Use of alternative fuels in heavy duty engines

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BACKGROUND

Emission standards as proposed in Europe and the United States for diesel engines will require a NO_X and particulate emission reduction by more than 90 % relatively the already very stringent requirements of today in the next 6 years. To comply with the proposed limits heavy cooled exhaust gas re-circulation (20 % at full load up to 50 % at low load) plus particulate traps and DENOX by SCR are proposed. The systems not only impose a fuel economy penalty but are very costly, unreliable and not fully developed yet. In addition their combination, as required, does not seem to be feasible. Heavy, cooled exhaust gas re-circulation not only requires a doubling of the current cooling systems but also strongly reduces the exhaust temperatures and thus makes continuous trap regeneration and operation of SCR and other catalytic systems impossible. Thus, without a technological breakthrough achievement, the required drastic emission reduction is questionable, which jeopardizes the very existence of diesel engine industries in the future.

The expected shortage of fossil fuels as well as the demand for reduction of CO_2 emissions from fossil fuels is another threat to the diesel engine industries. Synthetic bio-based fuels as well as alcohol fuels will therefore be more and more important as alternative fuels and need to be matched both to the engines and to the after-treatment system.

Optimisation of heavy-duty diesel engines for different alternative fuels will be reported, including ethanol and methanol with different ignition improver systems and synthetic Ficher-Tropch fuels. Based on these findings as well as literature reviews a forecast of future alternative fuel usage will be given.

ALCOHOL FUEL

Alcohol fuels, ethanol or methanol, have low cetane number, 9 respectively 3, and are therefore not possible to use in diesel engines without engine modifications. Normal practice is to add an ignition improver to the alcohol fuel. Ignition improvers available on the market are rather expensive and are normally mixed directly into the alcohol fuel. An early concept was to inject a small amount of diesel fuel into the cylinders before injecting the alcohol. This gives satisfactory operation but requires two fuel injection systems which increases cost and maintenance.

Dissolved ignition improvers of type polyethylene glycol (PEG) are used in Scania and Volvo engines with good success but alternative additives are of interest to investigate. A promising solution is to use an on-board reactor to generate ethers from the alcohol fuel. From ethanol (EtOH), diethyl ether (DEE) may be dehydrated and from methanol (MeOH), dimethyl ether (DME) may be dehydrated. Both these ethers have high cetane numbers, 90 respectively 60, and may be used as ignition improvers.

Alcohols, as non-soot fuels, do not provide the starting materials, necessary for the formation of aromatic rings, upon which the soot formation is initiated, nor the acetilenic species, which contribute to its growth. It is this characteristic, which makes alcohol an attractive candidate for use in diesel engines. Furthermore, lower NO_X levels are already reported in different papers, but the effect of alcohol fuels on exhaust emissions, particularly those which are currently unregulated, is uncertain and under discussion.

Two Volvo diesel engines have been developed to run on alcohol fuel, TD73 used in heavy-duty trucks and AH10A245 used in buses. The modifications for using alcohol are mainly increased compression ratio and larger fuel pump and fuel nozzles. Both engines were developed to run on ethanol with 7% PEG as ignition promoter and the bus engine was later also developed to use ether. Those tests have not included on-board manufactured ethers at the present stage, instead purchased ether has been premixed with alcohol in the initial tests and injected into the engine air inlet during the fumigation tests.

When using the premixing of EtOH and DEE it has proven to be necessary to mix in 60% DEE in order to run the engine over the whole range of operation. This agrees well with experience from other researchers when running on MeOH with mixed in DME. Performance as well as emissions are comparable with those obtained when running the engine on EtOH with PEG as ignition improver. All tests have been done according to the ECE R49 13 mode test and evaluation procedure. Comparing 7% PEG with 60% DEE shows the following emissions for the bus engine:

Fuel	EtOH + 7% PEG	EtOH +60% DEE	EtOH +fum. DEE	MeOH +fum. DME	
NOx	4.96	5.01	3.58	3.48	g/kWh
HC	0.23	0.27	1.27	0.80	g/kWh
CO	7.89	7.98	5.91	5.48	g/kWh

When using the fumigation technique, i.e. injecting a mixture of ether, alcohol and water into the air inlet of the engine in order to simulate the output from a dehydration reactor, testing has been completed using ethanol as well as methanol as the main fuel and the resulting emissions are shown above. When using an oxidizing catalyst both CO and HC will easily be reduced to levels of 0.1-0.2 g/kWh.

The amount of DME used in the tests was similar to the amount of DEE used i.e. 2-15% of the fuel flow, the higher values corresponding to low loads. These amounts of ether is easily produced on board the vehicle in a dehydration reactor of size similar to an oxidizing catalyst.

In addition to the regulated emissions reported above also the following unregulated emissions were measured. Formaldehyde (0.01 g/kWh), Acetaldehyde (0.02 g/kWh), Methanol (0.12 g/kWh), Ethanol (0.18 g/kWh), Acetic acid (0.16 g/kWh). All values are evaluated according the ECE R49 13 mode test cycle.

Further information on the tests may be found in references [1-3]. As a conclusion of using alcohol in diesel engines, NO_X will remain as a problem as it only may be reduced by a factor of 2-3 compared with conventional diesel fuels. Soot is no problem and HC and CO may be reduced using an oxidizing catalyst. The combination of alcohol and ether may, however, pave the road for new combustion concepts.

GAS TO LIQUID FUEL

GTL fuels can be processed by the Fischer Tropsch (FT) process, which gives a diesel fuel of high quality. Having low aromatic compounds, high cetane rating and almost zero sulphur content, the FT diesel fuel shows advantages over conventional diesel fuel. This fuel has been investigated to reveal and analyse its effect on a research diesel engine performance. Since the engine performance is closely related to in-cylinder processes, a detailed thermodynamic analysis is revealing the real thermo-chemistry history.

The test engine consists of the basic AVL Type 501 cylinder block and Volvo – 2 l cylinder head equipped with C-3 Lucas unit injector. Turbocharger performance of a six cylinder production engine was simulated by the AVL 5153 supercharging group according to discrete parameters red from Volvo test.

Experimental investigation has shown that FT fuels have a significant impact not only on the emissions levels, but also on other energetic parameters of the engine such as ignition delay, cylinder peak pressure, heat release gradient, indicated efficiency, fuel consumption etc.

The regulated emission, emitted by the diesel engine when it runs on FT fuels, are lower than those of MK1. The ECE R49 13 mode evaluation of specific weighted values have shown a general NO_X reduction by 6%, HC reduction by 17%, CO reduction by 10%, and Soot reduction by 19%. A small reduction by 1% in BSFC was observed as well. At some loads (from light load 10% to medium load 50%) the emission reductions were higher. Hence, reduction of NO_X reached 25%, HC 50% and CO 30%. Generally speaking, FT fuels are shown to be effective over the operating range of the engine, and particularly at high load and rated speed. These tests are reported in reference [4] and another test with the same engine but comparing regular diesel fuel and a FT fuel did give similar results, reference [5].

Detailed measurements of organic compounds in the exhaust showed that none of the FT-fuels produced any significant amounts of dangerous higher organic compounds for example PAH. The emissions were dominated completely by fuel components. There are only paraffins in the fuels, and there are basically only paraffins in the exhaust.

As a conclusion of the experimental investigation on single cylinder research engine it may be stated that FT fuels can be used in unmodified compression ignition engines with significant reduction of regulated emission and smoother thermodynamic performance. FT-fuels can also be produced from biomaterial, thus no CO_2 penalty, and the exhaust gases are much less toxic than from diesel fuels. NO_X will remain as a problem and a new combustion concept is required.

FUTURE USE OF ALTERNATIVE FUELS

From the testing reported above it is quit clear that future emission requirements will not be possible to archive without a new combustion concept.

The Homogeneous Charge Compression Ignition, HCCI, concept is a hybrid of the Spark Injection, SI, and Compression Ignition, CI, engine concepts. As in a diesel engine, the fuel is exposed to a sufficiently high temperature for auto-ignition to occur, but in HCCI, a homogeneous fuel/air mixture is used. The homogeneous mixture is created in the intake system, as in a SI engine, using a low-pressure injection system or a carburetor. No ignition system is necessary. To limit the rate of combustion very diluted mixtures must be used. This high dilution can be achieved by high air/fuel ratio and/or with Exhaust Gas Recycling, EGR. If the mixture is too rich, the rate of combustion becomes too rapid and will generate knock-related problems. A too lean mixture will lead to incomplete combustion or misfire.

With HCCI, cycle-to-cycle variations of combustion are very small, since combustion initiation takes place at many points at the same time. The whole mixture burns almost homogeneously. In this way, unstable flame propagation is avoided. One of the most appealing attributes of HCCI is the homogeneous combustion. This means that the temperature should be the same in the entire combustion chamber. This, in combination with the ultra lean mixtures required to control the combustion rate, gives a very low maximum temperature during the cycle. The NO_X emission levels reported from tests at LTH in Lund [6] are very low, less than 0.02 g/kWh, indicating that the maximum temperature during the cycle is approaching the limit of thermal NO_X production.

An alternative road to achieve HCCI, called Heat-Re-circulating Combustion, HRC [7], is used in industrial furnaces. In heat-recirculating combustion, the reactants are preheated prior to combustion by recycled exhaust gases. This has proven to be an effective method for energy savings and reduction of NO_X emissions. In this technology, for example, the only diluted air can be preheated to high temperatures, while rich fuel/air mixtures can be injected into preheated air to realize diffusion or partially premixed combustion.

In order to provide fundamental understanding of the physical and chemical processes that occur during combustion in high temperature air or exhaust gases with a low content of oxygen a study using a detailed chemistry approach has been performed at Chalmers [8]. The numerical solution methodology employed in the modelling uses a coupling of a generalized partially stirred reactor, PaSR, model with a high efficient numerics. The results clearly illustrate that the flame structure is significantly affected by oxygen concentration. Contrary to the hot air case, which shows a normal flame development, the case of the oxygen-depleted mixture shows a barely distinguishable flame front: the combustion zone is distributed over the chamber volume and the maximum temperature is only 150 K higher than the surrounding temperature. The predicted NOx concentration was found negligible.

These concepts are still requiring much more research efforts and will be developed for conventional as well as alternative fuels. The alternatives might, however, due to their larger flexibilities in composition have a better chance of success.

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