PHYSICO-CHEMICAL STUDIES OF QUERCETIN WITH CATIONIC SURFACTANT CTAB IN HYDRO-ETHANOLIC SOLVENT SYSTEM

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By

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DECLARATION

We hereby declare that the project titled **"Physico-chemical studies of Quercetin with cationic surfactant CTAB in hydro-ethanolic solvent system"** is submitted as Project Work carried out by us at Jaypee University of Information Technology, Solan under the guidance of **Dr. Poonam Sharma**. Any further extension, continuation or use of this project has to be undertaken with prior express written consent from the Supervisor, Jaypee University of Information Technology, Solan-173234.

We further declare that the project work or any part thereof has not been previously submitted for any degree or diploma in any university.

Signature of Student

Name: Himalya Attri

Signature of Student

Name: Diksha Sharma

Date :

SUPERVISOR'S CERTIFICATE

This is to certify that the work titled **"Physico-chemical studies of Quercetin with cationic surfactant CTAB in hydro-ethanolic solvent system"** submitted by **"Himalya Attri (151803) and Diksha Sharma (151816)"** in partial fulfilment for the award of Degree of Bachelor of Technology in Biotechnology of Jaypee University of Information Technology, Waknaghat has been carried out under my supervision. This work has not been partially or wholly submitted to any other University or Institute for the award of this or any other degree or diploma.

Signature of Supervisor ....

Name of Supervisor Dr. Poonam Sharma

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ACKNOWLEDGEMENT

“Every great achiever is inspired by a great mentor”. This acknowledgement is a profound expression of regard for all those who have made this work indelible.

We are highly indebted to **Dr. Sudhir Kumar**, Head, Department of Biotechnology and Bioinformatics for giving us the golden opportunity and amenities required to carry out our project successfully.

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We bow our head before the **Almighty God** whose blessing gave us the strength to make this successful venture and We dedicate our work and achievement in his lotus feet.

Thank you!

Signature of Student	....	....
Name of the Student	Himalya Attri	Diksha Sharma

Date :

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List of Symbols and Acronyms

CTAB	Cetyltrimethyl Ammonium Bromide
QC	Quercetin
EtOH	Ethanol
κ	Specific Conductance
CMC	Critical Micelle Concentration
η	Viscosity Co-efficient
η_r	Relative Viscosity
ΔH°_{m}	Standard Enthalpy Change
ΔS°_{m}	Standard Entropy Change
ΔG°_{m}	Standard Gibbs Free Energy Change
ϕ_v	Apparent Molar Volume
ϕ_k	Apparent Molar Compressibility

Abstract

Flavonoids are very well known for its use in pharmaceutical industry possessing various health benefits that can be utilised for tackling the problem of numerous health related diseases. Quercetin, a flavonoid possesses greater health benefits but its use is limited due to various insolubility and instability problems and thus, is taken into consideration. Thermodynamic and thermoacoustic properties of Quercetin at different concentration have been studied in interaction with CTAB surfactant in varied hydro-ethanolic concentrations at different temperatures. The conductivity of the overall system has been studied and further, it has been utilised to calculate Change in Enthalpy (ΔH), Entropy (ΔS) and Gibbs free Energy (ΔG) of micellization. The study revealed that though the interactions between Quercetin and CTAB are endothermic in nature, the reaction spontaneously proceeds in forward direction. Further, density and ultrasonic sound velocity parameters have been used to calculate the thermoacoustic parameters i.e. apparent molar volume and apparent adiabatic compressibility. Thermoacoustic properties revealed the dominance of hydrophobic interactions at higher surfactant concentration. The data has been found to be more favourable in hydro-ethanolic solution as compared to that of aqueous solution. Overall, the interactions are favourable for the system to be utilised for formulation development studies, drug development, medical administration, drug industry and pharmaceutical industries

CHAPTER-01

INTRODUCTION

AND

REVIEW OF LITERATURE

1.1 Introduction:

Plants and its parts are used for its scent, flavour or therapeutic properties. There are number of advantages associated with using plants and its phytoconstituents in pharmaceutical products. Plants have the capacity to synthesize different organic molecules called secondary metabolites. Secondary metabolites are not necessary for a cell (organism) to measure; however plays crucial role in ensuring the continuing existence of organism because it interferes within the interaction of cell with its surroundings. They shield plants against stresses, each organic phenomenon (nematodes, insects, fungi or animal grazing) and abiotic (moisture and higher temperature, heavy metals presence or injury). Secondary metabolites are used particularly as chemicals like medicines, fragrances, flavours, dyes and insecticides by human attributable to their nice measures. Secondary metabolites are characterised into three categories: Terpenes, Phenolic Compounds and Alkaloids and Sulfur compounds. Among these, Polyphenols are naturally occurring compounds found largely in the beverages, fruits, vegetables and cereals. Polyphenols are involved in defense against aggression by pathogens or ultraviolet radiation. Phenolic Compounds are sub- categorised into Anthocyanins, No flavonoids, Tannins and Flavonoids. Flavonoids are the most abundant and mostly studied group of Polyphenols.

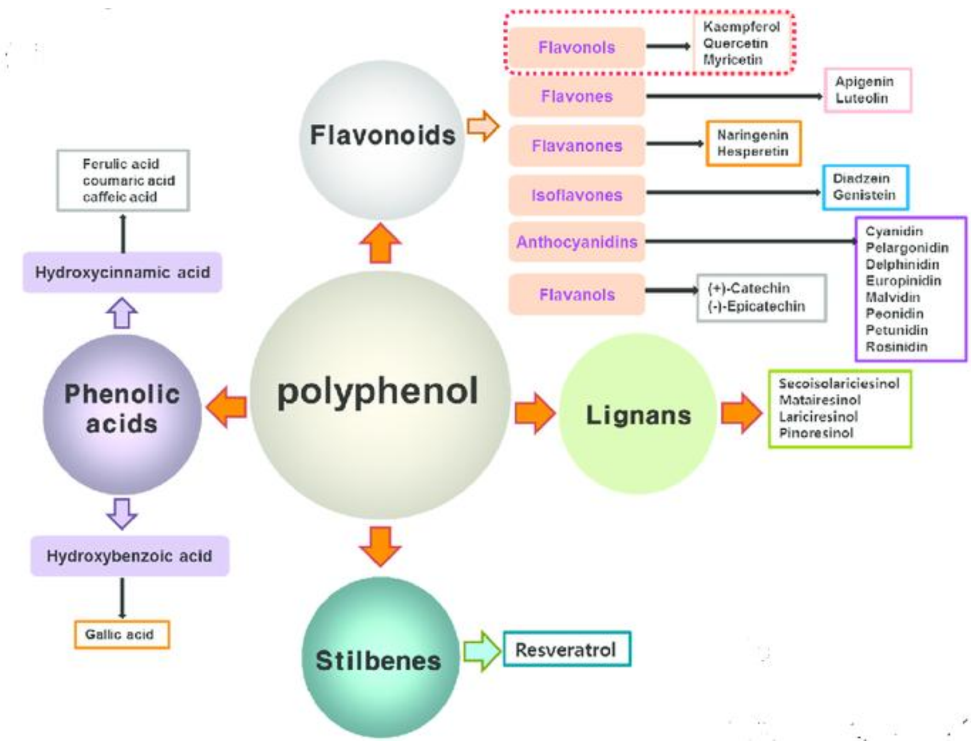

Figure 1: Classification of Polyphenols [1]

Flavonoids possess biological activities including antiallergenic, anti-inflammatory, antiviral and vasodilating actions. Flavonoids mostly found in vegetables, fruits, and certain beverages and largely derived from onion, have versatile beneficial antioxidant effects. A large number of varieties of flavonoids have been identified, and advantage of their potential beneficial effect on human health such as properties like antiplatelet, antiviral, anti-inflammatory, anti-allergic, antitumor, antioxidant, and treatment of neurodegenerative disorders makes flavonoid study of particular interest. Flavonoids are arranged into six classes as per the substance structure into flavonones, flavonols, flavonols, isoflavones, flavones and anthocyanidins.

Quercetin (3,3′,4′,5,7- pentahydroxy-flavone) [$C_{15}H_{10}O_7$], is one in all the foremost long flavonol found in fruits and vegetables. It possesses sturdy health edges, radical scavenging property sensitive to environmental changes like that in hydrogen ion concentration (pH), solvent polarity, use of micellar media, etc. The utilization of such flavonoids has been restricted, thanks to their instability and poor water solubility, low availableness and poor porosity under conditions encountered throughout food/pharmaceuticals merchandise processing (temperature, pH, light), within the gut (enzymes, pH, presence of alternative nutrients) or throughout storage (light, oxygen). These factors limit the benefits, the edges and potential health advantages of these compounds in useful food or pharmaceutical merchandise. These limitations can be overcome by use of surface-active agent nano-cavities, identified to resist degradation of pharmacologically active molecules and enhance bioavailability.

Surfactants are the surface dynamic operators which diminishes the surface strain of fluids by bringing down the interfacial pressure between two fluids. Surfactants are flexible synthetic mixes which are amphiphilic in nature comprising of hydrophilic head (anionic, cationic, non ionic and zwitterionic) and a hydrophobic tail. Indeed, even in little sum, these surfactants have capacity to modify the surface or interfacial free energies to a checked degree because of their property of adsorbing onto the interfaces or surfaces of the framework. Thus, surfactants are widely preferred in industrial applications such as dispersing, emulsifying, cleaning, washing, medicines, etc. Interaction of Quercetin flavonol with cationic surfactant has proven to be electrochemically stable.

Cetyltrimethyl ammonium bromide [$(C_{16}H_{33})N(CH_3)_3Br$], is a quaternary ammonium cationic surfactant. Its use is preferred in topical antiseptic cetrimide. It has been proved to be an effective antiseptic agent against microorganisms bacteria and fungi. It is also preferred as extraction buffer in DNA isolation.

Since surfactant blends have characteristic presence in various nourishment details/organic frameworks, because of their proficient solubilization, suspension, scattering, and transportation capacities, concentrating the communication of dietary flavonoid, Quercetin, with the blended micelles of cationic surfactants and subsequently its resulting effect on its general properties merit consideration. The reports with respect to the impact of double and tertiary blended micelles on the general movement of bioactive particles are rare and thus one of the principle destinations of the present examination.

The information of molecular mechanism of drug-membrane interaction is not solely of theoretical importance, however additionally of potential sensible implications [2]. For diagnosing, treatment, cure and prevention of a disease, drug molecules are preferred as these alter the physiological system of the body. Drug molecules are characterized by the presence of various useful functional groups such as polar (hydrophillic) and non-polar (hydrophobic) groups that are responsible for their therapeutic properties. So, a scientific information of the solution behavior of drug/molecules excipients is of great significance in understanding their physiological action [3]. Chemically, the drug action is represented as:

$$\text{Drug (D)} + \text{Receptor (R)} \longleftrightarrow \text{Drug Receptor Complex (DR)} \Longrightarrow \text{Response}$$

The interaction between drug and body are conveniently divided into two classes [4]:

(i) Pharmacodyanamic process (action of drug on the body)

(ii) Pharmacokinetic process (action of the body on the drug)

These above mentioned classes are the ultimate consequences of physicochemical interactions between drug/molecule excipients and functionally important molecules in the living organism. The term excipient means to receive, to assemble and to take out which signifies one among the properties of an excipient to confirm that a medicative product has weight, consistency and volume necessary for proper administration of the active principle.

Drug-actions i.e. drug reaching the blood stream, its extent of distribution, its binding to the receptors and finally producing the physiological action, all depend on numerous physicochemical properties chiefly decided by various interactions e.g. ionic, hydrogen bonding, charge transfer, covalent or hydrophobic interaction, etc. Transport property measurements are a powerful tool to study the behavior of assorted solutes/drugs in solutions.

Thermodynamic parameters as Change in Enthalpy ($\Delta H°_m$), Entropy ($\Delta S°_m$) and Gibbs free energy ($\Delta G°_m$) of micellization and Thermoacoustic parameters as ultrasonic velocity, viscosity, density and pressure plays a vital role in Absorption, Digestion, Metabolism and Excretion(ADME) pathway inside human body by entering as excipient. Rising resistance has demanded the study of these parameters while forming a formulation. So, an optimal concentration of flavonoid on interaction with surfactant will result into formation of useful topical formulations.

In this project, various parameters have been studied and techniques have been used to study the effect of intermolecular interactions of Quercetin (flavonoid) and CTAB (surfactant) in aqueous medium.

1.2 Background/Review of Literature:

In the following section, recent published studies on Quercetin, CTAB and drug-surfactant have been presented, illustrating the various kinds of interactions which these molecules can undergo. Techniques commonly employed for the purpose are spectroscopic, thermodynamic and thermoacoustic methods.

Quercetin, a plant-derived aglycone form of flavonoid glycosides, is useful against variety of diseases and conjointly used as nutritional supplement. Some of the beneficial effects include anti-infective, immunomodulatory, antihypertensive, gastroprotective effects, anti-diabetic, anti-viral, anti-allergy, anti-ulcer, antitumor, anti-inflammatory activity, anticancer and cardiovascular protection [5].

In B16 melanoma cells of mouse, Quercetin acts as melanogenesis inhibitor, a potent tyrosinase inhibitor, and an anticancer and antioxidant agent [6–10]. Following dose dependant manner, in B16 melanoma cells melanin production is being inhibited by Quercetin [11]. However in human melanoma cells, it has the opposite effect as a melanogenesis accelerator [6,12-17]. In its structure, Quercetin consists of heterocyclic pyrone ring, connected to phenolic moieties on both sides. It exists in the form of rutin (quercetin-3-rutinoside), a glycoside containing a disaccharide covalently attached to the quercetin unit Figure 2 [15,17-19].

As a therapeutic agent, Quercetin potential health benefits can be stated as:

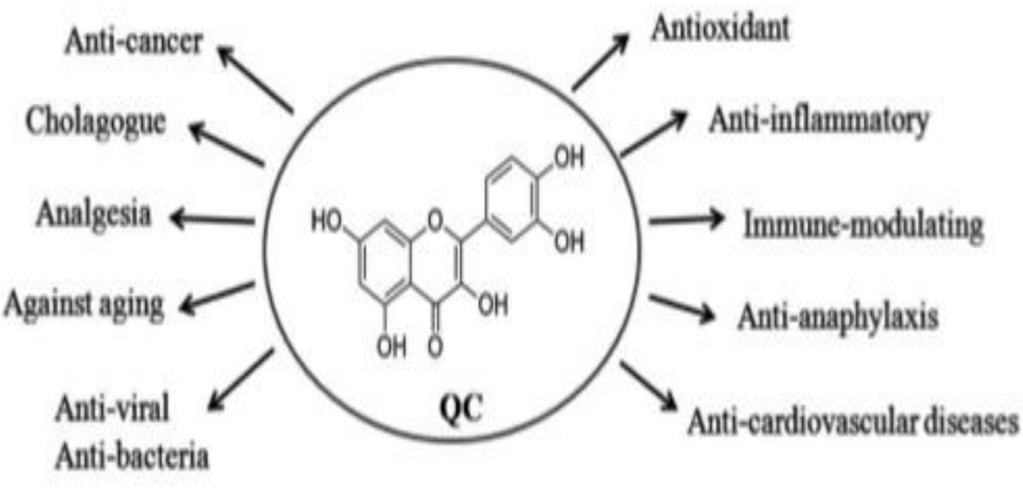

Figure 2: Health benefits of Quercetin [20]

Inflammation, a self-protection biological response generated when parts of human body are exposed to irritating or harmful stimuli. Its aim is to evacuate pathogens, any harmful stimuli or damaged cells and to initiate healing process. The inflammation process is the body's reaction trying to heal itself. A standout amongst the most amazing properties of Flavonoid Quercetin, is its capacity to adjust irritation and modulate inflammation. Quercetin inhibits enzymes that serves as the cause of inflammation like lipooxygenase and cyclooxygenase(COX) decreasing the leukotrienes and prostaglandins which are inflammatory mediators [21.22].

In most countries, Morbidity and Mortality rate is increasing at rapid state and the main cause of this increase is Cardiovascular diseases [23]. Greek Cardiologist conducted a study on thirty men who had coronary heart disease(CHD), It has been reported that Red Grape polyphenol extract consumption rich in Quercetin caused an increase in flow-mediated dilation of arteries, indicating improved endothelial health [24].

Quercetin improves the health of the endothelium and inhibits platelet aggregation. It reduces the risk of mortality caused by low-density lipoprotein(LDL). It also protects against Coronary Heart disease. Quercetin exhibit important vasorelaxtant properties on isolated arteries which prevents the development of cardiac hypertrophy and also helps to lower blood pressure [25]. Studies reveal that people who intake high amount of Flavonoid containing food supplements have lower cholesterol. In one of the study, it has been found that intake of Quercetin and alcohol-free red wine extract inhibits LDL oxidation [26].

Epidemiological study showed that the diet with more fruits and vegetables provides protection against cancer. Quercetin has anticancer properties which include growth factor suppression, antiproliferative and antioxidant [26]. Quercetin has potent anticarcinogenic properties. It also contributes as apoptosis inductor whereby it inhibits the spread of malignant cells and also decreases the tumor growth in brain, colon, liver, and other tissues [27-28].

Quercetin is known to exhibit antibacterial effects against almost all strains of bacteria, particularly affecting respiratory, urinary, gastrointestinal and dermal system. Their anti-replicative and anti-infective ability contributes to the antiviral characteristics. Viruses which commonly respond to flavonoids are Japanese encephalitis virus, respiratory syncytial virus, herpex simplex virus and adenovirus [29-31].

Quercetin exerts anti-allergy effects, act as a natural antihistamine, prevents the mast cells and other allergic substances from releasing histamine. Quercetin advantages have tremendous implications for treatment and prevention of asthama and bronchitis due to its ability to prevent allergic effects. The cell membrane of mast cells acts as immune gateway to the brain, the environment and emotional stress [32].

Quercetin when used in combination with fish oil showed features of neuroprotection in rat brain. It also showed beneficial effects against neurodegenerative disease [33-34].

In Pharmacokinetics, Ferry et al. studied the dose levels from 60–2000 mg/m^2 of intravenous injection of Quercetin on cancer patients. It has been determined that the safety dose of Quercetin is 945 mg/m^2. In toxic dose, quercetin caused hypertension, nephrotoxicity, emesis and reduction in serum potassium [35].

Novel delivery strategies like with liposomes/phospholipid complexes and formulations, inclusion complexes QC nanocrystals were used. Novel delivery strategy system faces problems as Lower drug loading and encapsulation efficiency, incomplete degradation of carrier, accumulation in organs and drug targetting. The inclusion of Cyclodextrin created risk of Nephrotoxicity [36].

The Quercetin antioxidant activity is observed to be more in the cationic surfactant than in anionic and non-ionic surfactant systems. Interaction of Quercitin with cationic surfactant is electrochemically stable and radical scavenging was best observed in cationic surfactant [20]

Presence of Decamethoxin (antiseptic drug) in cation solution favours tautomeric transition of enol to keto form of QC which provides greater Bond energy [37]. QC solubility increases with increasing temperature. Solubility of Quercetin is observed more in solution containing water and Ethanol as compared to that of solubility in solution containing water and methanol [38].

Cationic surfactant CTAB ($C_{19}H_{42}BrN$) having molecular weight 364.45g/mol - Cetyltrimethyl ammonium Bromide. It is a Quaternary ammonium surfactant. CMC of CTAB is 1mM at 25°C. Its structure is as follows:

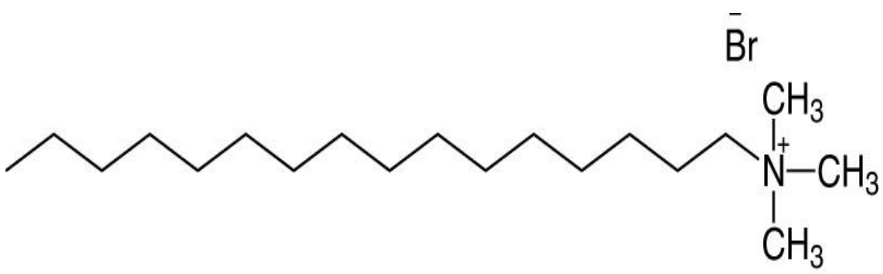

Figure 3: Structure of cationic surfactant CTAB

Adsorption of CTAB decreases with increasing temperature signifying exothermic natured process [39]. Absorption rate of CTAB is high on low doses. Strong alcohol-aqueous surfactant interactions results in decrease in magnitude of CMC on addition of alcohol [40]. Conductivity of CTAB increases with both increasing temperature and salt concentration(NaBr) [41].

The role, safety and importance of pharmaceutical excipients with respect to Active Pharmaceutical Ingredients have been examined. Most part of the medicine as far as its weight is concerned is constituted by excipients which guarantee the stability, dosage, and bioavailability of the active principle. The review of principle classes of excipients and its side effects have been examined in this review article [42].

The drug excipient interactions stated that although excipient be pharmacologically inert, it can intiate, participate or propagate in physical or chemical interactions with drug compounds, which may compromise the medicinal effectiveness [43].

The surfactant applications have been reviewed stating important role of surfactant in drug deliveries. The surfactants or pharmaceutically acceptable co-solvents have been employed to formulate compounds sparingly soluble in water. The surfactant system increases the solubility by guiding the mechanism to form micelles [44].

1.3 **Objectives:**

To determine the following parameters of Quercetin with cationic surfactant CTAB:

- Specific Conductance
- Viscosity
- Velocity
- Density

Utilizing these studies to calculate various thermodyamic and thermoacoustic parameters i.e.

- Change in enthalpy ($\Delta H°_m$), entropy ($\Delta S°_m$) and Gibbs free energy ($\Delta G°_m$)
- Apparent Molar Volume (ϕ_v)
- Apparent Adiabatic Compressibility (ϕ_k)

CHAPTER-02

MATERIALS AND METHODOLOGY

2.1 Materials/Equipment Used

2.1.1 Temperature Control and Thermostat:

All the measurements has been carried out in an automatic digital temperature controller high precision water thermostat (HARCO) having temperature control of accuracy $\pm$0.05°C.

2.1.2 Conductivity Meter:

It measures the amount of electrical current or conductance in a solution. It is useful in determining the overall health of a natural water body. It is based on the principle of measurement of ions by applying potential across the plates immersed in solution.

Electrical Conductivity is denoted by symbol **sigma (σ)**

Its SI unit is **Siemens per metre ($S \cdot m^{-1}$)**

Electric Conductivity depends on :

- Concentration of ion
- Temperature of the solution
- Specific nature of the ions

2.1.3 Viscometer:

An ubbelohde type viscometer or suspended-level viscometer is a measuring instrument which uses a capillary based method of measuring viscosity. The instrument is best suited for higher viscosity cellulosic polymer solutions.

The value obtained are independent of the total volume.

Viscosity is denoted by symbol **eta (ή)** and its SI unit is **centipoises(cp)**

2.1.4 Ultrasonic Velocity Meter:

Ultrasonic Velocity meter measures the velocity of fluid with ultrasound to calculate volume flow. It measures the difference between the transit time of ultrasonic pulses propagating with and against the flow direction.

Velocity is denoted by **μ** and its SI unit is **m/s**

2.2 Methodology

2.2.1 Conductance Measurement :

- Different solutions of Quercetin of different concentrations 1mM, 2mM and 3mM has been prepared with different solutions as in distilled water, 30% Ethanol, 70% Ethanol and 100%Ethanol.
- Surfactant concentration has been varied by successive addition of small installments of surfactant stock solution using pipette.
- The solutions conductivity has been measured at different temperatures as 20 °C, 25 ^{o}C, 30 ^{o}C, 35 ^{o}C and 40 ^{o}C.
- The cmc values of all the solutions have been determined from the plot of Conc. v/s Conductivity measured by conductivity meter.

2.2.2 Thermodynamic parameters:

The X_{CMC} data has been used to determine the thermodynamic parameters. The values of standard enthalpy change (ΔH^{o}_{m}), standard entropy change (ΔS^{o}_{m}) and standard Gibbs free energy change (ΔG^{o}_{m}) has been calculated using following equations:

$$\Delta H^{o}_{m} = - RT^{2} (2 - \alpha) [d (\ln X_{CMC}) / dT] \quad (i)$$

$$\Delta G^{o}_{m} = (2 - \alpha) RT (\ln X_{CMC}) \quad (ii)$$

$$\Delta S^{o}_{m} = (\Delta H^{o}_{m} - \Delta G^{o}_{m}) / T \quad (iii)$$

The $d(\ln X_{CMC})/dT$ denoted the slope of the straight line obtained by plotting $\ln X_{CMC}$ against temperature. The degree of ion dissociation (α), has been calculated from the relation, $\alpha = S_2/S_1$, where S_1 and S_2 are the slopes in the pre micellar and post micellar region.

2.2.3 Density and ultrasonic sound velocity measurements

The density (ρ) has been manually calculated with the help of specific gravity bottle and calibrated weighing balance. The ultrasonic sound velocity (μ) values has been calculated from Digital Ultrasonic Pulse-Echo Velocity meter for Liquids and Solids (VCT-70A), supplied by Vi Microsystems Pvt. Ltd., Chennai. The density and ultrasonic sound velocity values have been calculated for various concentrations of ethanol and surfactant at three different concentrations of Quercetin (1-3 mM).

2.2.4 Relative viscosity measurements:

The viscosity (η) measurements have been carried out in a calibrated jacketed ubbelhode viscometer. The desired temperature has been achieved with the help of water thermostat having a digital temperature controller, purchased from Harsh & Co., Ambala. From the obtained values, relative viscosities has been calculated by using the equation:

$$\eta_r = \eta/\eta_o = (t \times \rho)/(t_o \times \rho_o) \qquad \text{(iv)}$$

Here η, t and ρ are the viscosity, flow time and density of solution and η_o, t_o and ρ_o of solvents, respectively.

2.2.5 Apparent molar volume (ϕ_v) and apparent adiabatic compressibility (ϕ_k)

Density (ρ) and ultrasonic sound velocity (μ) values have been used to measure apparent molar volume and apparent adiabatic compressibility using the following relations:

$$\phi_k = \frac{1000(\beta - \beta_0)}{c.\rho_0} + \beta.\phi_v \qquad \text{(v)}$$

$$\phi_v = \frac{1000}{c}\left\{\frac{\rho_0 - \rho}{\rho_0}\right\} + \frac{M}{\rho_0} \qquad \text{(vi)}$$

where, c is the concentration of surfactant, ρ is the density of solution, ρ_0 is the density of solvent system, M is the molecular weight of surfactant, β and β_o are the adiabatic compressibility of the solution and solvent respectively, calculated from the relation $\beta = 1/\rho\mu^2$.

CHAPTER-03

RESULTS AND DISCUSSION

3.1 Results and Discussion :

3.1.1 Specific conductance

The values of CMC has been obtained by plotting the graph between specific conductance and surfactant concentration (Table 1). According to the literature, CMC of CTAB in pure water is 1mM [25°C]. In all the solutions, it has been found that the CMC values increases with increase in temperature.

Table 1. CMC data obtained by interaction of Quercetin (1-3 mM) with different concentrations of CTAB at different temperatures (20-40 °C)

	CMC (0% EtOH)			**CMC (30% EtOH)**			**CMC (70% EtOH)**			**CMC (100% EtOH)**		
Temp (°C)	**1mM**	**2mM**	**3mM**	**1mM**	**2mM**	**3mM**	**1mM**	**2mM**	**3mM**	**1mM**	**2mM**	**3mM**
20	0.9	1.4	1.12	1.15	1.05	1	1.1	1.12	1.05	1.15	1.17	1.2
25	1	1.5	1.14	0.95	1.1	1.05	1.15	1.15	1.1	1.25	1.3	1.25
30	1.07	1.52	1.23	0.93	1.17	1.15	1.2	1.28	1.15	1.27	1.32	1.3
35	1.1	1.54	1.3	0.9	1.25	1.3	1.25	1.22	1.2	1.29	1.38	1.32
40	1.5	1.6	135	0.85	1.3	1.25	1.28	1.25	1.25	1.32	1.4	1.37

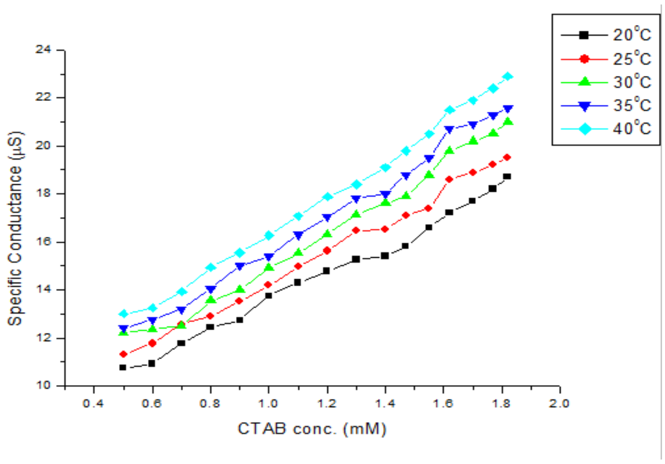

Figure 4: Variation of Specific Conductance (κ) with concentration of CTAB at different temperature in 1mM Quercetin.

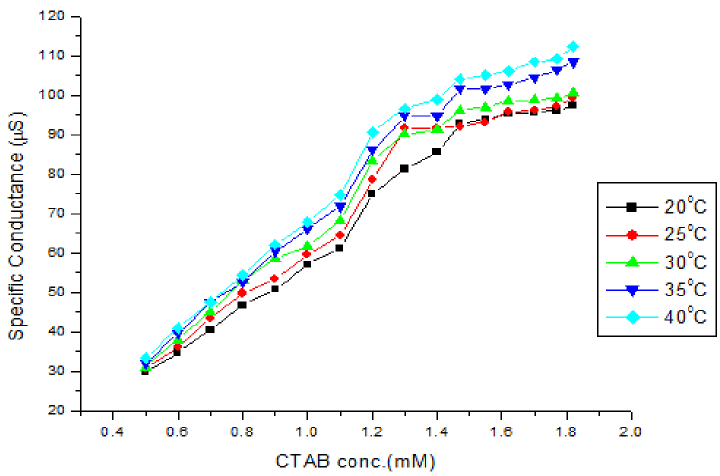

Figure 5: Variation of Specific Conductance (κ) with concentration of CTAB at different temperature in 2mM Quercetin.

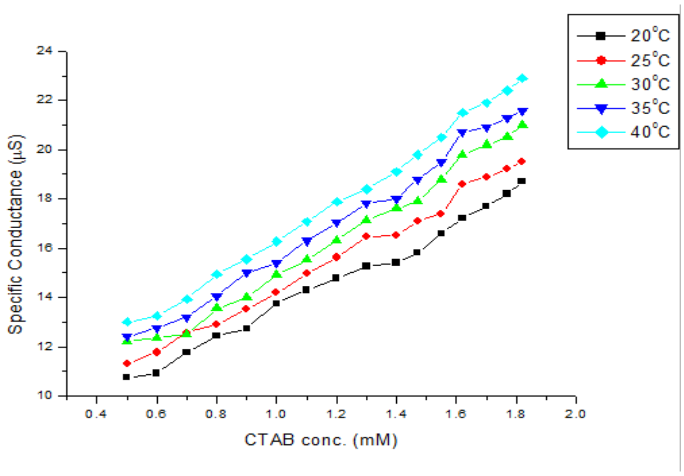

Figure 6: Variation of Specific Conductance (κ) with concentration of CTAB at different temperature in 3mM Quercetin.

3.1.2 Thermodynamic parameters:

The values of thermodynamic parameters i.e. standard enthalpy change (ΔH^{o}_{m}), standard entropy change (ΔS^{o}_{m}) and standard Gibbs free energy change (ΔG^{o}_{m}) for different concentrations of Quercetin (1-3 mM) in pure water are given in Table 2. Table 3, 4 and 5 represents the thermodynamic parameters for different concentrations of Quercetin (1-3 mM) in ethanol.

Table 2: Thermodynamic parameters for different concentrations of Quercetin (1-3 mM) in pure water at different temperatures (20-40 °C)

QC. Conc.	**T(°C)**	**CMC**	**X_{CMC}**	**ΔH^o_m**	**ΔG^o_m**	**ΔS^o_m**
1mM	20	0.0009	1.62011E-05	0.711678	-1.16614	0.093891
	25	0.001	1.80012E-05	1.111998	-1.43578	0.101911
	30	0.00107	1.92612E-05	1.601276	-1.70606	0.110244
	35	0.0011	1.97909E-05	2.179515	-1.98235	0.118911
	40	0.0015	2.70015E-05	2.846714	-2.1624	0.125228
2mM	20	0.00147	0.423631124	0.678422	-1.08456	0.088149
	25	0.0015	0.428571429	1.060035	-1.3515	0.096461
	30	0.00152	0.431818182	1.52645	-1.6185	0.104832
	35	0.00154	0.435028249	2.077669	-1.88444	0.113209
	40	0.0016	0.444444444	2.71369	-2.14094	0.121366
3mM	20	0.00112	2.01605E-05	0.701702	-1.12978	0.091574
	25	0.00114	2.05205E-05	1.096409	-1.40854	0.100198
	30	0.00123	2.21405E-05	1.578829	-1.6713	0.108338
	35	0.0013	2.34005E-05	2.148961	-1.93374	0.116649
	40	0.00135	2.43005E-05	2.806806	-2.19744	0.125106

Table 3: Thermodynamic parameters for different concentrations of Quercetin (1-3 mM) in 30% v/v ethanol at different temperatures (20-40 ^{o}C)

QC. Conc.	T(^{o}C)	CMC	X_{CMC}	ΔH^{o}_{m}	ΔG^{o}_{m}	ΔS^{o}_{m}
1mM	20	0.00115	2.06905E-05	0.731632	-1.12538	0.092851
	25	0.00095	1.70922E-05	1.143175	-1.44644	0.103585
	30	0.00093	1.67324E-05	1.646172	-1.74103	0.112907
	35	0.00090	1.61926E-05	2.240623	-2.04075	0.122325
	40	0.00085	1.5293E-05	2.926528	-2.35129	0.131945
2mM	20	0.00105	1.88913E-05	0.705027	-1.14051	0.092277
	25	0.00110	1.97909E-05	1.101605	-1.41597	0.100703
	30	0.00117	2.10503E-05	1.586311	-1.68377	0.109003
	35	0.00125	2.24896E-05	2.159146	-1.94516	0.117266
	40	0.00130	2.33892E-05	2.820109	-2.20999	0.125753
3mM	20	0.001	1.79918E-05	0.708353	-1.14862	0.092849
	25	0.00105	1.88913E-05	1.106801	-1.42564	0.101297
	30	0.00115	2.06905E-05	1.593794	-1.68807	0.109396
	35	0.0012	2.159E-05	2.16933	-1.95703	0.117896
	40	0.00125	2.24896E-05	2.833411	-2.22303	0.126411

Table 4: Thermodynamic parameters for different concentrations of Quercetin (1-3 mM) in 70% v/v ethanol at different temperatures (20-40 ^{o}C)

QC. Conc.	T(^{o}C)	CMC	X_{CMC}	ΔH^{o}_{m}	ΔG^{o}_{m}	ΔS^{o}_{m}
1mM	20	0.0011	0.035369775	0.705027	-1.13277	0.09189
	25	0.00115	0.036918138	1.101605	-1.40673	0.100333
	30	0.0012	0.038461538	1.586311	-1.67746	0.108792
	35	0.00125	0.04	2.159146	-1.94516	0.117266
	40	0.00128	0.040920716	2.820109	-2.21515	0.125881
2mM	20	0.00112	2.01507E-05	0.69505	-1.12978	0.091241
	25	0.00115	2.06905E-05	1.086016	-1.40673	0.09971
	30	0.0018	3.23847E-05	1.563863	-1.57633	0.104679
	35	0.00122	2.19499E-05	2.128592	-1.95222	0.116595
	40	0.00125	2.24896E-05	2.780202	-2.22303	0.125081
3mM	20	0.00105	1.88913E-05	0.708353	-1.14051	0.092443
	25	0.0011	1.97909E-05	1.106801	-1.41597	0.100911
	30	0.00115	2.06905E-05	1.593794	-1.68807	0.109396
	35	0.0012	2.159E-05	2.16933	-1.95703	0.117896
	40	0.00125	2.24896E-05	2.833411	-2.22303	0.126411

Table 5: Thermodynamic parameters for different concentrations of Quercetin (1-3 mM) in 100% v/v ethanol at different temperatures (20-40 ^{o}C)

QC. Conc.	T(^{o}C)	CMC	X_{CMC}	ΔH^{o}_{m}	ΔG^{o}_{m}	ΔS^{o}_{m}
1mM	20	0.00115	2.06905E-05	0.698376	-1.12538	0.091188
	25	0.00125	2.24896E-05	1.091213	-1.3894	0.099224
	30	0.00127	2.28494E-05	1.571346	-1.66332	0.107822
	35	0.00129	2.32092E-05	2.138777	-1.93599	0.116422
	40	0.00132	2.3749E-05	2.793504	-2.20491	0.12496
2mM	20	0.00117	2.10503E-05	0.69505	-1.12251	0.090878
	25	0.0013	2.33892E-05	1.086016	-1.38124	0.09869
	30	0.00132	2.3749E-05	1.563863	-1.65369	0.107252
	35	0.00138	2.48285E-05	2.128592	-1.91636	0.11557
	40	0.0014	2.51883E-05	2.780202	-2.18535	0.124139
3mM	20	0.0012	0.038461538	0.69505	-1.11831	0.090668
	25	0.00125	0.04	1.086016	-1.3894	0.099017
	30	0.0013	0.041533546	1.563863	-1.65749	0.107379
	35	0.00132	0.042145594	2.128592	-1.9293	0.11594
	40	0.00137	0.043672298	2.780202	-2.19255	0.124319

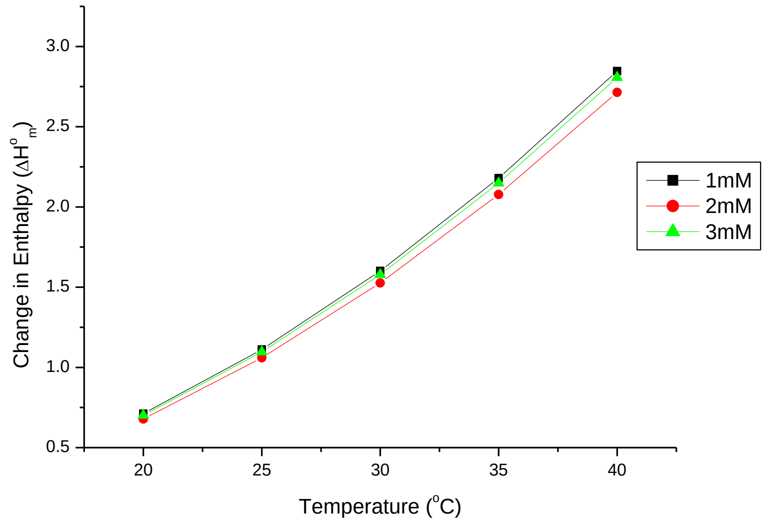

Figure 7: Graphical representation of Change in Enthalpy ($\Delta H°_m$) vs. Temperature for different concentrations of QC (1-3mM) in aqueous solution.

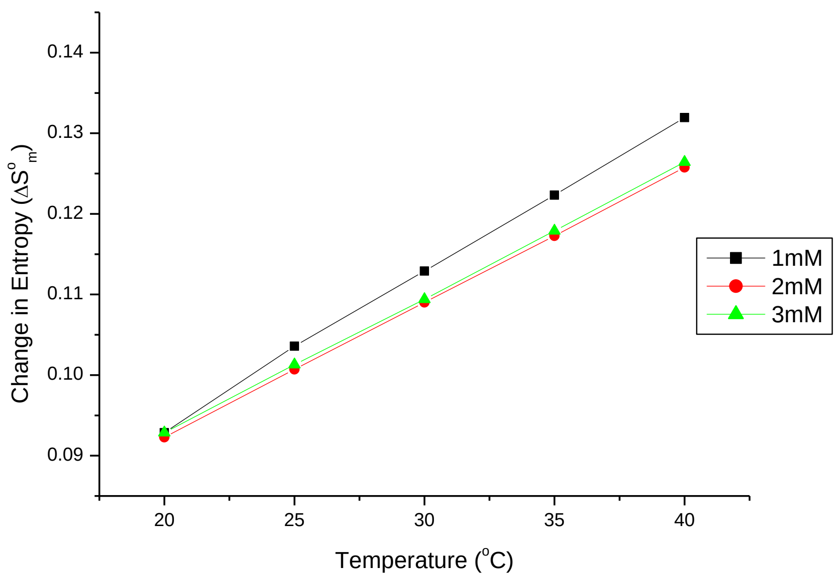

Figure 8: Graphical representation of Change in Entropy ($\Delta S°_m$) vs. Temperature for different concentrations of QC (1-3mM) in 30% v/v Ethanol solution

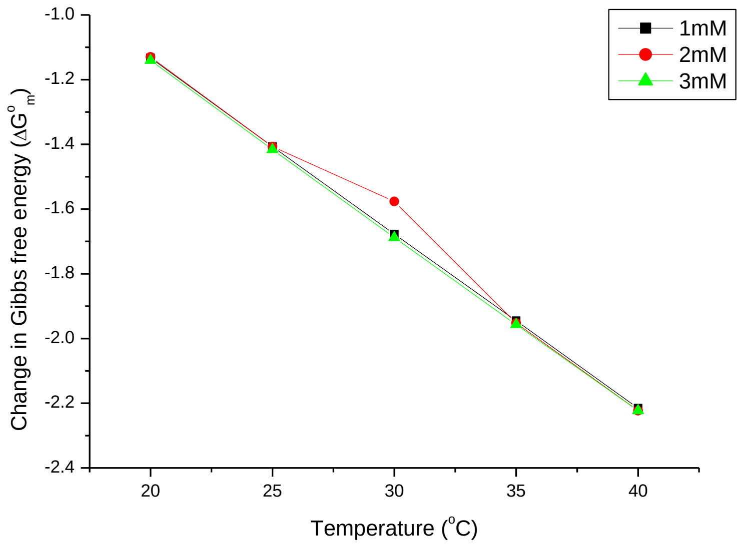

Figure 9: Graphical representation of Change in Gibbs free energy (ΔG°_m) vs. Temperature for different concentrations of QC (1-3mM) in 70% v/v Ethanol solution.

The data clearly shows that the values of ΔG^o_m in water and hydro-ethanolic solutions has been found to be negative for all concentrations and temperatures. On the other hand, the values of ΔH^o_m and ΔS^o_m has been found to be positive. The value of ΔS^o_m indicates that micellization in these studied systems is entropically controlled. The studies also suggest that the interactions between Quercetin and CTAB are endothermic in nature. The activity of Quercetin has been best observed at 40 °C for all concentrations of CTAB and hydro-ethanolic solutions.

3.1.3 Density and ultrasonic sound velocity measurements:

The density (ρ) and ultrasonic sound velocity (μ) has been measured for CTAB in presence of Quercetin (1-3 mM) at five different temperatures and four different hydro-ethanolic solutions. It has been found that the density and ultrasonic sound velocity are completely concentration and temperature dependent in all solution systems. The results of density and ultrasonic sound velocity are displayed in Table 6 and 7 respectively.

3.1.4 Relative viscosity measurements

The relative viscosity measurements of CTAB and Quercetin in pure ethanol, ethanol rich, water rich and pure water compositions have been conducted at five different temperatures. The viscosity values have been found to increase with increase in temperature at all temperatures and ethanolic concentrations. However, a decrease in values has been observed near the CMC values confirming that the micellization has been occurred. The values of relative viscosities are presented in Table 8.

3.1.5 Apparent molar volume (ϕ_v) and apparent adiabatic compressibility (ϕ_k)

Density (ρ) and ultrasonic sound velocity (μ) values have been used to measure apparent molar volume and apparent adiabatic compressibility. These parameters helped us in determining different kinds of interactions furnished by solute in the solution so that the structural consequences arising from solute-solvent interactions can be studied. The values obtained for apparent molar volume and apparent molar compressibility are represented in Tables 9 and 10 respectively.

Table 6: Density, ρ (g cm^{-3}) obtained by interaction of Quercetin (1-3 mM) with different concentrations of CTAB (0.5-1.77 mM) and ethanol at five different temperatures.

CTAB [mol kg^{-1}]	0% v/v EtOH					30% v/v EtOH					70% v/v EtOH					100% v/v EtOH				
Quercetin (1mM)																				
	20 °C	25 °C	30 °C	35 °C	40 °C	20 °C	25 °C	30 °C	35 °C	40 °C	20 °C	25 °C	30 °C	35 °C	40 °C	20 °C	25 °C	30 °C	35 °C	40 °C
0.5	0.996	1.009	1.003	0.998	0.996	0.954	0.941	0.930	0.927	0.930	0.8832	0.8802	0.8623	0.8651	0.7824	0.8642	0.8590	0.7891	0.7812	0.7821
0.7	0.997	1.019	1.003	0.993	0.991	0.942	0.950	0.921	0.932	0.910	0.8837	0.8804	0.8804	0.8702	0.7848	0.8851	0.8612	0.7942	0.7924	0.7904
0.9	0.996	1.013	1.003	0.995	0.993	0.912	0.932	0.907	0.942	0.920	0.8842	0.8816	0.8680	0.8691	0.7865	0.8605	0.8604	0.7984	0.7965	0.7894
1.1	0.999	1.011	0.999	0.996	0.994	0.923	0.934	0.910	0.975	0.940	0.8849	0.8732	0.8901	0.8686	0.8056	0.8647	0.8584	0.7905	0.7874	0.7898
1.3	1.001	1.015	0.9929	0.986	0.984	0.974	0.942	0.906	0.986	0.924	0.9012	0.8885	0.8732	0.8689	0.8074	0.8651	0.8601	0.7916	0.7884	0.7896
1.47	1.011	1.009	0.9927	0.983	0.981	0.942	0.941	0.902	0.915	0.924	0.9021	0.8890	0.8725	0.8672	0.8154	0.8654	0.8604	0.7945	0.7914	0.7895
1.62	0.998	1.015	0.9937	0.990	0.988	0.935	0.940	0.903	0.935	0.945	0.9024	0.8895	0.8805	0.8665	0.8172	0.8664	0.8605	0.7972	0.7946	0.7904
1.77	0.998	1.013	0.9933	0.986	0.984	0.915	0.932	0.913	0.957	0.930	0.9102	0.8897	0.8725	0.8668	0.8542	0.8885	0.8604	0.8004	0.7974	0.7908
Quercetin (2mM)																				
0.5	0.980	0.999	0.996	0.994	0.991	0.979	0.953	0.932	0.9452	0.9120	0.8820	0.8781	0.8624	0.8641	0.8782	0.8441	0.7915	0.7941	0.7812	0.7874
0.7	0.989	0.995	0.996	0.998	0.993	0.981	0.959	0.933	0.9453	0.9210	0.8835	0.8790	0.8784	0.8651	0.8784	0.8632	0.7926	0.7925	0.7902	0.7886
0.9	0.993	1.003	0.996	0.996	0.987	0.989	0.965	0.935	0.9422	0.9340	0.8605	0.8792	0.8662	0.8713	0.8793	0.8405	0.7954	0.7964	0.7943	0.7874
1.1	0.9878	0.989	0.987	0.986	0.984	0.990	0.966	0.951	0.9475	0.9142	0.8825	0.8804	0.8821	0.8705	0.8795	0.8445	0.7976	0.7834	0.7856	0.7874
1.3	0.9872	0.989	0.987	0.985	0.987	0.989	0.971	0.937	0.9496	0.9420	0.8836	0.8762	0.8712	0.8706	0.8797	0.8452	0.7945	0.7896	0.7861	0.7876
1.47	0.989	0.990	0.992	0.990	0.995	0.992	0.971	0.948	0.9363	0.9092	0.8845	0.8785	0.8704	0.8691	0.8786	0.8457	0.7998	0.7924	0.7896	0.7878
1.62	0.990	0.990	0.988	0.985	0.995	0.991	0.975	0.948	0.9432	0.9301	0.8847	0.8804	0.8764	0.8682	0.8780	0.8465	0.8014	0.7952	0.7934	0.7881
1.77	0.990	0.991	0.988	0.986	0.996	0.992	0.975	0.943	1.0542	0.9230	0.8849	0.8815	0.8672	0.8682	0.8790	0.8840	0.8002	0.7963	0.7956	0.7886
Quercetin (3mM)																				
0.5	0.989	1	0.996	0.994	0.993	0.9901	0.9860	0.9972	0.9912	0.9139	0.8801	0.8810	0.8831	0.8661	0.8782	0.8270	0.7890	0.7856	0.7782	0.7851
0.7	0.987	0.997	0.996	0.980	0.985	0.9920	0.9990	0.9940	0.9919	0.9177	0.8884	0.8824	0.8804	0.8674	0.8795	0.8635	0.7901	0.7901	0.7881	0.7862
0.9	0.988	0.993	0.991	0.991	0.990	0.9927	1	0.9894	0.9920	0.9179	0.8584	0.8835	0.8680	0.8738	0.8796	0.8204	0.7936	0.7942	0.7924	0.7852
1.1	0.991	0.992	0.990	0.992	0.990	0.9929	0.9862	0.9742	0.9960	0.9223	0.8802	0.8790	0.8824	0.8724	0.8777	0.8245	0.7952	0.7862	0.7836	0.7853
1.3	0.993	0.992	0.990	0.991	0.990	0.9935	1	0.9762	0.9872	0.9231	0.8814	0.8836	0.8735	0.8729	0.8779	0.8247	0.7924	0.7874	0.7845	0.7874
1.47	0.990	0.993	0.991	0.990	0.989	0.9965	0.9882	0.9736	1.010	0.9271	0.8824	0.8839	0.8725	0.8719	0.8795	0.8256	0.7976	0.7904	0.7876	0.7856
1.62	0.991	0.992	0.990	0.987	0.987	0.9939	0.9925	0.9719	0.9792	0.9293	0.8828	0.8851	0.8806	0.8704	0.8784	0.8304	0.7982	0.7894	0.7912	0.7864
1.77	0.995	0.990	0.987	0.986	0.986	0.9949	0.9836	0.9765	0.9735	0.9311	0.8829	0.8836	0.8715	0.8708	0.8796	0.8642	0.798.5	0.7963	0.7953	0.7864

Table 7: Ultrasonic sound velocity, μ (m s^{-1}) obtained by interaction of Quercetin (1-3 mM) with different concentrations of CTAB (0.5-1.77 mM) and ethanol at five different temperatures

CTAB [mol kg^{-1}]	0% v/v EtOH					30% v/v EtOH					70% v/v EtOH					100% v/v EtOH				
	Quercetin (1mM)																			
	20 °C	25 °C	30 °C	35 °C	40 °C	20 °C	25 °C	30 °C	35 °C	40 °C	20 °C	25 °C	30 °C	35 °C	40 °C	20 °C	25 °C	30 °C	35 °C	40 °C
0.5	1426.75	1416.3	1439.96	1440.10	1462.6	1570.99	1560.40	1551.18	1570.25	1553.11	1298.79	1317.4	1328.69	1345.29	1359.53	1198.79	1217.4	1133.2	1134.3	1114.7
0.7	1429.91	1418.61	1426.61	1451.40	1460.28	1570.25	1561.90	1551.90	1567.99	1544.01	1314.41	1324.9	1329.80	1347.12	1361.82	1214.41	1224.9	1133.7	1135.7	1117.8
0.9	1428.01	1416.75	1429.91	1450.45	1459.10	1572.41	1564.97	1556.64	1568.80	1545.47	1321.1	1328.7	1332.80	1347.17	1364.70	1221.1	1228.7	1134.1	1140.3	1121.1
1.1	1428.65	1422.98	1436.26	1451.10	1462.92	1573.31	1568.73	1561.90	1570.25	1545.47	1323.4	1327.1	1332.59	1342.04	1362.67	1223.4	1227.1	1133.0	1141.5	1123.7
1.3	1428.65	1426.12	1447.35	1456.99	1453.70	1574.84	1571.78	1561.90	1570.54	1542.52	1327.1	1330.4	1333.70	1351.15	1363.55	1227.1	1230.4	1131.1	1142.7	1123.8
1.47	1430.54	1424.87	1448.20	1468.24	1459.20	1575.61	1571.78	1562.24	1572.54	1544.47	1329.5	1333.1	1343.26	1334.17	1372.35	1229.5	1233.1	1133.0	1143.7	1123.8
1.62	1429.91	1427.38	1451.34	1462.92	1459.62	1577.92	1573.54	1564.93	1574.08	1547.69	1333.1	1335.4	1343.88	1347.90	1368.74	1233.1	1235.4	1134.0	1141.5	1124.1
1.77	1428.65	1431.81	1453.30	1462.92	1459.62	1579.46	1577.15	1570.25	1573.33	1549.18	1334.5	1337.4	1347.06	1342.87	1355.07	1234.5	1237.4	1133.0	1140.7	1123.1
	Quercetin (2mM)																			
0.5	1436.26	1417.99	1451.75	1452.30	1464.25	1551.41	1444.61	1500.22	1531.36	1503.06	1288.79	1307.41	1328.69	1345.29	1359.53	1188.79	1132.71	1123.2	1124.34	1112.74
0.7	1435.63	1418.61	1451.75	1452.30	1462.92	1552.80	1450.45	1512.92	1533.74	1510.09	1304.41	1314.91	1329.80	1347.12	1361.82	1214.41	1134.70	1123.6	1125.70	1115.83
0.9	1436.20	1418.61	1452.40	1453.10	1462.99	1554.39	1451.10	1525.02	1538.12	1512.92	1311.19	1318.79	1332.80	1347.17	1364.70	1211.91	1136.30	1124.1	1130.31	1115.83
1.1	1434.35	1418.40	1453.05	1455.30	1455.67	1558.14	1451.10	1532.28	1544.04	1512.21	1333.46	1317.15	1332.59	1342.64	1362.67	1188.17	1137.50	1123.0	1131.52	1111.12
1.3	1434.35	1420.21	1454.36	1455.30	1455.67	1555.14	1453.71	1528.66	1543.32	1515.75	1327.10	1320.45	1333.70	1351.15	1363.55	1187.36	1136.70	1121.1	1132.73	1113.74
1.47	1433.08	1424.31	1454.36	1456.10	1456.33	1557.30	1450.45	1521.46	1545.47	1512.92	1321.56	1323.17	1343.26	1334.17	1372.35	1184.17	1138.90	1123.0	1133.71	1113.88
1.62	1432.45	1430.21	1452.40	1453.40	1458.11	1555.14	1453.71	1531.36	1549.18	1516.04	1323.14	1325.42	1343.88	1347.90	1368.74	1181.71	1137.70	1124.0	1131.52	1114.12
1.77	1434.30	1434.20	1452.40	1453.40	1459.10	1556.17	1453.05	1533.01	1550.14	1516.96	1324.57	1327.41	1347.06	1342.87	1369.32	1186.41	1137.92	1123.0	1130.71	1113.11
	Quercetin (3mM)																			
0.5	1417.99	1443.97	1447.20	1460.28	1466.20	1432.92	1430.18	1431.18	1435.81	1418.26	1298.79	1317.41	1338.69	1355.29	1349.53	1178.79	1122.71	1113.21	1114.34	1102.74
0.7	1418.61	1446.45	1448.21	1461.60	1467.10	1435.63	1431.63	1444.61	1445.70	1430.15	1314.41	1324.91	1339.80	1357.12	1351.82	1204.41	1124.70	1113.68	1115.70	1105.83
0.9	1418.61	1446.55	1448.21	1461.60	1467.20	1434.99	1437.72	1445.90	1447.65	1435.25	1321.19	1328.79	1342.80	1357.17	1354.70	1201.91	1126.30	1114.10	1120.31	1105.83
1.1	1418.40	1446.65	1449.30	1462.26	1460.10	1445.26	1432.10	1447.85	1449.09	1437.24	1343.46	1327.15	1342.59	1352.64	1352.67	1178.77	1127.50	1113.07	1121.52	1101.12
1.3	1420.21	1445.35	1448.70	1460.25	1460.10	1449.15	1440.19	1443.32	1447.08	1420.12	1337.10	1330.45	1343.70	1361.15	1353.55	1177.36	1126.70	1111.12	1122.73	1103.74
1.47	1424.31	1451.10	1452.10	1460.94	1461.08	1455.02	1447.20	1447.85	1444.70	1412.35	1331.56	1333.17	1345.26	1344.17	1362.35	1174.17	1128.90	1113.04	1123.71	1103.88
1.62	1430.21	1448.50	1459.10	1458.20	1460.11	1453.71	1443.10	1450.45	1451.35	1424.10	1333.14	1335.42	1343.88	1348.90	1358.74	1171.71	1127.70	1114.01	1121.52	1104.12
1.77	1434.21	1447.85	1449.10	1455.67	1464.10	1456.70	1445.10	1453.05	1454.15	1437.10	1334.57	1327.41	1348.06	1352.87	1359.32	1176.41	1127.98	1113.02	1120.71	1103.11

Table 8: Relative viscosity, η_r (centipoise) obtained by interaction of Quercetin (1-3 mM) with different concentrations of CTAB (0-1.77 mM) and ethanol at five different temperatures

CTAB [mol kg^{-1}]	0% v/v EtOH					30% v/v EtOH					70% v/v EtOH					100% v/v EtOH				
	Quercetin (1mM)																			
	20 °C	25 °C	30 °C	35 °C	40 °C	20 °C	25 °C	30 °C	35 °C	40 °C	20 °C	25 °C	30 °C	35 °C	40 °C	20 °C	25 °C	30 °C	35 °C	40 °C
0.5	0.941	0.819	0.872	0.573	0.573	0.884	0.788	1.59	1.76	1.35	2.47	2.44	1.54	1.51	1.36	2.07	1.78	0.80	0.791	0.758
0.7	0.9261	0.848	0.815	0.625	0.626	0.87	0.809	1.63	2	1.28	2.37	2.31	1.65	1.59	1.42	2.02	2.04	0.80	0.792	0.775
0.9	0.9573	0.814	0.831	0.635	0.635	0.79	0.805	1.66	2.04	1.21	2.39	2.34	1.64	1.59	1.40	1.98	1.92	0.80	0.789	0.781
1.1	1.041	0.821	0.849	0.700	0.701	0.78	0.803	1.69	2.01	1.19	2.40	2.33	1.55	1.48	1.36	2.01	1.94	0.79	0.774	0.778
1.3	0.161	0.832	0.851	0.802	0.802	0.80	0.799	1.71	2	1.28	2.54	2.45	1.41	1.57	1.44	2.09	1.95	0.76	0.766	0.761
1.47	1.62	0.831	0.835	0.840	0.839	0.81	0.813	1.74	1.97	1.22	2.60	2.52	1.51	1.51	1.40	2.15	2.05	0.79	0.801	0.790
1.62	1.417	0.844	0.827	0.757	0.756	0.80	0.821	1.80	1.96	1.24	2.62	2.54	1.51	1.48	1.37	2.17	2.12	0.79	0.785	0.786
1.77	1.397	0.863	0.819	0.646	0.646	0.82	0.809	1.84	1.94	1.25	2.66	2.54	1.49	1.48	1.44	2.24	2.13	0.79	0.784	0.789
	Quercetin (2mM)																			
0.5	0.969	1.06	0.719	0.667	0.593	0.946	2.65	2.06	1.66	1.39	2.09	2.05	1.50	1.47	1.25	1.68	1.13	0.780	0.691	0.724
0.7	0.990	1.01	0.707	0.662	0.602	0.902	2.83	2.08	1.51	1.36	1.56	1.95	1.61	1.54	1.30	1.62	1.14	0.768	0.689	0.741
0.9	1.002	1.01	0.719	0.680	0.631	0.906	3.07	2.18	1.50	1.34	1.98	1.981.95	1.60	1.54	1.28	1.59	0.15	0.766	0.687	0.718
1.1	1.028	1.00	0.746	0.626	0.634	0.897	3.01	2.11	1.44	1.34	20.6	1.98	1.50	1.41	1.36	1.62	0.14	0.739	0.673	0.744
1.3	1.004	1.01	0.706	0.706	0.668	0.901	2.72	2.18	1.41	1.34	2.13	1.95	1.55	1.52	1.50	1.69	0.13	0.760	0.666	0.727
1.47	1.022	0.980	0.741	0.664	0.810	0.884	2.78	1.89	1.39	1.27	2.20	2.06	1.47	1.47	1.42	2.78	1.14	0.756	0.698	0.756
1.62	1.019	0.992	0.706	0.700	0.677	0.88	2.90	2.05	1.41	1.34	2.21	2.17	1.47	1.44	1.42	1.77	1.15	0.753	0.684	0.752
1.77	1.031	1.001	0.714	0.674	0.681	0.892	2.69	2.05	1.59	1.27	2.23	2.19	1.45	1.43	1.56	1.78	1.15	0.755	0.682	0.755
	Quercetin (3mM)																			
0.5	0.946	0.823	0.895	0.723	0.566	0.947	0.788	0.750	0.655	0.712	2.04	2.10	1.75	1.51	1.29	1.61	1.10	0.711	0.724	0.691
0.7	0.956	0.813	0.958	0.685	0.582	1.03	0.826	0.752	0.668	0.715	1.53	1.99	1.83	1.57	1.25	1.58	1.11	0.734	0.724	0.691
0.9	0.969	0.923	0.892	0.664	0.582	1.06	0.848	0.747	0.973	0.717	1.94	2.10	1.82	1.58	1.31	1.52	1.12	0.732	0.721	0.707
1.1	0.980	0.937	0.901	0.667	0.612	1.08	0.852	0.756	0.662	0.724	1.99	1.99	1.71	1.47	1.29	1.55	1.11	0.829	0.706	0.714
1.3	0.994	0.994	0.904	0.673	0.582	0.93	0.872	0.731	0.666	0.743	20.9	2.11	1.76	1.55	1.36	1.62	1.10	0.726	0.698	0.711
1.47	0.987	0.814	0.890	0.680	0.720	0.91	0.876	0.731	0.674	0.755	2.13	2.21	1.68	1.50	1.43	1.68	1.12	0.722	0.714	0.695
1.62	0.996	0.821	0.890	0.678	0.582	0.922	0.845	0.761	0.677	0.746	2.17	2.22	1.69	1.48	1.43	1.71	1.12	0.718	0.717	0.720
1.77	1	0.819	0.890	0.689	0.582	0.927	0.833	0.768	0.660	0.727	2.18	2.24	1.65	1.47	1.55	1.79	1.12	0.721	0.717	0.720

Table 9: Apparent molar volume, ϕ_V ($m^3 mol^{-1}$) for Quercetin (1-3 mM) with different concentrations of CTAB (0.5-1.77 mM) and water-ethanol at five different temperatures

CTAB [mol kg^{-1}]	0% v/v EtOH					30% v/v EtOH					70% v/v EtOH					100% v/v EtOH				
	20 °C	25 °C	30 °C	35 °C	40 °C	20 °C	25 °C	30 °C	35 °C	40 °C	20 °C	25 °C	30 °C	35 °C	40 °C	20 °C	25 °C	30 °C	35 °C	40 °C
Quercetin (1mM)																				
0.5	0.402611	-2.42468	-1.50161	-0.82599	-0.809	9.283334	11.93843	14.17026	14.56312	13.48189	26.91249	26.67133	31.13509	30.0272	55.49761	31.12124	32.22748	52.44145	54.89540	51.91361
0.7	0.172616	-3.16194	-1.08668	0.087149	0.10201	8.538651	7.089315	11.6228	9.57558	13.00608	18.85521	18.68295	18.84958	20.4990	39.17046	18.30615	22.63344	36.43279	36.67063	36.85209
0.9	0.24623	-1.814	-0.84511	-0.12318	-0.11239	10.52128	7.772869	10.90222	6.182172	8.788747	14.66525	13.82115	16.40645	16.0907	30.46601	17.88791	17.75393	27.63527	27.81671	28.84110
1.1	-0.14539	-1.2801	-0.32862	-0.19241	-0.18395	7.420424	6.15082	8.589637	1.791825	5.088426	11.88219	12.71388	10.83459	13.2857	21.87119	14.14624	14.77243	23.76439	24.06527	23.56814
1.3	-0.14604	-1.40522	0.210464	0.620218	0.63848	1.915046	4.505159	7.641421	0.636039	6.084638	8.408697	9.764597	10.85087	11.2418	18.38672	11.86704	12.29131	19.98530	20.23895	19.93000
1.47	-0.19706	-0.83116	0.199971	0.759009	0.77606	4.066224	4.060942	7.09074	5.916118	5.381017	7.436309	8.896859	9.685416	10.0322	15.42266	10.49470	10.85152	17.34918	17.57103	17.58156
1.62	0.000361	-1.13954	0.118911	0.226049	0.26483	4.180352	3.754751	6.35844	3.925305	3.455227	6.671675	7.757144	8.145112	9.18556	13.99468	9.440611	9.855139	15.45018	15.55147	15.92400
1.77	-0.01664	-0.9222	0.131761	0.438203	0.47487	5.146887	3.952496	5.134338	2.2036	3.80872	5.48615	6.884606	8.04389	8.40716	9.526371	7.024296	8.989459	13.87505	14.05526	14.57454
Quercetin (2mM)																				
0.5	3.721351	-0.40124	-0.08031	0.020602	0.24444	3.92981	9.262161	13.70877	10.45359	18.20835	26.39713	27.18904	31.13509	30.2948	26.21858	36.60660	52.24315	51.00573	54.89540	52.55779
0.7	1.331664	0.288376	-0.05726	-0.56121	-0.11563	2.509616	5.678067	9.627802	7.466958	11.29971	18.67178	19.23575	19.21937	21.4481	18.72767	22.42117	37.08863	36.88714	37.12727	37.31105
0.9	0.583262	-0.66631	-0.04446	-0.21286	0.59035	1.03582	3.695973	7.233637	6.182172	7.490109	17.88791	14.81759	16.70208	15.7971	14.42209	20.96408	28.31740	27.98511	28.16832	29.19898
1.1	0.959222	0.737938	0.795981	0.751617	0.76389	0.754706	2.926524	4.282675	4.54867	8.276739	11.99892	12.59527	11.76108	13.0449	11.79996	16.63959	22.88191	24.79316	24.35957	23.89015
1.3	0.859035	0.624465	0.673579	0.715243	0.40881	0.717218	2.066301	4.832416	3.677746	4.30565	10.05422	10.45757	11.0532	11.0381	9.934898	13.97186	19.72656	20.23181	20.48735	20.15276
1.47	0.634316	0.482811	0.248327	0.283765	-0.19258	0.4263	1.827384	3.431188	4.248075	7.024195	8.804385	9.072151	9.864757	9.85163	8.918155	12.35612	16.90898	17.56554	17.78903	17.80028
1.62	0.512571	0.43814	0.477297	0.574033	-0.17471	0.449653	1.397406	3.11352	3.365219	4.161344	7.989202	8.232175	8.465415	9.02132	8.036429	11.12572	15.15047	15.64503	15.74730	16.12232
1.77	0.469164	0.343454	0.436879	0.467245	-0.21688	0.354107	1.279013	3.165689	-0.61603	4.469047	7.312185	7.461694	8.267563	8.25683	7.333467	7.312185	13.95474	14.22994	14.23359	14.73786
Quercetin (3mM)																				
0.5	1.864184	-0.60145	-0.08031	0.020602	-0.16203	1.659916	2.238316	-0.28172	0.629707	8.91446	26.91249	26.41336	25.61708	29.7602	26.21858	41.47775	52.88407	53.89363	55.88286	53.20526
0.7	1.624362	0.000361	-0.05726	2.06796	1.05280	1.185759	-0.2865	0.23133	0.449895	6.432971	18.67178	18.68295	18.84958	21.0672	18.54257	22.42117	37.54527	37.34378	37.58624	37.77235
0.9	1.149331	0.449287	0.518393	0.349999	0.24921	0.922337	-0.33398	0.745131	0.236974	4.833175	18.18908	14.38861	16.70208	15.5049	14.40771	24.19032	28.66990	28.33671	28.52170	29.55868
1.1	0.662044	0.459953	0.51687	0.193954	0.20397	0.754706	1.017616	2.023333	0.751617	3.795917	12.23317	12.24108	11.76108	12.8053	11.76468	19.25398	23.16887	25.09048	24.65538	24.18446
1.3	0.403909	0.389247	0.437407	0.242419	0.17264	0.638653	-0.2311	1.551963	0.556996	3.316644	10.25199	9.96147	10.85087	10.8353	9.954791	16.29189	19.97101	20.47957	20.73701	20.21481
1.47	0.564837	0.275214	0.317526	0.283765	0.22220	0.564837	0.62191	1.58743	-0.40338	3.222244	8.978885	8.80951	9.685416	9.67188	8.786011	14.30778	17.12263	17.78299	18.00814	18.09733
1.62	0.449653	0.31243	0.351077	0.447044	0.32813	0.324196	0.31243	1.571153	0.958111	2.930364	8.147544	7.835868	8.145112	8.85783	8.092438	12.53228	15.44019	16.23549	15.94412	16.32165
1.77	0.182389	0.401041	0.494816	0.467245	0.35841	0.239513	0.807427	1.139957	1.232811	2.938552	7.457109	7.316442	8.118277	8.10720	7.333467	8.791612	14.13173	14.22994	14.23359	14.93849

Table 10: Apparent adiabatic compressibility, ϕ_K ($m^3mol^{-1}TPa^{-1}$) for Quercetin (1-3 mM) with different concentrations of CTAB (0.5-1.77 mM) and water-ethanol at five different temperatures

CTAB [mol kg⁻¹]	0% v/v EtOH					30% v/v EtOH					70% v/v EtOH					100% v/v EtOH				
	20 °C	25 °C	30 °C	35 °C	40 °C	20 °C	25 °C	30 °C	35 °C	40 °C	20 °C	25 °C	30 °C	35 °C	40 °C	20 °C	25 °C	30 °C	35 °C	40 °C
Quercetin (1mM)																				
0.5	198.538	-1197.75	-721.96	-399.001	-379.623	3942.83	3210.37	6332.43	6371.43	6010.61	18129.8	17463.0	20155	19469.2	39486.7	25064.3	23313.9	31723.1	34625.8	32948.9
0.7	84.6773	-1541.13	-530.744	41.6411	48.2493	3676.21	3458.96	5239.90	4179.01	3995.21	12373.7	12067.1	11952.7	13178.7	27502.98	14025.6	17534.5	33695.5	33897.6	37332.2
0.9	121.232	-891.718	-412.012	-38.8329	-33.1516	3465.97	3405.28	4960.56	2666.58	3999.61	9525.55	8824.86	10482.6	10337.8	21370.71	13947.4	13672.2	26923.1	26874.9	29233.8
1.1	-71.2455	-625.184	-159.433	-91.7263	-86.456	3247.86	2676.02	3869.25	2745.33	2966.38	7682.70	8249.54	6953.60	8626.44	14938.46	10938.2	11433.2	23430.7	23466.5	23759.3
1.3	-71.5459	-680.38	101.187	296.255	307.017	2920.77	1935.86	3457.31	2618.52	2779.61	5504.92	6233.24	6884.07	7200.51	12523.37	9111.00	9440	19747.7	19668.6	19995.5
1.47	-96.187	-405.616	96.0485	338.105	371.497	1798.77	1746.84	3220.99	2614.64	2451.98	4674.11	5675.40	6146.60	6599.18	10383.89	8025.18	8295.55	17020.3	16982	17626.0
1.62	0.17670	-550.663	56.8106	106.636	125.817	1745.69	1613.23	2875.23	1694.37	1834.54	4166.37	4909.44	5117.83	5925.71	9436.098	7168.98	7507.31	15074.4	15011.9	15951.4
1.77	-8.16725	-443.844	62.8050	207.556	226.519	1254.79	1504.94	2280.74	930.210	1706.44	3384.88	4329.60	5083.65	5464.56	6103.586	5189.89	6822.68	13510.4	13552.8	14625.9
Quercetin (2mM)																				
0.5	1840.80	-199.755	-38.2607	9.82690	115.048	1667.76	4657.12	6535.40	4717.14	8856.79	18018.7	18116.5	20459.5	19374.2	16156.12	30690.6	51477.2	50918.6	55601.9	53935.5
0.7	653.301	144.015	-27.2799	-266.614	-54.4119	1060.98	2814.33	4508.30	3338.98	3386.09	12427.8	12656.9	12378.6	13663.4	11501.38	17616.3	36370.8	36886.2	37086.9	38029.0
0.9	284.763	-330.105	-21.1605	-101.213	279.455	433.478	1818.89	3326.55	2774.02	3918.62	12098.4	9681.52	10857.3	9995.45	8809.777	16992.4	27586.7	27823.0	27768.0	29798.6
1.1	471.997	370.874	381.965	359.927	366.365	313.999	1438.73	2918.04	2014.73	3877.34	7630.91	8287.68	7509.06	8317.73	7229.536	13965.0	22188.6	23104.7	24236.8	24587.9
1.3	422.956	313.045	322.646	342.856	195.473	299.858	1006.97	2207.00	1927.27	2993.68	6465.17	6831.13	7134.33	6949.74	6075.547	11728.2	19228.0	20401.1	20314.7	20630.8
1.47	312.297	240.399	118.35	135.188	-91.2558	177.198	894.550	1563.56	1900.18	2409.74	3702.60	3888.38	6284.15	6368.92	3393.232	10427.9	16315.4	17585.1	17541.6	18213.3
1.62	232.324	216.360	229.012	275.886	-82.3883	167.613	678.207	1450.51	1486.95	1946.83	3162.25	3325.06	3330.83	3720.51	4881.807	9417.51	14612.9	15576.4	15509.8	16483.0
1.77	230.361	168.490	209.619	224.335	-102.282	147.403	621.311	1428.45	-255.092	1410.95	4714.60	4806.74	5243.04	5275.04	4449.493	5876.58	13469.8	14174.7	14003.7	15091.1
Quercetin (3mM)																				
0.5	937.445	-288.456	-38.5016	9.7198	-75.9041	816.595	909.970	937.955	255.104	2731.63	18129.8	17274.5	16188.5	18709.1	16396.44	36094.1	33175.6	32873.6	37844.7	35736.3
0.7	817.785	0.17310	-27.4134	987.777	496.585	581.133	711.84	511.517	181.445	2044.24	12239.4	12067.1	11932.7	13193.2	11543.65	17910.1	37571.1	36148.3	38318.4	39298.4
0.9	378.146	216.136	249.416	165.323	116.940	452.435	633.221	360.379	175.289	1598.16	12144.8	9228.80	10696.2	9642.42	8930.389	20421.3	28500	27253.2	28692.8	30792.0
1.1	332.059	221.351	248.538	91.4402	96.6429	364.964	410.879	291.951	150.475	1393.53	7702.06	7906.62	7397.61	8026.19	7312.389	16833.6	22924.7	24602.0	23034.3	23409.5
1.3	201.664	187.831	210.520	114.719	81.8013	307.187	318.920	263.319	124.887	1357.55	6508.85	6373.31	6884.07	6706.77	6179.402	14263.4	19863.6	19688.9	20983.5	21084.4
1.47	281.241	131.621	151.954	134.294	105.245	269.494	250.525	238.277	131.063	1233.59	5741.39	5613.32	6137.46	6145.88	5382.432	12579.3	16857.8	16922.7	18121.1	18919.1
1.62	221.821	150.108	166.570	213.009	155.943	154.490	225.631	169.119	121.145	1223.06	5197.64	4964.87	5124.99	5595.63	4992.452	10997.9	15214.6	15381.5	16025.4	17033.7
1.77	89.1148	193.244	238.742	223.635	170.273	0.01135	127.999	153.194	507.256	1194.39	4746.99	4702.50	5128.93	5091.43	4515.2	7352.54	13918.4	13323.0	14254.8	15618.7

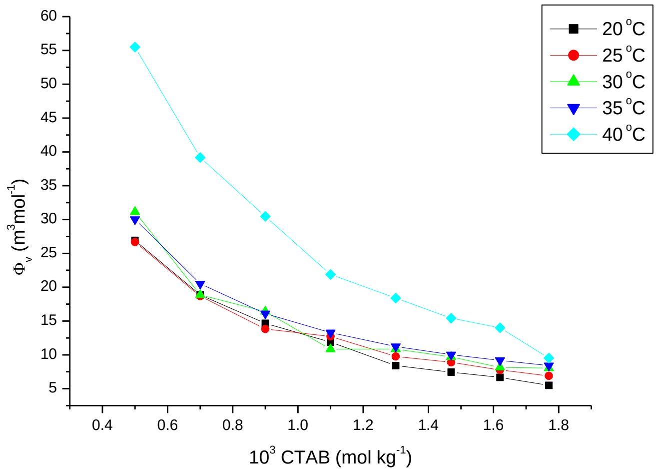

Figure 10: Graph representing Apparent molar volume (ϕ_v) vs. CTAB concentration in 70% v/v ethanol solution containing 1mM Quercetin at different temperatures

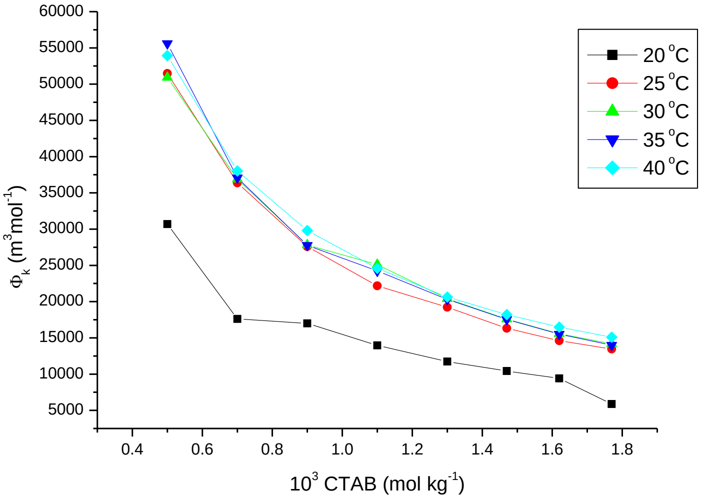

Figure 11: Graph representing Apparent adiabatic compressibility (ϕ_k) vs. CTAB concentration in 100% v/v ethanol solution containing 1mM Quercetin at different temperatures

The values of overall system in varied hydro-ethanolic concentrations have been observed to be positive. With increase in CTAB concentration, decrease in values have been observed assuring the presence of electrostatic interactions resulting in making the system more incompressible. Presence of strong hydrophobic interactions and solute-solvent interactions has been confirmed by the positive values obtained in the overall system. However in aqueous solution, uneven data has been obtained signifying the nature of interactions being unpredictable in pure water.

CHAPTER-04

CONCLUSION

4.1 Conclusion:

Physico-chemical studies including thermodynamic and thermoacoustic properties of flavonoid Quercetin has been studied in interaction with the cationic surfactant CTAB in order to study the flavonoid-surfactant interactions. The critical micelle concentration (cmc) has been observed to increase with the increasing temperature stating the major impact of solute-solvent interactions on micellization. Studies suggested that the interaction of Quercetin and CTAB are endothermic in nature. The positive values of change in enthalpy (ΔH^{o}_{m}) and change in entropy (ΔS^{o}_{m}) favoured the endothermic nature and degree of randomness for the overall system. The negative values of change in gibbs free energy (ΔG^{o}_{m}) favoured the system to proceed in forward direction. The overall study revealed that the interactions are endothermic and micellization of the system is entropically controlled. The thermoacoustic data has been used to determine the interactions within the sytem. It has been observed that at lower surfactant concentrations, the electrostatic interactions dominated the overall system whereas, on increasing the concentration of surfactant, hydrophobic interactions started dominating the system. The results obtained from apparent molar volume and compressibility studies signified that the data is consistent at hyrdo-ethanolic and absolute ethanolic concentration. On the other hand, no significant results have been obtained in aqueous solution. Overall, the interactions are favourable for the system to be utilised for formulation development studies and in pharmaceutical industries.

CHAPTER-05

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