EFFECT OF TEMPERATURE ON ULTRASONIC VELOCITY IN ADULTERATED MUSTARD OIL

Thesis

Submitted to the Punjab Agricultural University
in partial fulfilment of the requirements
for the degree of

MASTER OF SCIENCE
in
PHYSICS
(Minor Subject: Mathematics)

By

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2020

CERTIFICATE I

This is to certify that the thesis entitled "**Effect of temperature on ultrasonic velocity in adulterated mustard oil**" submitted for the degree of M.Sc. in the subject of **Physics** (Minor subject: **Mathematics**) of Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Parhanpreet Kaur (L-2018-BS-291-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE – II

This is to certify that the thesis entitled, "**Effect of temperature on ultrasonic velocity in adulterated mustard oil**" submitted by **Parhanpreet Kaur** (Admn. No. **L-2018-BS-291-M**) to the Punjab Agricultural University, Ludhiana, in partial fulfilment of the requirements for the degree of **M.Sc.** in the subject of **Physics** (Minor subject: **Mathematics**) has been approved by the Student's Advisory Committee after an oral examination on the same.

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ACKNOWLEDGEMENT

I would like to thank everyone who has helped and encouraged me for my research work and in my thesis submission.

I would like to express my sincere gratitude to my advisor ***Dr. Paramjit Singh*** *who guided and always encouraged me. His motivation and sincerity deeply inspired me to show dedication in my work. He taught me the systematic approach for executing the experiment. It was a great privilege to have him as my advisor. He was very kind in providing me the freedom to interrupt him anytime for discussion. I whole heartedly thank him for guiding me throughout my research. I have been very fortunate to work with such a fine physicist with creativity, strong dedication, enormous physics knowledge and having best sense of humour. I could not imagine having a better advisor for my research work.*

It is my privilege to express my gratitude to my advisory committee members, ***Dr. Narinder Kaur****, Assistant Professor of Mathematics,* ***Dr. Parveen Bala****, Assistant Professor of Physics and* ***Dr. Rajeev Sharma****, Assistant Professor of Physics and Dean PGS Nominee, who have been supportive in my research goals and provided me valuable ideas and suggestions regarding my research work. Special thanks to* ***Dr. M Javed****, Professor of Statistics, who worked actively to provide me with the protected academic time to pursue my research goals.*

I would like to thank my family for the unfailing love and support they have given me through the years. Words cannot express how grateful I am to my loving parents ***Mr. Hardial Singh*** *and* ***Mrs. Gurmeet Kaur*** *for their love and care. I feel myself blessed to have a dear younger brother* ***Ekjot Singh*** *who always cheers me.*

I am thankful to my friends ***Damini Vasudeva, Gurjeet Singh****,* ***Ramanpreet Kaur Amanpreet Kaur, Inderpreet Kaur, Charanjeet Kaur*** *and* ***Minnie Murria*** *for their motivation and assistance. Sincere thanks to all my seniors and juniors for their support. I would also like to thank all the non-teaching staff and* ***Mrs. Arvinder Kaur*** *for their constant encouragement.*

(Parhanpreet Kaur)

Title of the Thesis	:	Effect of temperature on ultrasonic velocity in adulterated mustard oil
Name of the student and Admission No.	:	Parhanpreet Kaur (L-2018-BS-291-M)
Major Subject	:	Physics
Minor Subject	:	Mathematics
Name and designation of Major Advisor	:	Dr. Paramjit Singh Professor of Physics
Degree to be Awarded	:	M.Sc. (Physics)
Year of award of degree	:	2020
Total pages in thesis	:	59 + Vita
Name of the University	:	Punjab Agricultural University, Ludhiana-141004, Punjab, India

ABSTRACT

The utilisation of edible oils for consumption has been in vogue since time immortal. The heavy consumption of edible oils lead to adulteration which degrades the quality and nutritional value of oils. Pure edible oil is adulterated with low quality oil having similar appearance as that of pure edible oil. The method to detect adulteration in edible oil should be a non-destructive test as it does not influence the chemical composition of sample. Ultrasonic waves are used for detection of adulteration because these are non-destructive, non-toxic and have many applications in food processing. In the present study, palm oil was used as an adulterant in pure mustard oil because of its similar appearance and easily mixing character. The parameters like ultrasonic velocity, viscosity and density were measured for different concentrations (100, 90, 80, 70 and 60%) of mustard oil at different temperature (30, 40, 50, 60 and 70˚C). From these parameters, further thermodynamic parameters like surface tension, adiabatic compressibility, bulk modulus, acoustic impedance and intermolecular free length were calculated. Except density, all parameters showed significant results with different temperature and concentration. Ultrasonic velocity, density, surface tension, bulk modulus and acoustic impedance were found to decrease linearly with temperature while viscosity decreased exponentially with temperature. Other parameters like adiabatic compressibility and intermolecular free length increased linearly with temperature. The linear correlation of logarithmic ultrasonic velocity with logarithmic density and ultrasonic velocity with logarithmic viscosity were observed. Another linear correlation between surface tension and intermolecular free length was also confirmed.

Keywords: Mustard oil, palm oil, ultrasonic velocity, viscosity, density and thermodynamic parameters.

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Signature of Major Advisor **Signature of Student**

ਥੀਸਿਸ ਦਾ ਸਿਰਲੇਖ	:	ਮਿਲਾਵਟੀ ਸਰੋਂ ਦੇ ਤੇਲ ਵਿੱਚ ਅਲਟਰਾਸੌਨਿਕ ਰਫਤਾਰ ਤੇ ਤਾਪਮਾਨ ਦਾ ਪ੍ਰਭਾਵ
ਵਿਦਿਆਰਥੀ ਦਾ ਨਾਮ ਅਤੇ ਦਾਖਲਾ ਨੰਬਰ	:	ਪੜ੍ਹਨਪ੍ਰੀਤ ਕੌਰ (ਐੱਲ-2018-ਬੀਐਸ-291-ਐੱਮ)
ਖਾਸ ਵਿਸ਼ਾ	:	ਭੌਤਿਕ ਵਿਗਿਆਨ
ਮਾਮੂਲੀ ਵਿਸ਼ਾ	:	ਗਣਿਤ
ਮੁੱਖ ਸਲਾਹਕਾਰ ਦਾ ਨਾਮ ਅਤੇ ਅਹੁਦਾ		ਡਾ. ਪਰਮਜੀਤ ਸਿੰਘ ਪ੍ਰੋਫੈਸਰ ਆਫ ਫਿਜ਼ਿਕਸ
ਡਿਗਰੀ ਪ੍ਰਦਾਨ ਕੀਤੀ ਜਾਣੀ	:	ਐੱਮ.ਐੱਸ.ਸੀ.(ਭੌਤਿਕ ਵਿਗਿਆਨ)
ਡਿਗਰੀ ਦਾ ਅਦਾਇਗੀ ਸਾਲ	:	2020
ਥੀਸਿਸ ਵਿੱਚ ਕੁੱਲ ਪੰਨੇ	:	59 + ਵੀਟਾ
ਯੂਨੀਵਰਸਿਟੀ ਦਾ ਨਾਮ	:	ਪੰਜਾਬ ਐਗਰੀਕਲਚਰਲ ਯੂਨੀਵਰਸਿਟੀ, ਲੁਧਿਆਣਾ-141004 ਪੰਜਾਬ, ਭਾਰਤ।

ਸਾਰ-ਅੰਸ਼

ਖਾਣ ਵਾਲੇ ਤੇਲ ਦੀ ਵਰਤੋਂ ਕਈ ਸਮਿਆਂ ਤੋਂ ਸਰਾਹੀ ਗਈ ਹੈ। ਖਾਣ ਵਾਲੇ ਤੇਲ ਦੀ ਵੱਡੀ ਖਪਤ ਹੋਣ ਕਾਰਣ ਇਹ ਮਿਲਾਵਟ ਦਾ ਮੁੱਖ ਟਿੱਚਾ ਬਣ ਗਿਆ ਹੈ ਜਿਸ ਕਾਰਨ ਮਾਰਕੀਟ ਵਿਚ ਅਸ਼ੁੱਧ ਤੇਲ ਵੀ ਉਪਲੱਬਧ ਹੈ। ਖਾਣ ਵਾਲੇ ਤੇਲ ਵਿਚ ਮਿਲਾਵਟ ਹੋਣ ਕਰਕੇ ਇਸ ਦੀ ਗੁਣਵੱਤਾ ਅਤੇ ਇਸਦਾ ਚਿਕਿਤਸਕ ਮੁੱਲ ਘੱਟ ਜਾਂਦਾ ਹੈ। ਸ਼ੁੱਧ ਖਾਣ ਵਾਲੇ ਤੇਲ ਦੀ ਮਿਲਾਵਟ ਸਮਾਨ ਦਿਖਣ ਵਾਲੇ ਘੱਟ ਗੁਣਵੱਤਾ ਵਾਲੇ ਤੇਲ ਨਾਲ ਕੀਤੀ ਜਾਂਦੀ ਹੈ। ਖਾਣ ਵਾਲੇ ਤੇਲ ਵਿਚ ਮਿਲਾਵਟ ਦਾ ਪਤਾ ਕਰਨ ਲਈ ਗੈਰ ਵਿਨਾਸ਼ਕਾਰੀ ਟੈਸਟ ਬਹੁਤ ਲਾਭਕਾਰੀ ਹੈ। ਇਹ ਟੈਸਟ ਖਾਣ ਵਾਲੇ ਤੇਲ ਦੀ ਰਸਾਇਣਕ ਬਣਤਰ ਨੂੰ ਪ੍ਰਭਾਵਿਤ ਨਹੀਂ ਕਰਦਾ। ਅਲਟਰਾਸੌਨਿਕ ਵੇਵ ਖੋਜ ਲਈ ਵਰਤੀ ਜਾਂਦੀਆਂ ਨੇ ਕਿਉਂਕਿ ਇਹ ਗੈਰ ਵਿਨਾਸ਼ਕਾਰੀ ਅਤੇ ਗੈਰ ਜ਼ਹਿਰੀਲੇ ਹੁੰਦੀਆਂ ਹਨ ਅਤੇ ਭੋਜਨ ਕਿਰਿਆ ਵਿੱਚ ਬਹੁਤ ਵਰਤੋਂ ਕੀਤੀ ਜਾਂਦੀ ਹੈ। ਮੌਜੂਦਾ ਅਧਿਐਨ ਵਿਚ ਸਰੋਂ ਦੇ ਤੇਲ ਵਿਚ ਪਾਮ ਤੇਲ ਦੀ ਵਰਤੋਂ ਮਿਲਾਵਟ ਦੇ ਤੌਰ ਤੇ ਕੀਤੀ ਗਈ ਕਿਉਂਕਿ ਇਹ ਸਮਾਨ ਦਿਖਣ ਵਾਲਾ ਤੇ ਛੇਤੀ ਘੁਲਣ ਵਾਲਾ ਹੈ। ਅਲਟਰਾਸੌਨਿਕ ਰਫਤਾਰ, ਗਾੜ੍ਹਾਪਣ ਅਤੇ ਘਣਤਾ ਦਾ ਸਰੋਂ ਦੇ ਤੇਲ ਦੇ ਵੱਖ-ਵੱਖ ਮਿਸ਼ਰਣ (100, 90, 80, 70 ਅਤੇ 60%) ਅਤੇ ਵੱਖਰੇ-ਵੱਖਰੇ ਤਾਪਮਾਨ (30, 40, 50, 60 ਅਤੇ 70 ਡਿਗਰੀ ਸੈਲਸੀਅਸ) ਲਈ ਮੁਲਾਂਕਣ ਕੀਤਾ ਗਿਆ। ਇਹਨਾਂ ਮਾਪਦੰਡਾਂ ਤੋਂ ਕੁਝ ਥਰਮੋਡਾਇਨਾਮੀਕ ਪੈਰਾਮੀਟਰ ਜਿਵੇਂ ਸਤਹ ਤਣਾਅ, ਐਡੀਆਬੈਟਿਕ ਕੌਮਪਰੈਸੀਬਿਲਟੀ, ਬਲਕ ਮੌਡੂਲਸ, ਧੁਨੀ ਪ੍ਰਤੀਬਿੰਬ ਅਤੇ ਅਣੂਆਂ ਵਿਚਲੀ ਵਾਧੂ ਲੰਬਾਈ ਵੀ ਹਿਸਾਬੇ ਗਏ। ਘਣਤਾ ਦੇ ਇਲਾਵਾ ਸਾਰੇ ਪੈਰਾਮੀਟਰ ਤਾਪਮਾਨ ਅਤੇ ਮਿਸ਼ਰਣ ਦੇ ਨਾਲ ਮਹੱਤਵਪੂਰਣ ਨਤੀਜੇ ਦਿਖਾਂਦੇ ਹਨ। ਗਾੜ੍ਹਾਪਣ ਤਾਪਮਾਨ ਦੇ ਬਦਲਣ ਨਾਲ ਤੇਜ਼ੀ ਨਾਲ ਘਟਿਆ ਜਦਕਿ, ਅਲਟਰਾਸੌਨਿਕ ਰਫਤਾਰ, ਘਣਤਾ, ਸਤਹ ਤਣਾਅ, ਬਲਕ ਮੌਡੂਲਸ ਅਤੇ ਧੁਨੀ ਪ੍ਰਤੀਬਿੰਬ ਤਾਪਮਾਨ ਨਾਲ ਇਕਸਾਰਤਾ ਨਾਲ ਘੱਟਦਾ ਹੈ। ਐਡੀਆਬੈਟਿਕ ਕੌਮਪਰੈਸੀਬਿਲਟੀ ਅਤੇ ਅਣੂਆਂ ਵਿਚਲੀ ਵਾਧੂ ਲੰਬਾਈ ਤਾਪਮਾਨ ਦੇ ਨਾਲ ਇਕਸਾਰਤਾ ਨਾਲ ਵੱਧਦੀ ਹੈ। ਲਾਗ ਅਲਟਰਾਸੌਨਿਕ ਰਫਤਾਰ ਦੇ ਲਾਗ ਘਣਤਾ ਨਾਲ ਅਤੇ ਅਲਟਰਾਸੌਨਿਕ ਰਫਤਾਰ ਦੇ ਲਾਗ ਗਾੜ੍ਹਾਪਣ ਨਾਲ ਮਹੱਤਵਪੂਰਣ ਸੰਬੰਧ ਦੇਖੇ ਗਏ। ਸਤਹ ਤਣਾਅ ਅਤੇ ਅਣੂਆਂ ਵਿਚਲੀ ਵਾਧੂ ਲੰਬਾਈ ਵਿਚ ਸੰਬੰਧ ਦੀ ਪੁਸ਼ਟੀ ਕੀਤੀ ਗਈ।

ਮੁੱਖ ਸ਼ਬਦ: ਸਰੋਂ ਦਾ ਤੇਲ, ਪਾਮ ਤੇਲ, ਅਲਟਰਾਸੌਨਿਕ ਰਫਤਾਰ, ਗਾੜ੍ਹਾਪਣ, ਘਣਤਾ, ਅਤੇ ਥਰਮੋਡਾਇਨਾਮੀਕ ਪੈਰਾਮੀਟਰ।

ਮੁੱਖ ਸਲਾਹਕਾਰ ਦੇ ਹਸਤਾਖਰ

ਵਿੱਦਿਆਰਥੀ ਦੇ ਹਸਤਾਖਰ

CONTENTS

CHAPTER - I

INTRODUCTION

Edible oils are fatty and viscous liquids which play a significant role in human diet. These are mainly vegetable oils and insoluble in water. Vegetable oils are extracted from seeds of plants such as sunflower, soybean, mustard and groundnut oil. Edible oils are important from food's point of perspective. These consist of primary unit of fatty acids and triglycerides. The hydrocarbons having straight chain aliphatic compounds ended with a carboxylic group are fatty acids and the esters of 1, 2, 3-tripropanol having residues of fatty acids are triglycerides. Edible oils have several fatty acids. These are grouped into three classes, namely saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA). These are produced by hydrogenation of vegetable oils. The polyunsaturated acids are essential for health and known as essential fatty acids. Edible oils generally consist of some amount of antioxidants so as to counteract auto oxidation which help in maintaining quality of oil.

Edible oils are used for various purposes like cooking and industrial use. Edible oils have major contribution in cooking and food product formulation. The main function of cooking oil is in frying, as it is a heat transfer medium and provides flavour and texture to food. A consumer prefers as oils because, these contain antioxidant and antimicrobial properties. These are rich source of energy carriers, oil soluble vitamins and fatty acids which are obligatory for human body. These have twice the caloric value of equivalent amount of sugar, energy of carbohydrates and protein in each gram. These play crucial role for prevention of disease and in growth of human body. These have a crucial role in cellular metabolism as these help in storing and providing energy. Edible oils having polyunsaturated and monounsaturated fats are preferred over saturated owing to their good effect on human health.

Kachchi ghani is cold crushing process for extracting oil from seeds at low temperature. This process is preferred as oil retains its natural properties and antioxidants. The kachchi ghani mustard oil is commonly used nutritious edible oil. It contains great amount of monounsaturated fatty acids and high amount of polyunsaturated fatty acids. It is also composed of minor components like protein, calcium, phytins, phenolics and natural anti-oxidants.

The qualitative properties of edible oils are influenced by many factors. The quality of edible oils is mainly determined by its physicochemical and microbiological characteristics. The consumption and commercialization of edible oils are attributed by these properties. Edible oils have great demand of consumption in national and international market. Therefore, this huge demand of edible oils is major cause of adulteration in oils.

Adulteration is addition of inferior, harmful and irrelevant substance in food intended to be sold, so as to affect its natural composition and quality. The authenticity of edible oils is important requirement of food industry. Edible oils are fluidic foods and these are easily

miscible with low quality liquids and vulnerable to adulteration. The adulterant substance has all comparable aspects such as colour, odour and taste but differs from its natural chemical composition. Adulterated edible oils are unhealthy for human use. The adulteration in edible oils leads to reduction in their nutritional and medicinal value and the adulterated product influences market growth economically. The consumer is being cheated through adulterated product because of impure and undesirable edible oils. Adulteration is a major problem from economic and social perspective. Adulteration in edible oils is simple because of almost similar appearance of all edible oils. The adulteration is mainly done in two ways. First one is by mixing of cold crushed oil with refining oil and another is adding cheaper oil in more expensive oil. In both type of adulteration, there is replacement of natural oil with lower quality oil.

There are different types of adulterants that can be added for distinct edible oils. Edible oils are adulterated such as mustard oil with palm oil, olive oil with cottonseed oil, virgin coconut oil with palm oil, olive oil with coconut oil, virgin coconut oil with sunflower oil, olive oil with sunflower oil, extra virgin olive oil with palm oil and mustard oil with argemone oil. The adulteration of edible oils cannot be detected easily through sensory parameters and visual inspection, because of its large natural variability such as plant species and processing. Also, the absolute analysis of edible oils is expensive. The detection of adulteration can be done by studying both major and minor components of oils. The analysis of edible oils can be done by their physiochemical properties. The physiochemical properties can be easily determined and are useful for distinguishing natural oil from adulterated oil and also, different types of oils.

The methods such as spectrophotometric method, high performance liquid chromatography, Nuclear Magneto Resonance (NMR), mass-spectroscopy/gas chromatography (MS-GC), differential scanning calorimetry (DSC) and fluorescence spectroscopy are used for detection of adulteration. As these methods are used to identify the adulteration in the sample, these susceptible to change in the composition, because sample is assigned to chemical methods. To get the sample as such after detection of impurity, the sample must be subjected to non-destructive test (NDT). NDT is an analysis technique used to identify the properties of the material or component without affecting its composition. Ultrasonic waves are used as NDT because these do not influence the composition of the sample under experiment.

Ultrasonic method is a versatile technique and is widely used for studying physiochemical properties of food materials. Ultrasound is a prominent technology to be used for food management because it is simple and energy saving relative to other techniques. This technique has great use in food processing for analysis and modifications of food materials. This technique includes the passage of known frequency ultrasonic waves through the food sample without affecting sample chemically. In food industry, this technique is used to deplete the processing time, advancing the shelf life and quality of food materials. This non-destructive

technique has gained much importance in assessing internal, inherent properties and nature of molecular interactions of oils and fats.

Ultrasonic waves are the mechanical waves and can propagate through any material because of very high frequency and far above the audible range of human hearing (20Hz-20KHz). On the basis of frequency, ultrasonic waves are classified as power ultrasound, high frequency ultrasound and diagnostic ultrasound having frequency 20KHz-100KHz, 100KHz-1MHz and 1MHz-50MHz respectively. Diagnostic ultrasound is used for studying chemical composition of food. When ultrasonic waves travel through the medium, the molecules vibrate to a very small distance in the direction parallel to ultrasonic waves. This vibration leads to transfer of momentum among the molecules and results to travelling of waves through the medium. Ultrasonic waves are generated due to oscillating pressure originated between the two opposite faces of the crystal under the influence of an alternating voltage which is called piezoelectric effect. This oscillating pressure results to oscillation in air molecules with the frequency of ultrasonic waves near the crystal and hence generating ultrasonic waves. This oscillating pressure corresponds to oscillation deformations in ultrasonic waves and these waves are called rheological waves.

Ultrasonic technique has tremendous use for accurately understanding the physiochemical properties, molecular interactions and structural behaviour of foods. The changes in intrinsic properties of oils by adulteration reveal to change in ultrasonic parameters of waves. The ultrasonic velocity of pure oil differs from adulterated oil. Ultrasonic interferometer measures the ultrasonic velocity by measuring distance between two consecutive maxima. The velocity of ultrasonic waves is temperature dependent and can be utilized to quantify adulteration in edible oils at different temperatures.

The thermodynamic parameters such as acoustic impedance, intermolecular free length, bulk modulus, surface tension and adiabatic compressibility are the measures of better qualitative and quantitative properties of food. The parameters are affected by factors such as chemical structure and shape of constituent molecules. These studies are useful for studying strength and nature of interionic or intermolecular interactions.

The dominant factor in studying the variation of ultrasonic velocity in pure and adulterated edible oil is intermolecular free length. The distance travelled by ultrasonic waves between the surfaces of neighbouring molecules is determined by intermolecular free length. In binary mixtures, intermolecular free length is the measure of interactions between the components. There is decrease or increase in free length depending upon strengthening or weakening of intermolecular interaction. The study of intermolecular free length helps to measure the extent to which a liquid is adulterated. The change in ultrasonic velocity can be studied by intermolecular free length which depends upon concentration. The compressibility

is also influenced by adulteration due to change in intermolecular free length. Thus, it is important for measurement to detect adulteration in edible oil.

Ultrasonic velocity is correlated to adiabatic compressibility which is a function of fractional decrease in volume when no heat flows through it. When ultrasonic waves are introduced in the medium, these are distracted by the components of medium. When a liquid medium is compressed, the work done is converted into heat. The generated heat can be escaped from the medium depending upon the thermal conductivity of fluid. When ultrasonic waves propagate through the medium, its path is restricted due to compressibility and leads to increase in ultrasonic velocity. Thus, adiabatic compressibility can be measured which in turn, helps to study ultrasonic velocity in the medium. Adiabatic compressibility is reciprocal of acoustic impedance. Acoustic impedance measures the energy transmitted or reflected by the interface which is separated by two media of different density. Hence, it helps to study changes in ultrasonic velocity more accurately. The surface tension is another pivotal parameter for studying properties of medium. Surface tension depends upon the intermolecular forces of the fluid and arises due to the molecules having infrequent energy present at the surface. In a fluid, molecules experience downward force and work is done to overcome this force and bring the molecule to the free surface and results to increase in potential energy. Each mechanical system tries to attain minimum potential energy and free surface of liquid also does the same and thus area contracts. This free surface accounts to tension and this is called surface tension of fluid. Bulk modulus is fundamental property of liquids. There is compression and depression of waves in liquid and resistance is offered to this mechanical nature of wave and this resistance is measured by bulk modulus. These thermodynamic parameters are correlated for effective measurement of adulteration in edible oils.

Viscosity is another physical property and is measurement of fluid's collective effect of cohesion and adhesion of molecules that explicit itself as an internal force opposing the flow of the fluid. Also, viscosity is the capacity of liquid to sustain deformations experienced due to shear stress. Viscosity is measured using viscometer and is reciprocal of fluidity which is measure of ease of flow. The resistance is offered when the movement between molecules occurs. The fluid moves over the boundary such that particles in contact with boundary possess same velocity whereas consecutive layers parallel to boundary have increasing velocity. Viscosity is influenced by molecular size, length of forces and temperature. It is found that there is decrease in viscosity with increase in temperature because intermolecular interactions decrease due to thermal effect (Valantina *et al* 2013). As the temperature increases, kinetic energy of molecules increases and tends to decrease in viscosity of liquid. Viscosity is an important parameter for processing of fluids in chemical industry. The measurement of viscosity is useful for analysis of adulteration. Pure edible oils are thick and highly viscous. Viscosity of natural edible oil is influenced by the quantity of adulterants added in it. Viscosity

of mustard oil decreases with increase in adulteration such as pure mustard oil has high viscosity than mustard oil adulterated with palm oil (Kumari *et al* 2015).

Density is an important parameter which is mass per unit volume. Density of each substance is unique and is ratio of heaviness of substance to constant volume and thus, helps to determine quality of any material. The measurement of density is used for identification of pure substances from its mixtures as, it is different for every substance. Density is an intensive property of substance being the ratio of two extensive properties. Density depends upon temperature. With increase in temperature, volume increases and hence density decreases. Density of mustard oil decreases with increase in palm oil concentration as density of pure mustard oil is greater than mustard oil adulterated with palm oil (Kumari *et al* 2015).

A plenty of information is available in literature on physiochemical, thermodynamical properties and quality of edible oils. The literature has wide information on processing and characteristics of edible oils. The analysis of variation of physiochemical and thermodynamical parameters of edible oil with temperature has not been studied. These properties have to be studied over range of concentration and temperature. The present study includes the variation in quality of mustard oil having adulteration with palm oil at different temperatures. This will help in useful correspondence between the effects of adulteration of mustard oil with palm oil on various physical parameters to that of pure mustard oil over a variable range of temperature. Therefore, the work is proposed to conduct and study the properties of mustard oil with following objectives:

- To study the ultrasonic velocity in adulterated mustard oil having different concentrations of palm oil at different temperatures.
- To study the viscosity in adulterated mustard oil having different concentrations of palm oil at different temperatures.
- Determination of density of adulterated mustard oil having different concentration of palm oil at different temperatures and calculation of different thermodynamical parameters.

CHAPTER II

REVIEW OF LITERATURE

The discovery of piezoelectric effect has lead to the development of the field of ultrasonic. The application of ultrasonic vibrations in detecting metal device was proposed in 1929. The ultrasonic testing had spread its wings as flaw detecting device and measuring materials as first practical ultrasonic testing method was patented in 1940. For the development of methods for characterising materials, ultrasonic energy was applied at industrial level in the middle of 20^{th} century. This interaction of high frequency sound waves with matter in ultrasonic technique results in prompting information about physiochemical properties. The major research work done for study of physiochemical properties of edible oils will be discussed in this chapter.

Gladwell *et al* (1985) studied the ultrasonic behaviour of edible oils such as castor oil, groundnut oil, olive oil, rapeseed oil and safflower oil. Shear and relaxation spectra were assessed. The measuring parameters were viscosity, velocity and density. The variation of shear viscosity with shear rate was determined on a Contravas Rheometer, density was measured by establishing the relation of density of the sample with natural frequency of the oscillator and velocity was determined by using ultrasonic pulse echo technique. From the measured data, it was observed that molecular arrangement is of long order and except the castor oil, other oils have comparable composition as oleic acid. Also, linoleic acid is the main component and the linear graphs of shear stress with shear rate indicated the Newtonian nature of the oils.

McClements and Povey (1987) studied the solid fat content of samples of tripalmitin, trilaurin, 1- oleodipalmitin and tristearin having mass fraction 0-20% at 25°C. The ultrasonic velocity of solid tristearin was determined by single pulse transmission method at 1MHz. It was observed that different saturated triglycerides have same increase in ultrasonic velocity with increasing the insoluble solid fat. Hence, ultrasonic technique could be applied in fat-oil mixtures for measuring the composition of solid fat content and analysing the solubility of triglycerides.

Javanaud and Rahalkar (1988) studied the velocity of sound in vegetable oils like corn oil, safflower oil, sunflower oil, soyabean oil, groundnut oil and olive oil at 2, 6 and 10MHz.Velocity was measured with Carstensen's double liquid system at 22°C, 23.9°C and 19.4°C with ultrasonic transducer at 2MHz. From the experimental data, it can be concluded that velocities can be correlated according to composition of vegetable oils.

Noureddini *et al* (1992) studied the variation of viscosity with temperature from 24°C to 110°C. Viscosity of vegetable oils and fatty acids was measured such as cramble, rapeseed, corn, soybean, milk-weed, coconut, lesquerella and C_9 to C_{22} respectively. The experiment was performed with Cannon-Fenske glass capillary kinematics viscometers. Results were

calculated by fitting the correlation constant. From the conclusions, it was observed that correlation coefficient is efficient for studying chemical processes.

McClements and Povey (1992) discussed the ultrasonic behaviour of some vegetable oils for characterizing edible oils and fats. Edible oils and fats have behaviour dependent on physiochemical properties. The measured parameters are ultrasonic velocity and attenuation coefficient. The change in these parameters was attributed to change in properties of ultrasonic. It was concluded that ultrasonic technique is useful for studying behaviour of edible oils and fats due to its non-destructive nature.

Sidek *et al* (1996) explained the propagation of ultrasonic waves to characterize quantitatively palm oil, palm olein oil with soybean oil, coconut oil and corn oil by utilizing the overlapping ultrasonic pulse echo technique to attain ultrasonic behaviour of oils from room temperature to 90˚C. The ultrasonic properties of the oils depend on molecular structure, viscosity and density. The attenuation and ultrasonic wave velocity at 5MHz were measured for samples of vegetable oils, palm olein and palm oil. From experimental data, it was concluded that there is decrease of sound velocity in oils with increasing temperature relating to its chain length and degree of unsaturation. The consecutive decrease in intensity of ultrasonic waves was attributed by viscosity, thermal conduction and molecular effects. From the attenuation-frequency relationship data, there was non-linear decrease over wide range of frequency due to the relaxation processes.

Coupland and McClements (1997) reviewed the physical parameters of water and edible oil at 20˚C. The properties such as viscosity, density, thermal conductivity, adiabatic expansion coefficient, specific heat, ultrasonic attenuation coefficient and ultrasonic velocity were studied. The values of these parameters were used to derive empirical relations and can be utilized to study dependence of parameters with temperature.

Chanamai and McClements (1998) measured ultrasonic attenuation coefficient having function of operating frequency from 1-60MHz at 25°C of corn oil, olive oil, safflower oil, peanut oil, canola oil and sunflower oil. From the data, it was observed that ultrasonic attenuation coefficient of edible oils is almost similar in a given range of frequency and their relation can be described by power law function.

Rodenbush *et al* (1999) explained the generalized method for determining density and viscosity of vegetable oils and fatty acids. The derived relation was related to chemical composition of oils. The density was calculated with absolute deviation of 0.21 and 0.77% for vegetable oils and fatty acids respectively. From the density, viscosity can be evaluated and hence, two parameters can be correlated for studying vegetable oils and fatty acids.

Szabo and Wu (2000) discussed the behaviour of viscoelastic materials by power law method which is derived from model based on time domain statement. It was observed that time domain method has advantages over relaxation method which is failed to explain energy

losses in viscoelastic materials. The variation of attenuation and velocity of propagation with frequency was calculated for longitudinal and shear elastic waves. From the power loss behaviour, a Voigt model was derived. The acoustic loss and velocity of waves in viscoelastic material was assent with predicted model. The energy losses in shear waves were larger than longitudinal waves. The results obtained from this model were compared with loss mechanics in dielectrics.

Buckin and Driscoll (2002) explained the ultrasonic spectroscopy for material analysis. It was observed that ultrasonic method is simple and non-invasive for determining intrinsic properties of materials. It was studied that ultrasonic attenuation and ultrasonic velocity are main parameters in ultrasonic spectroscopy. These parameters give information about interaction of ultrasonic waves with sample. The ultrasonic attenuation is measured by loss in energy due to change in decompression and compression of ultrasonic waves. The ultrasonic velocity was measured using stress and density of the medium. These parameters are very sensitive to intrinsic properties and have wide applications for studying composition of materials.

McClements *et al* (2002) compared the pulse NMR spectroscopy and ultrasonic technique for the measurement of solid fat composition. The samples were of anhydrous cocoa butter, anhydrous milk fat and mixtures of cocoa butter and anhydrous milk fat with canola oil having weight to weight ratio of 100 to 70%. The ultrasonic velocity was measured over cooling from 50-5^{o}C and heating from 5-50^{o}C. The measurement of ultrasonic velocity was done using ultrasonic spectrometer consisting of ultrasonic transducer having frequency 3.5MHz and receiver operating at 200MHz. A differential scanning calorimetry was used in pulsed NMR. From the observed data, it was analysed that solid fat composition obtained from two methods does not assent. There was significant change in ultrasonic velocity due to polymorphic state of solid fat.

Santos *et al* (2005) studied the behaviour of heated and unheated vegetable edible oils and their temperature dependence. The oil samples were soybean, sunflower, olive, rapeseed, corn and the mixtures of soybean (70%) and sunflower (97%) with olive oil. The variation of viscosity with temperature range from 10-80^{o}C was measured using Brookfield viscometer. It was observed that degree of degradation does not depend upon temperature and hence heated and cooled viscosity was same. At frying temperature 190^{o}C, there was increase in viscosity with temperature attributed by increase in saturation. The used and unused edible oils showed Newtonian behaviour.

Sankarappa *et al* (2005) studied the effect of temperature on ultrasonic velocity and density in the range from 298-333K. The samples were unrefined and refined edible oils such as sunflower oil, castor oil, coconut oil, groundnut oil and kardi oil. The saponification value was measured using titration method. The ultrasonic velocity was measured by ultrasonic

interferometer at operating frequency 3 MHz and density was measured using gravimetric method. It was observed that velocity and density decrease with temperature. The decrease in velocity with temperature was linear for unrefined sunflower oil and refined groundnut oil whereas nonlinear for unrefined and refined castor oil, coconut oil and unrefined kardi oil. The decrease in velocity is due to the transformation in intermolecular distance with temperature. Intermolecular distance increases with increase in temperature due to thermal energy. The variation of density with temperature of all edible oils was linear. From the experimental data, molar sound velocity, specific volume, molar compressibility, adiabatic compressibility and intermolecular free length were calculated for better analysis of edible oils.

Pasca and Dadarlat (2006) studied the properties of edible oils by measurement of ultrasonic attenuation so as to differentiate between fresh oil and adulterated or aged oil. The ultrasonic attenuation in fresh oil and aged oil or adulterated oil with carbon tetrachloride was measured using ultrasonic defectoscope. The oil under experiment was sunflower oil and experiment was done as a function of duration of treatment and oil concentration. By experimental method, it was concluded that ultrasonic attenuation increases with increasing concentration of oil for the samples having different treatment time. The change is due to the change in constituents of fatty acids. Also, with increase in ageing time, the ultrasonic attenuation remains unaffected. Hence, attenuation does not change with ageing or adulteration of oils.

Schaschke *et al* (2006) explained the variation of viscosity with high pressure ranging up to 150MPa. High pressure processing is significant for knowing composition, quality and flavour of food. The oil sample used was olive oil and viscosity was measured using sinker viscometer. The measurement was done electronically by recording fall time of sinker and viscosity was calculated. It was observed that at high pressure viscosity increases. From this experiment, a correlation can be derived with existing relationships between pressure and viscosity.

Gupta *et al* (2007) studied the temperature variation on viscosity of refined vegetable oils and a correlation was derived using a reference temperature at 20^{o}C. The viscosity was measured in the temperature range 298 to 338K using Redwood viscometer of rice bran oil, mustard oil, palm oil, sunflower oil, cottonseed oil and soybean oil. A correlation was derived between the reduced viscosity and reduced temperature for the study of viscosity of oils. From the correlation, it was concluded that oils have Arrhenius behaviour above the reference temperature. From the experimental data, it was observed that the viscosity of refined edible oils is more at 40-60^{o}C than 20^{o}C. The viscosity determined from empirical correlation and experimental method is consistent with each other.

Benedito *et al* (2007) studied the degradation and unsaturation in different frying oils using ultrasonic methods. The ultrasonic velocity was measured using ultrasonic transducer at

1MHz from 45°C to 25°C. For correct prediction, the viscosity and density were also measured using ball viscometer from 45°C to 25°C and specific gravity hydrometer at 20°C respectively. From the measured data, it was analysed that ultrasonic velocity decreases with temperature and the mean velocity temperature coefficients were 3.59 and 3.51 $ms^{-1}C^{-1}$ for monounsaturated and polyunsaturated oils respectively. The use of viscosity and density measurement utilizes ultrasonic method to identify 97.5% samples correctly.

Fasina and Colley (2008) studied the variation of specific heat capacity and viscosity of different vegetable oils with temperature having range 35 to 180°C. The specific heat capacity and viscosity were measured using controlled rheometer and differential scanning calorimetry respectively. From the observed data, it was studied that viscosity decreases exponentially with temperature while specific heat capacity increases linearly with temperature. The derived equations from this study helps for processing of oils.

Kalogianni *et al* (2011) studied the effect of viscosity, density and dynamical interfacial tension with respect to repeated frying of palm oil and olive oil. The data recorded for repeated frying was compared with data of normal heating of oils. The dynamical tension, viscosity and density were measured by BPT-1 tensiometer, cone and plate viscometer and TD1 tensiometer respectively. It was observed that viscosity increases in olive oil and palm oil. There was change in interfacial tension with respect to time in two types of oil. Hence, chemical properties can be measured by using this method.

Awad *et al* (2012) discussed the analysis, quality and processing of food materials using applications of ultrasound. This review explained the great applications of ultrasonic technique in food technology. Ultrasound is an advanced and green technology in food science. Ultrasonic waves are sound waves having frequency upper audible range of human hearing. Ultrasound has many advantages because it is of low cost, cheap, easy, non-invasive and less time consuming. It was explained that applications of ultrasound comprised of monitoring of food products, food enzymes and microbial inactivation. It was explained that ultrasound is of two types namely, low range ultrasound and high range ultrasound. Low range ultrasound having high frequency waves are used for analysis of physiochemical properties of food substances for the management of storage and processing which has a great importance for controlling the food quality. High power ultrasound having low frequency waves are used for food processing operations like freezing, drying, emulsification and extraction and high power ultrasound brings physiochemical changes in the food materials. In current food technology, vigorous attempts are continuing to unit automated ultrasound systems for the food production systems which are significant for environmental food materials.

Rostacki *et al* (2013) studied the phase transition in olive oil by measuring velocity of sound, volume, adiabatic compressibility and attenuation as a function of pressure having range upto 0.7GPa. The measurements were done at constant temperature of 293K. Ultrasonic

measurements were performed using ultrasonic transducer at 5MHz. The change in volume pressure was measured using digital calliper gauge. It was concluded that there are discontinuities in the parameters as a function of temperature showing the solid to liquid phase transition i.e. first transition. The large change was observed in attenuation due to first order transition. The phase transition of olive oil eventuated at 20^{o}C and 450MPa. The experimental technique can be used for advancement of food processing.

Yadav and Kumari (2013) reviewed the study of ultrasonic for the analysis of physical, chemical and dynamical properties of mustard oil. Mustard oil is widely used as cooking oil due to its medicinal power and has important physiological effects on human health. Mustard oil is important for its nutritional power and as bio fuel product. Mustard oil was characterized by chemical properties using analytical methods. The literature reviewed has pivot on analysis of physiochemical properties of mustard oil and its applications in food industry using ultrasonic technique. It has been studied that low power ultrasound is non-destructive, low cost and simple technique used for measurement of internal structure of materials with high accuracy. Ultrasonic is significant for research studies in analysis and modification of food materials. Ultrasound is used instead of enzyme or heat in cold press methods for pre-treatment. The study of composition, structure and physiochemical properties of materials in food industry is done by measuring the changes in ultrasonic parameters. The physiochemical properties contribute to change in acoustic parameters and results to study composition of materials. It was observed that mustard oil is safest oil for health and most commonly used edible oil. Mustard oil was analysed to help human body for increasing good cholesterol. As ultrasound has significant applications and hence can be used for production and processing of eco-friendly edible oils.

Valantina *et al* (2013) performed the contamination of virgin olive oil by coconut oil and sunflower oil (20% & 40%). The oil was sustained to heating at 210ºC repeatedly. The adulteration in oil was deliberated from the measured parameters such as ultrasonic velocity, viscosity, density, acoustic impedance, adiabatic compressibility and intermolecular free length. Viscosity had been measured with temperature using a Redwood viscometer and ultrasonic velocity was measured by Ultrasonic Interferometer at 2MHz. It was observed from the experiment data that viscosity of virgin olive oil decreases with increase in adulteration from 20% to 40% attributed by the factors such as density, molecular weight and degree of unsaturation.

Siddiqui and Ahmad (2013) discussed the surface tension, viscosity and volume flow rate of ten edible oils and 15 medicinal oils. The evaluation was done using simple capillary set up. It was observed that the oils containing triglycerols are correlated with rheological parameters. It was concluded that viscosity determined of edible oils is greater than medicinal oils while surface tension of all oils was lower than other liquids and volume flow rate can be

used for differentiating between edible and medicinal oils. Also, the study reveals that the changes in rheological properties contribute significantly for the analysis of composition and structure of oils.

Ebong *et al* (2014) analysed the edible oil products like palm kernel oil, palm oil, vegetable oils, coconut oil and groundnut oil. The samples of oil were adulterated by volume of 70%:30%. Determination of pure to adulterated oil was done by using rheological properties i.e. viscosity and density. Viscosity of pure to adulterated oil sample was evaluated by Stoke's law. For the measurement of density, 50ml density bottles were manipulated and relative densities of the edible oils were evaluated. It was observed that viscosity and density of pure and adulterated oil samples are almost similar. So, adulteration was insignificant in the sample.

Ali and Ali (2014) studied the ultrasonic velocity and density by using multi-frequency ultrasonic interferometer operating at frequency 1, 2, 3 and 5 MHz and specific gravity bottle respectively. From the values calculated of ultrasonic velocity and density, acoustic impedance was also calculated. The samples were coconut oil, cottonseed oil, sesame oil, palm oil, sunflower oil and groundnut oil. It was concluded that density of palm oil, cottonseed oil and coconut oil are 0.9145×10^3 kg/m^3, 0.941×10^3kg/m^3 and 0.947×10^3 kg/m^3 respectively. The density of groundnut oil and sesame oil was in between the density of palm oil and coconut oil. Ultrasonic velocity was observed to significant change at 1 and 2 MHz rather than 3 and 5 MHz. Palm oil had less acoustic impedance while cottonseed and coconut oil had maximum impedance and acoustic impedance of sunflower, groundnut and sesame oil fall in between the others. From the experiment, acoustic impedance can be utilized for calibration purpose and to detect adulteration of oils.

Kumari *et al* (2015) studied the rheological and ultrasonic parameters. The adulteration of palm oil (10% & 20%) in mustard oil and cottonseed oil (10% & 20%) in olive oil was done. The changes in ultrasonic velocity, viscosity, density, acoustic impedance, intermolecular free length and adiabatic compressibility were measured at 30°C. These parameters were influenced by change in quality of the sample. The change in viscosity with temperature had been measured by Brookfield viscometer and other ultrasonic measurements were analysed by ultrasonic interferometer at 5 MHz and density had been determined by pycnometer. It was concluded that oils having more unsaturated character are attributed to low viscosity and adulterated oils exhibit Newtonian behaviour. The variation in ultrasonic velocity and density was due to change in intermolecular free length.

Damirchi and Torbati (2015) explained the adulteration and detection methods of edible oils and fats. It was observed that adulteration is usually done by two methods namely, mixing of cold press oil with refined oil and addition of low price oil with high price oil. Adulteration of virgin olive oil with other vegetable oils like walnut, soybean, canola, rapeseed, mustard and peanut having concentration below 5% can be identified by composition of trans

fatty acids. The difference between experimental equivalent carbon number 42 in TAG and theoretical can also be utilized to identify adulteration of olive oil with other vegetable oils at level of 1%. The adulteration of hazelnut oil in olive oil can be identified by composition of TAG, Fourier-transform infrared (FT-IR) spectroscopy and ANN based NMR at a level of 10%, 25% and 8% respectively.

Alouache *et al* (2015) studied the ultrasonic behaviour of olive oil having adulteration of soya oil and results of ultrasonic measurements were correlated with physiochemical methods like viscosity, rancidity degree, UV specific extinction and acid index. Ultrasonic velocity, attenuation, density and viscosity were measured by using transducer in pulse echo mode having frequency of 2.25 MHz frequency. The samples prepared were olive oil (100%), soya oil (100%) and mixtures of soya oil i.e. 20%, 40%, 60% and 80%. From the measured data, it was studied that acidity and ultrasonic velocity increase with increasing percentage of soya oil. Ultrasonic attenuation coefficient was observed to decrease with increasing percentage of soya oil which was consistent with rancidity results. Also, viscosity and density decreased with percentage of soya oil. These results demonstrate that ultrasonic method can also be used for analysing oils rather than physiochemical methods due to non-invasive nature of ultrasonics.

Saxena *et al* (2015) explained the principle of ultrasonic interferometry and experimental methods for determining viscosity and density and various thermodynamic parameters were calculated. The ultrasonic, thermophysical and thermodynamic parameters have great importance in the measurement of physiochemical properties of liquids. It was explained that ultrasonic interferometer measures the velocity of ultrasonic waves in liquid sample with frequency ranging from 1-12MHz. Ultrasonic waves are generated by piezoelectric effect. The viscosity and density were obtained using dilatometer and Ostwald viscometer respectively. The study of these physical properties helps for determining pure component and intermolecular forces in the liquid medium.

Dikko *et al* (2015) studied the effect of temperature on surface tension in some vegetable oils. Vegetable oils used as samples were shear butter, corn oil, groundnut oil, cottonseed oil, palm oil and soya beans oil. Surface tension was measured in the temperature range 313 to 373K using capillary rise set up by maintaining constant temperature. Palm oil and cottonseed oil were observed to have high surface tension while shear butter had low surface tension in vegetable oils. It was concluded that the values of the surface tension obtained are consistent with surface tension calculated from modern machines.

Oroian and Gutt (2015) explained the change of temperature on physical properties such as viscosity, ultrasonic velocity, density and surface tension of vegetable oil. From these properties, a correlation between properties was established. The experiments were performed for eight vegetable oils that are corn oil, olive oil, sunflower oil, squash oil, grape seeds oil,

peanut oil, hazelnut oil and sesame oil in temperature range 20°-80°C. The density, ultrasonic velocity and viscosity were measured using pycnometer, flow detector with a dual element probe at frequency 4 MHz and Hoppler viscometer respectively. The surface tension was evaluated using values of ultrasonic velocity and density. It was observed that all the parameters decrease with increase in temperature. A significant regression coefficient (R^2 = 0.996) was obtained for density, ultrasonic velocity and surface tension. The significant correlations between viscosity and surface tension were obtained using modified Pelofsky model rather than exponential, polynomial and Pelofsky model.

Oliveira *et al* (2016) studied the speed of ultrasonic waves in soybean oil as a function of temperature in the range from 20ºC to 50ºC by applying pulse echo technique at 1 MHz with the respective measurement of uncertainty. From the data, it was concluded that velocity of sound decreases with increase in temperature linearly in soybean oil. It was explained that ultrasound is low cost and non-destructive technique and is significant for advancement of food industry. It demonstrated to establish a direct function between the behaviour of speed of sound and temperature with uncertainty of 7.0m/s (0.5%) and error of 6.4m/s.

Alouache *et al* (2016) studied the ultrasonic properties and shear viscosity for the identification of adulteration of soya oil in olive oil having proportions of 0%, 10%, 20%, 30%, 40%, 50%, 60%, 80%, and 100%. Ultrasonic measurements were done with pulse echo technique and viscosity was measured using Couette viscometer. From the results, it can be concluded that ultrasonic velocity and viscosity decrease by increasing the percentage of soya oil. The experimental results can be utilized for detection of adulteration in oils because of non-invasive nature of these methods.

Valantina *et al* (2016) compared the physiochemical properties of sesame oil and mustard oil from temperature 25–85°C and a relation was derived. The physical properties such as refractive index, conductivity, density and ultrasonic velocity were obtained using Abbe's refractometer, ASTM D2624, pycnometer and ultrasonic interferometer at 2 MHz respectively. The chemical properties such as iodine value, saponification value and free fatty acid content were measured using chemical methods. It was observed that ultrasonic velocity and conductance are negatively related to viscosity while refractive index is positively related. It was proved that correlation between physical and chemical properties of oils can be used for identifying quality of oils.

George *et al* (2017) performed adulteration of virgin coconut oil (VCO) with palm oil and sunflower oil with concentration of 5%-100% at temperature 30ºC. For detection of adulteration ultrasonic parameters such as reflection coefficient, attenuation coefficient and speed of propagation in pure and adulterated oil were measured using ultrasonic sensor system. The measurement cell was designed with simulation of multiple reflections having functioning ultrasonic transducer at 1 MHz using COMSOL. For improving the accuracy of the sensor

system, artificial neural network (ANN) technique was developed. It was found that ultrasonic velocity increases with increase in adulteration while attenuation coefficient and reflection coefficient decrease with increase in adulteration of sunflower oil and palm oil. Adulteration has been detected with precision of 99.53% for sunflower oil and 98.82% for palm oil supplemented in pure coconut oil.

Alias *et al* (2017) studied the effects of temperature on spectra obtained by employing ultrasound signal as pulse-echo technique captured by oscilloscope. Adulteration was carried out of virgin olive oil with palm oil. Samples prepared were 100% olive oil and ratio of 50:50 & 30:70 of olive oil and palm oil respectively. The experiments were done with olive oil at 27ºC, 30ºC and 33ºC. The frequency spectrum obtained at 40 KHz digitized by oscilloscope could be utilized to analyse materials. In the spectrum, the shifts in peak to peak value of amplitude were significant for characterizing the materials. The spectrum of ultrasound signal had also been changed with change in temperature of the sample.

Ghosh *et al* (2017) used the ultrasonic spectroscopy for study of variation of temperature with bulk modulus of edible oils. Ultrasonic spectroscopy is simple, non-invasive and low cost technique used for analysis of composition of food materials. Bulk modulus of three varieties of sunflower oil and extra virgin olive oil was measured using Navier's-Stoke equation in the temperature range from 5-40°C. Ultrasizer MSV was used for measuring attenuation coefficient and velocity of sound in the frequency 1-100MHz. It was observed that for different brands of oil, bulk modulus is not constant in the frequency range 12-100MHz and thus, shows the non-Newtonian behaviour of oils. The results of bulk modulus were not very significant and were unable to predict the different brands of oils. Also, it was concluded that ultrasonic spectroscopy is significant for analysis of food products.

Ali and Ahmad (2018) performed the experiment using ultrasonic technique to detect whether edible oil is recycled or not. Five edible oils namely coconut oil, sesame oil, groundnut oil, sunflower oil and palm oil were recycled for five times with 15-minute heating time. Ultrasonic multi frequency interferometer measured the ultrasonic velocity of edible oils in pure and recycled form operating at frequency 1 MHz at room temperature. Density of the pure and recycled edible oil was measured with specific gravity bottle. From the experiment, it was concluded that density of the oil increases with the number of recycles. Ultrasonic velocity was increased with the number of recycles. Ultrasonic velocity was observed to increase with recycling due to decrease in saturated fatty acids (SFA%) and increase in unsaturated fatty acids (USFA%). The change in fatty acids was due to change in molecular structure of oils because of thermal energy.

Yadav (2018) explained the current issues, detection methods and health effects of edible oil adulteration. It was observed that current issues of adulteration of oils are addition of cold press oil with refined oil, adulteration of mustard oil with argemone oil and contamination

of expensive oil with cheaper oil. This can be detected by techniques such as ESI-MS fingerprinting analysis, GC/MS technique, HPTLC and FTIR spectroscopy so as to rescue from health hazards of adulteration.

Alouache *et al* (2018) studied the viscoelastic properties of olive oil and soybean oil. To characterize the behaviour of oils, ultrasonic method and fractional time derivative model was used. The ultrasonic parameters were measured from frequency range 4 to 16MHz. The fractional model used represents the stress-strain relationship having fractional time derivative of an order 1 and 2. The results obtained from measurements of ultrasonic phase velocity, viscosity coefficient and relaxation time describe the benefit of using fractional model for characterizing the viscoelastic properties of oils. This helps to differentiate between types of oils.

Kumar *et al* (2018) studied the physiochemical properties of vegetable blended oils. Edible oils are necessary component of human diet because of nutritional benefits. It was studied that the physical and chemical properties are significant for analysis of quality of edible oils and their processing. The properties like density, specific gravity, peroxide value, acid value and pH value were measured for mustard oil, soybean oil, sunflower oil and groundnut oil with the number of treatments. These experiments were performed for the quality measurement of crude and blended vegetable oils. It was analysed that free fatty acids are increasing with increase in period of time of storage and storage conditions. It was concluded that 90% vegetable oils are edible oils.

Halim and Thoo (2018) explained the effect of ultrasonic technique on oxidative stability of edible oils. The samples taken for oxidative study were refined sunflower oil and refined palm oil. The effect of sonication time of ultrasound sunflower oil and ultrasound palm oil was measured using peroxide value. The ultrasound sunflower oil and ultrasound palm oil were stored at 60^{o}C for 24 days using accelerated storage technique. It was concluded that, peroxide value increases by increasing sonication time and ultrasound palm oil has high peroxide value than ultrasound palm oil. After a treatment of accelerated storage in 24 days, there was no significant difference in the quality of ultrasound sunflower oil and ultrasound palm oil. It was observed that ultrasound does not have any significant impact on oxidative stability of edible oils.

Yan *et al* (2019) advanced the pulse echo technique for characterizing vegetable oils. Ultrasonic velocity, viscosity and density of 30 extra virgin olive oil, 15 refined olive oil, 5 sunflower oil, 15 pomace olive oil, 10 rapeseed oil and 5 peanut oil were measured and results were correlated with fatty acid composition. From the experimental data, it was concluded that ultrasonic velocity and density decrease by increasing the temperature while viscosity of extra virgin olive oil increases. It can be concluded that degree of unsaturation results in low

viscosity, high velocity and high density. It was proved that ultrasonic technique can be utilized for depicting vegetable oils because of its non-destructive nature.

CHAPTER III

MATERIALS AND METHODS

In this chapter, the equipment and experimental procedure followed during the course of the study have been discussed in detail. Kachchi ghani mustard oil was selected to study the effect of temperature on ultrasonic velocity, viscosity and density of mustard oil adulterated with different concentration of palm oil. The various thermodynamic parameters such as bulk modulus, surface tension, intermolecular free length, acoustic impedance and adiabatic compressibility are calculated. The experiments were performed at the Post-Graduate Research Laboratory of Department of Mathematics, Statistics and Physics, Punjab Agricultural University, Ludhiana.

3.1 Selection of mustard oil sample

Kachchi ghani mustard oil was preferred instead of processed mustard oil, because the processed oil will be standardized already with the given standards of oil commission or it might contain some impurities which will not give the exact ultrasonic velocity and other parameters of mustard oil. Kachchi ghani mustard oil was purchased from the market.

3.2 Selection of adulterant palm oil

The refined palm oil was preferred as adulterant over raw palm oil because unscrupulous traders are mixing refined palm oil or cheap edible oils with cooking oils such as sunflower or mustard oil. Refined palm oil was purchased from the market.

3.3 Preparation of different mustard oil concentration

In this study, the raw mustard oil was adulterated with refined palm oil as impurity at four different concentrations 10%, 20%, 30% and 40% on volume by volume basis. The 0% and 100% impurity concentrations were the pure mustard oil and pure palm oil itself. These concentrations are heated at selected temperatures 30, 40, 50, 60 and 70˚C for about 15-20 minutes. To prepare 90% mustard oil concentration, 10ml of palm oil was added on 90ml of raw mustard oil and stirred properly to obtain a uniform mixture of mustard oil with palm oil. Similarly, 80, 70, 60% mustard oil concentrations were prepared by adding 20, 30, 40ml of palm oil respectively. The parameters like ultrasonic velocity, viscosity and density of these concentrations were determined in the selected temperature range (30-70˚C). The experiment for each property was performed with replication of thrice and mean value of replications was considered as the final value.

3.4 Descriptions of ultrasonic interferometer

Ultrasonic interferometer is an instrument used to measure ultrasonic wave velocity in liquid medium with high degree of precision. The apparatus contains of specially designed doubled wall brass cell having chromium plated surfaces with a capacity of 10 ml. The double wall permits water circulation all over the sample to sustain it at a constant known temperature.

The ultrasonic waves are produced by the piezoelectric crystal made up of quartz placed at the bottom of measuring cell as shown in the below Figure 3.1.

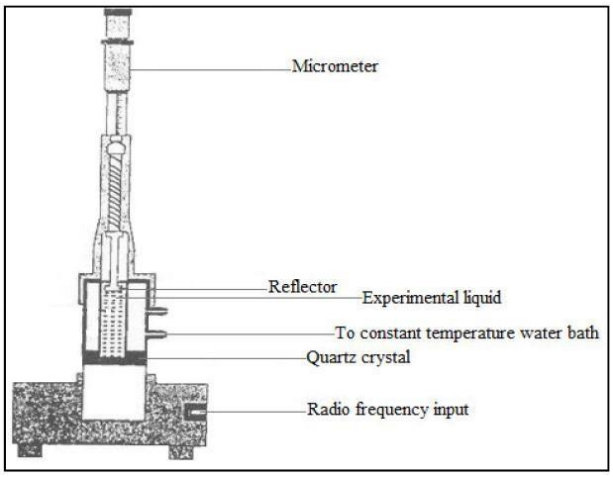

Figure 3.1 Measuring cell of ultrasonic interferometer

The ultrasonic waves are generated by the electrical approach with use of piezoelectric crystal. An oscillatory circuit supplies the electromotive force (EMF) and adjusting is obtained by variable condenser. Q is piezoelectric crystal arranged between A and B as shown in Figure 3.2. This forms a parallel plate condenser having crystal as a dielectric. The primary of the transformer is connected with the metal plates and primary is coupled to oscillatory circuit of triode valve. The resonance occurs when the natural frequency of triode value coincides with the crystal frequency, the crystal is put into mechanical vibrations due to phenomenon of reverse piezoelectric effect. With a quartz crystal, the acoustic waves of frequency 540 KHz can be produced. For the generation of high frequency waves, the plate has to be made strong and very thin so that, it may sustain the strain. In the fixed frequency variable path interferometer, the wavelength of the ultrasonic waves in the experimental liquid is determined and can be used to calculate the velocity of the waves in the given medium.

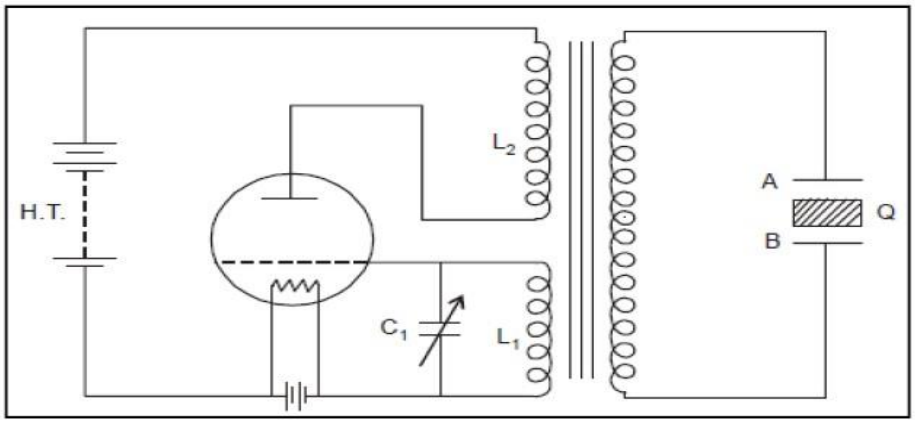

Figure 3.2 Oscillatory circuit in interferometer

The ultrasonic velocity measurement is established on a precise measurement of the wavelength of waves in the liquid medium. These ultrasonic waves are generated in the

interferometer by the piezoelectric effect. The quartz crystal is introduced to electrical potential which produces a known frequency (f) of ultrasonic waves. The ultrasonic waves produced are reflected through a movable metallic plate which is placed parallel to the quartz crystal. The distance between the plates must be exactly a whole multiple of the wavelength of sound waves for the generation of standing waves in the liquid medium. This acoustic resonance causes an electrical reaction on the high frequency generator and give rises to maximum anode current in the generator.

If variation is exactly half (λ/2) or multiple of the wavelength, then the anode current tends to maximum as the distance between the plates is increased or decreased. The ultrasonic waves travelling in the medium suffers some kind of resistance because of the constituent particles of the medium which gives different ultrasonic velocity for different medium. From the measurement of separation between successive adjacent maxima of anode current, the wavelength can be calculated from equation (3.1).

$$d = \lambda/2 \tag{3.1}$$

The velocity (v) and wavelength (λ) of the wave are shown by the equation (3.2).

$$v = \lambda f = 2df \tag{3.2}$$

3.5 Measurement of ultrasonic velocity

The ultrasonic velocity of mustard oil sample having different concentrations was measured using ultrasonic interferometer (Batra Trading Company, Timber Market, Ambala, Dual frequency 1 and 3 MHz) at constant frequency of 3 MHz and with least count of micrometer 0.01mm. The mustard oil sample of a specific concentration was poured into the measuring cell. The reading was recorded from the micrometer for the maximum of anode current designated in the ammeter with counts of ten maxima. The accurate final reading was then determined by subtracting the first maxima from the tenth maxima and dividing the result by ten. The experimental setup used for the ultrasonic measurement is shown in Figure 3.3.

Figure 3.3 Experimental setup for measurement of ultrasonic velocity

The ultrasonic velocity was measured of mustard oil sample having temperatures at 30˚C, 40˚C, 50˚C, 60˚C and 70˚C. The temperature was made constant using water bath. To sustain a particular temperature, the water from the water bath was circulated for 15 minutes before noting down the reading. The reading was taken for concentrations 60, 70, 80, 90, 100% mustard oil and pure palm oil at the given temperature range.

3.6 Measurement of viscosity

Viscosity is an efficient property to be considered when any flow measurements of fluids are made. It measures the resistance offered to the flow of liquid. If a fluid has large resistance, then it has high viscosity to its flow because its molecular makeup gives a lot of internal friction. The viscosity of mustard oil depends on many factors, mainly on temperature and chemical constituents. The viscosity is an important parameter which is considered in all the stages of mustard oil production.

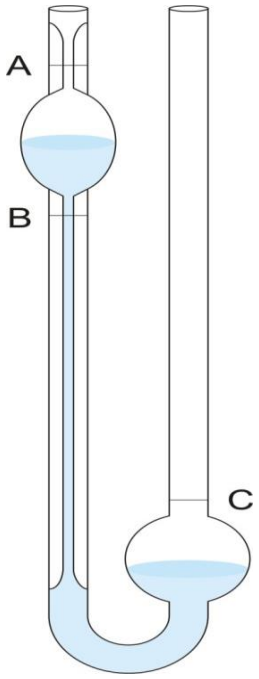

Figure 3.4 Ostwald viscometer

In the current study, viscosity of mustard oil was measured using Ostwald viscometer which was named after Wilhelm Ostwald. Ostwald viscometer or glass capillary viscometer is a generally used viscometer, which contains a U-shaped glass tube held vertically. One arm of the viscometer is a vertical section of narrow capillary tube having bulb above it. Another bulb is present on lower side of other arm. The sample is poured to fill up the lower bulb till mark (C) as shown in Figure 3.4. The liquid is drained into the upper bulb by suction. The liquid is permitted to flow down through the capillary into the lower bulb. The two marks, above and below the bulb, specify a known volume. The viscosity is determined by noting the time taken by the liquid to flow from the higher mark (A) to the lower mark (B). The viscometer must be first calibrated with the fluids of known viscosity such as water. For the calibration, distilled

water was used and time of flow was noted repeating this by three times. Knowing the viscosity of reference liquid water, viscosity of the sample liquid can be evaluated using the following equation (3.3).

$$\eta_1 = \eta_2 \frac{\rho_1 t_1}{\rho_2 t_2} \tag{3.3}$$

Where, $\eta_1$and η_2 are viscosities of mustard oil and distilled water, and ρ_1 and ρ_2 are densities of mustard oil and distilled water, and t_1 and t_2 are the time of flow of mustard oil and distilled water respectively.

To study the effect of temperature, the Ostwald viscometer was settled in the water bath and it must be ensured that both bulbs of viscometer should be properly immersed in the water. The viscosity of mustard oil was measured for 60, 70, 80, 90, 100% mustard oil and pure palm oil concentration having temperature at 30˚C, 40˚C, 50˚C, 60˚C and 70˚C. The observation was taken three times for each concentration and at a considered temperature, the mean of three readings was taken as final reading.

3.7 Measurement of density

Density is a materialize property of a substance which is mass per unit volume. To measure density, specific gravity method was used. Specific gravity is the ratio of the weight of a known volume of a substance to the weight of an equal volume of given sample. Specific gravity bottle is a pear shaped 25ml bottle with a glass stopper. It is constructed of borosilicate glass having good chemical resistance, minimal thermal expansion and has resistance to thermal shocks.

Figure 3.5 Specific gravity bottle

To measure density, the specific gravity bottle was weighed empty on an electronic balance. The mustard oil sample of a particular concentration was poured into the bottle. This should be properly done avoiding formation of any bubble in the bottle. The bottle containing mustard oil sample was then weighed. The weight of the empty bottle was subtracted from the

weight of the bottle containing the mustard oil sample. The determined mass of the mustard oil sample was divided with the volume. To observe the effect of temperature, the specific gravity bottle was placed in the temperature-controlled water bath. For a specific temperature, the bottle was kept in the water bath for 15 minutes and then, the bottle was taken out to be weighed. The density for every concentration was measured at the temperature range of 30˚C, 40˚C, 50˚C, 60˚C and 70˚C. The observation for a particular concentration at a temperature was recorded thrice and their average was standardized as the final reading.

3.8 Determination of other thermodynamic parameters

Using the above measured physicochemical properties, some other thermodynamic properties of mustard oil can be evaluated. The effect of temperature on the thermodynamic parameters of sample was determined using the obtained values of ultrasonic velocity and density as given in the following sections.

3.8.1 Determination of surface tension

Surface tension is the capacity of the liquid which makes it to attain the minimum surface area. It measures how much energy of interaction is stored between the molecules of a liquid at the liquid interface. The water molecules are attracted towards each other due to cohesive forces resulting net force to be zero. This cohesive force is being shared by all the adjacent molecules. The molecules having no neighbouring molecules above introduce strong attracting force to their adjacent molecules and thus pulled inward causing a surface behaving like an elastic sheet. If we pull a molecule, a restoring force acts due to cohesive forces acting on the molecule. At liquid-air interface, the surface tension is due to greater attraction of water molecules for each other (cohesion) than the water molecules in air (adhesion). The surface tension was determined using density and ultrasonic velocity from the following equation (3.4),

$$\sigma = 6.33\times10^{-10}\ \rho v^{1.5} \tag{3.4}$$

Where, v is the ultrasonic velocity in m/s, σ is surface tension in N/m and ρ is density in kg/m^3.

3.8.2 Determination of adiabatic compressibility

Adiabatic compressibility of a material is the ratio of its comparative volume change with a response to a pressure change. Compressibility is inverse of bulk modulus. A material which is easy to compress has high compressibility and having a low bulk modulus. The liquid medium or material that is difficult to compress has small compressibility and large bulk modulus. It is symbolized by Greek symbol, beta (β). The relation which is used to calculate adiabatic compressibility is given below by equation (3.5),

$$\beta = \frac{1}{\rho v^2} \tag{3.5}$$

Where, ρ is density of the liquid medium and v is ultrasonic velocity in medium. The adiabatic compressibility of liquid is measured in unit m^{2}N^{-1}.

3.8.3 Determination of bulk modulus

Bulk modulus is a numerical constant characterizing compressibility of a liquid. It describes the elastic properties of a substance while it is under pressure on all the surfaces. It is measure of the ability of a substance to withstand changes in volume when compression is applied on all surfaces. It is equal to ratio of applied pressure to its relative deformation. Thus, bulk modulus is mainly calculated for liquids. All materials are compressible. A fluid is called incompressible, if it has large bulk modulus. The volume of a given mass reduces when a force is exerted uniformly all over its surface. The bulk modulus is expressed in the form of ultrasonic velocity (v) and density (ρ) of liquid medium as shown below by equation (3.6),

$$K = \rho \times v^2 \tag{3.6}$$

Where, bulk modulus units are Nm^{-2}.

3.8.4 Determination of acoustic impedance

Acoustic impedance is the measure of resistance offered to the propagation of sound waves as they pass through a medium. When acoustic waves are generated from the transducer, generally most of the waves are reflected at the interface of the transducer and some are propagated in the material. This again results in reflection of energy at boundaries of the medium. A receiver receives this energy and converts into a signal. The intensity of this signal depends upon the acoustic impedance of the medium. Acoustic impedance changes with density of material in which waves propagate. The acoustic impedance (Z) is expressed as the product of ultrasonic velocity (v) and density (ρ) as given below by equation (3.7),

$$Z = \rho \times v \tag{3.7}$$

Where, the units of acoustic impedance are in $kgm^{-2}s^{-1}$ or Nsm^{-3}.

3.8.5 Determination of intermolecular free length

Intermolecular free length is distance among the surfaces of neighbouring or adjacent molecules. It measures the nature of molecular interaction. The analysis of free length helps to study the changes in ultrasonic velocity. Intermolecular free length is calculated by equation (3.8).

$$L = K_J \times \beta^{1/2} \tag{3.8}$$

Where, β is the acoustic impedance and K_J is the Jacobson's temperature dependent constant whose value can be evaluated by using the relation (Santhi *et al* 2012) in equation (3.9).

$$K_J = (18687+40.391T) \tag{3.9}$$

Where, T is the temperature in °C and this constant is independent of nature of medium.

3.9 Statistical analysis

The results of the experiments were significantly tested using software SPSS version 20.0. The analysis of variance (ANOVA) included Tukey's test applied on the experimental data. The regression analysis of data was done by fitting the parameters with concentration and temperature.

CHAPTER-IV

RESULTS AND DISCUSSION

The experimental results of the effect of temperature on ultrasonic velocity, viscosity and density and the calculated values of surface tension, adiabatic compressibility, bulk modulus, acoustic impedance and intermolecular free length from experimental data are explained in this chapter. Statistical analysis of observed data is accomplished to verify its significance. The following sections discuss results and relationships of each parameter.

4.1 Variation of ultrasonic velocity at different temperatures and concentrations

The plots of ultrasonic velocity of mustard oil sample as a function of temperature and concentration are plotted as shown in Figure 4.1 and 4.2 respectively. The ultrasonic velocity in pure mustard oil and palm oil was ranged from 1448 to 1432 m/s and 1324 to 1234 m/s respectively in the temperature range 30 to 70˚C. The values of mustard oil and palm oil show that pure mustard oil had high ultrasonic velocity and pure palm oil had low ultrasonic velocity. When palm oil was added in mustard oil, the ultrasonic velocity decreased with increase in concentration of palm oil. The decrease in velocity was more in pure palm oil than other concentrations. The ultrasonic velocity of mustard oil was 1440 m/s at 30°C and reported by Kumari *et al* (2015).

The ultrasonic velocity was decreased with increase in temperature at a particular concentration. The similar trend of ultrasonic velocity of heated and unheated mustard oil was studied by Valantina *et al* (2016). The ultrasonic velocity of mustard oil decreases with increase in temperature due to intermolecular free length. The intermolecular free length increases with increase in temperature due to increase in thermal energy (Kumari *et al* 2015). The molecules at high temperature have high energy and vibrate fast and therefore, ultrasonic waves can travel faster. Also, the close packing of molecule decreases the intermolecular free length because of increase in strength of intermolecular interaction and results to increase in ultrasonic velocity (Sankarappa *et al* 2005). By increasing the intermolecular free length, ultrasonic velocity decreases and vice versa. With increase in temperature, cohesive and pressure of molecules also increase and attributes to decrease in ultrasonic velocity.

The ultrasonic velocity decreased by increasing palm oil concentration in mustard oil. This is due to the fact that with the addition of palm oil, the constituents of mustard oil get disturbed and so ultrasonic velocity is affected. This can be explained by strong interaction of palm oil and mustard oil constituents. With increase in quantity of palm oil in mustard oil, the attraction between palm oil and mustard oil molecules increase and results to increase in intermolecular free length. This increases compressibility of molecules and hence ultrasonic velocity decreases. In case of palm oil, the ultrasonic velocity was decreased with increase in temperature.

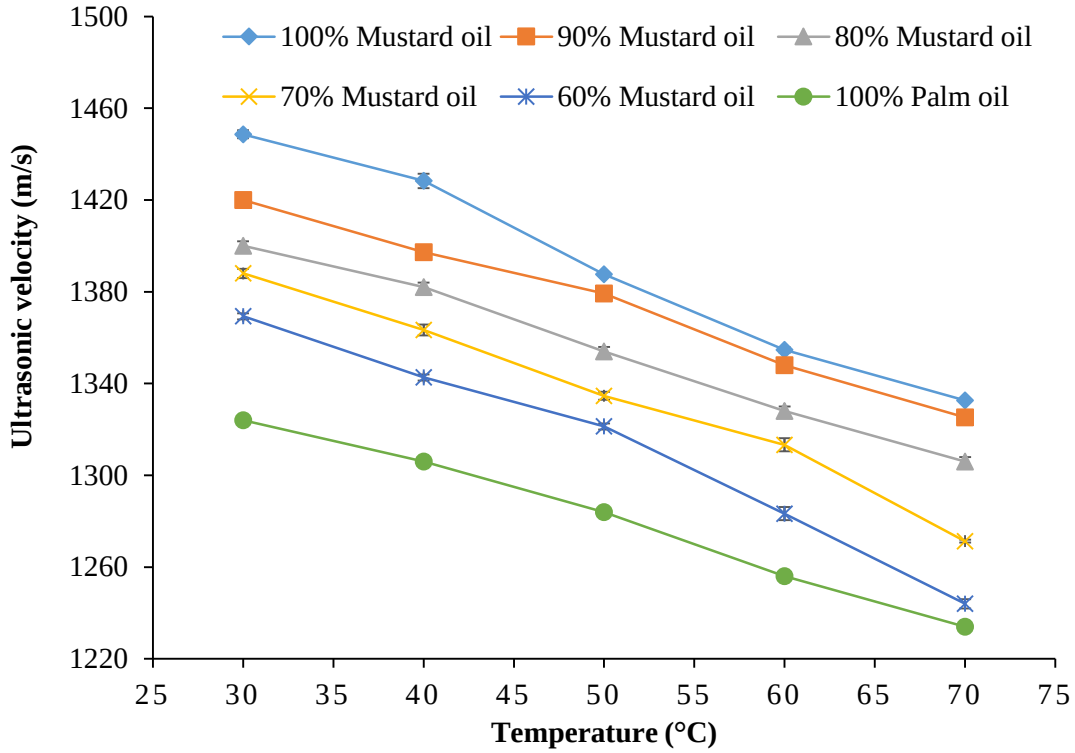

Figure 4.1 Variation of ultrasonic velocity of mustard oil at different temperatures

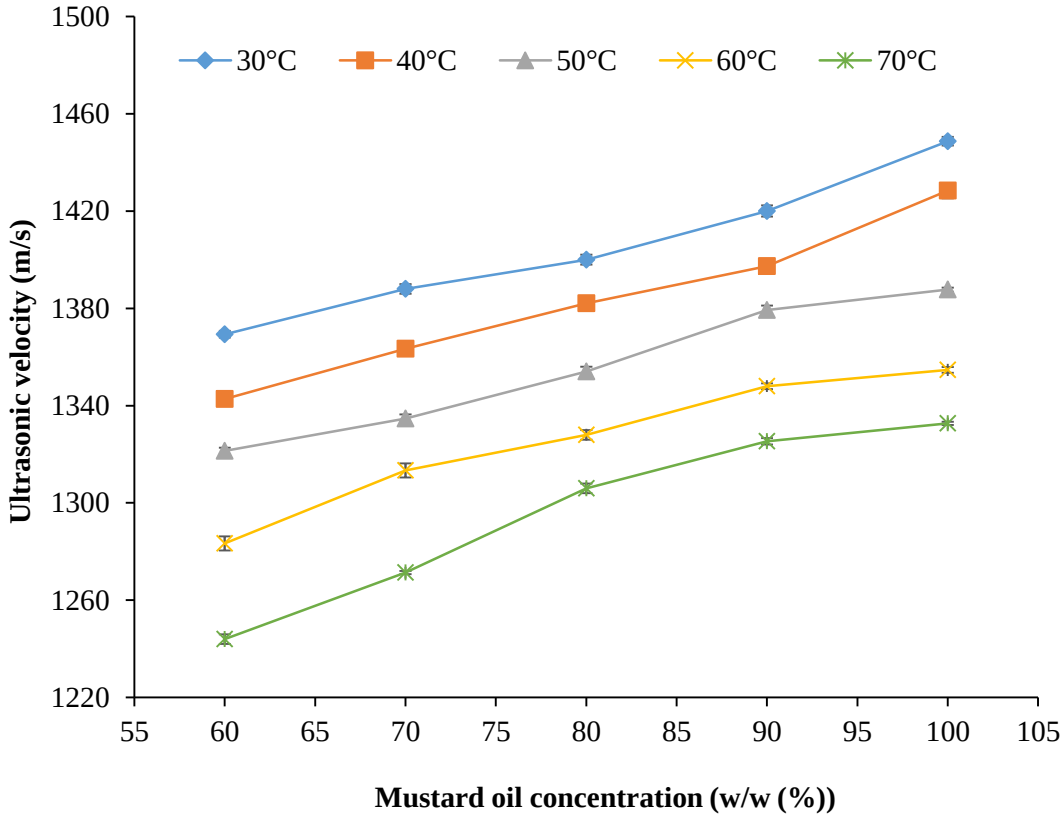

Figure 4.2 Variation of ultrasonic velocity of mustard oil at different concentrations

The similar trend of ultrasonic velocity of palm oil with temperature was reported by Sidek *et al* (1996). The decrease in velocity with temperature was due to chain length, thermal conduction and degree of unsaturation as explained by Javanaud and Rhalkar (1988). The increase in temperature tends to increase in chain length and thus results to increase in its compressibility and thus, reduces ultrasonic velocity.

The variation of ultrasonic velocity with temperature and concentration was correlated using one-way ANOVA at 5% level of significance. The experimental data obtained was linearly fitted which provided relations for ultrasonic velocity with temperature and concentration. The effect of temperature and mustard oil concentration on ultrasonic velocity was found to be significant. Table 4.1 and 4.2 show the statistical analysis of ultrasonic velocity with temperature and concentration respectively.

Table 4.1 Ultrasonic velocity of mustard oil at different temperatures

Temperature (°C)	**Ultrasonic velocity (m/s)**				
	100%	**90%**	**80%**	**70%**	**60%**
30	1448^{a}	1420^{a}	1400^{a}	1388^{a}	1369^{a}
40	1428^{b}	1397^{b}	1382^{b}	1363^{b}	1342^{b}
50	1387^{c}	1379^{c}	1354^{c}	1334^{c}	1321^{c}
60	1354^{d}	1348^{d}	1328^{d}	1313^{d}	1283^{d}
70	1332^{e}	1325^{e}	1306^{e}	1271^{e}	1244^{e}

The mean values in the table with small superscripts are significant in case of different temperatures at same concentration ($p<0.05$).

Table 4.2 Ultrasonic velocity of mustard oil at different concentrations

Mustard oil concentrations ((w/w) %)	**Ultrasonic velocity (m/s)**				
	30°C	**40°C**	**50°C**	**60°C**	**70°C**
100	1448^{a}	1428^{a}	1387^{a}	1354^{a}	1332^{a}
90	1420^{b}	1397^{b}	1379^{b}	1348^{b}	1325^{b}
80	1400^{c}	1382^{c}	1354^{c}	1328^{c}	1306^{c}
70	1388^{d}	1363^{d}	1334^{d}	1313^{d}	1271^{d}
60	1369^{e}	1342^{e}	1321^{e}	1283^{e}	1244^{e}

The mean values in the table with small superscripts are significant in case of different concentrations at same temperature ($p<0.05$).

The fitted correlation of ultrasonic velocity with temperature is given below,

$$V = a + b\,T$$

Where, V is the ultrasonic velocity of mustard oil in m/s

T is the temperature in °C

The values obtained of regression coefficients a and b, the coefficient of determination R^2 are shown in Table 4.3.

Table 4.3 Regression coefficients of ultrasonic velocity with temperature

Mustard oil concentration ((w/w) %)	a	b	R^2
100	1543.20	-3.05	0.99
90	1493.30	-2.38	0.99
80	1475.00	-2.42	0.99
70	1475.80	-2.83	0.98
60	1467.10	-3.10	0.99

*Significant at 5% level of significance ($p<0.05$)

The fitted correlation of ultrasonic velocity with concentrations is given below,

$$V = a + b\,C$$

where, V is the ultrasonic velocity of mustard oil in m/s

C is the concentration in (w/w) %

The values of regression coefficients a and b, the coefficient of determination R^2 are given in Table 4.4.

Table 4.4 Regression coefficients of ultrasonic velocity with concentration

Temperature (°C)	a	b	R^2
30	1252.70	1.90	0.97
40	1218.50	2.05	0.98
50	1213.51	1.77	0.98
60	1183.62	1.77	0.96
70	1110.82	2.31	0.95

*Significant at 5% level of significance ($p<0.05$)

4.2 Variation of viscosity at different temperatures and concentrations

The variation of viscosity of mustard oil at different temperatures and concentrations was plotted as shown in Figure 4.3 and 4.4 respectively. The plot shows the viscosity of 100%, 90%, 80%, 70% and 60% concentration of mustard oil having temperature in the range from 30°C to 70°C. For a considered concentration, viscosity decreased with increase in temperature. The viscosity of mustard oil decreased by increasing concentration of palm oil in mustard oil, at a specific temperature. The range of viscosity was 54.39 to 22.31m.Pa.s for pure mustard oil, 53.12 to 21.37m.Pa.s for 90%, 50.86 to 20.39m.Pa.s for 80%, 44.71 to 19.07m.Pa.s for 70%, 41.16 to 13.95m.Pa.s for 60% and 37.25 to 10.07m.Pa.s for pure palm oil in the temperature range 30-70°C. The viscosity of pure mustard oil was highest and pure palm oil was lowest.

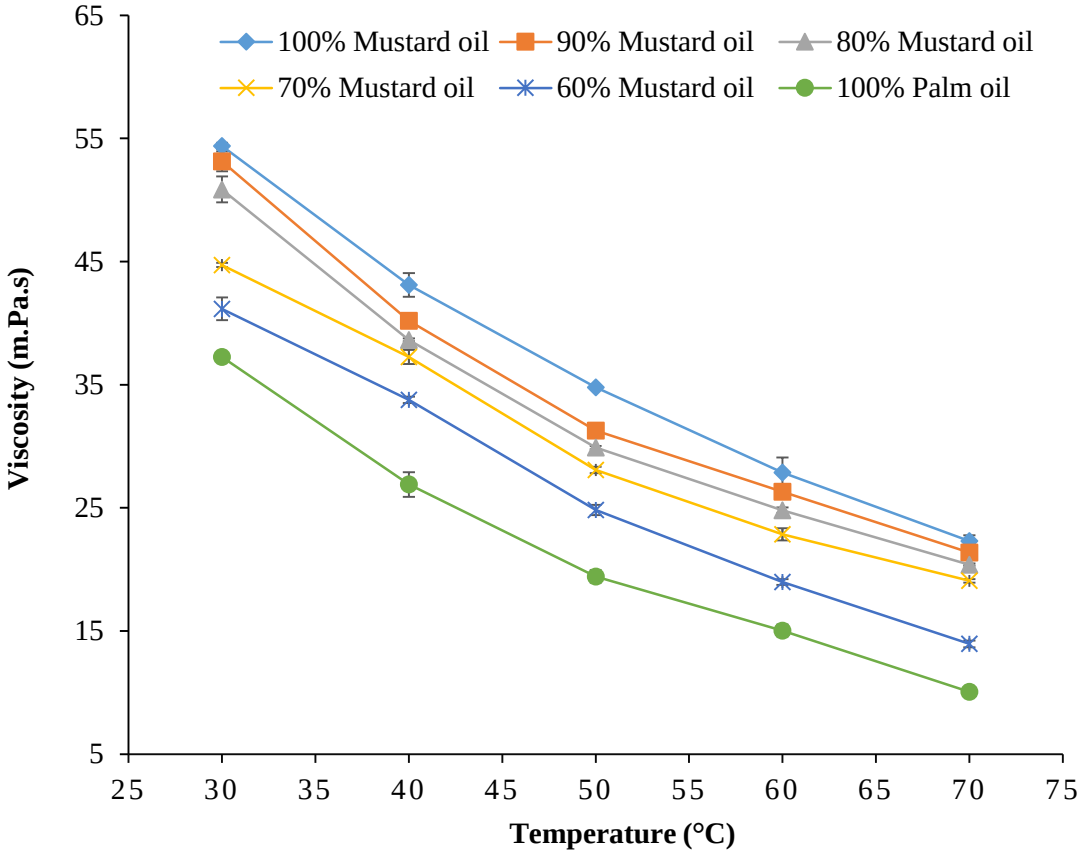

Figure 4.3 Variation of viscosity of mustard oil at different temperatures

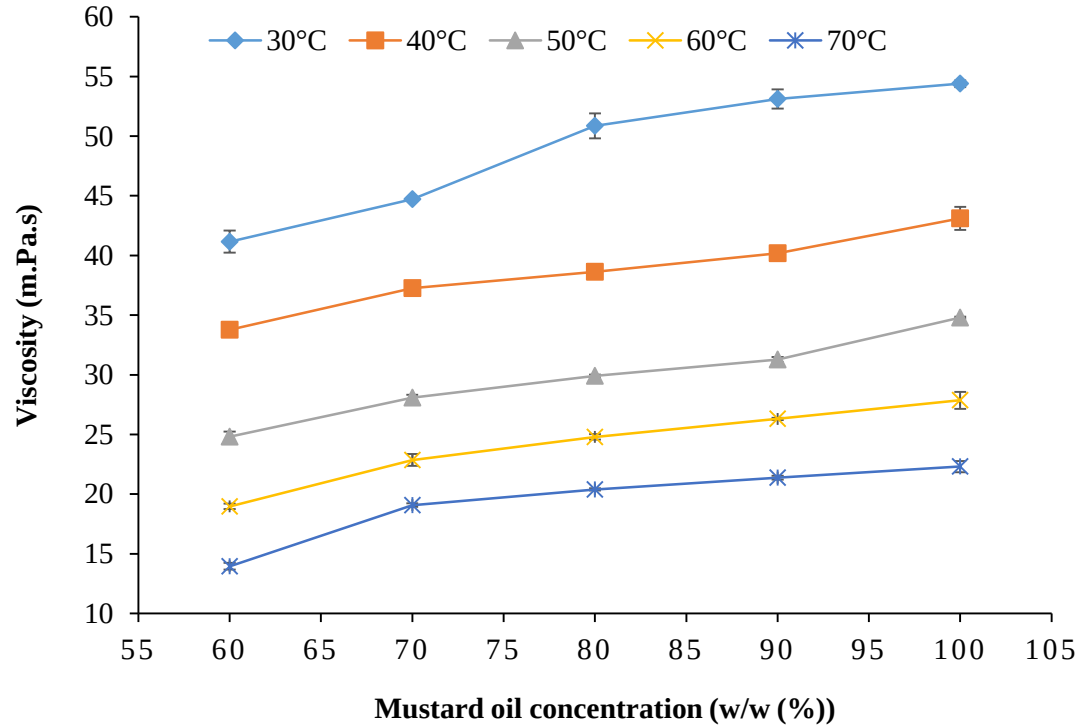

Figure 4.4 Variation of viscosity of mustard oil at different concentrations

Table 4.5 Viscosity of mustard oil at different temperatures

Temperature (°C)	Viscosity (m.Pa.s)				
	100%	**90%**	**80%**	**70%**	**60%**
30	54.39[a]	53.12[a]	50.86[a]	44.71[a]	41.16[a]
40	43.10[b]	40.19[b]	38.63[b]	37.25[b]	33.77[b]
50	34.79[c]	31.27[c]	29.89[c]	28.07[c]	24.82[c]
60	27.86[d]	26.30[d]	24.79[d]	22.86[d]	18.97[d]
70	22.31[e]	21.37[e]	20.39[e]	19.07[e]	13.95[e]

The mean values in the table with small superscripts are significant in case of different temperatures at same concentration ($p<0.05$).

Table 4.6 Viscosity of mustard oil at different concentrations

Mustard oil concentrations (w/w (%))	Viscosity (m.Pa.s)				
	30°C	**40°C**	**50°C**	**60°C**	**70°C**
100	54.39[a]	43.10[a]	34.79[a]	27.86[a]	22.31[a]
90	53.12[b]	40.19[b]	31.27[b]	26.30[b]	21.37[b]
80	50.86[c]	38.63[c]	29.89[c]	24.79[c]	20.39[c]
70	44.71[d]	37.25[d]	28.07[d]	22.86[d]	19.07[d]
60	41.16[e]	33.77[e]	24.82[e]	18.97[e]	13.95[e]

The figures followed by different superscripts in table are significantly different ($p<0.05$).

Viscosity decreased by increasing temperature at a particular concentration. The similar variation of viscosity of mustard oil with temperature in the range 25-85°C was studied by Valantina *et al* (2016). The decrease in viscosity with increase in temperature is due to molecular interaction. Molecular clustering is the dominant factor affecting the viscosity of liquid. With increase in temperature, molecular interaction decreases due to increase in intermolecular free length and hence, liquid medium has loose packed structure and offers low resistance to the flow of liquid. Also, the cohesive forces between molecules of the medium decrease with increase in temperature and viscosity decreases (Ebong *et al* 2014).

Viscosity depends upon the constituents of the substance. The viscosity was observed to decrease with quantity of adulteration, when olive oil was adulterated with 20% and 40% coconut oil and sunflower oil as reported by Valantina *et al* (2016). Viscosity decreased exponentially by increasing the concentration of palm oil in mustard oil. The similar trend was observed by Kumari *et al* (2015). At high concentration of mustard oil, the intermolecular distance between the components of medium is less and results to strong hydrogen bonding. This strong bonding attributes to high viscosity of pure mustard oil. With the addition of palm

oil, it disturbs the bond arrangement of constituents of pure mustard oil. This decreases the viscosity of mustard oil on introducing palm oil.

Viscosity recorded for all the mustard oil samples differ significantly at 5% level of significance. The data at different concentration and temperature was concerned by analysis of variance (ANOVA) as given in Table 4.5 and 4.6 respectively. The viscosity differs significantly from each other with change in temperature and concentration as observed from both tables. The values of regression coefficients and coefficient of determination (R^2) of viscosity variation with temperature and concentration are given in the Table 4.7 and 4.8 respectively. The exponential fit for viscosity is well supported by high R^2 values.

Table 4.7 Regression coefficients of viscosity with temperature

Mustard oil concentration (w/w (%))	**a**	**b**	**R^2**
100	105.38	-0.02	0.99
90	100.57	-0.02	0.99
80	97.23	-0.02	0.99
70	86.69	-0.03	0.99
60	97.10	-0.03	0.99

*Significant at 5% level of significance ($p<0.05$)

Table 4.8 Regression coefficients of viscosity with concentration

Temperature (°C)	**a**	**b**	**R^2**
30	27.09	0.01	0.93
40	24.50	0.01	0.96
50	15.80	0.01	0.97
60	11.57	0.01	0.92
70	8.25	0.02	0.80

*Significant at 5% level of significance ($p<0.05$)

The fitted correlation of viscosity with temperature is given below,

$$\eta = a\, e^{bT}$$

Where, T is the temperature in °C

η is the viscosity in m.Pa.s

The fitted correlation of viscosity with concentration is given below,

$$\eta = a\, e^{bC}$$

Where, C is the concentration in w/w (%)

4.3 Variation of density at different temperatures and concentrations

The variation of density for mustard oil samples in the experimental work at different temperatures and concentrations is plotted as shown in Figure 4.5 and 4.6 respectively. The density of mustard oil was decreased by increasing temperature and palm oil concentration. The density of pure mustard oil was highest as compared to other concentrations. The density measured ranges from 930 to 909kg/m^3 for pure mustard oil, 928 to 905kg/m^3 for 90%, 927 to 903kg/m^3 for 80%, 926 to 902kg/m^3 for 70%, 925 to 900kg/m^3 for 60% and 924 to 888kg/m^3 for pure palm oil in the temperature range 30˚ to 70˚C. The density of mustard oil was 904 kg/m^3 at 30°C as observed by Kumari *et al* (2015).

Table 4.9 Density of mustard oil at different temperatures

Temperature (˚C)	Density (kg/m^3)				
	100%	**90%**	**80%**	**70%**	**60%**
30	930^{a}	928^{a}	927^{a}	926^{a}	925^{a}
40	923^{b}	922^{b}	921^{b}	920^{b}	919^{b}
50	917^{c}	916^{bc}	915^{bc}	914^{b}	913^{b}
60	910^{cd}	908^{c}	907^{cd}	906^{c}	905^{c}
70	903^{d}	902^{c}	901^{d}	900^{d}	898^{d}

The mean values in the table with small superscripts are significant in case of different temperatures at same concentration ($p<0.05$).

Table 4.10 Density of mustard oil at different concentrations

Mustard oil concentrations (w/w (%))	Density (kg/m^3)				
	30°C	**40°C**	**50°C**	**60°C**	**70°C**
100	930^{a}	923^{a}	917^{a}	911^{a}	903^{a}
90	928^{b}	922^{b}	916^{b}	908^{b}	902^{a}
80	927^{b}	921^{bc}	915^{b}	907^{c}	901^{b}
70	926^{b}	920^{cd}	914^{b}	906^{d}	900^{bc}
60	925^{b}	919^{d}	913^{c}	905^{e}	898^{d}

The figures followed by different superscripts in table are significantly different ($p<0.05$).

Density was found to strongly influence by temperature. Density was observed to decrease linearly with increase in temperature. The similar trend of decrease in density with temperature of different edible oils was reported by Sankarappa *et al* (2005). When the temperature is increased, the bonds in the mustard oil sample break due to thermal energy and density is affected. With increase in temperature, intermolecular free length increases and constituents are loosely packed and results to decrease in density.

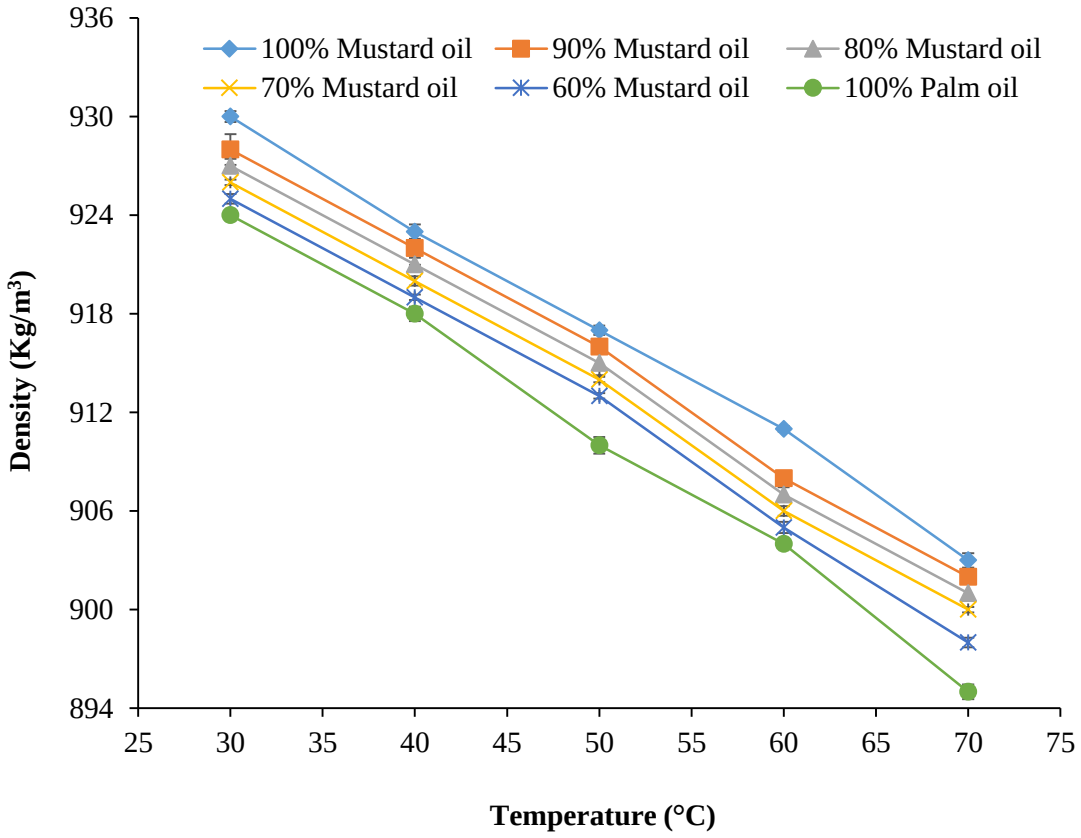

Figure 4.5 Variation of density of mustard oil at different temperatures

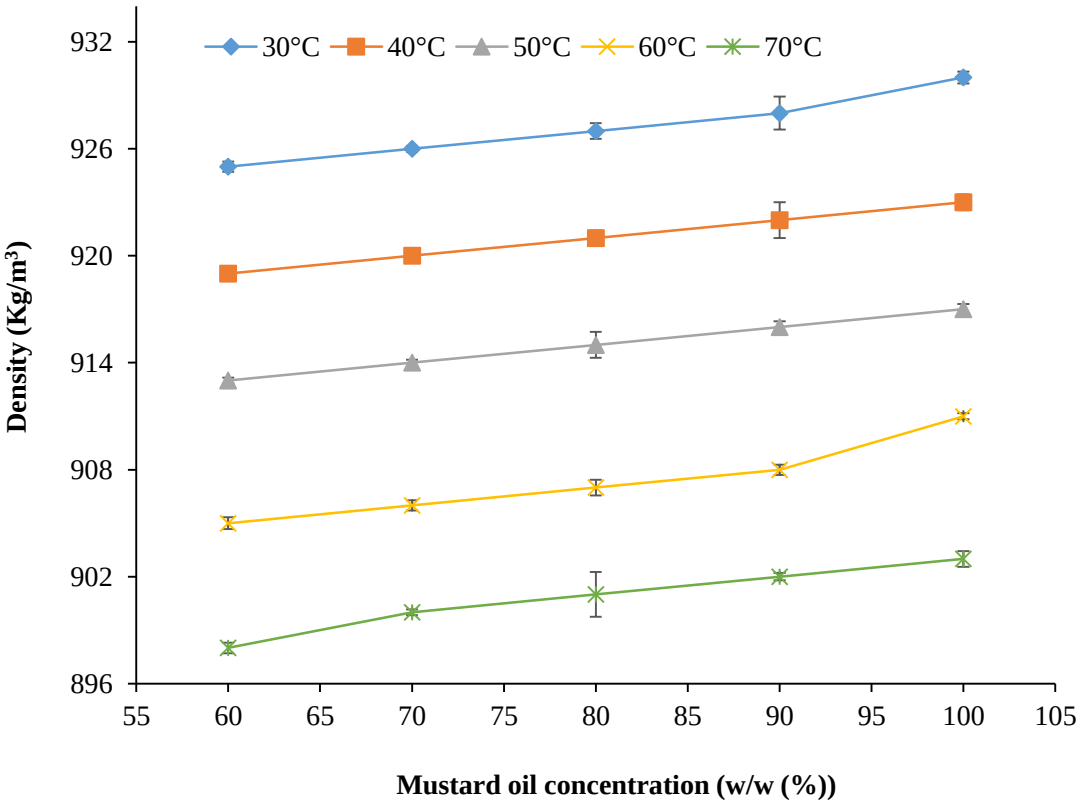

Figure 4.6 Variation of density of mustard oil at different concentrations

Density was found to decrease by increasing the concentration of palm oil in mustard oil. The density showed similar linear trend in mustard oil adulterated with palm oil (10% and 20%) as reported by Kumari *et al* (2015) at 30˚C. With the addition of palm oil, the constituents of mustard oil get disturbed and formation of new bonds occurs and influences its density. On increasing the temperature, this bond length increases as a result of mixing of different oil with different composition of long and short range fatty acids and results to decrease in density.

The data was analysed by ANOVA Tukey's test at 5% level of significance for mustard oil samples. Table 4.9 and 4.10 show the variation of density of mustard oil sample with temperature and concentration. The experimental data obtained was linearly fitted which provides a relation for density as a function of temperature and concentration. Values of regression coefficients and coefficient of determination (R^2) of density variation with temperature and concentration are given in the Table 4.11 and 4.12 respectively. The linear fit was confirmed by the value of R^2.

The fitted correlation of density with temperature is given below,

$$\rho = a + b\,T$$

Where, ρ is the density of mustard oil in Kg/m^3.

T is the temperature in ˚C

The values of regression coefficients a and b, the coefficient of determination R^2 are given in Table 4.11.

Table 4.11 Regression coefficients of density with temperature

Mustard oil concentration (w/w (%))	**a**	**b**	**R^2**
100	949.80	-0.66	0.99
90	948.20	-0.66	0.99
80	947.22	-0.66	0.99
70	946.21	-0.66	0.99
60	946.00	-0.68	0.99

*Significant at 5% level of significance ($p<0.05$)

The fitted correlation of density with concentrations is given below,

$$\rho = a + b\,C$$

Where, ρ is the density of mustard oil in Kg/m^3.

C is the concentration in w/w (%))

The values of regression coefficients a and b, the coefficient of determination R^2 are given in Table 4.12.

Table 4.12 Regression coefficients of density with concentration

Temperature (°C)	a	b	R^2
30	917.60	0.12	0.97
40	913.00	0.10	0.99
50	907.00	0.10	0.95
60	896.20	0.14	0.99
70	891.22	0.12	0.99

*Significant at 5% level of significance ($p<0.05$)

4.4 Variation of surface tension at different temperatures and concentrations

The surface tension calculated using ultrasonic velocity and density in the temperature range 30° to 70°C are given in the Table 4.13. The surface tension varied from 4.0×10^{-2} to 3.51×10^{-2} N/m for pure mustard oil and from 3.48×10^{-2} to 3.10×10^{-2} N/m for pure palm oil. The values calculated for surface tension were plotted at considered temperature range with all concentrations and at considered concentration range with all temperatures are shown in Figure 4.7 and 4.8 respectively. The surface tension was decreased by increasing the temperature and concentration of palm oil in mustard oil.

Table 4.13 Surface tension of mustard oil at different temperatures

Temperature (°C)	Surface tension (σ in N/m)×10^{-2}				
	100%	90%	80%	70%	60%
30	4.00	3.88	3.80	3.74	3.67
40	3.91	3.77	3.71	3.63	3.54
50	3.73	3.69	3.59	3.51	3.45
60	3.60	3.57	3.48	3.42	3.32
70	3.51	3.48	3.39	3.25	3.14

Surface tension depends upon the nature of medium which is in contact with the surface. The decrease in surface tension with temperature is more for pure mustard oil and pure palm oil has less surface tension than other concentrations. The surface tension was found to decrease by increasing the concentration of palm oil. The molecules which are distributed uniformly contribute to surface tension. The similar variation of surface tension with temperature was observed in the temperature range 40°to 70°C for vegetable oils by Dikko *et al* (2015).

Surface tension of mustard oil samples was observed to decrease with increase in temperature as shown in Figure 4.7. The surface tension of edible oils decreases with increase in temperature due to energy gained by molecules. This energy obtained overcomes the resistance and tends to pull back the molecules from each other. Surface tension of the liquid is directly associated to the interaction between molecules present on the surface.

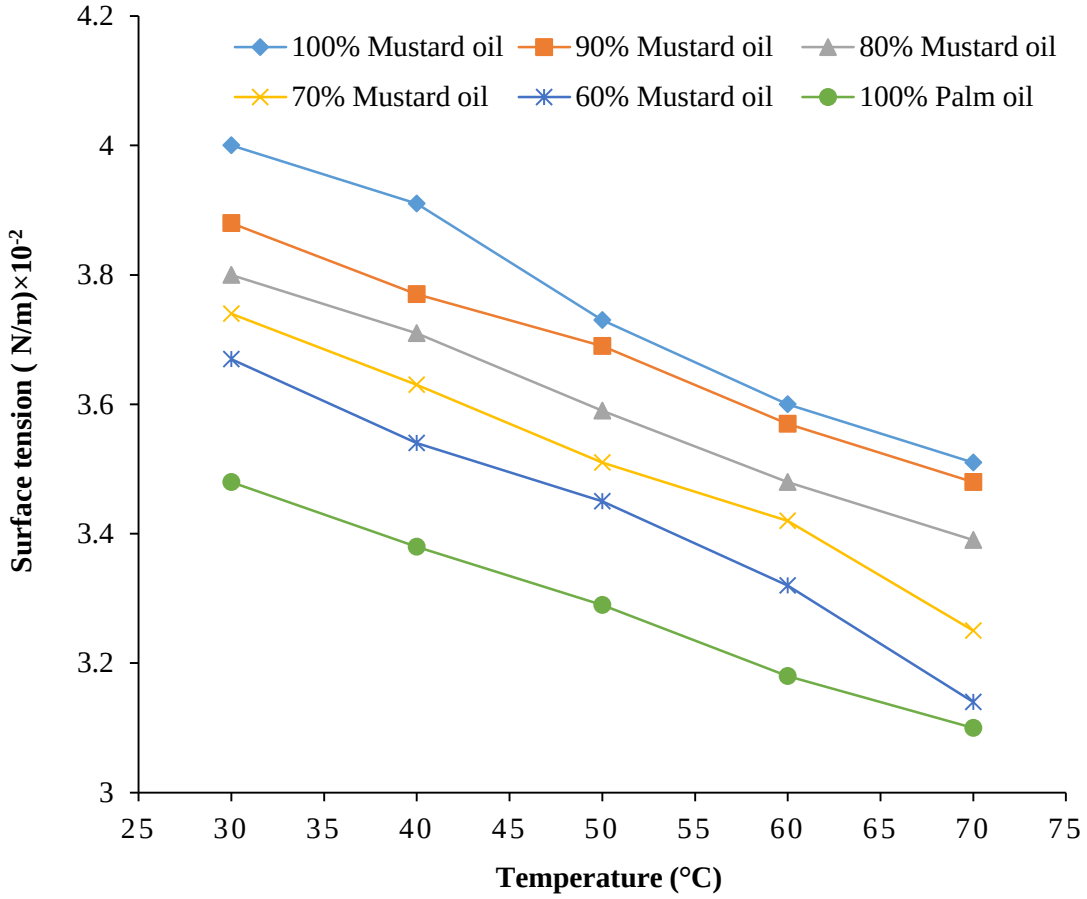

Figure 4.7 Variation of surface tension of mustard oil at different temperatures

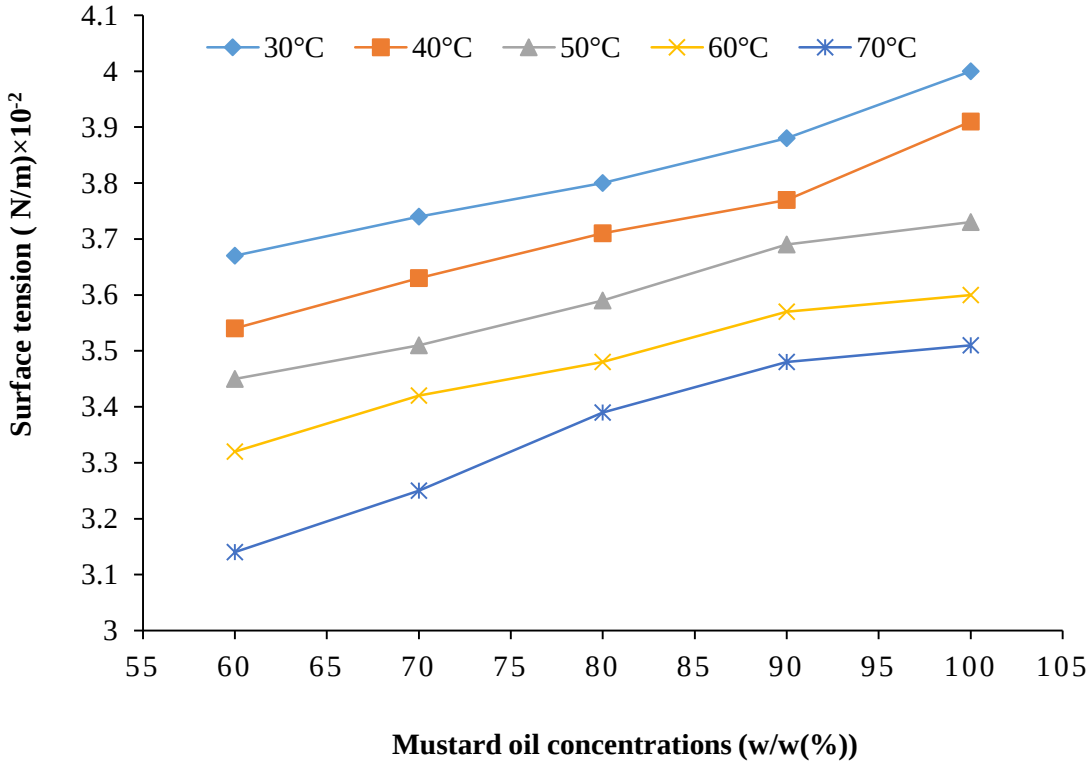

Figure 4.8 Variation of surface tension of mustard oil at different concentrations

The large surface tension is due to strong attraction between the molecules. As the temperature increases, the molecules are loosely bound and the kinetic energy of molecules increases and cohesive forces between the molecules decrease (Dikko *et al* 2015).

The variation of surface tension with concentration of mustard oil at a given temperature is depicted in Figure 4.8. Surface tension has decreased with increasing the concentration of palm oil. Surface tension decreased by increasing palm oil concentration in mustard oil because the sample gets diluted. This increases the intermolecular separation between the mustard oil molecules and is more in surface molecules than inner molecules of mustard oil. This attributes to decrease in interaction of surface molecules and surface tension is reduced in mustard oil. Palm oil has less density than other concentrations and intermolecular separation is more and results to less surface tension.

The data was analysed by determination coefficient R^2 for mustard oil samples. The experimental data obtained was linearly fitted which provides a relation for surface tension as a function of temperature and concentration. The surface tension decreased linearly with increase in temperature as shown in the following equation,

$$\sigma = a + b\,T$$

Where, σ is the surface tension of mustard oil in N/m

T is the temperature in ˚C

The regression coefficients a and b values with determination coefficients R^2 is shown in the Table 4.14.

Table 4.14. Regression coefficients of surface tension with temperature

Mustard oil concentration (w/w (%))	**a**	**b**	**R^2**
100	4.39	-0.01	0.99
90	4.17	-0.01	0.99
80	4.11	-0.01	0.99
70	4.10	-0.01	0.98
60	4.06	-0.01	0.98

*Significant at 5% level of significance ($p<0.05$)

The surface tension variations with concentrations was linear and its relation is,

$$\sigma = a + b\,C$$

Where, σ is the surface tension of mustard oil in N/m

C is the concentration in w/w %

The regression coefficients a and b values with determination coefficients R^2 is given in the Table 4.15.

Table 4.15. Regression coefficients of surface tension with concentration

Temperature (°C)	a	b	R^2
30	3.17	0.01	0.98
40	3.01	0.01	0.98
50	3.00	0.01	0.99
60	2.91	0.01	0.97
70	2.57	0.01	0.96

*Significant at 5% level of significance ($p<0.05$)

4.5 Variation of adiabatic compressibility at different temperatures and concentrations

The adiabatic compressibility evaluated from the values of density and ultrasonic velocity having different concentrations at different temperature is given in Table 4.16. The adiabatic compressibility was plotted at different temperatures ranged from 30˚ to 70˚C having different concentrations and at different concentrations having different temperatures as shown in Figure 4.9 and 4.10 respectively. The adiabatic compressibility for pure mustard oil was varied from 4.15×10^{-10} to $4.93 \times 10^{-10} m^2/N$ and for pure palm oil, the value was ranged from 4.98×10^{-10} to $5.81 \times 10^{-10} m^2/N$. The similar value of mustard oil was $5.31 \times 10^{-10} m^2/N$ calculated by Kumari *et al* (2015).

Table 4.16 Adiabatic compressibility of mustard oil at different temperatures

Temperature (°C)	Adiabatic compressibility (β in m^2/N) $\times 10^{-10}$				
	100%	90%	80%	70%	60%
30	4.15	4.32	4.44	4.53	4.66
40	4.26	4.48	4.59	4.72	4.87
50	4.54	4.6	4.78	4.93	5.03
60	4.77	4.82	4.98	5.10	5.31
70	4.93	4.99	5.15	5.45	5.70

Adiabatic compressibility increased by increasing concentration of palm oil in mustard oil. Palm oil was observed to have large adiabatic compressibility than other concentrations. Also, it increased with temperature increase and is for all concentrations. The increase in adiabatic compressibility with temperature was observed to be more in pure palm oil. The increase of adiabatic compressibility with temperature and concentration shows its inverse relation with ultrasonic velocity and density.

The increase in adiabatic compressibility with increase in temperature was linear as observed in the following equation,

$$\beta = a + b\,T$$

Where, β is the adiabatic compressibility in m^2/N

T is the temperature in ˚C

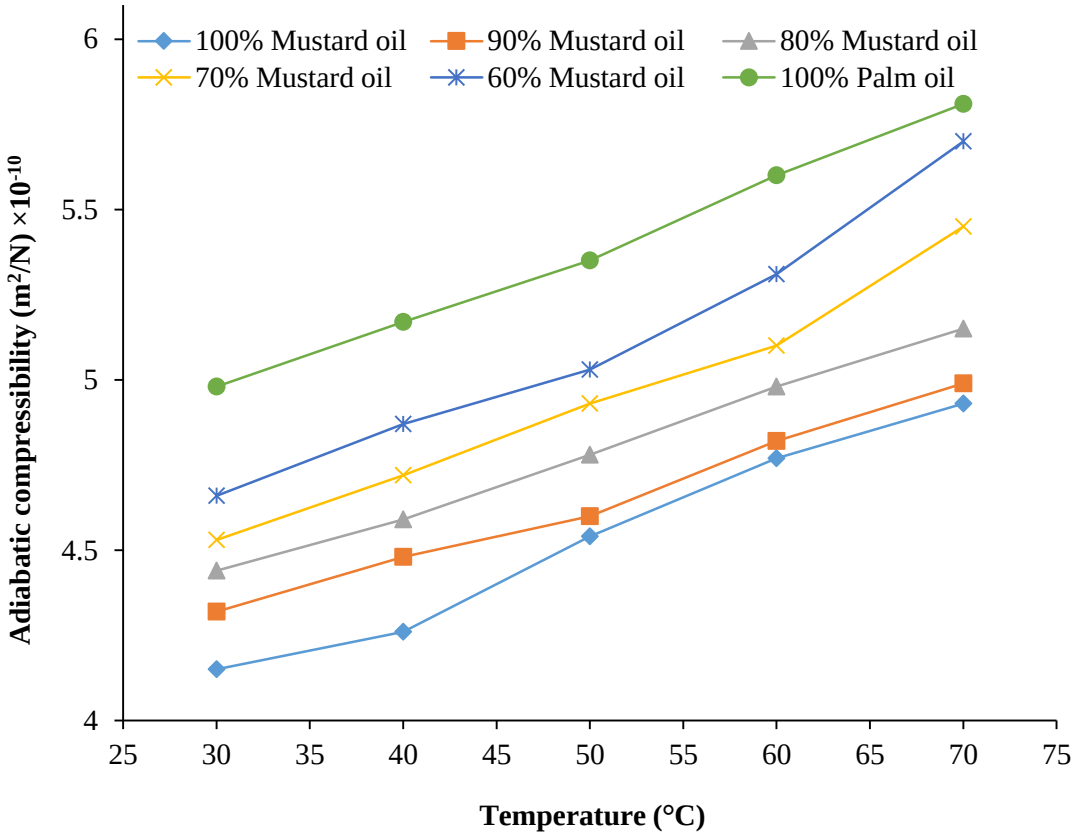

Figure 4.9 Variation of adiabatic compressibility of mustard oil at different temperatures

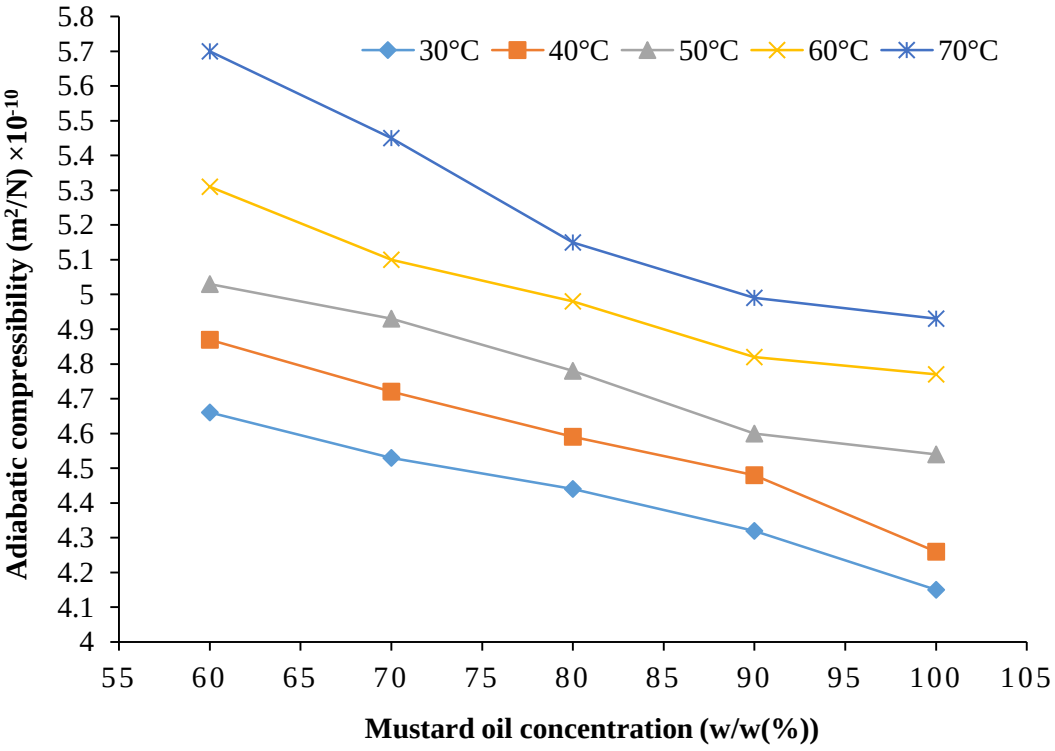

Figure 4.10 Variation of adiabatic compressibility of mustard oil at different concentrations

Table 4.17 Regression coefficients of adiabatic compressibility with temperature

Mustard oil concentration (w/w (%))	a	b	R^2
100	3.80	0.02	0.99
90	3.50	0.02	0.98
80	3.88	0.02	0.97
70	3.85	0.02	0.99
60	3.83	0.02	0.99

*Significant at 5% level of significance ($p<0.05$)

The increase in the adiabatic compressibility with increase in concentration was linear as observed in the following equation,

$$\beta = a + b\,C$$

Where, β is the adiabatic compressibility in m^2/N

C is the concentration in w/w (%))

Table 4.18 Regression coefficients of adiabatic compressibility with concentration

Temperature (°C)	a	b	R^2
30	5.40	-0.01	0.99
40	5.75	-0.01	0.99
50	5.82	-0.01	0.98
60	6.08	-0.01	0.96
70	6.84	-0.02	0.95

*Significant at 5% level of significance ($p<0.05$)

The adiabatic compressibility varied linearly with increase in temperature and concentration of palm oil in mustard oil. The regression coefficients a and b values with determination coefficients R^2 is shown in the Table 4.17 and 4.18.

The variation of adiabatic compressibility with the concentration of mustard oil is consistent with the results obtained by Kumari *et al* (2015). They observed to increase in adiabatic compressibility in mustard oil with addition of 10% and 20% palm oil at 30°C. This increase in adiabatic compressibility with concentration of palm oil is due to interaction of mustard oil and palm oil molecules. This interaction decreases the attraction between molecules of pure mustard oil results to increase in intermolecular free length. Therefore, the adiabatic compressibility increases with increase in concentration.

Adiabatic compressibility was observed to increase with increase in the temperature. The similar variation of adiabatic compressibility with temperature of mustard oil adulterated with palm oil was reported by Kumari *et al* (2015). This effect of temperature on sample may

be due to internal pressure which decreases with increase in temperature results to increase in free volume of the liquid. With increase in temperature, magnitude of interaction between the molecules decreases and tends to have loose packing of molecules. Hence, increase in intermolecular free length attributes to easy movement of molecules and results to increase in adiabatic compressibility by increasing temperature.

4.6 Variation of bulk modulus at different temperatures and concentrations

The values evaluated from ultrasonic velocity and density for bulk modulus having different concentrations at different temperatures in the range 30° to 70°C is shown in Table 4.19. The plot of bulk modulus versus temperature and concentration at different concentrations and at different temperatures are shown in Figure 4.11 and 4.12 respectively. It is observed from the graph that bulk modulus decreased with decrease in concentration of mustard oil in the temperature range 30˚ to 70˚C. The value of bulk modulus varied from 24.09×10^8 to 20.24×10^8 N/m^2 for pure mustard oil and the value ranged from 20.04×10^8 to 17.20×10^8 N/m^2 for pure palm oil. The regression coefficients a and b values with determination coefficients R^2 for different temperatures and different concentrations are shown in the Table 4.20 and 4.21 respectively.

Table 4.19 Bulk modulus of mustard oil at different temperatures

Temperature (°C)	**Bulk modulus (K in N/m^2) × 10^8**				
	100%	**90%**	**80%**	**70%**	**60%**
30	24.09	23.12	22.47	22.06	21.45
40	23.35	22.30	21.89	21.18	20.50
50	21.98	21.70	20.89	20.27	19.85
60	20.93	20.71	20.07	19.59	18.82
70	20.24	20.00	19.38	18.33	17.53

Bulk modulus of mustard oil samples was observed to decrease as temperature increases which is shown in graph 4.11. Bulk modulus has more decrease at higher temperatures than at lower temperatures. Bulk modulus was also observed to decrease with increase in concentration of palm oil in pure mustard oil. The sample with pure mustard oil has more decrease in bulk modulus as compared to other concentrations. The similar trend of bulk modulus of edible oils with temperature was investigated by Ghosh *et al* (2017). They observed the linear relationship of bulk modulus with temperature.

The temperature dependence of bulk modulus was found using regression analysis.

The linear relation obtained is shown as

$$K = a + b\,T$$

Where, K is the bulk modulus of mustard oil in N/m^2

T is the temperature in ˚C

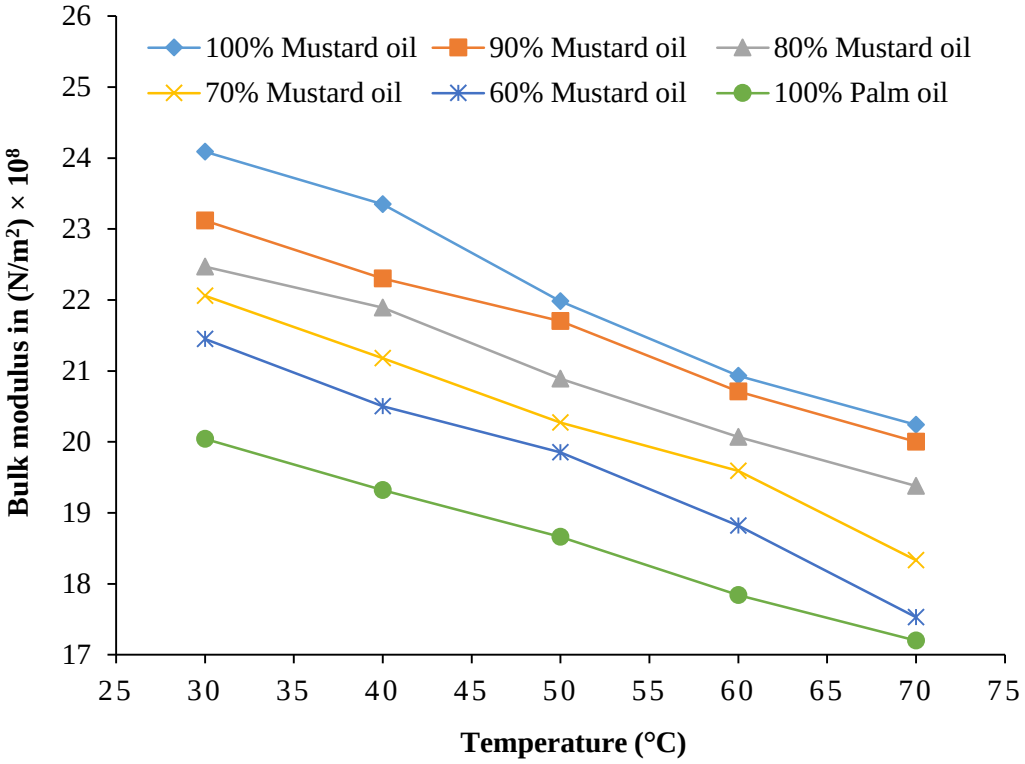

Figure 4.11 Variation of bulk modulus of mustard oil at different temperatures

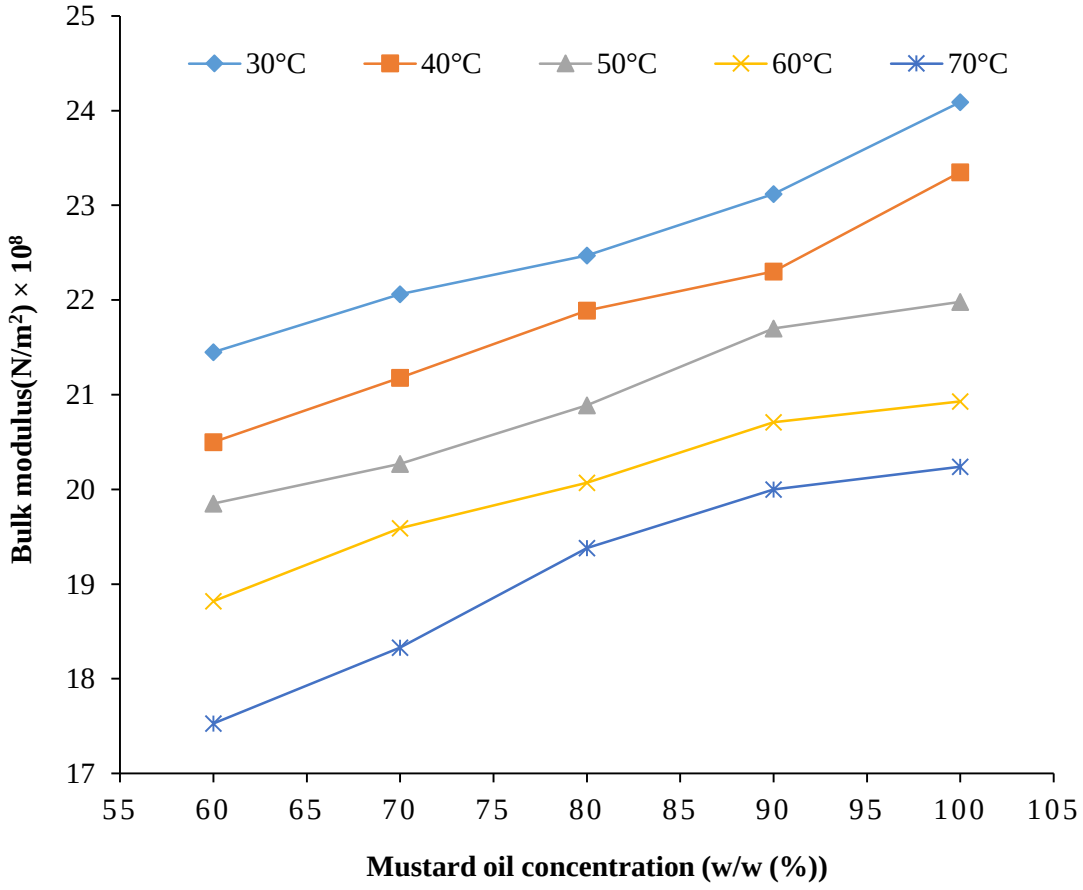

Figure 4.12 Variation of bulk modulus of mustard oil at different concentrations

Table 4.20 Regression coefficients of bulk modulus with temperature

Mustard oil concentration (w/w (%))	a	b	R^2
100	27.18	-0.10	0.98
90	25.48	-0.10	0.99
80	24.94	-0.10	0.99
70	24.81	-0.10	0.99
60	24.39	-0.10	0.99

*Significant at 5% level of significance ($p<0.05$)

The bulk modulus dependency on concentration is given as under,

$$K = a + b\,C$$

Where, K is the bulk modulus of mustard oil in N/m^2

C is the concentration in w/w (%)

Table 4.21 Regression coefficients of bulk modulus with temperature

Temperature (°C)	a	b	R^2
30	17.56	0.06	0.97
40	16.38	0.07	0.98
50	16.38	0.06	0.98
60	15.75	0.05	0.96
70	13.42	0.07	0.96

*Significant at 5% level of significance ($p<0.05$)

The values calculated for bulk modulus provides the information about the compressibility of the sample. Bulk modulus is the measure of resistance offered to the compressibility. As bulk modulus is reciprocal of compressibility so, decrease in bulk modulus determines the increase in compressibility of mustard oil samples. Compressibility is inversely related to ultrasonic velocity and thus ultrasonic velocity decreases with increase in temperature. At high temperatures, compressibility of mustard oil samples increases as a result of increase in intermolecular free length and molecules of the sample can easily move results to decrease in bulk modulus.

With the addition of palm oil in mustard oil, the bulk modulus decreased because interaction between mustard oil molecules decreases. This interaction turns in to increase in the intermolecular free length and consequences to increase in compressibility of mustard oil samples. Hence, bulk modulus of the sample decreases with increase in concentration of palm oil. This decrease in bulk modulus provides information that fluid has less resistance to its compressibility.

4.7 Variation of acoustic impedance at different temperatures and concentrations

The acoustic impedance of mustard oil against temperature in the range 30˚C to 70˚C having different concentrations and versus concentration having different temperatures are shown in Figure 4.13 and 4.14 respectively. The acoustic impedance decreased by increasing temperature and palm oil concentration in sample. The acoustic impedance for the pure mustard oil was ranged from 16.63×10^5 to 15.20×10^5 Ns/m^3 and for pure palm oil it varied from 15.14×10^5 to 13.94×10^5 Ns/m^3. The acoustic impedance of mustard oil was 13.06×10^5 Ns/m^3 as calculated by Kumari *et al* (2015) at 30^{o}C. The evaluated values of acoustic impedance using ultrasonic velocity and density are given in the Table 4.22.

The acoustic impedance was observed to decrease with the increase in temperature. Acoustic impedance also depends upon concentration of mustard oil. It decreases with decrease in concentration of mustard oil. The decrease of acoustic impedance with temperature was observed to be more as the concentration of palm oil increases in mustard oil sample.

Table 4.22 Acoustic impedance of mustard oil at different temperatures

Temperature (°C)	Acoustic impedance (Z in Ns/m^3) × 10^5				
	100%	90%	80%	70%	60%
30	16.63	16.28	16.05	15.89	15.67
40	16.35	15.96	15.77	15.54	15.27
50	15.85	15.73	15.43	15.20	15.02
60	15.46	15.36	15.11	14.92	14.61
70	15.20	15.10	14.84	14.42	14.09

As acoustic impedance is the measure of resistance offered to the path of ultrasonic waves. Thus, decrease in acoustic impedance due to temperature might be due to decrease in resistance. Acoustic impedance is directly related to ultrasonic velocity and density and hence, decrease in ultrasonic velocity and density attributes to decrease in acoustic impedance. The decrease in ultrasonic velocity with temperature gives information about the easy flow of sound waves through the sample results to decrease in acoustic impedance (Singh and Bhatt 2010).

The regression coefficients a and b values with determination coefficients R^2 for different temperatures and different concentrations are shown in the Table 4.23 and 4.24 respectively.

The temperature dependence of acoustic impedance was analysed using regression analysis. The acoustic impedance was observed to vary linearly with the increase in temperature as shown in the following equation

$$Z = a + b\,T$$

Where, Z is the acoustic impedance of mustard oil in Ns/m^3

T is the temperature in ˚C

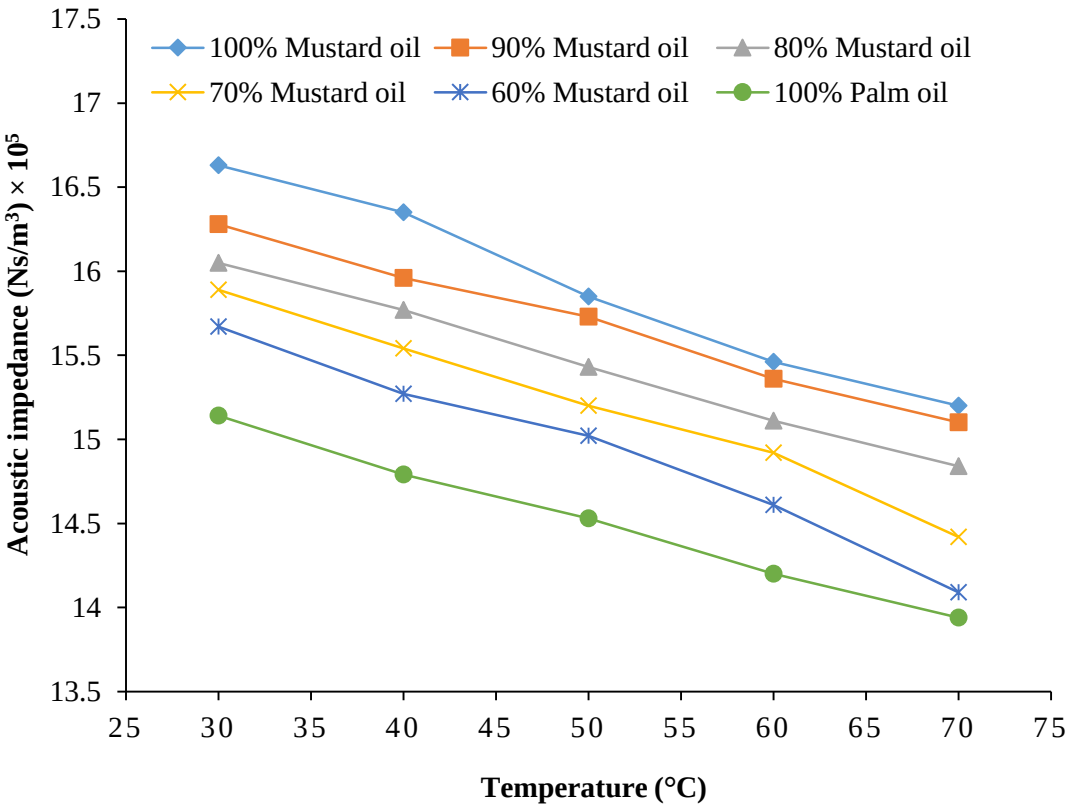

Figure 4.13 Variation of acoustic impedance mustard oil at different temperatures

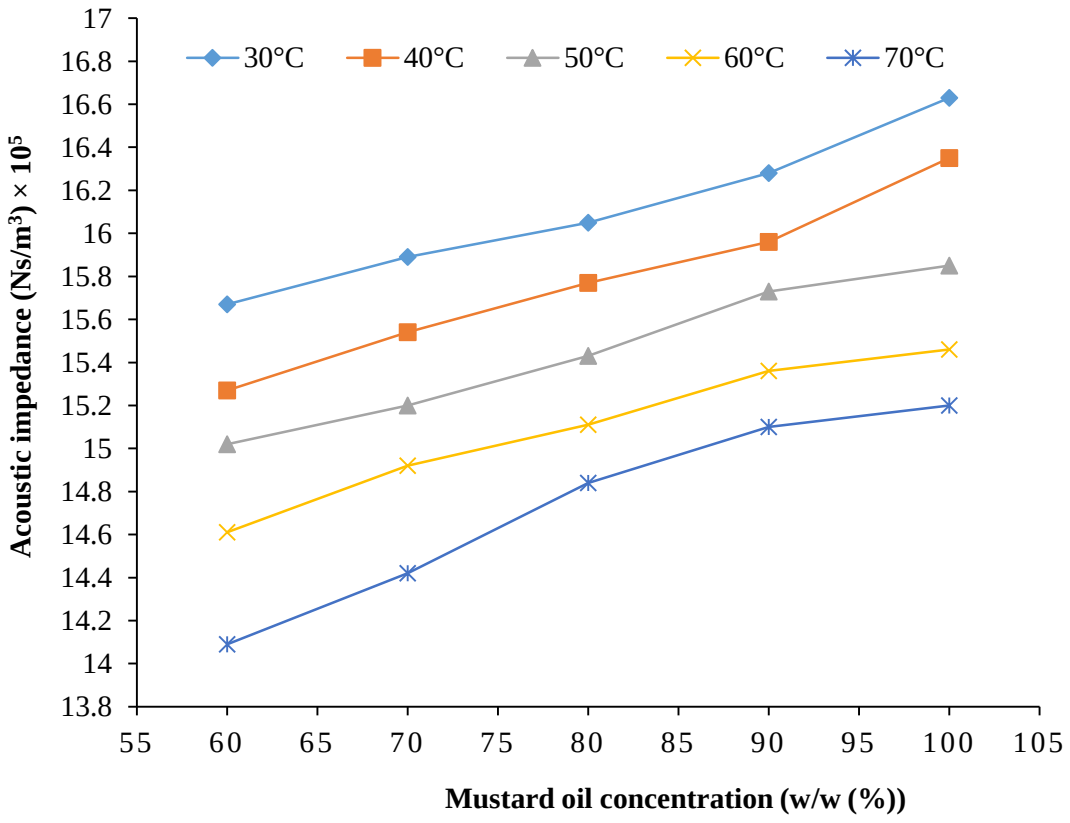

Figure 4.14 Variation of acoustic impedance of mustard oil at different concentrations

Table 4.23 Regression coefficients of acoustic impedance with temperature

Mustard oil concentration (w/w (%))	a	b	R^2
100	17.77	-0.04	0.99
90	17.16	-0.03	0.99
80	16.98	-0.03	0.99
70	16.97	-0.04	0.99
60	16.84	-0.04	0.98

*Significant at 5% level of significance ($p<0.05$)

The acoustic impedance was analysed using regression coefficient and observed to vary linearly with the increase in palm oil concentration as shown in the following equation,

$$Z = a + b\,C$$

Where, Z is the acoustic impedance of mustard oil in Ns/m^3

C is the concentration in (w/w (%))

Table 4.24 Regression coefficients of acoustic impedance with concentration

Temperature (°C)	a	b	R^2
30	14.25	0.02	0.97
40	13.71	0.02	0.98
50	13.69	0.02	0.98
60	13.38	0.02	0.96
70	12.41	0.03	0.95

*Significant at 5% level of significance ($p<0.05$)

The decrease in acoustic impedance by increasing the concentration of palm oil is due to interactions between the mustard oil and palm oil constituents. This interaction results to increase intermolecular free length due to dilution of the sample which tends to decrease in ultrasonic velocity and hence acoustic impedance decreases with the decrease in concentration of pure mustard oil.

4.8 Variation of intermolecular free length at different temperatures and concentrations

The intermolecular free length values calculated from adiabatic compressibility and Jacobson constant for different mustard oil samples at different temperatures is shown in Table 4.25. The plot of intermolecular free length with different concentrations of mustard oil versus temperature in range 30^o to 70^oC is shown in Figure 4.15 and plot of intermolecular free length having different temperatures versus different concentrations is shown in Figure 4.16. The intermolecular free length for pure mustard oil varied from 0.405 to 0.477Å and it ranged from 0.444 to 0.518 Å for pure palm oil.

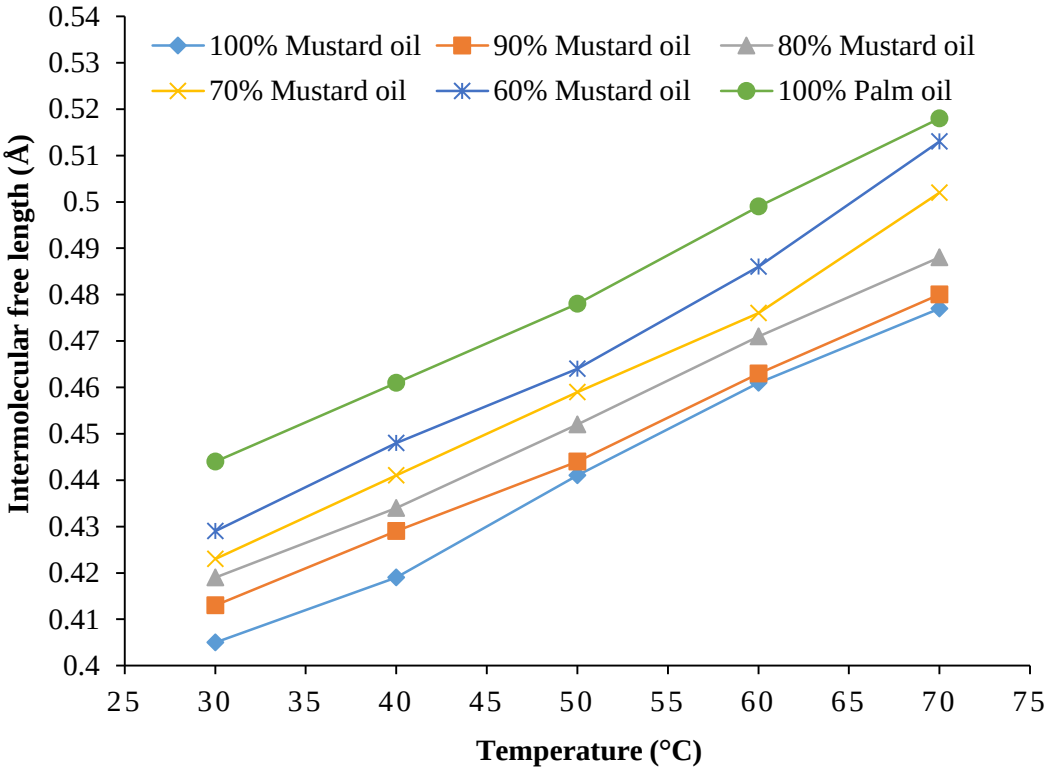

Figure 4.15 Variation of intermolecular free length of mustard oil at different temperatures

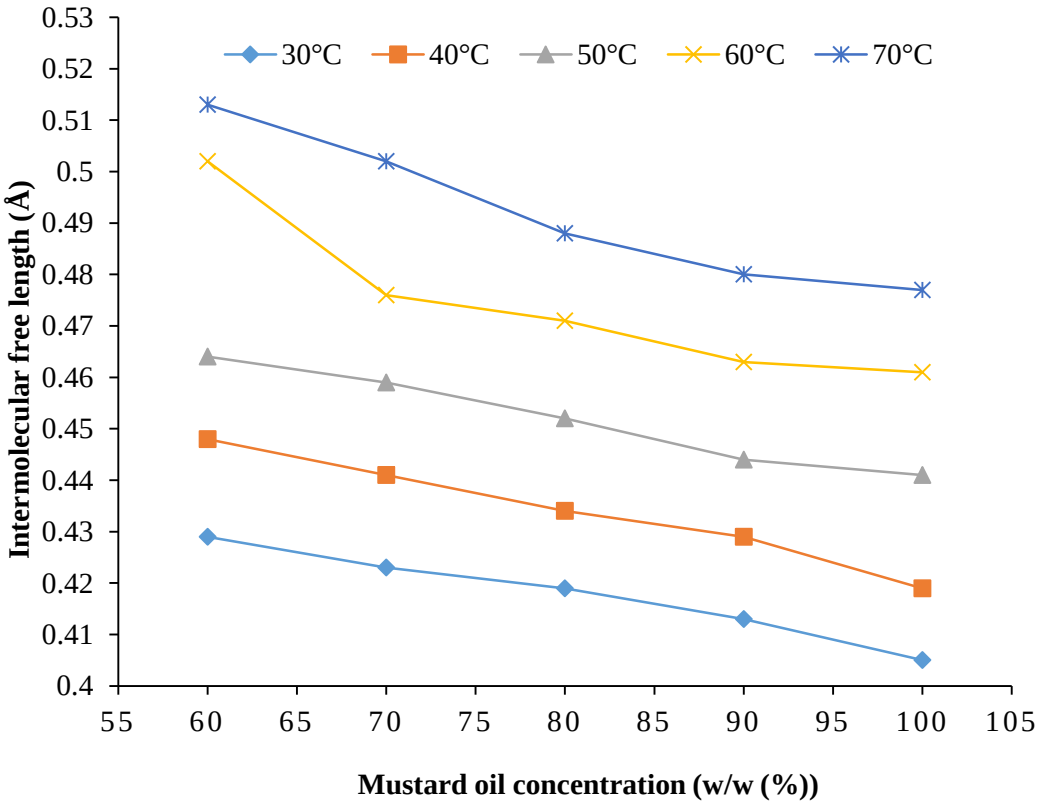

Figure 4.16 Variation of intermolecular free length of mustard oil at different concentrations

The intermolecular free length increased with increase in temperature and decrease in concentration of mustard oil.

Table 4.25 Intermolecular free length of mustard oil at different temperatures

Temperature (°C)	Intermolecular free length (L in Å)				
	100%	90%	80%	70%	60%
30	0.405	0.413	0.419	0.423	0.429
40	0.419	0.429	0.434	0.441	0.448
50	0.441	0.444	0.452	0.459	0.464
60	0.461	0.463	0.471	0.476	0.486
70	0.477	0.480	0.488	0.502	0.513

The similar trend of variation with concentration was observed in mustard oil adulterated with palm oil having concentration of 10% and 20% at 30°C by Kumari *et al* (2015). They observed the increase in intermolecular free length with increase in concentration of palm oil.

There intermolecular free length increased with in temperature due to interaction. This variation was observed for all concentrations of mustard oil. The increase in temperature results to decrease in interaction between the molecules as intermolecular free length is the distance between neighbouring molecules. Thus, molecules get away from each other and intermolecular distance increases. The dependence of intermolecular free length to temperature is clear from the R^2 value as shown in Table 4.26.

The intermolecular free length was observed to vary linearly with temperature as shown in the following equation

$$L = a + b\,T$$

Where, L is the intermolecular free length of mustard oil in Å

T is the temperature in ˚C

Table 4.26 Regression coefficients of intermolecular free length with temperature

Mustard oil Concentration (w/w (%))	a	b	R^2
100	0.35	0.00	0.99
90	0.36	0.00	0.99
80	0.37	0.00	0.99
70	0.36	0.00	0.99
60	0.37	0.00	0.99

*Significant at 5% level of significance ($p<0.05$)

Intermolecular free length was obtained to increase with increase in the concentration of palm oil because it has relation with adiabatic compressibility which increases with decrease in concentration of pure mustard oil. With addition of palm oil, the interaction between mustard oil molecules decreases due to weakening of intermolecular forces between the constituents of mustard oil and molecules are getting apart and results to increase in intermolecular free length. The variation with concentration is clear from regression coefficient. The dependence of intermolecular free length on concentration can be written as,

$$L = a + b\,C$$

Where, L is the intermolecular free length of mustard oil in Å

C is the concentration in w/w (%)

Table 4.27 Regression coefficients of intermolecular free length with concentration

Temperature (°C)	a	b	R^2
30	0.46	0.00	0.98
40	0.49	0.00	0.99
50	0.50	0.00	0.98
60	0.55	0.00	0.83
70	0.56	0.00	0.95

*Significant at 5% level of significance ($p<0.05$)

4.9 Correlation between ultrasonic velocity and density

The correlation between the ultrasonic velocity and density is plotted in graph having different concentration of mustard oil as shown in Figure 4.17. From this correlation, density can be calculated from ultrasonic velocity. The linear decrease in ultrasonic velocity with increase in temperature was observed and density also decreased linearly with increase in temperature. The ultrasonic velocity and density were measured in temperature range 30º to 70ºC having various concentrations of mustard oil. The logarithmic velocity and logarithmic density are evaluated to attain a linear relationship between the two as shown in Figure 4.17. This correlation will help in calculating density from the ultrasonic velocity at a particular temperature and concentration. This illustrates the increase in density with increase in ultrasonic velocity of mustard oil in the given temperature range 30º to 70ºC. This increase is more in case of pure mustard oil than the other concentrations. With decrease in ultrasonic velocity, density was also observed to decrease for all concentrations of mustard oil. The decrease is observed to be more in case of pure mustard oil as compared to pure palm oil.

The R^2 values given in the table show the logarithmic ultrasonic velocity depends upon logarithmic density. The relation between ultrasonic velocity and density is given below

$$\ln \rho = b \ln V + a$$

Where, V is ultrasonic velocity in m/s and ρ is density in Kg/m^3 of different concentrations of mustard oil

Table 4.28 Regression coefficients of logarithmic density with logarithmic ultrasonic velocity

Mustard oil concentration (w/w (%))	a	b	R^2
100	4.45	0.32	0.97
90	4.24	0.35	0.99
80	4.40	0.33	0.99
70	4.51	0.31	0.99
60	4.66	0.29	0.99

*Significant at 5% level of significance ($p<0.05$)

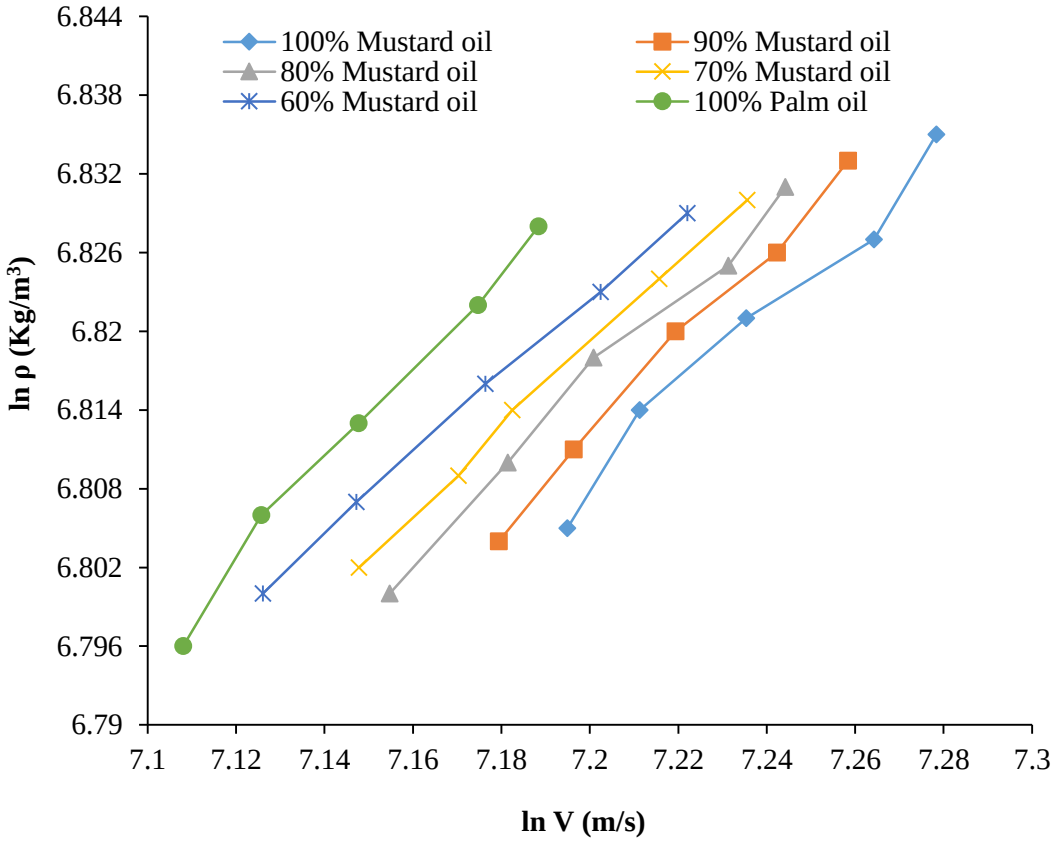

Figure 4.17 Correlation of ultrasonic velocity with density of mustard oil at different temperatures

The ultrasonic velocity is a parameter measured by ultrasonic interferometer and density was measured using specific gravity bottle. The ultrasonic velocity was measured using electrical method while density was measured using mechanical method. Therefore, measured

ultrasonic velocity has less error than measured density. The correlation has been found between the ultrasonic velocity and density.

4.10 Correlation between ultrasonic velocity and viscosity

The correlation between the ultrasonic velocity and viscosity having different concentration of mustard oil is plotted in graph as shown in Figure 4.18. From this correlation, viscosity can be calculated from ultrasonic velocity. The linear decrease in ultrasonic velocity with increase in temperature was observed while viscosity was decreased exponentially with increase in temperature. The ultrasonic velocity and viscosity were measured in temperature range 30º to 70ºC having various concentrations of mustard oil. The logarithmic viscosity is evaluated to attain a linear relationship between the ultrasonic velocity and viscosity as shown in Figure 4.18. This correlation will help in calculating viscosity from the ultrasonic velocity at a particular temperature and concentration. This illustrates the decrease in viscosity with decrease in ultrasonic velocity of mustard oil. This decrease is more in case of pure palm oil than the other concentrations. With decrease in ultrasonic velocity, the viscosity was also observed to decrease for all concentrations of mustard oil at a particular temperature. The decrease is observed to be more in case of pure palm oil.

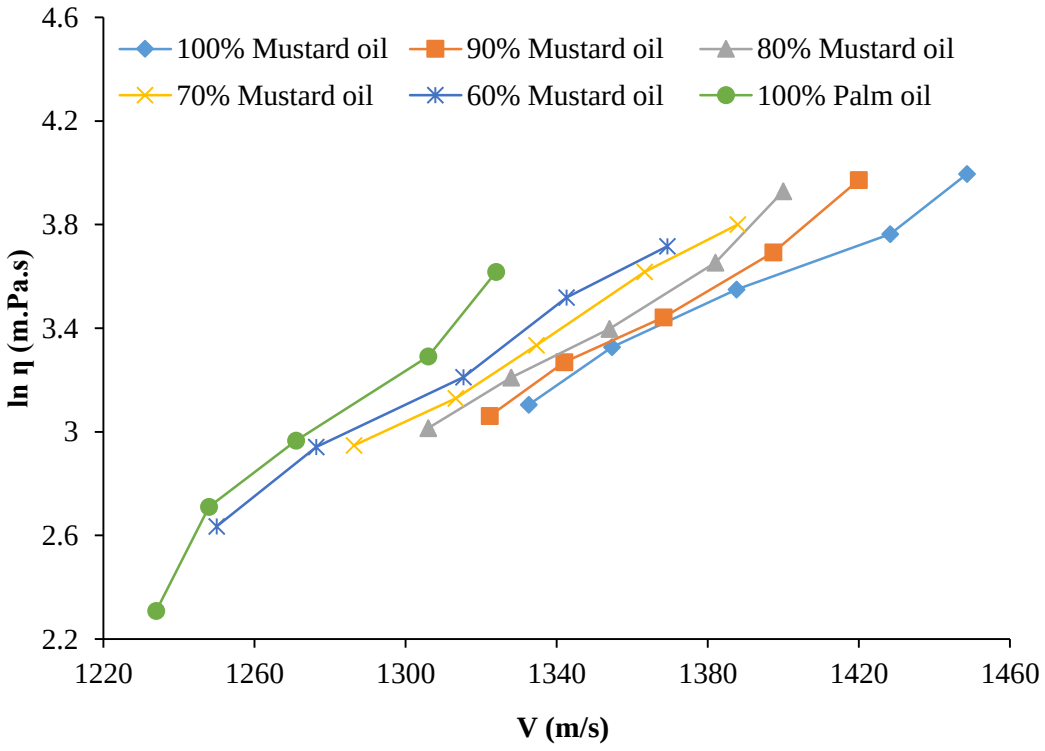

Figure 4.18 Correlation of ultrasonic velocity with viscosity of mustard oil at different temperatures

The measurement of ultrasonic velocity was done by ultrasonic interferometer and viscosity was measured using Ostwald viscometer. The technique of ultrasonic velocity measurement is electrical while method of determining viscosity is mechanical. Therefore,

measured ultrasonic velocity has more precision than measured viscosity. The correlation has been found between the ultrasonic velocity and viscosity.

The R^2 values given in the table show the logarithmic viscosity depends upon ultrasonic velocity. The relation between ultrasonic velocity and logarithmic viscosity is given below

$$\ln \eta = bV + a$$

Where, v is ultrasonic velocity in m/s and η is viscosity in m.Pa.s

Table 4.29 Regression coefficients of logarithmic viscosity with ultrasonic velocity

Mustard oil concentration ((w/w) %)	a	b	R^2
100	-6.41	0.01	0.99
90	-8.75	0.01	0.99
80	-9.91	0.01	0.98
70	-8.20	0.01	0.99
60	-8.53	0.01	0.99

*Significant at 5% level of significance ($p<0.05$)

4.11 Correlation between surface tension and intermolecular free length

The parameters surface tension and intermolecular free length were calculated from measured parameters like ultrasonic velocity and density theoretically. These parameters vary linearly with temperature in the range 30º to 70ºC having different concentrations of mustard oil. The correlation between surface tension and intermolecular free length of mustard oil was observed to be linear as given in Figure 4.19. With increase in surface tension, intermolecular free length decreases. It was observed that surface tension decreases with increase in temperature while intermolecular free length increases. Also, surface tension decreased with decrease in concentration of mustard oil while intermolecular free length increased by increasing the concentration of palm oil in the sample. The addition of adulterant into mustard oil increases the intermolecular free length resulting in lowering the quality of mustard oil.

Table 4.30 Regression coefficients of surface tension with intermolecular free length

Mustard oil concentration ((w/w) %)	a	b	R^2
100	0.97	-14.33	0.99
90	1.06	-16.77	0.99
80	1.05	-16.64	0.99
70	1.02	-16.18	0.99
60	1.01	-16.05	0.99

*Significant at 5% level of significance ($p<0.05$)

The value of regression coefficients a and b the coefficient of regression R^2 is given in Table 4.30. From the value of R^2, the correlation between σ and L is established. These parameters are significantly correlated and the variation is clear from the Figure 4.18. The linear variation between surface tension and intermolecular free length is shown in the following equation,

$$L = a + b\,\sigma$$

Where, σ is surface tension in N/m and L is intermolecular free length in Å.

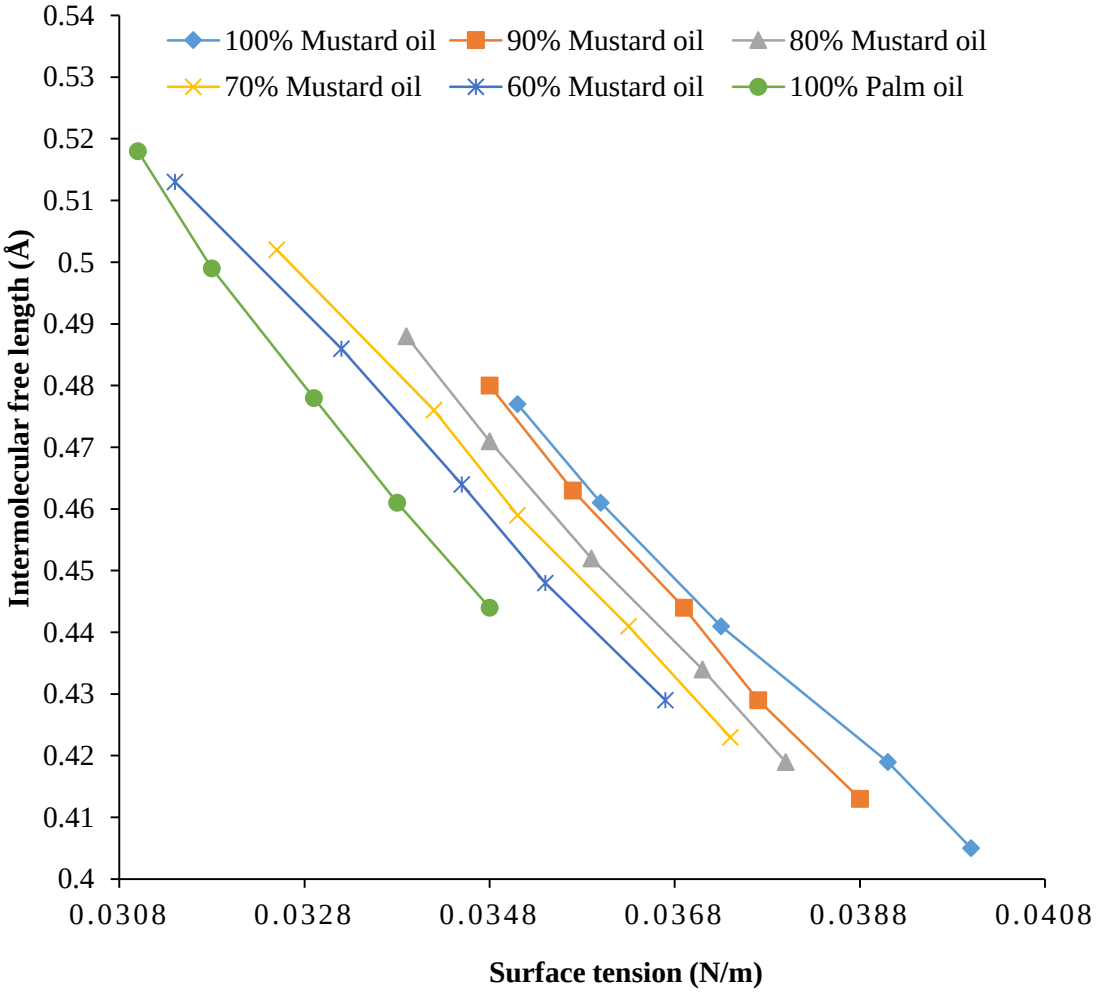

Figure 4.19 Correlation of surface tension with intermolecular free length of mustard oil at different temperatures

CHAPTER-V

SUMMARY

Chapter I is an introduction to the various physical, chemical, medicinal properties and consumption of edible oils. The importance of kachchi ghani mustard oil has been given in brief. The problem of adulteration of edible oils with other irrelevant adulterants, different types of adulterants in different edible oils and methods available for adulteration detection has been discussed. The basic motive behind this study is to enhance the demand for non-destructive techniques. The study has been mainly focussed on ultrasonic properties, viscosity and density for characterisation the quality of mustard oil adulterated with palm oil. Also, for better qualitative and quantitative analysis of mustard oil, different thermodynamic parameters have been also discussed in this chapter. The objectives of this study were also given in this chapter.

The second chapter shows an overview of the literature reviewed related to the study of mustard oil adulterated with palm oil, its properties and parameters. The properties like ultrasonic velocity, viscosity and density were observed for different concentrations of mustard oil. The variation of these parameters with the variation of temperature has been verified in the previous works. These results could be used as a reference for the present study. The literature reviewed showed dependence on temperature for ultrasonic velocity, viscosity and density and proportions of palm oil in mustard oil. The literature showed the variation in ultrasonic velocity with the increase in palm oil concentration in mustard oil. The correlation between different parameters was also observed which could offer the results for the quality of adulterated mustard oil.

The third chapter includes the materials and methods used for measuring the different parameters. The instruments, their working and experimental setup used for measuring ultrasonic velocity, viscosity and density have been explained in the chapter. The thermodynamic parameters calculated using the measured parameters have been mentioned there with the individual formulas used. The thermodynamic parameters were calculated from the values of ultrasonic velocity and density of mustard oil. Intermolecular free length was also calculated from acoustic impedance and Jacobson's constant which explains the reason for change in mustard oil properties with its palm oil adulteration.

The fourth chapter explains the results obtained and the complete description for such trends. The results obtained are presented in the form of graphs and tables. The mustard oil obtained was considered as pure for a good comparison with the other concentrations of mustard oil. The ultrasonic velocity was observed to decrease linearly with the increase in temperature from 30˚C to 70˚C. The ultrasonic velocity was also affected by concentration as it decreased with increase in the concentration of palm oil in mustard oil. The viscosity and density were

observed to decrease with increase in temperature. The viscosity decreased exponentially with temperature whereas density decreased linearly with temperature. The thermodynamic parameters were also explained through regression tables and graph of respective parameter. The surface tension, bulk modulus and acoustic impedance were observed to decrease linearly with increase in the temperature. Other parameters like adiabatic compressibility and intermolecular free length increased linearly with increase in temperature. Correlation of ultrasonic velocity with density, ultrasonic velocity with viscosity and surface tension with intermolecular free length were also observed.

The results obtained for ultrasonic velocity, viscosity and density were analysed using statistical tool. To study significance of the results obtained, the data obtained for these parameters were analysed using analysis of variance (ANOVA) which included Tukey's test. The analysis was done using SPSS software of version 20.0. The parameter density showed insignificant results with temperature. The change in parameter with temperature and concentration of mustard oil provide information about the change in its composition because of the palm oil. The values obtained provide a range for the pure as well as adulterated mustard oil which could be used for the comparison between different concentrations of mustard oil for the detection. Ultrasonic velocity concluded is suitable parameter for detection of adulteration, as this method is accurate and the results were significant for all concentrations of mustard oil.

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Publication in Conferences:

Kaur P and Tarsikka P S (2019) Effect of temperature on ultrasonic velocity in adulterated mustard oil, 7th Indian Association of Physics Teachers held at Panjab University, Chandigarh from Oct 3-5, 2019.