"Emissions from a Moped Fuelled by Gasoline/Ethanol Mixtures"

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Abstract.

A 50 cc moped was operated at idle conditions and at constant speed (30 km/h, which was maximum for this type of moped). Measurements of emissions of CO (carbon monoxide), HC (unburned hydrocarbons), CO_2 (carbon dioxide), smoke and particulate matter were carried out at these conditions with various mixtures of gasoline and ethanol as fuels. Particulate emissions were measured by diluting a part stream of the exhaust followed by particulate collection on a filter. The results showed that all emissions were reduced with increased ethanol content of the fuel. Especially the particulate emissions were reduced. With up to 10% ethanol content, the particulate emissions were reduced up to around 75%. Further increases in ethanol content did not change the particulate emissions.

Background.

In recent time it has become a more and more important question whether moped emissions make up a significant contribution to road traffic emissions in Denmark or not. This investigation was therefore carried out at The Technical University of Denmark in order to evaluate whether 2-wheeler and 2-stroke engines in general should be a topic for further investigations at The Technical University of Denmark.

The investigation was started up with a qualitative calculation of the 2-wheelers contribution to traffic emissions in Denmark. At the same time this contribution was compared with emissions from gasoline vehicles in order to get an indication of the role of these emissions in the total picture. The calculation is difficult to carry out for mopeds, because most Danish mopeds are Moped 30's, a rather uncommon moped, which can only go 30 km/h at most. Since this moped is not common in many other countries, there are not many measurements of vehicle emissions. Therefore we decided to carry out these measurements on a Moped 30. It was suggested to try an add ethanol to the fuel since Indian investigations [1] indicated a significant reduction of emissions of unburned hydrocarbons in particular. In this investigation we found that particulate emissions were reduced most.

Emissions from 2-wheelers in Denmark.

According to information about traffic in Denmark [2] the annual work, carried out by gasoline cars, mopeds and motorcycles, were as follows in 2002:

Vehicle:	Traffic Work:
Gasoline cars	37.213 (mio km)
Motorcycles	551 (mio km)
Moped 45	95 (mio km)

Table 1. Traffic work in 2002 in Denmark.

"Moped 45" includes only a part of all mopeds in Denmark. "45" mean that these mopeds have a maximum speed of 45 km/h. According to information from the importer of Peugeot mopeds, the number of imported "Moped 30" is 3 times the number of Moped 45 imported. So, we may assume that the total number of mopeds is 4 times the number of Moped 45.

It is, however, not likely that the smaller mopeds carry out the same traffic work as the Moped 45's. If we assume, that the traffic work is proportional to the maximum speed, then the traffic work from mopeds in relation to gasoline cars can be written as:

$$W_{traffic}^{mopeds} = W_{traffic}^{gasoline\ cars} \cdot \frac{95 \cdot \left(1 + \frac{30}{45} \cdot 3\right)}{37213} \qquad \textbf{[1]}$$
$$= W_{traffic}^{gasoline\ cars} \cdot 0{,}77\%$$

In the same manner we may calculate the relation between traffic work from motorcycles and gasoline cars:

$$W_{traffic}^{motorcycles} = W_{traffic}^{gasoline\ \ cars} \cdot \frac{551}{37213} \qquad \textbf{[2]}$$
$$= W_{traffic}^{gasoline\ \ cars} \cdot 1{,}48\%$$

The traffic work contributions from 2-wheelers does not seem to make up a significant part of the traffic work, compared to gasoline cars. However, the 2-wheelers emits much more unburned hydrocarbons and particulates than gasoline cars. Therefore the contributions of these emissions should be considered.

We keep on making more and more stringent regulations for passenger car emissions. We are now at a point where further reductions are pointless, unless regulations from motorcycles and mopeds are regulated as well. Fortunately this also seems to be a conclusion drawn by the Commission of the European Union, who initiated investigations on the need for more stringent regulations for these vehicles [3-4] in the 1990's. However, it is still not certain how much reduction in emissions from 2-wheelers that are required.

In order to shed a little more light on this we have tried to compare the relative few emission measurements that exists on 2-wheelers with the emissions from current gasoline vehicles. This is shown in Table 2. The values shown are emission factors, expressed in g/km. In the table are also shown the present regulation limits for the different vehicle categories.

In Table 3 are shown the ratio between the emission factors for the different moped/motorcycle engine technology and gasoline cars. In Table 4 are shown the similar ratio's between the regulated emission factors.

If we multiply these factors with the ratio between the traffic work from mopeds and motorcycles to gasoline cars, which we can obtain from equations [1] and [2], we obtain the relative contributions from 2-wheelers. This is shown in Table 5. As we see from Table 5 mopeds and motorcycles make up an important contribution to hydrocarbon emissions. Furthermore mopeds make up an important contribution to particulate emissions and motorcycles contributes significantly to CO emissions.

We must not forget that the above estimates are based on quite few measurements and that the emission factors behind the estimates are based on standard test procedures, which do not necessarily reflect real driving. However, a simple calculation like this indicates the importance of emissions from 2-wheelers and the demand for regulations (and research) for this type of vehicles. Emissions from 2-wheelers and 2-stroke engines in general therefore seems to be a topic that is relevant for further investigations/regulations.

Vehicle Type	**Gasoline Cars**	**Diesel Cars**	**2stroke -EFI**	**2stroke -Carb.**	**MC-4stroke EFI**	**MC-4stroke Carb.**	
Catalyst	TWC	OX	-	-	TWC	TWC	-
CO[1]	0,6	0,2	0,7	4,0	4,5	10,5	13
CO (regulated)[2]	2,3	0,64	8	8	13	13	13
HC	0,11	0,05	1,0	4,0	0,6	0,4	0,9
HC (regulated)	0,2		4	4	3	3	3
NOx	0,1	0,5	0,6	0,03	0,25	0,11	0,23
NOx (regulated)	0,15	0,5	0,1	0,1	0,3	0,3	0,3
HC+NOx		0,55	1,6	4,0			
HC+NOx (regulated)		0,55					
Particulates	0,002	0,03	0,01	0,06	0,003	0,005	0,003
Particulates (regulated)	(0,025)[3]	0,05 (0,025)[3]					

Table 2. Measured and regulated emission factors (g/km) from cars and motorcycles.
1: Measured emissions. Car emissions were measured on EURO 3 cars at The Technical University of Denmark [5] and motorcycle emissions were measured on 97/24/EC regulated motorcycles in U.K. [6].
2: Regulated emissions in EU.
3: EURO 4, to be implemented in 2005.

Ratio:	$\left(\frac{2stroke\ EFI}{Gasoline\ Cars}\right)$	$\left(\frac{2stroke\ Carb.}{Gasoline\ Cars}\right)$	$\left(\frac{4stroke\ EFI, TWC}{Gasoline\ Cars}\right)$	$\left(\frac{4stroke\ Carb., TWC}{Gasoline\ Cars}\right)$	$\left(\frac{4stroke\ Carb.}{Gasoline\ Cars}\right)$
CO	1,2	6,7	7,5	17,5	21,7
HC	9,1	36	5,5	3,6	8,2
NOx	6	0,06	2,5	1,1	2,0
Particulates	5,0	30	1,5	2,5	1,5

Table 3. Ratio between measured moped/motorcycle emissions and gasoline car emissions.

Ratio:	$\left(\frac{2stroke\ EFI}{Gasoline\ Cars}\right)$	$\left(\frac{2stroke\ Carb.}{Gasoline\ Cars}\right)$	$\left(\frac{4stroke\ EFI,TWC}{Gasoline\ Cars}\right)$	$\left(\frac{4stroke\ Carb.,TWC}{Gasoline\ Cars}\right)$	$\left(\frac{4stroke\ Carb.}{Gasoline\ Cars}\right)$
CO	3,5	3,5	5,7	5,7	5,7
HC	20	20	15	15	15
NOx	0,7	0,7	2	2	2
Particulates					

Table 4. Ratio between regulated moped/motorcycle emissions and gasoline car emissions.

	Mopeds (2stroke)	Motorcycles (4stroke)
CO	1-5 (3)	11-32 (8)
HC	7-28 (15)	5-12 (22)
NOx	0-5 (1)	2-4 (3)
Particulates	4-23 (-)	2-4 (-)

Table 5. Estimated emissions from motorcycles and mopeds in relation to gasoline car emissions in Denmark in 2002. In brackets are shown the same figures, calculated from emission regulation limits. Units are in percent.

Measurements on a Moped 30.

In order to see whether the emission factors presented in the preceding paragraph are relevant for the evaluation of Danish moped emissions, a new moped 30 was investigated with respect to emissions at the two most relevant constant driving conditions: idle and 30 km/h. The most relevant data of the vehicle are shown in Table 6.

49,1 cc engine (0 km)
Carburetted
Lubricant injected into carburettor
With catalytic converter
Fuel: mixtures of unleaded 95 and E85 (85% ethanol)

Table 6. Data for the moped 30.

As seen in the table we added different amounts of ethanol in order to see the effect of this on the emissions. This idea came from similar Indian measurements on 2-wheelers [1]. According to these, significant reductions in particularly hydrocarbon (HC) but also particulate emissions could be achieved by adding ethanol to the fuel. However, India is far away, and the experimental circumstances were not very clearly explained. We wanted to see what happened when ethanol was added to the fuel for a Danish "Moped 30".

In order to measure emissions the driving wheel of the moped was connected to a dynamo, which produced electrical power. The power produced by the moped was thus adjusted by connecting more or less bulbs to the electrical circuit. Two different load simulations were simulated in this way: 1) idle and 2) constant speed at 30 km/h. In order to keep the engine running smoothly, the measurements were carried out with hot engine. A part stream of the exhaust was collected in a 10 litre sample bag, which was afterwards analyzed for gaseous compounds. Samples of particulate matter were collected in first hand with a Bosch Smoke Meter. As mentioned later, we later on diluted the exhaust in a "mini-dilution tunnel". The equipment is shown in Figure 1.

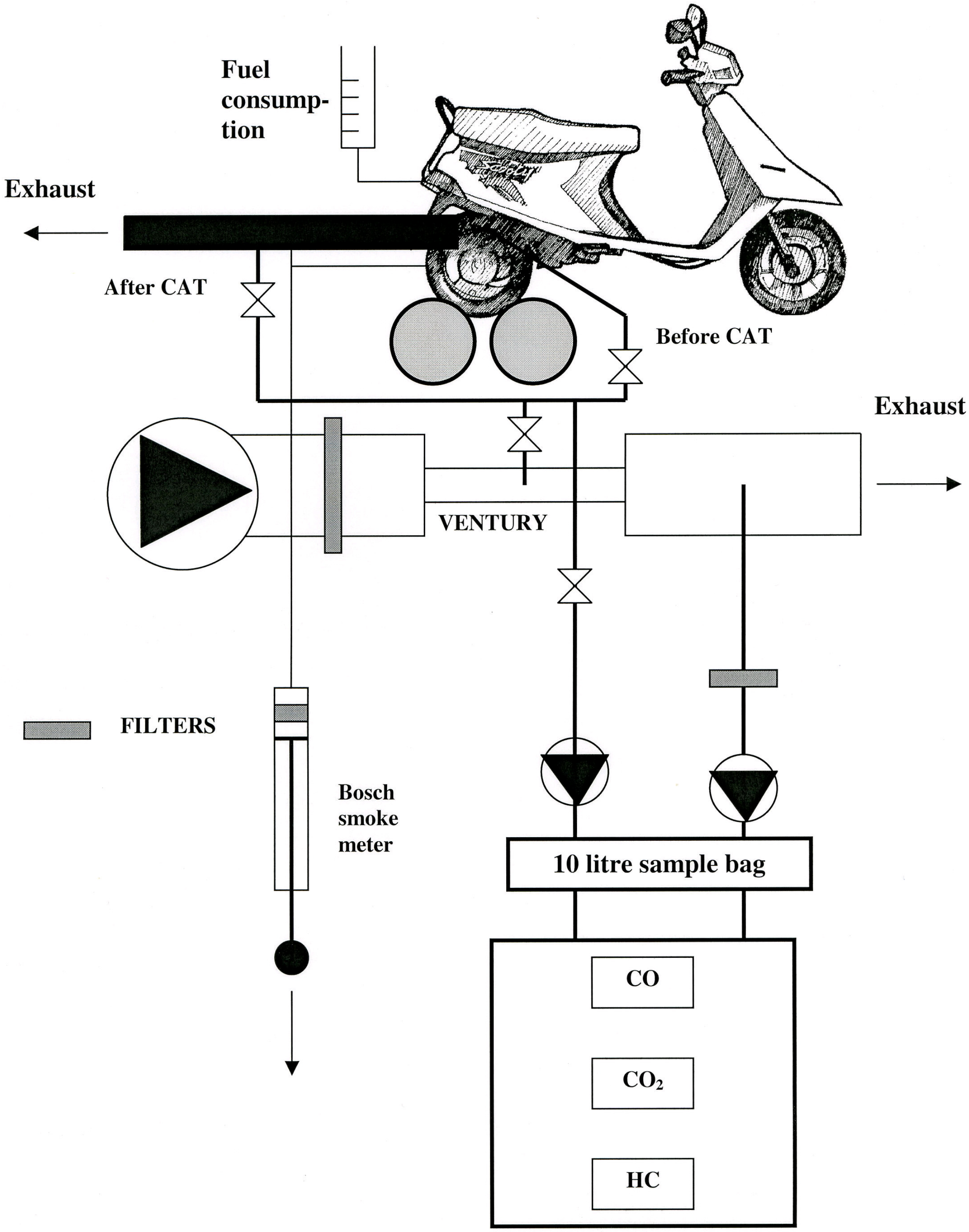

Figure 1. Experimental equipment.

The results of the measurements of gaseous emissions and smoke emissions as well as fuel consumptions are shown in the figures 2-6. From the Indian measurements [1] we would have expected about 60% reduction in soot emissions and about 70% reduction in HC emissions with 10% ethanol in gasoline. This seems indeed to be confirmed with respect to soot, but the reduction in HC seems to be much less - about 20% at most. However, we do notice a reduction.

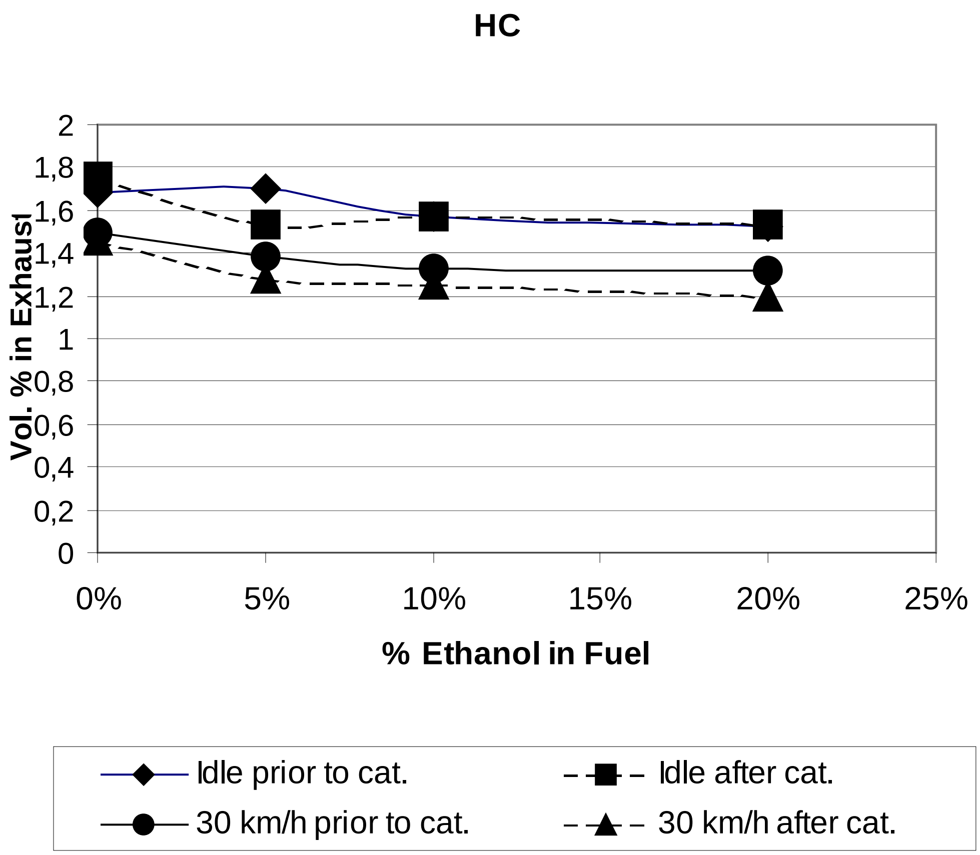

Figure 2. HC emissions vs. ethanol in fuel

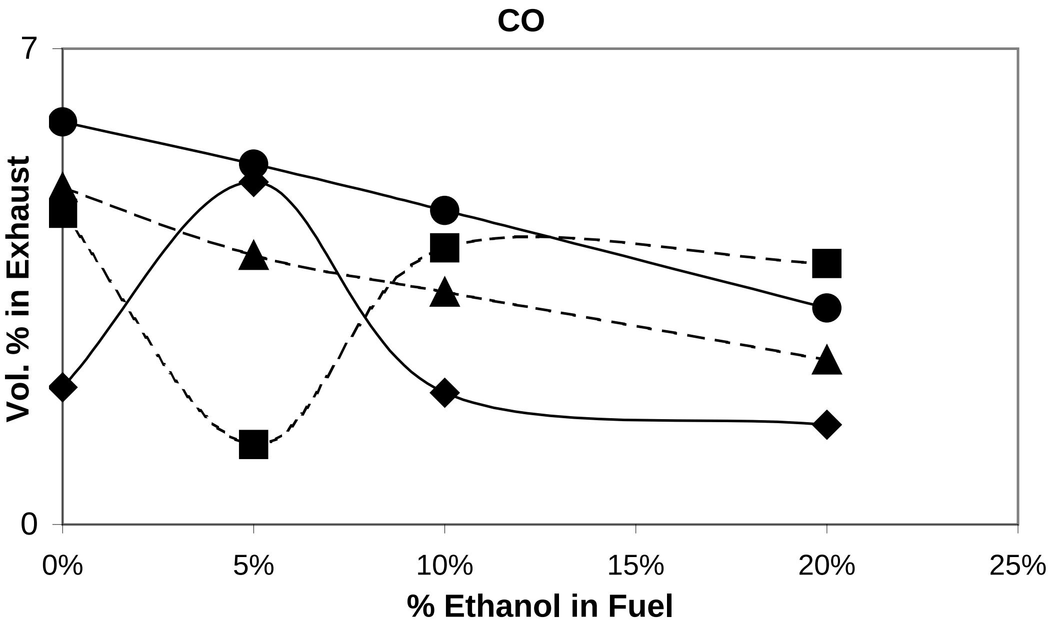

Figure 3. CO emissions vs. ethanol in fuel

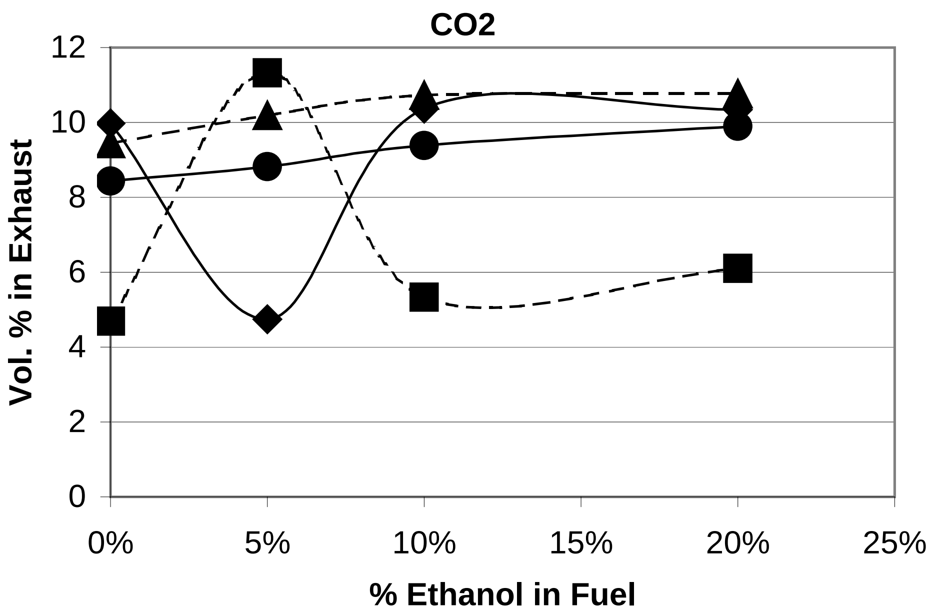

Figure 4. CO_2 emissions vs. ethanol in fuel

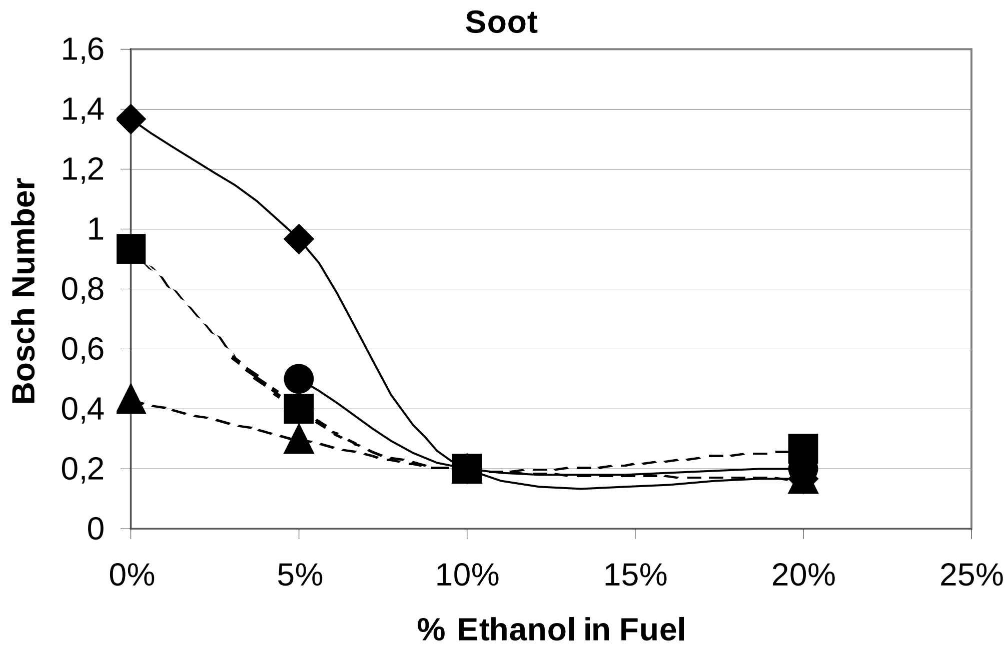

Figure 5. Soot emissions vs. ethanol in fuel

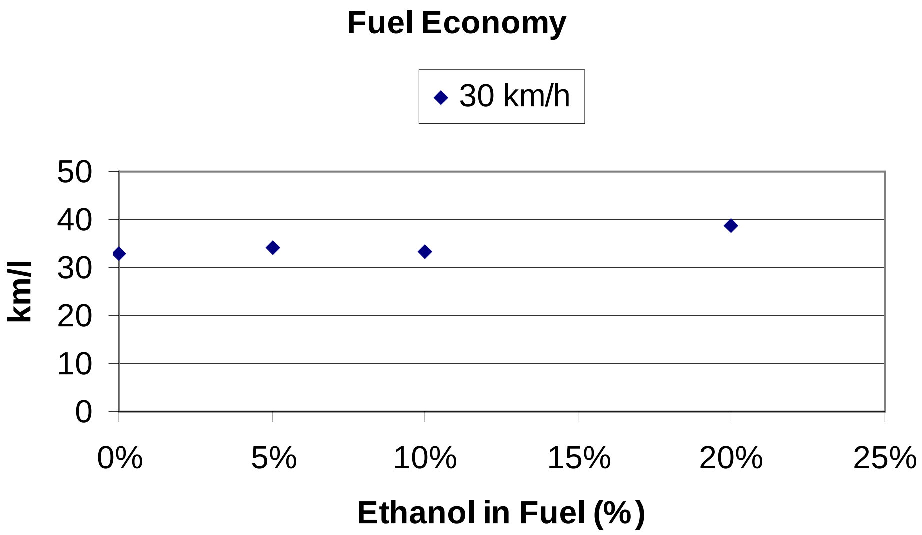

Figure 6. Fuel economy at 30 km/h

We notice that the reduction of the emissions of HC and soot increases up till 10% ethanol addition, further addition has no effect on the reductions.

CO is reduced as well at 30 km/h and fuel consumption is also improved

The excess air ratio increase during the combustion due to the oxygen content in ethanol, and this we believe causes the reduction in HC and CO, the increase in CO_2 and the improved fuel economy. The reason for the decrease in soot emissions is not fully understood, but most certainly also has something to do with the oxygen in the fuel. This may inhibit very fuel rich zones in the combustion chamber, where the precursers for soot may be formed.

In order to verify the soot measurements, we also did measurements of total particulate matter (soot+soluble particulate matter). These were carried out by diluting the exhaust and collecting the particulate matter from a part stream on a filter. The results are seen in the table 7. The measurements show that the total particulate emissions also are reduced by adding 10% ethanol to the gasoline. The reduction is in the same order of magnitude as the soot reduction.

	Gasoline		Gasoline with 10% Ethanol	
	Prior to cat	After cat	Prior to cat	After cat
Total particulate matter	0,106	0,024	0,048	0,011
SOF[1] (% of total)	0,0943 (89)	0,0063 (26)	0,048 (100)	0,0030 (27)
Inorganic	0,012	0,018	0,000	0,008

Table 7. Particulate emissions in g/km at 30 km/h with hot engine.

If we recalculate the emissions of HC and CO in the units, g/km, we obtain the following values at 30 km/h (100 % gasoline, after cat):

CO: 15,6 g/km
HC: 2,3 g/km
Total particulate matter: 0,024 g/km

This should be compared with the pre-estimated values in Table 2 for 2-stroke vehicles, since one of the main purposes with this investigation was to find out whether the available emission factors are relevant for Danish conditions. CO is seen to exceed the pre-estimated values with around 100%. HC measurements are in the same range as the pre-estimated values, and so is the particulate emission factor.

We see from the measurements before and after the cat, that the cat only takes up to 10 % of the CO and HC, whereas the cat seems to be quite efficient to the soluble organic fraction of the particulate matter (Table 7 and Figure 5). Therefore we must expect somewhat higher particulate emissions from the moped 30 as the cat deteriorates during lifetime.

[1] Soluble Organic Fraction of particulate matter

Conclusions.

-2-wheelers contributes considerably to the emissions of CO, HC and particulate matter in Denmark, compared with the contribution from gasoline cars (relative contributions are given in Table 5)

-emission factors from a new technology "moped 30" 2-wheeler where found to be in the range of previously estimated emission factors, used for the calculation of the emission contribution in Denmark with respect to HC and particulate matter, however, the CO emission factor was found to be 100 % higher with the new technology vehicle

-addition of ethanol to the gasoline reduced the emissions of HC and CO moderately, however, the smoke emissions were reduced dramatically with an increased ethanol content up to 10% ethanol (Figure 5) - further increase in ethanol content did not reduce smoke emissions further

-the fuel economy was improved with addition of ethanol to the gasoline

-the catalytic converter had moderate effect on the emissions of HC and CO, but did seem to be efficient to the reduction of the soluble organic fraction of the particulate emissions

References.

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