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Energy funding programme
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Dual Fuel Engine

Thermal Management for small Diesel ignited Natural Gas Engines

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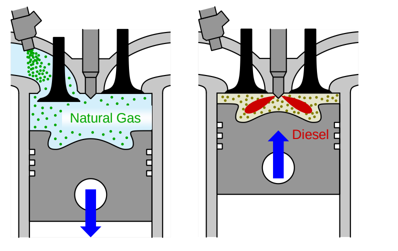
IDSC is participating in the «NextICE» project (Funding BFE)

Alternative fuels, such as biofuels, fossil natural gas or synthetic methane could help to lower CO_2 emission, while pursuing the «energy-change». The development of engine concepts with advanced thermal management strategies is necessary to ensure that recent emission limits are met. The goal is to use all the degrees of freedom provided by the engine control for optimizing engine performance (efficiency, CO_2) while meeting latest emission limits by taking into account engine-out emissions and exhaust aftertreatment efficiency. The «NextICE» project partners are: Aerothermochemistry and Combustion Systems Laboratory (ETH/LAV), Swiss Federal Laboratories for Materials Science and Technology (Empa), Institute for Dynamic Systems and Control (ETH/IDSC).

Dual Fuel Engine: Promising Approach for the Next Generation of Alternative Fuel Engines

The diesel ignited natural gas engine combines the advantages of two different fuel types in a compact passenger car engine. With very low CO2 abatement cost, natural gas acts as the primary fuel and is injected cylinder-individually into the intake port. Afterwards diesel is directly injected into the cylinders. It is the engine's «Spark Plug», i.e. once compression ignited, the diesel provides ignition centers for the premixed natural gas. The dual fuel engine at the laboratory of IDSC was built based on a commercial diesel engine. Since the capability to burn natural gas demanded only for slight modifications, the possibility to operate the engine conventionally with pure diesel could be fully preserved. A powerful rapid prototyping engine control unit on the testbench provides maximum flexibility in testing new engine control algorithms.

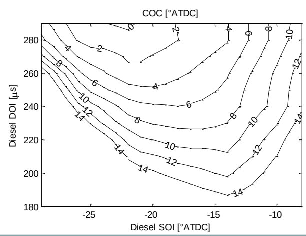
The natural gas injectors are mounted on the swirl flaps adapter.



Two important phases of the Dual Fuel operation: Natural Gas is injected upstream of the intake valve during the intake stroke. As the mixture is compressed, Diesel is directly injected.

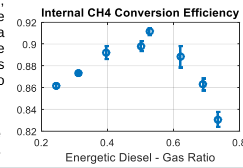
Control: Improve Performance through optimal Combustion Phasing

The combustion timing in the diesel ignited natural gas engine depends on the chemical reaction kinetics of the gas-diesel fuel mixture. The process is therefore prone to disturbances in temperature and composition. An effective way to overcome this problem is the application of cylinder individual feedback control on the measured cylinder pressure. The «center of combustion» (COC) is precisely controlled by manipulating the start and duration of the diesel injection (SOI/DOI). In comparison to a single-fuel engine, the fuel injection offers an additional degree of freedom that can be used for example to maximize the gas/diesel ratio or limit the maximum pressure gradient.

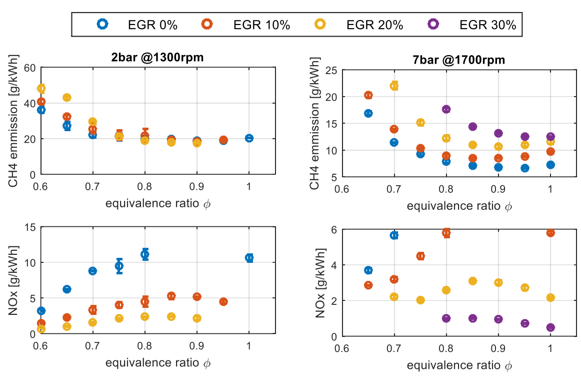


Does more diesel always improve the internal natural gas conversion?

Increasing the quantity of diesel injected at a certain operating point implies a reduction in the natural gas massflow. As a consequence the bulk mixture in the cylinders becomes leaner, which deteriorates the flame propagation. Especially for a stoichiometric combustion, the internal natural gas conversion is promoted when the diesel–gas ratio is minimized.



2.5 bar pme and 1500 rpm

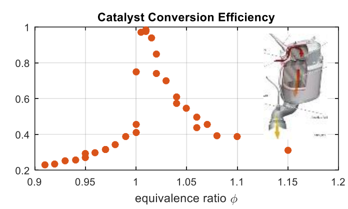


Measured engine-out emissions at low load and part load for different lambda and EGR rates. As the emissions do not meet the EURO6 Norm (~= 0.65 g/kWh) with any configuration, it becomes obvious that a CH_4 aftertreatment is mandatory.

CH4 aftertreatment: Challenge for lean burn concepts

The hydrocarbon engine-out emission of diesel ignited natural gas engines under part load and low load conditions do not comply with exhaust pollutant limits as EUROVI.

However, today's aftertreatment systems are only limited suitable for reducing methane. Effective methane conversion only takes place at specific equivalence ratios close to stoichiometric conditions. Hence, as long as there is no other lean aftertreatment solution the only way the dual fuel engine can comply with recent legal limits is under stoichiometric operation. Nevertheless, future solutions of operating the natural gas–diesel engine with aftertreatment systems which are not yet ready for the market should be addressed in this project.



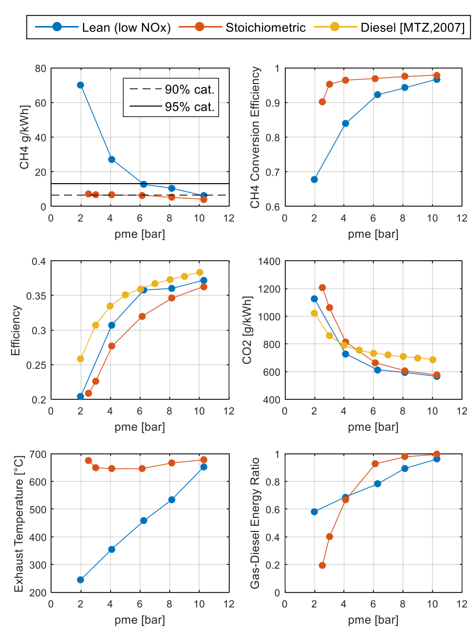
Outlook: Developing the optimal strategy

The flexibility in fuels demands a smart operation strategy that optimizes efficiency and CO_2 emission, while meeting recent pollution limits. Under low load conditions, this is a challenging task. The goal is to end up with a high level controller for the diesel ignited natural gas engine. The algorithm takes care of the thermal management as it considers engine-out emissions and the state of the exhaust aftertreatment system and, based on these parameters, chooses the operation mode that suits the requirements best. The operation modes of interest are «dual fuel lean» and «dual fuel stoichiometric» as well as «diesel only». Every particular mode features advantages and drawbacks either in terms of efficiency, CO_2 emission or pollutant emission. Only when the full potential of all engine modes is exploited, the dual fuel engine can compete with conventional engines under part load and low load conditions.

A fundamental analysis is being conducted, considering all potential aftertreatment systems (e.g. SCR, NOx trap) including not yet commercially available systems as lean CH_4 catalysts.

High Level Control

	Diesel Only	Dual Fuel Lean	Dual Fuel Stoichiometric
η	+	+	-
CO_2	-	+	+
Aftertreatment	+	-	+



Comparison of different strategies for operating the dual fuel engine. The best strategy in terms of CO2 emission is not necessarily the most fuel efficient strategy. In the low load region the stoichiometric combustion enables high internal CH_4 conversion while providing high exhaust gas temperatures, which are favorable for the exhaust aftertreatment's efficiency. The acceptable engine-out emissions are outlined assuming the catalytic efficiency of the aftertreatment system has values of 90% and 95%.

Fast CO_2 Measurement with the NDIR500: Estimating EGR Rates

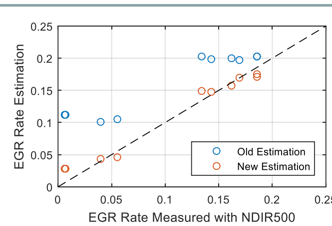
The rate of recirculated exhaust gas (EGR) can be determined by measuring the CO_2 concentration in the intake and the exhaust manifold. The EGR rate x_{EGR} is expressed as

$$x_{EGR} = \frac{(CO_2)_{int}}{(CO_2)_{exh}}$$

under the following assumptions:

1. The atmospheric air is CO_2 free
2. The molar mass of the exhaust mixture is identical to the molar mass of the intake mixture

Thanks to the NDIR500 new concepts for estimating the actual EGR rate can be validated.



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