

**INFLUENCE OF SOME ADDITIVES ON THE
EFFECINCY OF
VISCOSITY INDEX IMPROVER
FOR
BASE LUBRICATING OILS**

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of the Requirements for the Degree of
Master of Science
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Chemical Engineering**

By


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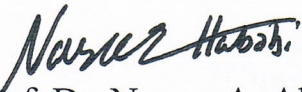
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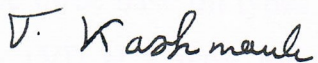
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Abstract

The effects of three different additives formulations which are Lubrizol 21001, HiTEC 8722B and HiTEC 340 on the efficiency of viscosity index improver (VII) namely Olefin Copolymer of three base lubricating oils 40, 60 and 150 stock at four temperatures 40, 60, 80 and 100°C were investigated.

The base oils' blends were prepared with a concentration range of 2-10 wt% from additives and olefin copolymer (OCP). The results give a noticeable decrease in the kinematic viscosity of the three types of base lubricating oil with increasing temperature.

Blending the three base oil types with the H-340 additive shows the maximum viscosity index (VI) at 2 wt% for 40, 60 and 150 stock. This concentration is helpful in selecting the base oil type and the recommended dosage of H-340 for producing effective and economic automotive gear oil.

The efficiency of OCP (VII) is decreased with an increasing rate when blended with 4 and 8 wt% of Lubrizol 21001 for the three base oil types. But the efficiency is increased when adding 4 wt% of H-8722B in 40 stock and decreased when adding 8 wt%. For 60 and 150 stock the OCP efficiency decreased by adding 4 and 8 wt% of H-8722B.

In the other hand, the efficiency of OCP for 60 and 150 stock is decreased with a high percentage by adding 4 and 8 wt% of H-340. While the efficiency for 40 stock is increased by adding 4 wt% of H-340 and decreased with insignificant percentage when adding 8 wt%.

The relative, specific and reduced viscosities were measured to estimate the intrinsic viscosity (IV) for base oils at different weight percent of additives and OCP and at four temperatures (40, 60, 80 and 100°C). The results indicated that the IV increase with increasing temperatures and concentrations.

Finally, a number of VI correlations have been obtained depending on the results predicted in this study. The correlations represent the functional relationships between the VI and the concentration of OCP for three types of base lubricating oil and for each type of additives.

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Notations

Symbol	Description	Unit
Roman Letter Symbols		
A	Constant in Equation 2.28	
A₁	Constant in Equation 2.13	
a	Constant in Equation 2.6	
a₁	Constant in Equation 2.15	
a₂	Constant in Equation 2.15	
a₃	Constant in Equation 2.15	
B	Constant in Equation 2.28	
B₁	Constant in Equation 2.13	
b	Constant in Equation 2.6	
b₁	Constant in Equation 2.1	
b₂	Constant in Equation 2.1	
C	Constant in Equation 2.28	
C₁	Constant in Equation 2.10 = 3.0020	
C_i	Concentration of Component i	g/cm ³
C_{OCP}	Concentration of Olefin Copolymer	g/cm ³
c	Constant in Equation 2.3	
D	Constant in Equation 2.28	
D₁	Constant in Equation 2.14	
E	Constant in Equation 2.28	
H	Series of Reference Lubricating Oil Fractions Assigned a VI of 100	
I_{bl}	The Refutas Blend Index	
I_i	Refutas Index of Component i	
K	Constant in Equation 2.13	
K_w	Watson Characterization Factor	
k	Function of the Temperature Range Alone and is Independent of the Nature of the Oil	
L	Series of Reference Lubricating Oil Fractions Assigned a VI of 0	
M_w	Molecular Weight	g/mole
n	Constant Characteristic for Each Oil Depends on the Chosen Temperature Range	
P_c	Critical Pressure	Pa
s	Constant in Equation 2.11	

T	Absolute Temperature	K
T_b	Boiling Point	K
T_c	Critical Temperature	K
T_f	Temperature in Fahrenheit	°F
T_p	Pour Point	K
T_{red}	Reduced Temperature	
T₀	Initial Temperature	K
t	Flow Time of Solution	s
t₀	Flow Time of a Solvent	s
w_i	The Weight Fraction of Component i	
wt._a	Weight Percent of Additive	
X_A	Composition of Light Component	
X_i	The Percentage of a Given Component in the Blend	
x_i	The Mole Fraction of Component i	
y	Oil Gravity (API)	

Greek Letter Symbols

[η]	Intrinsic Viscosity	
η	Viscosity of a Polymer Solution	cSt
η₀	Viscosity of a Pure Solvent	cSt
η_{sp.}	Specific Viscosity	cSt
η_{rel.}	Relative Viscosity	cSt
η_{red.}	Reduced Viscosity	cSt
μ	Dynamic Viscosity	Pa.s
μ_i	The Dynamic Viscosity of Component i	cP
μ₀	Dynamic Viscosity at T ₀	Pa.s
μ_{mix.}	The Dynamic Viscosity of Mixture	cP
μ_{OD}	Dead Oil Dynamic Viscosity	Pa.s
v₁	Kinematic Viscosity at the lower temperature	cSt
v₂	Kinematic Viscosity at the Higher Temperature	cSt
v	Kinematic Viscosity	cSt
v_b	Kinematic Viscosity of the Blend	cSt
v_i	Kinematic Viscosity of the blend's components	cSt
v_H	Kinematic Viscosity at 311 of the Series H	cSt
v_L	Kinematic Viscosity at 311 of the Series L	cSt
v_U	Kinematic Viscosity of Oil at 311 K	cSt
k'	Huggins Constant	
k''	Kreamer Constant	

k'''	Suhulz-Blaschke Constant
ω_0	Acentric Factor

Subscripts

0	At time = 0
A	Light Component
a	Additive
b	Blend
c	Critical
f	Fahrenheit
i	Component i
mix.	Mixture
OCP	Olefin Copolymer
OD	Dead Oil
o	Pure Solvent (without additive)
red.	Reduced
rel.	Relative
sp.	Specific
W	Watson
w	Weight

Abbreviations

ACEA	European Automobile Manufacturers Association
API	American Petroleum Institute
ASTM	American Standard Test Method
ECN	Effect Carbon Number
EP	Extreme Pressure
EPC	Statistical Copolymer
IV	Intrinsic Viscosity
LOA	Lubricating oil additive
OCP	Olefin Copolymer
OEM	Original Element Manufacturer
PAMA	Poly Alkyl Methacrylate
PBR	Poly Butadiene Rubber
PDMA	Poly n-decyl Methylacrelate
PDMAEMA	Poly dimethylaminoethyl Methacrylate
PHMA	Homologous Poly <i>n</i> -alkyl Methacrylate
PIB	Polyisobutylene
PMA	Polymethacrylate
PMMA	Poly Methylmethacrylate
PODMA	Poly Olefin dimethacrylate
PP	Pour Point
PS	Poly Styrene
SAE	Society of Automotive Engineers
SHBC	Hydrogenated Butadiene
SSI	Shear Stability Index
TBN	Total Base Number
VAc	Vinyl Acetate
VI	Viscosity Index
VII	Viscosity Index Improver
VP	Vinyl Pyrrolidone
VW	Volkswagen

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Chapter One

Introduction

1.1 General

A lubricant (also referred as lube) is defined as a substance introduced between two surfaces in relative motion ⁽¹⁾. Lubricants include substances that have a wide range of physical properties. They are usually in liquid state such as lubricating oils, solid state such as graphite and gas state such as air that may be used in certain applications ⁽²⁾.

Lubricant may serve many purposes such as conducting the heat of friction away from the bearings, serving as a seal to exclude undesirable substances from the area being lubricated, acting as a carrier for rust preventive, anti-friction agents, extreme pressure additives and other properties. However, their primary purpose is in general to lubricate, i.e., to reduce friction ⁽³⁾.

The principal source of lubricating oils is the fractions that are left after components; namely gasoline, kerosene and diesel oil during crude oil distillation. Generally, lubricating oils have a boiling point above 350°C and these are obtained as the main products from vacuum distillation units ⁽⁴⁾.

Lubricating oils are composed of paraffins, naphthalenes, aromatics and unsaturated compounds. The chief molecular structure of lubricating oils seems to be naphthalene and aromatic rings arranged in group of many as six with paraffin side chains. The more such chains the more paraffinic the oil will be. Naphthenic crudes give more rings with less side chains. Normal paraffin (long chains) in this range is usually waxy in nature and has to be separated for maintaining free flow of oil. Thus crude oil is rich with paraffin chains gives high viscosity index and high stability lube oils ⁽⁴⁾.

Auxiliary materials, added to their liquids to enhance their properties in one direction or another to meet the requirements of special applications, are commonly employed, known as additives which are the most important of the numerous materials that have been proposed for this purpose ⁽⁵⁾.

Lubricating oil additives are normally used in low concentrations from a fraction of a one percent to five percent or may be more. Their purposes may be one or more of the following ⁽³⁾:

- 1) Improve lubricity under "boundary" condition.
- 2) Impart extreme pressure characteristics.
- 3) Reduce pour point.
- 4) Improve viscosity-temperature relationship (raise viscosity index).
- 5) Inhibit oxidation.
- 6) Combat catalytic effect of metals and contaminants.
- 7) Reduce bearing corrosion.
- 8) Disperse sludge particles.
- 9) Cause emulsification (e.g. soluble cutting oils).
- 10) Reduce or eliminate rusting.
- 11) Reduce or eliminate foaming.
- 12) Reduce ring and cylinder wear.

The selection of right additive or of the most suitable combination of additives depends on the specific use of the oil ⁽²⁾. The specific use of the oil is whether for otto or diesel engines, turbines, automotive gears and so on.

The most important property of lubricating oil is its viscosity, which is a measure of its internal friction or ability to flow and largely determines its suitability for any particular application ⁽²⁾.

The viscosity of an oil decreases with rise in temperature but to varying degree depending on the type of crude oil from which it is derived and the refining treatment to which it has been subjected. The relationship between viscosity and temperature is the significance for lubricating oils since most oils have to operate over a range of temperature. There are many ways of expressing this relationship but the one firmly established in the petroleum industry is viscosity index (VI) system, even though it is an arbitrary system and more fundamental methods have been suggested ⁽⁶⁾.

In other hand this study will show the relation between the intrinsic viscosity and temperature because intrinsic viscosity reflects the ability of a polymer in solution to enhance the viscosity of the solution. The viscosity behavior of macromolecular substances in solutions is one of the most frequently used approaches for characterization.

The intrinsic viscosity number is defined as the limiting value of the specific viscosity/concentration ratio at zero concentration ⁽⁷⁾.

The used Iraqi base lubricating oils in this study are Paraffinic which are distinguished by a molecular structure composed of long chains of hydrocarbons. Paraffinic oils contain paraffin wax and are the most widely used base stock for lubricating oils. Paraffinic oils have excellent stability, higher pour point, higher viscosity index, low volatility and high flash points ⁽⁸⁾. The three types of base-stocks that were obtained from Al-Daura Refinery, called 40, 60 and 150 stock which were processed as base lubricating oil without additives having °API gravity values of 35.76, 28.26 and 25.72, respectively ⁽⁹⁾.

Many researchers have been investigated those types of oils with different types of additives and viscosity index improvers such as, **Alwash (2001)** ⁽¹⁰⁾, **Al-Mamoory (2002)** ⁽¹¹⁾, **Al-Taa'ay (2004)** ⁽¹²⁾ and **Omran (2009)** ⁽¹³⁾.

1.2 Aim of the Work

The aim of the present work is to study the effect of some additives on the efficiency of the viscosity index improver for base lubricating oils (40, 60 and 150 stock) by using three types of additives (Lubrizol 21001, HiTEC 8722B and HiTEC 340) and one type of viscosity index improver OCP (PVC-100XA) . Also the relation between the intrinsic viscosity with temperature will be expressed which inhibits the decrease of kinematic viscosity with temperature. Finally, appropriate relations will be found to predict the viscosity index of the blends at appropriate concentrations of viscosity index improver for the three types of base lubricating oil of each additive.

Chapter Two

Literature Survey

2.1 General

Viscosity is an important single physical property of lubricants because it largely determines the oil ability to lubricate. It depend on temperature, it decreases as temperature increases; therefore, temperature must always be specified in determining the viscosity of a material ⁽²⁾.

Viscosity can be measured by timing the flow of a given volume of the liquid through a properly calibrated tube of capillary size and the result is the kinematic viscosity expressed in centipoises (cP) or centistokes (cSt) ⁽¹⁴⁾. However, determination of viscosity at various temperatures allows a calculation to be made of the viscosity index ⁽¹⁵⁾.

The viscosity index (VI) is an arbitrary scale for comparing the rates of viscosity changes of lubricating oil with temperature ⁽¹⁶⁾, and VI is the most commonly used method for expressing the relationship between viscosity and temperature ⁽³⁾. VI have many types of compounds used as VI improvers such as olefin copolymers (OCPs), polyalkyl methacrylates (PAMAs), polyisobutylenes (PIBs), poly butadiene rubber (PBR) and many other kinds. The reason of using them is to lower the rate of viscosity changes with temperature ⁽¹⁶⁾.

In the other hand, one of the ways of improving the quality of fluid lubricants is by the addition of small controlled quantities of certain substances capable of changing their properties in the desired manner. These substances are generally called "additives" while their beneficial effect has been recognized for many years; additives have only been widely used for the last decades ⁽¹⁵⁾. As the progressive development of engines and general machinery it becomes necessary so as to improve the quality of lubricating oils by new methods of refining and eventually to use additives either to reinforce existing qualities or to confer additional properties ⁽²⁾.

The additives have accepted features of lubricants as of other petroleum products and most lubricants contain one or more than one additive ⁽¹⁷⁾.

Lubricating oil additives (LOAs) are used to enhance the performance of the lubricants and functional fluids. Each additive is selected for its ability to perform one or more specific functions in combination with other additives. Selected additives are formulated into packages for using them with a specific lubricant base stock ⁽²⁾. The side effects of some additives may be detrimental to the performance of the lubricant in other directions; therefore, they must be carefully selected and also their quality and quantity must be precisely controlled ⁽¹⁵⁾.

Additives are usually called after their particular function, but many additives are multi- functional; will give the same idea of their multiplicity to name the chief functions they fulfill which are as follows: to increase oxidation stability (anti-oxidant); to keep contaminants in suspension (dispersants); to prevent wear (anti-wear); to prevent suffering from extreme pressure (EP agent); to depress the pour point (PP depressant); to prevent rusting (anti-rust); to prevent foaming (anti-foam) and to improve the viscosity index (VIIs) ⁽¹⁷⁾.

2.2 Literature Review for Viscosity

An adequate knowledge of viscosity plays a very important role in a variety of interesting engineering problems involving fluid flow and momentum transfer. This much needed information is scattered throughout the literature, as data obtained from experimental measurements or as values computed according to one or other theoretical procedure, as may be seen from an examination of the many source cited for a limited number of materials ⁽¹⁸⁾.

The viscosity behavior of oil stocks is qualitatively similar to that of pure liquids. Lubricating oils are known to thin out or grow less viscous, as the temperature increases, but no theory has as yet been formulated which can precisely predict the variation in viscosity of these liquids with temperature ⁽¹⁹⁾.

Walther (1931) ⁽²⁰⁾ set an equation which was used commonly for correlating the viscosity-temperature behavior of petroleum products, as follows:

$$\log(v + 0.7) = b_1 + b_2 \log T \quad (2.1)$$

Where: v is the kinematic viscosity in cSt, b_1 and b_2 are constants and T is the absolute temperature in K.

Until recently the widely used methods for predicting oil viscosity were those of **Beal (1946)** ⁽²¹⁾ for dead oil and **Chew and Connally (1959)** ⁽²²⁾ for live oil systems. While Beal correlated dead oil viscosity as a function of API gravity and temperature, Chew and Connally presented a correlation for the effect of dissolved gas on oil viscosity.

The API Technical Data Book (1971) ⁽²³⁾ set a nomograph with an average absolute error of 21%. This proof was useful over the years and at present is accepted as an industry-wide standard for predicting viscosities of light to moderately heavy oils. **Abbot et.al (1978)** ⁽²⁴⁾ reduced the API nomograph into equations with reasonable accuracy but these were found to be subjected singularities. Because of this shortcoming, the correlation cannot be extrapolated into regions where no experimental data are available. The literature contains reports of various forms of viscosity-temperature functions for liquid types such as the exponential and double exponential forms which were received considerable attention.

Letsou and Stiel (1973) ⁽²⁵⁾ proposed a corresponding state approach that uses the acentric factor (ω_o) as follows:

$$\eta_\varepsilon = \frac{(\eta_\varepsilon)^o + \omega_o(\eta_\varepsilon)^\lambda}{\varepsilon} \quad (2.2)$$

Where:

$$(\eta_\varepsilon)^o = 0.015174 - 0.012135 T_{red} + 0.0075 T_{red}^2 \quad (2.3)$$

$$(\eta_\varepsilon)^\lambda = 0.042552 - 0.07674 T_{red} + 0.034 T_{red}^2 \quad (2.4)$$

$$\varepsilon = T_c^{1/6} / (M^{1/2} \times P_c^{2/3}) \quad (2.5)$$

Where: T_c and P_c are the critical temperature and pressure respectively, M is the molecular weight.

Beggs and Robinson (1975) ⁽²⁶⁾ presented an empirical viscosity correlation equation for dead or gas-free oil as a function of API gravity and temperature.

$$\log \log(\mu_{OD} + 1) = a_1 + a_2 y + a_3 \log T_f \quad (2.6)$$

Where: μ_{OD} denotes the dead oil dynamic viscosity, a_1 , a_2 and a_3 are constants, y denotes oil gravity (API) and T_f denotes the temperature in °F. **Emmanuel (1990)** ⁽²⁷⁾ modified Beggs and Robinson equation by finding a significant deviation between measured and calculated viscosity values. This modification is given by the following equation:

$$\log \log(\mu_{OD} + 1) = 1.8653 - 0.025086y - 0.56441 \log T_f \quad (2.7)$$

Amin et.al (1994) ⁽²⁸⁾ extended that work by introducing molecular weight as an additional parameter beside the other two parameters of API and 50% boiling point temperature and the final form is:

$$v = \left[(-1.954 * 10^{-3}) + 0.0906 \exp.(-7.773 + M_w * 10^{-3}) * \exp.((67.45 + \exp.(5.329 + 0.00329T_b)) + 44.263(M_w/API)) / T \right] \quad (2.8)$$

Amin and Maddox (1980) ⁽²⁹⁾ carried out extensive research work on a correlative procedure for predicting the viscosity of the petroleum fraction at different temperature. Several modifications of **Eyring (1936)** ⁽³⁰⁾ equations were used and the one which best correlated viscosity data was found to be of the following form:

$$v = a \exp.\left(\frac{b}{T}\right) \quad (2.9)$$

Where: v is the kinematic viscosity in cSt, a and b are constants and T is the absolute temperature in K. The parameter b was formulated by **Beg et.al (1988)** ⁽¹⁹⁾ by the following expression at 15°C:

$$b = \exp.(5.471 + 0.00342 T_b) \quad (2.10)$$

The parameter a was correlated with API gravity, 50% boiling point T_b , and parameter b by the following expression:

$$a = -0.0339 \text{ API}^{0.188} + 0.241 \left(\frac{T_b}{b} \right) \quad (2.11)$$

Baltatu (1982) ⁽³¹⁾ proposed the use of the modified corresponding- state reported by **Ely and Hanely (1981)** ⁽³²⁾ to predict the viscosity of petroleum fractions. The input data required are the pseudocritical parameters, the molecular weight and acentric factor for each fraction of interest. The acentric factor, which is the key parameter in the proposed correlation, brings considerable uncertainties concerning its estimation for petroleum fractions. This primary result of the compounded inaccuracies introduced by the estimation of intermediate correlating parameters such as a critical temperature, critical pressure and the choice from the several values of the boiling point. The alternative approach has been to develop generalized correlations based on the experimental kinematic viscosity.

Afterwards **Reid et.al (1987)** ⁽³³⁾ and **Viswanath and Natarajan (1989)** ⁽³⁴⁾ have published values of the constants for equations of pure compounds for which experimental data exist along with the recommended temperature range.

Numerous correlative and predictive methods, including an approach by **Allan and Teja (1991)** ⁽³⁵⁾ based on 3-parameter viscosity-temperature correlation which is known as Vogel equation and a method developed by **Orbey and Sandler (1993)** ⁽³⁶⁾ for the effect of temperature on the viscosity of liquid hydrocarbons have been proposed.

A correlation was developed by **Mehrotra (1994)** ⁽³⁷⁾ for pure hydrocarbon and has the following form:

$$\log(\mu + 0.8) = 100 \times (0.01 \times T)^c \quad (2.12)$$

$$c = -5.745 + 0.616 \times \ln(\text{ECN} - 40.468(\text{ECN})^{-1.5}) \quad (2.13)$$

Where: μ denotes the dynamic viscosity of the pure liquid hydrocarbon in mPa.S, T denotes the absolute temperature in K, and ECN is the effect carbon number.

ECN for petroleum fractions was calculated by:

$$\text{ECN}(T_p, \text{API}) = -1799.8195 - 0.0403386 T_p + 8.19416 \times 10^{-5} T_p^2 - 352.5229(T_p/\text{API})^{0.1} + 2158(T_p/\text{API})^{0.02} \quad (2.14)$$

Where: API at 15°C and T_p is the pour point in K.

A modification for Mehrotra eq. has been considered for the development of new generalized correlation for viscosity-temperature prediction ⁽³³⁾. The modification has been done by replacing μ by ν , kinematic viscosity and petroleum fraction in cSt, and changing the constant 0.8 by 0.7 as follows:

$$\log(\mu + 0.7) = 100 \times (0.01 \times T)^c \quad (2.15)$$

2.3 Literature Review for Viscosity and Viscosity Index of Blends

In principle the process of blending is the same in all these instance but the details will vary according to the nature of the complexity of the mixture, for example gasoline components can be blended readily by very simple mixing, lube oils may require moderate heating (60-80°C), waxes and bitumen require more heating and mixing of hot bitumen with cold volatile solvent obviously requires more care than the cold mixing of lube oils ⁽²⁾. Blending can be carried out either intermittently by (batch blending) or continuously by (in-line blending) ⁽⁵⁾. The last step in the manufacture of lube oil is the blending of base stocks to meet viscosity requirements and the incorporation of specific additives ⁽³⁾.

The API recommends the modified **Kendal and Monroe (1917)** equation for the blending of pure hydrocarbons ⁽³⁸⁾ which is in the following form:

$$\mu_{\text{mix}} = \left(\sum_{i=1}^n x_i \mu_i^{1/3} \right)^3 \quad (2.16)$$

Where: μ_{mix} is the dynamic viscosity of mixture, in cP, n number of components, x_i is the mole fraction of component I and μ_i is the dynamic viscosity of component i, in cP.

It is advantageous to be able to predict the physical properties of oil stock mixture from the properties of its components. **Nelson (1958)** ⁽³⁹⁾, **Rybak (1972)**

⁽⁴⁰⁾, **Kosakov (1972)** ⁽⁴¹⁾ and **Gurevich (1972)** ⁽⁴²⁾, produced methods for calculating the viscosity of petroleum products blends, based on some properties of individual blend components.

Eigenson and Ivchenko (1979) ⁽⁴³⁾ concluded that the ASTM-D341 method equation, on weight-ratio basis, can be used in calculating the viscosities of blend with a high degree of accuracy (error within limits of μ 5%). Also the **API (1977)** ⁽⁴⁴⁾ recommended the ASTM-D341 method for petroleum liquids mixtures.

The most widely used approaches in calculating petroleum product blends is the **ASTM-D341 (1981)** method ⁽⁴⁵⁾, which is based on Wright's method with the use of the standard viscosity-temperature charts to predict the viscosities of the blends of petroleum products, and depend on the additive quantity $\log \log (v_b+0.8)$ as follows:

$$\mathbf{\log \log (v_b + 0.8) = \sum \frac{X_i}{100} \log \log (v_i + 0.8)} \quad (2.17)$$

Where: v_b and v_i are the kinematic viscosities at a given temperature of the blend and of the blend's components respectively, in cSt and X_i is the percentage of given component in the blend.

The **Refutas** viscosity blending function is widely used to predict the kinematic viscosity of petroleum products blends. This method considers blending indices, provided in special labels, which are aggregated on a weight basis ⁽⁴⁶⁾.

The Refutas function I can be calculated from this equation:

$$\mathbf{I = f(v) = 23.097 + 33.468 \log \log (v + 0.8)} \quad (2.18)$$

The **Refutas (1989)** indicates of the components of known viscosities at the same temperature of the mixture, are first determined, and the index of blend is then calculated, based on the weight fraction of each component.

$$\mathbf{I_{bl} = \sum I_i w_i} \quad (2.19)$$

Where: I_{bl} is the blend Refutas index and w_i is the weight fraction of component i.

This method has been reported to be applicable to all blends of petroleum products but is less accurate for extreme blends such as gasoline and residues. The percentage derivations of the predicted viscosities from experimental values are of the order of 2% from middle distillates ⁽⁴⁶⁾.

Viscosity index (VI) is a commonly used method of measuring a fluid's change of viscosity in relation to temperature. VI is an index to emphasize the degree of refinement or the chemical composition of the base oil ⁽⁴⁷⁾.

Dean and Davis (1929) ⁽⁴⁸⁾ proposed VI for industrial characterization of automotive lubricants. It was an indication of viscosity-temperature characteristic of oils in terms of its Saybolt viscosities at 311 and 372 K. Two series of reference lubricating oil fractions (H and L) were used for comparison. Series H and L oils were assigned a VI of 100 and 0, respectively. The VI of an oil under test was calculated from the equation:

$$\mathbf{VI = 100 \times \frac{(v_L - v_U)}{(v_L - v_H)}} \quad (2.20)$$

Where: v_L and v_H are kinematic viscosities at 311 K of the series L and H having the same kinematic viscosity at 372 K and v_U is the kinematic viscosity of oil at 311 K.

Thus, the viscosity of an oil of higher VI is less affected by temperature and therefore, it is a better oil.

Subsequently, **Hardiman and Nissan (1945)** ⁽⁴⁹⁾ proposed revision to the VI system. They found that VI system failed for VI greater than 130, and comparison became meaningless. They sought to make the VI applicable at any two temperatures and wider range of oils. They reported the following empirical equations for the VI:

$$\mathbf{VI = 3.63(60 - 10^n)} \quad (2.21)$$

Where: n is a constant characteristic for each oil depends on the temperature range chosen and it is given by:

$$n = \frac{(\ln v_1 - \ln k)}{\ln v_2} \quad (2.22)$$

Where: v_1 is the kinematic viscosity in cSt at the lower temperature, v_2 is the kinematic viscosity in cSt at the higher temperature and k is a function of the temperature range alone and is independent of the nature of the oil. For the temperature range 311-372 K, they determined k to be 2.714. And they found good correlation between their suggested VI and that of Dean and Davis, their suggested one having the advantage of applicability to a wider range of oils.

Singh, Miadonge and Pultagunta (1993) ⁽⁵⁰⁾ developed a simple and generalized correlation for predicting temperature effect on the absolute viscosity of bitumen and heavy oils was as follows:

$$\frac{\log(\mu) + C_1}{\log(\mu_o) + C_1} = \left(\frac{T_0}{T}\right)^s \quad (2.23)$$

Where: μ is the absolute dynamic viscosity in Pa.s, T denotes the absolute temperature in K, $C_1 = 3.0020$, $T_0 = 303.15K$ and s as follows:

$$s = 0.066940 \times \log(\mu_o) + 3.5565 \quad (2.24)$$

This correlation allows the prediction of the viscosity of bitumen and heavy oils over a wide range of temperature by making only a single viscosity measurement, μ_o on the sample at any convenient temperature, T_o .

Moore et.al (1997) ⁽⁵¹⁾ reported the calculation of the VI squalane from non-equilibrium molecular dynamic simulations. This computational approach offers the possibility of predicting the performance of potential multigrade engine oils prior to synthesis.

VI calculation for a blend of two lubricating oils by the ASTM D341 method is not always precise. The VI established by direct measurements of the blend usually is found to be higher than the blend VI calculated by the ASTM D341 method ⁽⁵²⁾.

Capillary viscometer has been employed by **LaRiviere et.al (2000)** ⁽⁵³⁾. To measure the viscosities of dilute polymer solutions over the temperature range 0f - 10 to 150°C. The thickening effects of the olefin copolymer and the hydrogenated diene copolymer are found to be higher at low temperatures (e.g. 40°C) than at higher ones (e.g. 100°C), phenomenon for which was attributed to stronger intermolecular hydrodynamic interactions at low temperatures.

Hedrich et.al (2000) ⁽⁵⁴⁾ reported the effects of VIIs on low temperature pumpability of engine oil and fuel consumption. It has been reported in the literature that for increased fuel efficiency of automobiles, lube oils contain hydrocarbons with viscosity more than 4 cSt at 100°C.

Erickson et.al (2000) ⁽⁵⁵⁾ studied that in many lubrication processes, lube oils containing polymer additives that are subject to high shear rate through very small clearance channels. While the influence of shear rate on the performance of these lubricants has been well examined, very little is known about the effects of channel size. In their study a specially designed microchannel viscometer has been used to characterize experimentally the influence of channel height on the effective viscosity of oil lubricants with two different polymer additives (a radial hydrogenated styrene–isoprene copolymer and an A–B–A block ethylene–propylene copolymer) commonly used as VI modifiers. The mass concentration of the polymer solutions ranged from 0.5% to 1.5%. The viscosity was measured over a range of shear rates in steel slit microchannels with heights of 4.5, 7 and 11.5 μ m, respectively. For all solutions a significant viscosity dependence on channel size was observed. In the higher shear rate range the smaller channels exhibited a lower viscosity while in the lower shear rate range all solutions exhibited a significant increase in viscosity. Generally, this observed increase in viscosity is more dramatic in the smaller channels.

Alwash (2001) ⁽¹⁰⁾ measured the kinematic viscosity for three selected base lubricating oil-stock with a wide range of °API gravities. An appreciable decrease in viscosity of heavy oil stocks was achieved by increasing the percentage of lighter

blend components. Also the VI and PP were measured for the oil-stock and an increase in the VI was noticeable and generally the PP of mixtures is decreased when the weight percent of light component increased.

A model was used to estimate the kinematic viscosity of oil stocks at different temperatures for binary mixtures and it was based on °API gravity at 15°C, as follows:

$$\ln v = \left(\frac{1}{T}\right)^{0.009} + \frac{\left[A + \frac{B}{T-T_p} + \frac{C}{(T-T_p)^2} + (D \times \text{API}) + \frac{E(T)}{\text{API}}\right]}{X_A^{0.009}} \quad (2.25)$$

Where: T_p is the pour point, API is the American Petroleum institute gravity, X_A is the composition of light component, A, B, C, D and E are constants and T is the temperature in K.

Al-Mamoory (2002) ⁽¹¹⁾ modified equation (2.23) and investigated the effect of three types of additives (paranox 5263, paranox 2281 and OCP) two types are dispersant and one is VII on the three types of base lubricating oils (40, 60 and 150 stock). Also the effect of the temperature changes and the concentration on the dynamic viscosity of different types of mixtures, such as binary mixture and multi-component mixtures was studied. The dynamic viscosity of the mixture is increased when the weight percent of additives increases.

The modified model was used to estimate the dynamic viscosity of oil-stocks with additives at different temperatures for mixtures with an overall absolute error of 7.6% as follows:

$$\frac{\log(\mu+K)}{\log(\mu_o)+C_1} = \left(\frac{T_0}{T}\right)^S \quad (2.26)$$

Where:
$$\mathbf{K} = -[(\mathbf{A}_1 \times \mathbf{wt}_a) + \mathbf{B}_1] \quad (2.27)$$

$$\mathbf{S} = (\mathbf{D}_1 \times \log \mu_o) + (\mathbf{A}_1 \times \mathbf{wt}_a) \quad (2.28)$$

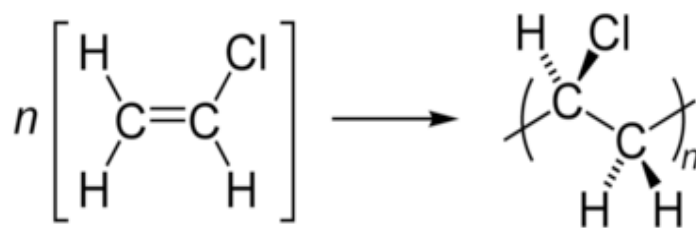
Where: μ = the dynamic viscosity of blends in cP, μ_o = the dynamic viscosity of blends in cP at $T_0 = 303.15\text{K}$, \mathbf{wt}_a =weight fraction of additive, $A_1 = 0.7792$, $B_1 = 6.4459$, $C_1 = -0.0519$ and $D_1 = 0.9109$.

Al-Taa'ay (2004) ⁽¹²⁾ studied the ability of some additives to raise the viscosity for base oil-stock. Three base oil types (40, 60 and 150 stock) and three types of polymers (polyisoprene 1502, polyisoprene 1320 and polyisoprene butile) were used for the purpose. The same equation (2.12) of dynamic viscosity of oil-stocks with additives at different temperatures for binary mixtures were used and compared between the measured and calculated viscosities of the studied Iraqi oil-stock blends for different temperatures and was found to be satisfactory with an overall average absolute error of 8.2%.

2.4 Polyvinyl Chloride

Is one of the many types of the Olefin Copolymer (OCP). Polyvinyl chloride is commonly abbreviated PVC, is the third-most widely produced plastic, after polyethylene and polypropylene. PVC is used in construction because it is more effective than traditional materials such as copper, iron or wood in pipe and profile applications. It can be made softer and more flexible by the addition of plasticizers, the most widely used being phthalates. In this form, it is also used in clothing and upholstery, electrical cable insulation, inflatable products and many applications in which it replaces rubber ⁽⁵⁶⁾.

Polyvinyl chloride is produced by polymerization of the monomer vinyl chloride (VCM), as shown below and The molecular formula is $(C_2H_3Cl)_n$ ⁽⁵⁶⁾.



Mohamed et.al (1994) ⁽⁵⁷⁾ synthesized styrene alkylmethacrylate succinimide phosphoric acid additives at different styrene/methacrylate mole ratios and evaluated for use in multigrade engine oil formulations as multifunctional VIIs having both antioxidant and dispersant properties. The optimum performance

properties of the synthesized products were found and were obtained by using styrene/methacrylate mole ratio of 0.35 and a temperature of 140-145°C for 4-5 h.

The potential for using the copolymers as VII in multigrade engine oils has been investigated by **Ghosh et.al (1998)**⁽⁵⁸⁾ which used iso-decyl methacrylate and 1-decene and found that the copolymers can serve as better VII than usual PMAs.

Ghosh et.al (1998)⁽⁵⁹⁾ studied the effects of mineral base oil viscosity, composition of the base oil and polymer concentration on shear stability index (SSI). Also the magnitude of SSI was found to be dependent on polymer chemistry and the nature of base oil.

Bratz(2000)⁽⁶⁰⁾ formulated some SAE 15W-40 multigrade oils, using PMA of different molecular weights with a mixture of base oils 150N and 500N. They found that viscometric properties as well as shear stability depended strongly on the polymer concentration and molecular weight of the VII. However, the evaporation losses were strongly dominated by the volatility properties of the base oil.

Chen et.al (2001)⁽⁶¹⁾ reported the results of an experimental study on the influence of VII on performance of gasoline engine fuel and oil. They found that the dispersant type polymethacrylate (PMA) and olefin copolymer (OCP) with high molecular weight are helpful to improve the fuel economy performance of the aero engines.

Abdel-Azim et.al (2001)⁽⁶²⁾ studied four sets of copolymeric additives and synthesized them via copolymerization of dialkyl fumarates and dialkyl maleates with vinyl acetate (VAc) and vinylpyrrolidone (VP) monomers. The dialkyl esters were prepared by the esterification of maleic and fumaric acids with a series of n-alkanol having an increasing number of carbon atoms to produce two groups of diesters. The completion of esterification reaction was confirmed by spectroscopic analysis. The molecular weights of the prepared esters and copolymers were determined and the influences of different parameters on the molecular weight of the produced copolymers were discussed. The efficiency of the prepared

copolymers as VI and flow improvers (PP depressants) was investigated. It has been found that the dialkyl ester/VP copolymers are more efficient as VIIs than dialkyl ester/VAc copolymers. On the other hand, it has been found that the copolymers based on didoecyl fumarate/VAc are the most effective pour point depressants.

Tanveer et.al (2006) ⁽⁶³⁾ studied the enhancement of VI of some kinds of base oils by the addition of VIIs [Polyisobutylene (PIB) and polybutadiene rubber (PBR)]. VI of blended oils, made from some kinds of base oils by the addition of PIB and PBR, is found to pass through the maximum. The occurrence of maximum was observed depending on the base oil used and the type and concentration of VII.

Onyeji (2011) ⁽⁶⁴⁾ investigated the effects of four different additive formulations on the VI of two base lubricating oils at two temperatures 40 and 100°C. The base oils were blended with the additives in three different proportions. All the four additive formulations used improved the viscosities of all the blends in all the proportions and at both temperatures. The blends can be classified as very high VI being above 110. This means that they will undergo very little change in viscosity with temperature extremes and so can be considered to have stable viscosity.

2.5 Intrinsic Viscosity

Intrinsic Viscosity (IV) is the specific hydrodynamic volume of dissolved polymer in an infinite dilution $C \rightarrow 0$ ⁽⁶⁵⁾. Another definition which is the ratio of a solution's specific viscosity to the concentration of the solute, extrapolated to zero concentration. IV reflects the capability of a polymer in solution to enhance the viscosity of the solution. The viscosity behavior of macromolecular substances in the solution is one of the most frequently used approaches for characterization ⁽⁷⁾.

IV is based on the flow time of polymer solution through a narrow capillary relative to the flow time of the pure solvent through the capillary. The unit of IV is

inverse concentration. IV is simple, inexpensive to obtain and reproducible between different laboratories ^(66, 67).

The variation of the viscosity number with concentration depends on the type of molecule as well as the solvent. In general, the IV of linear macromolecular substances is related to the molecular weight or degree of polymerization. In linear macromolecules, viscosity number measurements can provide a method for the rapid determination of molecular weight when the relationship between viscosity and the molecular weight has been established ⁽⁷⁾.

Generally, the IV of polymers should be determined by one of the following equations by Huggins ⁽⁶⁸⁾, Kreamer ⁽⁶⁹⁾ and Scuhulz-Blaschke ⁽⁷⁰⁾ respectively:

$$\frac{\eta_{sp}}{C_i} = [\eta] + k'[\eta]^2 C_i \quad (2.29)$$

$$\frac{\ln \eta_{rel}}{C_i} = [\eta] - k''[\eta]^2 C_i \quad (2.30)$$

$$\frac{\eta_{sp}}{C_i} = [\eta] + k'''[\eta]^2 \eta_{sp} \quad (2.31)$$

Where: k' , k'' and k''' are constants for a given polymer-solvent-temperature system. The value of $k' + k''$ has been shown to be equal to 0.5 ⁽⁷¹⁾.

The viscosity of a polymer solution (η) is higher than that (η_o) of the pure solvent at a specified temperature and the increase in medium viscosity on dissolving the polymer in the solvent is a function of both molecular weight and concentration of the polymer solute ⁽⁷²⁾. In the case of dilute polymer solutions, the viscosities of the solvent and the solution at a given temperature would be proportional to their flow times in a given capillary viscometer as the relative viscosity which can be expressed by the following equation:

$$\eta_{rel} = \frac{\eta}{\eta_o} = \frac{t}{t_o} \quad (2.32)$$

Where: t_o is the flow time of a given volume of solvent and t is the flow time of the same volume of solution. While the specific viscosity (η_{sp}) is defined by the following equation:

$$\eta_{sp} = \frac{\eta - \eta_o}{\eta_o} = \frac{t - t_o}{t_o} = \eta_{rel} - 1 \quad (2.33)$$

The specific viscosity is divided by the concentration of solute is known as the reduced viscosity (η_{red}) which is used in the calculation of the intrinsic viscosity⁽⁷²⁾.

The polymers are usually added to hydrocarbons and other solvents which are used for different purposes. For example, some types of polymers are used for base lubricating oil to increase the VI and other types of polymers are used for reducing the energy requirements of crude oil or other of solvents transportation through pipes⁽⁷³⁾.

Maderek and Wolf (1988)⁽⁷⁴⁾ used poly n-decyl methylacrylate (PDMA), statistical copolymer (EPC) and hydrogenated butadiene (SHBC) as additives for base oil in different temperatures (37.8, 60, 80 and 98.9°C) and found that when increasing the polymer concentration in the base oil and temperature, the IV will be increase.

The effect of VI improvers on viscosity of engine oils was investigated by **Wu et.al (2002)**⁽⁷⁵⁾; a model that describes the changes of final oil viscosity with the viscosity of base oil was proposed which is a linear equation with an intercept. Their model does not agree with the equations developed by Kreamer or Huggins.

Kornelije et.al (2005)⁽⁷⁶⁾ miscibility and molecular interactions of poly dimethylaminoethyl methacrylate (PDMAEMA) and series of homologous poly *n*-alkyl methacrylates (PHMA) , as well as between PDMAEMA and poly ethylene-*co*-propylene (EPC) or polystyrene (PS), were investigated by the dilute solution viscometry, in toluene as a model solvent for mineral base oil at 30°C. The specific, reduced and intrinsic viscosities as well as viscometric interaction parameters were determined for binary, polymer/toluene, and ternary, PDMAEMA/ (PAMA or EPC or PS)/toluene systems. The PDMAEMA / (PMMA or PHMA or PODMA or EPC) investigated polymer/polymer pairs showed the negative viscometric interaction parameter values that calculated applying the Catsiff-Hewett and Krigbaum-Wall theoretical equations. Therefore, these polymer mixtures were found to be immiscible. The observed repulsive molecular interactions originate from the differences in polymer composition and structure. This conclusion was supported

by calculations employing the group contribution approach of Coleman, Graf and Painter, where the interaction parameter values.

Omran (2009) ⁽¹³⁾ studied the effect of some additives on the intrinsic viscosity of Iraqi base lubricating oil. The additives were types of Olefin Copolymer namely OCP₁, OCP₂, OCP₃ and other type of additive of Poly Alkyl Mathacrylates (PAMA) with the three types of Iraqi base oil namely 40, 60 and 150 stock. The IV of a solution was concluded to be increased with increasing the concentration of additive and the temperature.

Ghosh et.al (2011) ⁽⁷⁷⁾ Copolymers of sunflower oil with methyl methacrylate and decyl acrylate were synthesized and characterized. IV and viscometric molecular weight were determined by using Huggins and Mark-Houwink equation respectively. VI of the additive doped base oils were evaluated and compared with that of the mineral base oils. VI values of the additive doped base oils depend on the nature of mineral base oils used and the type and concentration of VIIs. For a comparison, respective homopolymers e.g. polymer of sunflower oil, poly(methyl methacrylate) and poly(decyl acrylate) were also prepared, characterized and evaluated in the similar fashion.

Al-Jboori (2011) ⁽⁷⁸⁾ studied the IV and flow activation energy for several polymers which are used in some industrial applications, such as polyisobutylene of types Oppanol B 150, 200 and 250 with different molecular weights that dissolved in crude oil and gas oil. In addition three types of olefin copolymer (OCP) which are Viscoplex-4-677, Viscoplex-215496 and Lubrizol R7077 which dissolved in crude oil. Also it was found that the IV of polyisobutylene decreases as the temperature of crude and gas oil increase and the Viscoplex-4-677 behaves the same of polyisobutylene where it can be used as drag reduction agent.

Chapter Three

Experimental Work

3.1 Materials

3.1.1 Oil Stock

Oils are generally classified as refined and synthetic. Paraffinic and naphthenic oils are refined from crude oil while synthetic oils are manufactured. Iraqi oil is Paraffinic while European oil is Naphthenic.

Paraffinic oils are distinguished by a molecular structure composed of long chains of hydrocarbons, excellent stability (higher resistance to oxidation), higher PP, higher VI, low volatility and, consequently, high flash points and low specific gravities ⁽⁸⁾.

In this study, the experimental work will be carried out on the three types of base-stocks that were obtained from Al-Daura Refinery, called 40, 60 and 150 stock. These types of base stocks were processed as basic lubricating oil without additives. The °API gravity values are 35.76, 28.26 and 25.72 for 40, 60 and 150 stock. The main properties of those three types of oil stocks were obtained in Al-Daura Refinery Laboratory as listed in table 3-1 ⁽⁹⁾:

Table 3-1 Properties of Oil Stocks ⁽⁹⁾

Specification	40 stock	60 stock	150 stock
Kinematic Viscosity at 40°C, cSt	18.1	66.5	319.94
Kinematic Viscosity at 100°C, cSt	3.14	8.84	24.28
Viscosity Index	110	105	97
Specific Gravity at 15.6°C	0.846	0.8857	0.90
Pour Point, °C	-24	-6	zero
Sulfur Content, wt%	0.62	1.26	1.8
Color, ASTM	0.5	1.0	7.5

3.1.2 Viscosity Index Improver

The VI is an indicator of the change in viscosity as the temperature is changed. VIIs are used to limit the rate of change of viscosity with temperature. These improvers have little effect on oil viscosity at low temperatures. However, when heated, the improvers enable the oil viscosity to increase within the limited range permitted by the type and concentration of the additive ⁽⁸⁾.

In this study olefin copolymer (OCP) of type PVC-100 XA, is used as a VII for base lubricating oil. OCP is a polymer composed of two or more different monomer. The OCPs have unknown structure, different companies are producing them. This type of VII is designed to provide a careful balance of thickening power, low-temperature fluidity, shear stability and high-temperature viscosity ⁽⁷⁹⁾.

3.1.3 Additives

Oil quality is established by the refining processes and additives. Although the overall performance of an oil can be improved by introducing additives, a poor quality oil cannot be converted into a premium quality oil by introducing additives. Furthermore, there are limits to the amount of additives that can be introduced to improve performance. Beyond these limits, the benefits are minimal or may provide no gains in performance; they also may increase the cost of lubricants. In this study three types (Lubrizol 21001, HiTEC 8722B and HiTEC 340) will be used as solutes.

Lubrizol 21001 is a multipurpose additive for otto engine. Its properties are listed below in table 3-2 ⁽⁹⁾:

Table 3-2 Properties of Lubrizol 21001 Additive ⁽⁹⁾

Properties	Magnitude
Viscosity at 100°C, cSt	245
Viscosity at 40°C, cSt	5440
Appearance	Dark, Viscous Liquid
Specific Gravity at 15.6°C	0.978
Pour Point, °C	-15
Flash Point, °C	171
P, wt%	1.26
Zn, wt%	1.40
Ca, wt%	2.63
N₂, wt%	0.60
S, wt%	3.2
Sulfated Ash, wt%	11.0

HiTEC 8722B is a multipurpose additive for diesel engine. Its properties are listed below in table 3-3 ⁽⁸⁰⁾:

Table 3-3 Properties of H-8722B Additive ⁽⁸⁰⁾

Properties	Magnitude
Viscosity at 100°C, cSt	137
Density at 15.6°C, g/ml	0.998
Appearance	Dark Brown, Viscous liquid
*TBN, Mg KOH/g	97
P, wt%	1.28
Zn, wt%	1.41
Ca, wt%	3.05

* TBN: Total Base Number.

HiTEC 340 is an economic automotive gear oil additive. Its properties are listed below in table 3-4 ⁽⁸¹⁾:

Table 3-4 Properties of H-340 Additive ⁽⁸¹⁾

Properties	Magnitude
Viscosity at 100°C, cSt	8.4
Density at 15°C, g/ml	1.098
Appearance	Clear Yellow liquid
Specific Gravity at 15.6°C	1.10
Maximum Handling Temperature, °C	40

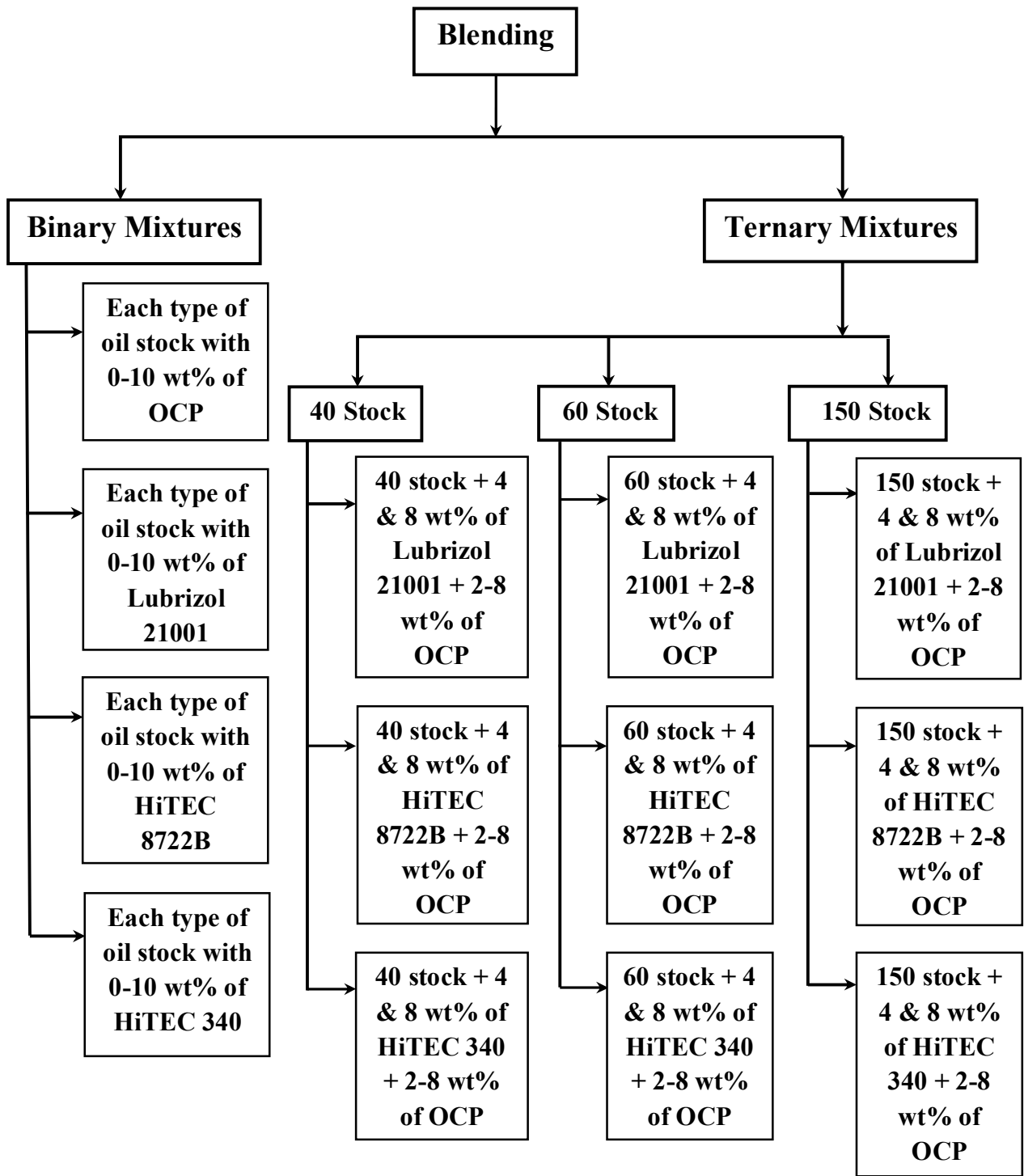
3.2 Blending

The composition of each mixture was prepared as weigh percentage for more accuracy. Mixing process was made by stirring and heating to 50-60°C at the same time to ensure thorough mixing, using mixer and heater as shown below in Figure 3-1.



Figure 3-1 Mixer and Heater with Samples

Viscosity measurements were taken immediately, after preparing the mixture to avoid deposit formation or vaporizing the light ends. All these measurements were taken at the atmospheric pressure.



3.3 Viscosity Measurement Procedure

1. Preparing the mixtures from pure solvents (40, 60 nd 150 stock), VII (OCP) as solute and additives (Lubrizol 21001, HiTEC 8722B and HiTEC 340) in concentration range as mentioned above.
2. The two oil bathes were used set at 40 and 100°C because they were the only temperatures used in the Laboratory of Al-Daura Refinery while the water bath was set first for 60°C and secondly for 80°C, Figures 3-2 and 3-3 shown the oil and water bath, respectively.
3. Cannon Fenske Routine Viscometers (the glass capillary type) with different sizes were used for measuring the time of the solvent (t_0) and time of mixtures (t) which are used in calculating the kinematic viscosity of transparent Newtonian liquids according to the **Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (ASTM D 445–03)** ⁽⁸²⁾.
4. Ubbelohde Viscometer (the glass capillary type) with different sizes was used to measure the time of the solvent (t_0) and time of mixtures (t) used to calculate the intrinsic viscosity according to the **Standardized Test Method for Determining Inherent Viscosity of PET (ASTM D4603)** ⁽⁸³⁾.



Figure 3-2 Oil Bath

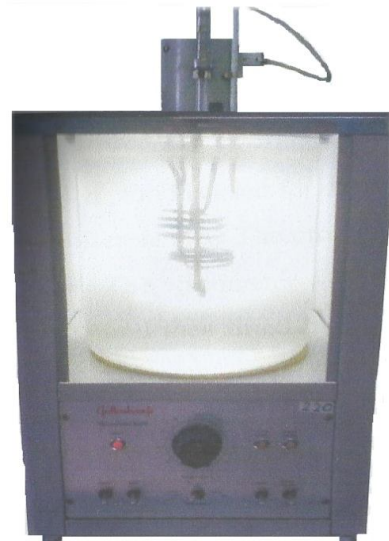


Figure 3-3 Water Bath

3.4 Viscometers

3.4.1 Cannon Fenske routine Viscometer

Cannon-Fenske Routine Viscometer shown in Figure 3-4 which is used for fast and easy viscosity testing of transparent Newtonian liquids and specially designed for applications in chemical and petroleum industries ⁽⁸²⁾.

3.4.2 Ubbelohde Viscometer

This viscometer shown in Figure 3-5 is the most useful kind of viscometers for determining IV. The previous viscometer does not provide for this, because it will give erroneous results in the IV determination ⁽⁸³⁾.

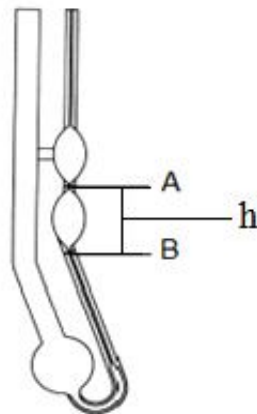


Figure 3-4 Fenske Routine Viscometer

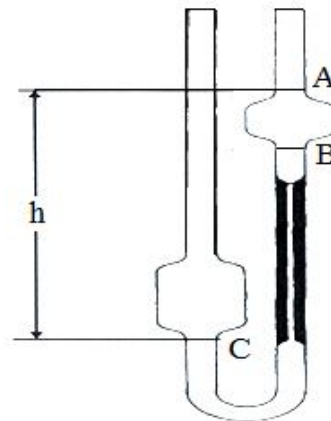


Figure 3-5 Ubbelohde Viscometer

3.5 Procedure Steps for Measuring Viscosity

- 1) Preparing blends and heating to about 50-60°C to ensure thorough mixing as mentioned before.
- 2) The calibrated viscometers used (both types) were cleaned using suitable solvent (water or benzene) and then dried by passing clean dry air to remove the final traces of solvents.
- 3) The solution is placed in the suitable size viscometer (about 15ml).

- 4) Then the viscometers were placed into holder and inserted in the constant temperature oil or water bath for at least 15 minutes before measuring to become free of air bubbles and maintained to the bath's temperature.
- 5) The solution was pulled above point A (in both types) and the time was measured when the solution flow from point A until it reaches point B (using stop watch). The solution flows through the capillary viscometer or the narrow diameter section of viscometer because the height difference (h) between C and A which belongs to the hydrostatic head or driving pressure.
- 6) These flow times are used to calculate both the kinematic viscosity and the intrinsic viscosity.

3.6 Calculations

a) Cannon Fenske routine Viscometer measurements

Times measured are used to calculate the kinematic viscosity using the following equation:

$$\nu = t \times f \quad (3.1)$$

Where: ν = kinematic viscosity, (mm²/s), f = viscometer factor and t = measured time, (s).

The VI is an arbitrary scale for comparing the rates of viscosity changes of lubricating oil with temperature. The VI scale was set up by the **Society of Automotive Engineers (SAE)**. The temperatures chosen arbitrarily for reference are 40 and 100°C.

b) Ubbelohde Viscometer measurements

- 1) The times of blank solvent (t_0) and solution (t) are used to calculate the relative viscosity according to the following equation:

$$\eta_{rel.} = t/t_0 \quad (3.2)$$

- 2) The Specific viscosity is from:

$$\eta_{sp.} = \frac{t-t_0}{t_0} = \eta_{rel.} - 1 \quad (3.3)$$

- 3) Then reduced viscosity is determined as follows using the concentration value of the solute (C):

$$\eta_{red.} = \eta_{sp.}/C \quad (3.4)$$

- 4) The $\eta_{red.}$ Was plotted versus concentration to get the intrinsic viscosity $[\eta]$ as shown in Figure 3-6 ⁽⁸⁴⁾:

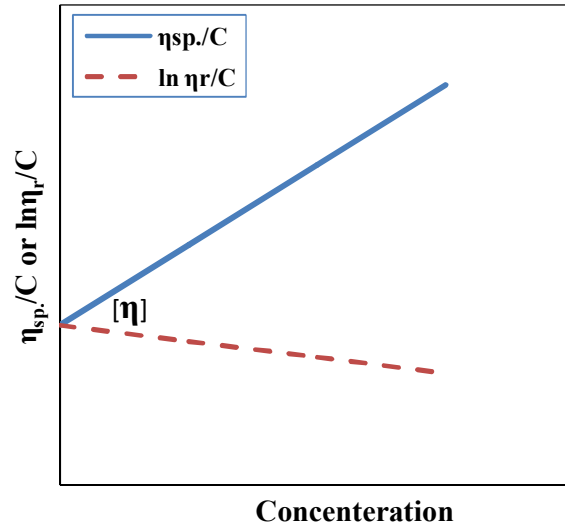


Figure 3-6 $\eta_{sp.}/C$ or $\ln \eta_r/C$ Versus Concentration

Chapter Four

Results and Discussion

4.1 Introduction

This study deals with kinematic viscosity, viscosity index and intrinsic viscosity for the three types of base lubricating oil (40, 60 and 150 stock) to investigate the effect of some additives (Lubrizol 21001, H-8722B and H-340) on the efficiency of viscosity index improver (OCP PVC-100XA). A number of correlations between the VI and OCP concentration will be found.

4.2 Kinematic Viscosity and Viscosity Index for Base Lubricating Oil

The effect of temperature on the kinematic viscosity of the three types of base lubricating oil was measured. The results are listed in Appendix A and sketched in Figure 4-1. It can be indicated a noticeable decrease in the viscosity of the three types of base lubricating oil with the increase in temperature.

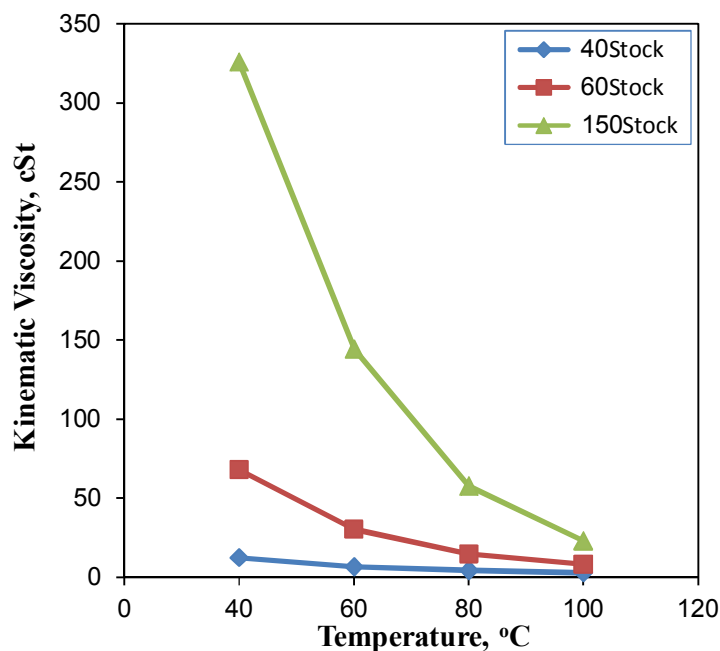


Figure 4-1 Effect of Temperature on the Kinematic Viscosity of the Three Types of Base Lubricating Oil

Figure 4-1 shows that the heavy oil stock (150 stock) with low °API of 23.90 has a significantly high kinematic viscosity comparing with that of middle and light oil stock (60 and 40 stock) which have °API gravity of 29.24 and 34.976 respectively. Also the rate of decrease in the Kinematic viscosity of the heavy lubricating oil is higher than that of the light one, i.e. the rate of decrease is about 93%, 87% and 75% for 150, 60 and 40 stock, respectively. This can be attributed to the fact that the rate of change in oil stock viscosity with temperature depends largely on its Kind. Kinds of oil differ from each other in their viscosity, volatility, and toxicity. Viscosity refers to an oil's resistance to flow, volatility refers to how quickly the oil evaporates into the air and toxicity refers to how poisonous⁽⁸⁵⁾.

Al-Mamoory (2002)⁽¹¹⁾, **Al-Taa'ay (2004)**⁽¹²⁾ and **Omran (2009)**⁽¹³⁾ obtained the same results for the change of viscosity of the three types of base oil with temperature.

In other hand, VI which is an arbitrary measure for the change of viscosity with temperature was determined. In Table 4-1 the listed values of VI are obtained from the SAE VI scale at the two reference temperatures 40 and 100°C:

Table 4-1 Viscosity Index of Base Lubricating Oil

Base Lubricating Oil Type	VI
40 stock	106
60 stock	97
150 stock	90

4.3 Effect of OCP on the Viscosity Index and Intrinsic Viscosity for Base Lubricating Oils

In this study, blends from the three types of base stocks with different concentrations of OCP (PVC-100XA) (VII) with a range of 0-10 wt% were prepared. Those blends give a significance increase in the kinematic viscosity, VI and IV as the weight percentage of OCP increase. This is because OCP composed

of long and flexible polymer molecules that interact with the base stocks and this interaction leads to increase the resistance to flow.

The concentration of OCP must be limited, because the additional effects may then arise from intermolecular forces and entanglements between chains. Therefore, OCP is excellent in economical efficiency, because it exhibits the effect even if it is added in a small amount⁽⁸⁶⁾.

The values of kinematic viscosity for the three base lubricating oil types are listed and drawn in Appendix A. It is noticed that the increasing of the concentration of OCP will increase in the viscosity of 40 stock more than 60 and 150 stock and that can be expressed by the VI which is shown in the values listed in Appendix B and sketched in Figure 4-2:

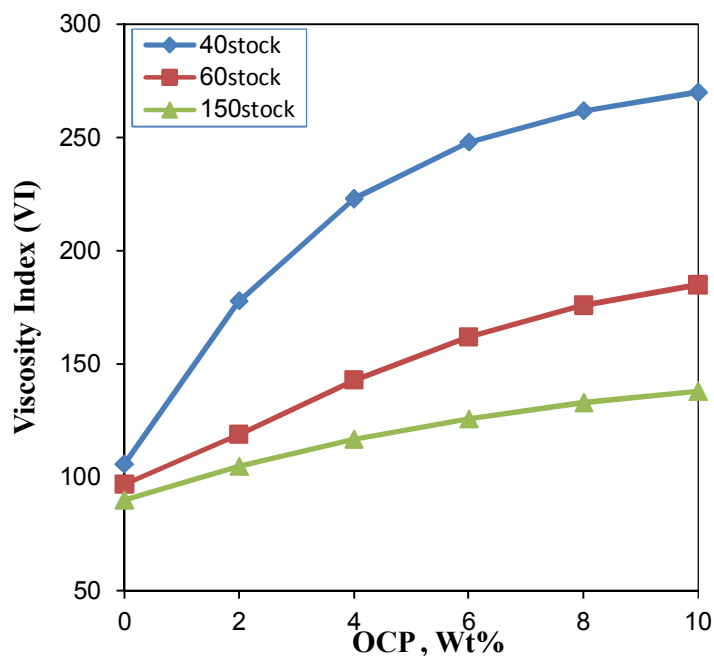


Figure 4-2 Effect of OCP on Viscosity Index of the Three Types of Base Lubricating Oil

Figure 4-2 shows that the increase in OCP concentration, which blended with the three types of base oil, will improve the VI. It affects 40 stock by 154%, 60 stock by 90% and 150 stock by 57%, by adding 10 wt% of OCP. Also, the

improving in VI will be with a decreasing rate as the concentration of OCP increased.

VIIs act through swelling of the polymer chain as the temperature rises to offset the decrease in base oil viscosity. This results in an increase in the hydrodynamic polymer coil size, which increases the fluid flow resistance⁽⁸⁷⁾.

In other hand the relative, specific and reduced viscosities were measured to estimate the IV for base stocks at different weight percentage of OCP and at four temperatures (40, 60, 80 and 100°C) as listed in Appendix C. Figure 4-3 shows the effect of OCP on the IV for the three base oils.

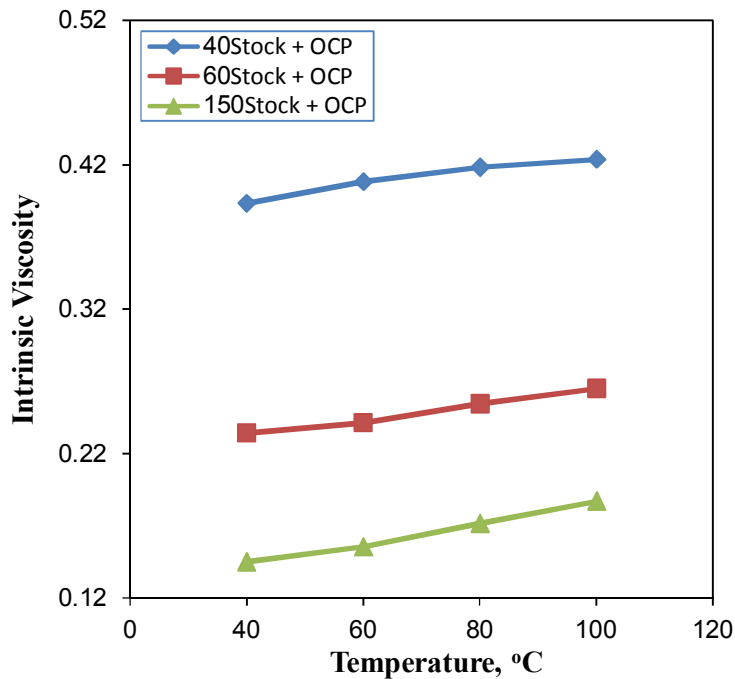


Figure 4-3 Intrinsic Viscosity of 40 stock, 60 stock and 150 stock with OCP at Different Temperatures

From Figure 4-3 it can be noticed that the intrinsic viscosity increase with increasing the temperature. Unfortunately OCP behaves with an unknown manner because the unknown polymeric structure of it.

But by considering the three types of base oil were a bad solvent so by increasing the temperature the penetration will be better, and that will result the increase in the IV⁽⁸⁸⁾.

4.4 Effect of Additives on the Viscosity Index and Intrinsic Viscosity for Base Lubricating Oils

In this study three types of additives which are Lubrizol 21001, HiTEC 8722B, and HiTEC 340 will blend with the three base oil types with the three types of base oil in a concentration range of 0-10 wt% and temperature range of 40-100°C. And there effects on the kinematic viscosity, VI and IV for three types of base oil are shown below.

4.4.1 Effect of Lubrizol 21001

This additive is a multipurpose additive package for Otto engine. Blends from the three types of base stocks with different concentrations of Lubrizol 21001 with a range of 0-10 wt% were prepared. Those blends gave a noticeable increase in the kinematic viscosity, VI and IV as the weight percentage of Lubrizol 21001 increase. The values of kinematic viscosity for the three base lubricating oil types are listed and sketched in Appendix A. Values of VI are listed in Appendix B and shown in Figure 4-4, shown the effect of Lubrizol 21001 on the three base oil types.

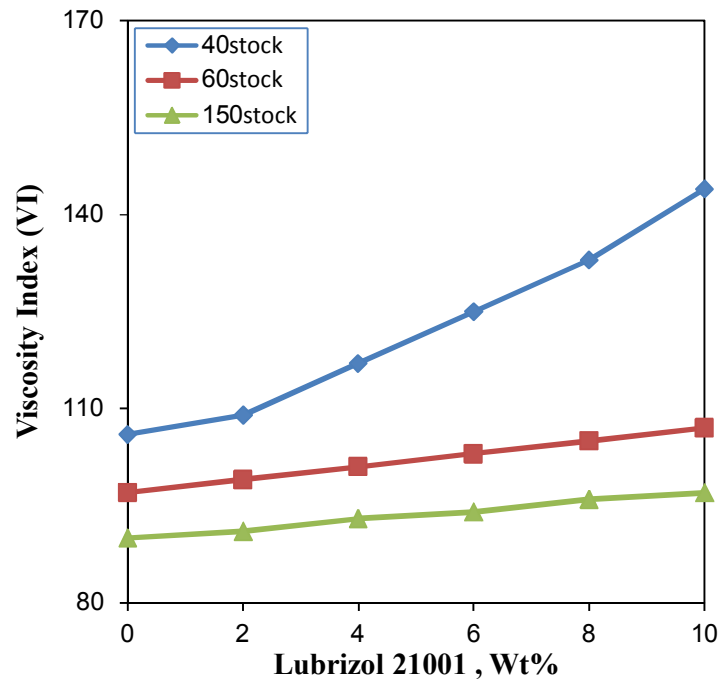


Figure 4-4 Effect of Lubrizol 21001 on VI of the Three Types of Base Lubricating Oil

It has been found that the enhancement in the VI for light base oil type (40 stock) is more pronounced than for heavy oil types (60 and 150 stock). The increasing in VI is about 35%, 10% and 8% for 40, 60 and 150 stock, respectively when adding 10 wt% of Lubrizol 21001. Also it has been noticed that the rate of improvement in the VI for 40 stock is in a range of 3-8%, while it is 2% for 60 and 150 stock with every 2 wt% added from Lubrizol 21001.

The addition of this polymer to the three types of base oil results in the interaction (diffusion) of the oil into the space around the polymer molecules and can act because the hydrodynamic polymer coil size increases as the temperature rises to offset the decrease in base oil viscosity⁽⁸⁸⁾.

The relative, specific and reduced viscosities were measured to estimate the IV for base stocks at different weight percent of Lubrizol 21001 and at four temperatures (40, 60, 80 and 100°C) as listed in Appendix C. Figure 4-5 shows the effect of Lubrizol 21001 on the IV for the three base lubricating oils.

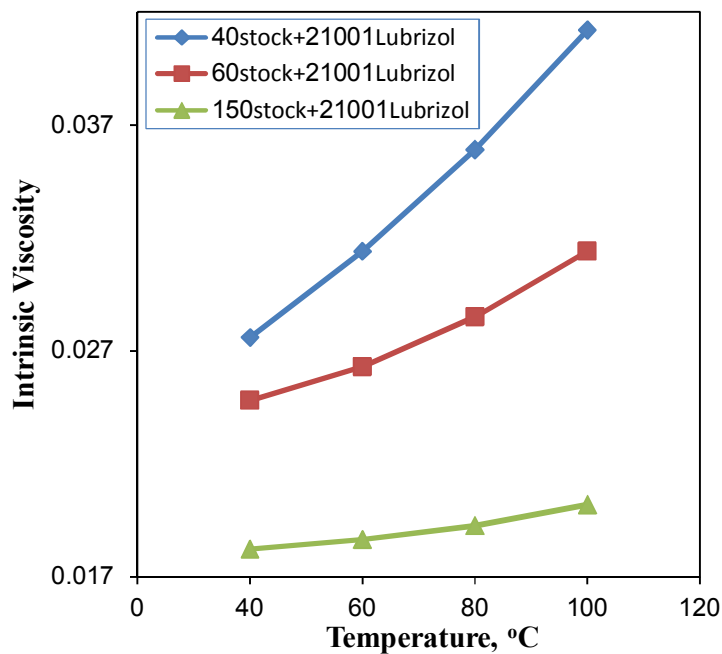


Figure 4-5 Intrinsic Viscosity of 40 stock with Lubrizol 21001 at Different Temperatures

From Figure 4-5 it can be shown that by increasing the temperature, the IV of the three base oil types increased. This shows that Lubrizol 21001 is acting as a

neutral polymer in the lubricating oil. Neutral polymers have the property of increasing the IV with increasing of polymer concentration, because the structure of this additive may not contain a carboxyl group which has the ability to ionize the solvent and the effective electrostatic repulsion that makes this polymer chains highly extended ⁽⁸⁸⁾.

Al-Jboori (2011) ⁽⁷⁸⁾ had the same behavior of this additive when it blended with the crude oil.

4.4.2 Effect of H-8722B

This additive is a multipurpose additive for diesel engine. Its effect on kinematic viscosity for the three types of base oil are listed and drawn in Appendix A. The increasing of the concentration of H-8722B will increase the VI as listed in Appendix B and sketched in Figure 4-6:

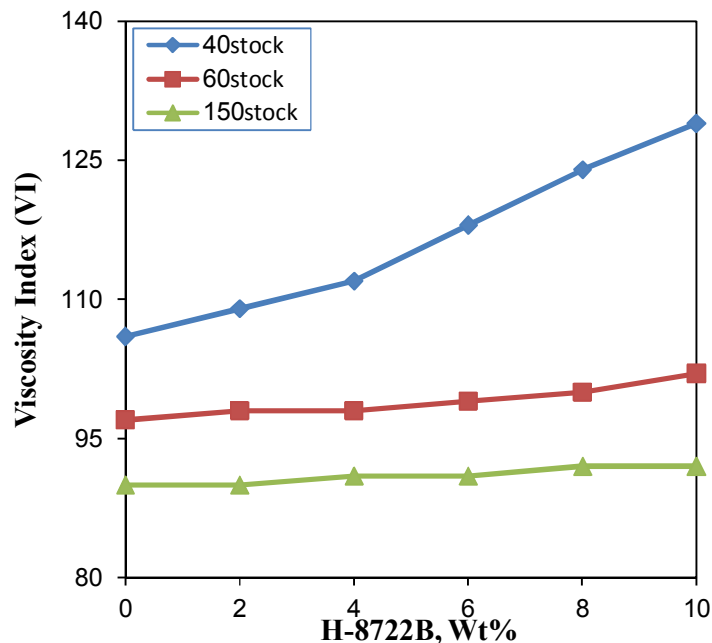


Figure 4-6 Effect of H-8722B on Viscosity Index of the Three Types of Base Lubricating Oil

It has been found that the improving in the VI for 40 stock is very noticeable more than for 60 and 150 stock. The increasing in VI is about 22%, 5% and 2% for

40, 60 and 150 stock, respectively when adding 10 wt% of H-8722B. So it recommended using such additive with light oil types like 40 stock because of its insignificance effect on 60 and 150 stock.

These results reveal that the rate of reaction increases with decreasing the chain length of the polymer. And that reaction occurs when two reactant molecules are getting in contact with each other through a number of collisions leading to the completion of the reaction. Similar behavior of the polymer chains was obtained by **Abdel-Azim** ⁽⁶²⁾.

The relative, specific and reduced viscosities were measured to estimate the intrinsic viscosity for base stocks at different weight percentage of H-8722B and at four temperatures (40, 60, 80 and 100°C) as listed in Appendix C. Figure 4-7 shows the effect of H-8722B on the IV for the three base oils.

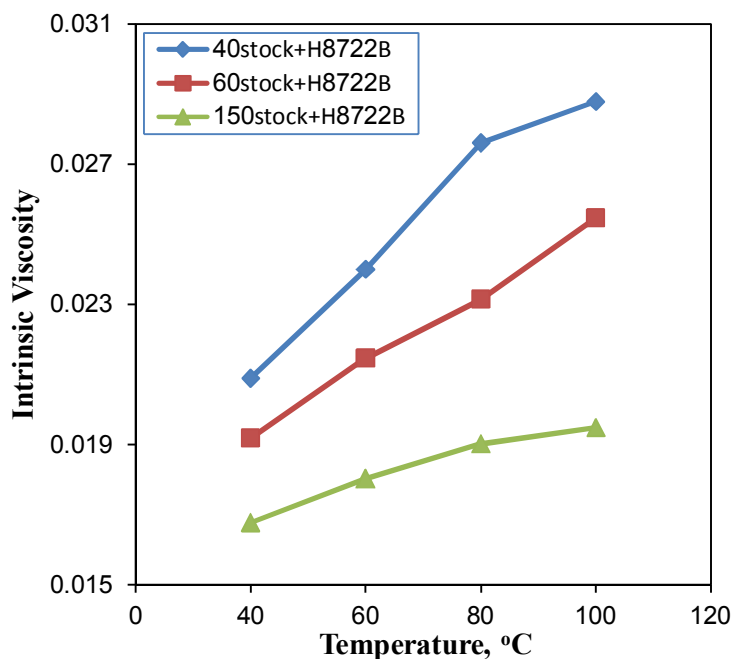


Figure 4-7 Intrinsic Viscosity of 40 stock, 60 stock and 150 stock with H-8722B at Different Temperatures

From Figure 4-7 it can be shown that the increase of the temperature and the concentration of H-8722B will slightly increase the intrinsic viscosity for all the three types of base oil. This shows that the failure of a polymer solution to reach

high values of intrinsic viscosity that is usually attributed to the presence of a yield stress, below which the solution acts like a solid and thus can withstand this level of stress without shear⁽⁵⁸⁾.

4.4.3 Effect of H-340

This additive is an economic automotive gear oil additive package. Values of VI are listed in Appendix B and sketched in Figure 4-8 shown the effect of H-340 on the three base oil types.

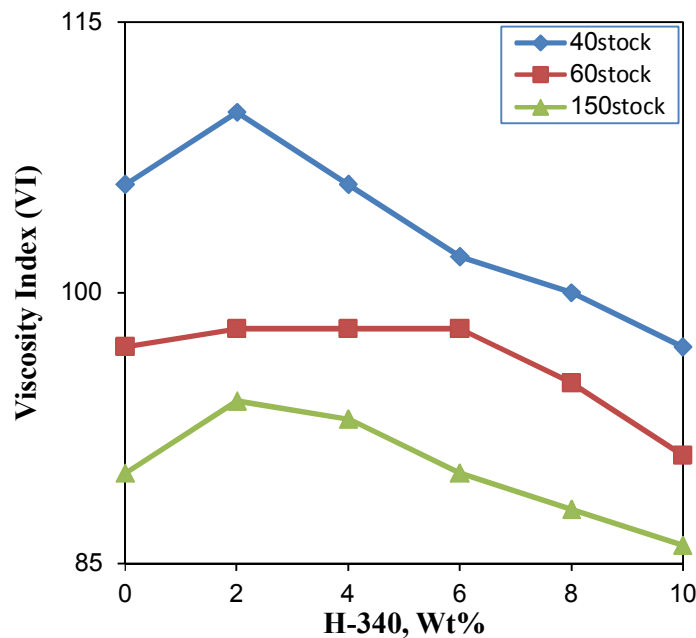


Figure 4-8 Effect of H-340 on Viscosity Index of the Three Types of Base Lubricating Oil

It can be seen from this figure that the maximum VI is obtained at different concentrations of H-340. These concentrations are 2 wt% for 40, 60 and 150 stock. This concentration is helpful in selecting the base oil type and the suitable dosage of H-340 for producing effective and economic automotive gear oil.

Such behavior of additive on the VI was also obtained by using the PIB and PBR with the base oil types⁽⁶⁰⁾.

The relative, specific and reduced viscosities were measured to estimate the IV for 40 stock at different weight percentage of H-340 and at four temperatures

(40, 60, 80 and 100°C) are listed in Appendix C. Figure 4-9 shows the effect of H-340 on the IV for 40 stock only. That because the inability to determine the values of reduced viscosity for 60 and 150 stock due to the negative values of their specific viscosity.

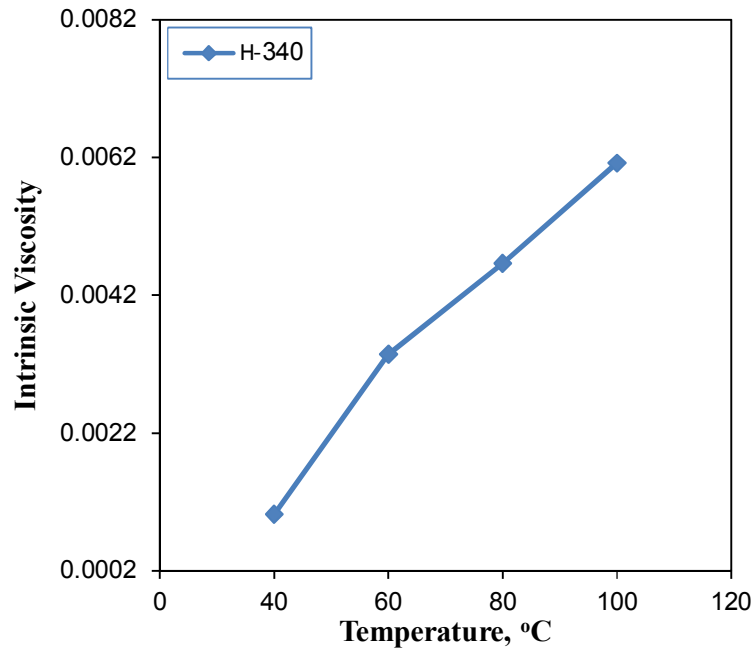


Figure 4-9 Intrinsic Viscosity of 40 stock with H-340 at Different Temperatures

Obviously, as the temperature rises, the polymer chains become more relaxed and tend to be fully extended, this result in an increase in the hydrodynamic polymer coil size, which increases the fluid flow resistance and lead the IV to increase⁽⁸⁹⁾.

4.5 Effect of Additives on the Efficiency of Viscosity Index Improver for Base Lubricating Oils

In this section, blends of a base stock, OCP and an additive were prepared in order to study the influence of the three additives on the efficiency of the VII. Kinematic viscosities of the blends were measured using Cannon Fenske Routine

viscometer and the values of VI were obtained from the SAE VI scale. Intrinsic viscosities of the blends also were measured using Ubbelohde viscometer.

4.5.1 Influence of Lubrizol 21001

Two sets of mixtures were made using Lubrizol 21001 with a concentration of 4 wt% in the first set and 8 wt% in the second with the three types of base stocks (40, 60 and 150 stocks) and OCP in a concentration range of 2-8 wt%. The results on the kinematic viscosity are expressed in Appendix A. The effect of Lubrizol 21001 on the VI on the three types of base lubricating oil and OCP are listed in Appendix B and 4-8 and drawn in Figures 4-10 to 4-12.

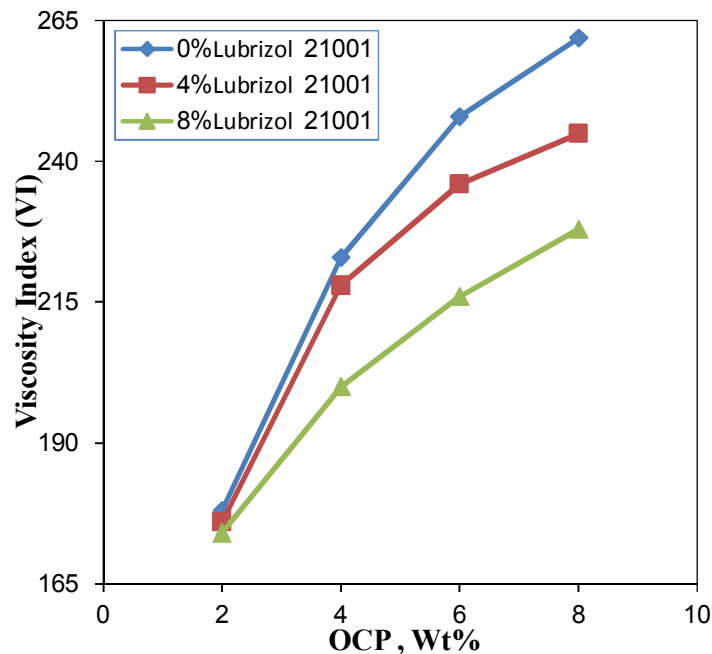


Figure 4-10 Effect of OCP on Viscosity Index of 40 stock + 0, 4 and 8 wt% of Lubrizol 21001

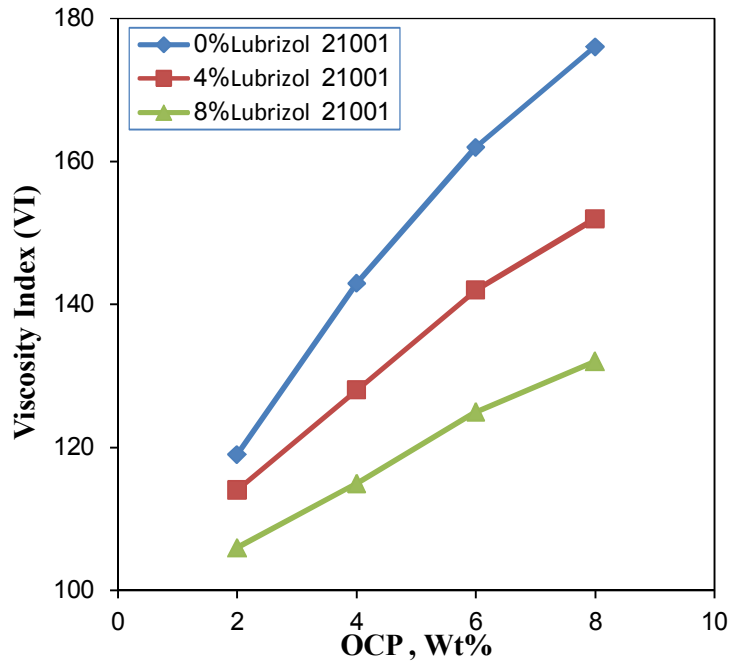


Figure 4-11 Effect of OCP on Viscosity Index of 60 stock + 0, 4 and 8 wt% of Lubrizol 21001

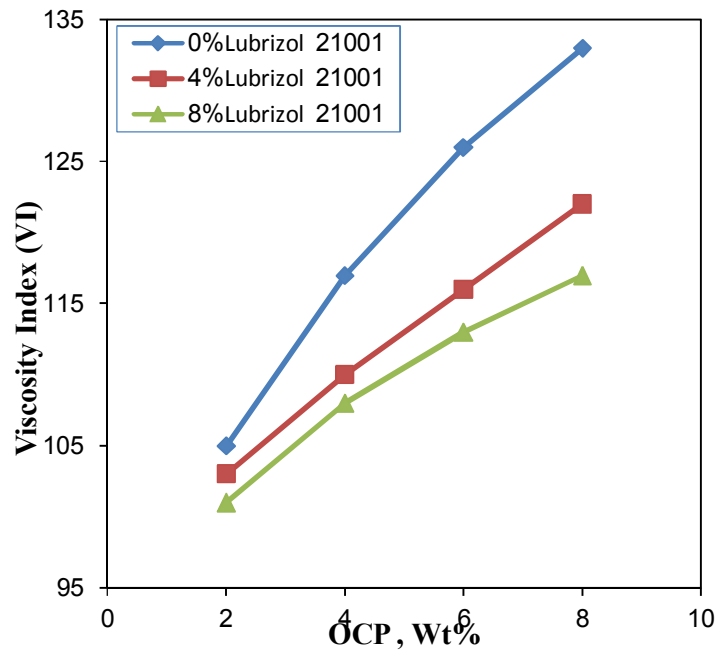


Figure 4-12 Effect of OCP on Viscosity Index of 150 stock + 0, 4 and 8 wt% of Lubrizol 21001

From the Figures 4-10 to 4-12 it can be shown that at a specific concentration of Lubrizol 21001, when blended with the three types of base oil, the VI will be improved with the increasing of OCP concentration. Also it can be noticed that at all OCP concentrations the VI will be decreased as the concentration of Lubrizol 21001 increased.

The efficiency of OCP is performed by measuring the VI of blends before and after adding Lubrizol 21001. For 40 and 150 stock, the decreasing rate of OCP efficiency is calculated to be about 7% and 10% by adding 4 and 8 wt% of Lubrizol 21001, respectively. While the decreasing rate of the efficiency is obtained to be about 10% and 16% when 60 stock is blended with 4 and 8 wt% of Lubrizol 21001, respectively. So it is not preferred to use Lubrizol 21001 as lubricating oil additive in the presence of OCP because it lowers the VI as well as the efficiency of the VII.

That can be attributed to the fact that as the reaction proceeds, the kinematic viscosity of the reacted mixture increases gradually and it increases it can be presumed that many pendant carboxylic groups may be buried in the micro gel particles of the polymer⁽⁷²⁾.

The relative, specific and reduced viscosities of the prepared blends were obtained to estimate the IV and are listed in Appendix C. Figures 4-13 to 4-15 showing the effect of Lubrizol 21001 on the intrinsic viscosity for the three base oils.

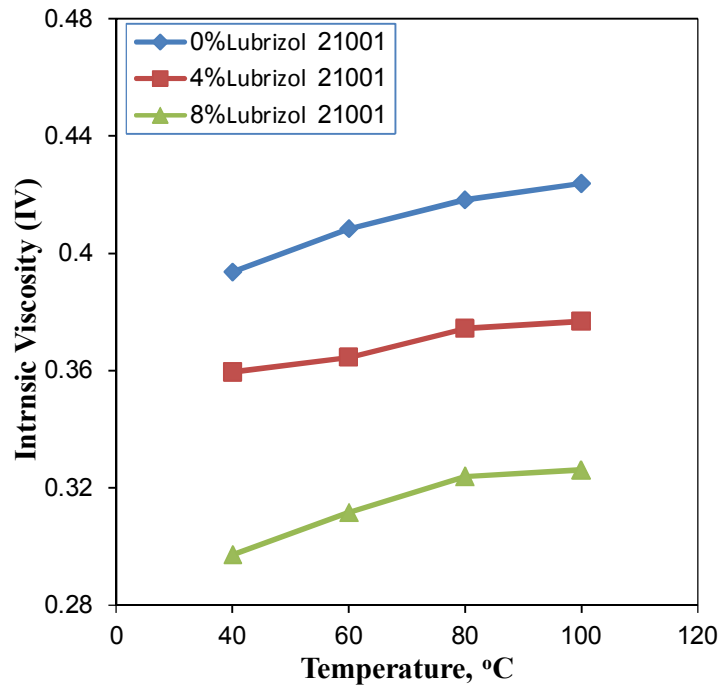


Figure 4-13 Intrinsic Viscosity of 40 stock Blended with OCP and with 4 and 8 wt% of Lubrizol 21001 at Different Temperatures

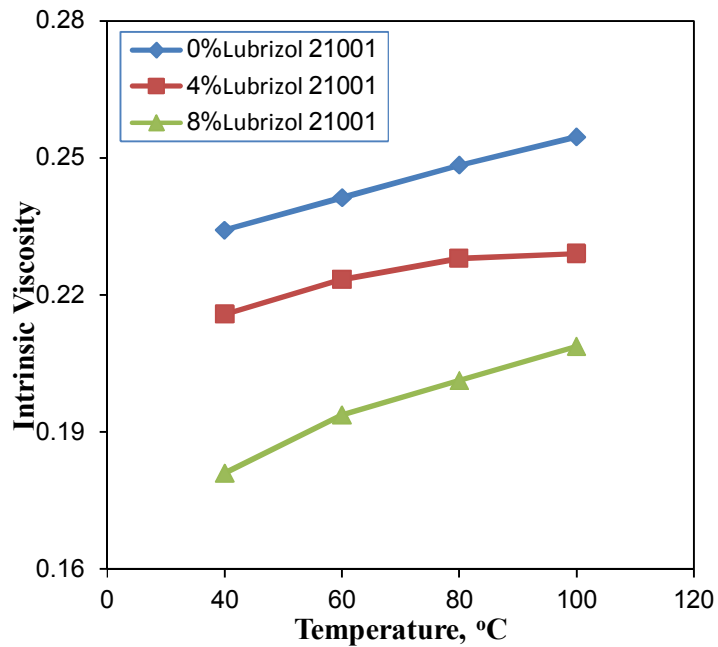


Figure 4-14 Intrinsic Viscosity of 60 stock Blended with OCP and with 4 and 8 wt% of Lubrizol 21001 Different Temperature

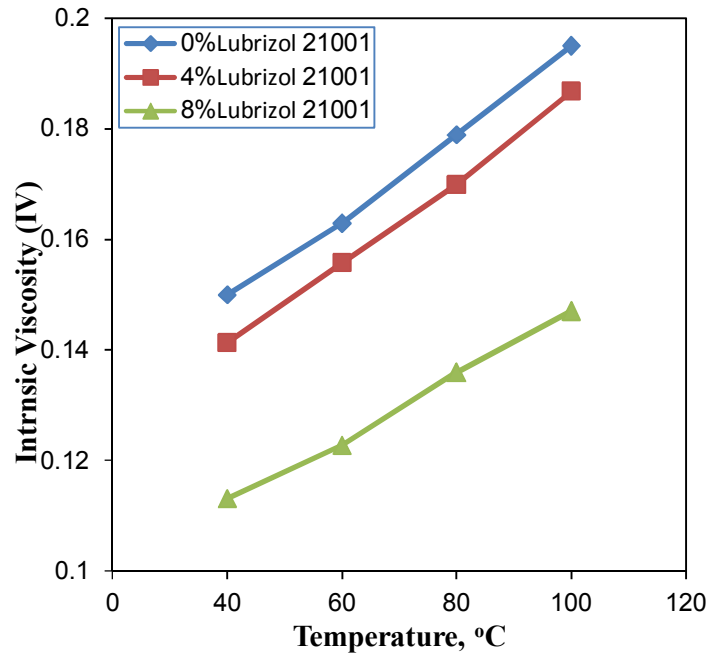


Figure 4-15 Intrinsic Viscosity of 150 stock Blended with OCP and with 4 and 8 wt% of Lubrizol 21001 at Different Temperatures

Distinctly, from Figures 4-13 to 4-15 at a specific concentration of Lubrizol 21001, increasing both the concentration of OCP and temperatures will increase the IV because Lubrizol 21001 is a neutral polymer which has the property of increasing the IV with increasing the polymer concentration, because the structure of this additive may contain a carboxyl group which have the ability to ionize the polar solvent and the effective electrostatic repulsion that makes the polymer chain highly extended and lead to increase the IV ⁽⁸⁸⁾.

4.5.2 Influence of H-8722B

Two sets of mixtures were made using H-8722B with a concentration of 4 wt% in the first set and 8 wt% in the second with the three types of base stocks (40, 60 and 150 stocks) and OCP in a concentration range of 2-8 wt%. The results on the kinematic viscosity are expressed in are expressed in Appendix A. The effect of H-8722B on the VI on the three types of base oil and OCP are listed in Appendix B and drawn in Figures 4-16 to 4-18.

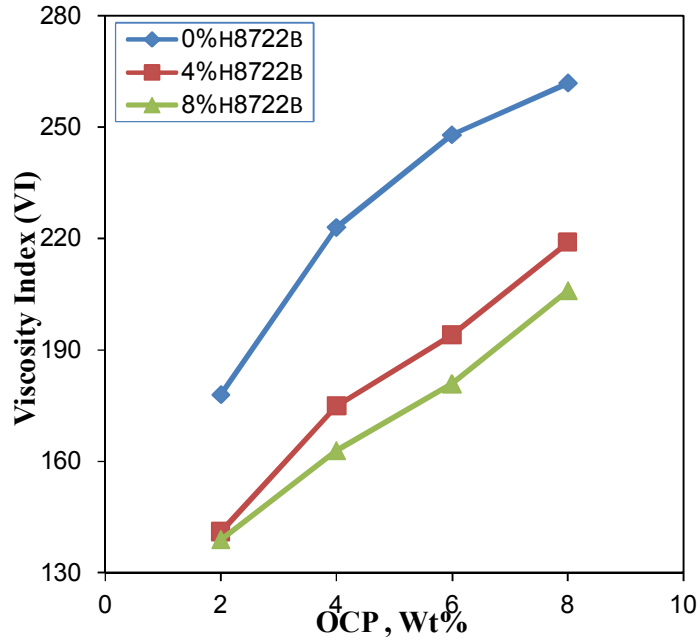


Figure 4-16 Effect of OCP on Viscosity Index of 40 stock + 0, 4 and 8 wt% of H-8722B

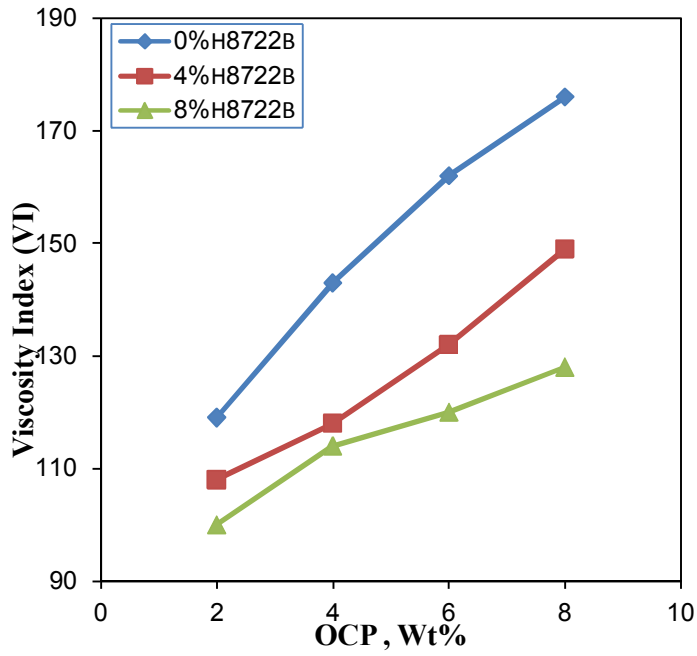


Figure 4-17 Effect of OCP on Viscosity Index of 60 stock + 0, 4 and 8 wt% of H-8722B

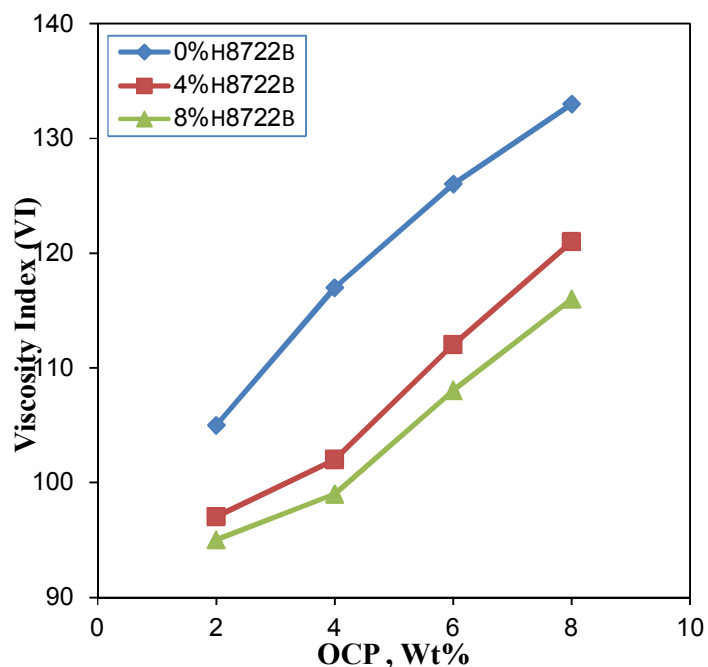


Figure 4-18 Effect of OCP on Viscosity Index of 150 stock + 0, 4 and 8 wt% of H-8722B

From the results it can be indicated that the VI is improved with increasing OCP concentration at the two concentrations of H-8722B because this additive is composed of long and flexible polymer molecules that interact with the base oil and OCP.

This interaction will cause greater volume and the base oil produces a proportionally greater thickening effect which in return raises the VI of the oil ⁽⁹⁰⁾.

In the other hand at all OCP concentrations the VI will be decreased as the concentration of H-8722B increased.

With respect to the efficiency of OCP, the 60 stock showed the same behavior as in adding Lubrizol 21001 by having the highest decreasing rate for the OCP efficiency which was about 7% and 14% by adding 4 and 8 wt% of H-8722B, respectively. While for 150 stock the decreasing rate is obtained to be about 2% by adding 4 wt% and being 4% by adding 8 wt% of H-8722B.

It is interesting to know that for 40 stock the efficiency is increased by 5% when adding 4 wt% while it decreased by insignificant value when adding 8 wt%

of H-8722B so it is better to use H-8722B as lubricating oil additive in the presence of OCP by adding 4 wt% or less.

The relative, specific and reduced viscosities were measured to estimate the IV for the prepared blends as listed in Appendix C. And Figures from 4-19 to 4-21 show the effect of H-8722B on the IV for the base oil types.

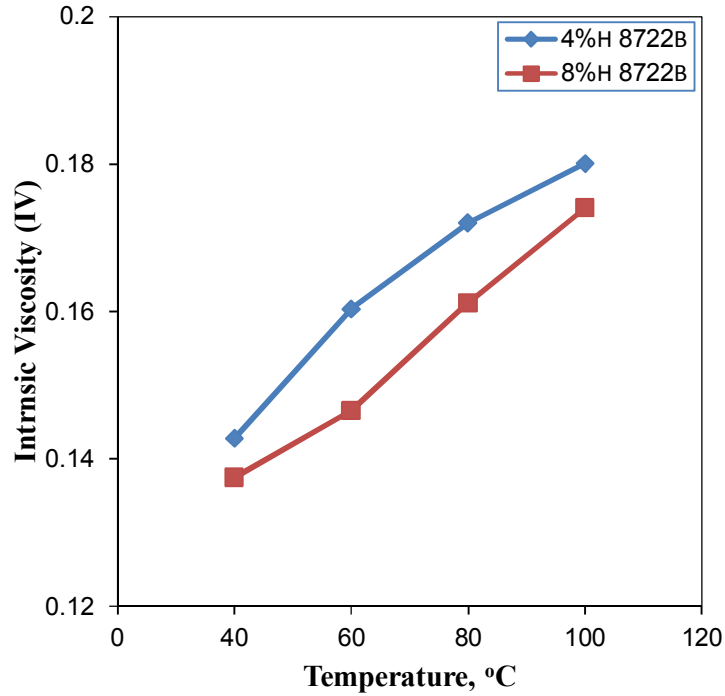


Figure 4-19 Intrinsic Viscosity of 40 stock Blended with OCP and with 4 and 8 wt% of H-8722B at Different Temperatures

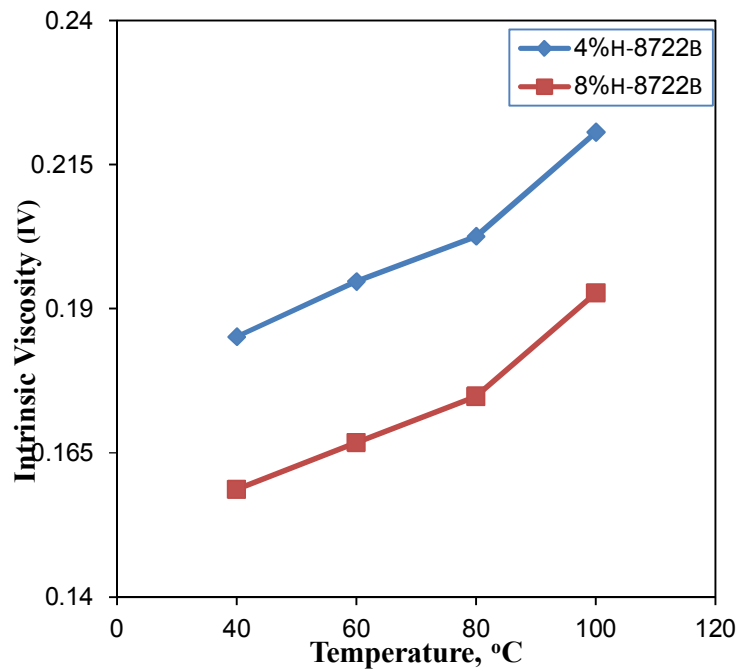


Figure 4-20 Intrinsic Viscosity of 60 stock Blended with OCP and with 4 and 8 wt% of H-8722B at Different Temperatures

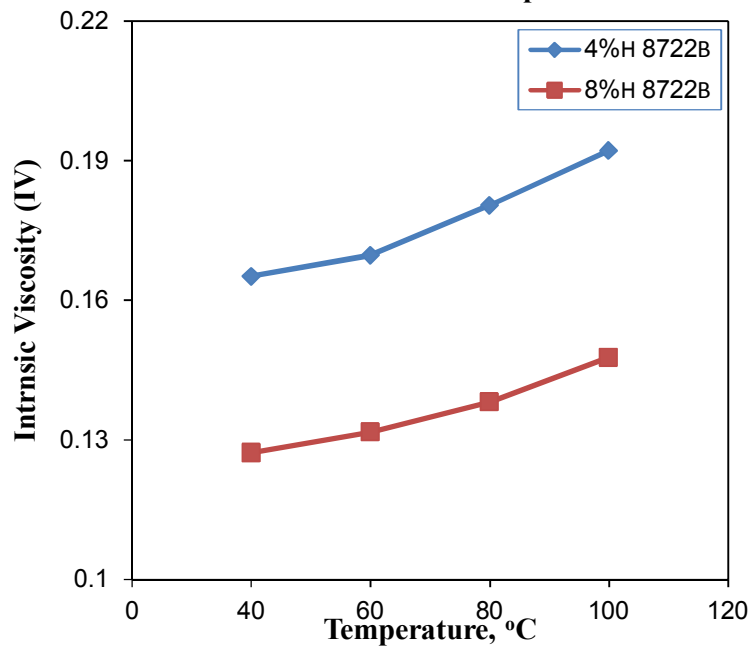


Figure 4-21 Intrinsic Viscosity of 150 stock Blended with OCP and with 4 and 8 wt% of H-8722B at Different Temperatures

Figures from 4-19 to 4-21 it can be shown that the increase of the temperature and the concentration of H-8722B will increase the IV for all the three types of base oil. This shows that the associated interaction of this polymer

molecules and OCP molecules in the base oil will overlap with each other causing the increase in the IV.

4.5.3 Influence of H-340

Two sets of mixtures were made using H-340 with a concentration of 4 wt% in the first set and 8 wt% in the second with the three types of base stocks (40, 60 and 150 stocks) and OCP in a concentration range of 2-8 wt%. Its effect on the kinematic viscosity for three types of base oil is shown in Appendix A. Values of VI are listed in Appendix B and sketched in Figures from 4-22 to 4-24 shown the effect of H-340 on the three base oil types and OCP.

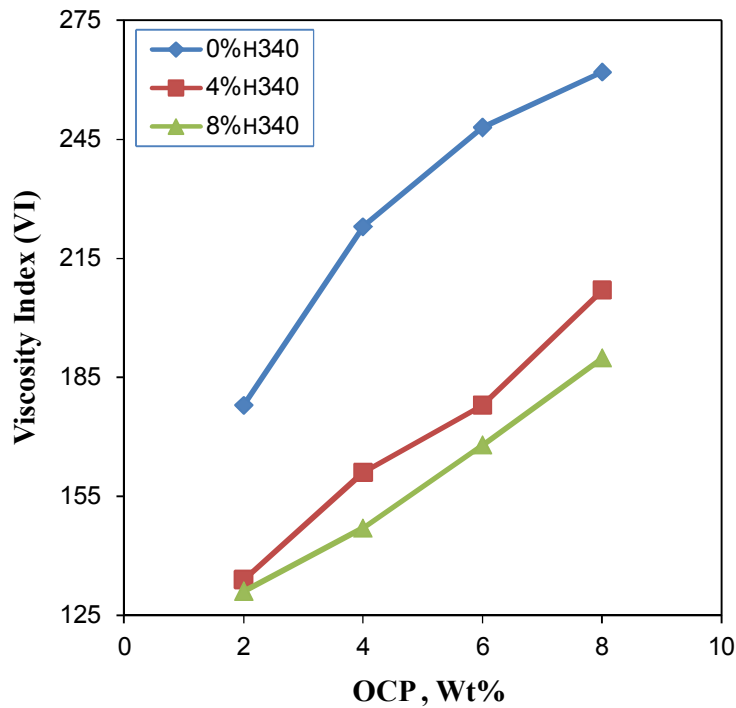


Figure 4-22 Effect of OCP on Viscosity Index of 40 stock + 4 and 8 wt% of H-340

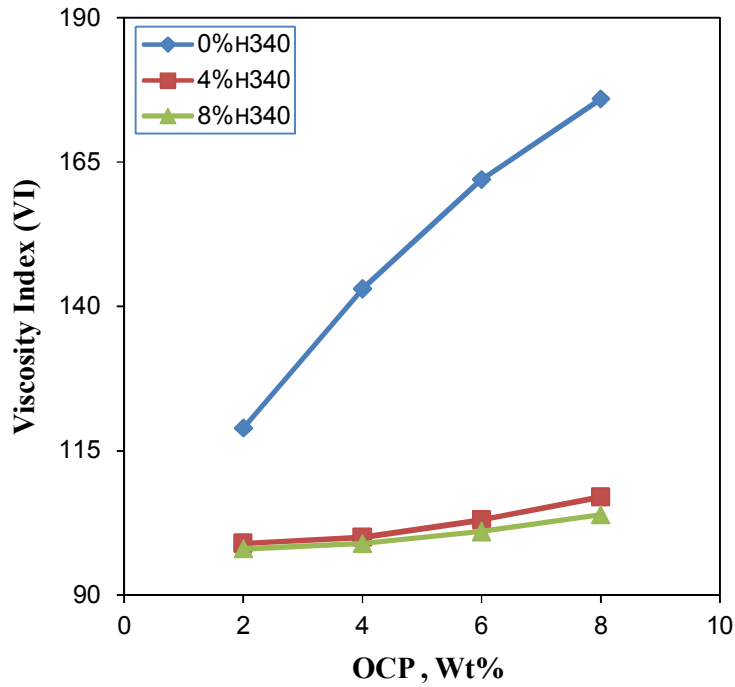


Figure 4-23 Effect of OCP on Viscosity Index of 60 stock + 4 and 8 wt% of H-340

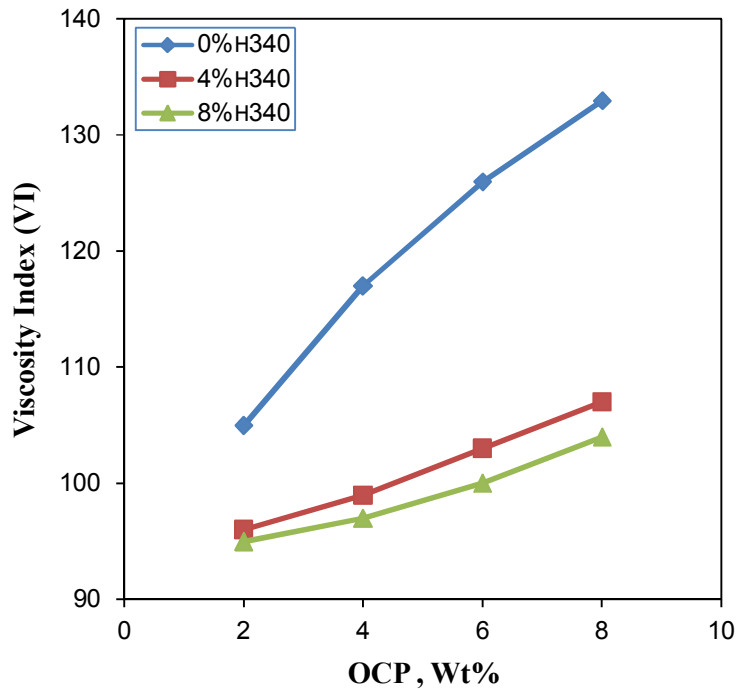


Figure 4-24 Effect of OCP on Viscosity Index of 150 stock + 4 and 8 wt% of H-340

Generally from Figures 4-22 to 4-24 it can be noticed that the VI is improved with increasing OCP concentration at the two concentrations of H-340. And at all OCP concentrations the VI will be decreased as the concentration of H-

340 increased. As for the efficiency of OCP, this additive would strongly decrease the OCP efficiency of the 60 stock, the decreasing rate for the OCP which was about 27% and 28% by adding 4 and 8 wt% of H-340, respectively. While for 150 stock the decreasing rate is obtained to be about 13% by adding 4 wt% and being about 14% by adding 8 wt% of H-340.

It is a coincidence that for 40 stock the efficiency at 4 wt% of H-340 is increased just like in H-8722B which it was by about 5% and it also decreased when adding 8 wt% of H-340. So it is better to use H-340 as lubricating oil additive in the presence of OCP by adding 4 wt% or less.

Those results can be explained as follows. The rate of reaction of the more bulky molecules is less than that of the less bulky one. In this respect, the assumptions that the molecules exist as a coil leads to the supposition that the diffusion and hence the activity of the molecules decreases with the increasing in the chain length ⁽⁸⁹⁾.

The relative, specific and reduced viscosities were measured to estimate the IV for the prepared blends as listed in Appendix C. Figures from 4-25 to 4-27 show the effect of H-340 on the IV for the base oil types.

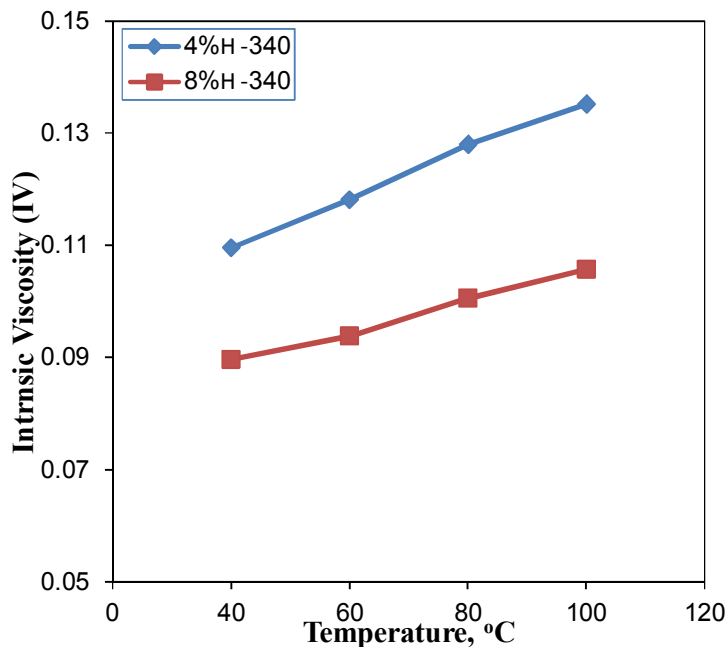


Figure 4-25 Intrinsic Viscosity of 40 stock Blended with OCP and with 4 and 8 wt% of H-340 at Different Temperatures

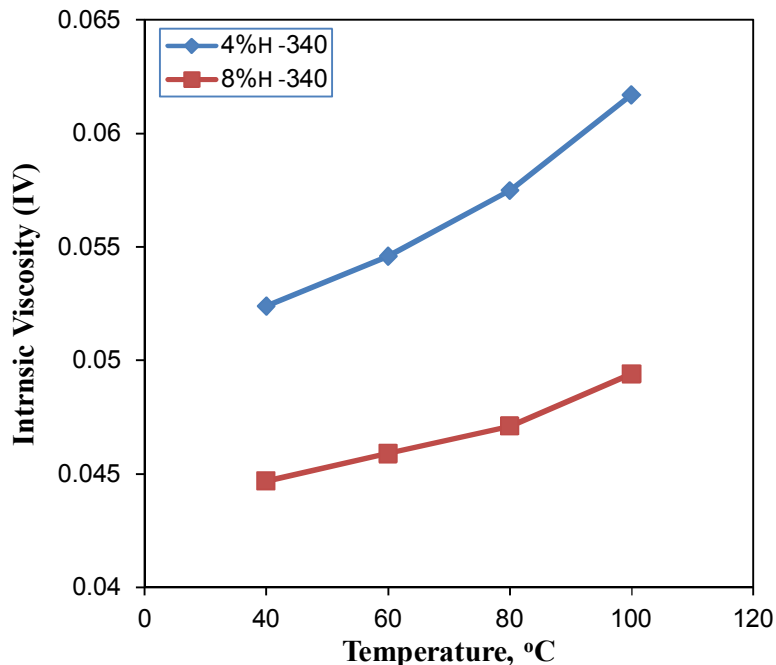


Figure 4-26 Intrinsic Viscosity of 60 stock Blended with OCP and with 4 and 8 wt% of H-340 at Different Temperatures

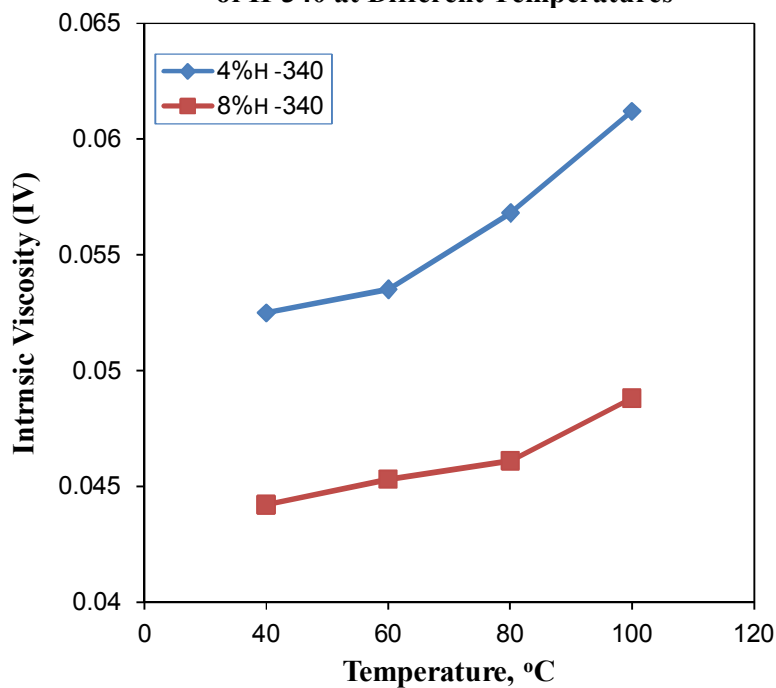


Figure 4-27 Intrinsic Viscosity of 150 stock Blended with OCP and with 4 and 8 wt% H-340 at Different Temperatures

The Figures 4-25 to 4-27 showed that the increasing of the IV of the 40 stock is higher than both 60 stock and 150 stock. Generally this results from the polymer changing its physical configuration with increasing temperature of the

mixture. It is believed that the polymer molecule in solution exists as a random coil, which is swollen by the base oil solvent. The volume of this molecule determines the viscosity increase. And when the penetration of the solvent gets better, especially with temperature increasing, then the intrinsic viscosity will increase⁽⁹⁰⁾.

4.6 Correlations for Viscosity Index

A number of VI correlations have been obtained in this section using the regression analysis and depending on the results which presented in the previous sections of this chapter.

The functional relationships are between the VI and the concentration of OCP for three types of base lubricating oil and for each type of additives.

From the Table 4-3 three correlations between VI and the OCP concentration (0-10 wt%) were obtained as shown below:

For 40 stock: (correlation coefficient = 99.8%)

$$VI = -1.9821C_{OCP}^2 + 35.493C_{OCP} + 109.71 \quad (4.1)$$

For 60 stock: (correlation coefficient = 98.8%)

$$VI = 9C_{OCP} + 102 \quad (4.2)$$

For 150 stock: (correlation coefficient = 99.2%)

$$VI = 4.7571C_{OCP} + 94.381 \quad (4.3)$$

For Lubrizol 21001 it has been noticed that the correlations at 4 wt% of this additive is different from the correlations of 8 wt%. From Tables 4-7 and 4-8 the functional relationships were obtained as follows:

At 4 wt% of Lubrizol 21001 and OCP concentration (0-8 wt%):

For 40 stock: (correlation coefficient = 99.8%)

$$VI = -2.0625C_{OCP}^2 + 31.875C_{OCP} + 121.25 \quad (4.4)$$

For 60 stock: (correlation coefficient = 99.7%)

$$VI = 6.4C_{OCP} + 102 \quad (4.5)$$

For 150 stock: (correlation coefficient = 99.9%)

$$VI = 3.151C_{OCP} + 97 \quad (4.6)$$

At 8 wt% of Lubrizol 21001 and OCP concentration (0-8 wt%):

For 40 stock: (correlation coefficient = 99.9%)

$$VI = -0.875C_{OCP}^2 + 17.65C_{OCP} + 142.5 \quad (4.7)$$

For 60 stock: (correlation coefficient = 99.4%)

$$VI = 4.5C_{OCP} + 96.5 \quad (4.8)$$

For 150 stock: (correlation coefficient = 99.2%)

$$VI = 2.65C_{OCP} + 96.5 \quad (4.9)$$

Also for H-8722B the functional relationships were obtained using the regression analysis depending on Tables 4-9 and 4-10. The correlations are given below:

At 4 wt% of H-8722B and OCP concentration (0-8 wt%):

For 40 stock: (correlation coefficient = 99.7%)

$$VI = -0.5625C_{OCP}^2 + 18.275C_{OCP} + 107.75 \quad (4.10)$$

For 60 stock: (correlation coefficient = 99.4%)

$$VI = 6.85C_{OCP} + 92.5 \quad (4.11)$$

For 150 stock: (correlation coefficient = 99.2%)

$$VI = 4.1C_{OCP} + 87.5 \quad (4.12)$$

At 8 wt% of H-8722B and OCP concentration (0-8 wt%):

For 40 stock: (correlation coefficient = 99.8%)

$$VI = 10.95C_{OCP} + 117.5 \quad (4.13)$$

For 60 stock: (correlation coefficient = 99.4%)

$$VI = 4.5C_{OCP} + 93 \quad (4.14)$$

For 150 stock: (correlation coefficient = 98.9%)

$$VI = 3.6C_{OCP} + 86.5 \quad (4.15)$$

For H-340 the correlations at 4 wt% of this additive is different from the correlations of 8 wt%. These functional relationships were obtained depending on Tables 4-11 and 4-12 as follows:

At 4 wt% of H-340 and OCP concentration (0-8 wt%):

For 40 stock: (correlation coefficient = 99.6%)

$$VI = 11.8C_{OCP} + 111 \quad (4.16)$$

For 60 stock: (correlation coefficient = 97.0%)

$$VI = 1.35C_{OCP} + 95.5 \quad (4.17)$$

For 150 stock: (correlation coefficient = 99.5%)

$$VI = 1.9C_{OCP} + 92 \quad (4.18)$$

At 8 wt% of H-340 and OCP concentration (0-8 wt%):

For 40 stock: (correlation coefficient = 99.8%)

$$VI = 9.9C_{OCP} + 109.5 \quad (4.19)$$

For 60 stock: (correlation coefficient = 97.6%)

$$VI = C_{OCP} + 95.5 \quad (4.20)$$

For 150 stock: (correlation coefficient = 98.9%)

$$VI = 1.5C_{OCP} + 91.5 \quad (4.21)$$

For the correlations above the error percentage is in the range of 2-3%. These functional relationships are applicable only for this set of blends and it can be applied usefully for determining the VI values at any OCP concentration or vice versa.

Chapter Five

Conclusions and Recommendations

5.1 Conclusions

From the proposed study, the following conclusions have been extracted:

1. The kinematic viscosity of the heavy oil (150 stock) is affected by increasing temperature more than the medium oil (60 stock) and light oil (40 stock).
2. The kinematic viscosity of the mixtures prepared from base oil, viscosity index improver and additives will decrease with increasing temperature as their resistance to flow will decrease, while their intrinsic viscosity will increase.
3. The used additives (Lubrizol 21001, H-8722B and H-340) are packages containing a polymeric chain which behaves as a viscosity index improver. So when those additives are blended with the base oil only the viscosity index will increase slightly and this is recommended in monograde oils. While when those additives are blended with the base oil and with a viscosity index improver like OCP, the obtained oil will be a multigrade oil.
4. The maximum value of the viscosity index for the three types of base oils (40, 60 and 150 stock) will be obtained when blended with 2 wt% of H-340 additive, but it will decrease at higher concentrations.
5. The reduced viscosity of the three base oil types will increase with increasing the concentration of OCP (VII) and additives (Lubrizol 21001 and H-8722B).
6. The efficiency of OCP is decreased with an increasing rate when blended with 4 and 8 wt% of Lubrizol 21001 for all the three base oil types.
7. The efficiency of OCP is increased when adding 4 wt% of H-8722B in 40 stock and decreased when adding 8 wt%. For 60 stock the OCP efficiency

decreased by adding 4 and 8 wt%. While for 150 stock the efficiency of OCP will decreased by adding 4 and 8 wt% of H-8722B.

8. H-340 would strongly decrease the efficiency of OCP for 60 and 150 stock by adding 4 and 8 wt% of H-340. While for 40 stock the efficiency at 4 wt% of H-340 is increased and decreased when adding 8 wt% of H-340.

5.2 Recommendations

The following recommendations are proposed in order to extend the reported investigation in this thesis:

1. Study the influence of another type of viscosity index improvers for base lubricating oil, like polyalkyl methacrylates (PAMAs), poly isobutylenes (PIBs) or may be other type, by using the same used additives.
2. Influence of other types of additives like anti-corrosion, anti-foam, pour point dispersant or many other types of additives on the efficiency of OCP in the three base oil types.
3. Estimation the flow activation energy of the whole studied system.
4. Estimation of the Mark-Houwink constants (k and a) for the used system in spite of the unknown molecular weights.
5. Study the rheological behavior of the whole studied system weather it is Newtonian or non Newtonian and show if it is Pseudo, dilatanz, thixotropy or rheopexy and drowing figures between shear stress and shear rate.
6. Estimation the intrinsic viscosity equations' constants of Huggins, Kreamer and Scuhulz-Blaschke.
7. Investigation the structure of the used OCP (PVC-100XA) and additives (Lubrizol 21001, HiTEC 8722B and HiTEC 340).
8. Study the effect of varying the pressure for the used system.

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Appendix A

Kinematic Viscosity

Table A-1 Kinematic Viscosity of 40 stock Blended with OCP at Different Temperatures

OCP wt%	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
0	12.735	6.925	4.509	3.126
2	18.537	10.106	6.621	4.619
4	24.677	13.688	8.999	6.270
6	32.729	17.971	11.841	8.359
8	42.685	23.554	15.756	10.995
10	55.049	30.375	20.142	14.165

Table A-2 Kinematic Viscosity of 40 stock Blended with Lubrizol 21001 at Different Temperatures

Lubrizol 21001 wt.%	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
0	12.735	6.925	4.509	3.126
2	13.836	7.460	4.812	3.312
4	15.045	8.070	5.204	3.547
6	16.485	8.831	5.664	3.824
8	17.875	9.589	6.161	4.098
10	19.397	10.392	6.677	4.424

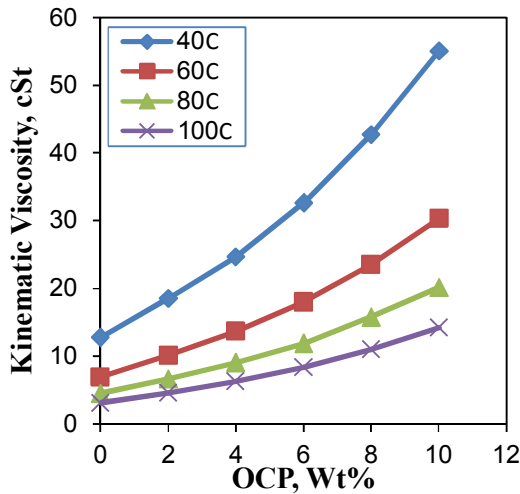


Figure A-1

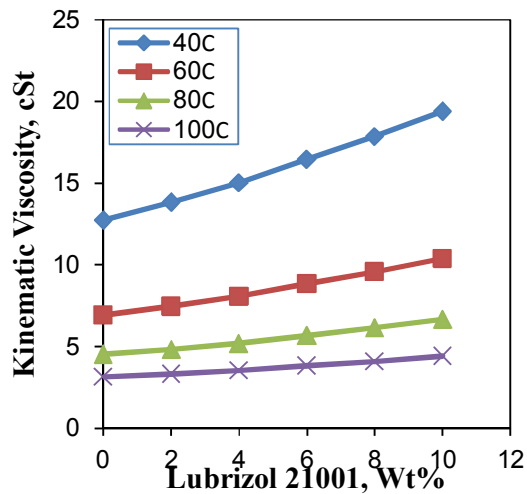


Figure A-2

Table A-3 Kinematic Viscosity of 40 stock and 4 wt% of Lubrizol 21001 with Different Concentrations of OCP at Different Temperatures

OCP wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
2	22.335	12.169	7.848	5.203
4	32.375	17.517	11.225	7.642
6	42.464	23.032	14.704	10.104
8	52.995	28.592	18.339	12.593

Table A-4 Kinematic Viscosity of 40 stock and 8 wt% of Lubrizol 21001 with Different Concentrations of OCP at Different Temperatures

OCP wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
2	20.886	11.318	7.236	4.951
4	30.422	16.339	10.266	6.942
6	42.174	22.407	14.071	9.411
8	55.192	28.959	18.261	12.305

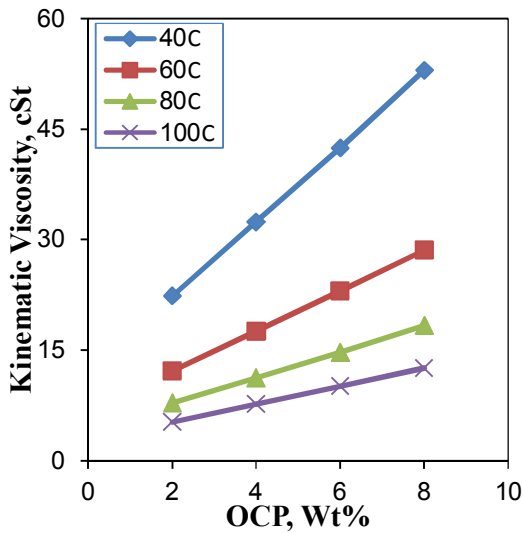


Figure A-3

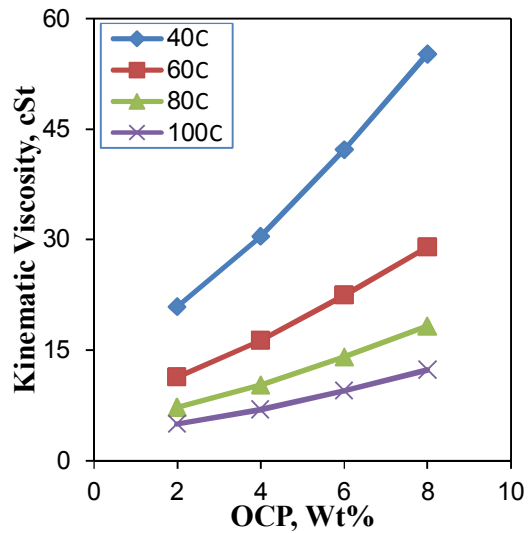


Figure A-4

Table A-5 Kinematic Viscosity of 40 stock Blended with H-8722B at Different Temperatures

H-8722B wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
0	12.735	6.925	4.509	3.126
2	13.554	7.351	4.754	3.275
4	14.424	7.791	5.016	3.425
6	15.572	8.319	5.336	3.629
8	16.828	8.963	5.692	3.871
10	18.114	9.632	6.152	4.098

Table A-6 Kinematic Viscosity of 40 stock and 4 wt% of H-8722B with Different Concentrations of OCP at Different Temperatures

OCP wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
2	17.751	9.425	6.109	4.152
4	23.962	12.559	8.049	5.454
6	31.003	16.119	10.312	6.916
8	38.642	19.918	12.839	8.842

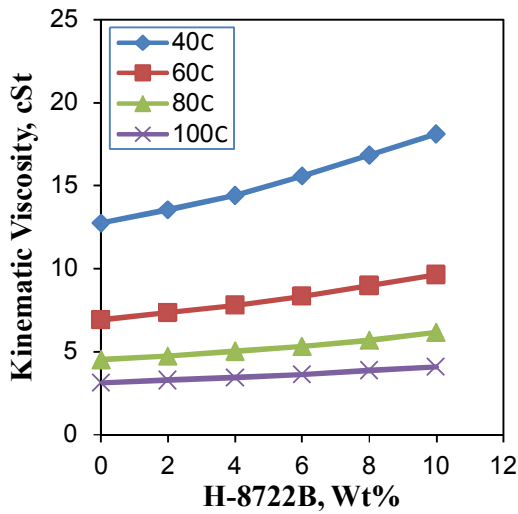


Figure A-5

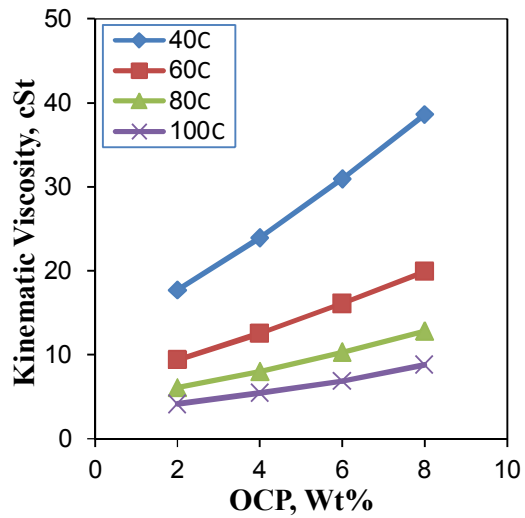


Figure A-6

Table A-7 Kinematic Viscosity of 40 stock and 8 wt% of H-8722B with Different Concentrations of OCP at Different Temperatures

OCP wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
2	17.589	9.380	6.034	4.114
4	22.983	12.116	7.670	5.145
6	29.672	15.335	9.742	6.478
8	36.625	19.144	12.370	8.139

Table A-8 Kinematic Viscosity of 40 stock Blended with H-340 at Different Temperatures

H-340 wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
0	12.735	7.925	5.509	3.126
2	12.435	7.219	4.860	3.108
4	11.829	6.880	4.018	2.985
6	11.123	6.183	3.961	2.850
8	10.523	5.228	3.562	2.743
10	9.783	4.279	3.006	2.611

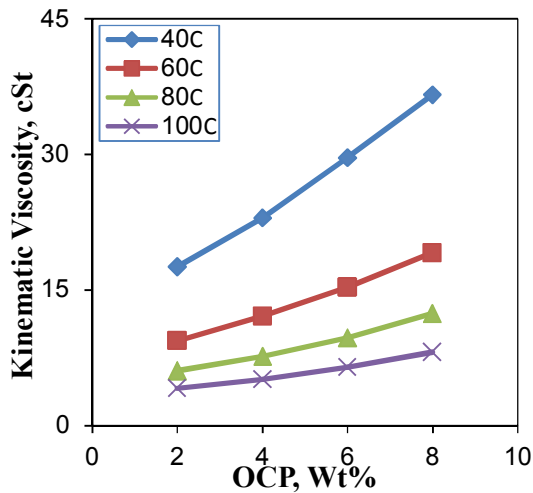


Figure A-7

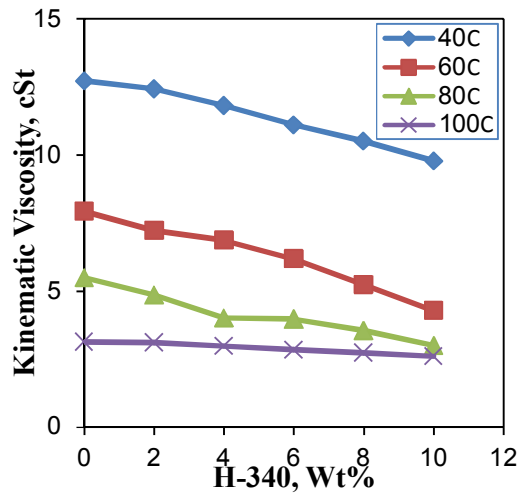


Figure A-8

Table A-9 Kinematic Viscosity of 40 stock and 4 wt% of H-340 with Different Concentrations of OCP at Different Temperatures

OCP wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
2	16.387	8.8463	5.6692	3.8835
4	20.769	11.052	7.0171	4.8127
6	25.723	13.438	8.5044	5.7746
8	30.523	18.175	10.286	7.0835

Table A-10 Kinematic Viscosity of 40 stock and 8 wt% of H-340 with Different Concentrations of OCP at Different Temperatures

OCP wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
2	15.611	8.3724	5.4110	3.7403
4	19.418	10.439	6.5897	4.4567
6	23.149	12.334	7.8854	5.3348
8	28.227	15.007	9.1951	6.2715

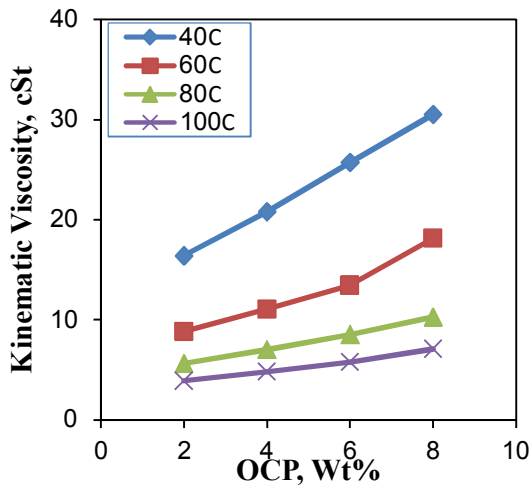


Figure A-9

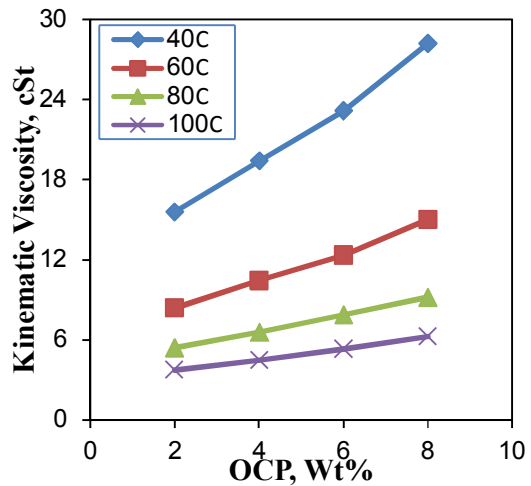


Figure A-10

Table A-11 Kinematic Viscosity of 60 stock Blended with OCP at Different Temperatures

OCP wt%	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
0	68.216	30.654	14.987	8.642
2	96.029	41.987	20.750	12.180
4	122.685	56.512	27.369	16.368
6	158.125	73.628	37.335	21.602
8	194.418	89.619	46.992	27.107
10	228.286	105.89	55.228	32.002

Table A-12 Kinematic Viscosity of 60 stock Blended with Lubrizol 21001 at Different Temperatures

Lubrizol 21001wt.%	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
0	68.215	30.654	14.987	8.6421
2	73.137	32.513	15.757	9.1069
4	78.149	34.536	16.536	9.6107
6	84.225	37.084	17.889	10.287
8	91.109	39.877	18.954	10.926
10	99.037	42.576	20.275	11.694

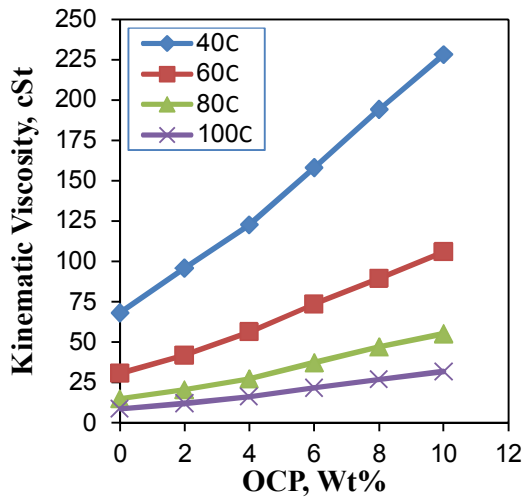


Figure A-11

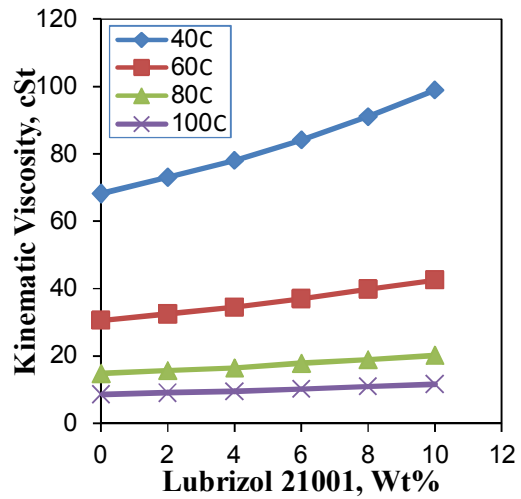


Figure A-12

Table A-13 Kinematic Viscosity of 60 stock and 4 wt% of Lubrizol 21001 with Different Concentrations of OCP at Different Temperatures

OCP wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
2	103.295	45.366	22.045	12.469
4	140.203	60.835	29.574	16.721
6	181.631	79.059	37.931	21.649
8	226.119	100.354	48.291	26.728

Table A-14 Kinematic Viscosity of 60 stock and 8 wt% of Lubrizol 21001 with Different Concentrations of OCP at Different Temperatures

OCP wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
2	100.021	44.599	21.115	11.748
4	131.031	60.679	29.216	14.889
6	184.621	81.671	38.279	19.974
8	239.046	106.21	49.223	24.817

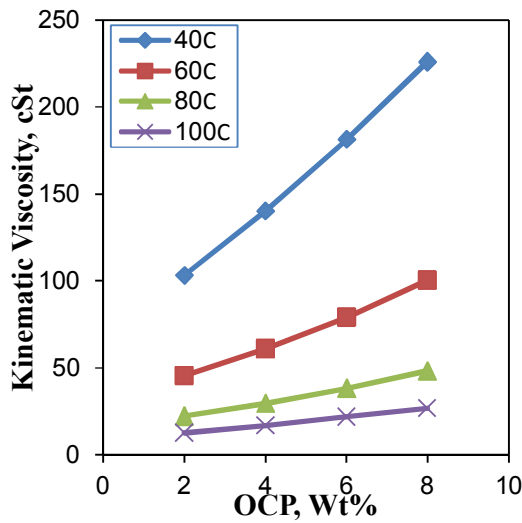


Figure A-13

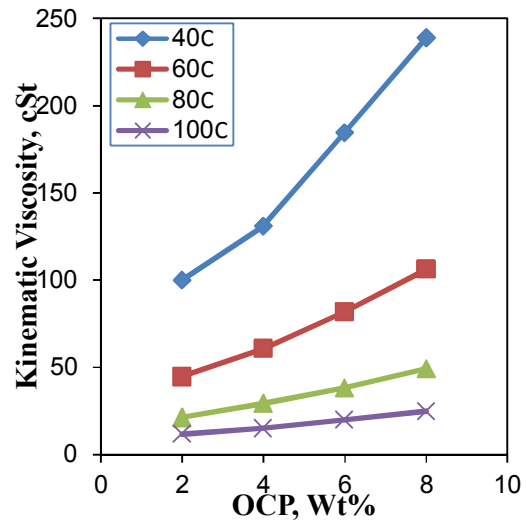


Figure A-14

Table A-15 Kinematic Viscosity of 60 stock Blended with H-8722B at Different Temperatures

H-8722B wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
0	68.215	30.654	14.986	8.642
2	71.810	32.059	15.554	8.951
4	75.843	32.531	16.159	9.283
6	80.085	35.372	16.932	9.679
8	84.402	37.413	17.915	10.109
10	89.360	39.664	19.002	10.675

Table A-16 Kinematic Viscosity of 60 stock and 4 wt% of H-8722B with Different Concentrations of OCP at Different Temperatures

OCP wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
2	100.502	44.535	21.148	11.911
4	135.185	59.914	27.773	15.447
6	178.352	76.459	36.132	20.215
8	219.962	94.446	45.893	25.843

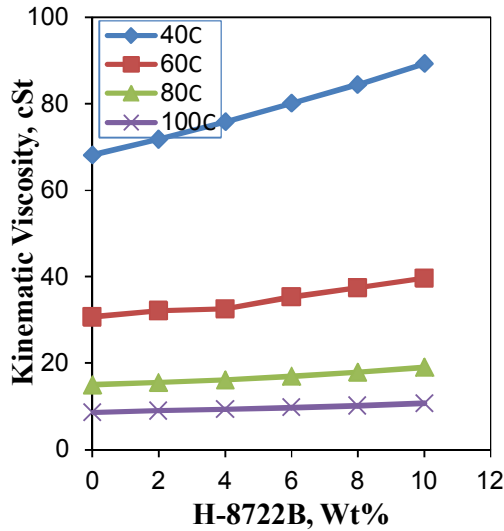


Figure A-15

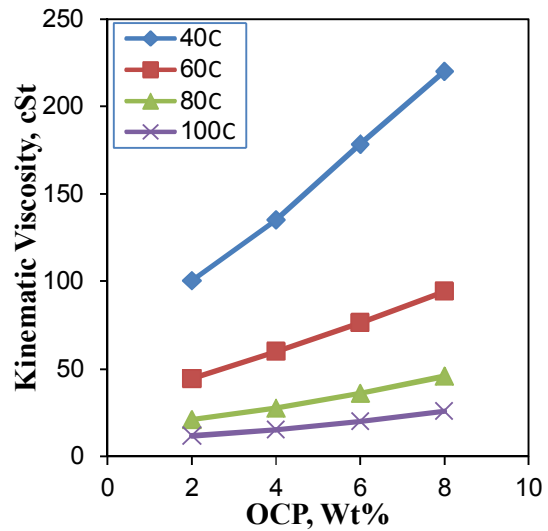


Figure A-16

Table A-17 Kinematic Viscosity of 60 stock and 8 wt% of H-8722B with Different Concentrations of OCP at Different Temperatures

OCP wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
2	96.100	41.898	19.949	11.073
4	125.874	55.992	26.211	14.354
6	172.307	71.371	32.579	18.435
8	225.172	92.161	41.948	23.272

Table A-18 Kinematic Viscosity of 60 stock Blended with H-340 at Different Temperatures

H-340 wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
0	68.215	30.654	14.986	8.642
2	67.633	30.524	14.897	8.637
4	67.440	30.262	14.753	8.602
6	66.258	29.499	14.275	8.498
8	65.289	29.303	14.203	8.301
10	64.932	29.089	14.092	8.138

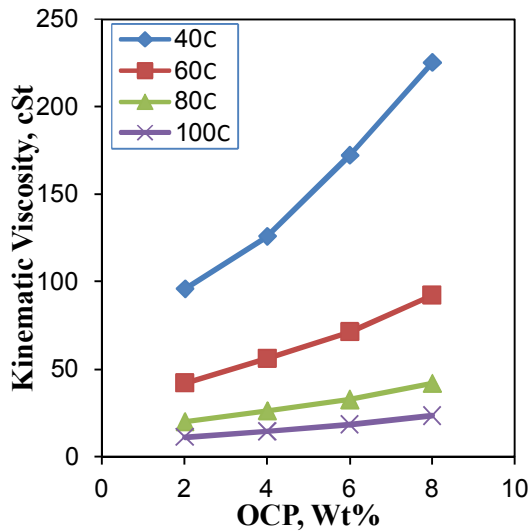


Figure A-17

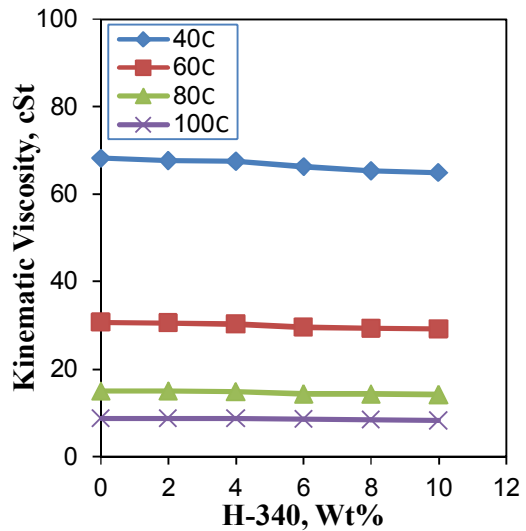


Figure A-18

Table A-19 Kinematic Viscosity of 60 stock and 4 wt% of H-340 with Different Concentrations of OCP at Different Temperatures

OCP wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
2	74.287	33.121	16.115	9.238
4	82.193	36.333	17.599	9.918
6	96.335	41.263	19.957	11.272
8	115.849	48.907	23.487	13.065

Table A-20 Kinematic Viscosity of 60 stock and 8 wt% of H-340 with Different Concentrations of OCP at Different Temperatures

OCP wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
2	72.046	32.264	15.708	9.006
4	76.854	34.051	16.489	9.466
6	86.579	38.166	18.280	10.344
8	98.427	43.237	20.546	11.502

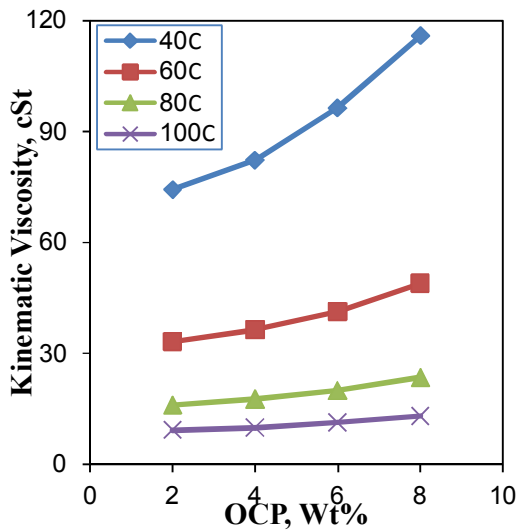


Figure A-19

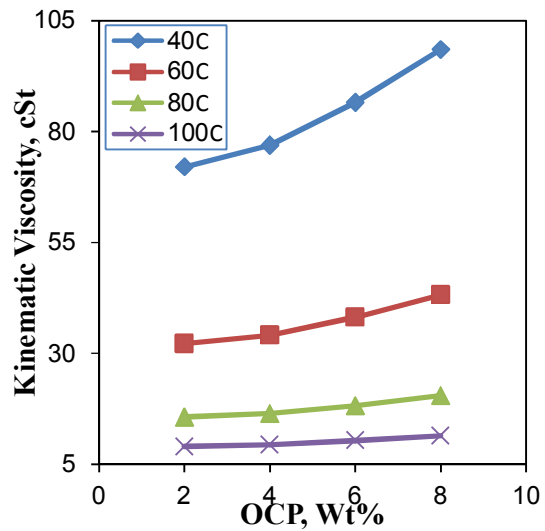


Figure A-20

Table A-21 Kinematic Viscosity of 150 stock Blended with OCP at Different Temperatures

OCP wt%	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
0	325.967	144.649	57.683	23.349
2	440.191	195.999	78.431	31.828
4	558.350	248.596	99.548	40.822
6	680.787	303.488	121.474	49.503
8	813.748	362.329	145.256	58.924
10	946.110	420.580	168.633	67.533

Table A-22 Kinematic Viscosity of 150 stock Blended with Lubrizol 21001 at Different Temperatures

Lubrizol 21001wt.%	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
0	325.967	244.649	117.683	23.349
2	353.577	264.279	126.014	24.702
4	368.696	274.844	131.944	25.892
6	383.979	286.430	136.716	26.716
8	394.935	293.668	140.131	27.587
10	406.068	301.172	144.436	28.488

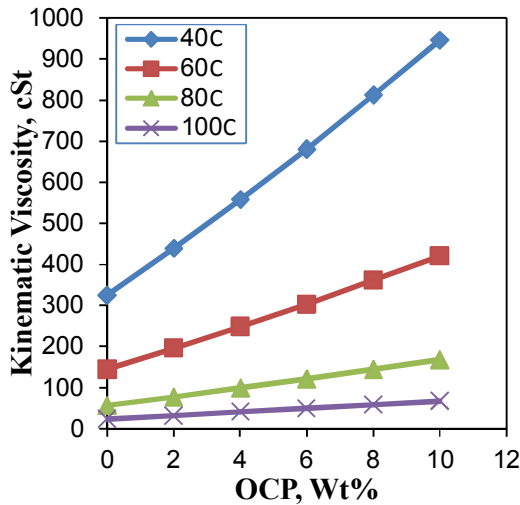


Figure A-21

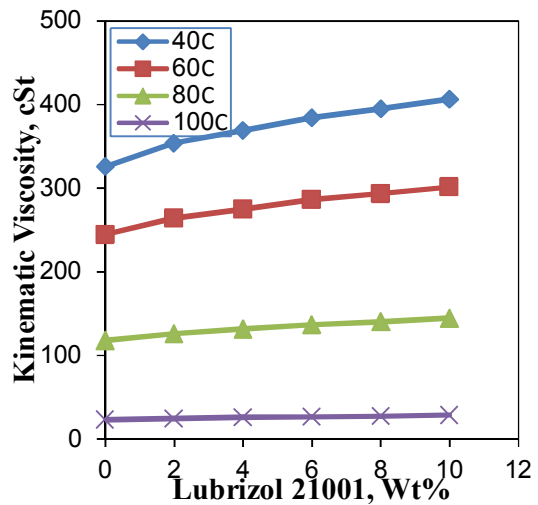


Figure A-22

Table A-23 Kinematic Viscosity of 150 stock and 4 wt% of Lubrizol 21001 with Different Concentrations of OCP at Different Temperatures

OCP wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
2	500.058	372.947	178.701	34.896
4	650.338	469.894	217.021	42.862
6	760.681	560.319	262.541	49.730
8	830.962	616.586	294.746	55.177

Table A-24 Kinematic Viscosity of 150 stock and 8 wt% of Lubrizol 21001 with Different Concentrations of OCP at Different Temperatures

OCP wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
2	484.608	361.617	172.631	33.137
4	620.146	458.745	214.289	41.074
6	708.880	523.745	240.323	46.544
8	756.827	557.947	263.984	49.911

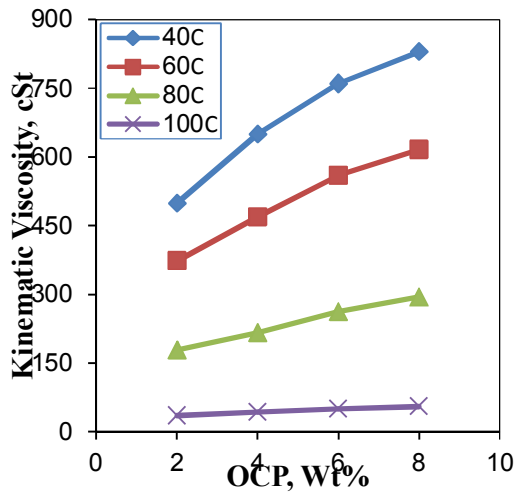


Figure A-23

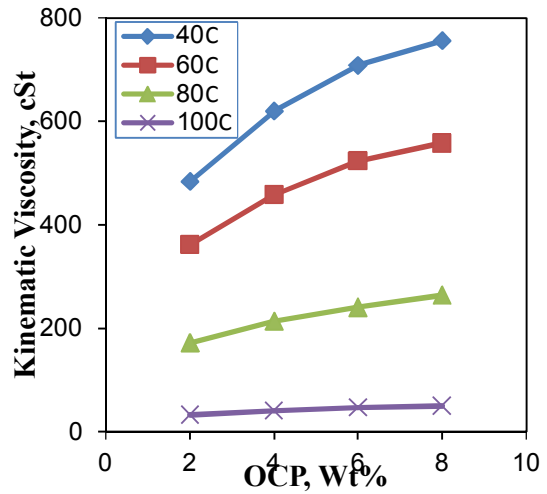


Figure A-24

Table A-25 Kinematic Viscosity of 150 stock Blended with H-8722B at Different Temperatures

H-8722B wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
0	325.967	244.649	117.683	23.349
2	349.477	260.351	124.614	24.495
4	367.756	274.745	130.049	25.468
6	381.060	284.479	135.349	26.062
8	391.520	292.213	139.268	26.716
10	399.594	293.287	139.901	27.105

Table A-23 Kinematic Viscosity of 150 stock and 4 wt% of H-8722B with Different Concentrations of OCP at Different Temperatures

OCP wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
2	495.234	363.819	167.897	32.281
4	645.167	468.373	215.755	40.226
6	746.100	553.958	260.469	47.730
8	819.931	602.586	287.274	54.247

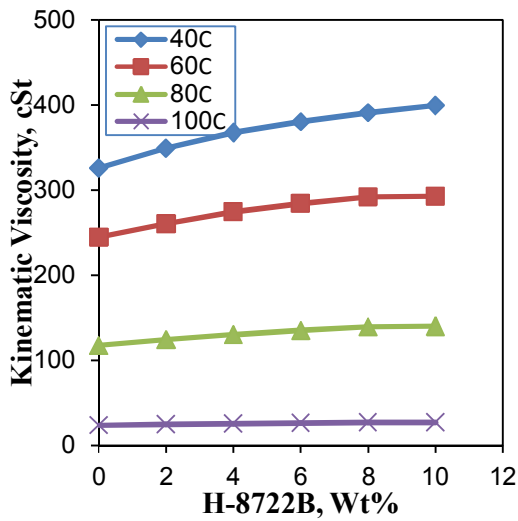


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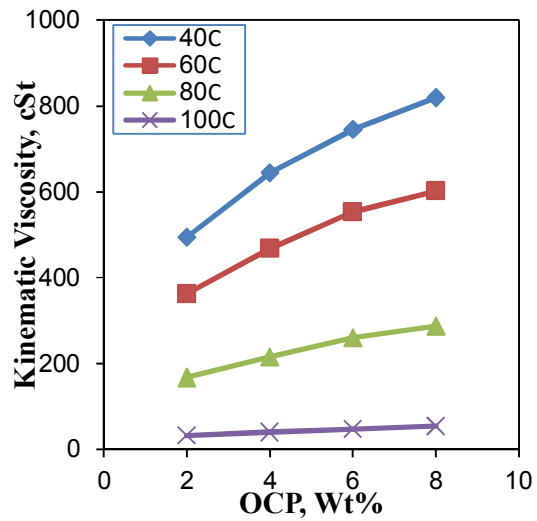


Figure A-26

Table A-27 Kinematic Viscosity of 150 stock and 8 wt% of H-8722B with Different Concentrations of OCP at Different Temperatures

OCP wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
2	479.848	354.373	163.556	31.277
4	611.425	442.426	199.698	37.957
6	693.952	505.489	235.155	44.079
8	744.767	551.437	259.209	49.085

Table A-28 Kinematic Viscosity of 150 stock Blended with H-340 at Different Temperatures

H-340 wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
0	325.967	244.649	114.683	23.349
2	311.546	244.181	117.506	23.332
4	300.565	235.553	114.637	23.102
6	295.944	232.075	112.561	22.017
8	282.120	219.564	108.379	20.962
10	279.035	215.373	103.936	20.572

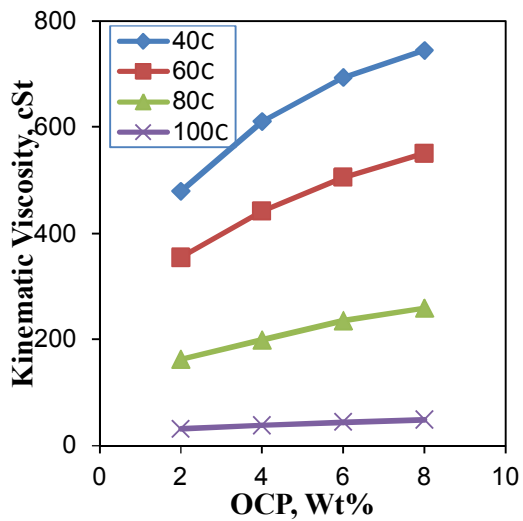


Figure A-27

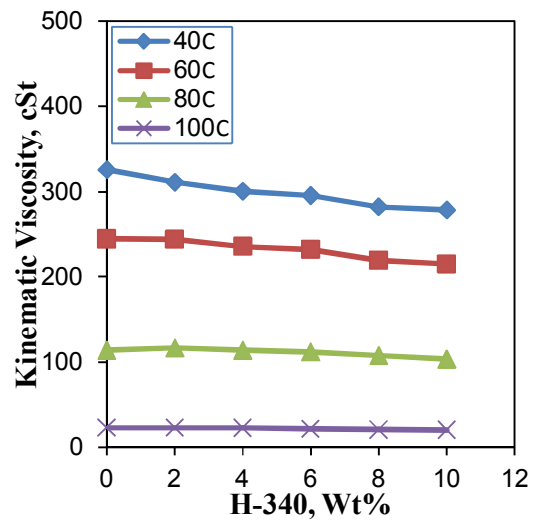


Figure A-28

Table A-29 Kinematic Viscosity of 150 stock and 4 wt% of H-340 with Different Concentrations of OCP at Different Temperatures

OCP wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
2	380.832	284.575	136.136	26.975
4	430.568	319.585	152.256	29.972
6	467.991	347.447	165.672	32.663
8	483.415	360.224	173.019	34.336

Table A-30 Kinematic Viscosity of 150 stock and 8 wt% of H-340 with Different Concentrations of OCP at Different Temperatures

OCP wt. %	Viscosity at 40°C	Viscosity at 60°C	Viscosity at 80°C	Viscosity at 100°C
2	372.682	278.628	133.426	26.361
4	416.198	309.554	146.813	28.796
6	442.069	328.926	156.836	30.785
8	462.609	345.745	165.684	32.665

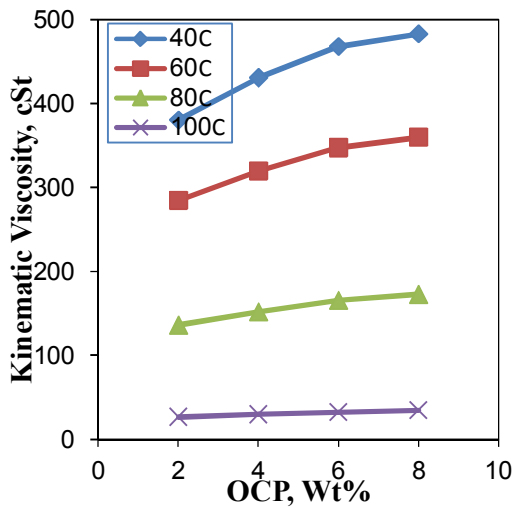


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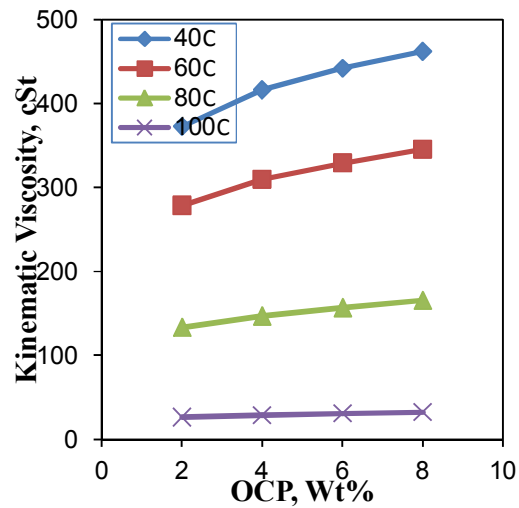


Figure A-30

Appendix B

Viscosity Index

Table B-1 Kinematic Viscosities of Base Lubricating Oil at Different Temperatures

Base Lubricating Oil Type	Kinematic Viscosity, cSt			
	40°C	60°C	80°C	100°C
40 stock	12.735	6.925	4.509	3.126
60 stock	68.216	30.654	14.987	8.642
150 stock	325.967	144.649	57.683	23.349

Table B-2 Viscosity Index Values of Base Oil Blended with OCP

OCP wt%	VI of 40 stock	VI of 60 stock	VI of 150 stock
0	106	97	90
2	178	119	105
4	223	143	117
6	248	162	126
8	262	176	133
10	270	185	138

Table B-3 VI Values of Base Oil Blended with Lubrizol 21001

Lubrizol 21001 wt%	VI of 40 stock	VI of 60 stock	VI of 150 stock
0	106	97	90
2	109	99	91
4	117	101	93
6	125	103	94
8	133	105	96
10	144	107	97

Table B-4 Viscosity Index Values of Base Oil Blended with H-8722B

H-8722B wt%	VI of 40 stock	VI of 60 stock	VI of 150 stock
0	106	97	90
2	109	98	90
4	112	98	91
6	118	99	91
8	124	100	92
10	129	102	92

Table B-5 Viscosity Index Values of Base Oil Blended with H-340

H-340 wt%	VI of 40 stock	VI of 60 stock	VI of 150 stock
0	106	97	90
2	110	98	94
4	106	98	93
6	102	98	90
8	100	95	88
10	97	91	86

Table B-6 Viscosity Index Values of Base Oil and 4 wt% of Lubrizol 21001 with Different Concentrations of OCP at Different Temperatures

OCP wt%	VI of 40 stock	VI of 60 stock	VI of 150 stock
2	176	114	103
4	218	128	110
6	236	142	116
8	245	152	122

Table B-7 Viscosity Index Values of Base Oil and 8 wt% of Lubrizol 21001 with Different Concentrations of OCP at Different Temperatures

OCP wt%	VI of 40 stock	VI of 60 stock	VI of 150 stock
2	174	106	101
4	200	113	108
6	216	125	113
8	228	132	117

Table B-8 Viscosity Index Values of Base Oil and 4 wt% of H-8722B with Different Concentrations of OCP at Different Temperatures

OCP wt%	VI of 40 stock	VI of 60 stock	VI of 150 stock
2	141	108	97
4	175	118	102
6	194	132	112
8	219	149	121

Table B-9 Viscosity Index Values of Base Oil and 8 wt% of H-8722B with Different Concentrations of OCP at Different Temperatures

OCP wt%	VI of 40 stock	VI of 60 stock	VI of 150 stock
2	139	100	95
4	163	114	99
6	181	120	108
8	206	128	116

Table B-10 VI Values of Base Oil and 4 wt% of H-340 with Different Concentrations of OCP at Different Temperatures

OCP wt%	VI of 40 stock	VI of 60 stock	VI of 150 stock
2	134	99	96
4	161	100	99
6	178	103	103
8	207	107	107

Table B-11 VI Values of Base Oil and 8 wt% of H-340 with Different Concentrations of OCP at Different Temperatures

OCP wt%	VI of 40 stock	VI of 60 stock	VI of 150 stock
2	131	98	95
4	147	99	97
6	168	101	100
8	190	104	104

Appendix C

Relative, Specific, Reduced and Intrinsic Viscosity

Table C-1 40 stock Blended with OCP at 40°C, (t₀ = 113.79 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	[η]
2	205.32	1.8044	0.8044	0.40220	0.3936
4	302.83	2.6613	1.6613	0.41533	
6	403.08	3.5423	2.5423	0.42372	
8	510.14	4.4832	3.4832	0.43553	
10	618.12	5.4321	4.4321	0.44321	

Table C-2 40 stock Blended with OCP at 60°C, (t₀ = 104.77 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	[η]
2	191.84	1.8311	0.8311	0.41555	0.4084
4	284.22	2.7128	1.7128	0.42820	
6	377.47	3.6028	2.6028	0.43380	
8	477.64	4.5589	3.5589	0.44486	
10	577.47	5.5118	4.5118	0.45118	

Table C-3 40 stock Blended with OCP at 80°C, (t₀ = 80.88 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	[η]
2	150.26	1.8578	0.8578	0.42890	0.4183
4	221.22	2.7352	1.7352	0.43380	
6	294.17	3.6371	2.6371	0.43952	
8	369.96	4.5742	3.5742	0.44678	
10	454.81	5.6233	4.6233	0.46233	

Table C-4 40 stock Blended with OCP at 100°C, (t₀ = 60.17 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	[η]
2	112.34	1.8670	0.8670	0.43350	0.4238
4	166.24	2.7628	1.7628	0.44070	
6	221.05	3.6738	2.6738	0.44562	
8	277.85	4.6177	3.6177	0.45221	
10	342.08	5.6852	4.6852	0.46852	

Table C-5 40 stock Blended with Lubrizol 21001 at 40°C, (t₀ = 113.79 sec)

Lubrizol 21001 wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	[η]
2	120.56	1.0595	0.0595	0.02975	0.0276
4	129.11	1.1345	0.1345	0.03363	
6	139.19	1.2232	0.2232	0.03720	
8	149.16	1.3108	0.3108	0.03885	
10	161.04	1.4152	0.4152	0.04152	

Table C-6 40 stock Blended with Lubrizol 21001 at 60°C, (t₀ = 104.77 sec)

Lubrizol 21001wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	[η]
2	111.90	1.0681	0.0681	0.03405	0.0314
4	120.92	1.1541	0.1541	0.03853	
6	131.58	1.2559	0.2559	0.04265	
8	143.16	1.3664	0.3664	0.04580	
10	155.13	1.4807	0.4807	0.04807	

Table C-7 40 stock Blended with Lubrizol 21001 at 80°C, (t₀ = 80.88 sec)

Lubrizol 21001wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	[η]
2	87.12	1.0772	0.0772	0.03860	0.0359
4	94.25	1.1653	0.1653	0.04133	
6	103.14	1.2752	0.2752	0.04587	
8	111.99	1.3846	0.3846	0.04808	
10	121.37	1.5006	0.5006	0.05006	

Table C-8 40 stock Blended with Lubrizol 21001 at 100°C, (t₀ = 60.17 sec)

Lubrizol 21001wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	[η]
2	65.37	1.0865	0.0865	0.04325	0.0412
4	71.08	1.1813	0.1813	0.04533	
6	77.89	1.2945	0.2945	0.04908	
8	84.46	1.4037	0.4037	0.05046	
10	91.65	1.5232	0.5232	0.05232	

Table C-9 40 stock Blended with 4 wt% of Lubrizol 21001 at 40°C, (t₀ = 113.79 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	[η]
2	196.66	1.7283	0.7283	0.36415	0.3595
4	281.80	2.4765	1.4765	0.36913	
6	367.77	3.2320	2.2320	0.37200	
8	458.38	4.0283	3.0283	0.37854	

Table C-10 40 stock Blended with 4 wt% of Lubrizol 21001 at 60°C, (t₀ = 104.77 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	[η]
2	182.32	1.7402	0.7402	0.37010	0.3646
4	260.80	2.4893	1.4893	0.37233	
6	341.63	3.2608	2.2608	0.37680	
8	426.08	4.0668	3.0668	0.38335	

Table C-11 40 stock Blended with 4 wt% of Lubrizol 21001 at 80°C, (t₀ = 80.88 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	142.11	1.7570	0.7570	0.37850	0.3743
4	204.58	2.5294	1.5294	0.38235	
6	268.99	3.3258	2.3258	0.38763	
8	333.92	4.1286	3.1286	0.39108	

Table C-12 40 stock Blended with 4 wt% of Lubrizol 21001 at 100°C, (t₀ = 60.17 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	106.10	1.7633	0.7633	0.38165	0.3768
4	152.96	2.5421	1.5421	0.38553	
6	200.64	3.3346	2.3346	0.38910	
8	250.39	4.1614	3.1614	0.39518	

Table C-13 40 stock Blended with 8 wt% of Lubrizol 21001 at 40°C, (t₀ = 113.79 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	184.76	1.6237	0.6237	0.31185	0.2972
4	261.77	2.3005	1.3005	0.32513	
6	344.60	3.0284	2.0284	0.33807	
8	436.96	3.8401	2.8401	0.35501	

Table C-14 40 stock Blended with 8 wt% of Lubrizol 21001 at 60°C, (t₀ = 104.77 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	172.32	1.6447	0.6447	0.32235	0.3116
4	246.90	2.3566	1.3566	0.33915	
6	321.88	3.0723	2.0723	0.34538	
8	407.50	3.8895	2.8895	0.36119	

Table C-15 40 stock Blended with 8 wt% of Lubrizol 21001 at 80°C, (t₀ = 80.88 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	135.41	1.6742	0.6742	0.33710	0.3238
4	194.06	2.3994	1.3994	0.34985	
6	254.41	3.1455	2.1455	0.35758	
8	325.27	4.0216	3.0216	0.37770	

Table C-16 40 stock Blended with 8 wt% of Lubrizol 21001 at 100°C, (t₀ = 60.17 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	101.09	1.6801	0.6801	0.34005	0.3261
4	145.18	2.4128	1.4128	0.35320	
6	192.04	3.1916	2.1916	0.36527	
8	243.89	4.0533	3.0533	0.38166	

Table C-17 40 stock Blended with H-8722B at 40°C, ($t_0 = 113.79$ sec)

H-8722B wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	119.19	1.0475	0.0475	0.02375	0.0209
4	124.67	1.0956	0.0956	0.02390	
6	132.09	1.1608	0.1608	0.02680	
8	140.91	1.2383	0.2383	0.02979	
10	149.22	1.3114	0.3114	0.03114	

Table C-18 40 stock Blended with H-8722B at 60°C, ($t_0 = 104.77$ sec)

H-8722B wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	110.45	1.0542	0.0542	0.02710	0.0240
4	116.55	1.1124	0.1124	0.02808	
6	123.96	1.1832	0.1832	0.03053	
8	132.24	1.2622	0.2622	0.03278	
10	142.93	1.3642	0.3642	0.03642	

Table C-19 40 stock Blended with H-8722B at 80°C, ($t_0 = 80.88$ sec)

H-8722B wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	85.85	1.0614	0.0614	0.03070	0.0276
4	90.98	1.1249	0.1249	0.03123	
6	97.15	1.2012	0.2012	0.03353	
8	104.67	1.2941	0.2941	0.03676	
10	112.49	1.3908	0.3908	0.03908	

Table C-20 40 stock Blended with H-8722B at 100°C, ($t_0 = 60.17$ sec)

H-8722B wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	64.04	1.0643	0.0643	0.03215	0.0288
4	68.15	1.1326	0.1326	0.03315	
6	73.58	1.2229	0.2229	0.03715	
8	79.51	1.3214	0.3214	0.04018	
10	85.59	1.4225	0.4225	0.04225	

Table C-21 40 stock Blended with 4 wt% of H-8722B at 40°C, ($t_0 = 113.79$ sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	151.12	1.3281	0.3281	0.16405	0.1428
4	198.52	1.7446	0.7446	0.18615	
6	251.73	2.2122	1.2122	0.20203	
8	321.83	2.8283	1.8283	0.22854	

Table C-22 40 stock Blended with 4 wt% of H-8722B at 60°C, (t₀ = 104.77 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	141.94	1.3548	0.3548	0.17740	0.1604
4	187.00	1.7849	0.7849	0.19623	
6	239.59	2.2868	1.2868	0.21447	
8	298.29	2.8471	1.8471	0.23089	

Table C-23 40 stock Blended with 4 wt% of H-8722B at 80°C, (t₀ = 80.88 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	110.88	1.3709	0.3709	0.18545	0.1720
4	151.54	1.8736	0.8736	0.21840	
6	191.16	2.3635	1.3635	0.22725	
8	240.37	2.9719	1.9719	0.24649	

Table C-24 40 stock Blended with 4 wt% of H-8722B at 100°C, (t₀ = 60.17 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	83.87	1.3939	0.3939	0.19695	0.1801
4	113.22	1.8817	0.8817	0.22043	
6	146.48	2.4344	1.4344	0.23907	
8	182.58	3.0344	2.0344	0.25430	

Table C-25 40 stock Blended with 8 wt% of H-8722B at 40°C, (t₀ = 113.79 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	148.37	1.3039	0.3039	0.15195	0.1375
4	186.37	1.6378	0.6378	0.15945	
6	228.96	2.0121	1.0121	0.16868	
8	285.34	2.5076	1.5076	0.18845	

Table C-26 40 stock Blended with 8 wt% of H-8722B at 60°C, (t₀ = 104.77 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	140.19	1.3381	0.3381	0.16905	0.1466
4	178.20	1.7009	0.7009	0.17523	
6	226.35	2.1604	1.1604	0.19340	
8	287.41	2.7432	1.7432	0.21790	

Table C-27 40 stock Blended with 8 wt% of H-8722B at 80°C, (t₀ = 80.88 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	109.55	1.3545	0.3545	0.17725	0.1612
4	141.49	1.7494	0.7494	0.18735	
6	179.09	2.2143	1.2143	0.20238	
8	223.78	2.7643	1.7643	0.22054	

Table C-28 40 stock Blended with 8 wt% of H-8722B at 100°C, (t₀ = 60.17 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	83.10	1.3811	0.3811	0.19055	0.1741
4	108.56	1.8042	0.8042	0.20105	
6	139.11	2.3119	1.3119	0.21865	
8	168.23	2.7959	1.7959	0.22449	

Table C-29 40 stock Blended with H-340 at 40°C, (t₀ = 113.79 sec)

H-340 wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	114.28	1.0043	0.0043	0.00215	0.00102
4	114.96	1.0103	0.0103	0.00258	
6	116.03	1.0197	0.0197	0.00328	
8	118.07	1.0376	0.0376	0.00470	
10	119.99	1.0545	0.0545	0.00545	

Table C-30 40 stock Blended with H-340 at 60°C, (t₀ = 104.77 sec)

H-340 wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	105.62	1.0081	0.0081	0.00405	0.00334
4	106.68	1.0182	0.0182	0.00455	
6	107.89	1.0298	0.0298	0.00497	
8	109.66	1.0467	0.0467	0.00584	
10	111.59	1.0651	0.0651	0.00651	

Table C-31 40 stock Blended with H-340 at 80°C, (t₀ = 80.88 sec)

H-340 wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	81.72	1.0104	0.0104	0.00520	0.00466
4	82.73	1.0229	0.0229	0.00573	
6	83.98	1.0383	0.0383	0.00638	
8	85.29	1.0545	0.0545	0.00681	
10	86.91	1.0746	0.0746	0.00746	

Table C-32 40 stock Blended with H-340 at 100°C, (t₀ = 60.17 sec)

H-340 wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	60.96	1.0132	0.0132	0.00660	0.00612
4	61.85	1.0279	0.0279	0.00698	
6	62.94	1.0460	0.0460	0.00767	
8	63.89	1.0618	0.0618	0.00773	
10	65.31	1.0855	0.0855	0.00855	

Table C-33 40 stock Blended with 4 wt% of H-340 at 40°C, (t₀ = 113.79 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	141.36	1.2423	0.2423	0.12115	0.1096
4	175.18	1.5395	0.5395	0.13488	
6	210.20	1.8473	0.8473	0.14122	
8	257.84	2.2659	1.2659	0.15824	

Table C-34 40 stock Blended with 4 wt% of H-340 at 60°C, (t₀ = 104.77 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	131.72	1.2572	0.2572	0.12860	0.1182
4	163.03	1.5561	0.5561	0.13903	
6	197.59	1.8859	0.8859	0.14765	
8	238.97	2.2809	1.2809	0.16011	

Table C-35 40 stock Blended with 4 wt% of H-340 at 80°C, (t₀ = 80.88 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	102.83	1.2714	0.2714	0.13570	0.1280
4	128.33	1.5867	0.5867	0.14668	
6	154.02	1.9043	0.9043	0.15072	
8	212.25	2.6243	1.6243	0.16243	

Table C-36 40 stock Blended with 4 wt% of H-340 at 100°C, (t₀ = 60.17 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	77.43	1.2869	0.2869	0.14345	0.1352
4	98.13	1.6309	0.6309	0.15773	
6	121.54	2.0199	1.0199	0.16998	
8	144.22	2.3968	1.3968	0.17460	

Table C-37 40 stock Blended with 8 wt% of H-340 at 40°C, (t₀ = 113.79 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	136.37	1.1984	0.1984	0.09920	0.0896
4	163.69	1.4386	0.4386	0.10965	
6	194.18	1.7065	0.7065	0.11775	
8	231.01	2.0301	1.0301	0.12876	

Table C-38 40 stock Blended with 8 wt% of H-340 at 60°C, (t₀ = 104.77 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	126.34	1.2059	0.2059	0.10295	0.0938
4	154.36	1.4733	0.4733	0.11833	
6	183.20	1.7486	0.7486	0.12477	
8	219.50	2.0951	1.0951	0.13689	

Table C-39 40 stock Blended with 8 wt% of H-340 at 80°C, (t₀ = 80.88 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	98.65	1.2197	0.2197	0.10985	0.1006
4	121.91	1.5073	0.5073	0.12683	
6	144.05	1.7810	0.7810	0.13017	
8	175.26	2.1669	1.1669	0.14586	

Table C-40 40 stock Blended with 8 wt% of H-340 at 100°C, (t₀ = 60.17 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	73.88	1.2279	0.2279	0.11395	0.1057
4	92.71	1.5408	0.5408	0.13520	
6	110.44	1.8355	0.8355	0.13925	
8	133.37	2.2166	1.2166	0.15208	

Table C-41 60 stock Blended with OCP at 40°C, (t₀ = 127.53 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	184.02	1.4822	0.4822	0.24110	0.2342
4	259.00	2.0309	1.0309	0.25773	
6	327.50	2.5680	1.5680	0.26134	
8	406.27	3.1857	2.1857	0.27321	
10	486.27	3.8130	2.8130	0.28130	

Table C-42 60 stock Blended with OCP at 60°C, (t₀ = 106.22 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	159.33	1.5000	0.5000	0.25000	0.2413
4	216.65	2.0396	1.0396	0.25990	
6	274.81	2.5872	1.5872	0.26453	
8	340.39	3.2046	2.2046	0.27557	
10	409.49	3.8551	2.8551	0.28551	

Table C-43 60 stock Blended with OCP at 80°C, (t₀ = 85.06 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	128.48	1.5105	0.5105	0.25525	0.2485
4	175.62	2.0647	1.0647	0.26617	
6	222.59	2.6169	1.6169	0.26948	
8	274.98	3.2328	1.2328	0.27910	
10	329.29	3.8713	2.8713	0.28713	

Table C-44 60 stock Blended with OCP at 100°C, (t₀ = 77.53 sec)

OCP wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	118.09	1.5232	0.5232	0.26160	0.2546
4	161.98	2.0893	1.0893	0.27233	
6	206.43	2.6626	1.6626	0.27710	
8	253.31	3.2673	2.2673	0.28341	
10	306.34	3.9512	2.9512	0.29512	

Table C-45 60 stock Blended with Lubrizol 21001 at 40°C, (t₀ = 127.53 sec)

Lubrizol 21001 wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	134.39	1.0538	0.0538	0.02690	0.0248
4	141.83	1.1121	0.1121	0.02803	
6	151.81	1.1904	0.1904	0.03173	
8	161.24	1.2643	0.2643	0.03304	
10	172.60	1.3532	0.3532	0.03532	

Table C-46 60 stock Blended with Lubrizol 21001 at 60°C, (t₀ = 106.22 sec)

Lubrizol 21001 wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	112.32	1.0574	0.0574	0.02870	0.0263
4	118.99	1.1202	0.1202	0.03005	
6	127.17	1.1972	0.1972	0.03287	
8	136.91	1.2889	0.2889	0.03611	
10	145.39	1.3688	0.3688	0.03688	

Table C-47 60 stock Blended with Lubrizol 21001 at 80°C, (t₀ = 85.06 sec)

Lubrizol 21001 wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	90.38	1.0625	0.0625	0.03125	0.0285
4	96.17	1.1306	0.1306	0.03265	
6	103.93	1.2218	0.2218	0.03697	
8	111.33	1.3088	0.3088	0.03860	
10	119.93	1.4099	0.4099	0.04099	

Table C-48 60 stock Blended with Lubrizol 21001 at 100°C, (t₀ = 77.53 sec)

Lubrizol 21001 wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	82.86	1.0688	0.0688	0.03440	0.0314
4	88.51	1.1416	0.1416	0.03540	
6	95.26	1.2287	0.2287	0.03812	
8	95.73	1.2347	0.2347	0.04195	
10	111.01	1.4318	0.4318	0.04318	

Table C-49 60 stock Blended with 4 wt% of Lubrizol 21001 at 40°C, (t₀ = 127.53 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	186.04	1.4588	0.4588	0.22940	0.2158
4	246.75	1.9348	0.9348	0.23770	
6	319.48	2.5051	1.5051	0.25085	
8	398.51	3.1248	2.1248	0.26560	

Table C-50 60 stock Blended with 4 wt% Lubrizol 21001 at 60°C, (t₀ = 106.22 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	156.24	1.4709	0.4709	0.23545	0.2180
4	209.60	1.9733	0.9733	0.24333	
6	268.83	2.5309	1.5309	0.25515	
8	342.26	3.2222	2.2222	0.27778	

Table C-51 60 stock Blended with 4 wt% Lubrizol 21001 at 80°C, (t₀ = 85.06 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	125.91	1.4802	0.4802	0.24010	0.2234
4	168.81	1.9848	0.9848	0.24620	
6	219.38	2.5791	1.5791	0.26318	
8	278.47	3.2738	2.2738	0.28423	

Table C-52 60 stock Blended with 4 wt% Lubrizol 21001 at 100°C, (t₀ = 77.53 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	116.16	1.4983	0.4983	0.24915	0.2291
4	156.25	2.0153	1.0153	0.25383	
6	202.81	2.6159	1.6159	0.26932	
8	259.68	3.3494	2.3494	0.29368	

Table C-53 60 stock Blended with 8 wt% Lubrizol 21001 at 40°C, (t₀ = 127.53 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	178.996	1.4035	0.4035	0.20175	0.1810
4	235.59	1.8473	0.8473	0.21183	
6	303.23	2.3777	1.3777	0.22962	
8	386.68	3.0321	2.0321	0.25401	

Table C-54 60 stock Blended with 8 wt% Lubrizol 21001 at 60°C, (t₀ = 106.22 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	149.65	1.4089	0.4089	0.21445	0.1938
4	201.13	1.8935	0.8935	0.22338	
6	259.85	2.4463	1.4463	0.24105	
8	331.87	3.1244	2.1244	0.26555	

Table C-55 60 stock Blended with 8 wt% Lubrizol 21001 at 80°C, (t₀ = 85.06 sec)

OCP wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	122.56	1.4409	0.4409	0.22045	0.2013
4	164.97	1.9395	0.9395	0.23488	
6	214.38	2.5203	1.5203	0.25338	
8	271.58	3.1928	2.1928	0.27410	

Table C-56 60 stock Blended with 8 wt% Lubrizol 21001 at 100°C, (t₀ = 77.53 sec)

OCP wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	113.05	1.4581	0.4581	0.22905	0.2088
4	151.38	1.9525	0.9525	0.23813	
6	197.73	2.5504	1.5504	0.25840	
8	250.69	3.2335	2.2335	0.27919	

Table C-57 60 stock Blended with H-8722B at 40°C, (t₀ = 127.53 sec)

H-8722B wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	133.03	1.0432	0.0432	0.02160	0.01918
4	139.19	1.0914	0.0914	0.02285	
6	146.37	1.1477	0.1477	0.02462	
8	154.78	1.2137	0.2137	0.02671	
10	165.19	1.2953	0.2953	0.02953	

Table C-58 60 stock Blended with H-8722B at 60°C, (t₀ = 106.22 sec)

H-8722B wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	111.31	1.0479	0.0479	0.02395	0.02147
4	117.50	1.1026	0.1026	0.02565	
6	123.83	1.1658	0.1658	0.02763	
8	131.32	1.2363	0.2363	0.02954	
10	141.05	1.3279	0.3279	0.03279	

Table C-59 60 stock Blended with H-8722B at 80°C, (t₀ = 85.06 sec)

H-8722B wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	89.47	1.0518	0.0518	0.02590	0.02315
4	94.41	1.1099	0.1099	0.02748	
6	100.19	1.1779	0.1779	0.02965	
8	106.53	1.2524	0.2524	0.03155	
10	115.16	1.3539	0.3539	0.03539	

Table C-60 60 stock Blended with H-8722B at 100°C, ($t_0 = 77.53$ sec)

H-8722B wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	81.93	1.0568	0.0568	0.02840	0.02547
4	86.81	1.1197	0.1197	0.02993	
6	92.41	1.1919	0.1919	0.03198	
8	99.03	1.2773	0.2773	0.03466	
10	106.98	1.3799	0.3799	0.03799	

Table C-61 60 stock Blended with 4 wt% of H-8722B at 40°C, ($t_0 = 127.53$ sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	178.06	1.3962	0.3962	0.20180	0.1852
4	233.05	1.8274	0.8274	0.20685	
6	202.54	2.3811	1.3811	0.23018	
8	372.12	2.9179	1.9179	0.23974	

Table C-62 60 stock Blended with 4 wt% of H-8722B at 60°C, ($t_0 = 106.22$ sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	149.89	1.4111	0.4111	0.20855	0.1948
4	201.11	1.8933	0.8933	0.22330	
6	262.45	2.4708	1.4708	0.24513	
8	320.17	3.0142	2.0142	0.25178	

Table C-63 60 stock Blended with 4 wt% of H-8722B at 80°C, ($t_0 = 85.06$ sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	121.88	1.4329	0.4329	0.21645	0.2026
4	163.19	1.9185	0.9185	0.22963	
6	212.68	2.5003	1.5003	0.25005	
8	260.72	3.0651	2.0651	0.25814	

Table C-64 60 stock Blended with 4 wt% of H-8722B at 100°C, ($t_0 = 77.53$ sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	114.22	1.4732	0.4732	0.23660	0.2206
4	153.64	1.9817	0.9817	0.24543	
6	202.70	2.6145	1.6145	0.26908	
8	249.99	3.2244	2.2244	0.27805	

Table C-65 60 stock Blended with 8 wt% of H-8722B at 40°C, ($t_0 = 127.53$ sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	172.09	1.3494	0.3494	0.17470	0.1587
4	221.99	1.7407	0.7407	0.18518	
6	279.71	2.1933	1.1933	0.19888	
8	349.93	2.7439	1.7439	0.21799	

Table C-66 60 stock Blended with 8 wt% of H-8722B at 60°C, ($t_0 = 106.22$ sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	145.84	1.3711	0.3711	0.18555	0.1668
4	190.02	1.7889	0.7889	0.19723	
6	243.68	2.2941	1.2941	0.21568	
8	305.82	2.8791	1.8791	0.23489	

Table C-67 60 stock Blended with 8 wt% of H-8722B at 80°C, ($t_0 = 85.06$ sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	118.30	1.3908	0.3908	0.19540	0.1748
4	155.37	1.8266	0.8266	0.20665	
6	200.09	2.3523	1.3523	0.22538	
8	254.36	2.9904	1.9904	0.24880	

Table C-68 60 stock Blended with 8 wt% of H-8722B at 100°C, ($t_0 = 77.53$ sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	110.77	1.4287	0.4287	0.21435	0.1928
4	147.61	1.9039	0.9039	0.22598	
6	191.18	2.4659	1.4659	0.24432	
8	244.75	3.1568	2.1568	0.26960	

Table C-69 60 stock Blended with of H-340 at 40°C, ($t_0 = 127.53$ sec)

H-340 wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	126.44	0.9911	-	-	-
4	126.08	0.9886	-	-	
6	123.87	0.9713	-	-	
8	122.06	0.9571	-	-	
10	121.39	0.9518	-	-	

Table C-70 60 stock Blended with of H-340 at 60°C, ($t_0 = 106.22$ sec)

H-340 wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	105.44	0.9958	-	-	-
4	104.86	0.9872	-	-	
6	102.22	0.9623	-	-	
8	101.54	0.9559	-	-	
10	100.80	0.9489	-	-	

Table C-71 60 stock Blended with of H-340 at 80°C, ($t_0 = 85.06$ sec)

H-340 wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	84.55	0.9940	-	-	-
4	83.73	0.9844	-	-	
6	81.02	0.9525	-	-	
8	80.61	0.9477	-	-	
10	79.98	0.9403	-	-	

Table C-72 60 stock Blended with of H-340 at 100°C, (t₀ = 77.53 sec)

H-340 wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	77.48	0.9994	-	-	-
4	77.17	0.9954	-	-	
6	76.24	0.9834	-	-	
8	74.47	0.9605	-	-	
10	73.01	0.9417	-	-	

Table C-73 60 stock Blended with of 4 wt% of H-340 at 40°C, (t₀ = 127.53 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	141.64	1.1106	0.1106	0.05530	0.0524
4	156.56	1.2276	0.2276	0.05690	
6	172.06	1.3492	0.3492	0.05820	
8	191.60	1.5024	0.5024	0.06280	

Table C-74 60 stock Blended with of 4 wt% of H-340 at 60°C, (t₀ = 106.22 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	118.46	1.1152	0.1152	0.05760	0.0546
4	130.99	1.2332	0.2332	0.05830	
6	144.27	1.3582	0.3582	0.05970	
8	161.03	1.5160	0.5160	0.06450	

Table C-75 60 stock Blended with of 4 wt% of H-340 at 80°C, (t₀ = 85.06 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	95.19	1.1191	0.1191	0.05955	0.0575
4	106.60	1.2532	0.2532	0.06330	
6	118.54	1.3936	0.3936	0.06560	
8	129.70	1.5248	0.5248	0.06740	

Table C-76 60 stock Blended with of 4 wt% of H-340 at 100°C, (t₀ = 77.53 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	87.48	1.1284	0.1284	0.06420	0.0617
4	98.09	1.2652	0.2652	0.06630	
6	109.53	1.4127	0.4127	0.06878	
8	121.86	1.5718	0.5718	0.07148	

Table C-77 60 stock Blended with of 8 wt% of H-340 at 40°C, (t₀ = 127.53 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	139.40	1.0931	0.0931	0.04655	0.0447
4	151.66	1.1892	0.1892	0.04730	
6	165.47	1.2975	0.2975	0.04958	
8	179.57	1.4081	0.4081	0.05101	

Table C-78 60 stock Blended with of 8 wt% of H-340 at 60°C, (t₀ = 106.22 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	116.32	1.0951	0.0951	0.04755	0.0459
4	126.96	1.1953	0.1953	0.04883	
6	138.25	1.3015	0.3015	0.05025	
8	150.63	1.4181	0.4181	0.05226	

Table C-79 60 stock Blended with of 8 wt% of H-340 at 80°C, (t₀ = 85.06 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	93.32	1.0971	0.0971	0.04855	0.0471
4	102.52	1.2053	0.2053	0.05133	
6	112.03	1.3171	0.3171	0.05285	
8	122.02	1.4345	0.4345	0.05431	

Table C-80 60 stock Blended with of 8 wt% of H-340 at 100°C, (t₀ = 77.53 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	85.42	1.1018	0.1018	0.05090	0.0494
4	94.07	1.2133	0.2133	0.05333	
6	103.05	1.3292	0.3292	0.05487	
8	112.49	1.4509	0.4509	0.05636	

Table C-81 150 stock Blended with OCP at 40°C, (t₀ = 256.78 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	350.66	1.3656	0.3656	0.18280	0.1500
4	455.25	1.7729	0.7729	0.19323	
6	582.51	2.2685	1.2685	0.21142	
8	805.36	3.1364	2.1364	0.26705	
10	955.07	3.7194	2.7194	0.27194	

Table C-82 150 stock Blended with OCP at 60°C, (t₀ = 229.97 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	319.36	1.3887	0.3887	0.19435	0.1629
4	409.81	1.7820	0.7820	0.19550	
6	553.45	2.4066	1.4066	0.23443	
8	734.92	3.1957	2.1957	0.27446	
10	862.92	3.7523	2.7523	0.27523	

Table C-83 150 stock Blended with OCP at 80°C, (t₀ = 206.31 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	287.76	1.3948	0.3948	0.19740	0.1789
4	394.71	1.9132	0.9132	0.22830	
6	510.25	2.4732	1.4732	0.24553	
8	657.47	3.1868	2.1868	0.27335	
10	800.65	3.8808	2.8808	0.28808	

Table C-84 150 stock Blended with OCP at 100°C, (t₀ = 180.33 sec)

OCP wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	[η]
2	261.28	1.4489	0.4489	0.22455	0.1950
4	349.44	1.9378	0.9378	0.23455	
6	452.11	2.5071	1.5071	0.25118	
8	579.38	3.2129	2.2129	0.27661	
10	741.16	4.1100	3.1100	0.31100	

Table C-85 150 stock Blended with Lubrizol 21001 at 40°C, (t₀ = 256.78 sec)

Lubrizol 21001 wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	[η]
2	268.00	1.0437	0.0437	0.02185	0.01822
4	280.09	1.0908	0.0908	0.02270	
6	293.81	1.1442	0.1442	0.02403	
8	312.71	1.2178	0.2178	0.02723	
10	338.82	1.3195	0.3195	0.03195	

Table C-86 150 stock Blended with Lubrizol 21001 at 60°C, (t₀ = 229.97 sec)

Lubrizol 21001 wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	[η]
2	240.59	1.0462	0.0462	0.02310	0.01865
4	251.96	1.0956	0.0956	0.02393	
6	267.29	1.1623	0.1623	0.02705	
8	285.94	1.2434	0.2434	0.03043	
10	311.95	1.3565	0.3565	0.03565	

Table C-87 150 stock Blended with Lubrizol 21001 at 80°C, (t₀ = 206.31 sec)

Lubrizol 21001 wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	[η]
2	216.52	1.0495	0.0495	0.02475	0.01926
4	227.09	1.1007	0.1007	0.02518	
6	241.75	1.1718	0.1718	0.02863	
8	257.64	1.2488	0.2488	0.03110	
10	287.99	1.3959	0.3959	0.03959	

Table C-88 150 stock Blended with Lubrizol 21001 at 100°C, (t₀ = 180.33 sec)

Lubrizol 21001 wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	[η]
2	189.78	1.0524	0.0524	0.02620	0.02020
4	199.77	1.1078	0.1078	0.02695	
6	212.41	1.1779	0.1779	0.02965	
8	227.61	1.2622	0.2622	0.03278	
10	256.69	1.4234	0.4234	0.04234	

Table C-89 150 stock Blended with 4 wt% of Lubrizol 21001 at 40°C, (t₀ = 256.78 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	344.29	1.3408	0.3408	0.17040	0.1413
4	450.19	1.7532	0.7532	0.18830	
6	578.68	2.2536	1.2536	0.20893	
8	764.69	2.9779	1.9779	0.24723	

Table C-90 150 stock Blended with 4 wt% of Lubrizol 21001 at 60°C, (t₀ = 229.97 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	313.15	1.3617	0.3617	0.18085	0.1558
4	413.16	1.7966	0.7966	0.19915	
6	534.96	2.3262	1.3262	0.22103	
8	690.37	3.0020	2.0020	0.25025	

Table C-91 150 stock Blended with 4 wt% of Lubrizol 21001 at 80°C, (t₀ = 206.31 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	285.22	1.3825	0.3825	0.19125	0.1699
4	386.25	1.8722	0.8722	0.21805	
6	497.43	2.4111	1.4111	0.23518	
8	637.42	3.0896	2.0896	0.26120	

Table C-92 150 stock Blended with 4 wt% of Lubrizol 21001 at 100°C, (t₀ = 180.33 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	255.20	1.4152	0.4152	0.20760	0.1868
4	340.66	1.8891	0.8891	0.22228	
6	443.02	2.4567	1.4567	0.24278	
8	562.74	3.1206	2.1206	0.26508	

Table C-93 150 stock Blended with 8 wt% of Lubrizol 21001 at 40°C, (t₀ = 256.78 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	329.81	1.2844	0.2844	0.14220	0.1131
4	426.85	1.6623	0.6623	0.16557	
6	549.18	2.1387	1.1387	0.18978	
8	718.16	2.7968	1.7968	0.22460	

Table C-94 150 stock Blended with 8 wt% of Lubrizol 21001 at 60°C, (t₀ = 229.97 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	300.06	1.3048	0.3048	0.15240	0.1228
4	389.73	1.6947	0.6947	0.17368	
6	513.16	2.2314	1.2314	0.20523	
8	659.46	2.8676	1.8676	0.23345	

Table C-95 150 stock Blended with 8 wt% of Lubrizol 21001 at 80°C, ($t_0 = 206.31$ sec)

OCP wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	272.37	1.3202	0.3202	0.16008	0.1359
4	363.21	1.7605	0.7605	0.19013	
6	477.11	2.3126	1.3126	0.21877	
8	600.86	2.9124	1.9124	0.23905	

Table C-96 150 stock Blended with 8 wt% of Lubrizol 21001 at 100°C, ($t_0 = 180.33$ sec)

OCP wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	242.09	1.3425	0.3425	0.17125	0.1470
4	321.55	1.7831	0.7831	0.19578	
6	424.46	2.3538	1.3538	0.22863	
8	532.84	2.9548	1.9548	0.24435	

Table C-97 150 stock Blended with H-8722B at 40°C, ($t_0 = 256.78$ sec)

H-8722B wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	266.38	1.0374	0.0374	0.01870	0.01678
4	277.66	1.0813	0.0813	0.02033	
6	289.65	1.1280	0.1280	0.02134	
8	305.41	1.1894	0.1894	0.02368	
10	322.64	1.2565	0.2565	0.02565	

Table C-98 150 stock Blended with H-8722B at 60°C, ($t_0 = 229.97$ sec)

H-8722B wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	239.12	1.0398	0.0398	0.01990	0.01802
4	251.06	1.0917	0.0917	0.02293	
6	264.49	1.1501	0.1501	0.02502	
8	278.31	1.2102	0.2102	0.02618	
10	297.69	1.2945	0.2945	0.02945	

Table C-99 150 stock Blended with H-8722B at 80°C, ($t_0 = 206.31$ sec)

H-8722B wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	215.20	1.0431	0.0431	0.02155	0.01903
4	226.36	1.0972	0.0972	0.02430	
6	239.89	1.1628	0.1628	0.02713	
8	255.39	1.2379	0.2379	0.02974	
10	272.24	1.3210	0.3210	0.03210	

Table C-100 150 stock Blended with H-8722B at 100°C, (t₀ = 180.33 sec)

H-8722B wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	188.84	1.0472	0.0472	0.02360	0.01949
4	198.47	1.1006	0.1006	0.02515	
6	210.81	1.1690	0.1690	0.02817	
8	226.33	1.2551	0.2564	0.03205	
10	245.34	1.3605	0.3605	0.03605	

Table C-101 150 stock Blended with 4 wt% of H-8722B at 40°C, (t₀ = 256.78 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	344.70	1.3424	0.3424	0.17120	0.1652
4	440.66	1.7161	0.7161	0.17903	
6	539.80	2.1022	1.1022	0.18370	
8	649.63	2.5299	1.5299	0.19124	

Table C-102 150 stock Blended with 4 wt% of H-8722B at 60°C, (t₀ = 229.97 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	312.83	1.3603	0.3603	0.18015	0.1697
4	406.79	1.7689	0.7689	0.19223	
6	517.46	2.2501	1.2501	0.20835	
8	622.48	2.7068	1.7068	0.21335	

Table C-103 150 stock Blended with 4 wt% of H-8722B at 80°C, (t₀ = 206.31 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	285.74	1.3850	0.3850	0.19250	0.1804
4	380.21	1.8429	0.8429	0.21073	
6	485.61	2.3538	1.3538	0.22563	
8	595.08	2.8844	1.8844	0.23555	

Table C-104 150 stock Blended with 4 wt% of H-8722B at 100°C, (t₀ = 180.33 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	254.43	1.4109	0.4109	0.20545	0.1922
4	341.06	1.8913	0.8913	0.22283	
6	435.57	2.4154	1.4154	0.23590	
8	540.49	2.9972	1.9972	0.24965	

Table C-105 150 stock Blended with 8 wt% of H-8722B at 40°C, (t₀ = 256.78 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	327.52	1.2755	0.2755	0.13775	0.1272
4	408.77	1.5918	0.5918	0.14795	
6	497.74	1.9384	0.9384	0.15640	
8	605.49	2.3580	1.3580	0.16975	

Table C-106 150 stock Blended with 8 wt% of H-8722B at 60°C, (t₀ = 229.97 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	297.35	1.2929	0.2929	0.14645	0.1317
4	383.02	1.6655	0.6655	0.16638	
6	470.38	2.0454	1.0454	0.17423	
8	590.38	2.5672	1.5672	0.19590	

Table C-107 150 stock Blended with 8 wt% of H-8722B at 80°C, (t₀ = 206.31 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	270.99	1.3135	0.3135	0.15675	0.1381
4	352.96	1.7108	0.7108	0.17770	
6	456.48	2.2126	1.2126	0.20210	
8	559.90	2.7139	1.7139	0.21424	

Table C-108 150 stock Blended with 8 wt% of H-8722B at 100°C, (t₀ = 180.33 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	241.84	1.3411	0.3411	0.17055	0.1477
4	316.05	1.7526	0.7526	0.18815	
6	417.21	2.3136	1.3136	0.21893	
8	517.69	2.8708	1.8708	0.23385	

Table C-109 150 stock Blended with H-340 at 40°C, (t₀ = 256.78 sec)

H-340 wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	245.42	0.9558	-	-	-
4	236.77	0.9221	-	-	
6	233.13	0.9079	-	-	
8	222.24	0.8655	-	-	
10	219.81	0.8560	-	-	

Table C-110 150 stock Blended with H-340 at 60°C, (t₀ = 229.97 sec)

H-340 wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	229.53	0.9981	-	-	-
4	221.42	0.9628	-	-	
6	218.15	0.9486	-	-	
8	206.39	0.8975	-	-	
10	202.45	0.8803	-	-	

Table C-111 150 stock Blended with H-340 at 80°C, (t₀ = 206.31 sec)

H-340 wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	206.12	0.9991	-	-	-
4	200.97	0.9741	-	-	
6	197.33	0.9565	-	-	
8	190.00	0.9209	-	-	
10	182.21	0.8832	-	-	

Table C-112 150 stock Blended with H-340 at 100°C, ($t_0 = 180.33$ sec)

H-340 wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	180.20	0.9993	-	-	-
4	178.42	0.9894	-	-	
6	170.04	0.9429	-	-	
8	161.89	0.8977	-	-	
10	158.88	0.8811	-	-	

Table C-113 150 stock Blended with 4 wt% of H-340 at 40°C, ($t_0 = 256.78$ sec)

OCP wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	286.77	1.1168	0.1168	0.05840	0.0523
4	325.06	1.2659	0.2659	0.06648	
6	369.09	1.4374	0.4374	0.07290	
8	418.35	1.6292	0.6292	0.07865	

Table C-114 150 stock Blended with 4 wt% of H-340 at 60°C, ($t_0 = 229.97$ sec)

OCP wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	257.45	1.1195	0.1195	0.05975	0.0535
4	293.42	1.2759	0.2759	0.06898	
6	335.64	1.4595	0.4595	0.07658	
8	380.09	1.6528	0.6528	0.08160	

Table C-115 150 stock Blended with 4 wt% of H-340 at 80°C, ($t_0 = 206.31$ sec)

OCP wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	231.91	1.1241	0.1241	0.06205	0.0568
4	266.57	1.2921	0.2921	0.07303	
6	305.19	1.4793	0.4793	0.07988	
8	344.29	1.6688	0.6688	0.08360	

Table C-116 150 stock Blended with 4 wt% of H-340 at 100°C, ($t_0 = 180.33$ sec)

OCP wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	203.88	1.1306	0.1306	0.06530	0.0612
4	235.60	1.3065	0.3065	0.07663	
6	270.39	1.4994	0.4994	0.08323	
8	303.17	1.6812	0.6812	0.08515	

Table C-117 150 stock Blended with 8 wt% of H-340 at 40°C, ($t_0 = 256.78$ sec)

OCP wt. %	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	282.36	1.0996	0.0996	0.04980	0.0442
4	311.29	1.2123	0.2123	0.05308	
6	346.63	1.3499	0.3499	0.05832	
8	389.18	1.5156	0.5156	0.06445	

Table C-118 150 stock Blended with 8 wt% of H-340 at 60°C, (t₀ = 229.97 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	253.40	1.1019	0.1019	0.05095	0.0453
4	280.98	1.2218	0.2218	0.05545	
6	315.56	1.3722	0.3722	0.06203	
8	353.05	1.5352	0.5352	0.06690	

Table C-119 150 stock Blended with 8 wt% of H-340 at 80°C, (t₀ = 206.31 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	228.19	1.1061	0.1061	0.05305	0.0461
4	253.69	1.2297	0.2297	0.05743	
6	287.16	1.3919	0.3919	0.06532	
8	324.24	1.5716	0.5716	0.07145	

Table C-120 150 stock Blended with 8 wt% of H-340 at 100°C, (t₀ = 180.33 sec)

OCP wt.%	t (sec)	$\eta_{rel.}$	$\eta_{sp.}$	$\eta_{red.}$	$[\eta]$
2	200.31	1.1108	0.1108	0.05540	0.0488
4	223.88	1.2415	0.2415	0.06038	
6	254.12	1.4092	0.4092	0.06820	
8	286.58	1.5892	0.5892	0.07365	

الخلاصة

في هذا البحث تمت دراسة تأثير ثلاثة أنواع من المضافات المستحصلة من مصفى الدورة في بغداد والتي هي HiTEC 8722B و Lubrizol 21001 و HiTEC 340 على كفاءة محسن مؤشر اللزوجة من نوع Olefin Copolymer والذي يستخدم لزيت التزييت الأساس الثلاثة المستحصلة أيضا من مصفى الدورة والتي هي 40 و 60 و 150 stock . وتمت الدراسة عند أربع درجات حرارة هي 40، 60، 80 و 100 °م.

تراكيز المضافات ومحسن مؤشر اللزوجة المذكورين أعلاه والتي خلطت مع زيوت التزييت الأساس الثلاث كانت بين 2 الى 10 %wt. أظهرت النتائج إنخفاضا ملحوظا في اللزوجة الحركية مصاحبا لإرتفاع درجات الحرارة.

لقد وجد عند خلط المضاف HiTEC 340 إنه يسبب إرتفاعا في مؤشر اللزوجة عند تراكيز تختلف باختلاف نوع زيت التزييت. فمثلا للنوعين 40 و 150 stock كان التركيز 2 %wt. بينما للنوع 60 stock كان عند التراكيز 2 و 4 و 6 %wt. و الفائدة من معرفة هذه التراكيز تتمثل في تحديد التركيز الأفضل لإنتاج زيت ناقل الحركة يكون إقتصادي وذو كفاءة عالية.

من جهة أخرى وجد إن كفاءة محسن مؤشر اللزوجة (OCP) تقل بمعدل تصاعدي عند خلط 4 و 8 %wt من المضاف Lubrizol 21001 لأنواع زيوت التزييت الثلاث. ولكن هذه الكفاءة تتحسن بإضافة 4 %wt من المضاف HiTEC 8722B عند خلطه مع الزيت 40 stock وتقل عند إضافة 8 %wt منه. بينما للنوعين 60 و 150 stock فإن كفاءة OCP تقل عند كلا التركيزين 4 و 8 %wt.

لوحظ إنه عند خلط المضاف HiTEC 340 وبكلا التركيزين 4 و 8 %wt فإن كفاءة محسن مؤشر اللزوجة تنخفض بمقدار كبير للنوعين 60 و 150 stock. بينما عند خلطه مع الزيت 40 stock وبتركيز 4 %wt فإن الكفاءة تزداد بينما تقل عند خلطه بتركيز 8 %wt.

وقد تم حساب اللزوجة الجوهرية أيضا والتي أظهرت نتائجها إرتفاعا مصاحبا لإرتفاع درجات الحرارة والتراكيز. أيضا تم إيجاد عدة معادلات تربط بين مؤشر اللزوجة وتركيز محسن مؤشر اللزوجة لكل نوع من زيوت التزييت الثلاث ولكل نوع من المضافات الثلاثة المستخدمة.

شكر وتقدير

بسم الله الرحمن الرحيم
(وقل إعملوا فسيرى الله عملكم ورسوله والمؤمنون)
صدق الله العظيم

أتوجه بالشكر والأمتنان والتقدير

إلى من لا يطيب الليل إلا بشكره ولا يطيب النهار إلا بطاعته.. ولا تطيب الآخرة إلا بعفوه.. ولا تطيب الجنة إلا برويته.. (الله جل جلاله)

إلى من بلغ الرسالة وأدى الأمانة ونصح الأمة.. إلى نبي الرحمة ونور العالمين.. (سيدنا محمد صلى الله عليه وآله وسلم)

إلى من علمني حروفاً من ذهب وكلمات من درر.. إلى من صاغ علمه حروفاً ومن فكره منارة تنير مسيرة العلم والنجاح.. إلى الذي تفضل بإشرافه على هذا البحث.. (مشرقي وأساتذتي الفاضل الدكتور طالب بهجت كشمولة)

إلى الذين حملوا أقدس رسالة في الحياة.. إلى الذين مهدوا لي طريق العلم والمعرفة.. (السيد رئيس القسم المحترم وجميع أساتذتي الأفاضل)

إلى القلوب الطيبة التي حاولت تذليل كل عائق أمامي.. فكانوا رسلاً للعلم والأخلاق.. (منتسبي مصفى الدورة / قسم البحوث والسيطرة النوعية / مختبر الدهون)

إلى من علمني الصبر والنجاح.. إلى من افتقده في مواجهة الصعاب.. إلى من لم تمهله الدنيا لأرتوي من حنانه ويرتعش قلبي لذكره.. إلى من أفتخر بذكر اسمه.. (والدي الحبيب (رحمه الله))

إلى من ركع العطاء أمام قدميها.. إلى من أعطتنا من دمها وروحها وعمرها حبا وتصميماً ودفعاً لغدٍ أجمل.. إلى الغالية التي لا نرى الأمل إلا من خلال عينيها.. (والدتي الحبيبة)

إلى من كلفه الله بالهبة والوقار.. إلى من علمني العطاء بدون انتظار.. أرجو من الله أن يمد في عمره ليرى ثماراً قد حان قطافها بعد طول انتظار.. وستبقى كلماته نجوم أهدني بها اليوم وفي الغد وإلى الأبد.. (زوجي العزيز)

إلى زهرتا النرجس اللتان تفيضان حباً وطفولةً ونقاءً وعتراً.. إلى العصفورتان اللتان مازالتا تخطيان على أدرج العمر الأولى.. (ابنتاي الغاليتان)

إلى سندي وقوتي وملادي بعد الله.. إلى من معكما أكون أنا.. إلى ريحانتا حياتي.. (أخي وأختي الحنونين).

طبيبة نايف جاسم السعيد

تأثير بعض المضافات على كفاءة مؤشر محسن اللزوجة لزيوت التزيت الأساس

رسالة

مقدمة إلى كلية الهندسة في جامعة النهريين
وهي جزء من متطلبات نيل درجة ماجستير علوم
في الهندسة الكيماوية

من قبل

طيبة نايف جاسم السعيد
(بكالوريوس علوم في الهندسة الكيماوية، 2008)

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