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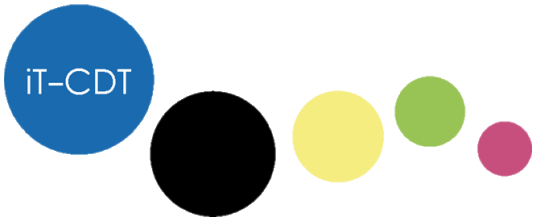

Instrumenting an Auto Engine to Measure Viscosity in-Situ

Team Report

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Abstract

In previous research two different ultrasonic techniques have been used to measure fluid viscosity: the pulse-echo method and the Stamina method. This paper investigates these techniques' ability to accurately measure the viscosity of degraded engine oils, and compares these measurements with those of a work bench rotational viscometer. The ultrasonic techniques produced viscosity measurements which were lower than the results from the rotational viscometer in all but one case, in which the Stamina measurement was slightly larger than the rotational viscometer's. This paper puts forward a hypothesis that these results are due to the ultrasonic techniques use of an oscillating wave that entrains and measures only the smaller molecular weight substance, thus giving an artificially low viscosity. In addition, the Stamina method's viscosity reading was consistently higher than the pulse echo method; this paper contends that this is due to the Stamina method's continuous wave transmitting more energy into the system, therefore entraining more of the heavy molecular weight substance and giving a more realistic viscosity measurement.

Contents

1. Introduction

Within a car engine 20% of the fuels energy is lost due to frictional losses. Lubricants are used reduce the effects of friction and as a result increase the efficiency. The purpose of the lubricant within a car engine is to minimise wear, reduce friction and increase efficiency. Viscosity is an important factor for any lubrication system.

Inevitably over time lubricants degrade due to contamination, oxidation, thermal breakdown etc. For a given car engine, manufacturers will recommend an oil change interval to optimise the performance of the vehicle. This could lead to potentially wasting large amounts of oil or the performance of the engine not being optimised, leading to unwanted wear and inefficiencies.

Current viscometers have been unviable within car engines due to several reasons which are discussed in this report. An alternative to the conventional in line viscometers is sensing via polarised ultrasonic waves. Ultrasonic sensing allows for cheap, reliable data to be collected continuously. Hence the overall aim of this project is to develop a new kind of sensor based on ultrasound to measure viscosity in a working car engine.

1.1 Aims

- Verify the use of ultrasonic sensors compared to current methods.
- Apply ultrasonic viscometer to real world applications.
- Determine ultrasonic sensor's capability for detecting degradation in engine oils.

1.2 Objectives

- Complete a Market survey to understand the current products.
- Understand how ultrasonic piezo-sensors work.
- Use LabVIEW to drive the measurement system.
- Use Matlab code to analyse the results and model behaviour.

2. Literature Review

For this project a brief literature review has been compiled to understand: the importance of viscosity, current methods of measurement, the potential of ultrasound and the current market for in line viscometers. This section will briefly summarise the information gathered.

2.1 Viscosity of oil

	Decreases Viscosity	Increases Viscosity
Changes to base oil (molecular changes)	▼ Thermal cracking of oil molecules ▼ Shear thinning of VI improvers	▼ Polymerization ▼ Oxidation ▼ Evaporative losses ▼ Formation of carbon and oxide insolubles
Additions to base oil (contamination)	■ Fuel ■ Refrigerant ■ Solvents ▼ Wrong oil (low viscosity)	■ Water (emulsions) ■ Aeration ▼ Soot ▼ Antifreeze (glycol) ▼ Wrong oil (high viscosity)

▼ Noncorrectable change
■ Correctable by removal of the contaminant if feasible

Figure 2.1: Common causes of viscosity change (1)

Lubricants are often optimised for a certain engineering systems but during their use their properties tend to degrade due to various factors (i.e. oxidation, thermal cracking etc.). Figure 2.1 shows a table detailing the possible viscosity of the oil as it is used within the engine (1). The figure shows most of the effects on viscosity cannot be rectified hence the need to regularly change and recycle the oil from within the car engine. The change in viscosity can have a large impact on the performance of a vehicle, for example a significant reduction in oil viscosity can lead to:

- A reduction in oil film thickness causes high amounts of wear.
- Heat generation caused by high levels of friction.
- Potential for high levels of contamination due to reduced oil film thickness.

Conversely, an increase in oil viscosity can lead to:

- Excessive heat generation in the fluid.
- Inefficiencies due to the force required to overcome fluid friction.
- Poor cold start operation.

2.2 Viscosity Measurement

Several methods of measuring viscosity are currently used within laboratories, including Gravimetric capillary principle, rotational principle and the rolling/falling ball principle (2).

- ***Gravimetric capillary principle*** uses gravity as its driving force hence giving a value for kinematic viscosity. Highly accurate due to constant gravitational force applied (i.e. not artificially generated). For highly viscous samples the gravimetric capillary method is not effective as the force of gravity is too weak.
- ***Rotational principle*** is suited to more viscous fluids as the force input can be increased and set for the appropriate fluid. Rotational viscometers use a motor drive to output both dynamic and shear viscosity results.
- ***Rolling / falling ball principle*** similarly to the gravimetric capillary principle it also uses gravity as the driving force. A ball is rolled through a closed capillary filled with the sample fluid and set an inclination of approximately 10 – 80 degrees for a falling ball viscometer. For any angle greater than 80 degrees the instrument is referred to as falling ball viscometer.

2.3 Market research

To gain an understanding of current in line viscometers market research has been carried out to understand the current viability of usage within the car engine. Several different categories exist on the market including: falling ball method, rotary viscometers and gravimetric capillary method. See appendix table 1, 2 and 3 for a complete market survey completed from direct industry (3).

Prices for in line viscometers range from approximately £5000 to £18,000, as a result this makes current in line viscometers unviable within a standard mass production road car. With the development and improvement in the use of ultrasonic sensors, engineers are exploring the idea of using ultrasonic sensors within car engines to gather live data regarding the quality of the oil. This will allow consumers to accurately change their oil once the fluid is no longer optimising the performance of the vehicle. Hence the use of ultrasonic sensors should reduce the amount of waste oil.

2.4 Ultrasound

The acoustic viscometer works by transmitting an ultrasonic shear polarized wave. This wave travels through the solid component before reaching a boundary between solid-liquid interfaces. At this point the ultrasonic energy is partly transmitted and dissipated in the fluid, and partly reflected back to the ultrasonic source as an echo wave (4). By calculating the ratio between the energy reflected back and the initial wave energy (reflection coefficient), the viscosity of the fluid can be found.

This method has limitations such as when the acoustic impedance of the solid is much higher than the acoustic impedance of the liquid, the reflection coefficient tends to one (4) and therefore is not sensitive to fluid viscosity.

To overcome this a matching layer is introduced. This matching layer is placed between the solid-liquid interface and has a thickness of a quarter of a wavelength. This matching layer provides two functions:

1) The waves superimpose in-phase, producing a larger resultant.
2) The reflected wave from the layer cancels out the incident wave.(4)

This leads to an increase in transmitted energy into the oil and reduces the reflected energy, improving the sensitivity to the lubricant.

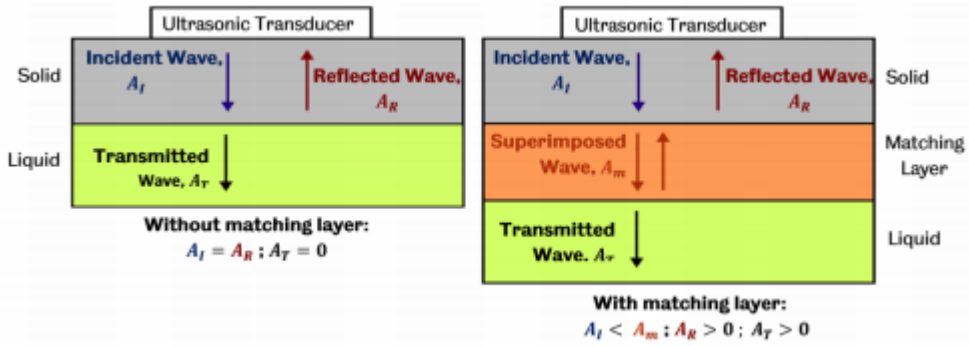

Figure 2.2: matching layer

There are two different ultrasonic techniques: pulse-echo and Stamina. The main difference between the pulse-echo (Chirp) method and Stamina are in the initial waveform sent out; whilst the former uses a single burst, the latter uses a

continuous, standing wave. This means the Stamina method is more sensitive to attenuation due to the repeated number of reflections.

2.4.1 Maxwell Method Chirp Pulse

There are two different methods that can be used to calculate the viscosity using the pulse echo method. The first method uses the Maxwell equation.

$$R = 1 - \frac{4z_s z_l}{\left(z_m + \frac{z_s z_l}{z_m}\right)^2}$$

Equation 1- Maxwell Reflection Coefficient

Where the impedances are equal to:

$$z_s = \rho_s c_s$$

Equation 2- Acoustic Impedance of a Solid

$$z_l = \sqrt{\rho_l G}$$

Equation 3- Acoustic Impedance of a Liquid

$$z_m = \sqrt{z_s \sqrt{\rho_l 2\pi f \eta}}$$

Equation 4- Acoustic Impedance of a Matching Layer

2.4.2 Logarithmic Model Chirp Pulse

The second method available is to compare results collected from completing the analysis on oils with known viscosity. This is often advantageous to using the Maxwell method as the Maxwell equation requires many parameters which may not be possible to obtain. The disadvantage to using this method is that it is often not as accurate.

The analysis method was carried out using MATLAB and Microsoft Excel. MATLAB was selected for the data manipulation as it allows for a script to be created and Microsoft Excel was used to display the data due to its graphical output. The strategy taken to analyse the raw data using MATLAB was:

1) Importation of data.
2) Comparison of the amplitude and frequency.
3) Filtration of the data.
4) Calculating the reflection coefficient.

The importation of data was completed using the inbuilt MATLAB function. A minimum of two files could be loaded, and a maximum of five, with the first file having to be the reference value. The columns loaded from the raw data files were the FFT amplitude and the frequency.

A second module was then run where the frequency was plotted against the FFT amplitude. This was completed to allow visual representation of the received signal. From the plot resonance can very quickly be observed.

Before the reflection coefficient could be calculated a basic filtering system, consisting of three sections was set up to remove any noise. The third module of the program, the first filtering module, set the first three values of each data set to zero. This allowed for a period of 3.6621 Hz for the signal to settle. The second filtration module set any value of the voltage amplitude that was less than 20% of the maximum amplitude to zero. This removed large sections of the signal which were not needed. This does not disrupt the minimum reflection coefficient as when the resonance occurs the amplitude of the received signal increases dramatically[5]. The third and final filtration method was an iterative method which calculated the difference between the amplitude for the oil and the reference value for each frequency. If the difference was less than 5% of the maximum amplitude of the reflection coefficient then the amplitude of the oil was set to equal the amplitude of the reflection coefficient, creating a reflection coefficient of 1. If this third filtering method was not applied there would be large sets of reflective coefficients where resonance has not occurred, but when the division of the amplitudes takes place, some of the values are extremely small, creating large reflection coefficients and skewing the data.

The final MATLAB module calculated the reflective coefficient by completing element division of the filtered amplitude of the oil and reference vectors. The minimum value of the calculation was then displayed as this is the reflection coefficient of the oil when resonance occurs.

The data for the known oils were then plotted against the viscosity and a logarithmic line of best fit was calculated. The equation of the line of best fit was then used to calculate the viscosity for the unknown oils using their reflective coefficients.

2.4.3 STAMINA

To analyse the STAMINA raw data it was loaded into an externally sourced LabVIEW program which filtered the data and outputs the reflective coefficient. As with the chirp ultrasound method the data was loaded into Microsoft Excel and the reflection coefficient for the oils with the known viscosity were plotted against the viscosity and a logarithmic line of best fit was created. The equation from the line of best fit was then used to calculate the viscosity for the oils with unknown viscosity.

3 Methodology

To verify the use of the ultrasonic data, the results will be compared to viscosities measured using the Brookfield DV1 viscometer with a sc4-18 small spindle adapter. This device was chosen due to its availability and ease of use. This section will detail the processes used for both the rotary viscometer and the ultrasonic testing.

3.1 Viscometer

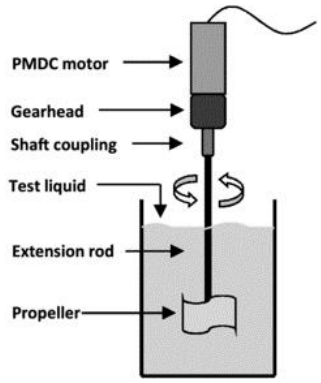

Figure 3.1: Diagram of Rotational Viscometer

Figure 3.1 shows a schematic of a rotational viscometer. Rotational viscometers are submerged in the fluid with a rotating propeller measuring the resistance to movement applied by the fluid. The resistance to movement is measured through the on board motor and measuring unit.

Figure 3.2: Brookfield viscometer DV1 with heating bath

Figure 3.2 is a picture of the Brookfield viscometer used for this project. A heating bath is used to raise the temperature of the oil to 40 and 100 degrees. The engine oils being tested consisted of 5 degraded oils, labelled: U4, U8, U11, U12,

U16. All these oils were sent by Volvo, who undertook some oil analysis of their own which can be found in table 3.2 and table 3.3.

All sample viscosities measured with ultrasound techniques needed data for comparison from another source of testing, in this case the Brookfield viscometer. The viscometer is made up of a spindle that rotates in a small sample chamber; it calculates the resistance from the fluid and relates this to the viscosity.

The viscosity of each sample was measured at 40°C and 100°C and these results were used to calculate the samples' viscosity at a full range of temperatures using ASTM D341-09[5]. These two particular temperatures were chosen to directly compare to and verify the viscosity measurements provided by the degraded oil supplier (Volvo).

The sample viscosities were also measured at two shear rates for each temperature; 13.2s-1 and 26.4s-1 at 40°C, 26.4s-1 and 66s-1 at 100°C. Two different shear rates were used to assess how Newtonian the behaviour of the oils was. Changing the shear rate also changed the measurable viscosity range of the viscometer, this is why different pairs of shear rates had to be used at the different temperatures. However, when plotting the viscosity-temperature graph described above non-Newtonian effects can provide inaccuracies hence the need for a common shear rate for each temperature.

Each temperature and shear rate combination was carried out 3 times, with the average viscosity being taken from these results. The variance in results was small enough to suggest that 3 tests were enough to obtain a relatively accurate measurement.

3.2 Ultrasound

3.2.1 Instrumentation

The following figure displays the set up for acquiring the experimental data. The probe consisted of two 5 MHz piezoelectric ultrasonic shear mode transducers attached to an aluminium bulk material with a thin polyamide matching layer. The transducers were previously set up in a pitch – catch mode, whereby one transducer transmits the ultrasonic wave into the probe whilst the other receives the reflected wave. The Picoscope (5000A Series) served as a waveform generator and oscilloscope to receive data from the probe. A bespoke LabVIEW programme was then used to acquire data from the Picoscope for real

time analysis and storage of the data files. The programme also allowed user control of the waveform parameters transmitted by the transducer, producing either a chirp pulse or stamina wave.

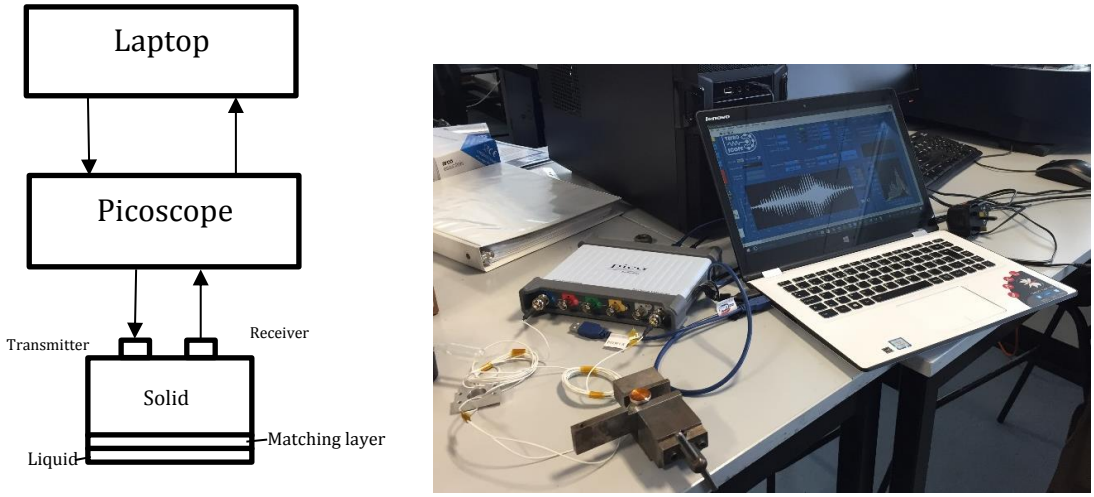

Figure 3.3 – Schematic of equipment set up (left) and image of set up (right).

The ultrasonic probe consisted an aluminium workpiece with a 50µm thick polyamide matching layer bonded to the surface. Two piezoelectric transducers are bonded to the reverse side of the workpiece.

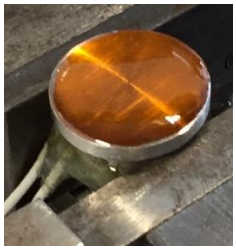

Figure 3.4 – Ultrasonic probe with oil on matching layer surface.

3.2.2 Reference Oil Samples

Degraded oils were provided by Volvo, with all the requisite information attached. A selection of standard oils were chosen to cover the viscosity range of Volvo oils. Table 3.1 shows the selected Cannon standard viscosity oils and their viscosities at 20 C and 25 C. Table 3.2 shows the Volvo oil pre-recorded viscosities. All oils were tested with Chirp and Stamina methods, to compare with conventional cone viscometer to examine sensitivity to viscosity.

Table 3.1 – Labelled and documented viscosities for Cannon standard viscosity oils.

Oil	Labelled		CSVdoc	
	Viscosity (cP)		Viscosity (cP)	
	20°C	25°C	20°C	25°C
N100	275.5	197.5	283	202
S200	467.2	345.2	460	340
S20	?	28.79	37	29
N35	73.41	55.56	75	56
S60	139.2	102.4	141	104

Table 3.2 – Volvo data for oil grade and viscosity

Oil Sample ID	Sample ID	Sample Type	Oil Grade	Visc. @ 40°C (cP)	Visc. @ 100°C (cP)
U4	12655	Engine Test	10W30	101.5	14.1
U8	12692	Customer	15W40	98.3	13.6
U11	12704	Customer	?	74.8	12.3
U12	12819	Engine Test	5W30	46.3	8.5
U16	5934	Engine Test	10W30	?	?

Table 3.3 – Volvo data for Contamination of engine oils

Oil Sample ID	Soot %	Fe	Pb	Oxidation	Fuel Dil.%
U4	2.5	87	6	?	< 3
U8	1.7	129	14	?	< 3
U11	1.8	91	6	23.4	< 3
U12	1.7	78	4	66.6	17.3
U16	4.7	?	?	?	?

In addition to the oil grade and viscosity, data was provided on the content of various contaminants including iron, lead and soot content, oxidation and fuel dilution. No units were provided for oxidation, iron or lead measurements. The values highlighted red in Table 3.3 show the maximum known value for each contaminant.

4. Results

4.1 Viscometer Data

Table 4.1-Brookfield Viscosity Measurements

Oil	40°C		100°C	
	Shear Rate (s-1)	Dynamic Viscosity (cP)	Shear Rate (s-1)	Dynamic Viscosity (cP)
U4	13.2	92.8	26.4	13.5
	26.4	91.25	66	12.44
U8	13.2	88.2	26.4	12.8
	26.4	87.55	66	11.8
U11	13.2	66.2	26.4	11.7
	26.4	66.05	66	10.5
U12	13.2	42	26.4	8.2
	26.4	40.55	66	7.6
U16	13.2	88.5	26.4	13.3
	26.4	88	66	12.34

Table 4.2 – Reflection coefficient of engine oils compared with Brookfield and calculated viscosities.

Oil	Viscosity (cP)			
	R	Brookfield	Oil Labels (log)	CVSd (log)
U4	0.3722	244.2	151.70	154.07
U8	0.3694	219.55	154.37	156.88
U11	0.4554	144.75	90.19	90.08
U12	0.5325	83.55	55.70	54.77
U16	0.4004	195.9	127.18	128.44

4.2 Chirp Ultrasound

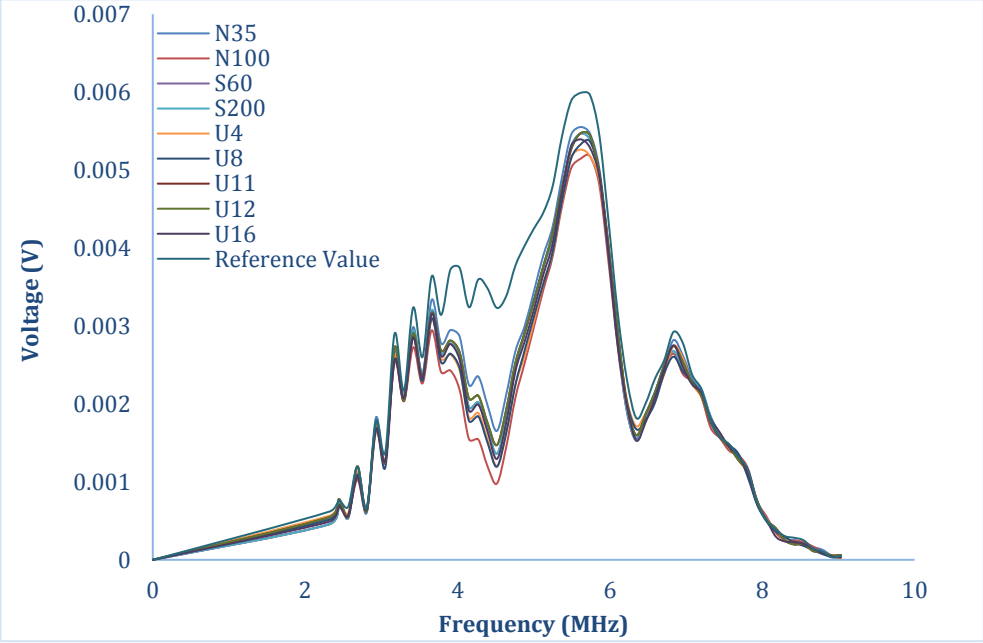

Figure 4.1- Voltage versus Frequency When a Chirp Signal Is Applied

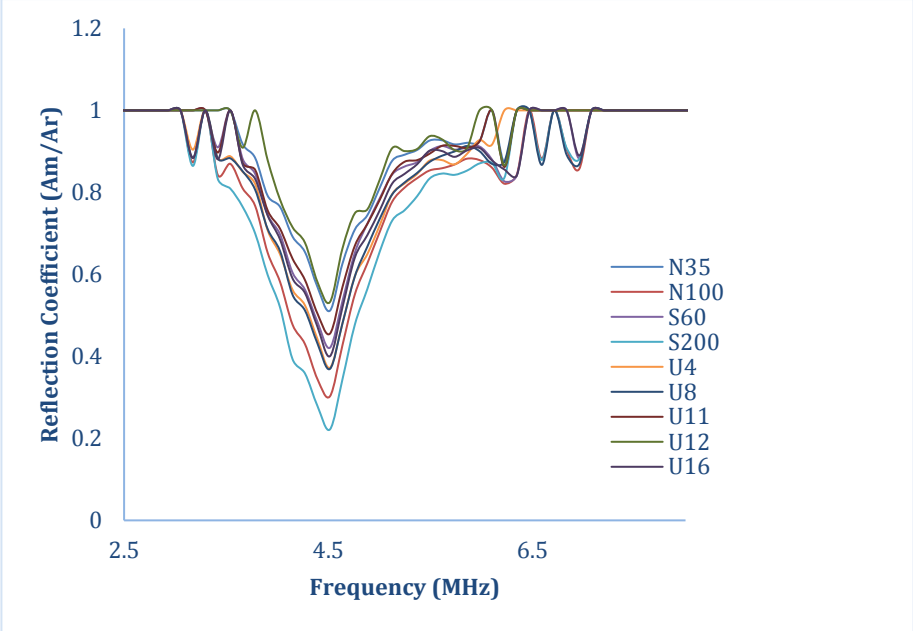

Figure 4.2- Reflection Coefficient versus Frequency When a Chirp Signal Is Applied

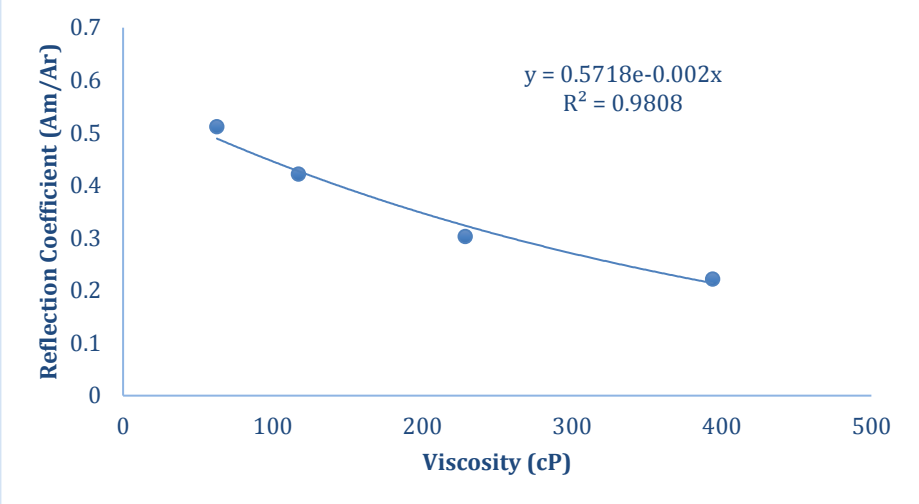

Figure 4.3- Reflection Coefficient versus Viscosity for Known Oils When a Chirp Signal Is Applied

Table 4.3- Viscosity of used oils using the chirp method

Oil	Viscosity (cP)
U4	214.7
U8	218.4
U11	113.8
U12	35.6
U16	178.2

4.3 Stamina Ultrasound

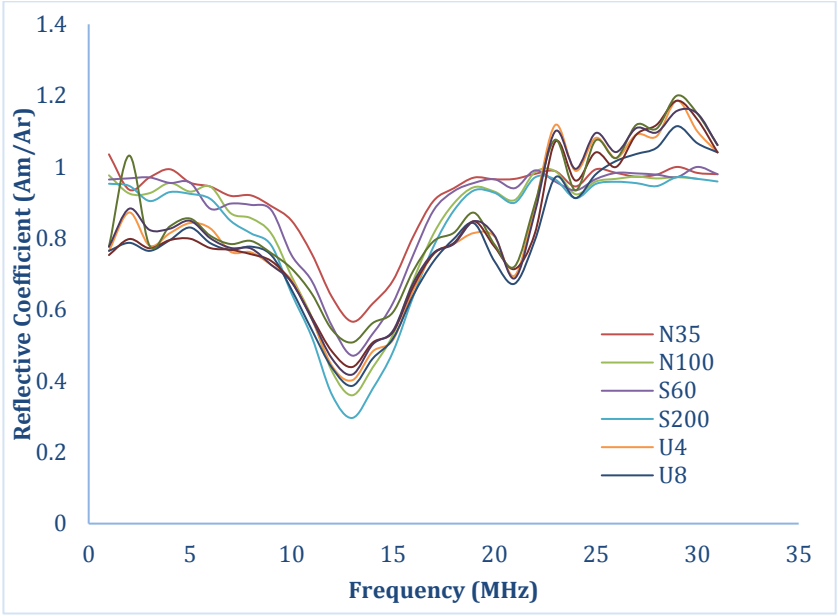

Figure 4.4- Reflective Coefficient versus Frequency for Different Oils Using STAMINA Method

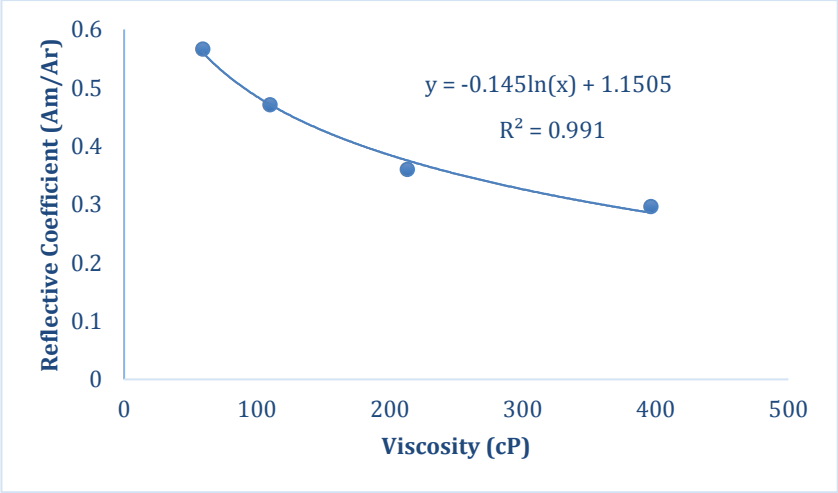

Figure 4.5 - Reflective Coefficient versus Viscosity for Known Oils Using STAMINA Method

Table 4.4 -Viscosity for Oils Calculated By Using STAMINA Method

Oil	Viscosity (cP)
U4	174.4
U8	194.6
U11	135.1
U12	84.1
U16	156.3

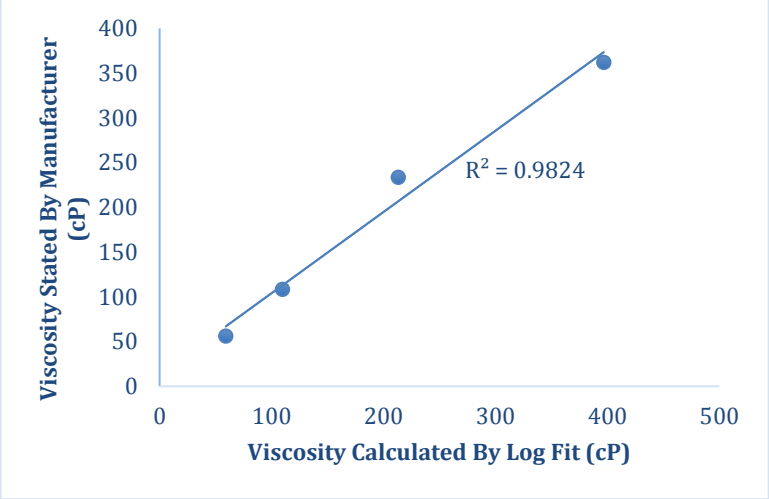

Figure 4.6-Comparison of Viscosities between STAMINA Method and Viscosities Supplied by Manufacturer

4.4 Comparison between Viscometer and Ultrasound

Table 4.5-Comparison of Viscosities between Brookfield, chirp and STAMINA methods

oil	Viscosity (cP)		
	Brookfield	Chirp	Stamina
U4	244.2	154.07	174.39
U8	219.55	156.88	194.57
U11	144.75	90.08	135.08
U12	83.55	54.77	84.06
U16	195.9	128.44	156.31

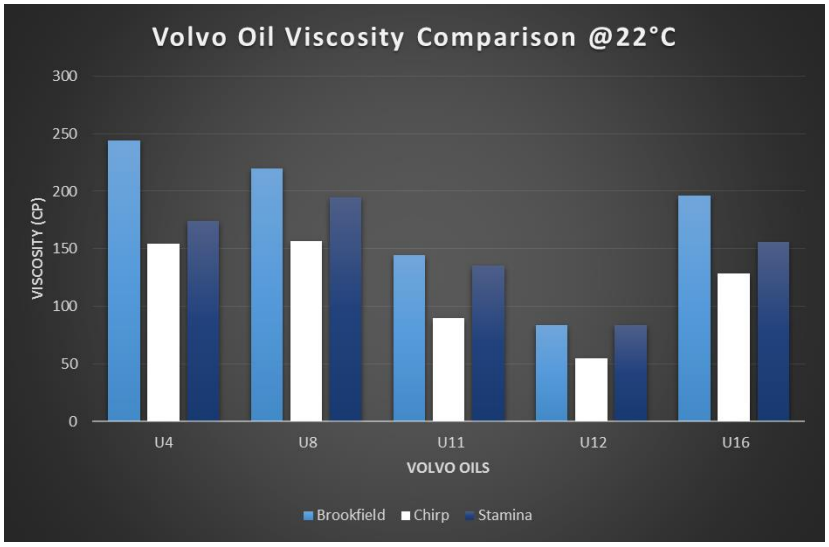

Figure 4.7 – Volvo oil comparison for Brookfield viscometer, Chirp and Stamina results.

5. Discussion

5.1. Brookfield Viscometer Measurements

The Brookfield viscometer uses a tried and tested measurement technique to obtain viscosity; in addition, there lack of variance in the measurements taken. These realities suggest that this measurement technique can be considered reliable and a good basis of comparison with the little tested ultrasonic techniques.

Comparing the Brookfield results to the viscosity measurements undertaken by Volvo show that the Volvo results are always larger. Without knowing the exact method Volvo used it is hard to comment on this discrepancy, though when the Brookfield measurements were being taken the initial viscosity reading was larger than the viscosity reading once the temperature had settled, this may suggest Volvo had not allowed the temperature to settle before taking a measurement.

5.2 Conventional vs Ultrasound

The results show that the viscosity measurements from a conventional viscometer are larger than those acquired using both ultrasound techniques for the Volvo engine oils. A possible explanation for this dissimilarity is to do with the way mechanical and oscillatory shear effect the molecules within an oil. A rotational viscometer shears the whole fluid whereas ultrasonic shear waves affects simpler aspects of the base oil as the oscillation is significantly faster than relaxation time of the additives (polymers) (6). This means the polymers present in the oil do not have an effect on the ultrasonic viscosity measurement whereas it may do for conventional viscometer measurements, presenting a possible reason for the difference.

Liquid loading of an oil onto an ultrasonic sensor may also cause entrainment of a thin liquid film (7). This entrainment may cause a damping of the oscillating wave or a change to resonance frequency of resonator or the propagating wave. Degradation of oil causes inhomogeneity of the base oil (8), this means some areas will have more agglomerated particles than others causing areas of differing molecular weight. It could be the case where there is only enough energy transmitted into the fluid to entrain the smaller molecular weight

substance thus producing an artificially lower viscosity measurement whilst heavier molecules require more energy to entrain thus going unmeasured. This is not the case however for U12, which may suggest that contaminants in the oil also affect the viscosity measurement.

As there are many unknowns in the contamination data provided, it is difficult to predict why there is this difference. U12 appears to have a larger known fuel dilution compared to the other oils. Simpler molecules with a lower molecular weight effect the reflected wave and therefore the viscosity measurement. It could be assumed that a larger proportion of short chain hydrocarbons in the oil may oscillate and effect the reflected wave result, influencing the viscosity measurement. However as all the Volvo oils have different grades, excluding U4 and U16, it is difficult to assess which contaminant influences the ultrasound results. Ideally, engine oils with the same grade and different amounts of degradation should be examined. This would help determine the effects of contaminants and oxidation products on ultrasonic viscosity measurements.

5.3 Stamina vs Chirp

The stamina measurements are closer to that of the conventional viscometer than the chirp (pulse echo) measurements. Stamina differs from chirps as it a continuous sinusoidal wave with a varying voltage at a particular frequency while chirp is a sinusoidal pulse with a modulated frequency over time. As the stamina wave is continuous, its time resolution is equal to the wave frequency yielding a faster response time compared to pulse echo where successive measurements depend on the pulse rate [5]. As a continuous wave is transmitted through the sensor towards the matching layer and the oil, a continuous reflection coefficient is produced rather than a pulsing one, providing more consistent and more sensitive results for viscosity measurements. This could be a possible reason as to why Stamina provided closer measurements to the pulse echo method.

6. Conclusion

The viscosity measurements obtained using the Brookfield viscometer were reasonably accurate and repeatable. All oils tested showed some shear thinning characteristics, suggesting they were Non-Newtonian in nature. The oils tested with the ultrasonic methods yielded lower viscosity results compared to the measurements from the conventional viscometer, bar the U12 STAMINA result. These differences may have arisen due to an entrained thin film of lower molecular weight present in the oil, giving a lower viscosity result. Furthermore, ultrasound may affect smaller simpler molecules more than long chain molecules, which also gives a lower viscosity result.

Further work will need to be completed to find whether the concentration or amount of contaminants affects the reflected wave coefficient for ultrasonic techniques, and how degraded additives influence the reflected wave differently to fresh additives. Engine oils of the same grade but different levels of known contamination should be tested with ultrasonic methods to assess contamination effects on viscosity measurements. A wider range of oils with known viscosities should be tested to allow for a logarithmic curve to be produced that is more accurate.

i. Appendix

i.i References

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i.ii Market Research

i.ii.i Vibrating viscometers

Table 1: current in-line Vibrating viscometers on the market

Manufacturer - name	Picture	Description	Price
Anton Paar L-vis 510		L-Vis 510 is an inline viscometer, which is absorbed straight to the production liquid. It simultaneously shows the viscosity and temperature of lubricants, starch adhesives, suspensions, and other various process liquids. The unit is capable of 24-hour production monitoring. The unit comes in three different versions. Firstly, L-Vis 510 Smart Sensor integrated with an mPDS 5 evaluation unit. Secondly, L-Vis 510 Smart Sensor with Operating Terminal (OT), where the measurement values are showed on the instrument, no evaluation device is needed. Lastly, the L-Vis 510 Smart Sensor, with a Remote Operating Terminal (ROT), which is mountable at a distance of 250 meters from the sensor.	£16-18k
hydramotion - XL7 series		In the last 15 years Hydramotion has revolutionised process viscosity measurement from an expensive, uncertain practice to a level where reliability and performance can exceed that of the lab. The XL7 viscometer is responsible for this revolution and leads the world in defining new standards of performance, reliability and cost. The XL7 series represents a wide range of standard viscometers, covering nearly all applications. In addition, custom instruments can be made for special situations.	
Hydramotion - XL7-HT2		Cool heads, hot toes. Continuously measuring viscosity at high temperature requires a special breed of viscometer. The XL7-HT2 model is capable of direct process viscosity measurement at up to 450°C (842°F) without the need for cooling jackets or ancillary pipework.	
a fraser MIVI		The in-line MIVI, manufactured by Sofraser, is a process viscometer equipped with PTFE, ADLC, Enamel vibrating rod coating. It has an operating temperature that ranges from -55 °C up to 300 °C, maximum pressure range of 1,900 bar and a protection class of IP67. The process viscometer is suitable for 3A design sanitary applications.	

i.ii.iiRotary viscometers

Table 2: current in-line Rotary viscometers on the market

Manufacturer - name	Picture	Description	Price
Brookfield ametek - 10 - 500000 cP TT-100		Brookfield's TT-110 In-Line Viscometers are engineered to deliver comprehensive levels of problem-free service operations that require continuous product viscosity monitoring and control. They feature viscosity rates that range from 10 cP to 500,000 cP.	
Marimex - VA-300 series		The VA-300 series is provides technically feasible designs. The ViscoScope sensor may come with a nozzle, and at times, a block lange for sensor mounting. This feature results to a dead volume, which is connected by a non-active extension or NAE. The length and diameter of the NAE are determined to attune with the nozzle's size. This will prevent the medium from collecting in the dead volume. Additionally, the device is available in different models such as VA-300M, VA-300H, VA-300L, VA-300X, and VA-300S. It offers a speed flow of 10 m/sec. or 33 ft./sec.	
Marimex - VA 100 series		The VA-100 is ideally designed to provide an excellent quality performance and functionality. It is a high quality sensor which is mainly used for standard installation processes. The apparatus is highly integrated with NPT and several metric threads. The device is specifically installed in small tanks, pipes and several flow through cells. It is also ideally constructed for low and intermediate viscosity ranges which runs up to 130°C process temperatures.	
Micro Motion - max. 100 cSt, -50 - +200 7829		The 7829 Viscomaster and 7829 Viscomaster Dynamic Viscosity Transmitters are major innovations in the measurement and control of heavy fuel oil (HFO) that supply engines, turbines and burners in Marine and Power applications. Through their multivariable design, the 7829 Viscomaster Transmitters accurately measure viscosity, density and temperature in real time, allowing true kinematic viscosity analysis. These meters incorporate an integrally mounted transmitter that has two analog outputs and RS485 Modbus as standard. As an established, proven design, the 7829 Viscomaster viscosity transmitters have been approved by Lloyds Register for marine environments and have a wide range of equivalent worldwide marine approvals.	

i.ii.iii Capillary viscometer

Table 3: current in-line Capillary viscometers on the market

Manufacturer - name	Picture	Description	Price
Agilent Technologies - capillary viscometer		The Agilent Viscometers are detectors used for measuring the viscosity of GPC/SEX and is designed to be included into Agilents integrated GPC systems. With its rugged, proven four capillary bridge design, the integration of refractive index (RI) and the viscosity detections gives a highly accurate determination of molecular weight for all of the polumer types defined on the Universal Calibration principle. It is also a valuable structural arrangement and branching information with is not accessible from other concentration detector alone.	
capillary viscometer - 0.1 - 100000 cPs MOFB		For applications where it is desirable to have the wetted parts exposed to facilitate removal of built-up fluids	

i.ii.iv Rolling ball viscometers

Table 4: current in-line Rolling Ball viscometers on the market

Manufacturer - name	Picture	Description	Price
Brookfield ametek - 5 - 100000 cP TT-220		The TT-220 by Beookfield is a Open tank viscometer which is designed for pen tank applications that has a volume capacity of 5 to 20 gallon or 20 to 75 liters. This is the ideal tool for controlling and monitoring constant viscosity. Also, it can be used in coating and printing operations.	
Galvanic - nametre		The In-line viscometer, manufactured by Nameter®, employ a torsional oscillation measuring method which results in an accurate output for a wide range of materials as well as process conditions. This device is used in monitoring as well as controlling applications. This transducer offers a fixed 316L SS construction and is factory calibrated to NIST traceable standards. It can measure viscosity ranging from 0.1cP up to 1,000,000cP in temperatures ranging from -40°C up to 400°C. This device can be installed in pipelines as well as in tanks. It can withstand numerous types of mediums including asphalt, refined oil, foods, petrochemical and polymer.	