410	0.003	0.029
Methyl isobutyl ketone	4.607	4.608	4.617	4.611	0.006	0.119

Methyl cyclohexane	7.725	7.727	7.730	7.727	0.003	0.033
Morpholine	7.110	7.107	7.108	7.108	0.002	0.021
N,N dimethylacetamide	8.235	8.238	8.242	8.238	0.004	0.043
N,N-Diethylaniline	10.385	10.387	10.380	10.384	0.004	0.035
N,N-Dimethylaniline	9.817	9.815	9.817	9.816	0.001	0.012
N,N-Dimethylformamide	7.935	7.928	7.927	7.930	0.004	0.055
Naphthalene	11.348	11.348	11.352	11.349	0.002	0.020
Nitrobenzene	11.327	11.330	11.332	11.330	0.003	0.022
Nitromethane	11.897	11.898	11.898	11.898	0.001	0.005
Nonylamine	8.697	8.690	8.702	8.696	0.006	0.069
N,propyl alcohol	3.852	3.918	3.940	3.903	0.046	1.173
o-anisaldehyde	12.533	12.545	12.540	12.539	0.006	0.048
Octanoic acid	12.923	12.927	12.927	12.926	0.002	0.018
Octylamine	7.857	7.842	7.840	7.846	0.009	0.118
Pentan-1-ol	7.047	7.050	7.045	7.047	0.003	0.036
Phenol	13.317	13.322	13.323	13.321	0.003	0.024
Phenylacetic Acid	15.908	15.900	15.893	15.900	0.008	0.047
Piperidine	4.698	4.688	4.688	4.691	0.006	0.123
Propanoic Acid	9.105	9.100	9.102	9.102	0.003	0.028
Propionitrile	4.380	4.383	4.380	4.381	0.002	0.040
Propylene Carbonate	12.072	12.078	12.068	12.073	0.005	0.042
Pyrazine	6.190	6.197	6.198	6.195	0.004	0.070
Pyridine	6.455	6.460	6.463	6.459	0.004	0.063
Pyrrole	9.010	9.095	9.120	9.075	0.058	0.635
Quinoline	12.787	12.780	12.778	12.782	0.005	0.037
Tetrachloroethylene	4.792	4.777	4.775	4.781	0.009	0.194
Tetrahydrofuran	3.467	3.468	3.470	3.468	0.002	0.044
Toluene	4.967	4.952	4.947	4.955	0.010	0.210
Triethyl amine	3.290	3.298	3.302	3.297	0.006	0.185

Table 3.2. Retention time (min) for ZB –35 (35% Phenyl 65% dimethyl polysiloxane) columns

Solute	**Run1**	**Run2**	**Run3**	**Avg**	**Stdev**	**%RSD**
1 -Chloronaphthalene	11.783	11.762	11.665	11.737	0.063	0.536
1,2-Dibromoethane	4.995	4.993	4.992	4.993	0.002	0.031
1,2-Dichlorobenzene	8.082	8.100	8.087	8.090	0.009	0.115
1,2-Dimethylbenzene	6.185	6.183	6.187	6.185	0.002	0.032
1,3,5-Trimethylbenzene	6.920	6.912	6.913	6.915	0.004	0.063
1-Bromohexane	6.468	6.463	6.458	6.463	0.005	0.077

1-Bromopropane	2.840	2.840	2.842	2.841	0.001	0.041
1-Butanol	3.167	3.155	3.152	3.158	0.008	0.251
1-Nitronaphthalene	13.948	13.948	13.950	13.949	0.001	0.008
1-Nonene	4.850	4.848	4.848	4.849	0.001	0.024
1-Octanol	7.580	7.580	7.582	7.581	0.001	0.015
1-Octene	3.720	3.723	3.723	3.722	0.002	0.047
2 -Methyl -2 propanol	2.418	2.422	2.415	2.418	0.004	0.145
2-Propanol	2.327	2.328	2.328	2.328	0.001	0.025
2-Acetylpyridine	8.352	8.328	8.339	8.340	0.012	0.144
2-Butanone	3.372	3.380	3.380	3.377	0.005	0.137
2-Butoxyethanol	5.865	5.980	5.925	5.923	0.058	0.971
2-Chlorobenzoic acid	11.548	11.517	11.528	11.531	0.016	0.136
2-Chlorophenol	7.588	7.587	7.582	7.586	0.003	0.042
2-Methyl -2-Pentanol	3.618	3.618	3.615	3.617	0.002	0.048
2-Picoline	5.605	5.627	5.618	5.617	0.011	0.197
4-Chlorophenol	9.700	9.707	9.705	9.704	0.004	0.037
4-Methyl-2 pentanol	4.315	4.315	4.312	4.314	0.002	0.040
4-Nitrophenol	13.168	13.167	13.162	13.166	0.003	0.024
4-Nitrotoluene	9.857	9.852	9.853	9.854	0.003	0.027
Acenaphthene	12.698	12.695	12.692	12.695	0.003	0.024
Acetanilide	12.018	12.015	12.010	12.014	0.004	0.034
Acetic Acid	3.438	3.395	3.465	3.433	0.035	1.028
Acetic anhydride	4.143	4.133	4.128	4.135	0.008	0.185
Acetone	2.978	2.960	2.952	2.963	0.013	0.449
Acetophenone	8.738	8.727	8.740	8.735	0.007	0.080
Alpha pinene	6.138	6.132	6.130	6.133	0.004	0.068
Amyl acetate	6.245	6.242	6.233	6.240	0.006	0.100
Aniline	7.813	7.828	7.817	7.819	0.008	0.099
Aspirin	10.008	10.008	10.008	10.008	0.000	0.000
Benzene	3.767	3.770	3.765	3.767	0.003	0.067
Benzoic Acid	9.533	9.548	9.508	9.530	0.020	0.212
Benzonitrile	7.948	7.948	7.947	7.948	0.001	0.007
Benzophenone	13.937	13.938	13.932	13.936	0.003	0.023
Benzyl alcohol	7.913	7.960	7.958	7.944	0.027	0.335
Benzyl bromide	8.635	8.628	8.623	8.629	0.006	0.070
Benzyl chloride	7.980	7.980	7.988	7.983	0.005	0.058
Biphenyl	11.625	11.632	11.630	11.629	0.004	0.031
Butyric acid	4.047	4.043	4.050	4.047	0.004	0.087
Butyronitrile	4.062	4.065	4.068	4.065	0.003	0.074

Chlorobenzene	5.730	5.735	5.727	5.731	0.004	0.071
Cyclohexane	2.883	2.875	2.873	2.877	0.005	0.184
Cyclohexanol	5.797	5.783	5.802	5.794	0.010	0.170
Diisopropylamine	3.182	3.182	3.182	3.182	0.000	0.000
Dimethyl carbonate	2.978	2.978	2.978	2.978	0.000	0.000
Ethanol	2.827	2.833	2.830	2.830	0.003	0.106
Ethanolamine	3.755	3.835	3.890	3.827	0.068	1.774
Ethyl Acetate	3.377	3.377	3.375	3.376	0.001	0.034
Ethyl benzoate	9.522	9.527	9.527	9.525	0.003	0.030
Ethyl decanoate	10.812	10.815	10.788	10.805	0.015	0.137
Ethylbenzene	5.623	5.627	5.627	5.626	0.002	0.041
Ethylene glycol	4.035	4.008	3.962	4.002	0.037	0.922
Formamide	6.693	6.692	6.658	6.681	0.020	0.298
Iodobenzene	7.887	7.892	7.897	7.892	0.005	0.063
Isopentyl acetate	5.793	5.782	5.777	5.784	0.008	0.142
Isoquinoline	10.858	10.845	10.848	10.850	0.007	0.063
Lactic acid	4.527	4.527	4.522	4.525	0.003	0.064
L-menthol	8.670	8.670	8.667	8.669	0.002	0.020
m, Toluic acid	10.405	10.408	10.432	10.415	0.015	0.142
Methyl Acetate	3.015	3.017	3.016	3.016	0.001	0.033
Methyl isobutyl ketone	4.403	4.410	4.415	4.409	0.006	0.137
Methyl-4-hydroxybenzoate	12.380	12.383	12.387	12.383	0.004	0.028
Morpholine	5.418	5.412	5.425	5.418	0.007	0.120
N,N dimethylacetamide	6.268	6.250	6.243	6.254	0.013	0.206
N,N-diethylaniline	9.940	9.935	9.942	9.939	0.004	0.036
Naphthalene	9.858	9.858	9.857	9.858	0.001	0.006
Nitrobenzene	9.048	9.052	9.048	9.049	0.002	0.026
Nitromethane	2.873	2.853	2.855	2.860	0.011	0.385
Nonylamine	8.540	8.537	8.530	8.536	0.005	0.060
o-anisaldehyde	11.250	11.232	11.228	11.237	0.012	0.104
O-cresol	8.322	8.300	8.312	8.311	0.011	0.133
Octanoic acid	8.095	8.095	8.093	8.094	0.001	0.014
Octylamine	7.507	7.507	7.498	7.504	0.005	0.069
Pentan-1-ol	4.578	4.572	4.577	4.576	0.003	0.070
Phenol	7.462	7.472	7.455	7.463	0.009	0.114
Phenyl acetic Acid	10.375	10.385	10.380	10.380	0.005	0.048
Piperidine	4.482	4.480	4.478	4.480	0.002	0.045
Propanoic Acid	4.020	4.055	4.060	4.045	0.022	0.539
Propionitrile	2.893	2.900	2.898	2.897	0.004	0.124

Pyrazine	4.277	4.287	4.283	4.282	0.005	0.118
Pyridine	4.892	4.880	4.877	4.883	0.008	0.163
Pyrrole	4.463	4.458	4.465	4.462	0.004	0.081
Quinoline	10.642	10.662	10.647	10.650	0.010	0.098
Resorcinol	10.868	10.862	10.860	10.863	0.004	0.038
Tetrachloroethylene	5.038	5.042	5.038	5.039	0.002	0.046
Toluene	4.737	4.732	4.730	4.733	0.004	0.076
Triethyl amine	3.330	3.327	3.323	3.327	0.004	0.106
Vanillin	12.137	12.145	12.137	12.140	0.005	0.038

Table 3.3. Retention time for TR 1 MS (100% dimethyl polysiloxane) column

Solute	**Run1**	**Run 2**	**Run 3**	**Average**	**Stdev**	**%RSD**
1,2-Dibromoethane	4.375	4.378	4.373	4.375	0.003	0.058
1,2-Dichlorobenzene	9.143	9.150	9.150	9.148	0.004	0.044
1,3,5-Trimethylbenzene	8.620	8.623	8.622	8.622	0.002	0.018
1-Bromohexane	8.038	8.042	8.047	8.042	0.005	0.056
1-Bromopropane	2.725	2.718	2.723	2.722	0.004	0.132
1-Butanol	3.263	3.270	3.267	3.267	0.004	0.108
1-Chloronaphthalene	12.572	12.558	12.560	12.563	0.008	0.060
1-Nitronaphthalene	14.257	14.260	14.258	14.258	0.002	0.011
1-Nonene	5.728	5.743	5.748	5.740	0.010	0.181
1-Octanol	7.818	7.820	7.832	7.823	0.008	0.097
1-Octene	4.462	4.463	4.460	4.462	0.002	0.034
2 - Methyl -2 propanol	2.507	2.502	2.495	2.501	0.006	0.241
2 Propanol	2.202	2.200	2.200	2.201	0.001	0.052
2-Acetylpyridine	9.003	8.997	8.997	8.999	0.003	0.038
2-Butanone	4.475	4.485	4.478	4.479	0.005	0.115
2-Butoxyethanol	5.913	5.910	5.912	5.912	0.002	0.026
2-Chlorophenol	8.678	8.683	8.678	8.680	0.003	0.033
2-Methyl -2-Pentanol	3.918	3.915	3.917	3.917	0.002	0.039
2-Picoline	6.575	6.573	6.572	6.573	0.002	0.023
4-Chlorophenol	9.012	9.007	9.008	9.009	0.003	0.029
4-Methyl-2 pentanol	4.163	4.165	4.167	4.165	0.002	0.048
4-Nitrotoluene	9.198	9.205	9.205	9.203	0.004	0.044
Acenaphthene	13.408	13.422	13.417	13.416	0.007	0.053
Acetanilide	12.295	12.257	12.250	12.267	0.024	0.197
Acetic Acid	4.653	4.638	4.658	4.650	0.010	0.224
Acetic anhydride	2.507	2.508	2.505	2.507	0.002	0.061
Acetone	4.322	4.225	4.128	4.225	0.097	2.296

Acetophenone	9.423	9.450	9.428	9.434	0.014	0.152
Alpha pinene	8.360	8.362	8.353	8.358	0.005	0.057
Amyl acetate	7.733	7.742	7.743	7.739	0.006	0.071
Aniline	8.395	8.400	8.400	8.398	0.003	0.034
Benzene	5.010	5.030	5.033	5.024	0.013	0.249
Benzoic Acid	10.485	10.495	10.503	10.494	0.009	0.086
Benzonitrile	8.415	8.405	8.400	8.407	0.008	0.091
Benzophenone	14.418	14.412	14.412	14.414	0.003	0.024
Benzyl alcohol	7.248	7.250	7.250	7.249	0.001	0.016
Benzyl bromide	8.032	8.027	8.027	8.029	0.003	0.036
Benzyl chloride	8.903	8.887	8.885	8.892	0.010	0.111
Biphenyl	12.467	12.465	12.467	12.466	0.001	0.009
Butyric acid	5.148	5.310	5.295	5.251	0.090	1.705
Butyronitrile	3.160	3.162	3.155	3.159	0.004	0.114
Chlorobenzene	8.152	8.145	8.147	8.148	0.004	0.044
Cyclohexane	3.328	3.323	3.313	3.321	0.008	0.230
Cyclohexanol	5.602	5.627	5.632	5.620	0.016	0.286
Diisopropylamine	3.275	3.273	3.272	3.273	0.002	0.047
Dimethyl carbonate	2.868	2.867	2.863	2.866	0.003	0.092
Ethanol	3.930	3.935	3.935	3.933	0.003	0.073
Ethanolamine	3.342	3.372	3.323	3.346	0.025	0.738
Ethyl Acetate	4.580	4.572	4.577	4.576	0.004	0.088
Ethyl Acetoacetate	6.103	6.110	6.115	6.109	0.006	0.099
Ethyl benzoate	10.515	10.502	10.495	10.504	0.010	0.097
Ethyl decanoate	12.503	12.500	12.498	12.500	0.003	0.020
Ethylbenzene	5.417	5.420	5.422	5.420	0.003	0.046
Ethylene glycol	3.658	3.658	3.765	3.694	0.062	1.672
Formamide	6.697	6.647	6.605	6.650	0.046	0.693
Iodobenzene	7.437	7.438	7.438	7.438	0.001	0.008
Isopentyl acetate	7.433	7.418	7.408	7.420	0.013	0.170
Isoquinoline	11.408	11.395	11.392	11.398	0.009	0.075
Lactic acid	7.547	8.065	7.613	7.742	0.282	3.642
L-menthol	8.862	8.860	8.860	8.861	0.001	0.013
Methyl Acetate	4.245	4.245	4.247	4.246	0.001	0.027
Methyl isobutyl ketone	5.710	5.705	5.703	5.706	0.004	0.063
Methyl-4-hydroxybenzoate	12.907	12.895	12.843	12.882	0.034	0.264
Morpholine	6.277	6.272	6.273	6.274	0.003	0.042
n-Propyl alcohol	4.080	4.085	4.080	4.082	0.003	0.071
N,N dimethylacetamide	5.232	5.240	5.232	5.235	0.005	0.088

N,N dimethylaniline	9.717	9.717	9.712	9.715	0.003	0.030
N,N-diethylaniline	11.068	11.063	11.067	11.066	0.003	0.024
Naphthalene	10.793	10.817	10.800	10.803	0.012	0.114
Nitrobenzene	9.653	9.633	9.635	9.640	0.011	0.114
Nonylamine	10.333	10.332	10.343	10.336	0.006	0.059
o-anisaldehyde	11.957	11.955	11.952	11.955	0.003	0.021
Octanoic acid	8.368	8.368	8.368	8.368	0.000	0.000
Octylamine	9.268	9.272	9.278	9.273	0.005	0.054
Pentan-1-ol	6.043	6.033	6.033	6.036	0.006	0.096
Phenanthrene	15.665	15.665	15.657	15.662	0.005	0.029
Phenol	8.468	8.470	8.473	8.470	0.003	0.030
Phenyl acetic Acid	11.187	11.187	11.185	11.186	0.001	0.010
Piperidine	4.173	4.178	4.173	4.175	0.003	0.069
Propionitrile	2.600	2.602	2.598	2.600	0.002	0.077
Pyrazine	3.597	3.598	3.602	3.599	0.003	0.074
Pyridine	5.725	5.737	5.723	5.728	0.008	0.132
Pyrrole	4.035	4.027	4.025	4.029	0.005	0.131
Quinoline	11.177	11.175	11.173	11.175	0.002	0.018
Resorcinol	11.353	11.373	11.403	11.376	0.025	0.221
Tetrachloroethylene	6.647	6.647	6.645	6.646	0.001	0.017
Toluene	6.103	6.100	6.100	6.101	0.002	0.028
Triethylamine	3.520	3.518	3.515	3.518	0.003	0.072
Vanillin	12.487	12.487	12.532	12.502	0.026	0.208
Xanthene	14.718	14.720	14.725	14.721	0.004	0.024

Table 3.4. Retention time for TR 5(5 % phenyl methyl polysiloxane) column

Solute	**Run1**	**Run 2**	**Run 3**	**Avg**	**Stdev**	**%RSD**
1-Chloronaphthalene	10.778	10.772	10.773	10.774	0.003	0.030
1,2-Dibromoethane	4.330	4.332	4.333	4.332	0.002	0.035
1,2-Dichlorobenzene	7.292	7.285	7.300	7.292	0.008	0.103
1,2-Dimethylbenzene	5.610	5.612	5.618	5.613	0.004	0.074
1,3,5-Trimethylbenzene	6.492	6.483	6.483	6.486	0.005	0.080
1-Bromohexane	6.113	6.108	6.107	6.109	0.003	0.053
1-Bromopropane	2.705	2.710	2.710	2.708	0.003	0.107
1-Butanol	2.638	2.632	2.637	2.636	0.003	0.122
1-Nitronaphthalene	12.570	12.570	12.572	12.571	0.001	0.009
1-Nonene	5.343	5.348	5.345	5.345	0.003	0.047
1-Octene	4.095	4.113	4.125	4.111	0.015	0.367
2-Propanol	2.215	2.263	2.267	2.248	0.029	1.287

2-Acetylpyridine	7.258	7.255	7.253	7.255	0.003	0.035
2-Butanone	2.675	2.647	2.645	2.656	0.017	0.632
2-Chlorobenzoic acid	10.612	10.652	10.600	10.621	0.027	0.256
2-Chlorophenol	6.760	6.760	6.767	6.762	0.004	0.060
2-Picoline	4.602	4.602	4.597	4.600	0.003	0.063
3-Amino-1-propanol	4.865	4.857	4.867	4.863	0.005	0.109
3-Nitrobenzoic acid	12.262	12.265	12.263	12.263	0.002	0.012
4-Chlorophenol	8.388	8.383	8.372	8.381	0.008	0.098
4-Methyl-2 pentanol	3.478	3.553	3.487	3.506	0.041	1.168
Acenaphthene	11.613	11.612	11.610	11.612	0.002	0.013
Acetanilide	10.608	10.608	10.605	10.607	0.002	0.016
Acetic Acid	2.873	2.863	2.867	2.868	0.005	0.176
Acetone	2.348	2.343	2.342	2.344	0.003	0.137
Acetophenone	7.657	7.668	7.672	7.666	0.008	0.101
Alpha pinene	6.140	6.132	6.135	6.136	0.004	0.066
Amyl acetate	5.808	5.812	5.808	5.809	0.002	0.040
Aniline	6.607	6.600	6.605	6.604	0.004	0.055
Benzoic Acid	9.100	9.160	9.128	9.129	0.030	0.329
Benzonitrile	6.685	6.690	6.698	6.691	0.007	0.098
Benzophenone	12.705	12.712	12.713	12.710	0.004	0.034
Benzyl alcohol	7.130	7.145	7.155	7.143	0.013	0.176
Benzyl chloride	7.007	7.003	7.007	7.006	0.002	0.033
Biphenyl	10.690	10.688	10.683	10.687	0.004	0.034
Butyronitrile	2.738	2.710	2.720	2.723	0.014	0.521
Chlorobenzene	5.008	5.003	5.008	5.006	0.003	0.058
Cyclohexane	2.605	2.607	2.602	2.605	0.003	0.097
Cyclohexanol	4.975	4.988	4.985	4.983	0.007	0.137
Diisopropylamine	2.603	2.592	2.585	2.593	0.009	0.350
Ethanol	2.300	2.270	2.273	2.281	0.017	0.724
Ethyl Acetate	2.727	2.691	2.718	2.712	0.019	0.691
Ethyl benzoate	8.733	8.735	8.730	8.733	0.003	0.029
Ethyl decanoate	10.685	10.685	10.687	10.686	0.001	0.011
Ethylbenzene	4.618	4.618	4.620	4.619	0.001	0.025
Formamide	4.947	4.950	4.952	4.950	0.003	0.051
Iodobenzene	6.775	6.770	6.787	6.777	0.009	0.129
Isopentyl acetate	5.400	5.392	5.390	5.394	0.005	0.098
Isoquinoline	9.665	9.665	9.655	9.662	0.006	0.060
Lactic acid	5.803	6.092	5.880	5.925	0.150	2.526
L-menthol	8.530	8.532	8.527	8.530	0.003	0.030

Methyl Acetate	2.425	2.412	2.417	2.418	0.007	0.271
Methyl isobutyl ketone	3.748	3.743	3.745	3.745	0.003	0.067
Methyl-4-hydroxybenzoate	11.228	11.217	11.220	11.222	0.006	0.051
Morpholine	4.492	4.492	4.490	4.491	0.001	0.026
n-Propyl alcohol	2.513	2.333	2.337	2.394	0.103	4.293
N,N dimethylaniline	7.895	7.897	7.895	7.896	0.001	0.015
N,N-Diethylaniline	9.253	9.255	9.255	9.254	0.001	0.012
Naphthalene	8.897	8.902	8.893	8.897	0.005	0.051
Nitrobenzene	7.937	7.940	7.935	7.937	0.003	0.032
Nitromethane	2.148	2.182	2.187	2.172	0.021	0.977
Nonylamine	8.418	8.415	8.413	8.415	0.003	0.030
o-anisaldehyde	9.413	9.415	9.415	9.414	0.001	0.012
Octylamine	7.313	7.297	7.295	7.302	0.010	0.135
Pentan-1-ol	4.058	4.058	4.067	4.061	0.005	0.128
Phenanthrene	13.943	13.945	13.940	13.943	0.003	0.018
Phenol	6.607	6.620	6.617	6.615	0.007	0.103
Phenyl acetic Acid	9.398	9.423	9.393	9.405	0.016	0.171
Piperidine	3.472	3.480	3.478	3.477	0.004	0.120
Propanoic Acid	3.835	3.827	3.852	3.838	0.013	0.333
Propionitrile	2.203	2.202	2.198	2.201	0.003	0.120
Pyridine	3.778	3.797	3.795	3.790	0.010	0.275
Pyrrole	3.533	3.528	3.507	3.523	0.014	0.392
Quinoline	9.428	9.437	9.437	9.434	0.005	0.055
Resorcinol	9.685	9.680	9.687	9.684	0.004	0.037
Tetrachloroethylene	4.572	4.572	4.572	4.572	0.000	0.000
Toluene	4.015	4.003	3.997	4.005	0.009	0.229
Triethylamine	2.778	2.773	2.767	2.773	0.006	0.199
Vanillin	10.818	10.817	10.820	10.818	0.002	0.014
Xanthene	12.960	12.973	12.975	12.969	0.008	0.063

Table 3.5. Retention time for TG 5- MS (5% diphenyl 95% dimethyl polysiloxane) column

Solute	**Run1**	**Run 2**	**Run 3**	**Avg**	**Stdev**	**%RSD**
1,2-Dichlorobenzene	7.227	7.225	7.232	7.228	0.004	0.050
1,2-Dimethylbenzene	5.488	5.488	5.488	5.488	0.000	0.000
1,3,5-Trimethylbenzene	6.403	6.398	6.403	6.401	0.003	0.045
1,2- Dibromoethane	4.330	4.332	4.333	4.332	0.002	0.035
1-Bromohexane	5.985	5.985	5.985	5.985	0.000	0.000
1-Bromopropane	2.705	2.710	2.710	2.708	0.003	0.107

1-Butanol	3.042	3.048	3.060	3.050	0.009	0.300
1-Nitronaphthalene	12.502	12.500	12.498	12.500	0.002	0.016
1-Nonene	5.343	5.348	5.345	5.345	0.003	0.047
1-Octene	4.095	4.113	4.125	4.111	0.015	0.367
2-Methyl -2 propanol	2.352	2.340	2.338	2.343	0.008	0.323
2-Propanol	2.215	2.263	2.267	2.248	0.029	1.287
2-Acetylpyridine	7.152	7.158	7.153	7.154	0.003	0.045
2-Butanone	2.562	2.560	2.645	2.589	0.049	1.874
2-Butoxyethanol	5.718	5.723	5.715	5.719	0.004	0.071
2-Chlorobenzoic acid	10.452	10.478	10.462	10.464	0.013	0.125
2-Chlorophenol	6.680	6.678	6.673	6.677	0.004	0.054
2-Methyl -2-Pentanol	3.648	3.685	3.658	3.664	0.019	0.522
2-Picoline	4.452	4.460	4.467	4.460	0.008	0.168
3-Amino-1-propanol	4.800	4.737	4.812	4.783	0.040	0.842
3-Nitrobenzoic acid	12.155	12.168	12.175	12.166	0.010	0.083
4-Chlorophenol	8.902	8.892	8.888	8.894	0.007	0.081
4-Methyl-2 pentanol	3.970	3.970	3.982	3.974	0.007	0.174
4-Nitrophenol	11.752	11.752	11.752	11.752	0.000	0.000
Acenaphthene	11.566	11.555	11.552	11.558	0.007	0.064
Acetanilide	10.537	10.548	10.535	10.540	0.007	0.066
Acetic Acid	2.678	2.687	2.688	2.684	0.006	0.205
Acetone	2.222	2.222	2.220	2.221	0.001	0.052
Acetophenone	7.592	7.582	7.580	7.585	0.006	0.085
Amyl acetate	5.722	5.717	5.717	5.719	0.003	0.050
Aniline	6.552	6.550	6.548	6.550	0.002	0.031
Aspirin	9.915	9.932	9.942	9.930	0.014	0.137
Benzene	2.987	2.990	2.982	2.986	0.004	0.135
Benzoic Acid	9.032	9.020	9.070	9.041	0.026	0.289
Benzonitrile	6.633	6.640	6.633	6.635	0.004	0.061
Benzophenone	12.533	12.650	12.655	12.613	0.069	0.547
Benzyl alcohol	7.130	7.145	7.155	7.143	0.013	0.176
Benzyl bromide	7.967	7.970	7.962	7.966	0.004	0.051
Benzyl chloride	6.972	6.967	6.967	6.969	0.003	0.041
Biphenyl	10.647	10.637	10.637	10.640	0.006	0.054
Butyronitrile	3.095	3.108	3.107	3.103	0.007	0.233
Chlorobenzene	4.893	4.903	4.897	4.898	0.005	0.103
Cyclohexane	3.012	3.015	3.010	3.012	0.003	0.084
Cyclohexanol	5.492	5.522	5.502	5.505	0.015	0.277
Diisopropylamine	2.995	2.990	2.988	2.991	0.004	0.121

Dimethyl carbonate	2.712	2.713	2.717	2.714	0.003	0.097
Ethanol	2.150	2.150	2.155	2.152	0.003	0.134
Ethanolamine	3.127	3.167	3.132	3.142	0.022	0.694
Ethyl Acetate	2.648	2.647	2.652	2.649	0.003	0.100
Ethyl benzoate	8.638	8.652	8.645	8.645	0.007	0.081
Ethyl decanoate	10.603	10.605	10.610	10.606	0.004	0.034
Ethylbenzene	5.182	5.187	5.188	5.186	0.003	0.062
Formamide	5.158	5.132	5.115	5.135	0.022	0.422
Iodobenzene	7.348	7.343	7.340	7.344	0.004	0.055
Isopentyl acetate	5.293	5.255	5.237	5.262	0.029	0.543
Isoquinoline	9.595	9.588	9.582	9.588	0.007	0.068
Lactic acid	3.927	3.930	3.883	3.913	0.026	0.672
L-menthol	8.530	8.532	8.527	8.530	0.003	0.030
Methyl Acetate	2.317	2.302	2.293	2.304	0.012	0.526
Methyl isobutyl ketone	3.662	3.680	3.662	3.668	0.010	0.283
Methyl-4-hydroxybenzoate	11.133	11.125	11.125	11.128	0.005	0.042
Morpholine	4.250	4.252	4.245	4.249	0.004	0.085
n-Propyl alcohol	2.223	2.222	2.218	2.221	0.003	0.119
N,N- dimethylacetamide	5.248	5.242	5.258	5.249	0.008	0.154
N,N- dimethylaniline	7.842	7.823	7.830	7.832	0.010	0.123
N,N-Diethylaniline	9.172	9.173	9.170	9.172	0.002	0.017
Naphthalene	8.838	8.833	8.837	8.836	0.003	0.030
Nitrobenzene	7.835	7.825	7.827	7.829	0.005	0.068
Nitromethane	2.473	2.465	2.460	2.466	0.007	0.266
Nonylamine	8.313	8.307	8.310	8.310	0.003	0.036
o-anisaldehyde	10.172	10.173	10.172	10.172	0.001	0.006
o-cresol	7.378	7.368	7.375	7.374	0.005	0.070
Octylamine	7.228	7.232	7.230	7.230	0.002	0.028
Pentan-1-ol	3.932	3.932	3.930	3.931	0.001	0.029
Phenanthrene	13.830	13.825	13.827	13.827	0.003	0.018
Phenol	6.530	6.525	6.513	6.523	0.009	0.134
Phenyl acetic Acid	9.440	9.432	9.427	9.433	0.007	0.070
Piperidine	3.943	3.948	3.943	3.945	0.003	0.073
Propanoic Acid	3.835	3.827	3.852	3.838	0.013	0.333
Propionitrile	2.525	2.528	2.527	2.527	0.002	0.060
Pyridine	3.705	3.698	3.698	3.700	0.004	0.109
Pyrrole	3.900	3.900	3.903	3.901	0.002	0.044
Quinoline	9.367	9.363	9.372	9.367	0.005	0.048
Resorcinol	9.578	9.580	9.575	9.578	0.003	0.026

Tetrachloroethylene	4.482	4.478	4.475	4.478	0.004	0.078
Toluene	3.977	3.972	3.970	3.973	0.004	0.091
Triethylamine	3.205	3.200	3.198	3.201	0.004	0.113
Vanillin	10.737	10.730	10.733	10.733	0.004	0.033

Table 3.6. Retention time (min) for TG 1301 MS (6% cyanopropylphenyl 94% dimethyl polysiloxane) column

Solute	**Run1**	**Run 2**	**Run 3**	**Avg**	**Stdev**	**%RSD**
1-Chloronaphthalene	11.177	11.158	11.153	11.163	0.013	0.113
1,2-Dibromoethane	4.780	4.780	4.775	4.778	0.003	0.060
1,2-Dichlorobenzene	7.565	7.567	7.563	7.565	0.002	0.026
1,2-Dimethylbenzene	5.705	5.718	5.723	5.715	0.009	0.163
1,3,5-trimethylbenzene	6.577	6.573	6.565	6.572	0.006	0.093
1-Bromohexane	6.248	6.242	6.243	6.244	0.003	0.051
1-Bromopropane	2.760	2.767	2.772	2.766	0.006	0.218
1-Butanol	3.503	3.487	3.482	3.491	0.011	0.314
1-Nonene	5.332	5.333	5.333	5.333	0.001	0.011
1-Octanol	8.050	8.043	8.048	8.047	0.004	0.045
1-Octene	4.117	4.118	4.118	4.118	0.001	0.014
2-MEthyl -2 propanol	2.503	2.497	2.492	2.497	0.006	0.221
2-Propanol	2.333	2.345	2.352	2.343	0.010	0.410
2-Acetylpyridine	7.722	7.720	7.725	7.722	0.003	0.033
2-Butanone	2.897	2.900	2.898	2.898	0.002	0.053
2-Butoxyethanol	6.172	6.178	6.177	6.176	0.003	0.052
2-Chlorophenol	7.467	7.463	7.470	7.467	0.004	0.047
2-Methyl -2-Pentanol	4.095	4.078	4.085	4.086	0.009	0.209
2-Picoline	4.872	4.870	4.875	4.872	0.003	0.052
3-Amino-1-propanol	5.713	5.732	5.728	5.724	0.010	0.175
4-Chlorophenol	6.195	6.197	6.195	6.196	0.001	0.019
4-Methyl-2 pentanol	4.460	4.457	4.448	4.455	0.006	0.140
4-Nitrotoluene	9.752	9.750	9.750	9.751	0.001	0.012
Acenaphthene	12.003	12.000	11.995	11.999	0.004	0.034
Acetic Acid	3.442	3.425	3.417	3.428	0.013	0.372
Acetic anhydride	4.262	4.258	4.262	4.261	0.002	0.054
Acetophenone	8.240	8.238	8.238	8.239	0.001	0.014
Alpha pinene	5.985	5.980	5.980	5.982	0.003	0.048
Amyl acetate	6.105	6.108	6.102	6.105	0.003	0.049
Aniline	7.398	7.400	7.403	7.400	0.003	0.034
Benzene	3.187	3.187	3.185	3.186	0.001	0.036

Benzoic Acid	10.032	10.150	10.045	10.076	0.065	0.642
Benzonitrile	7.432	7.432	7.430	7.431	0.001	0.016
Benzyl alcohol	8.005	8.018	8.018	8.014	0.008	0.094
Benzyl bromide	8.285	8.295	8.292	8.291	0.005	0.062
Benzyl chloride	7.408	7.412	7.418	7.413	0.005	0.068
Biphenyl	11.038	11.047	11.050	11.045	0.006	0.057
Butyric acid	5.685	5.750	5.728	5.721	0.033	0.578
Butyronitrile	3.688	3.688	3.685	3.687	0.002	0.047
Chlorobenzene	5.175	5.175	5.180	5.177	0.003	0.056
Cyclohexane	2.965	2.947	2.947	2.953	0.010	0.352
Cyclohexanol	6.030	6.052	6.050	6.044	0.012	0.201
Diisopropylamine	3.007	3.005	3.005	3.006	0.001	0.038
Ethanol	2.362	2.358	2.360	2.360	0.002	0.085
Ethanolamine	3.867	3.852	3.860	3.860	0.008	0.194
Ethyl Acetate	2.902	2.903	2.902	2.902	0.001	0.020
Ethyl Acetoacetate	6.715	6.720	6.717	6.717	0.003	0.037
Ethyl benzoate	9.115	9.122	9.138	9.125	0.012	0.129
Ethyl decanoate	10.952	10.952	10.943	10.949	0.005	0.047
Ethyl benzene	5.253	5.258	5.252	5.254	0.003	0.061
Ethylene glycol	4.597	4.522	4.713	4.611	0.096	2.087
Formamide	6.375	6.387	6.376	6.379	0.007	0.104
Iodobenzene	7.528	7.525	7.525	7.526	0.002	0.023
Isoquinoline	10.243	10.252	10.262	10.252	0.010	0.093
Lactic acid	4.513	4.505	4.495	4.504	0.009	0.200
L-menthol	9.013	9.010	9.003	9.009	0.005	0.057
Malonic acid	8.510	8.505	8.508	8.508	0.003	0.030
Methyl isobutyl ketone	4.137	4.132	4.133	4.134	0.003	0.064
Morpholine	4.912	4.925	4.903	4.913	0.011	0.225
n-Propyl alcohol	2.465	2.465	2.462	2.464	0.002	0.070
N,N- dimethylacetamide	6.207	6.210	6.208	6.208	0.002	0.025
N,N- dimethylaniline	8.237	8.233	8.237	8.236	0.002	0.028
N,N-diethylaniline	9.577	9.593	9.568	9.579	0.013	0.132
Naphthalene	9.313	9.320	9.320	9.318	0.004	0.043
Nitrobenzene	8.543	8.543	8.538	8.541	0.003	0.034
Nitromethane	2.860	2.855	2.852	2.856	0.004	0.142
Nonylamine	8.538	8.537	8.542	8.539	0.003	0.031
o-anisaldehyde	10.675	10.677	10.677	10.676	0.001	0.011
o-cresol	8.512	8.518	8.522	8.517	0.005	0.059
Octanoic acid	9.532	9.557	9.527	9.539	0.016	0.169

Octylamine	7.430	7.428	7.433	7.430	0.003	0.034
Pentan-1-ol	4.580	4.580	4.580	4.580	0.000	0.000
Phenol	7.978	7.970	7.963	7.970	0.008	0.094
Piperidine	4.057	4.062	4.058	4.059	0.003	0.065
Propanoic Acid	4.567	4.573	4.548	4.563	0.013	0.286
Propionitrile	2.900	2.903	2.905	2.903	0.003	0.087
Pyridine	4.152	4.147	4.145	4.148	0.004	0.087
Pyrrole	4.790	4.795	4.803	4.796	0.007	0.137
Quinoline	9.955	9.950	9.958	9.954	0.004	0.041
Tetrachloroethylene	4.550	4.542	4.542	4.545	0.005	0.102
Toluene	4.165	4.163	4.163	4.164	0.001	0.028
Triethylamine	3.178	3.173	3.170	3.174	0.004	0.127

Table 3.7. Experimental gas-to-liquid partition coefficient data (E, S, A, B, and L) from the literature [50, 52-53].

SOLUTE	E	S	A	B	L
1-Butanol	0.224	0.420	0.370	0.480	2.601
1,2-Dibromoethane	0.747	0.760	0.100	0.170	3.382
1,2-Dichlorobenzene	0.872	0.780	0.000	0.040	4.518
1,2-Dimethylbenzene	0.663	0.560	0.000	0.160	3.939
1,3,5-Trimethylbenzene	0.649	0.520	0.000	0.190	4.344
1-Bromohexane	0.349	0.400	0.000	0.120	4.130
1-Bromopropane	0.366	0.400	0.000	0.120	2.620
1-Chloronaphthalene	1.417	1.000	0.000	0.140	5.856
1-Nitronaphthalene	1.600	1.590	0.000	0.290	7.056
1-Nonene	0.090	0.080	0.000	0.070	4.073
1-Octanol	0.199	0.420	0.370	0.480	4.619
1-Octene	0.094	0.080	0.000	0.070	3.568
2 Methyl-2- pentanol	0.169	0.300	0.310	0.640	3.240
2 Methyl-2-propanol	0.180	0.300	0.310	0.600	1.963
2-Propanol	0.212	0.360	0.330	0.560	1.764
2-Acetylpyridine	0.730	1.090	0.000	0.620	4.425
2-Bromophenol	1.037	0.850	0.350	0.300	4.802
2-Butanone	0.166	0.700	0.000	0.510	2.287
2-Butoxyethanol	0.201	0.530	0.260	0.830	3.656
2-Chlorobenzoic acid	0.840	1.010	0.680	0.400	4.840
2-Chlorophenol	0.853	0.880	0.320	0.310	4.178
2-Methyl-1-propanol	0.217	0.390	0.370	0.480	2.413
2-Naphthol	1.520	1.080	0.610	0.400	6.200

2-Octanol	0.158	0.360	0.330	0.360	1.295
2-Picoline	0.598	0.750	0.000	0.580	3.422
3-Amino-1-propanol	0.465	0.850	0.380	0.950	3.016
3-Nitrobenzoic acid	0.990	1.130	0.730	0.530	5.535
4-Chlorophenol	0.915	1.080	0.670	0.200	4.775
4-Methyl-2-pentanol	0.167	0.330	0.330	0.550	3.263
4-Nitrophenol	1.070	1.720	0.820	0.260	5.876
4-Nitrotoluene	0.870	1.110	0.000	0.280	5.154
Acenaphthene	1.604	1.050	0.000	0.220	6.469
Acetamide	0.460	1.300	0.550	0.690	2.990
Acetanilide	0.900	1.370	0.400	0.670	5.570
Acetic Acid	0.265	0.640	0.620	0.440	1.816
Acetic Anhydride	0.174	0.800	0.080	0.730	2.735
Acetone	0.179	0.700	0.040	0.490	1.696
Acetophenone	0.818	1.010	0.000	0.480	4.501
Alpha pinene	0.446	0.140	0.000	0.120	4.308
Amyl acetate	0.067	0.600	0.000	0.450	3.844
Aniline	0.955	0.960	0.260	0.410	3.934
Aspirin	0.781	1.690	0.710	0.670	6.279
Benzene	0.610	0.520	0.000	0.140	2.786
Benzoic Acid	0.730	0.900	0.590	0.400	4.657
Benzonitrile	0.742	1.110	0.000	0.330	4.039
Benzophenone	1.450	1.500	0.000	0.500	6.852
Benzyl alcohol	0.803	0.870	0.390	0.560	4.221
Benzyl Bromide	1.014	0.980	0.000	0.200	4.672
Benzyl chloride	0.821	0.860	0.000	0.140	4.353
Biphenyl	1.360	0.990	0.000	0.260	6.014
Bromobenzene	0.882	0.730	0.000	0.090	4.041
Butyric Acid	0.210	0.640	0.610	0.450	2.750
Butyronitrile	0.188	0.900	0.000	0.020	2.548
Caffeine	1.500	1.820	0.080	1.250	7.838
Chloroacetic acid	0.427	1.030	0.790	0.350	2.862
Chlorobenzene	0.718	0.650	0.000	0.070	3.657
Cyclohexane	0.310	1.000	0.000	0.000	2.964
Cyclohexanol	0.460	0.540	0.320	0.570	3.758
Diiodomethane	1.200	0.690	0.050	0.170	3.857
Diisopropylamine	0.053	0.210	0.070	0.740	2.893
Dimethyl Carbonate	0.142	0.540	0.000	0.570	2.328
Ethanol	0.246	0.420	0.370	0.480	1.485

Ethanolamine	0.458	0.670	0.520	0.900	2.432
Ethyl Acetate	0.106	0.620	0.000	0.450	2.314
Ethyl acetoacetate	0.208	0.800	0.000	0.860	3.752
Ethyl benzene	0.613	0.510	0.000	0.150	3.778
Ethyl benzoate	0.689	0.850	0.000	0.460	5.075
Ethyl decanoate	0.013	0.580	0.000	0.450	6.180
Ethyl glycol	0.404	0.900	0.580	0.780	2.661
Formamide	0.468	1.310	0.640	0.570	2.447
Formic Acid	0.343	0.750	0.760	0.330	1.545
Imidazole	0.710	0.850	0.420	0.780	4.018
Indole	1.200	1.120	0.440	0.220	5.505
Iodobenzene	1.188	0.820	0.000	0.120	4.502
Iso-pentyl acetate	0.051	0.570	0.000	0.470	3.740
Isoquinoline	1.211	1.000	0.000	0.540	5.595
L Menthol	0.400	0.500	0.230	0.580	5.177
Lactic acid	0.350	0.860	0.720	0.720	2.874
Malonic acid	0.380	1.460	0.990	0.590	3.616
Methyl Acetate	0.142	0.640	0.000	0.450	1.911
Methyl Benzoate	0.733	0.850	0.000	0.460	4.704
Methyl isobutyl ketone	0.111	0.650	0.000	0.510	3.089
Methyl-4-hydroxybenzoate	0.900	1.370	0.690	0.450	5.716
Morpholine	0.434	0.790	0.060	0.910	3.289
m-Toluic acid	0.730	0.890	0.600	0.400	4.819
N,N-Dimethyl acetamide	0.363	1.380	0.000	0.800	3.639
N,N-Diethyl aniline	0.953	0.800	0.000	0.410	5.287
N,N-Dimethyl aniline	0.957	0.810	0.000	0.410	4.701
N,N-Dimethylformamide	0.367	1.310	0.000	0.740	3.173
Naphthalene	1.340	0.920	0.000	0.200	5.161
Nitrobenzene	0.871	1.110	0.000	0.280	4.557
Nitromethane	0.313	0.950	0.060	0.310	1.892
Nonylamine	0.187	0.350	0.160	0.610	5.100
N,propyl alcohol	0.236	0.420	0.370	0.480	2.031
o-anisaldehyde	0.956	1.120	0.000	0.590	5.300
o-cresol	0.840	0.860	0.520	0.300	0.916
Octanoic acid	0.150	0.650	0.620	0.450	4.680
Octylamine	0.187	0.350	0.160	0.610	4.600
Pentan-1-ol	0.219	0.420	0.370	0.480	3.106
Phenanthrene	2.005	1.290	0.000	0.260	7.632
Phenol	0.805	0.890	0.600	0.300	3.766

Phenyl acetic Acid	0.730	1.080	0.660	0.570	4.962
Piperazine	0.570	0.850	0.300	1.140	3.438
Piperidine	0.422	0.400	0.060	0.770	3.075
Propanoic acid	0.233	0.650	0.610	0.440	2.276
Propionitrile	0.162	0.900	0.020	0.360	2.082
Propylene Carbonate	0.319	1.370	0.000	0.600	3.088
Pyrazine	0.629	0.820	0.000	0.640	2.875
Pyridine	0.631	0.840	0.000	0.520	3.022
Pyrrole	0.613	0.910	0.220	0.250	2.792
Quinoline	1.268	0.970	0.000	0.540	5.457
Resorcinol	0.980	1.110	1.090	0.520	4.618
Tetrachloroethylene	0.640	0.440	0.000	0.000	3.584
Tetrahydrofuran	0.289	0.520	0.000	0.480	2.636
Toluene	0.601	0.520	0.000	0.140	3.325
Triethylamine	0.101	0.150	0.000	0.790	3.040
Vanillin	1.028	1.280	0.330	0.680	5.730
Xanthene	1.502	1.070	0.000	0.230	7.153

The statistical software for social science (SPSS) were used to generate the log of experimental data first, then the process coefficients (c, e, s, a, b, l) and R^2 were obtained from the experimental data using multiple linear regression analysis (MLRA) method. The process co-efficient are used to acquire the log of retention time calculated ($logt_R calc$) as follow

Log = c + e.E+ s.S + a.A + b.B + l.L

ZB wax plus:

c=0.243, e= 0.043, s= 0.249, a= 0.242, b=0.008, l= 0.105, R^2= 0.7005, F =51.391, SD =0.0480 N= 84

Log (calculated) = 0.243 + 0.043E + 0.249S +0.242A + 0.008B + 0.105L (13)

ZB-35:

c= 0.250, e= 0.097, s= 0.075, a= 0.098, b= -0.027, l= 0.108, R^2= 0.862, F = 113.177, SD= 0.037,

N= 85

Log (calculated) = 0.250 + 0.097E + 0.075S + 0.098A – 0.027B + 0.108 L (14)

TR1-MS:

c= 0.250, e=-0.043, s= 0.109, a= 0.105, b=-0.097, l=0.137, R^2= 0.802, F=83.966, SD= 0.031,

N= 90

Log (calculated) = 0.250 – 0.043E + 0.109S + 0.105A – 0.097B + 0.137L (15)

TR-5:

c= 0.063, e=-0.032, s= 0.078, a= 0.160, b= -0.024, L =0.157, R^2= 0.927, F =215.887, SD= 0.023

N= 90

Log (calculated): 0.063- 0.032E +0.078S + 0.160A- 0.024B + 0.157L (16)

TG-5MS:

c= 0.151, e=0.066, s= 0.037, a=0.133, b=-0.021, l=0.129, R^2= 0.873, F =122.144, SD=0.038

N= 88

Log (calculated): 0.151 + 0.066E + 0.037S +0.133A - 0.021B + 0.129L (17)

TG-1301MS:

c=0.107, e= 0.030, s= 0.146, a= 0.167, b= 0.002, l= 0.134, R^2= 0.816, F= 84.634, SD=0.040

N= 82

Log (calculated) = 0.107 + 0.030E + 0.146S + 0.167 A + 0.002B + 0.134L (18)

R^2 is the linear correlation coefficient square, F is the Fisher F-statistic, SD is the standard deviation and N is the number of compounds

Here below are the experimental log and the calculated log of the six columns listed in Tables 3.8 to 3.13.

Table 3.8. Experimental $Logt_R$ and $Logt_R$ calculated for column ZB wax plus

Solute	**Log exp**	**Log calc**	**Solute**	**Log exp**	**Log calc**
1-Bromohexane	0.786	0.792	Nonylamine	0.939	0.917
1,2-Dichlorobenzene	0.970	0.949	o-anisaldehyde	1.098	1.124
1,2-Dimethylbenzene	0.812	0.826	Octylamine*	0.895	0.865
2-Acetylpyridine	1.012	1.015	Phenyl acetic Acid	1.201	1.229
2-Butanone	0.593	0.669	Propylene Carbonate*	1.082	0.927
2-Chlorophenol*	1.084	1.017	Pyridine	0.810	0.801
2-Picoline	0.834	0.819	Quinoline	1.107	1.116
3-Amino-1-propanol*	0.985	0.891	Tetrachloroethylene	0.680	0.756
Acetamide	1.055	1.039	Tetrahydrofuran*	0.540	0.666
Acetic Acid*	0.960	0.758	Toluene	0.695	0.749
Acetone*	0.504	0.617	1-Butanol	0.745	0.724
Acetophenone	1.027	1.006	1-Octanol*	0.971	0.918
Alpha pinene	0.683	0.750	2-Butoxyethanol*	0.909	0.835
Amyl acetate	0.800	0.803	2-Methyl -2-Pentanol	0.708	0.745
Aniline*	1.056	1.002	4-Chlorophenol	1.186	1.216
Benzene*	0.603	0.692	4-Methyl-2 pentanol	0.764	0.759
Benzoic Acid*	1.197	1.133	4-Nitrotoluene	1.075	1.100
Benzonitrile	1.013	0.978	Acetic anhydride*	0.820	0.762
Benzyl chloride	0.979	0.951	Benzyl bromide	1.005	1.023
Biphenyl	1.103	1.182	Butyric acid*	0.987	0.851
Bromobenzene	0.906	0.888	Butyronitrile	0.710	0.746
Chlorobenzene	0.830	0.820	Cyclohexane	0.525	0.592
Diiodomethane	0.848	0.885	Cyclohexanol	0.912	0.874
Ethanol	0.599	0.607	Diisopropylamine*	0.515	0.624
Ethyl Acetate*	0.555	0.649	Dimethyl carbonate	0.606	0.633
Ethyl benzoate	1.031	1.021	Ethanolamine*	0.906	0.818
Ethyl decanoate	1.017	1.040	Ethyl Acetoacetate*	0.934	0.852
Formamide	1.004	1.006	Ethylbenzene	0.732	0.794
Isoquinoline	1.117	1.136	Ethylene glycol*	1.003	0.910
Lactic acid*	0.887	0.954	Formic acid*	0.524	0.793
Mesitylene	0.850	0.858	Iodobenzene	0.961	0.972
Methyl acetate*	0.512	0.613	Malonic acid*	0.926	1.247
Methyl benzoate	1.017	0.984	N,N	0.916	0.991

			dimethylacetamide*		
Methyl isobutyl ketone	0.664	0.738	Nitromethane*	1.075	0.709
Methyl cyclohexane*	0.888	0.617	Octanoic acid*	1.111	1.056
Morpholine	0.852	0.826	Piperidine	0.671	0.704
N,propyl alcohol	0.591	0.664	Propionitrile	0.642	0.700
N,N-Diethylaniline	1.016	1.042	Pyrrole*	0.958	0.844
N,N-Dimethylaniline	0.992	0.983	Triethyl amine*	0.518	0.610
N,N-Dimethylformamide	0.899	0.924	Pentan-1-ol*	0.848	0.777
Naphthalene	1.055	1.073	Phenol*	1.125	1.042
Nitrobenzene	1.054	1.038	1-Bromopropane*	0.461	0.609
1-Nonene*	0.543	0.652	1-Octene*	0.417	0.601
2- Propanol	0.534	0.605	Propanoic Acid*	0.959	0.803

*(asterisk) signifies compounds that are outliers and are not used for the least square method.

Table 3.9. Experimental $Logt_R$ and $Logt_R$ calculated for column ZB 35

Solute	**Log exp**	**Log calc**	**Solute**	**Log exp**	**Log calc**
1,3,5-Trimethylbenzene	0.840	0.809	Octylamine*	0.875	0.792
1-Bromohexane*	0.810	0.748	Pentane-1-ol	0.660	0.655
1 -Chloronaphthalene	1.070	1.092	Phenol	0.873	0.849
1-Nitronaphthalene*	1.145	1.291	Phenylacetic Acid	1.016	0.994
1,2-Dichlorobenzene	0.908	0.873	Pyridine	0.689	0.683
1,2-Dimethylbenzene	0.791	0.769	Quinoline	1.027	1.027
2-Acetylpyridine	0.921	0.869	Resorcinol	1.036	1.025
2-Butanone	0.529	0.545	Tetrachloroethylene	0.702	0.719
2-Chlorobenzoic acid*	1.062	0.989	Toluene	0.675	0.691
2-Chlorophenol	0.880	0.871	Vanillin	1.084	1.092
2-Picoline	0.749	0.717	1-Butanol*	0.499	0.599
4-Nitrophenol*	1.119	1.201	1,2-Dibromoethane*	0.698	0.741
Acenaphthene*	1.104	1.182	1-Bromopropane*	0.453	0.580
Acetanilide	1.080	1.076	1-Nonene	0.686	0.691
Acetic Acid	0.536	0.559	1-Octanol	0.880	0.823
Acetone	0.472	0.484	1-Octene*	0.571	0.634
Acetophenone*	0.941	0.881	2 Propanol*	0.367	0.495
Alpha pinene	0.788	0.755	2-Butoxyethanol*	0.773	0.710
Amyl acetate*	0.795	0.702	2-Methyl -2-Pentanol*	0.558	0.648
Aniline	0.893	0.853	2 - Methyl -2 propanol*	0.384	0.507
Aspirin*	1.000	1.201	4-Chlorophenol	0.987	0.996

Benzene*	0.576	0.632	4-Methyl-2 pentanol	0.635	0.656
Benzoic Acid	0.979	0.940	4-Nitrotoluene	0.994	0.969
Benzonitrile*	0.900	0.832	Acetic anhydride	0.616	0.610
Benzophenone*	1.144	1.245	Benzyl alcohol	0.900	0.874
Benzyl chloride	0.902	0.856	Benzyl bromide	0.936	0.919
Biphenyl*	1.066	1.102	Butyric acid*	0.607	0.657
Chlorobenzene	0.758	0.751	Butyronitrile	0.609	0.594
Ethanol	0.452	0.476	Cyclohexane*	0.459	0.590
Ethyl Acetate	0.528	0.536	Cyclohexanol	0.763	0.755
Ethyl benzoate	0.979	0.920	Diisopropylamine*	0.503	0.566
Ethyl decanoate*	1.034	0.957	Dimethyl carbonate*	0.474	0.533
Formamide*	0.825	0.705	Ethanolamine*	0.583	0.634
Isopentyl acetate*	0.762	0.686	Ethylbenzene	0.750	0.742
Isoquinoline	1.035	1.039	Iodobenzene	0.897	0.904
Lactic acid*	0.656	0.711	Ethylene glycol*	0.602	0.681
Methyl Acetate	0.479	0.496	L-menthol	0.938	0.896
Methyl isobutyl ketone	0.644	0.625	N,N- dimethyl acetamide	0.796	0.769
Methyl-4-hydroxybenzoate	1.093	1.123	Nitromethane*	0.456	0.543
Morpholine	0.734	0.692	Octanoic acid	0.908	0.869
m, Toluic acid*	1.018	0.958	Piperidine	0.651	0.636
N,N-Diethylaniline	0.997	0.965	Propanoic Acid	0.607	0.607
Naphthalene	0.994	1.000	Propionitrile*	0.462	0.542
Nitrobenzene	0.957	0.902	Pyrazine	0.632	0.663
Nonylamine*	0.931	0.848	Pyrrole*	0.650	0.686
o-anisaldehyde*	1.051	0.991	Triethyl amine*	0.522	0.575
o-cresol*	0.920	0.522			

*(asterisk) signifies compounds that are outliers and are not used for the least square method.

Table 3.10. Experimental $Logt_R$ and $Logt_R$ calculated for column TR-1MS

Solute	**Log exp**	**Log calc**	**Solute**	**Log exp**	**Log calc**
1,3,5-Trimethylbenzene	0.936	0.875	n-Propyl alcohol	0.611	0.579
1-bromohexane	0.905	0.855	o-anisaldehyde*	1.078	0.994
1 -chloronaphthalene	1.099	1.096	Octylamine*	0.967	0.874
1-nitronaphthalene*	1.154	1.281	Pentane-1-ol	0.781	0.720
1,2-Dichlorobenzene	0.961	0.932	Phenanthrene*	1.195	1.320
2-acetylpyridine*	0.954	0.880	Phenol*	0.928	0.874
2-butanone	0.651	0.598	Phenyl acetic Acid	1.049	1.023
2-chlorophenol	0.939	0.896	Pyridine	0.758	0.690
2-picoline	0.818	0.728	Quinoline	1.048	0.997

acenaphthene	1.128	1.165	Resorcinol	1.056	1.023
Acetanilide	1.089	1.084	Tetrachloroethylene	0.823	0.792
Acetic Acid	0.667	0.600	Toluene	0.785	0.749
Acetone	0.626	0.527	Vanillin	1.097	1.084
Acetophenone*	0.975	0.897	Xanthene	1.168	1.258
Alpha pinene*	0.922	0.852	1-Butanol*	0.514	0.654
Amyl acetate*	0.889	0.804	1-octanol	0.893	0.919
Aniline*	0.924	0.849	2-butoxyethanol	0.772	0.748
Benzene	0.701	0.678	2-Methyl -2-Pentanol*	0.593	0.703
Benzoic Acid	1.021	0.981	2 - Methyl -2 propanol*	0.398	0.540
Benzonitrile*	0.925	0.867	4-Chlorophenol*	0.955	1.039
Benzophenone	1.159	1.225	4-Methyl-2 pentanol*	0.620	0.722
Benzyl chloride	0.949	0.907	4-Nitrotoluene	0.964	1.015
Biphenyl	1.096	1.103	Acetic anhydride*	0.399	0.646
Chlorobenzene*	0.911	0.809	Benzyl bromide	0.905	0.945
Ethanol	0.595	0.507	Butyric acid	0.720	0.722
Ethyl Acetate	0.661	0.604	Butyronitrile*	0.500	0.668
Ethyl benzoate	1.021	0.965	Cyclohexane*	0.521	0.692
Ethyl decanoate	1.097	1.110	Cyclohexanol	0.750	0.792
Formamide*	0.823	0.721	Diisopropylamine*	0.515	0.617
Isopentyl acetate*	0.870	0.786	Dimethyl carbonate*	0.457	0.583
Isoquinoline	1.057	1.020	Ethanolamine	0.524	0.610
Lactic acid*	0.889	0.731	Ethyl Acetoacetate	0.786	0.754
Methyl Acetate	0.628	0.552	Ethylbenzene	0.734	0.806
Methyl isobutyl ketone	0.756	0.700	Iodobenzene	0.871	0.913
Methyl-4-hydroxybenzoate	1.110	1.160	Ethylene glycol*	0.567	0.683
Morpholine*	0.798	0.685	N,N-dimethylacetamide	0.719	0.793
N,N-Diethylaniline	1.044	0.986	Octanoic acid	0.923	0.978
N,N dimethylaniline*	0.987	0.910	Piperidine	0.621	0.641
Naphthalene	1.034	0.993	Propionitrile*	0.415	0.609
Nitrobenzene	0.984	0.936	Pyrrole*	0.605	0.722
Nonylamine*	1.014	0.939	Triethylamine	0.546	0.616

*(asterisk) signifies compounds that are outliers and are not used for the least square method.

Table 3.11. Experimental $Logt_R$ and $Logt_R$ calculated for column TR-5

Solute	Log exp	Log calc	Solute	Log exp	Log calc
1,3, 5-Trimethylbenzene	0.812	0.741	N,N-dimethylaniline*	0.897	0.795
1-Bromohexane	0.786	0.718	Naphthalene*	0.949	0.857
1 -Chloronaphthalene	1.032	0.969	Nitrobenzene*	0.900	0.804
1-Nitronaphthalene*	1.099	1.189	Nonylamine	0.925	0.890
1,2-Dichlorobenzene*	0.863	0.778	n-Propyl alcohol*	0.379	0.448
1,2-Dimethylbenzene	0.749	0.680	o-anisaldehyde	0.974	0.909
2-Acetylpyridine	0.861	0.783	Octylamine	0.863	0.812
2-Butanone	0.424	0.454	Pentan-1-ol	0.609	0.618
2-Chlorobenzoic acid	1.026	0.949	Phenanthrene*	1.144	1.231
2-Chlorophenol	0.830	0.778	Phenol	0.821	0.763
2-Picoline	0.663	0.608	Phenylacetic Acid	0.973	0.973
3-Amino-1-propanol	0.687	0.612	Pyridine	0.579	0.551
3-Nitrobenzoic acid	1.089	1.063	Quinoline	0.975	0.904
Acenaphthene	1.065	1.056	Resorcinol	0.986	0.976
Acetanilide*	1.026	1.036	Tetrachloroethylene	0.660	0.620
Acetic Acid	0.458	0.470	Toluene	0.603	0.585
Acetone	0.370	0.367	Vanillin	1.034	1.035
Acetophenone*	0.885	0.786	Xanthene*	1.113	1.171
Alpha pinene	0.788	0.720	1-Butanol*	0.421	0.538
Amyl acetate	0.764	0.698	1.2 dibromoethane	0.637	0.619
Aniline*	0.820	0.728	1-Bromopropane*	0.433	0.480
Benzoic Acid	0.960	0.904	1-Nonene	0.728	0.701
Benzonitrile*	0.825	0.730	1-octene	0.614	0.622
Benzophenone*	1.104	1.154	2 propanol*	0.352	0.394
Benzyl chloride*	0.845	0.759	4-chlorophenol*	0.923	0.943
Biphenyl	1.029	0.994	4-Methyl-2 pentanol*	0.545	0.630
Chlorobenzene	0.700	0.642	Benzyl alcohol	0.854	0.793
Ethanol	0.358	0.361	Butyronitrile*	0.435	0.513
Ethyl Acetate	0.433	0.457	Cyclohexane*	0.416	0.517
Ethyl benzoate	0.941	0.872	Cyclohexanol*	0.697	0.704
Ethyl decanoate*	1.029	1.067	Diisopropylamine*	0.414	0.524
Formamide*	0.695	0.609	Ethylbenzene	0.665	0.654
Isopentyl acetate	0.732	0.680	Iodobenzene	0.831	0.757
Isoquinoline	0.985	0.931	L-menthol	0.931	0.913
Lactic acid*	0.773	0.658	Nitromethane*	0.337	0.417
Methyl Acetate	0.383	0.393	Piperidine	0.541	0.542

Methyl isobutyl ketone	0.573	0.580	Propanoic Acid	0.584	0.544
Methyl-4-hydroxybenzoate*	1.050	1.111	Propionitrile*	0.343	0.445
Morpholine	0.652	0.602	Pyrrole	0.547	0.564
N,N-Diethylaniline	0.966	0.887	Triethylamine*	0.443	0.527

*(asterisk) signifies compounds that are outliers and are not used for the least square method.

Table 3.12. Experimental $Logt_R$ and $Logt_R$ calculated for column TG-5MS

Solute	**Log exp**	**Log calc**	**Solute**	**Log exp**	**Log calc**
1,3, 5-Trimethylbenzene	0.806	0.769	Nonylamine*	0.920	0.843
1-Bromohexane*	0.777	0.719	n-Propyl alcohol*	0.347	0.483
1-Nitronaphthalene*	1.097	1.220	o-anisaldehyde*	1.007	0.927
1,2-Dichlorobenzene	0.859	0.819	o-cresol*	0.868	0.419
1,2-Dimethylbenzene	0.739	0.720	Octylamine*	0.859	0.778
2-Acetylpyridine	0.855	0.797	Pentan-1-ol	0.595	0.621
2-Butanone	0.413	0.472	Phenanthrene*	1.141	1.310
2-Chlorobenzoic acid*	1.020	0.950	Phenol	0.814	0.796
2-Chlorophenol	0.825	0.815	Phenyl acetic Acid	0.975	0.955
2-Picoline	0.649	0.647	Pyridine	0.568	0.603
3-Amino-1-propanol	0.680	0.633	Quinoline	0.972	0.963
3-Nitrobenzoic acid	1.085	1.058	Resorcinol	0.981	0.987
4-Nitrophenol	1.070	1.147	Tetrachloroethylene	0.651	0.672
Acenaphthene	1.063	1.126	Toluene	0.599	0.636
Acetanilide	1.023	1.019	Vanillin	1.031	1.035
Acetic Acid*	0.429	0.500	1-Butanol*	0.484	0.556
Acetone	0.347	0.403	1,2 dibromoethane	0.637	0.674
Acetophenone	0.880	0.813	1-Bromopropane*	0.433	0.525
Amyl acetate*	0.757	0.664	1-Nonene	0.728	0.684
Aniline	0.816	0.783	1-Octene	0.614	0.619
Aspirin*	0.997	1.155	2 Propanol*	0.352	0.438
Benzene*	0.475	0.567	2-Butoxyethanol*	0.757	0.673
Benzoic Acid	0.956	0.903	2-Methyl -2-Pentanol*	0.564	0.619
Benzonitrile*	0.822	0.755	2 - Methyl -2 propanol*	0.370	0.456
Benzophenone	1.101	1.176	4-Chlorophenol	0.949	0.952
Benzyl chloride	0.843	0.796	4-Methyl-2 pentanol	0.599	0.627
Biphenyl	1.027	1.048	Benzyl alcohol	0.854	0.821
Chlorobenzene	0.690	0.693	Benzyl bromide	0.901	0.853
Ethanol	0.333	0.413	Butyronitrile	0.492	0.518

Ethyl Acetate	0.423	0.470	Cyclohexane*	0.479	0.558
Ethyl benzoate*	0.937	0.873	Cyclohexanol	0.741	0.717
Ethyl decanoate	1.026	0.961	Diisopropylamine	0.476	0.529
Formamide*	0.711	0.619	Dimethyl carbonate	0.434	0.469
Isopentyl acetate*	0.721	0.648	Ethanolamine*	0.497	0.570
Isoquinoline	0.982	0.978	Ethyl benzene	0.715	0.695
Lactic acid*	0.593	0.657	Iodobenzene	0.866	0.838
Methyl Acetate	0.362	0.421	L-menthol	0.931	0.882
Methyl isobutyl ketone	0.564	0.570	N,N-dimethylacetamide	0.720	0.679
Methyl-4-hydroxybenzoate	1.046	1.081	Nitromethane	0.392	0.452
Morpholine	0.628	0.622	Piperidine	0.596	0.582
N,N-Diethylaniline	0.962	0.917	Propanoic Acid	0.584	0.556
N,N dimethylaniline	0.894	0.842	Propionitrile	0.403	0.459
Naphthalene	0.946	0.935	Pyrrole	0.591	0.609
Nitrobenzene	0.894	0.832	Triethylamine	0.505	0.539

*(asterisk) signifies compounds that are outliers and are not used for the least square method

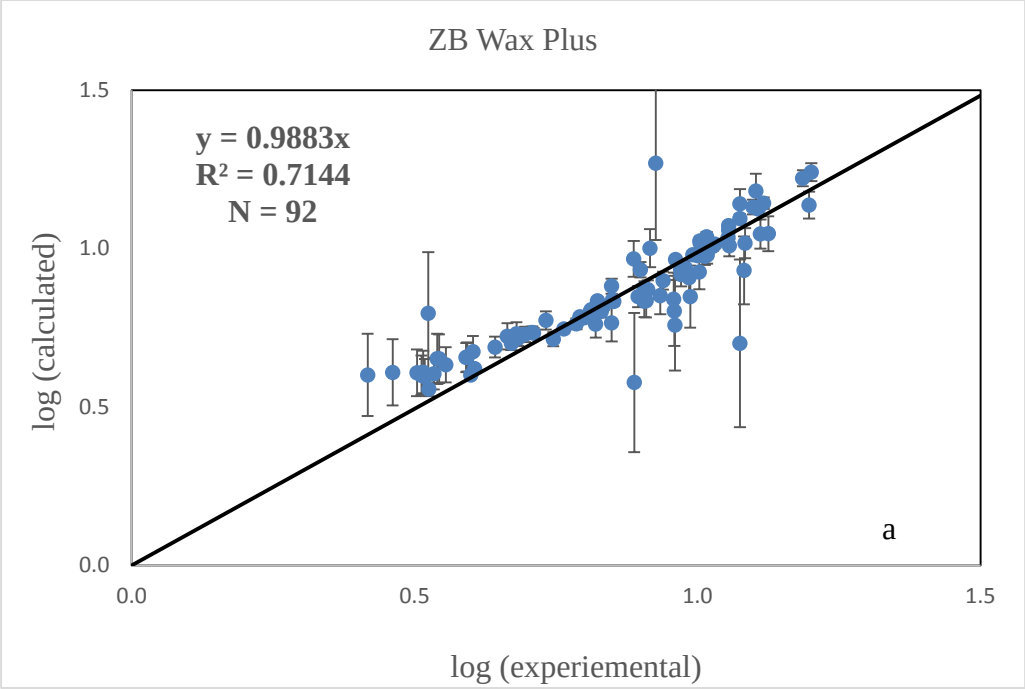
Table 3.13. Experimental $Logt_R$ and $Logt_R$ calculated for column TG-1301MS

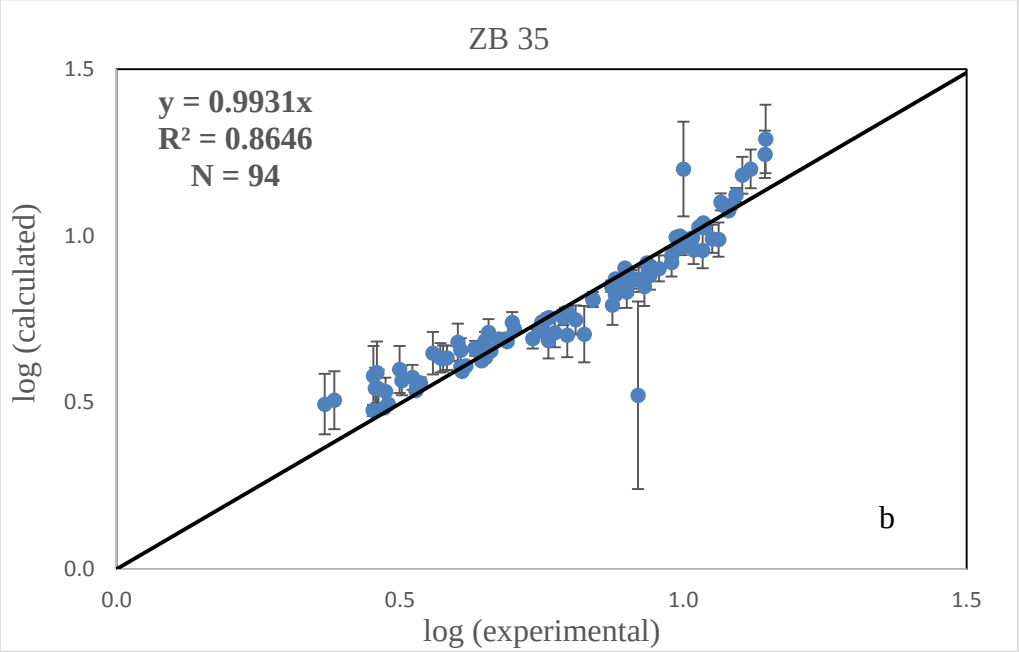
Solute	**Log exp**	**Log calc**	**Solute**	**Log exp**	**Log calc**
1,3,5-Trimethylbenzene	0.818	0.781	Phenol	0.901	0.863
1-Bromohexane*	0.795	0.724	Pyridine	0.618	0.658
1-Chloronaphthalene	1.048	1.076	Quinoline	0.998	1.015
1,2-Dichlorobenzene	0.879	0.850	Tetrachloroethylene	0.658	0.671
1,2-Dimethylbenzene	0.757	0.735	Toluene	0.619	0.648
2-Acetylpyridine	0.888	0.879	1-Butanol	0.543	0.585
2-Butanone	0.462	0.525	1,2-Dibromoethane	0.679	0.713
2-Chlorophenol	0.873	0.872	1-Bromopropane	0.442	0.531
2-Picoline	0.688	0.695	1-Nonene*	0.727	0.659
3-Amino-1-propanol	0.758	0.714	1-Octanol	0.906	0.843
Acenaphthene*	1.079	1.170	1-Octene	0.615	0.594
Acetic Acid	0.535	0.558	2 Propanol*	0.370	0.463
Acetophenone	0.916	0.880	2-Butoxyethanol*	0.791	0.719
Alpha pinene*	0.777	0.712	2-Methyl -2-Pentanol	0.611	0.638
Amyl acetate*	0.786	0.705	2 - Methyl -2 propanol	0.397	0.475
Aniline	0.869	0.847	4-Chlorophenol*	0.792	1.035
Benzene*	0.503	0.580	4-Methyl-2 pentanol	0.649	0.648

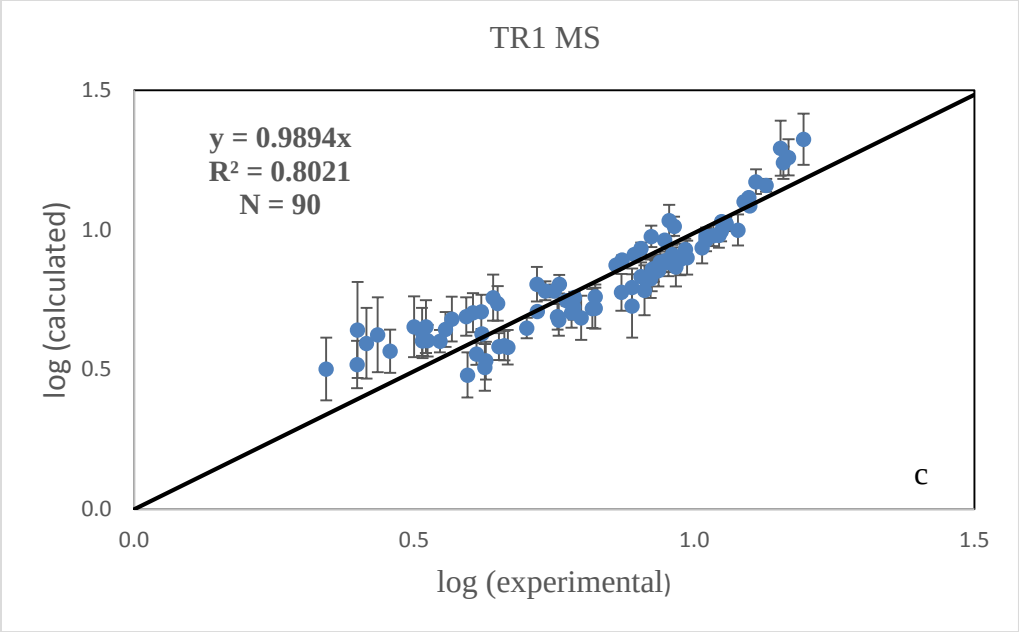
Benzoic Acid	1.003	0.974	4-Nitrotoluene	0.989	0.980
Benzonitrile	0.871	0.832	Acetic anhydride	0.629	0.610
Benzyl chloride	0.870	0.839	Benzyl alcohol	0.904	0.885
Biphenyl	1.043	1.093	Benzyl bromide	0.919	0.905
Chlorobenzene	0.714	0.715	Butyric acid*	0.757	0.674
Ethanol	0.373	0.443	Butyronitrile	0.567	0.588
Ethyl Acetate	0.463	0.514	Cyclohexane	0.470	0.529
Ethyl benzoate	0.960	0.925	Cyclohexanol	0.781	0.753
Ethyl decanoate	1.039	0.999	Diisopropylamine	0.478	0.538
Formamide*	0.805	0.749	Ethanolamine	0.587	0.634
Isoquinoline	1.011	1.035	Ethyl Acetoacetate*	0.827	0.729
Lactic acid*	0.654	0.746	Ethylbenzene	0.721	0.705
Methyl isobutyl ketone	0.616	0.618	Ethylene glycol	0.664	0.704
Morpholine	0.691	0.687	Iodobenzene	0.877	0.867
N,N-Diethylaniline	0.981	0.955	L-menthol	0.955	0.912
N,N- dimethylaniline	0.916	0.882	Malonic acid	0.930	0.972
Naphthalene	0.969	0.972	N,N-dimethylacetamide	0.793	0.806
Nitrobenzene	0.932	0.904	Nitromethane	0.456	0.526
Nonylamine*	0.931	0.860	Octanoic acid	0.979	0.922
n-Propyl alcohol*	0.392	0.513	Piperidine	0.608	0.602
o-anisaldehyde	1.028	1.004	Propanoic Acid	0.659	0.616
o-cresol*	0.930	0.483	Propionitrile	0.463	0.530
Octylamine*	0.871	0.796	Pyrrole	0.681	0.673
Pentan-1-ol	0.661	0.650	Triethylamine	0.502	0.539

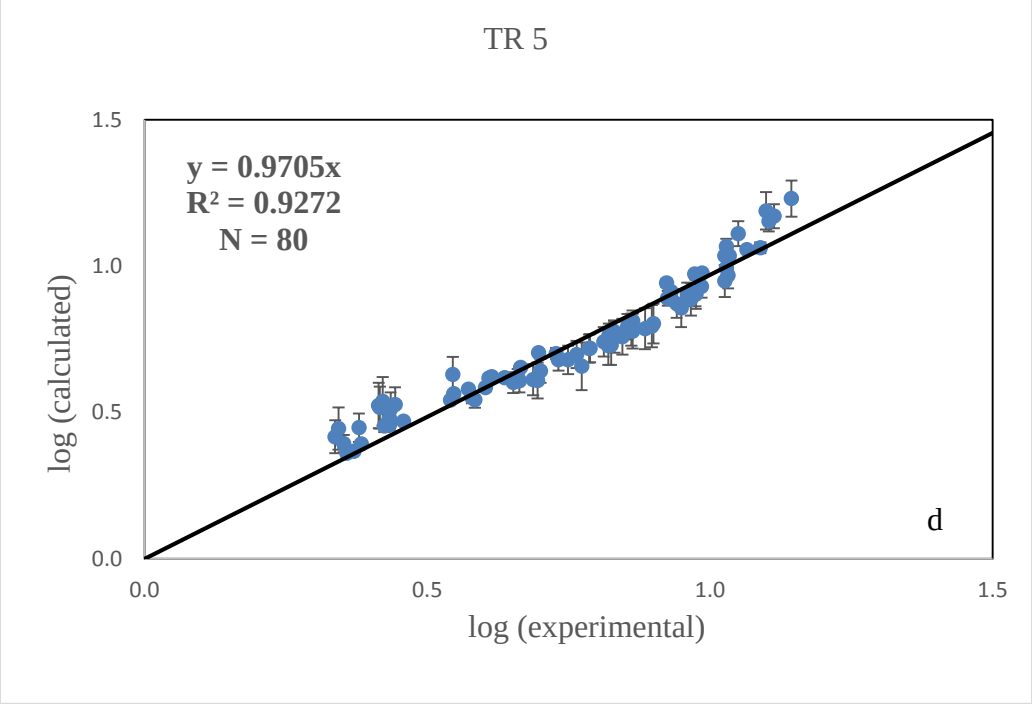
*(asterisk) signifies compounds that are outliers and are not used for the least square method

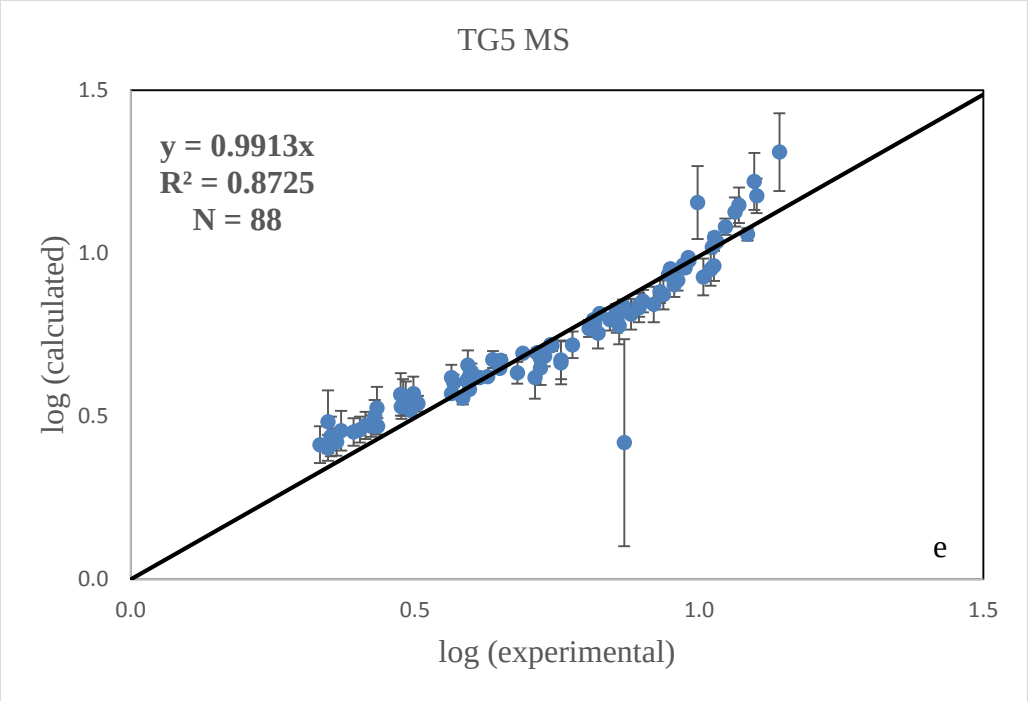
Shown below are the linear correlation between the $Logt_R$ (experimental) and $Logt_R$ (calculated) for the six columns used in Figure 3.1


ZB Wax Plus
y = 0.9883x
R² = 0.7144
N = 92
a
log (calculated)
log (experiemental)
0.0
0.5
1.0
1.5


ZB 35
y = 0.9931x
R² = 0.8646
N = 94
b
log (calculated)
log (experimental)
0.0
0.5
1.0
1.5


TR1 MS
y = 0.9894x
R² = 0.8021
N = 90
log (calculated)
log (experimental)
0.0
0.5
1.0
1.5
c


TR 5
y = 0.9705x
R² = 0.9272
N = 80
log (calculated)
log (experimental)
0.0
0.5
1.0
1.5
d



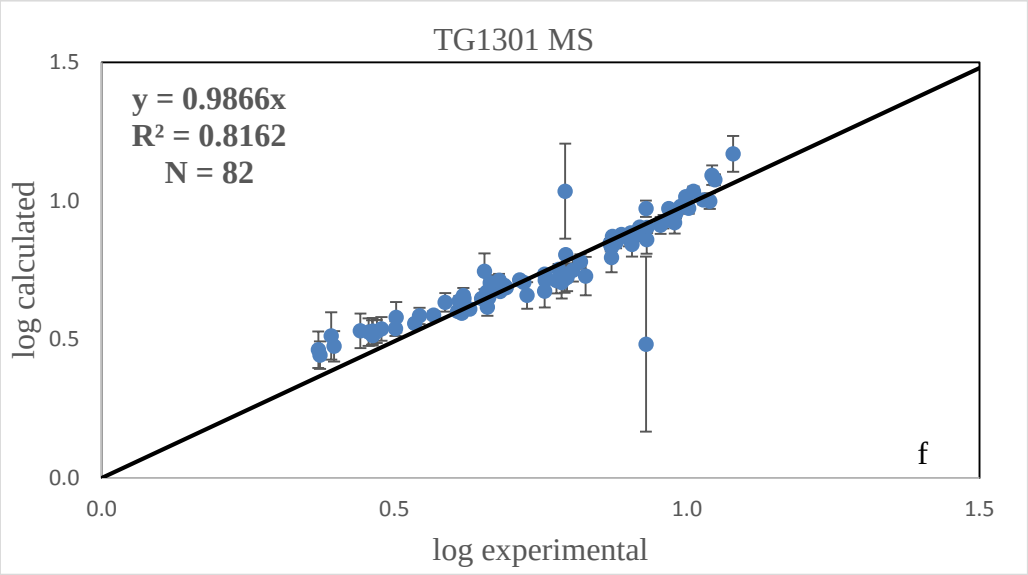
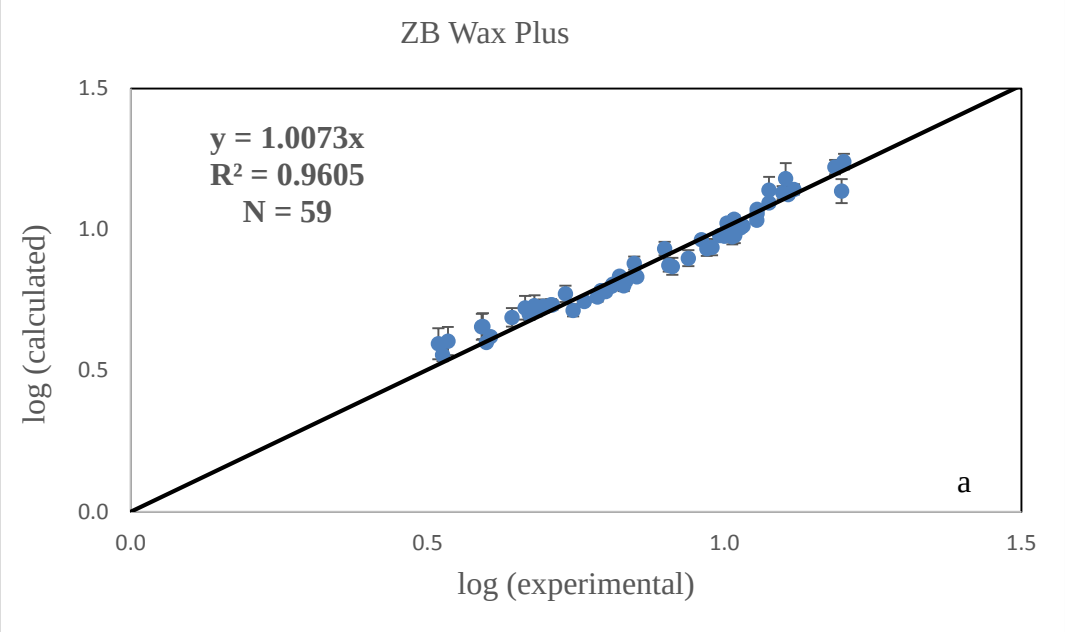


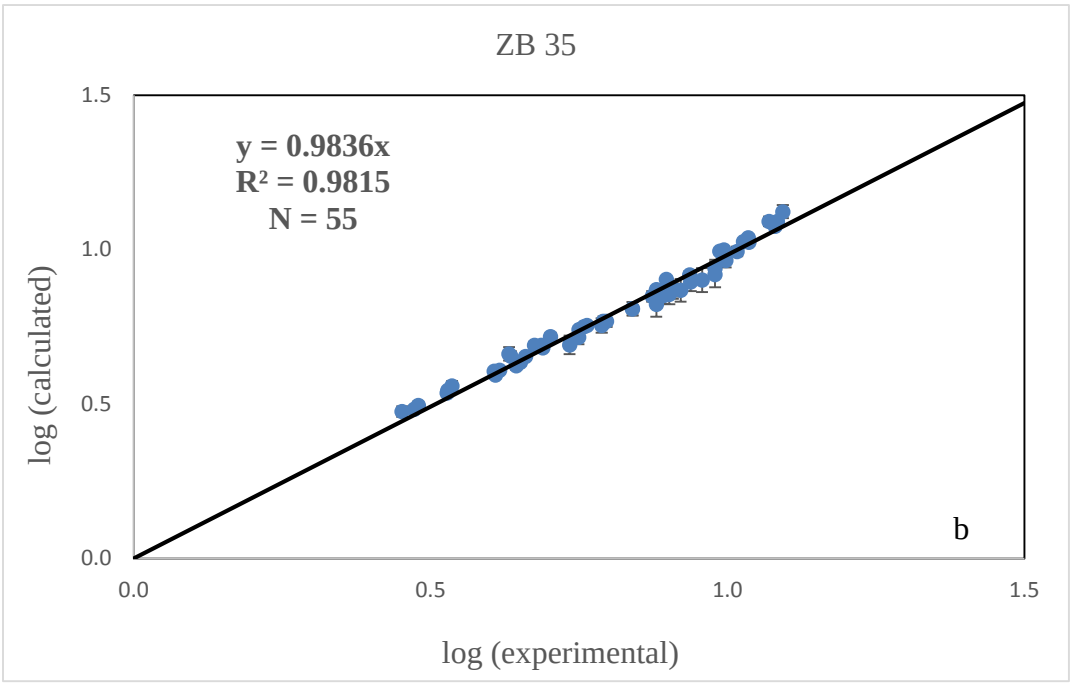
Figure 3.1. Correlation of $Logt_R$ (calculated) and $Logt_R$ (experimentally) observed for the six columns.
ZB wax plus (a), ZB 35(b), TR-1MS(c), TR-5(d), TG-5MS (e), TG-1301MS (f)

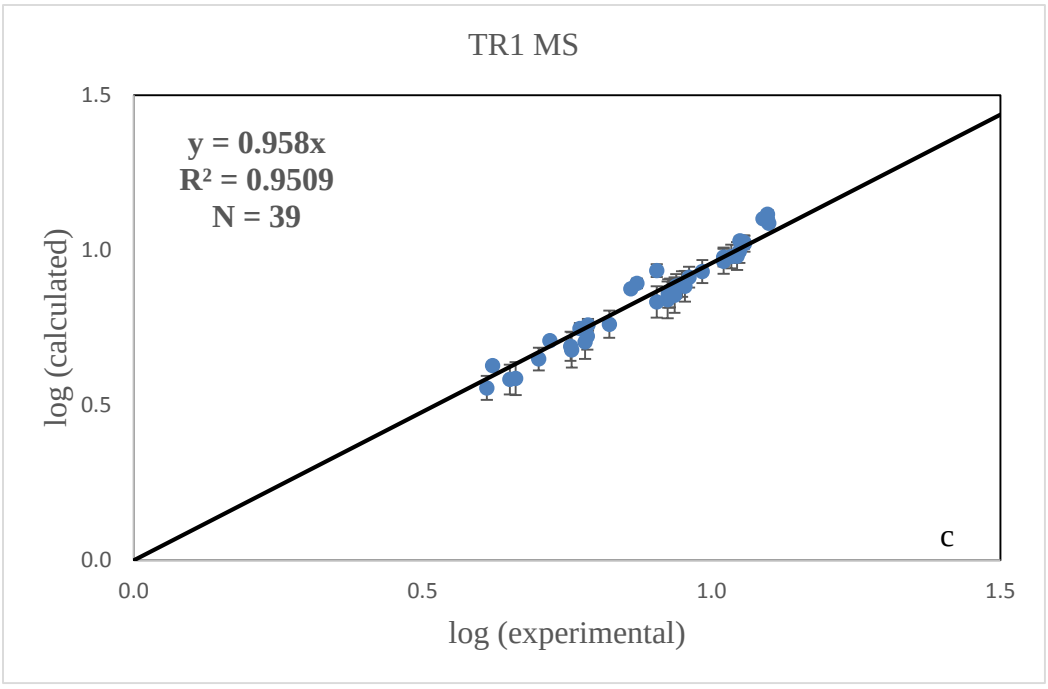
3.2 Discussion

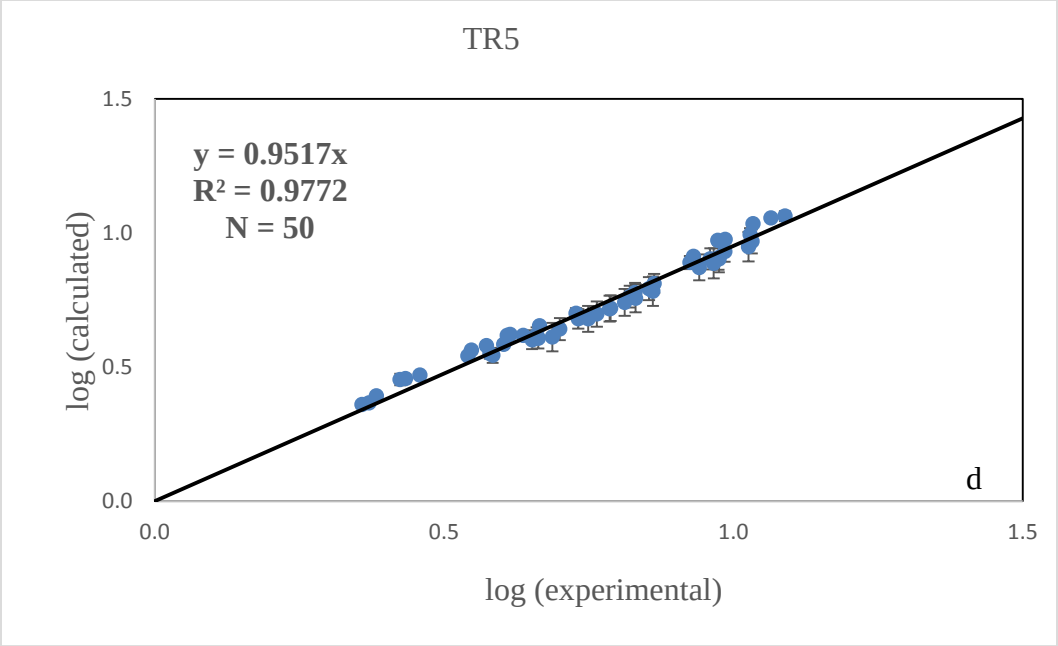
3.2.1 Active Compounds for Each Column

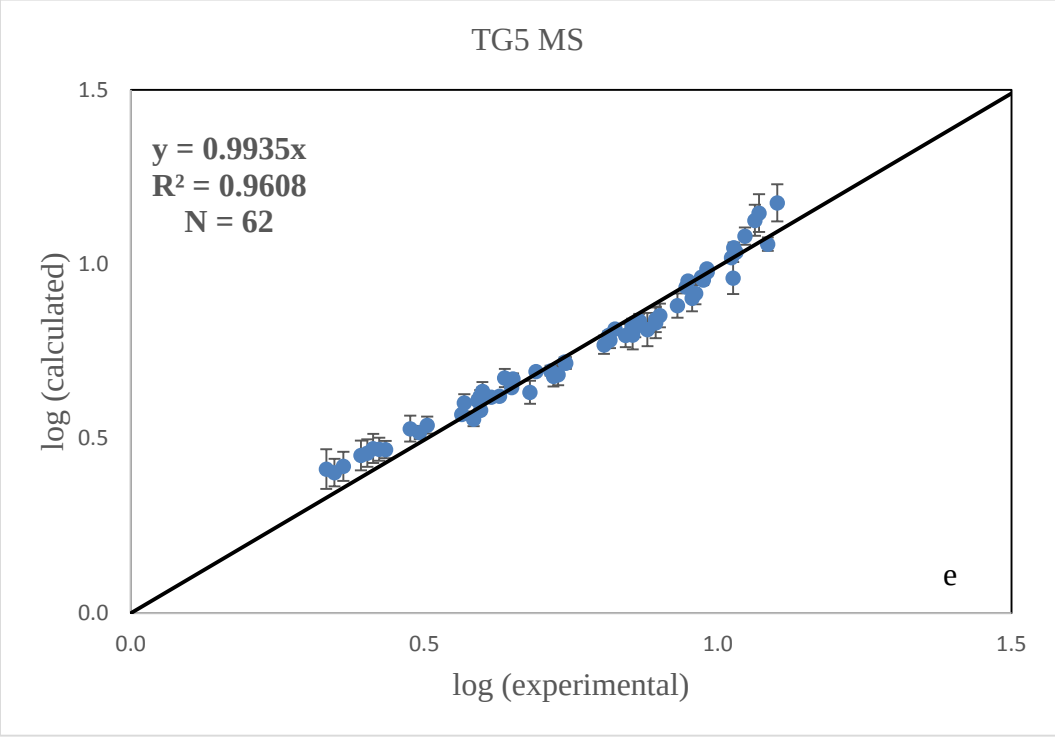
After analysis of the data, the least square method was applied to characterize the correlation between the $Logt_R$ (calculated) and the $Logt_R$ (experimental) in this study. Not all data fit on the trend line, thus the outliers were removed by using the standard error bar for each points. Table 3.8.1 to table 3.8.6 shows all effective or active compounds and all outliers that were removed. The correlation coefficient of $Logt_R$ (calculated) and $Logt_R$ (experimental) got better or increase close to 1 which indicated a better correlation between data when outliers are removed. Below are the correlations between the experimental and calculated log for all six columns with no outliers.




ZB 35
y = 0.9836x
R² = 0.9815
N = 55
b
log (calculated)
log (experimental)
0.0
0.5
1.0
1.5


TR1 MS
y = 0.958x
R² = 0.9509
N = 39
c
log (calculated)
log (experimental)
0.0
0.5
1.0
1.5


TR5
y = 0.9517x
R² = 0.9772
N = 50
d
log (calculated)
log (experimental)
0.0
0.5
1.0
1.5


TG5 MS
y = 0.9935x
R² = 0.9608
N = 62
e
log (calculated)
log (experimental)
0.0
0.5
1.0
1.5

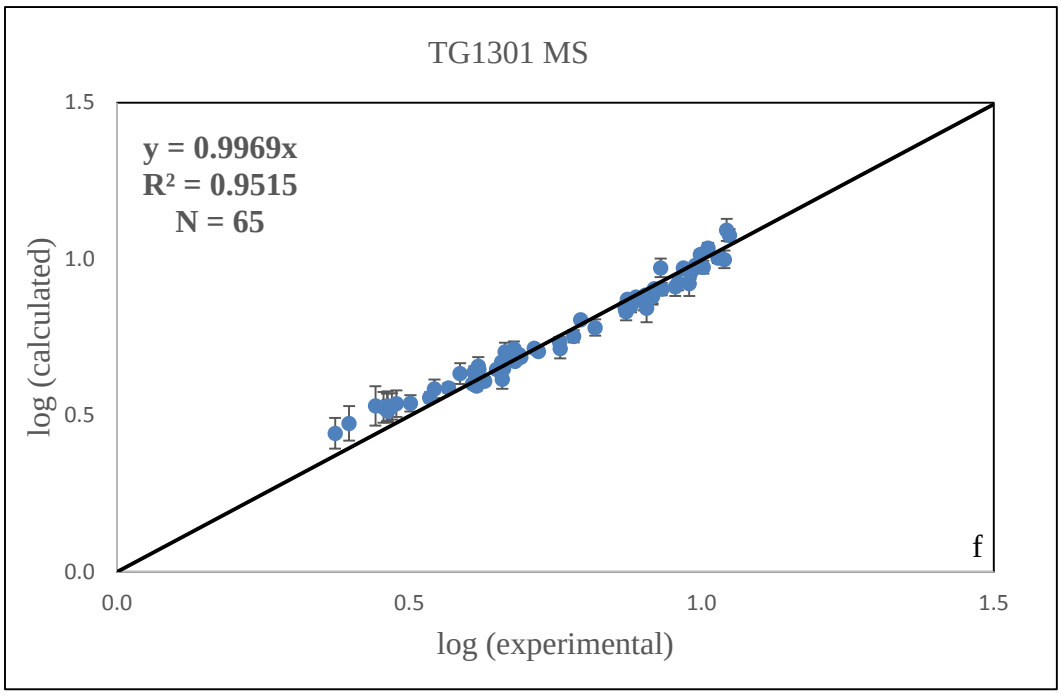


Figure 3.2. Correlation of $Logt_R$ (calculated) and $Logt_R$ (experimentally) observed for the six columns ZB wax plus (a), ZB 35(b), TR- 1MS(c), TR-5(d), TG-5MS (e), TG1301 MS (f) for just active compounds.

After the removal of the outliers, the linear coefficients (R^2) of the six columns increased. The R^2 now lies between 0.95 and 0.98 which is close to 1 meaning that the experimental and calculated values of active compounds have a good correlation. The six columns used have different polarities; from non-polar, mid or low polarity to a polar stationary phase. Depending on the type of organic compounds used, not all samples would interaction very well on each stationary phase. Some organic compounds would interact better with one stationary phase than the other. We do not anticipate all compounds to interact due to the difference of the stationary phase of all six columns. The rule of like dissolves like is convenient, compounds that are non-polar would interact very well with non-polar stationary phase and polar compounds would do the same with polar stationary phase. The mid and low polarity stationary phase can interact well

with polar and non- polar organic compounds depending on their boiling point and how strong they interact with the stationary phase.

The removal of ineffective compounds or outliers allows the recalculation of new process coefficient with only the active or effective compounds.

With the new process coefficients, a new set of Abraham solvation model equations are established

ZB wax plus:

c= 0.177, e= 0.036, s= 0.284, a= 0.272, b= 0.007, l= 0.112, R^2 = 0.961, SD= 0.013, F=377.789

N= 59

Log (calculated) = 0.177 + 0.036E + 0.284S + 0.272A + 0.07B + 0.112L (19)

ZB 35:

c=0.191, e=0.061, s=0.087, a=0.082, b=-0.003, l=0.127, R^2= 0.982, SD=0.010, F= 682.767

N=55

Log (calculated) = 0.191 + 0.061E + 0.087S + 0.082A – 0.003B + 0.127 (20)

TR1 MS:

c=0.361, e=-0.048, s= 0.131, a= 0.086, b= -0.133, l= 0.121, R^2= 0.951, SD= 0.017, F= 172.851

N=39

Log (calculated) =0.361 – 0.048E + 0.131S +0.086A – 0.133B + 0.121L (21)

TR-5:

c=0.055, e=-0.047, s= 0.064, a= 0.146, b= -0.014, l =0.161, R^2= 0.977, SD= 0.018, F= 445.857

N=50

Log (calculated) = 0.055 – 0.047E + 0.064S +0.146A – 0.014B + 0.161L (22)

TG-5 MS:

c=0.106, e= 0.057, s= 0.011, a= 0.129, b=-0.010, l=0.146, R^2= 0.961, SD=0.015, F= 377.789

N=62

Log (calculated) = 0.106 + 0.057E + 0.011S + 0.129A – 0.010B + 0.146L (23)

TG1301 MS:

c=0.028, e=0.007, s=0.155, a=0.184, b= 0.009, l=0.154, R^2= 0.952, SD= 0.014, F= 422.273

N=65

Log (calculated) = 0.028+ 0.007E +0.155S + 0.184A + 0.009B + 0.154L (24)

3.2.2 Data Interpretation

The coefficients e, s, a, b, l and v are not just curve- fitting constants. The process coefficients reflect specific solute-solvent interactions that correspond to chemical properties of the solvent phase. They represent the stationary phase contribution to intermolecular interaction. The process coefficient or regression coefficients are very important, because they will encode stationary phase properties. The coefficient can be considered as constants that characterized the stationary phase. The gas phase will be the reference for such characterization because all gas chromatography data refers to transfer from the gas phase to the stationary phase. Therefore the process coefficient does not just represent a new method for characterization of stationary phase, but they also contain chemical information about the stationary phase. The process coefficients are the average value over the range of temperatures. The interpretation of the regression constants are as follows. The e-coefficient will determine the phase interaction with solutes through π-and n- electrons pairs. Usually the e coefficient is positive, but for phase that contains

strong electronegativity such as fluorine, the e can be negative. The s coefficient shows the tendency of the phase to interact with dipolar or polarizable solutes. The a coefficient indicates the hydrogen bond basicity of the phase because acidic solute will interact with a basic phase and the b coefficient measure the hydrogen- bond acidity of the phase. The l co-efficient is a measure of size needed to form solvent cavity and dispersion forces. Thus we expected the l values to increase as the size of molecule increases [54, 55]. The ZB wax plus (polyethylene glycol or PEG) column is the most polar and acidic among the six columns. The process coefficient s (=0.284) and a (=0.272) for ZB wax plus columns are the highest compared to the other columns which is a good prediction because of the polarity of ZB wax plus column. In reference to table 1.3 above, the PEG functional group has a strong dipole and moderate hydrogen bonding. Since TG 1301 MS column is one of the mid polar column among the six columns used, the process coefficient s (=0.155) and a (=0.184) are the second highest after the ZB wax plus column because of the cyano functional group in the stationary phase. In reference to table 1.3, it's shown that the cyano functional group has a strong dipole interaction and moderate hydrogen bonding. The remaining columns, ZB 35, TR-5, TG 5-MS and TR 1-MS have mid polarity, low polarity and non-polar stationary phase with methyl and phenyl group. The stationary phase interactions in reference to Tale 1.3 indicate that methyl and phenyl group has none to weak dipole and none to weak hydrogen bonding. The process coefficients s and a value for those four columns are lower compared to ZB wax and TG1301MS. It is significant to note that the s, a, and b processes for gas- phase must be positive or close to zero because interactions between the phase and the solute will increase the solubility of a gaseous solute. The process coefficients s, a, and b for ZB wax plus(s=0.284, a=0.272, b= 0.007) and TG 1301 MS(s=0.155, a= 0.184, b= 0.009) are all positive. The regression coefficients s, a, and b for ZB 35(s= 0.087, a= 0.082. b=-

0.003), TG5-MS(s=0.011, a= 0.129, b = -0.01), TR 5(s= 0.064, a= 0.146. b= -0.014), TR1 MS(s= 0.131, a = 0.086, b=-0.133) are positive except for the basicity which is close to zero. TR 1 MS has an exception by having a high negative value of b coefficients. If more compounds are added, the process coefficients can be recalculated and thus produce new stationary equations. Most stationary phases in gas chromatography do not have a strong hydrogen bonding; therefore the basicity and B descriptors are not suitable to be determined by gas chromatography. In general the constants s, a, b, l all decrease with increase in temperature [7, 55].

3.2.3 Molecular Descriptors

Drugs studied are nicotine, methamphetamine, oxycodone, ketamine, and heroin.

Molecular descriptors for those drugs are calculated by converting average retention time into calculated log of retention time ($Logt_R$ calculated). The $Logt_R$ calculated are compared with the experimental determined values. Microsoft solver is used to minimize the sum of squares on the set of describes system equations. The systems equations contains known process coefficients (e, s, a, b, l or v) which are determined by multiple linear regression analysis (MLRA) method. The sums of squares are set at a minimum to fit the targeted cell S, A, B and L [56]. Gas chromatography was used to measure the drugs retention time. Table3.8. show the retention time of illicit drugs and Table 3.8.8 show a summary of coefficients for GC stationary phases.

Table 3.14. Retention time (min) of illicit drugs

Illicit drug	**Column**	**Run1**	**Run2**	**Run3**	**Avg**	**Stdev**	**%RSD**
Ketamine	ZB Wax	17.747	17.758	17.762	17.756	0.008	0.044
	ZB 35	15.465	15.463	15.463	15.464	0.001	0.007
	TR 1 MS	14.248	14.253	14.253	14.251	0.003	0.020
	TR 5	14.208	14.213	14.218	14.213	0.005	0.035
	TG 5 MS	14.613	14.615	14.612	14.613	0.002	0.010
	TG 1301 MS	14.945	14.957	14.952	14.951	0.006	0.040

Heroin	ZB 35	22.137	22.128	22.143	22.136	0.008	0.034
	TR 1 MS	18.972	18.970	18.972	18.971	0.001	0.006
	TR 5	19.075	19.057	19.058	19.063	0.010	0.053
	TG 5 MS	19.722	19.725	19.700	19.716	0.014	0.069
	TG 1301 MS	20.888	20.920	20.915	20.908	0.017	0.082
Methamphetamine	ZB Wax	11.968	11.965	11.965	11.966	0.002	0.014
	TR 1 MS	5.585	5.585	5.563	5.578	0.013	0.228
	TR 5	7.120	7.118	7.118	7.119	0.001	0.016
	TG 5 MS	6.148	6.148	6.158	6.151	0.006	0.094
	TG 1301 MS	12.618	12.618	12.623	12.620	0.003	0.023
Oxycodone	TG 5 MS	11.682	11.698	11.682	11.687	0.009	0.079
Nicotine	ZB Wax	11.897	11.898	11.900	11.898	0.002	0.013

Table 3.15. Process coefficients for GC stationary phases

Column	**c**	**e**	**s**	**a**	**b**	**l**	**v**
ZB Wax Plus	0.177	0.036	0.284	0.272	0.007	0.112	0.000
ZB 35	0.191	0.061	0.087	0.082	-0.003	0.127	0.000
TR1 MS	0.361	-0.048	0.131	0.086	-0.133	0.121	0.000
TR5	0.055	-0.047	0.064	0.146	-0.014	0.161	0.000
TG5 MS	0.106	0.057	0.011	0.129	-0.010	0.146	0.000
TG1301 MS	0.028	0.007	0.155	0.184	0.009	0.154	0.000
Octanol/water	0.088	0.562	-1.054	0.034	-3.460	0.000	3.814

Not all illicit drugs ran on all six columns. The results show the run of each drug on each column they did elute. The excess molar refraction and the McGowan volume V, were found from the literature [50-52]. Since there are few data points for the illicit drugs, a very good correlation is not expected therefore the introduction of octanol/water partition coefficient is added to the data set. The log of P (octanol/water) can be found in literature. The log of P is a condense to condense phase, thus the McGowan volume needs to be added. The Abraham model equation for octanol/water is represented as:

Octanol/water, c= 0.088, e=0.562, s= -1.054, a= 0.034, b=-3.460, v= 3.814

$$\text{LogP(calculated)} = 0.088 + 0.562E - 1.054S + 0.034A - 3.460B + 3.814V \quad (25)$$

The log of P (eq.25) is combined with the previous six stationary equation (eq.19 to eq.24) to predict the solute descriptors for illicit drugs.

3.2.3.1 Nicotine

Calculated log of retention time is determine through equation 19 to equation 25 (Table 3.9.1)

Table 3.16. Observed and calculated retention data for nicotine

Stationary phase	Experimental $Logt_R$	Calculated $Logt_R$
ZB wax plus	1.075	1.075
Octanol/water	1.170	1.170

The literature solute descriptors for Nicotine are: E= 0.865, S= 0.880, A= 0.000. B= 1.090, L= 5.880, V= 1.371[ref.62]

Table 3.17. Predicted solute descriptors for nicotine

Descriptors	E	**S**	**A**	**B**	L	V
Values	0.865	**0.870**	**0.000**	**1.073**	5.880	1.371

The solute descriptors in bold are the calculated one. The remaining descriptors obtained from the literature were kept constant. The standard deviation for the predicted solutes descriptors for nicotine is $6.23*10^{-8}$ log unit. Nicotine did run only on ZB wax plus column; thus only two stationary equations are represented. The two data set is not enough to conclude. The calculated A descriptor is 0.000; there is no acidic characteristic in nicotine. Overall nicotine is considered as a weak base because of the two nitrogen, its B descriptor is 1.073 which displays basic tendency. Nicotine does also show sign of polarity with the S descriptor of 0.870. Tobacco is a plant grown for its leaves, which are smoke, chewed for a variety of effects. Nicotine is contained in tobacco, it's an addictive substance.

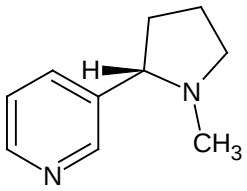


Figure 3.3. Structure of nicotine

3.2.3.2 Oxycodone

Calculated log of retention time is determined through equation 19 to equation 25(Table 3.9.3)

Table 3.18. Observed and calculated retention data for oxycodone

Stationary phase	Experimental $Logt_R$	Calculated $Logt_R$
TG 5MS	1.067	1.068
Octanol/water	1.260	1.260

The literature solute descriptors for oxycodone are E= 2.015, S= 2.815, A= 0.286, B= 2.228, V= 2.264

Table 3.19. Predicted solute descriptors for oxycodone

Descriptors	E	**S**	**A**	**B**	**L**	V
Values	2.015	**2.564**	**0.286**	**1.706**	**5.471**	2.264

The solute descriptors in bold are the calculated one. The overall standard deviation for the predicted solutes descriptors for oxycodone is $8.12*10^{-7}$ log unit. The oxycodone did run only on TG5MS column (5% diphenyl 95% dimethyl polysiloxane). Since there are few data sets, a good conclusion cannot be made. The oxycodone(Figure 3.4) structure has one hydrogen that exhibit the acidic characteristic, thus the A descriptor is 0.286. overall the drug is basic because of the amine group. The nitrogen(strong electronegativity element) also gives the polarizability characteristic of the drug with S = 2.564, the hydroxide group create a strong base group with the B value = 1.706. Oxycodone is an opioid, use to treat moderate to severe pain.

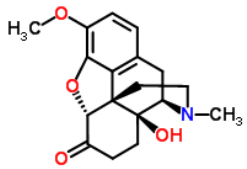


Figure 3.4. Structure of oxycodone

3.2.3.3 Methamphetamine

Calculated log of retention time is determined through equation 19 to equation 25(Table 3.9.5)

Table 3.20. Observed and calculated retention data for methamphetamine

Stationary phase	Experimental $Logt_R$	Calculated $Logt_R$
ZB was plus	1.077	1.130
ZB 35	---	---
TR1MS	0.746	0.798
TR5	0.852	0.854
TG5MS	0.788	0.877
TG1301MS	1.101	0.935
Octanol/water	0.207	0.206

The literature solute descriptors for methamphetamine are E^a= 0.740, S^b= 0.800, A^c=0.130, B^d= 0.590, V^e= 1.380 [a, b, c, d, e](C.West,G. Guenegou, Y. Zhang, L- Morin-Allory, Insights into chiral recognition mechanisms in supercritical fluid chromatography. II. Factors contributing to enantiomer separation on tris-(3, 5-dimethylphenylcarbonate) of amylose and cellulose stationary phases. J. chromatography A 1218(2011) 2018-2057.

Table 3.21. Predicted solute descriptors for methamphetamine

Descriptors	E	**S**	**A**	**B**	**L**	V
Values	0.830	**0.296**	**1.570**	**1.008**	**3.619**	1.380

The values in bold are the calculated solute descriptors. The overall standard deviation for the predicted solute descriptors for methamphetamine is 0.090 log unit. The A and B descriptors will depend on the process coefficients a and b and also on the interaction between

the solute and the stationary phase. All coefficients reflect differences in the properties of two phases between which the solute are being transferred. By observing the structure of methamphetamine (Figure 3.5), there is only one hydrogens that can form hydrogen bond, but the A descriptors is a little bit high with A= 1.570. The hydrogen bond interaction is highly dependent on the specific atoms present and on the orientation of the molecule involved in the interaction. This occurs when a hydrogen atom is covalently bonded to an electronegativity element such as nitrogen, oxygen, fluorine and at the same time interacting with the lone electrons on the nearby electronegativity element(or in some case with the π system of aromatic rings). Also one can expect a higher solute descriptor value of A (hydrogen bond acidic) when one of the other four solute descriptors (E, S, B, L) is very low. The drug also shows some basic tendency because of the amine group; with the B descriptor equal 1.008. The nitrogen with the lone pair also makes the drug a little polar with the S value of 0.296. The A descriptor characterizes solute hydrogen bond donating ability. If neither phase can donate hydrogen bonds then the coefficient B will be zero. The Ostwald descriptor L is a combination of solute properties, one being a general measure of solute size and the second being the ability of a solute to interact with a solvent phase through dispersion forces. The S descriptor has dipolarity and polarizability effect within it, so does the L parameter, thus it's difficult to separate or to distinguish the exact distribution of polarity, dispersion and induction effects in the coefficient of these parameters [57, 58]. Methamphetamine improves concentration, energy and alertness while decreasing appetite and fatigue.

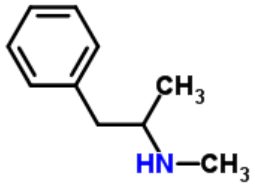


Figure 3.5. Structure of methamphetamine

3.2.3.4 Heroin

Calculating log of retention time is determined through equation19 to equation 25(Table 3.9.7)

Table 3.22. Observed and calculated retention data for heroin

Stationary phase	Experimental $Logt_R$	Calculated $Logt_R$
ZB wax plus	---	---
ZB 35	1.345	1.387
TR1MS	1.278	1.124
TR5	1.280	1.248
TG5MS	1.294	1.244
TG1301MS	1.320	1.486
Octanol/water	1.580	1.586

The literature solute descriptors for heroin are E= 1.530, S= 2.21, A = 0.00, B = 1.92, V =2.6598

Table 3.23. Predicted solute descriptors for heroin

Descriptors	E	**S**	**A**	**B**	**L**	V
Values	1.937	**2.224**	**0.000**	**2.136**	**7.021**	2.660

The calculated solute descriptors are in bold. The overall standard deviation for the predicted solutes descriptors for heroin is 0.106 log unit. The structure of heroin (Figure 3.6) shows that there are no acidic hydrogen, therefore heroin exhibits no acidic characteristic. The A descriptor is zero, meaning there is no hydrogen bond ability in heroin. The heroin shows some basicity due to the nitrogen element with the B descriptor value of 2.136. The S descriptor has dipolarity and polarizability within it, thus the S descriptor value is 2.224. Nitrogen and oxygen do contribute to the polarizability and dipolarity of heroin. It's very difficult to discern the exact

distribution of polarity, dispersion and induce effects in the coefficient of those parameters as mentioned for the methamphetamine [57-58]. The size of L does increase as the solutes increase. Heroin is highly addictive drug derived from morphine which is obtained from opium poppy plant.

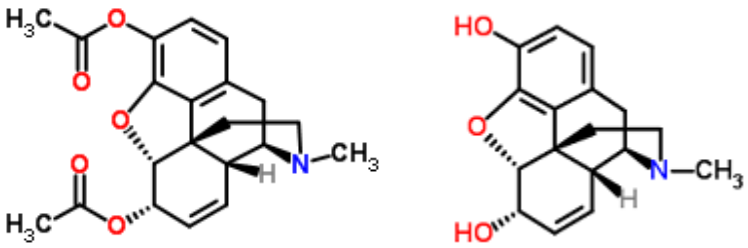


Figure 3.6. Structure of heroin (left) and morphine(right)

3.2.3.5 Ketamine

Calculating log of retention time is determined through equation19 to equation 25(Table 3.9.9)

Table 3.24. Observed and calculated retention data for ketamine

Stationary phase	Experimental $Logt_R$	Calculated $Logt_R$
ZB wax plus	1.249	1.264
ZB 35	1.189	1.203
TR1MS	1.153	1.079
TR5	1.152	1.147
TG5MS	1.164	1.154
TG1301MS	1.174	1.226
Octanol/water	2.900	2.903

The solute descriptors for ketamine are E^a= 1.280, S^b= 1.420, A^c =0.130, B^d =0.890, V^e= 1.832. [a, b, c, d,e](C.West,G. Guenegou, Y. Zhang, L- Morin-Allory, Insights into chiral recognition mechanisms in supercritical fluid chromatography. II. Factors contributing to enantiomer separation on tris-(3, 5-dimethylphenylcarbonate) of amylose and cellulose stationary phases. J. chromatography A 1218(2011) 2018-2057.

Table 3.25. Predicted solute descriptors for Ketamine

Descriptors	E	**S**	**A**	**B**	**L**	V
Values	1.393	**1.004**	**0.000**	**1.125**	**6.640**	1.832

The calculated solute descriptors values are in bold. The overall standard deviation for the predicted solutes descriptors for ketamine is 0.041 log unit. Although the calculated descriptor A shows no ability of hydrogen bond, A is zero; it's obvious that ketamine has some hydrogen bond ability by looking at its structure. There is one hydrogen donor in ketamine structure. The molecule shows some tendency of being basic with the nitrogen element. The chlorine, nitrogen and oxygen element emphasize the polarity effect on ketamine; thus the S descriptor is 1.004. One can expect a high value on the polarity descriptor, but as mentioned early on, the S and L descriptors both have dipolarity and polarizability include in their parameter which makes it harder to know the exact distribution of polarity, dispersion and induce effects in the coefficient of these parameters. The dipole –dipole interaction depend on the orientation of the molecule. Ketamine is considered a dissociative anesthetic, which means the drug distorts the users' perception of sight and sound, and produces feelings of detachment from the environment.

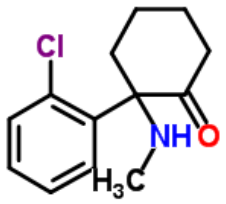


Figure 3.7. Structure of ketamine

Table 3.26Summary of predicted solute descriptors for nicotine, oxycodone, methamphetamine, heroin and ketamine

Drugs	E	S	A	B	L	V
Nicotine	0.865	0.870	0.000	1.073	5.469	1.371
Oxycodone	2.015	2.563	0.286	1.706	5.471	2.264
Methamphetamine	0.830	0.296	1.570	1.008	3.619	1.380

Heroin	1.937	2.224	0.000	2.136	7.021	2.660
Ketamine	1.393	1.004	0.000	1.125	6.640	1.832

3.3 Conclusion

The Abraham solvation model is a good approach to predict drugs properties. The Abraham solvation model parameter can be used to characterize the gas chromatography stationary phase by providing some important chemical information about the stationary phase. The Abraham solvation model predicts fairly accurate molecular descriptors. It's important to know the drugs properties in order for one to model or study a new drugs. Once the drugs properties are known from the solute descriptors, we can predict on how drug will interact with different phase or different system. Then one can understand how the drugs will interact with some biological barrier. The cost of putting the drugs to the market is very high, by using the Abraham model solvation equation; one can reduce the time and money that needed to be spent. The instrument use to acquire the retention time is the gas chromatograph with the flame ionization detector. Mathematical correlations between the logarithm of retention time of illicit drugs and the solute descriptors from the Abraham model can be established. Linear free energy relationship (LFER) of Abraham model predicts retention behavior of most compounds and drugs by comparing the experimental logarithm of retention data with the calculated logarithm of retention data. Not all drugs did run on all six columns used in this experiment. Some drugs have higher boiling point that exceed the maximum temperature of the gas chromatography column. Some drugs are not volatile enough and can't be run on GC. The b basicity process coefficient is not very suitable to found or calculated with the gas chromatography due to the lack of stationary phase with strong hydrogen bonding ability. In order to improve the accuracy of the prediction, it's necessary to have more data point for the drugs. More stationary phase can also be added to improve the prediction. The HPLC (high pressure liquid chromatography) can

also be used to study drugs because of the GC limitation of temperature. This experiment shows that all linear free energy relationship parameters of solutes may be determined using gas chromatography or experimental techniques. The solvation model can help facilitate the prediction of further system properties for compounds lacking experimental values. The molecular solute descriptors obtained from this experiment have many chemical, biological and pharmaceutical important properties. The molecular solute descriptors can be used to predict skin permeability, whether or not the drug can cross the brain blood barrier. The obtained molecular solute descriptors for the illicit drugs studied in this experiment are important to determine why such drug can cross the brain easily compared to the other drugs based on the acidity, basicity or polarity of the drug. The process coefficients are the average value over the range of temperatures. In this study, we were able to determine the solute descriptors for the illicit drugs experimentally, not by using software or any computational method.

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