Methanol as a Fuel for Modern Spark-Ignition Engines: Efficiency Study

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Abstract—**Methanol is an alternative fuel that can be used in spark-ignition engines and has the potential to decarbonise transport and secure domestic energy supply. Because of the lower volumetric energy content of methanol compared to gasoline, higher efficiencies with methanol-fueled engines are desirable. Although the growing interest in methanol-fueled vehicles, there is insufficient knowledge of how the full potential of methanol as an engine fuel can be exploited. This master dissertation investigates the use of higher compression ratios and applying different load control strategies with respect to efficiencies and emissions of 3 methanol-adapted test engines. The efficiencies obtained with methanol are higher than with gasoline and the efficiencies obtained with both EGR and lean combustion are higher in comparison with throttled stoichiometric operation. With a high compression ratio (19.5:1) and turbocharging, efficiencies comparable to diesel engines are possible. Methanol reduces NO_x emissions and the reduction is larger when EGR or lean burn is applied. To explore the full potential of methanol, turbocharging and direct injection have to be investigated in the future.**

Keywords—**Internal combustion engine, methanol, EGR, lean combustion, efficiency, emissions**

I. Introduction

There are several approaches to de-carbonize transport, for example hydrogen and electrification [1]. The inherently low energy density and high associated infrastructure cost make the break-through of hydrogen as a competitor with alternative liquid fuels questionable on the short term. Electric vehicles have the problem of a very limited range, compared to conventional ICE vehicles, due to the very low net volumetric energy density of batteries [2].

Methanol and ethanol are promising alternative fuels, with less infrastructural difficulties: as liquids, they are compatible with the existing distributing and fuelling systems. Methanol can be produced from a wide variety of renewable sources (e.g. gasification agricultural byproducts) and alternative fossil fuel based feed stocks (e.g. coal and natural gas). Several workers have even proposed a sustainable closed-carbon cycle where methanol is synthesized from renewable hydrogen and atmospheric CO_2. This way, methanol can be seen as a liquid hydrogen carrier [3].

Because of the lower volumetric energy content of methanol compared to gasoline, it is desirable to have higher efficiencies with methanol-fueled engines. Due to the characteristics of methanol, higher efficiencies compared to gasoline are possible. The combustion characteristics of methanol offer also the potential of applying load control strategies with EGR and lean combustion which can improve the efficiency. Methanol also permits the use of optimal values for spark advance, higher compression ratios and high degrees of turbocharging, without the occurrence of knock. This is due to the charge cooling and the higher octane number of methanol. The potential of methanol is investigated in this master dissertation.

II. Research and Results

First, an efficiency comparison between hydrogen, methanol and gasoline was done on a $1.8\,\mathrm{l}$ Volvo 4-cylinder gasoline production engine modified for tri-fuel operation. Second, the effect of EGR and lean-burn on performance and emissions with methanol operation was investigated on a 1-cylinder Audi-NSU test engine with a cooled EGR system. Finally, research on the effect of a higher compression ratio in combination with EGR and turbocharging was done on a methanol-adapted VW $1.9\,\mathrm{l}$ TDI diesel engine with a compression ratio of 19.5:1. This engine is equipped with a variable nozzle turbine (Garett VNT15) and a cooled EGR system.

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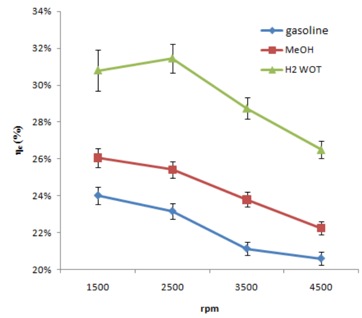
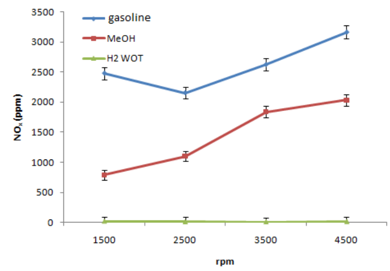
A. *Efficiency comparison*

The measurements on the Volvo-engine show very clearly that hydrogen WOT operation enables the highest BTE. These elevated efficiencies are largely due to reduced flow losses and the lean mixtures of hydrogen. The efficiency gains are most distinct at low loads, where this strategy yields up to $30\,\%$ relative increase of BTE compared to gasoline operation. Also, at low loads, the tailpipe NO_x emissions are very low (below the $100\,\mathrm{ppm}$ threshold [4]). The efficiency benefit of methanol is more modest (5-$10\,\%$ relative increase compared to gasoline). Those efficiency improvements can be obtained without the use of alternative load control strategies and are due to reduced pumping losses, the increased burning velocity and a slight decrease in cooling losses (lower flame temperature). Reduced combustion temperatures, moreover, cause a considerable reduction ($30\,\%$ and beyond) in engine-out NO_x emissions. These results are presented in figure 1.



(a) BTE at $40\,\mathrm{Nm}$

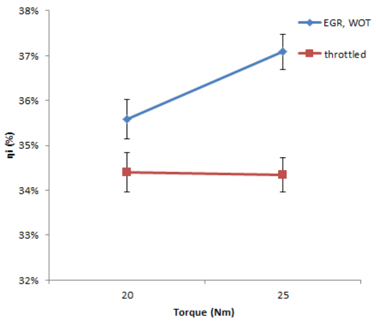


(b) NO_x at $40\,\mathrm{Nm}$

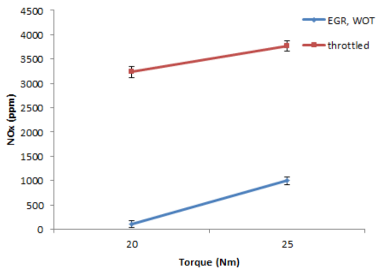
Fig. 1: BTE and engine-out NO_x emissions: comparison between gasoline, methanol and hydrogen at $40\,\mathrm{Nm}$

B. *Effect of EGR and lean combustion*

The results on the Audi-engine indicate that methanol is more EGR tolerant than gasoline, due to its higher flame speed. An EGR tolerance of $27\,\%$ was found when methanol was used. The efficiencies of the methanol-fueled engine obtained with EGR are higher to those obtained with throttled stoichiometric operation. The improvement in efficiency is most apparent when the indicated efficiencies are compared because the error margins are smaller than when BTE is compared. The advantages of EGR (quasi zero pumping losses, lower heat losses) are partly offset by the disadvantage (less isochoric combustion).Measurements of the NO_x emissions show a tremendous decrease when EGR is used due to the effect of dilution and the higher heat capacities of the recirculated exhaust gases, which lead to lower peak temperatures in the cylinder. These results are presented in figure 2.



(a) Indicated efficiency



(b) NO_x emissions

Fig. 2: Indicated efficiency and engine-out NO_x emissions: comparison between EGR and throttling at $1500\,\mathrm{rpm}$

Because of the high flame speed and wide flammability limits of methanol, applying lean combustion as a load control strategy is attractive with methanol operation. The efficiencies obtained with lean-burn are higher compared to throttled stoichiometric operation. Again, the advantages of lean-burn (quasi-zero pumping losses, lower heat losses) are partly offset by the disadvantage (less isochoric combustion).The NO_x emissions at lean combustion operation, are lower than for throttled stoichiometric-fuelling but are not low enough (below $100\,\mathrm{ppm}$) to overcome the disadvantage of the lower conversion rate of the TWC. Figure 3 gives a graphic presentation of the results.

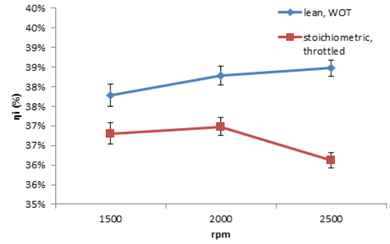
C. *Possibilities higher compression ratio*

The measurements on the VW-engine show that the potential of methanol can be exploited more on a converted diesel engine. Due to the higher compression ratio and turbocharging, higher efficiencies can be achieved in comparison with a converted gasoline engine. Further, the higher compression ratio makes it possible to operate at higher levels of EGR due to the higher flame speed of methanol.

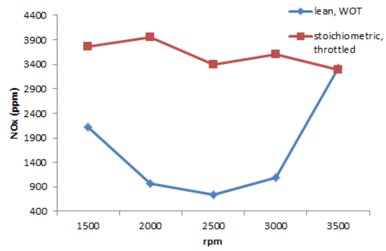
An EGR tolerance of $48.17\,\%$ was found when methanol was used with wide open throttle. The control strategy with EGR and WOT results in efficiencies up to $42\,\%$. These efficiencies are higher then when the throttle is used to control the load, because of the lower pumping and heat losses. Due to the high levels of EGR, NO_x emissions reduce tremendously because of the lower in cylinder temperatures. These results are presented in figure 4.

III. Conclusions

From both the literature and the results obtained on the test engines, it is clear that methanol has a lot of potential as an alternative fuel. Higher efficiencies (5-10 $\%$ relative increase compared to gasoline) and lower NO_x emissions can be achieved with methanol on a regular gasoline engine.

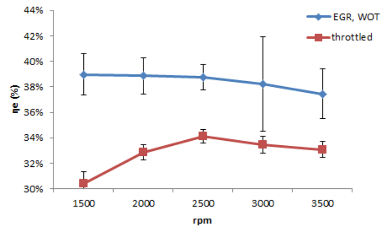


(a) Indicated efficiency

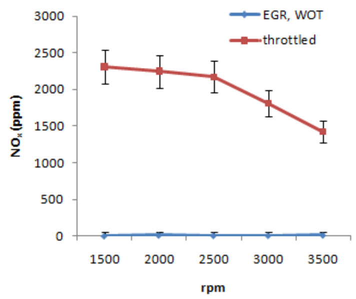


(b) NO_x emissions

Fig. 3: Indicated efficiency and engine-out NO_x emissions: comparison between lean combustion and stoichiometric-fuelling at $30\,\mathrm{Nm}$



(a) BTE at $100\,\mathrm{Nm}$



(b) NO_x emissions at $100\,\mathrm{Nm}$

Fig. 4: Efficiency and engine-out NO_x emissions: WOT+EGR vs. throttling at $100\,\mathrm{Nm}$

It is found that methanol is more EGR tolerant than gasoline and has potential for lean-burn operation. For both EGR and lean-burn, higher efficiencies and a reduction of NO_x emissions are found. Due to the fact that methanol is more resistive to knock and therefore can be used with higher compression ratios, even efficiencies compared to diesel engines are achievable. This can be seen when methanol is used in a modified VW diesel engine. Efficiencies up to 42% are found. To explore the full potential of methanol, turbocharging and direct injection have to be investigated in the future.

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