PROPOSALS FOR SOLUTIONS TO PROBLEMS RELATED TO THE USE OF F-34 (SFP) AND HIGH SULPHUR DIESEL ON GROUND EQUIPMENT USING ADVANCED REDUCTION EMISSION TECHNOLOGIES

1.0 INTRODUCTION

1.1 Background

1.1.1 Fuel Issues

The AC/112 NATO Fuels and Lubricants Working Group (NATO FLWG) made an official request at its 2005 meeting to the Research and Technologies Organisation (RTO). It requested assistance to solve the problem caused by the stringent European (Euro 4/5) and equivalent US emission legislation imposing advanced emission reduction technologies for all Road Vehicles.

It has been identified that these emission reduction technologies require the use of low sulphur fuels (LSF).

F-34 used under NATO Single Fuel Policy (SFP) is a fuel with high sulphur content when it is compared to European or US compliant diesel fuels. High Sulphur Fuel (HSF) is a potential problem to NATO forces when vehicles and equipment are fitted with advanced emission reduction devices that require Low Sulphur (LS) fuel use. The problems can be either operational, emission related or both.

NATO future operations will be expeditionary; the available local diesel fuel is not likely to be compliant with low sulphur diesel specifications (i.e. EN 590). Therefore NATO forces must have a known worldwide available, standard fuel (F-34) and equipment capable of using such high sulphur fuels (HSF).

1.1.2 Legislation and Applicability to Military Forces

The RTO/Applied Vehicle Technology (AVT) Exploratory Team (ET-073) initially considered the legal implications regarding commercial manufacturer formal type approval of vehicles to Euro 4/5 standards. It was found that for military operational road vehicles, the EU current motor vehicle framework emission regulations on type approval of motor vehicles[1] were not applicable. Therefore ET-073 focussed their effort addressing technical and operational issues related to the use of SFP and high sulphur diesel fuel and to give guidance and advice in the procurement of future equipment.

2.0 DISCUSSION

Previous AVT-035 report did not address market solutions especially regarding the use of HSF.

The ET-073 evaluated the current manufacturers' emission reduction technologies by conducting a literature search and by collecting manufacturers and suppliers data from the participating nations. The survey indicated that manufacturers had developed their emission reduction technologies specifically for LS fuel use. It was

[1] 70/156/EEC and particularly the daughter directives the daughter Directives being 2005/55/EC (88/77/EEC) or (70/220/EEC) or ECE 49/02 and 83/04 as last amended for motor vehicle emissions.

also found that a new technology suitable for HSF is not likely to be developed only for the needs of military users.

Therefore, the ET-073 needed to consider current technologies adapting these to best meet military requirements. As a consequence of this, nations such as Germany conducted work in close relationship with the industry to identify possible solutions.

The ET-073 team agreed following programme of work addressing the short term and long term strategies:

- Considering the need for a quick answer to the NATO Pipeline Committee (NPC), it was decided to provide a guidance and advice document based on current technologies to procurement services.
- To address the long term impact of the use of HSF, it was decided that more work was needed and that this would be best addressed in the new Task Group AVT-159 investigating of "Impact of Changing Fuel on upon Land, Sea and Air Vehicles".

2.1 Possible Current Technology Vehicle Exhaust Emissions Solutions

The emission control technologies that engine manufacturers currently use are the following:

1) Exhaust Gas Recirculation (EGR) to control NO_x emission accompanied by increased boost pressure and advanced start of injection to control soot.
2) Diesel Particulate Filter (DPF) to control soot emissions.
3) Oxidation Catalysts to control CO and HC emissions and to meet the high temperatures for regenerating the DPF.
4) Selective Catalytic Reduction (SCR) systems to control NO_x.
5) Lean NO_x Traps (LNT) to control NO_x emissions.

Most manufacturers use (combinations of) several technological solutions. The ones that specifically require the use of a low sulphur fuel are 2, 4 and particularly 5. Technological solution "5" is so sensitive to high sulphur fuel because its use will lead to absorber poisoning drastically limiting its efficiency.

2.2 Effects

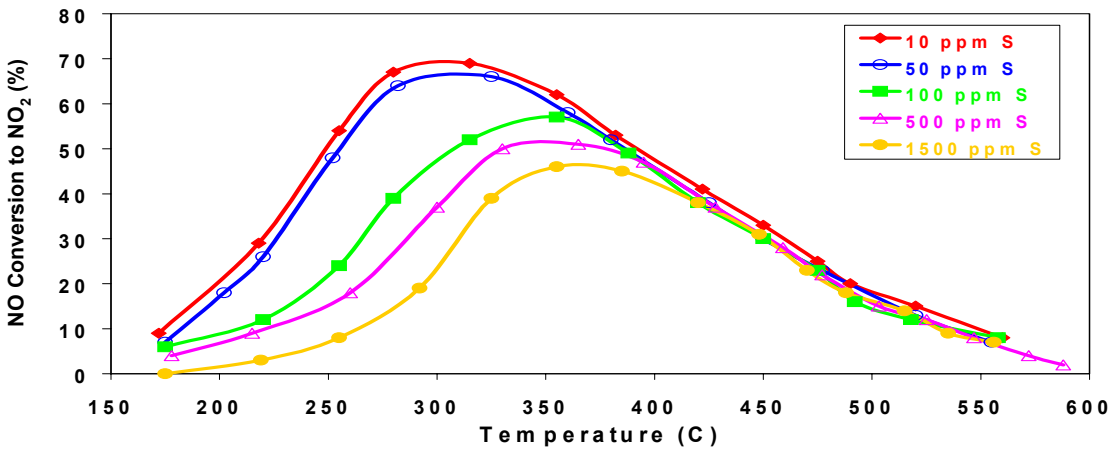
2.2.1 Effect of Sulphur Contained in the Fuel

- Inhibits catalyst performance by strong adsorption on surface and competes for space on the catalyst surface with pollutants.
- Limits the amount of NO_2 formed on an oxidising catalyst – a problem for some particulate DPFs and NO_x adsorbers that rely on NO_2 for their regeneration.
- Reacts with chemical NO_x traps more strongly than NO_x – this decreases NO_x storage capacity and requires more vigorous and frequent regeneration; increasing fuel consumption.
- Creates sulphate particles that are measured by current sampling and measurement techniques, with any emission control system that includes a precious metal catalyst with an oxidising function.
- Contributes to coating the catalyst surface.

2.2.2 Effect of Sulphur on Advanced Emission Reduction Technologies

2.2.2.1 Diesel Oxidation Catalysts (DOCs)

- An oxidation catalyst will reduce the soluble organic fraction (SOF) of the particulate by up to 90%. Destruction of the SOF is important because this portion of the particulate contains numerous chemicals of concern to health experts. Control of the SOF enables the oxidation catalyst to reduce total particulate emissions by 25 to 50 percent, depending on the constituents that make up the total particulate. This technology also reduces diesel smoke and eliminates the pungent diesel exhaust odour. DOC technology has been successfully used on all diesel cars sold in Europe since 1996. DOCs may also be used in conjunction with a DPF, NO_x absorber, a $DeNO_x$ catalyst, or SCR to "clean-up" any by-pass of injected hydrocarbons or ammonia. It has been identified that high sulphur reduces the efficiency of the catalyst by reducing its operating temperature and by increasing the formation of sulphated ash. The low operating temperature of the oxidation catalyst reduces the formation of NO_2 needed for the regeneration of the DPF.



2.2.2.2 Fuel Sulphur Effects on Diesel Particulate Filter (DPF).

- HSF will cause two different types of negative effects. The first will reduce the catalyst efficiency by reducing the high the operating temperature needed for regenerating the DPF. The second one will be caused by the oxidation of sulphur dioxide resulting in high levels of sulphated ash and total particulate mass. Depending on the DPF design the experienced negative effects will differ as follows:

1) Fuel Sulphur Effects on Wall Flow Diesel Particulate Filter (WF-DPF)

   The WF-DPF is a honey comb structure with parallel pipes. These pipes are alternating closed and opened. The inlet pipe at one end and the outlet pipe at the other. Thus gas may only flow through the wall of the filter. Soot particles will be collected in the inlet pipe.

   Using HSF will result in an increased loading of the filter and causing frequent regenerating cycles. Additionally, to the reduced performance of the oxidation catalyst will result in an overload and a blocking of the filter. The filter must then be replaced or regenerated externally.

2) Fuel Sulphur Effects on Flow-Through Metallic Particulate Matter Filter (M-PMF)

   M-PMF is structured in a layered stack consisting of corrugation foil with shovels and porous fleece. Exhaust gas is introduced to both up and down side of fleeces by shovels, and then soot is trapped

while gaseous components pass the fleece. The nitrogen oxides produced in the oxidation pre-catalyst cause the soot particles to be burned continuously.

As explained in Annex A, the use of HSF will reduce the over all efficiency of the system but will not block the M-PMF.

*2.2.2.3 Fuel Sulphur Effects on **S**elective **C**atalytic Reduction-System (**SCR**-System)*

The **SCR**-System eliminates NO_x from the exhaust gas for diesel engines by using urea dissolved in water and a catalytic converter for use in trucks and passenger cars. This technology requires no modification of the engine.

The function of the SCR-System (see Annex B page 9) is as follows.

The SCR-System is an integrated exhaust-system. Using the catalytic reduction process the harmful nitrous oxides (NO_x) are converted into nitrogen (N_2) and water (H_2O). The emission of nitrous oxides is consequently reduced by 90%.

In a two-stage process the urea decomposes to ammonia (NH_3) which then reacts with the nitrogen oxides (NO_x) and leads to formation of nitrogen and water.

An aqueous urea solution (urea dissolved in water) containing 32.5% of urea used as a reducing agent, which is added to the exhaust gas by injection nozzle after the Oxidation-catalyst and before the SCR-catalyst.

The injection of urea (vol. required approximately 3 – 4% of diesel consumption) is controlled by the Emission Control Unit (ECU) and requires several ECU (engine power, temperature of the engine, etc.) input parameters.

The operation in trucks and passenger cars can be seen in Annex B page 10-13.

It is expected that the use HSF will decrease the efficiency of the oxidation catalyst but more testing is required to qualify the exact impact.

2.2.3 Current Emission Technology Solutions

The solution for overcoming the use problem of HSF depends mainly on the emissions control technology; considering the available information from the literature search and assessment testing. It is apparent that the most promising current technological solutions are as follows:

- EGR
  - This solution is less sensitive to HSF usage. It is possible to use fuels with sulphur content up to 3000 ppm. However other longer term maintenance issues still require to be considered and should be proven by projects i.e. durability, wear of valves, liners and compressions rings. A system control option that may help longer term wear using HSF is to enable the system to maintain the EGR valve closed.
- DPF
  - The use of WF-DPF is not recommended because the use of HSF will lead to filter blocking. Systems fitted with such a device will require being by-passed or removed when operating on HSF.
  - The use of M-PMF is more suitable because although efficiency is reduced, the filter will not block.

- Oxidation Catalyst
  - The best option to overcome the adverse impact of HSF on this device is to bypass the catalyst.
  - If not possible to by-pass then action must be taken to address any negative effect to the ECU.
- SCR
  - The use of a HSF will definitely have a very negative effect on the SCR system. But in this case it is relatively easy to bypass the system without significant affect on the engine. When using HSF it would be acceptable not to carry urea product and an ECU may be changed or modified to give the required signals to maintain correct engine operation.
- LNT
  - This is the worst case solution for HSF. The use LNT will lead to severe catalyst poisoning. It is extremely difficult to by pass the catalyst in this case because the ECU utilizes signals form various sensors to adjust the operation of the engine. The engine operates periodically under lean and rich operating modes. Rich operation will require frequent regeneration of the LNT. **Therefore this system is unsuitable for operation on HSF.**
- ECU
  - Stringent emission legislation requires an on board diagnostic system (OBD) integrated in the ECU to control the exhaust gas quality. HSF use will negatively impact on ECU and action must be taken to overcome the engine performance reduction by modifying or replacing the ECU. This has already been successfully applied by the UK and German MODs.

3.0 RECOMMENDATIONS

Evaluating the available information the ET-073 team came to following recommendations:

- Future equipment fitted with advanced emission reduction technologies should be able to operate on SFP (F-34) and high sulphur diesel fuel.
- Technologies using EGR, DPF and SCR will all be affected when using HSF. However, actions can be taken to overcome problems by by-passing these systems, modifying the ECU or a combination.
- LNT technology has been identified as unsuitable for military equipment when using HSF.
- Industry should be made aware that the military will prefer the technology that reduces logistic footprint.
- Further investigate the impact of (very) HSF on current SCR and future technologies. It is recommended that this could be addressed in the programme of work of the AVT-159 – Impact of Changing Fuel upon Land, Sea and Air Vehicles. The acceptance of this report concludes the ET-073 work.

Special Note

- Where NATO Nations decide to procure and use Commercial off the Shelf (COTS) vehicles, the Euro 4/5 legislation for type approval will apply. They will need to use commercial type approved technology solutions and a service modification may not be legally or contractually available. The UK MOD requires consideration of fuel issues for Military Logistics Vehicles in contracts by reference to a MOD defence Standard[2].

[2] MOD Defence Standard 23-6 Issue 4 dated 1 November 2005 (Paragraph 7 Working Fluids).