Analysis and Preliminary Design of Oxymethylene ether (OME) Driven Mobile Machines

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Introduction

The global warming drives current politics to pursue the goal of reducing greenhouse gases (CO_2e). The European Union (EU) for example has planned to reduce 80% of their greenhouse gases until 2050 compared to 1990 (European Commission, 2018). The increasing policy goals require different measures in all sectors. A switch to alternative systems like using an alternative sustainable energy carrier is a promising solution for mobile machines.

Energy carriers produced from biomass or synthetically with sustainable energy as e.g. from wind power plants are considered sustainable, because they are part of a closed cycle. The greenhouse gases emitted during combustion from sustainable energy carriers are considered to be zero, because they are originally being absorbed from the atmosphere during e.g. the growths of the biomass.

According to Ays and Geimer requirements for a mobile machine are different from a car (Ays and Geimer, 2017). This is mainly due to the traction drive and the working functions in a mobile machine as well as its application. In order to find an alternative energy carrier for mobile machines, it is essential to consider not only the gravimetric density but also the volumetric density. In Geimer and Ays, exemplary on a combine harvester different energy carrier were compared to each with regard to their gravimetric and volumetric density (Geimer and Ays 2014). Geimer and Ays showed that energy carriers produced from biomass are promising alternatives for mobile machines.

In the following oxymethylene ether (OME) will be examined as an alternative energy carrier for mobile machines. First the basics will be described as well as the sustainability aspect of OME will be analyzed based on literature reviews. Then will follow the description of the drive concept design methodology applied for different mobile machines types. Finally, these concepts will be evaluated exemplary on a digging roller, a tractor and a mining excavator and compared to conventional drive systems.

Analysis of OME based on literature reviews

Basic knowledge

OME is considered as further developed fuel form of dimethyl ether (DME) or methanol. The use of these two fuels: dimethyl ether (DME) and methanol are considered to be limited because of their toxicity and high vapor pressure at ambient temperatures (Maus and Jacob 2014). On the contrary, OME is a non-toxic and colorless liquid fuel. It is the short form of oxygen-containing oligomeric oxymethylene ethers [$CH_3O\text{-}(CH_2O\text{-})_nCH_3$]. The physical properties of the individual OME_n ($n \geq 1$) depend on their chain length. (Oestreich 2017, 62; Pélerin et al. 2017, 441; Lumpp et al. 2011, 199; Lautenschütz et al. 2011, 133)

Sustainability of OME during its production

In order to estimate the greenhouse gas effect of OME production a well-to tank analysis takes place. For the following analysis, the same amount of emissions is assumed to be emitted for the production of OME_1 and OME_n ($n > 1$).

The production of OME is based on methanol and can be produced by various synthesis routes. Usually methanol is obtained from fossil raw materials but can also be produced from renewable raw materials like biomass or directly from CO_2 and H_2.

In order to determine the well-to-tank emissions for OME from fossil raw materials different steps are necessary. First the well-to-tank emissions for methanol from natural gas and coal production will be determined. Then will follow the determination of the amount of greenhouse gas emissions during conversion of methanol to OME. The sum of these two greenhouse gas emission values will result in the total emitted greenhouse gas amount during OME production from fossil sources.

According to Edwards et al. the well-to-tank emissions for methanol from natural gas and coal are 32 and 125 g CO_2e/MJ, respectively (Edwards et al. 2014, 18). These values will be added to the CO_2e emissions amount released during production of OME from methanol. In a first step the energy consumed during production of OME from methanol has to be identified. According to DEutz et al. the electricity energy amounts to 0.017 MJ/kg (Deutz et al. 2017a, 4). The necessary heat is supplied by the natural gas boiler and amounts to 4.56 MJ/kg, under the condition that the heat from the methanol production can be used in the OME production process (ibid.). Further, according to Artz et al., 0.371 kg CO_2e /kW h is emitted for electricity when using the EU-27 grid mix electricity and 0.071 kg CO_2e /MJ is emitted for the heat supply when using natural gas boiler (Artz et al., 437). Therefore, the CO_2e emissions to convert methanol to OME is calculated to be equal to 0.324 kg CO_2e/ kg OME. By using the OME_1

heating value of 23.3 kJ/g, the CO_2e emissions to convert methanol to OME equals to 14 g CO_2e /MJ OME. The detailed calculation are shown in equation (1).

CO_2e emissions from methanol to OME:

$$m_{CO_2e} = \left(0.371 \ * \frac{0.017}{3.6} + 4.56 * 0.071\right) * \frac{1{,}000}{23.3} = 14 \ g \ CO_2e/MJ \qquad (1)$$

Consequently, the sum of greenhouse gas emissions for the methanol production with the total emitted greenhouse gas amount during production of OME from methanol result in the emission amount of OME production from natural gas with 46 g/MJ and from coal with 139 g/MJ

According to Mahbub et al., OME can be produced in a sustainable way based on two different types of biomass: from tree and from residual forest wood (Mahbub et al. 2017, 1247ff). The well-to-tank emissions for OME from tree biomass and residual forest wood are respectively 26 g CO_2e/MJ and 18 g CO_2e/MJ. By using CO_2 from biogas plant the well-to-tank emissions for OME_1 correspond to 21 g CO_2e/MJ (based on Deutz et al. 2017, 338).

The well-to-tank emissions are summarized in Table 1. Compared to the diesel production with 35 g CO_2e/MJ (Mahbub et al. 2017, 1260), OME production from fossil raw materials emits more greenhouse gas emissions. On the contrary, regenerative OME production is more environmentally friendly than the diesel production.

Table 1: Well-to-tank emissions from various OME production paths (Mahbub et al. 2017, 1260; Peng et al. 2017; Edwards et al. 2014, 18; Deutz et al. 2017a)

Well-to-tank CO_2e emissions in g/MJ	
Diesel	35
OME (coal)	139
OME (natural gas)	46
OME (tree biomass)[1]	26
OME (residual forest)[1]	18
OME (CO_2 from biogas plant)[1]	21

[1] The CO_2 gases absorbed during the growth of the plant are not included in the well-to-tank value.

OME as a diesel alternative and diesel additive

Table 2 shows the physical properties of diesel and of the individual OME_n ($n \geq 1$). The comparison shows that OME_{3-5} is a suitable alternative fuel for diesel engines, because the boiling point of OME_{3-5} (156-242 °C) is similar to the standard diesel (180-390 °C).

Table 2: Physical and chemical properties of OME compared to conventional diesel (Oestreich 2017, 62; Pélerin et al. 2017, 441; Lumpp et al. 2011, 199; Lautenschütz et al. 2011, 133)

Parameter	Unit	Diesel	OME_1	OME_2	OME_3	OME_4	OME_5
Structure	–	C_mH_n (< C_8H_{18})	$C_3H_8O_2$	$C_4H_{10}O_3$	$C_5H_{12}O_4$	$C_6H_{14}O_5$	$C_7H_{16}O_6$
Oxygen percentage	*wt.%*	0	42,1	45,2	47	48,1	48,9
Density (15 °C)	*kg/m³*	0,82-0,845	0,870	0,972	1,039	1,083	1,114
Heating Value	*kJ/g*	43,2	23,3	20,3	19,6	19,0	18,5
Flashing Point	*°C*	> 55	< -20	16	54	88	115
Cetane Number		> 51	28	67	72	84	93
Boiling Point	*°C*	180-390	42	105	156	202	242
Viscosity (40°C)	*mm²/s*	2-4,5	Sample evaporated before measurement	0,559	0,866	1.33	1,96

The higher cetane number of OME_{3-5} (72-93) compared to conventional diesel (> 51) leads to faster ignition and higher efficiency (Oestreich 2017, 62). The heating value of OME (18.5-23.3 MJ/kg) is lower than that of diesel fuel (approx. 42 MJ/kg), which leads to lower efficiency, but the significantly higher density (OME: 0.87-1.114 kg/m³; diesel: approx. 0.83 kg/m³) can somewhat compensate for this disadvantage (Härtl et al. 2017, 54).

According to a test in a single engine (V_{cyl} = 0.5 L) by Rösel, the efficiency of OME fuel is approximately 1.1 times compared to the efficiency of diesel in lower load and lower speed (N = 1,500 rpm [1]/ imep [2]= 4.2 bar) and in higher load with higher speed (N = 2280 rpm, imep = 14 bar). In higher load with lower speed (N = 1,250 rpm / imep = 14 bar) the efficiency is about 0.9 times to that of the diesel fuel. In summary, it can be concluded that the efficiency of OME is similar to that of diesel. (Rösel 2018, 507f)

The efficiency of diesel engines is assumed to be 34% in Geimer and Ays (Geimer and Ays 2014, 19). Consequently efficiency of engine operating with OME will be assumed to be equal with 34%.

Further, OME has a higher flash point than conventional diesel fuel, so it is better in meeting the safety criterion (Zhang et al. 2016, 8). The boiling point of OME_{3-5} is lower than that of diesel. This means that OME has a better volatility than diesel fuel (Liu et al. 2016). Moreover, OME is miscible with diesel fuel in any ratio and has no toxicity (Lumpp et al. 2011, 199).

[1] rpm = revolution per minute
[2] imep = indicated mean effective pressure

Various tests were carried out on light-duty diesel engines and heavy-duty diesel engines. According to Bhatelia et al., Pélerin et al. and Sun et al. the exhaust gas behavior of OME can be summarized as follow (Bhatelia et al. 2017, 3; Pélerin et al. 2017, 439ff; Lautenschütz et al. 2016, 132; Sun et al. 2016, 1):

- The high concentration of C–O bonds leads to higher raw CO emission compared to a diesel drive system. CO emission increases significantly at $\lambda < 1.1$ which, however, can be totally converted in the catalyst.
- The absence of C-C bond and the high oxygen content (> 42%) leads to no soot formation for pure OME combustion, so that a DPF (diesel particulate filter) is not required.
- Further, the pure OME burned at high temperature, leads to higher NO_x emissions. However, due to no soot emissions with pure OME the soot-NO_x conflict can be avoided. This means that the diesel engine can be operated with an air ratio $\lambda = 1$ with higher EGR[3]-rate. Under that condition NO_x emissions can be reduced up to 0.1 mg/kW h. Moreover, OME fuel combustion with an air-fuel ratio of $\lambda = 1$ can be combined with a three-way-catalyst (TWC).
- Higher methane emissions are observed at $\lambda < 1.1$ and are not converted in the catalysts. Methane has a 25 times higher greenhouse effect than CO_2 (Ays & Geimer, 2017, 148).
- Methane have a high stability, therefore a higher temperature is required, in order to convert methane totally in catalysts. For this reason additional system requirements on the material of the catalyst coating are conceivable. Further testing are necessary to determine whether an electrically heated catalyst is required, especially for cold start phases (Pélerin et al. 2017, 447).
- The greenhouse gas emissions released during combustion of OME in the engine are according to Mahbub 92 g/MJ for diesel fuel and 90 g/MJ for OME fuel (Mahbub et al. 2017, 1260). OME can be produced by renewable raw materials. This means, that the OME combustion is part of a closed CO_2 cycle for OME produced from biomass. Therefore the emitted greenhouse gas emissions during combustion of OME are considered to be equal to zero (Maus 2010, 12).

Based on these analysis results, the well-to-wheel emissions for OME, estimating the total greenhouse gas emissions released by using OME from different sources can be calculated and are summarized in Table 3. The results shows that OME from fossil raw materials have a higher greenhouse effect than diesel. On the contrary, using renewable OME as a diesel

[3] EGR stands for “exhaust gas recirculation”

alternative can significantly reduce greenhouse gas emissions compared to conventional diesel.

Table 3: Well-to-wheel emissions of OME compared to diesel

Well-to-wheel emissions in g CO_2e/MJ	
Diesel	127
OME (coal)	228
OME (natural gas)	136
OME (tree biomass)[1]	26
OME (residual forest)[1]	18
OME (CO_2 from biogas plant)[1]	21

[1] The CO_2 gases absorbed during the growth of the plant are not included in the well-to-tank value. Sustainable OME production are part of a closed cycle. The greenhouse gas emission emitted during combustion are considered to be equal to zero. Therefore the well-to-tank values equals well-to wheel values.

Commercial production of OME on a technical scale is not yet established, as there is still a lack of an efficient process that meets economic and environmental requirements (Dahmen et al. 2017, 9). Adding OME in fossil diesel fuel is therefore possible for a transitional period. The soot content is reduced already by up to 90% by using 20% OME_{3-4} in diesel fuel (Maus and Jacob 2014, 13). In conclusion, OME is ideal as alternative to diesel or as diesel additive, and suitable for diesel engines.

In order to choose the right OME powertrain concept for the different types of mobile machine, a preliminary design of a driving concept after the morphological box method has been developed.

Preliminary design of a driving concept

The morphological box in Figure 1 shows the design method of possible OME powertrain concepts for mobile machines. Each level represents a step for the designing process. The first step is to choose, if OME will be used as pure fuel or as diesel fuel additive. For OME_{3-6}-diesel the mixture of various mixture ratios are possible.

The second step consists in identifying the right tank capacity, depending on the application of the mobile machine. Due to the lower energy density of pure OME_{3-6}, the tank with the fuel requires twice as much of installation space and weighs two times more than a diesel tank. For a 15% OME_{3-6} diesel mixture, for example, the weight is about 1.2 times more than that of the tank with diesel. Therefore, for machines that have short working shifts or can be filled several times per shift, pure OME can be used despite the lower energy density. On the other hand, for small machines, OME_{3-6} diesel mixture is recommended, because the required installation space for such tanks is smaller than the pure OME_{3-6} tank with the same energy content.

The high oxygen content (42-49 wt.%) of OME makes it necessary to have an adapted injection system (Omari et al. 2018). Injection systems are divided into conventional cam-operated systems and the common rail injection system (Eckert and Rakowski 2009, 126). The advantage of the cam-operated injection system is its compact construction, which is recommended for small machines (Schaefer 2017, 664). The common-rail system is more appropriate for machines that have higher driving power, because of its high flexibility in the position and quantity of the injection, leading to a more effective combustion (Projahn 2018, 289).

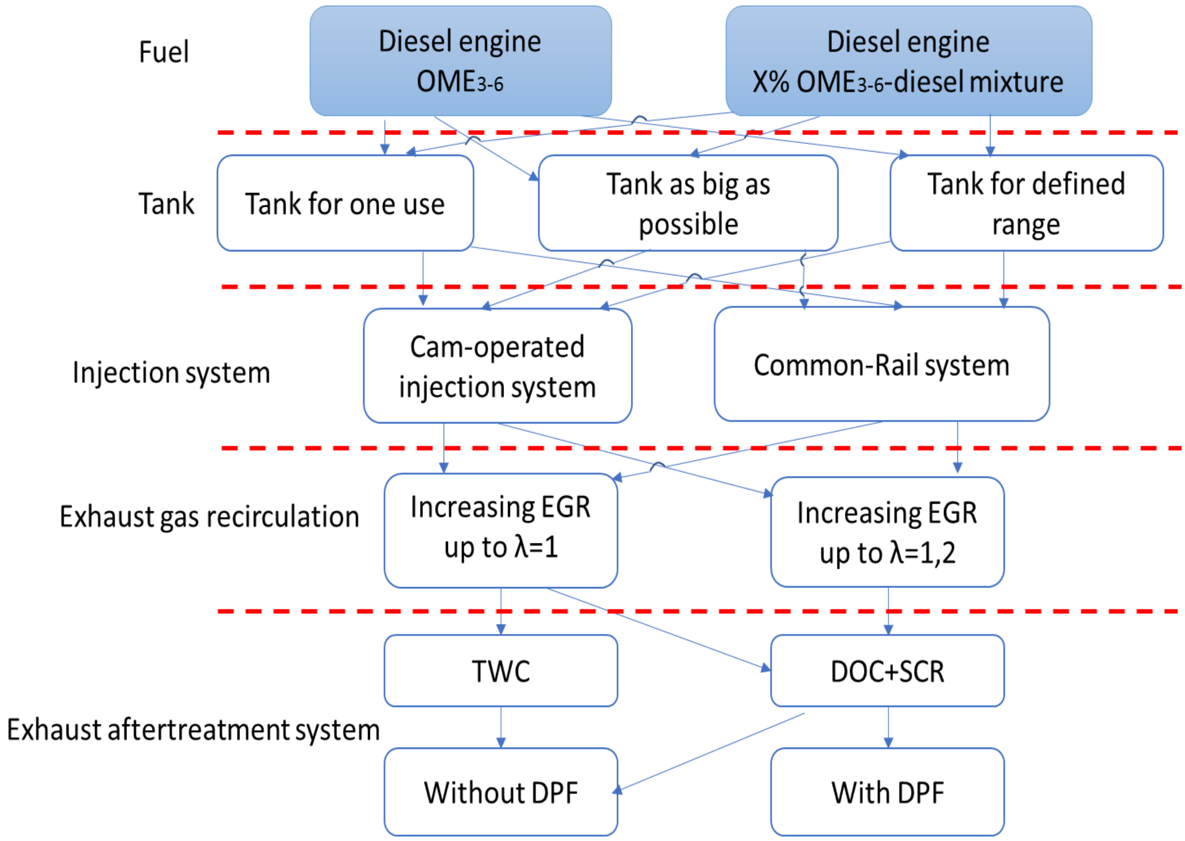

Figure 1: Design method for possible OME powertrain concept of mobile machines

Afterwards, the EGR (exhaust gas recirculation) amount can be defined. For OME_{3-6} fuel the engines can be operated at $\lambda = 1$ by higher EGR-rate. The engines with OME_{3-6} diesel mixture can be operated just like conventional diesel engines only at $\lambda > 1.2$, because otherwise black smoke occurs at $\lambda \leq 1.2$. (Härtl et al. 2017, 55)

Finally, the composition design of the exhaust after-treatment system takes place. The Diesel Oxidation Catalysts (DOC) combined with the Diesel Particulate Filters (DPF) and the Selective Catalytic Reduction (SCR) are the "standard system" for current powertrain systems of mobile machines with higher power than 56 kW. For machines in the power segment below

56 kW, the SCR is dispensable due to higher allowed NO_x limits according to EU Stage V (NO_x + HC: 4.7 to 7.5 g/kW h). (Lüders and Kruger 2018, 886)
As a result of the absence of soot emission for pure OME, the DPF can be removed of the exhaust after-treatment system. This results in savings in installation space, which is important especially for small machines. In addition, if stoichiometric operation of the engine with pure OME takes place, the use of a three-way catalyst (TWC) instead of a DOC combined with a SCR is enabled.

After having described the preliminary design of a driving concept after the morphological box method, examples of preliminary design of driving concept for different mobile machines sizes are described below.

Mobile machines below 56 kW power

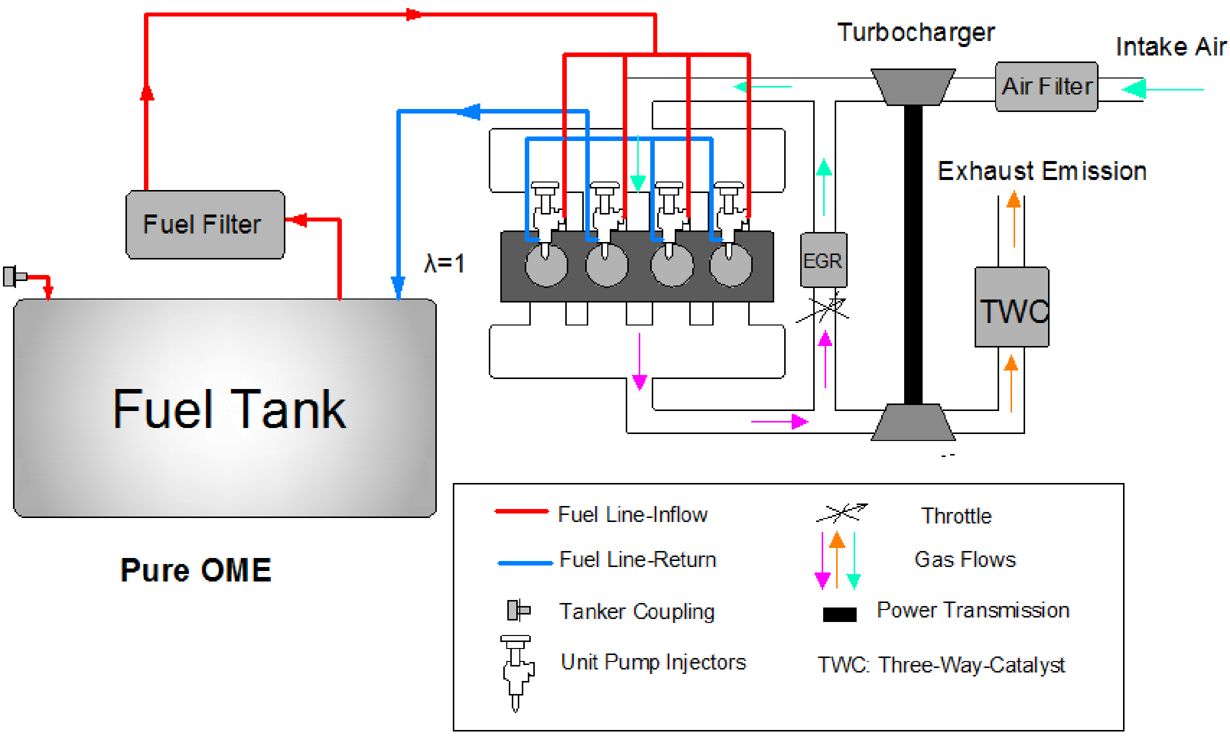

Figure 2: Pure OME with cam-operated injection system

Small machines require a compact design due to limited installation space. The tank volume must be as small as possible. Therefore, the tank content is generally designed for the energy carrier amount of one working shift. For pure $OME_{3\text{-}6}$ fuel, the amount of energy is smaller than diesel for the same tank volume, so that multiple refueling per working shift is necessary. Due to the low power of small engines, the cam-operated injection system is sufficiently efficient

and can simplify the powertrain system. The exhaust after-treatment system is as well simplified compared to conventional diesel engines. The DPF is not needed for a pure OME fuel running system. The SCR is dispensable because of the allowed NO_x emissions amount according to EU Stage V emissions regulations for machines with power below 56 kW.
With pure $OME_{3\text{-}6}$ fuel, small machines can be operated with an air ratio of up to 1, so that a TWC can be used instead of DOC. The entire system corresponds to Figure 2.

Mobile agricultural and forestry machines with more than 56 kW power

Large agricultural and forestry machines are operated over a long period of time and refueling in the field or forest is a major problem. This is the reason why as few tank interruptions as possible are required and therefore the largest possible tank capacity is necessary. On the other side, too much weight for such machines has to be avoided in order to not damage the field and the forest. For pure $OME_{3\text{-}6}$, the tank system (volume and weight) is doubled at the same energy content as the diesel fuel, which is not favorable. While the weight of the tank system of a 15% $OME_{3\text{-}6}$ diesel mixture is only approx. 1.2 times bigger than that of the diesel tank system. Consequently, the $OME_{3\text{-}6}$ diesel mixture is preferred.
The exhaust after-treatment system remains identical to a pure diesel powertrain system with a DOC, a DPF and a SCR. The entire system corresponds to Figure 3.

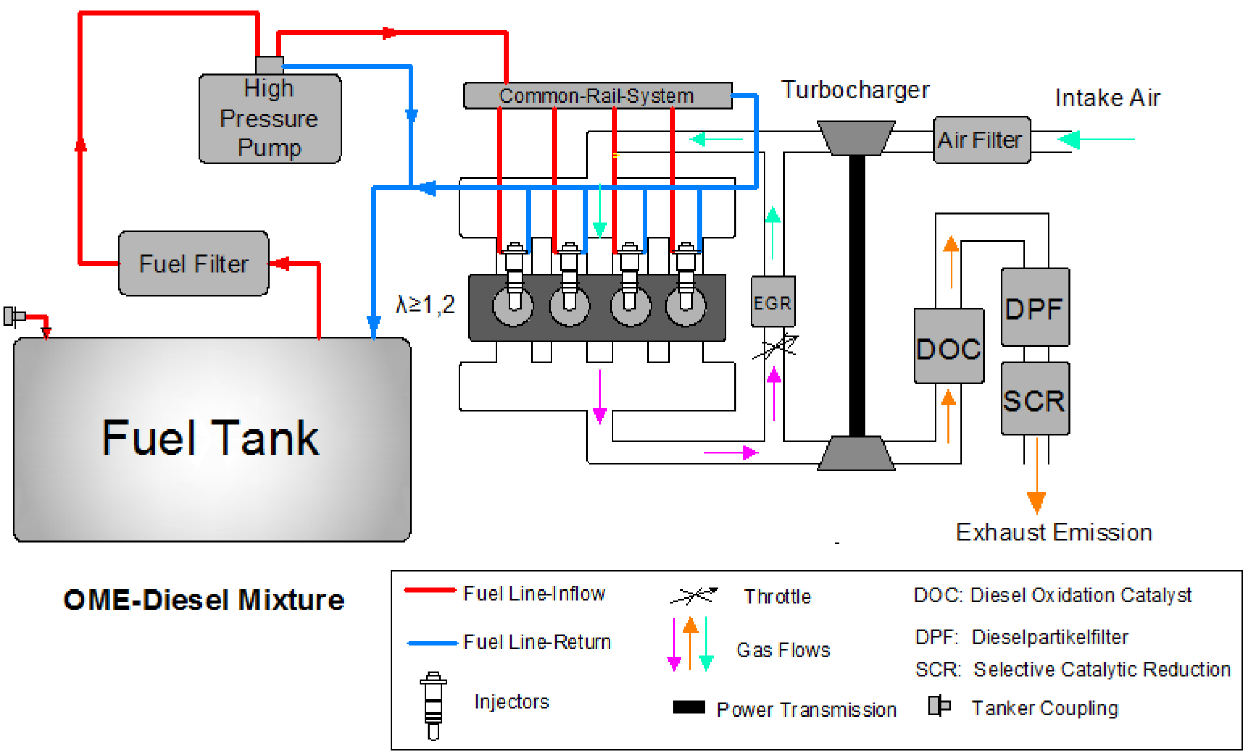

Figure 3: OME-diesel mixture with common-rail system

Mobile construction machines with more than 56 kW power

Mobile construction machines are operated at high power. In this case, common rail systems are used. Construction machines are often used in 2-shift or 3-shift operation and the longest possible operating time per working shift is required. A maximum tank capacity is therefore necessary to achieve at least one working shift. For machines that hardly drive or drive very slowly, an increase in weight is accepted. This means that pure $OME_{3\text{-}6}$ is used. Some construction machines drive at high speeds and accelerations. It remains to be seen whether such machines will be allowed to gain in weight.

When using the $OME_{3\text{-}6}$ fuel, the diesel engines can be operated with the air ratio equal to 1 ($\lambda = 1$). With $\lambda = 1$ the efficiency is greatly reduced, while with $\lambda \geq 1.2$ the efficiency remains at the high level (Pélerin et al. 2017, 445). So that the diesel engines are not economical for construction machinery in stoichiometric operation. In this case, a TWC cannot be used. The exhaust after-treatment system consists of a DOC and a SCR. The entire system corresponds to Figure 4.

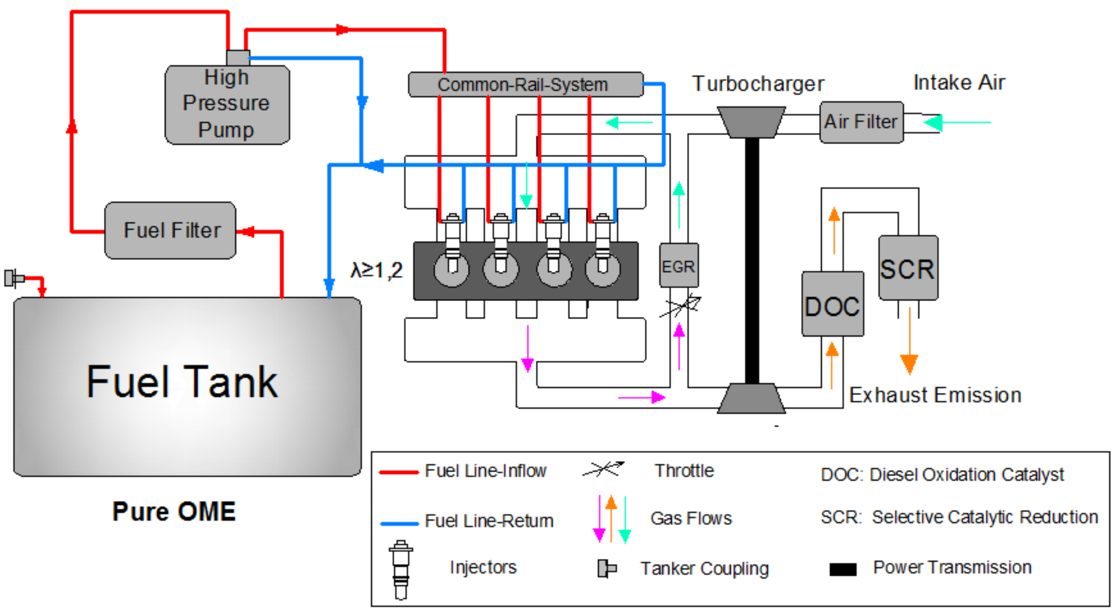

Figure 4: Pure OME with common-rail system

Mining machines

Mining machines are usually fuelled by a tanker truck. The machines operate continuously, consequently as few tank interruptions as possible are required. Therefore, the tank capacity should be as large as possible, in order to achieve at least one working shift. Such machines are equipped with the common rail system due to their high power output.

Pure OME_{3-6} fuel is selected, which means the diesel engines can be operated with the air ratio equal to 1 ($\lambda = 1$) or 1.2 ($\lambda \geq 1.2$). Similar to mobile construction machines with more than 56 kW power, the exhaust after-treatment system consists of DOC and SCR. The entire system corresponds to Figure 4.

Evaluation of the driving concepts

For the evaluation of the driving concepts four exemplary machines are analyzed. The trench roller for the category “Mobile machines below 56 kW power”, the tractor for the category “Mobile agricultural and forestry machines with more than 56 kW power”, the wheel loader for the category “mobile construction machines with more than 56 kW power” and the mining excavator for the category “mining machines”.

Trench roller

A trench roller is chosen for the category of machines below 56 kW power. For the analyses, the engine power is assumed to be 15 kW with a tank volume of 28 l and a total weight of 1500 kg. A full diesel tank corresponds to 341 MJ [4]energy output. With an engine load of 40%, the tank content lasts approximatively 16 h.

A weight of the diesel tank system is calculated to 26 kg and the OME_{3-6} tank system would weighs approximately 57 kg. Based on the total weight, the 31 kg additional weight corresponds to a weight growth of 2%. This machine drives at a low speed and accelerates slightly. A slight increase in weight is advantageous for sealing the soil. Thus, the increase in weight is bearable. For the 15% OME_{3-6} diesel mixture, a weight growth of the tank system is about 5 kg and corresponds to 0.3% based on the total weight. The use of both fuels is considered positive for trench rollers.

Tractor

A tractor is chosen as an example of agricultural machines. The engine power of the machine is assumed to be 130 kW with a fuel tank volume of 400 l and a total weight of 8,000 kg. Similar to the counting process of the trench roller, the diesel tank energy content is about 14,163 MJ. With an engine load of 70%, the weight of the diesel tank system is about 370 kg and the operating time around 15 h.

The weight of the OME_{3-6} tank system and the weight of OME_{3-6}-diesel mixture tank system are calculated. The weight of the OME_{3-6} tank system is approximatively 810 kg. Based on the total weight of 8,000 kg, 440 kg additional weight corresponds to a weight increase of 6%. It

[4] Following data for the diesel engine were used: ρ_{diesel} = 0,83 kg/L; calorific value of diesel = 43,2 MJ/kg; weight factor of the OME_{3-6} tank system = 2.2; $\eta_{diesel\ engine}$ = 0,34 (Geimer and Ays 2014)

must be further investigated whether the increased weight would damage the soil. The weight of the 15% $OME_{3\text{-}6}$-diesel mixture tank system would be 74 kg. The weight increase would correspond to 0.9%.

Wheel loader

A wheel loader is chosen for the category of "construction machines with more than 56 kW power". It is assumed that the machine has a total weight of 30 t and an engine power of 250 kW. The tank volume is 350 l. The weight of the diesel tank system is approximatively 290 kg and the weight of the $OME_{3\text{-}6}$ tank system is about 700 kg. Based on the total weight, 410 kg additional weight corresponds to a weight increase of 1%. Further investigations are necessary to know whether this increase can be permitted for frequently accelerating machines. The weight of the 15% $OME_{3\text{-}6}$-diesel mixture tank system would be 65 kg. The weight increase would correspond to 0.2%.

Mining excavator

The last example is a mining excavator. It is assumed that, the machine has a total weight of 800 t and an engine power of 3,000 kW. The tank volume is also 18,000 l. By using the same calculation method, the increased weight with pure $OME_{3\text{-}6}$ is approximatively 20 t and corresponds to a weight increase of 2%. The weight growth by using 15% $OME_{3\text{-}6}$ diesel mixture would be 3 t. This weight increase would correspond to 0.4%.

Table 4: Comparison of different machine concepts

Machines	Engine power [kW]	Diesel tank volume [L]	$OME_{3\text{-}6}$		15% $OME_{3\text{-}6}$	
			Additional weight [kg]	Weight increase [%]	Additional weight [kg]	Weight increase [%]
Trench roller	15	28	31	2	5	0.3
Wheel loader	250	350	410	1	65	0.2
Tractor	130	400	440	6	74	0.9
Mining excavator	3,000	18,000	20,000	2	3,000	0.4

Four machines from each category were evaluated and the results are presented in Table 4. Both fuels for trench roller and mining excavator are evaluated as positive. Whether the weight increase is acceptable for the wheel loader, that drive and speed up frequently, or the tractor, that may possibly damage the soil, must be further investigated. Using sustainable OME even in small amount (15% $OME_{3\text{-}6}$-diesle mixture) reduces the overall emitted greenhouse gases (well-to-wheel). 15% sustainable $OME_{3\text{-}6}$-diesel mixture reduces compared to diesel the greenhouse gas emissions by 2-3% and pure $OME_{3\text{-}6}$ by 80-86%.

Economical aspects

The organization for Economic Cooperation and Development (OECD) states that direct damages and indirect consequences, such as adaptation measures due to global warming, cost today 30€[5] per t CO_2e and in 2020 will cost 60 € per t CO_2e (OECD 2018). In the case of a 30 t wheel loader with e.g. a service life of 25,000 hours and a fuel consumption of 14 l/h, this would correspond to 1,113 t CO_2e emissions and 33,390 € or in 2020 to 66,780 €. The implementation of alternative energy carriers per machine will cost less than direct damages and indirect consequences due to global warming. Consequently, it becomes clear that an alternative sustainable energy carrier like OME is a promising solution for mobile machines.

Summary and future perspectives

The global warming and the stricter emission limits are currently the main drives for analyzing and developing alternative fuels. One possibility is OME, which has similar properties as diesel fuel. OME can be used as diesel alternative or diesel additive.

OME fuel is produced from methanol with fossil or sustainable raw material. In case of a production from sustainable raw material, CO_2e emissions can decrease significantly compared to diesel (see Table 3). Further, due to the absence of soot emission during combustion of pure OME, the Diesel Particulate Filters (DPF) of the exhaust after-treatment system can be omitted.

An OME design method in form of a morphological box was developed in order to facilitate the preliminary design of OME powertrains for mobile machines. Different powertrains were chosen for different types of mobile machines. Finally, the concept was evaluated exemplary for a mobile machine from each category: a trench roller, a wheel loader, a tractor and a mining excavator. For a valid design requirements, environmental constraints, duty cycles of a specific mobile machine, etc. need to be further investigated.

In conclusion, sustainable OME is a possible fuel alternative or diesel additive for mobile machines in order to reduce greenhouse gas emissions (up to 86% with pure OME). However,

[5] 30€ per t CO_2e is a low-end estimate of today carbon costs and is valid for “42 OECD and G20 countries, representing 80% of world emissions“ (OECD 2018).

due to the limited availability of sustainable OME (Dahmen et al. 2017, 9), only an admixture in diesel is currently an option for reducing pollutants and CO_2e.

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