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DTU Report

End-Report of Annex XX of the IEA/AMF of the IEA: 'DME as an Automotive Fuel II'

PART 2

Date	19 November 2001
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Project code DTU	MEK-ET-ES 2001-04
Research period	januari 2000-november 2001
Number of pages	11
Number of appendices	2

Summary

The standard method for testing the lubricity of diesel oil was altered so that it can handle DME. The testing of neat DME revealed that its lubricity is very low. Adding anti-wear agents in small proportions to the DME augmented the lubricity very effectively though. In this way the lubricity of diesel oil could be reached and even surpassed. Using a newly developed viscometer for volatile fuels, the viscosity of DME was determined for the first time. It is 24 times lower than that of diesel oil and it is not raised significantly when the DME is blended with reasonable amounts of additive. It is suspected that, in order to use DME in conventional injection systems, a very high (perhaps unreachable) lubricity is required because of the low viscosity level.

Contents

1 Introduction

This Annex runs under the Implementing Agreement on Advanced Motor Fuels of the International Energy Agency (IEA). It can be considered as successor of the Annex XIV ‘DME as an Automotive Fuel’.

Recent research has shown that Dimethyl Ether is an excellent alternative to conventional diesel fuel. This means high efficiency combined with smoke-free combustion and low NOx emissions. However, despite the very promising possibilities of Dimethyl Ether as an automotive fuel, conventional fuel injection systems suffer from extreme wear using DME. This is caused by relatively low viscosity and poor lubricating properties of DME.

This second part of the report deals with an investigation on improving the lubricity and viscosity of DME by adding different lubricants.

2 Subtask 1: Wear tests in DME with lubricant

2.1 The Lubricity of DME

A high-lubricity diesel fuel has the ability to protect surfaces from wear when they are lubricated in the boundary lubrication regime. This is very important for the lifetime of diesel engine injection equipment. The lubricity of diesel fuel is currently determined by the high frequency reciprocating rig (HFRR), which is covered by several standards. The principle of the HFRR is to slide a steel ball against a steel disk with a reciprocating motion for a given time. As the contact between the specimens is only lubricated by the investigated fuel, the size of the wear scar on the ball is a measure of the lubricity of the fuel. This measure is called the wear scar diameter (WSD) and is given in microns.

The HFRR was modified so that it can handle DME. This new method is called the medium frequency pressurised reciprocating rig (MFPRR) and is described in appendix D and reference [2].

The lubricity of pure DME was established to be very low as it is shown in figure 2.1.

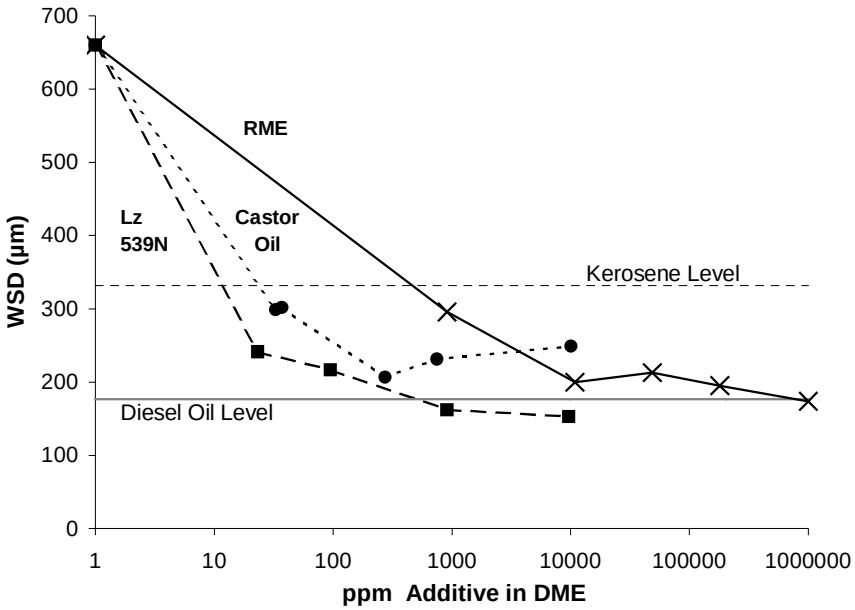

Figure 2.1: The results of the MFPRR lubricity tests. The lubricities of kerosene and diesel oil are shown for comparison.

The low lubricity of DME can be compared to that of kerosene and diesel oil by observing figure 2.1. DME was blended with various additives, which are described in a part of table 2.1.

Additive	Application	Density @ 25 °C (Kg/m^3)	Kin. Viscosity @ 25 °C (cSt)
Rapeseed Oil Methyl Ester (RME)	Food	870.3	5.905
Rapeseed Oil	Food	900	62.06
Lubrizol 539N	Diesel Oil Lubricity Enhancer	890	31.43
Castor Oil 927	Two Stroke oil	953	350.3
Palm Oil	Food	950	Solid
Candle	Candle Lights	950,8	Solid
Lard	Food	950	Solid

Table 2.1: The additives used in the DME blends.

The main conclusion of the measurements in figure 2.1 is that a few ppm of additive raise the lubricity of DME considerably. The Lubrizol 539N was the most effective as blends of DME and 800 ppm or above of this additive have a lubricity comparable or even higher than that of diesel oil.

2.2 The Viscosity of DME

A volatile fuel viscometer (VFVM) was developed, which is described in appendix E and in reference [3].

The viscosity of DME, both neat and additised, was established and the results involving less than 10 percent additive are shown in figure 2.2.

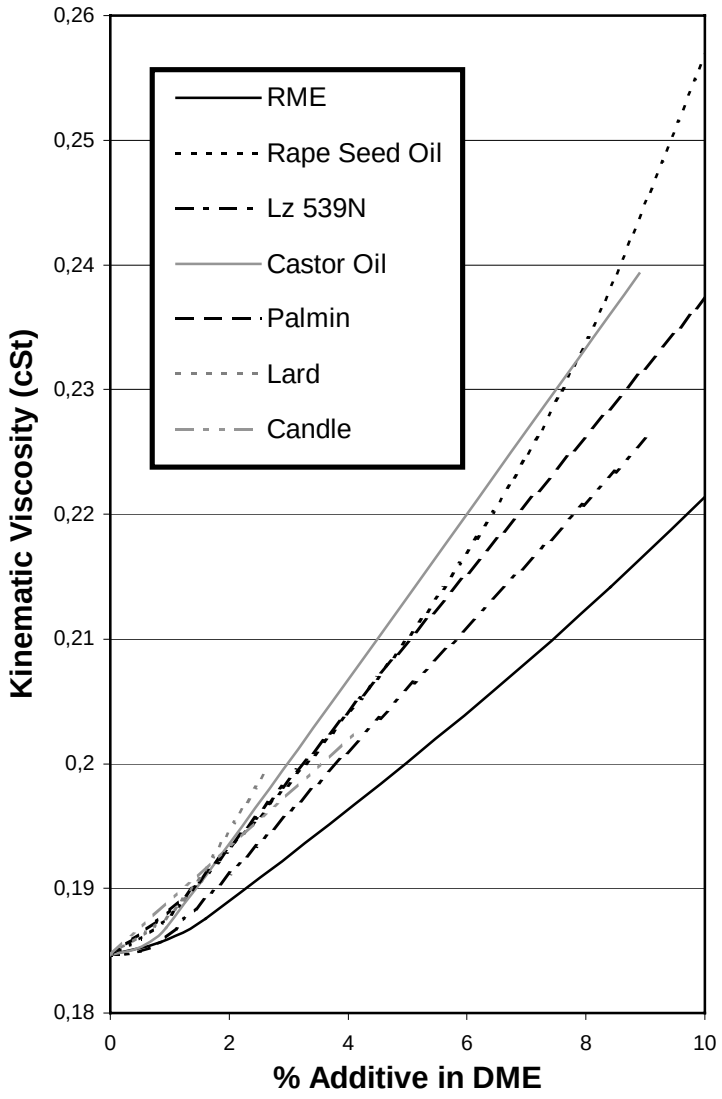

Figure 2.2: Kinematic viscosity of DME blends.

This figure shows that the kinematic viscosity of neat DME is only 0.185 cSt, which is 24 times lower than that of diesel oil. The used additives are described in table 2.1. Their effect on DME viscosity is not significant in dosages below 10 percent as it is shown in figure 2.2.

In order to reach a viscosity similar to that of diesel oil, DME must be blended with much larger proportions of additive as figure 2.3 shows.

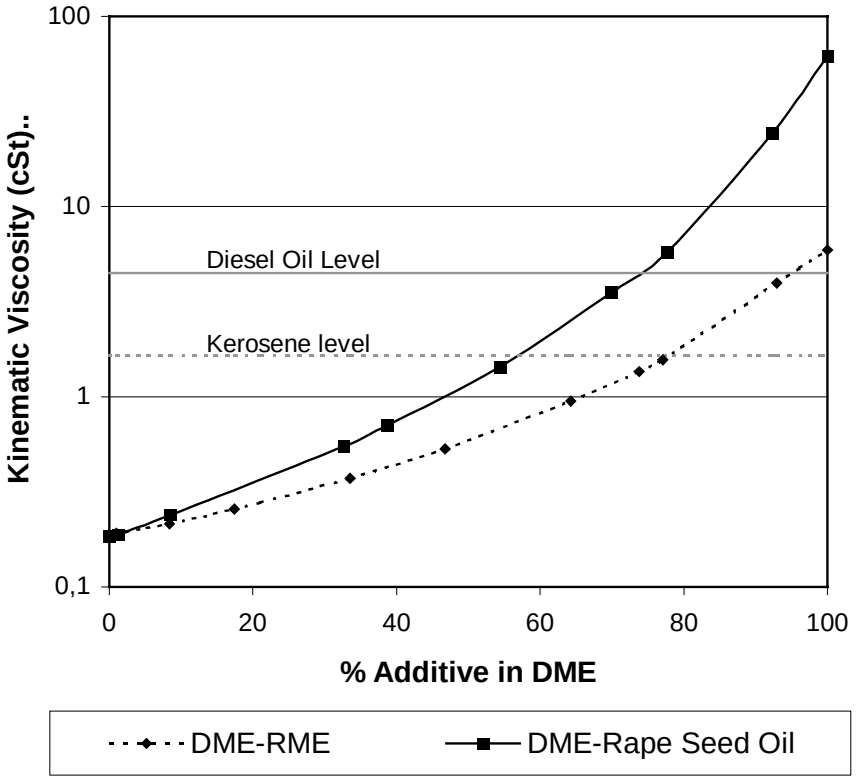

Figure 2.3: The kinematic viscosity of DME blended with RME and rapeseed oil. The viscosities of kerosene and diesel oil are shown for comparison.

Figure 2.3 reveals that only DME blended with over 75 percent rapeseed oil or 95 percent rapeseed oil methyl ester (RME) reaches a viscosity comparable to that of diesel oil.

2.3 The Correlation between Lubricity/Viscosity and Wear

Tests of a large number of liquid fuels using the standard lubricity method HFRR have shown that the diesel oil lubricity level only ensures full lifetime of the injection pumps if the fuel at the same time has a viscosity similar to that of ordinary diesel fuel. If the fuel has a lower viscosity such as that of kerosene, the lubricity level should be as high as that of RME. These relations are illustrated in figure 2.4 as the two areas “pass” and “fail”.

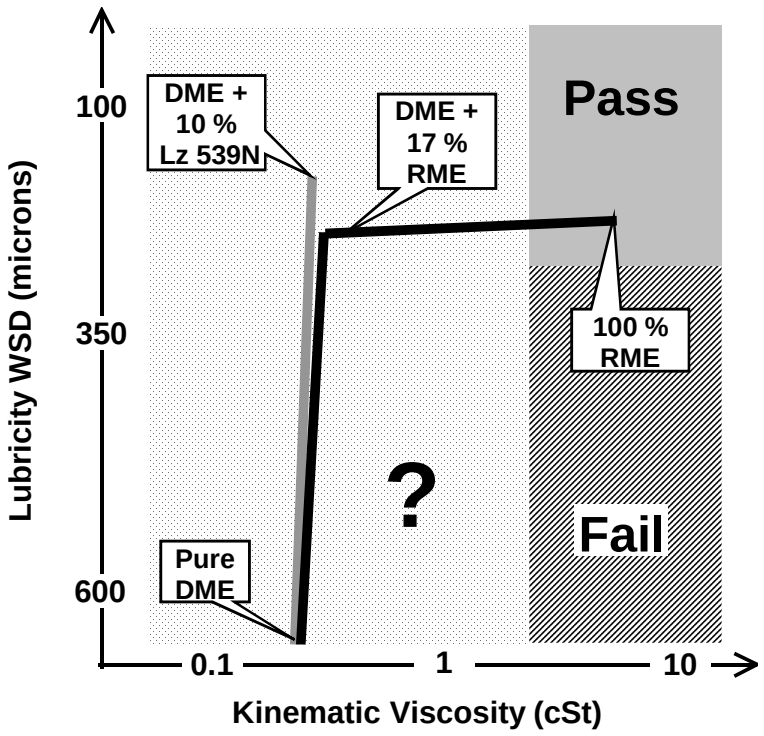

Figure 2.4: The lubricity of selected blends compared to their viscosity. The grey line covers DME-Lubrizol 539N blends with 0 to 10 percent additive and the black line covers DME-RME blends with 0 to 100 percent additive. The known pass and fail areas are shown as well as an undetermined one marked with a "?".

As soon as the viscosity drops below that of kerosene, the pass/fail limit is undetermined shown as the area marked "?" in figure 4.4. The DME, neat and reasonably additised, is situated in this area. Figure 4.4 shows examples with Lubrizol 539N and RME. Only blends with over 95 percent RME reaches the "pass" area.

As a result of the above, it is not recommended to use conventional diesel engine injection equipment for DME. The use of reasonable proportions of additive in DME can reduce the need for wear protection of the pump components, though.

3 Conclusions and recommendations

3.1 Conclusions

Subtask 1: Wear tests with DME and additive

The lubricity of DME, neat and additised, was investigated using the medium frequency pressurised reciprocating rig (MFPRR). These tests show that the lubricity of DME can be raised to a level comparable to that of diesel oil when blended with additives in small proportions.

The viscosity of DME was not established until the volatile fuel viscometer (VFVM) was developed. With this method, the kinematic viscosity of pure DME was measured at 0.185 cSt at 25 ^{o}C, which is 24 times lower than that of diesel oil. This low viscosity of DME is not raised significantly by reasonable amounts of additives regardless of their nature.

The level of lubricity that ensures full lifetime of conventional diesel injection equipment is only established for fuels with viscosities above one cSt at 25 ^{o}C. The adequate lubricity level needed for the low viscosity fuel DME is not established but it is expected that it will be very high, perhaps even unreachable. Conventional injection equipment can be used for blends of 10 percent DME and 90 percent other fuels as, for example, rapeseed oil methyl ester.

3.2 Recommendations

Subtask 1: Wear tests with DME and additive

- Conventional diesel engine injection equipment should not be envisaged for the handling of pure or lightly additised DME.

- Other diesel fuels blended with no more than 10 percent DME are suited for existing injection pumps.

- Tests should be performed that establish the ability of various materials and surface coatings to cope with lightly additised DME. The additising of DME could reduce the cost of the injection systems significantly by lowering the need for wear protection of the pump components.

4 References

[2] Sivebaek, I.M., Sorenson S. C. “Dimethyl Ether (DME) – Assessment of Lubricity Using the Medium Frequency Pressurised Reciprocating Rig Version 2 (MFPRR2).” SAE Paper 2000-01-2970. 2000.

[3] Sivebaek, I.M., Sorenson S. C., Jakobsen J. “Dimethyl Ether (DME) – Assessment of Viscosity Using the New Volatile Fuel Viscometer (VFVM)” SAE Paper 2001-01-2013. 2001.

A MFPRR (Medium Frequency Pressurised Reciprocating Rig) Details

The MFPRR was developed as a HFRR that can cope with DME. This means allowing pressurisation and avoiding dynamic sealing. This last point is important because of the incompatibility between the dissolving power of DME and elastomers. Figure A1 shows the rig of the MFPRR.

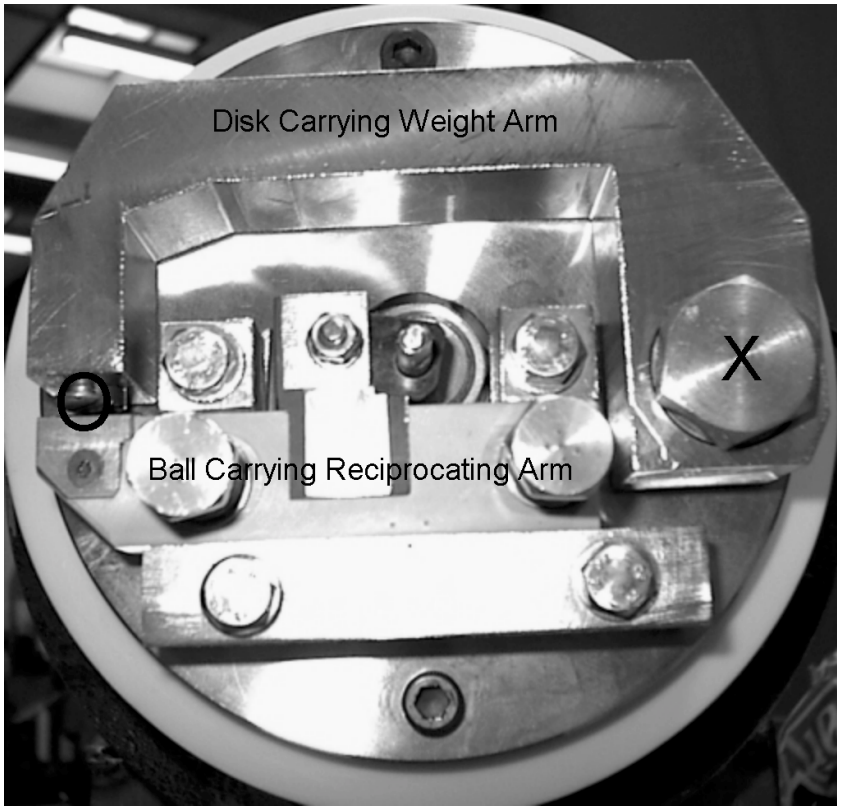

Figure A1: The inside of the MFPRR.

The upper part of the rig is a disk carrying weight arm, which is able to rotate freely around the X-axis as shown in figure 1. The lower part is a ball carrying arm and the contact between the test specimens is shown with an O in figure A1. The ball arm, and thereby the ball, is given a reciprocating motion by the crank/con-rod assembly shown in the middle of the rig. The shaft entraining the crank is driven by a magnetic coupling situated as shown in figure A2.

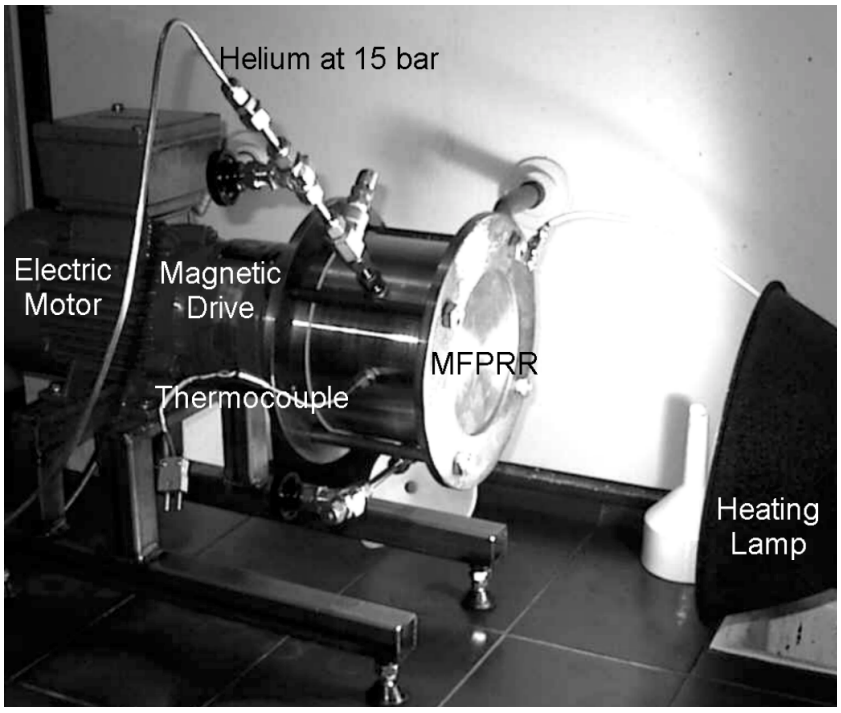

Figure A2: The different components of the MFPRR.

The advantage of this kind of transmission is that dynamic sealing is avoided as the shaft is driven by the electric motor through a shroud by magnets. Figure A2 also shows the tank pressurised at 15 bar by helium. This tank contains the rig, which is completely immersed in fuel during testing. A lamp provides the necessary heat in order to keep the right temperature, which is monitored by a thermocouple.

The test conditions for the MFPRR differ from the ones for the HFRR as shown in table A1.

Test	HFRR	MFPRR
Fuel vol. (ml)	2 +/- 0.2	300
Fuel temp. (^{o}C)	25 or 60 +/- 2	25 +/- 2
Stroke (mm)	1 +/- 0.02	5 +/- 0.1
Frequency (Hz)	50	10
Applied load (g)	200	220
Bath surface area (cm^2)	6 +/- 1	No limit
Relative humidity (%)	>30	No limit
Pressure (bar)	Ambient	15
Repeatability (µm)	80 @ 60 ^{o}C	30

Table A1: Test conditions for the MFPRR and the HFRR

B VFVM (Volatile Fuel Viscometer) Details

Adapting a viscometer for DME measurements also requires that it is developed so that it can cope with the properties of DME.

In order to measure the viscosity accurately, a glass capillary viscometer is chosen. The use of this type of viscometers is covered by several standards. For measuring the low viscosity of DME the smallest Cannon-Manning Semi micro is chosen: A number 25. This is shown in figure B1.

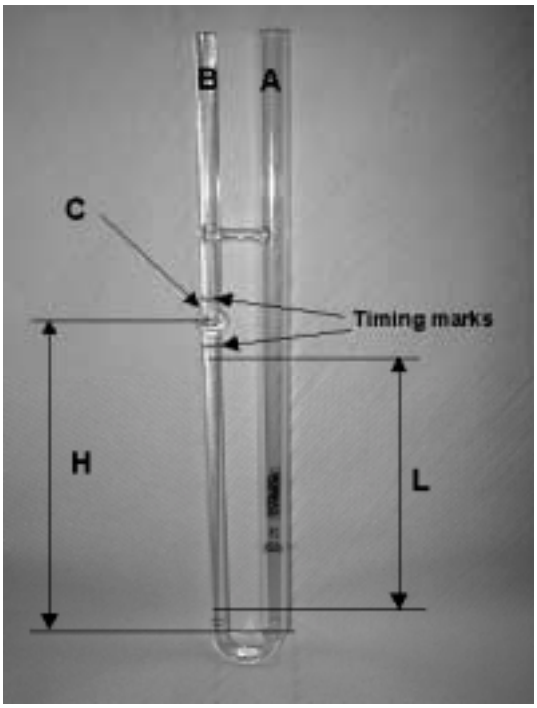

Figure B1: The Cannon-Manning Semi micro viscometer. For explanation of the letters, see text.

The principle of the method is to measure the time t (s) elapsed for a given volume of liquid, contained in the timing bulb C, to pass through a capillary tube of length L (m). The driving pressure is the head of liquid, H (m), in the viscometer. The measurement is completed when the meniscus of the liquid has passed from the upper timing mark to the lower one. According to the Hagen-Poiseuille law, the kinematic viscosity υ of the liquid is then proportional to the elapsed time t. Equation 1 gives the constant of proportionality V called the viscometer constant:

$$\nu = V * t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\_1$$

Where ν is given in cSt and V in cSt/s. The dynamic viscosity μ is then given by equation 2:

$$\mu = 10^{-3} * \nu * \rho \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Equation\_2$$

Where ρ is the mass density of the liquid in kg/m^3. Equation 2 gives the dynamic viscosity in cP, which is the same as mPa.s.

In order to pressurise the method, the glass viscometer is put into a glass tube shown in figure B2.

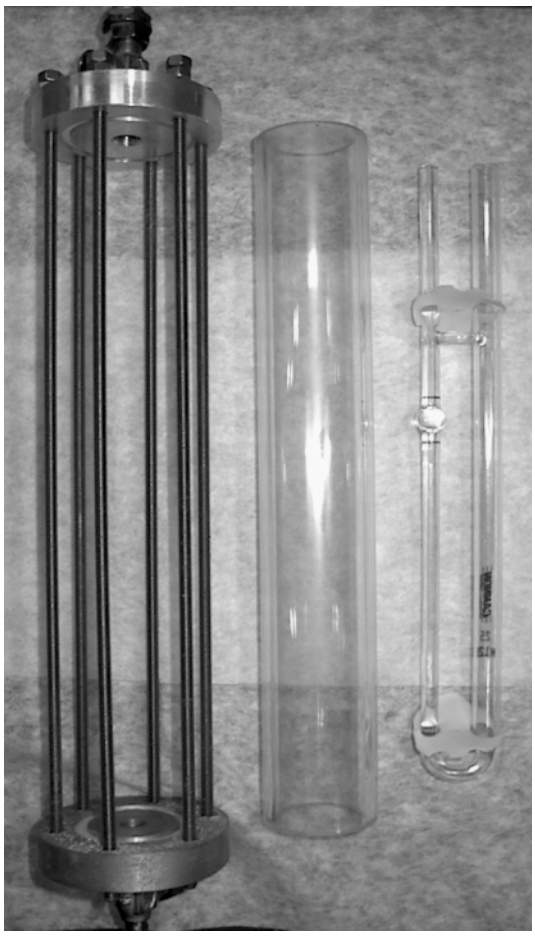

Figure B2: The VFVM components. From left to right: Aluminium covers with six tightening bolts, the glass tube and the standard viscometer with PTFE holders.

To keep the viscometer straight in the tube, it is fitted with holders made of poly tetra flour ethylene (PTFE), which is resistant towards DME. The glass tube is closed by two end covers tightened with six bolts. The gaskets are made of PTFE.

The measuring procedure is very dependent on the volume of DME filled into the VFVM through the valves fitted to the end covers as shown in figure B2. This amount should be between 0.15 and 0.4 litres.

When filled, the VFVM is immersed in a bath set at a given constant temperature and is left there for 30 minutes. In order to identify the different components of the viscometer, each of these are assigned with a letter as shown in figure B1. “A” is the tube with a large inner diameter and “B” is the one including the capillary part. “C” is assigned for the timing bulb.

As shown in figure B3, tube A of the standard viscometer is filled by rotating the VFVM into a horizontal position.

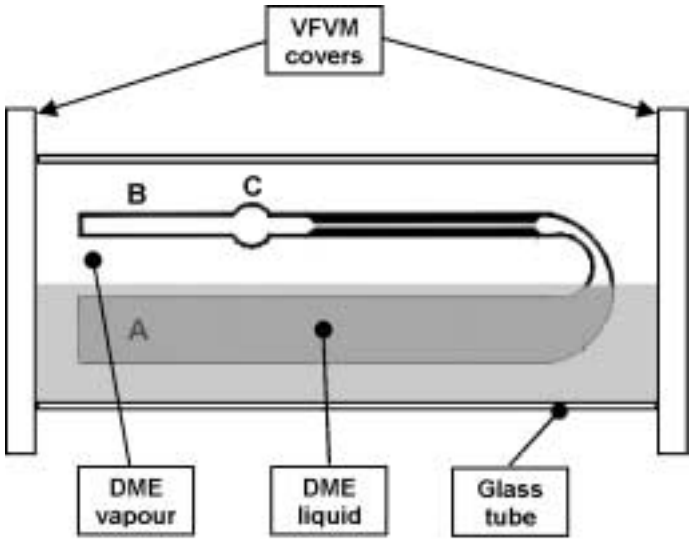

Figure B3: Filling of the VFVM. The viscometer is rotated to a horizontal position and tube A is thereby filled with fuel. Tube B is above the liquid level.

The VFVM is then raised to a vertical position and the fuel from tube A is now filling tube B. This loading of the viscometer is shown in figure B4. In order to speed up this process, tube A is refilled twice during the loading.

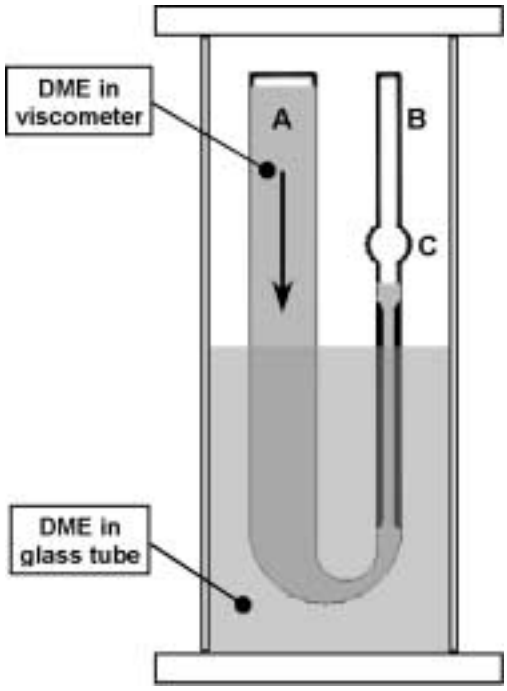

Figure B4: The loading of the VFVM. The fuel from the filled tube A is filling tube B schematically shown by the arrow.

When tube B is completely filled with fuel the VFVM is again put into a horizontal position but this time tube B is immersed in the fuel as shown in figure B5.

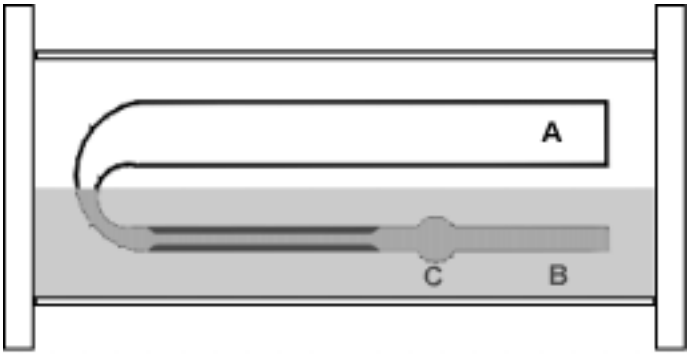

Figure B5: Rotating the VFVM to a horizontal position empties Tube A. Tube B is immersed in the fuel.

Rotating the VFVM a few degrees now empties tube A. The presence of the two viscometer holders facilitates this emptying as they slow down the fuel flow during the rotating of the VFVM.

The VFVM is put into the measuring mode by again turning it into a vertical position as shown in figure B6.

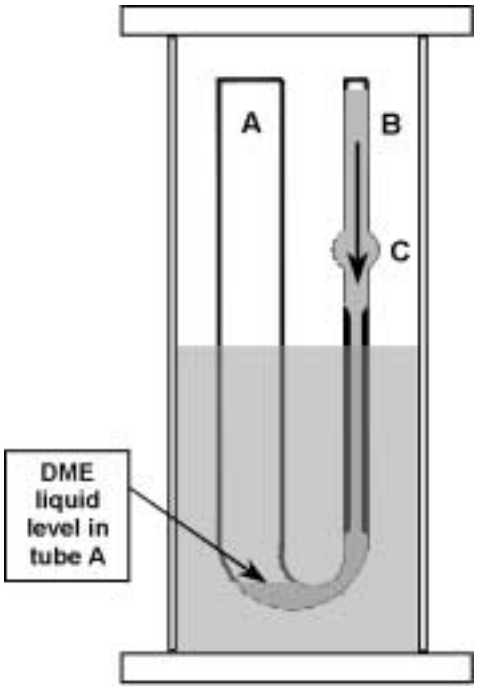

Figure B6: Tube A is nearly empty and the measuring is now in progress as indicated by the shown arrow.

The result of the test is the time needed for the fuel meniscus to flow from the upper timing mark to the lower one. The measurement is repeated a couple of times in order to ensure that the fuel has reached the temperature of the bath.

All the measurements in this report were made at the vapour pressure of DME and at 25 ^{o}C. No external pressurisation source was used.