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THE EFFECT OF RENEWABLE DIESEL OIL ON ENGINE PERFORMANCE

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THE EFFECT OF RENEWABLE DIESEL OIL ON ENGINE PERFORMANCE

In this study, the effects of renewable NExBTL diesel on engine performance were compared with standard diesel and 50-50 % mix of NExBTL and DFO. The target was to determine if it would be possible to reduce the fuel consumption of the engine with two research fuels by optimizing fuel injection parameters and the use of exhaust gas recirculation, while maintaining nitrous oxide emission levels achieved with diesel. Two different rates of EGR settings were used, and in addition fuel injection parameters were optimized with lower EGR valve settings to bring NO_X to the reference level. In the last part of the study a transient cycle was used to compare fuels.

In-cylinder data was collected and analyzed via a cylinder pressure sensor and engine indicating system. The main target was to compare the results of cylinder pressures, heat release rates and ignition delays between different fuels.

The base levels of NO_X were quite similar with all fuels. The greatest advantages for the two research fuels in comparison to diesel were seen in significantly lower smoke numbers.

Fuel injection parameter optimization did not produce significant reduction in fuel consumption, as the base results of NO_X were quite similar with all fuels, which made optimization possibilities quite narrow.

The use of EGR reduced the NO_X significantly but simultaneously the amount of smoke rose. When NO_X was brought back to the reference levels by optimizing the fuel injection parameters, notable gains in fuel consumption were noticed. At the same time the smoke numbers were clearly higher than the reference level.

No significant constant differences between the three fuels were seen in in-cylinder results. At some lower load points shorter ignition delay of NExBTL was measured.

The NO_X results of transient cycle were quite close to each other when using different fuels. Only slight changes in fuel consumption were noticed in these runs.

KEYWORDS: Diesel engine, exhaust gas emissions, biofuel, renewable fuel, NExBTL, hydrotreated vegetable oil (HVO), exhaust gas recirculation (EGR).

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UUSIUTUVAN DIESELÖLJYN VAIKUTUS MOOTTORIN SUORITUSARVOIHIN

Tässä tutkimuksessa tutkittiin uusiutuvan NExBTL-dieselöljyn vaikutuksia moottorin suoritusarvoihin. Vertailua tehtiin tavallisella dieselillä ja NExBTL:n ja dieselin sekoituksella (seossuhde 50–50 %) ajettuihin tuloksiin. Ensi vaiheessa tavoitteena oli selvittää, olisiko moottorin polttoaineen kulutusta mahdollista alentaa optimoimalla moottoria tutkimuspolttoaineille paremmin sopivaksi. Typen oksidien (NO_X) päästö pyrittiin pitämään standardi dieselin tasolla.

Tämän jälkeen moottoriin asennettiin pakokaasun takaisinkierrätysjärjestelmä (EGR) typen oksidien pienentämiseksi. Käytössä oli kaksi erilaista EGR-säätötasoa, joiden lisäksi pienemmällä EGR-säädöllä polttoaineen ruiskutusparametrit optimoitiin siten, että NO_X nousi takaisin referenssitasolle. Tutkimuksen viimeisessä vaiheessa oli vuorossa transienttisykli kaikilla polttoaineilla.

Sylinterinpainetietoja kerättiin kaikissa staattisissa kuormapisteissä. Käytössä oli sylinterinpaineanturi ja indikointilaitteisto. Tarkoitus oli selvittää sylinterinpaineen, lämmönvapautumisen ja sytytysjättämän eroja eri polttoaineilla.

Typen oksidien lähtötasoissa ei ollut suuria eroja eri polttoaineilla kun käytössä olivat vakiot moottorinruiskutusparametrit. NExBTL ja 50–50 % -polttoainesekoitus tuottivat selvästi dieseliä alhaisemmat savutuslukemat.

Typen oksidien lähtötasojen olleessa hyvin lähellä toisiaan eri polttoaineilla, polttoaineruiskutuksen optimoinnilla ei ollut mahdollista parantaa polttoaineen kulutusta merkittävästi, sillä NO_X:n piti pysyä samalla tasolla dieselillä mitattujen arvojen kanssa.

Pakokaasun takaisinkierrätys alensi NO_X-päästöjä tuntuvasti, mutta samalla savutus kasvoi. Selkeä parannus polttoaineen kulutuksessa oli havaittavissa kun polttoaineen ruiskutusparametrit oli optimoitu siten, että NO_X nousi referenssitasoille. Savutus tällöin oli kuitenkin selvästi lähtöarvoja suurempi.

Sylinteripaineista lasketuissa tuloksissa ei ollut nähtävissä suuria eroja eri polttoaineiden välillä. NExBTL-polttoaineella osassa tutkimuspisteistä havaittiin lyhyempi sytytysjättämä kuin muilla polttoaineilla.

Transienttisyklin NO_X-tulokset olivat hyvin lähellä toisiaan kaikilla polttoaineilla. Myös polttoaineen kulutuslukemat olivat melko yhteneviä eri polttoaineiden kesken.

ASIASANAT: Diesel moottori, pakokaasupäästöt, biodiesel, uusiutuva diesel, NExBTL, hydrokäsitelty kasviöljy (HVO), pakokaasun takaisinkierrätys (EGR).

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SYMBOLS AND ABBREVIATIONS

BMEP	Brake mean effective pressure
BSFC	Brake specific fuel consumption
$BSNO_X$	Brake specific nitrogen oxides
CO	Carbon monoxide
CO_2	Carbon dioxide
CR	Common rail (fuel injection system)
DFO	Diesel fuel oil
DME	Dimethyl ether
ECU	Electronic control unit
eEGR	External exhaust gas recirculation
EGR	Exhaust gas recirculation
EGR %	Calculated percent of exhaust gas recirculation
EN590	Standard for diesel fuel oils
FTD	Fischer-Tropsch diesel
FSN	Filter smoke number (smoke measuring unit)
HC	Hydrocarbon
HRR	Heat release rate
HVO	Hydrotreated vegetable oil
Main	Main injection of fuel in common rail system
NExBTL	Next Generation Biomass to Liquid, name for Neste Oil renewable fuel
NO_X	Nitrogen oxides
NRSC	Non-road steady cycle
NRTC	Non-road transient cycle
O_2	Oxygen
P1…P6	Load points 1…6 used in the test runs
Pilot	Pre-injection of fuel in common rail system
PM	Particulate mass or particulate matter

Post	Fuel injection after the main injection in common rail system
Ref	Reference
SFC	Specific fuel consumption
TDC	Top dead center
50-50 % mix	Fuel blend which consists of 50 % DFO and 50 % NExBTL

1 INTRODUCTION

1.1 Diesel Engine: Use and Challenges

Currently the diesel engine is very popular in various applications. It is commonly used in commercial and personal vehicles and the popularity of diesel engines is growing. The challenges with using diesel engines concentrates on three main issues: the limited quantity of crude oil reserves, the total amount of diesel fuel oil consumed and the exhaust emissions of the burning process.

The world’s oil reserves are estimated to last for only about 40 years. The price of the oil is estimated to rise if demand outstrips supply. This could cause great problems not only in the operation of engines but also the balance in the world and in the worst scenarios cause an extensive chaos. This causes a need for finding alternative fuels to be able to use engines in the future.

Diesel engines consume a great amount of diesel fuel. For example the road usage of diesel engines has an 81 % share of energy consumption in the transportation. With the development of suitable alternative fuels the problem rises with the volume of production of these fuels. Fuel consumption reduction is a priority in the current situation.

Diesel engine exhaust gas emissions contribute significantly to the world’s total pollution. Diesel engines produce mostly NO_X, HC, PM/smoke, CO_2 and CO emissions. These emissions have a negative effect on the health of the population (e.g. cancer, cardiovascular and respiratory problems), global climate changes and general pollution of air, water and soil. In the last 20…25 years the legislation has guided engine manufacturers to develop engines that produce less emissions. Focusing on fuel injection optimization, engine combustion and parameter control, exhaust gas recirculation and control, exhaust gas after-treatment systems and alternative fuels, it is possible to reduce emissions considerably.

(Pahl 2005, 1-3; Kegl et al. 2013, 1-3; DieselNet 2015a)

1.2 Diesel Engine Emission Legislation and Bioenergy Mandates

The strictest diesel engine emission legislations are found at the moment in the European Union, the USA and Japan. The European Union's emission legislation is divided into five different sectors: cars and light trucks, heavy-duty truck and bus engines, nonroad (off-road) diesel engines, motorcycles and small utility vehicles. (DieselNet 2015a)

The experimental studies of this thesis concentrated on the performance of an off-road diesel engine. The evolution of exhaust gas emission standards for engines with net power in the region of research engine (100 kW) can be seen in Table 1.1. The standard Stage 3B concerning the research engine is highlighted.

Table 1.1. Stage I-V exhaust gas emission standard evolution (DieselNet 2015a).

Stage	**Net Power**	**Date†**	**CO**	**HC**	**HC+NOx**	**NOx**	**PM**	PN
	kW		g/kWh					1/kWh
Stage I	75 ≤ P < 130	1999.01	5	1.3	9.2	0.7	-	-
Stage II	75 ≤ P < 130	2003.01	5	1	6	0.3	-	-
Stage III A	75 ≤ P < 130	2007.01	5	-	4	-	0.3	-
Stage III B	75 ≤ P < 130	2012.01	5	0.19	-	3.3	0.025	-
Stage IV	56 ≤ P < 130	2014.1	5	0.19	-	0.4	0.025	-
NRE-v/c-5	56 ≤ P < 130	2020	5	0.19	-	0.4	0.015	1×1012

The effort to decrease the effects of greenhouse gas emissions caused by transportation exhaust has been taken. The goal is to improve sustainability. The direct way is to improve energy conversion and emission control of the engine and the indirect way is through a closed CO_2 cycle using biofuels. (Mollenhauer et al. 2010, 94-95)

Several countries globally have agreed to certain mandates in the usage of bio- and renewable fuels. The European Union has set a goal for 20 % of the energy used to be renewable by the year 2020. For transportation, the goal for renewable energy use is 10 % of the total energy by the year 2020. (Directive 2009/28/EC)

In Finland the target for renewable energy use in transportation is even greater: 20 % by the year 2020. (Petroleum & Biofuels Association - Finland 2015)

1.3 The Aim of the Study

The aim of this thesis was to study the effects of the use of renewable diesel fuel on a diesel engine performance, exhaust gas emissions and qualities. The experimental studies were performed with a modern off-road diesel engine. The research results acquired by using three different fuels were under comparison. The focus was especially on the changes in the heat release and cylinder pressure of the engine. Also a literature review was conducted on these matters.

The studies were performed in co-operation with the Finnish oil and refining company Neste Oil, that provided the fuels used in the experimental studies. The research engine and software for controlling the engine parameters were provided by a Finnish diesel engine manufacturer AGCO Power.

2 BIO- AND RENEWABLE FUELS IN DIESEL ENGINES

2.1 First and Second Generation Biofuels

2.1.1 First Generation Biofuels

The term biofuel indicates that the fuel is made of some other than fossil origin. One way to separate different biofuels is to divide them into first and second generation biofuels. In some sources the term “third generation biofuels” is also used to describe the latest of alternative fuels. The categorization into different generations is not completely unanimous, as some variation of terms occurs in the literature.

First generation biofuels are produced primary from food crops. Some examples of these fuels are: pure vegetable oils, bioethanol, biodiesel produced from vegetable oil and biogas produced from waste. Problems with using first generation biofuels lie with the fact that the raw material used for biofuel can be used for food and animal feeds.

Usually diesel engines need a series of modification to be able to successfully use first generation biofuels. In some cases it is possible to blend biofuels with fossil fuels, for example according to EN 590 and DIN 51628 fuel standards, biodiesel can be added to diesel fuel up to 7 % in volume.

(Sims et al. 2010, 1570-1571; Mollenhauer et al. 2010, 96; Kegl et al. 2013, 76-78; DieselNet 2015b; Petroleum & Biofuels Association - Finland 2015)

2.1.2 Second Generation Biofuels

Second generation biofuels are produced from non-food biomass, but from by-products, waste and dedicated feedstocks. For example the following fuels can be produced so that it is possible to call them second generation biofuels: Gas-to-Liquid (GTL), Biomass-to-Liquid (BTL), dimethyl ether (DME), alcohols, methane, propane and hydrogen.

Many of these fuels require diesel engines to be modified to enable proper usage. For example gaseous fuels require large modifications to the diesel engine to even attempt to use it.

It is possible to blend second generation biofuels with fossil fuels. Currently in Finland diesel and gasoline fuels, which contain bio-originated parts are commercially available.

Gas-to-Liquid (GTL) is a fuel which is made by converting gas into diesel fuel by using the Fischer-Tropsch process. Biomass-to-Liquid (BTL) uses also the Fischer-Tropsch process to produce fuel from biomass. These fuels have quite similar chemistry and properties to Neste Oil NExBTL fuel presented later.

(Sims et al. 2010, 1571; Mollenhauer et al. 2010, 98-99; Kegl et al. 2013, 63-64)

2.2 Neste Oil NExBTL

2.2.1 General Information

The name NExBTL comes from words Next Generation Biomass to Liquid. It was developed and patented by the Finnish oil and refining company Neste Oil. Any biomass, for example vegetable oil or animal fat, can be used as raw material for manufacturing NExBTL. Currently Neste Oil uses twelve different materials for making the renewable diesel. (Neste Oil 2015b)

NExBTL can be blended in all proportions with traditional fossil diesel fuel and it increases the quality of the blend. The quality of the NExBTL itself is not dependent on the raw materials used. The fuel can be also used in all current fuel distribution logistical systems without modifications. (Neste Oil 2015c)

Since 2012 Neste Oil has been providing customers with Neste Pro Diesel which contains the minimum of 15 % of NExBTL. NExBTL can be used to meet the given bioenergy mandates cost-efficiently. For example in California, USA, it will be soon possible to buy fuel that contains 98.5 % of NExBTL (Diesel HPR by Propel Fuels). (Neste Oil 2015e; Taloussanomat 2015)

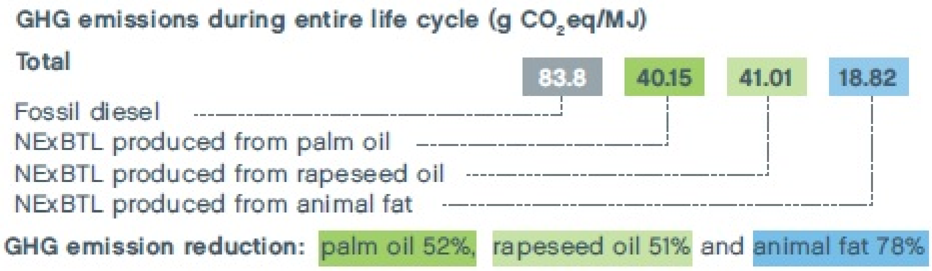
Currently the majority of NExBTL is used as a traffic fuel but it is also possible to use it e.g. in airplanes, ships, generators and turbines. It is also possible to use NExBTL as a raw material for renewable plastics by the chemical industry. In the future NExBTL can be used as a power source for fuel cells, as it is possible to reform NExBTL into hydrogen, because it does not contain sulfur. The product family of NExBTL is shown in Figure 2.1. (Neste Oil 2015d; Neste Oil 2015g)

Figure 2.1. Product family of NExBTL (Neste Oil 2015d).

NExBTL is more user-friendly for the mechanics and maintenance personnel of the vehicles and engines, as it is much less toxic than the conventional diesel. It has been determined that NExBTL does not irritate the skin or eyes and it is biodegradable. (Nylund et al. 2011, 31-32)

Several studies have been performed by various parties to determine the greenhouse gas emissions of producing NExBTL. Table 2.1 shows, that the reduction of greenhouse gas emissions during the entire life-cycle is 51 % at minimum with NExBTL. The level of reduction is determined by the raw material used for NExBTL production. When NExBTL is produced from animal fat, the reduction is very high, up to 78 %. (Neste Oil 2015a)

Table 2.1. Greenhouse gas emissions of NExBTL during entire life cycle (Neste Oil Annual Report 2010, 45).



GHG emissions during entire life cycle (g CO_2eq/MJ)

Total	
Fossil diesel	83.8
NExBTL produced from palm oil	40.15
NExBTL produced from rapeseed oil	41.01
NExBTL produced from animal fat	18.82

GHG emission reduction: palm oil 52%, rapeseed oil 51% and animal fat 78%

2.2.2 The Manufacturing and Chemistry of NExBTL

The manufacturing process of NExBTL is called Hydrotreating of Vegetable Oils (HVO) and it can be used for animal fats as well. The process consists of cleaning raw materials of any impurities, after which they are hydrotreated using high temperature. This splits the triglyceride into three different chains and expels oxygen from the triglyceride molecules. Isomerization is performed to enhance the flow quality of the product in cold conditions. The procedure enables to make hydrocarbons with similar chemical properties to fossil diesel. The simplified process of making NExBTL is presented in Figure 2.2. (Nylund et al. 2011, 26; Neste Oil 2015c)

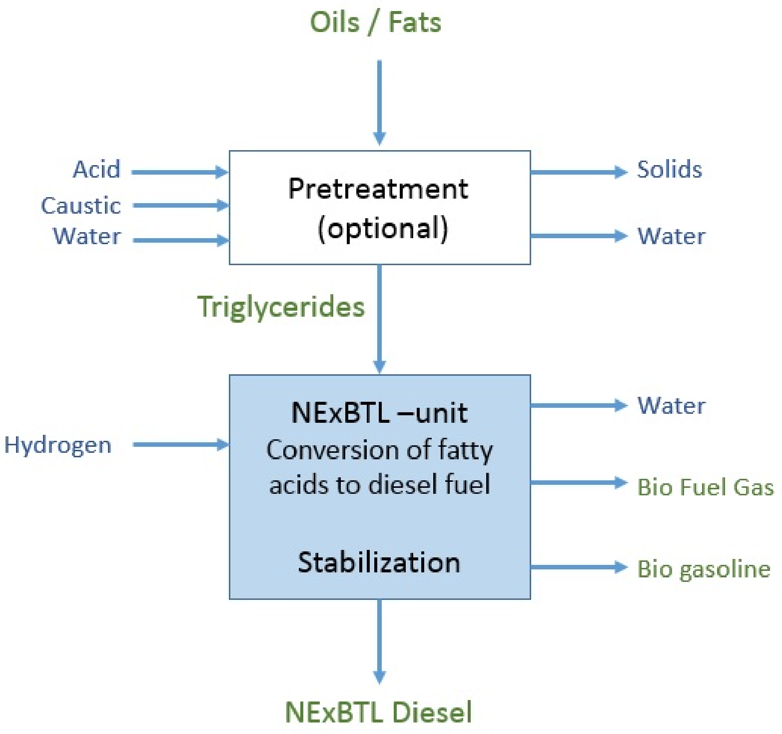


Figure 2.2. NExBTL process (Neste Oil 2015f).

HVO has a blend of straight chain and branched paraffin hydrocarbon molecules. The carbon numbers are generally $C_{15}…C_{18}$. The chemical composition of HVO is fairly equal to Gas to Liquids (GTL) and Biomass to Liquids (BTL) diesels made using the Fischer-Tropsch process. The isomerization process enables to make winter and arctic grades of the fuel. Lubrication additives are necessary for HVO to meet the HFRR specification (<460 µm) for fuel injection system wear protection. The amount of HVO in blend can be determined using ^{14}C isotope methods. The simplified chemical process of NExBTL is shown in Figure 2.3 below. (Neste Oil 2015c)

NExBTL can be stored for longer times than conventional second generation biodiesel and it does not accumulate water. The NExBTL can be used in cold weather conditions as it is possible to alternate the manufacturing process so that the cloud temperature of the fuel can be as low as -40 °C. (Neste Oil 2015c)

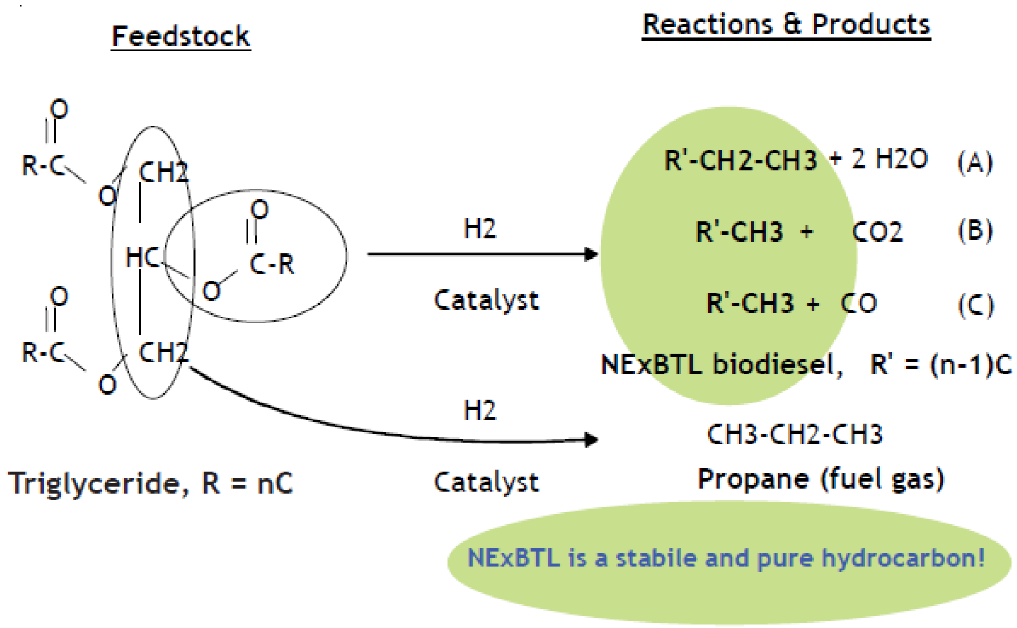


Figure 2.3. Simplified NExBTL chemical process (Neste Oil 2015c).

NExBTL does not include any aromatics, oxygen and sulfur and it is practically odorless. The cetane number of NExBTL is very high, higher than 70, but simultaneously the density is low, approximately 780 kg/m^3. NExBTL has the highest heating value of the current biofuels. Since aromatics affects greatly the formation of soot in diesel engines, NExBTL has a promise for lower smoke and PM. (Sugiyama et al. 2011, 2; Neste Oil 2015a; Neste Oil 2015c)

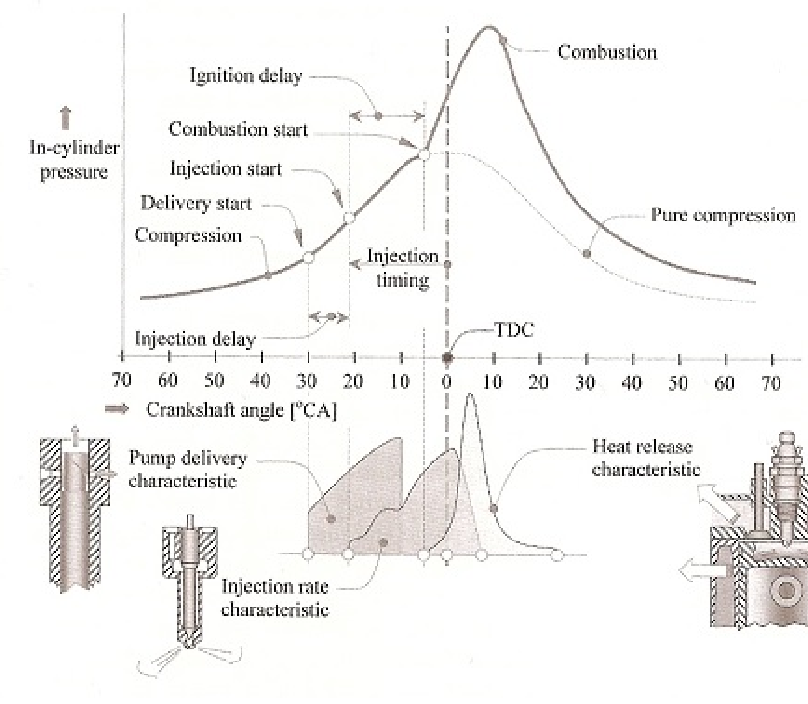
When pure NExBTL is used in the diesel engine without any parameter optimization, a small increase in volumetric fuel consumption will occur and simultaneously the power of the engine will decrease slightly. Although the heating value per mass (MJ/kg) of NExBTL is even higher than that of diesel, the lower density of NExBTL causes the volumetric heating value (MJ/l) be lower than that of DFO, the difference being 4-6 %. (Nylund et al. 2011, 30)

3 HEAT RELEASE IN DIESEL ENGINE AND EXHAUST GAS RECIRCULATION

3.1 Heat Release in Diesel Engine

3.1.1 Generally about Heat Release

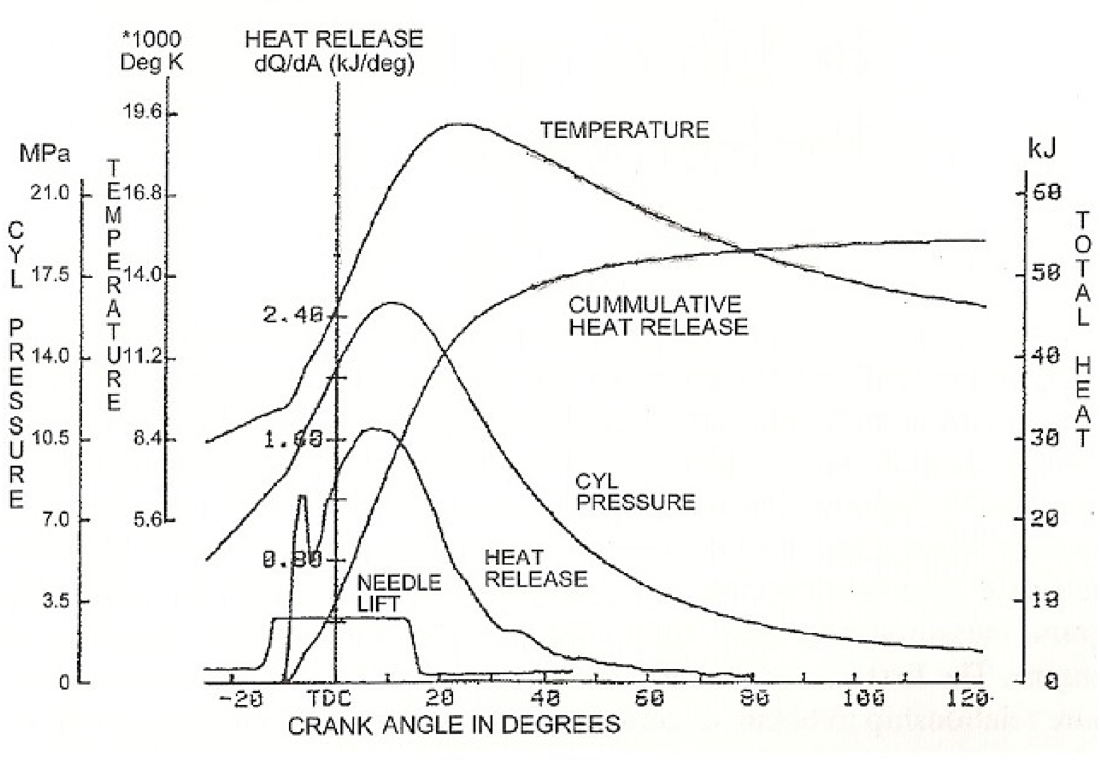
Heat Release Rate or *Heat Release* is a term used to describe at which speed the chemical energy, imported by fuel to the engine cylinder, is released in the combustion reaction. Cylinder pressure and engine crank angle data is used to calculate the heat release. The typical cylinder pressure curve of a diesel engine is presented in Picture 3.1. (Heywood 1988, 497, Kegl 2013, 15)



Picture 3.1. Cylinder pressure, fuel delivery rate, injection rate and heat release in cylinder (Kegl 2013, 15).

As Picture 3.1 shows, the time passed from the order of the engine management unit for the injector to begin injecting to the actual start of injection is called injection delay. Ignition delay respectively, is the time which passes between the actual start of the fuel injection until the actual combustion occurs. (Kegl 2013, 15)

Heat release is a good tool used for diagnosing engine performance. Heat release is determined at each position of the crank angle. The quantities often used for heat release are kJ/deg (Hsu) or kJ/m^{3}deg (AVL) (crank angle is in degrees). In addition to heat release, the total cumulative heat release can be calculated by integration of momentary heat releases at every position of the crank, Picture 3.2. (Hsu 2002, 13-14, 18)



Picture 3.2. Heat release rate, cumulative heat release, cylinder pressure and temperature in the cylinder (Hsu 2002, 14).

In the calculations of heat release the same principles are used as in the engine combustion modelling, only in reverse. The first law of thermodynamics to an open system is used to evaluate the combustion process. The cylinder pressure information and the volume of the cylinder at each crank angle are used to calculate the heat release. From Picture 3.2 it is possible to see the heat release rate curve of a diesel engine. (Hsu 2002, 13-14)

It is quite challenging to make a universal model for all applications and some assumptions need to be made to simplify the process, but even with the simple model a lot of information about the combustion process can be gained. It is important to use possible assumptions and simplifications constantly to have constant results from the calculations. (Hsu 2002, 13-14)

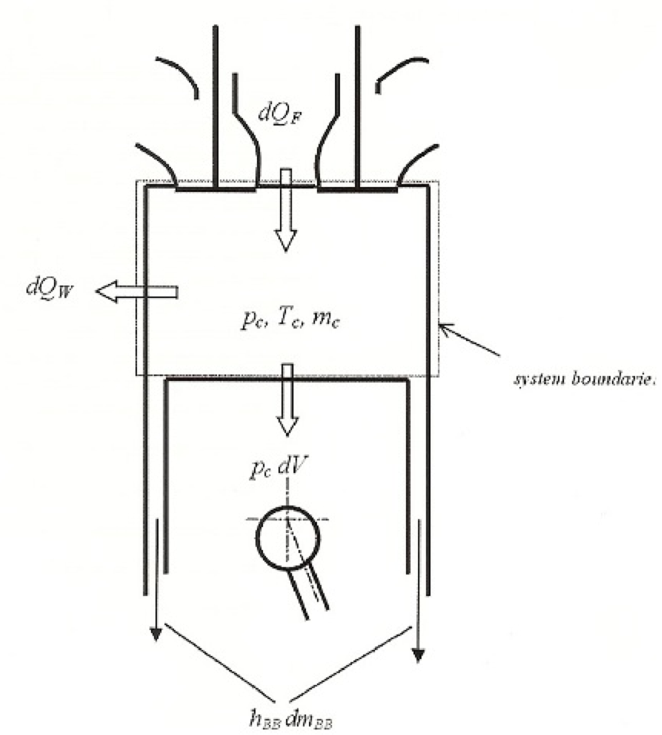
The model used to determine the heat release in this thesis is a one-dimensional “one-zone” model. In this model the conditions inside the cylinder for pressure, temperature and substance composition are dictated by time-dependent values. Local changes to these values are overlooked. The time-dependent result curve is dictated by using continuity, the first law of thermodynamics and ideal gas equation. Inlet and outlet valves are closed during the time of compression and gas expansion strokes (high pressure phase). Thus the only changes in the cylinder come from the fuel injected, heat loss to the walls of the cylinder and the piston ring blow-by. (Hsu 2002, 14-15; AVL 2003a, 5-6)

Integrated heat transfer to the walls of the cylinder is between 10 and 25 % of the total heat released for the total combustion period. The amount of unburned fuel in the cylinder at the end of combustion is very small and in many cases it is possible to overlook the effect of unburned fuel. (Heywood 1988, 509-511; Hsu 2002, 16)

The momentary energy content in the cylinder is dictated by the following aspects, Picture 3.3:

- the volume work of the piston moving ($p_C dV$)
- the combustion energy (dQ_F)
- the heat loss to the walls of the cylinder (dQ_W)
- the piston ring blow-by ($h_{BB} dm_{BB}$)

(Hsu 2002, 14-15; AVL 2003a, 5-6)



Picture 3.3. Energy content in the cylinder at the time of high pressure phase (AVL 2003a, 6).

Every crank angle is equivalent to a specific volume in the cylinder, so that it is possible to derive the needed pressure and volume information from the measured cylinder pressure and crank angle data. (Hsu 2002, 15)

Generally speaking, the heat transferred (lost) to the walls of the cylinder is usually less than 15 % of the total heat. The blow-by past the piston rings can be calculated if the fuel injection timing, duration, quantity and temperature are recorded. However, even if this is left out to simplify the calculation model, the total understanding of the system is not lost. (Hsu 2002, 17)

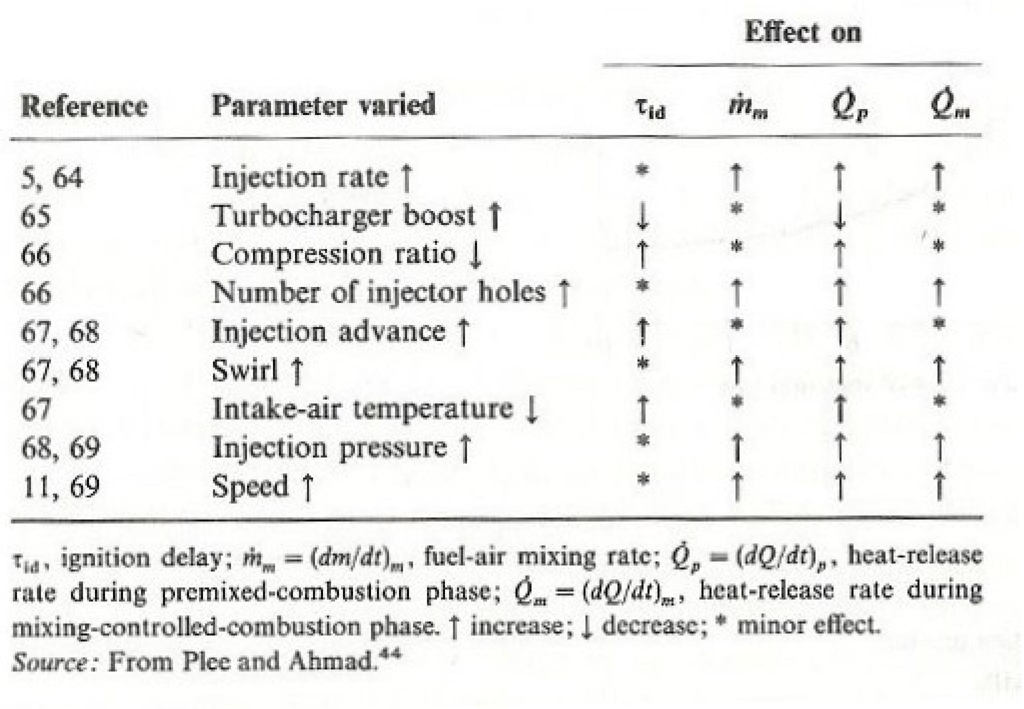
3.1.2 Engine Design and Operation Parameters Effects on Heat Release

Several variables affect the heat release of the engine. Different engine designs, fuels, turbochargers, fuel injection parameters, among other factors, change the cylinder pressure curve and heat release. It has been determined that the primary controlling factor on the initial peak of the heat release rate is the mixing process of fuel-air. Some factors to the heat release curve are presented in the following paragraph. (Heywood 1988, 560-562)

When the fuel injection is advanced, the peaks of the heat release curve are higher, because fuel and air have more time to mix properly. The increasing of fuel injection pressure results in higher heat release initial peak, because when fuel is injected into the cylinder at a higher pressure, the fuel-air mix is more rapid. (Heywood 1988, 560-562)

The usual effects on heat release are listed in Table 3.1.

Table 3.1. Effect of engine design and operating parameters on heat release rates (Heywood 1988, 562).



		Effect on			
Reference	Parameter varied	τ_{id}	$\dot{m}_m$	$\dot{Q}_p$	$\dot{Q}_m$
5, 64	Injection rate ↑	*	↑	↑	↑
65	Turbocharger boost ↑	↓	*	↓	*
66	Compression ratio ↓	↑	*	↑	*
66	Number of injector holes ↑	*	↑	↑	↑
67, 68	Injection advance ↑	↑	*	↑	*
67, 68	Swirl ↑	*	↑	↑	↑
67	Intake-air temperature ↓	↑	*	↑	*
68, 69	Injection pressure ↑	*	↑	↑	↑
11, 69	Speed ↑	*	↑	↑	↑

τ_{id}, ignition delay; $\dot{m}_m = (dm/dt)_m$, fuel-air mixing rate; $\dot{Q}_p = (dQ/dt)_p$, heat-release rate during premixed-combustion phase; $\dot{Q}_m = (dQ/dt)_m$, heat-release rate during mixing-controlled-combustion phase. ↑ increase; ↓ decrease; * minor effect.
Source: From Plee and Ahmad.[44]

Because the cetane number of NExBTL (and Fischer-Tropsch Diesel) is higher than that of mineral diesel, the ignition delay is shorter, which usually leads to lower heat release peak values. This lowers combustion noise, especially when pilot injection is not used. (Kegl 2013, 74; Neste Oil 2015b)

3.1.3 The Used Formulas and Methods

The formula used by AVL IndiCom program to calculate the heat release (Q_i) in this thesis was:

$$Q_i = \frac{K}{\kappa - 1}\left[\kappa \cdot p_i \cdot (V_{i+n} - V_{i-n}) + V_i \cdot (p_{i+n} - p_{i-n})\right]$$

Explanation of terms:

n = interval (1 deg. crank angle)

κ = polytropic coefficient

p = cylinder pressure (bar)

V = volume (m^3)

K = constant (100… due to unit conversion)

The polytropic coefficient was constant 1.37 for diesel engines. The calculation range is usually between -30…+90 degrees and resolution is 1 degree. In this thesis however, the resolution of 0.5 degrees was used for higher accuracy. (AVL 2003b, 11, 73)

Ignition delays were calculated by using the information from fuel injector needle movement compared to the starting of the first rise in heat releases. To determine the starting of heat release the limiting value of 7.0 kJ/m^3deg was used, i.e. the first time the heat release reached more than 7.0 kJ/m^3deg the ignition was considered to begin. This eliminated the effect of rises in the heat release curve without the actual ignition. In the test runs conducted without the pilot injection the limiting value at some points needed to be set even higher to ensure accurate calculation of ignition delay.

The difference in crank angle values, achieved from this information, was then calculated. This information was then calculated further by using the speed information of the engine to determine the time passed between the starting of injection and starting of ignition.

3.2 Exhaust Gas Recirculation (EGR)

Currently the critical topics in diesel engine emission regulation are nitrous oxide (NO_X) and Particulate Mass (PM) control. An important factor for the manufacturer, as well as the consumer, is also engine specific fuel consumption (SFC). (Kegl et al. 2013, 81)

To reduce NO_X emissions it is important to take measures to prevent them from forming. An effective way to do this is to lower the combustion temperature. A well-known and widely used method is Exhaust Gas Recirculation (EGR). In the EGR system part of the exhaust gas is directed back into the engine by mixing it with the intake air of the engine. The increased heat capacity of the inert exhaust gas lowers the burning temperature in the cylinder. As the peak flame temperatures reduce, less NO_X emissions develop. (Heywood 1988, 102, 591, Mollenhauer et al. 2010, 71-72; Kegl et al. 2013, 81-82)

The EGR systems can be divided into internal and external. In the internal EGR the recirculation is created by altering the timing of the exhaust and intake valves. In the external EGR (eEGR) the exhaust gas is led to the intake manifold via controlling the valve and EGR pipes. In this thesis the focus was on the external EGR system.

The EGR system lowers the NO_X emissions considerably, but in some cases challenges are faced with the increased PM emissions and fuel consumption of the engine. Especially the use of higher rate of EGR at the higher loads can cause problems. The use of EGR slows the combustion and moves the peak of the combustion towards retardation and this can affect the fuel consumption negatively. When the EGR system is used, the exhaust gas replaces some amount of oxygen in the cylinder which leads to the relatively incomplete combustion and rises the formation of PM emissions. (Mollenhauer et al. 2010, 452-453; Kegl et al. 2013, 61-62, 207)

However in some cases, especially at lower loads, the use of the EGR can even improve specific brake consumption and PM emission as the effects of recirculation depend greatly on the characteristics of the basic engine and amount of EGR rates used. (Kegl et al. 2013, 61-62, 208)

Usually EGR systems are used in turbocharged diesel engines. External EGR systems can be divided into several types by the way the exhaust gas is led to the intake air. “High pressure EGR” is when the exhaust gas is taken before the turbine and mixed with the intake air after the intercooler. In this case the turbocharger used is a critical component for producing enough pressure to enable recirculated exhaust gas transport to the intake of the engine. In other words the pressure in the exhaust manifold must be higher than the pressure in the intake manifold. (Mollenhauer et al. 2010, 71-72)

In “low pressure EGR” the exhaust gas is taken after the turbine and possibly after the exhaust gas aftertreatment systems (e.g. Diesel Particulate Filter) and connected with the intake air before the compressor. This system, however, can stress the conventional compressors and intercoolers. In this case the EGR gas flow is enabled by the higher pressure in the engine exhaust pipe than at the compressor inlet. (Kegl et al. 2013, 60)

Both systems require an EGR valve which can be operated electronically, pneumatically or hydraulically, to control the amount of EGR gas flow to the intake air. If the EGR is additionally cooled via an EGR cooler, connected to the engine cooling water circulation, the efficiency of the EGR system rises considerably. The cooling of the recirculated exhaust gas also helps control the rise in the engine fuel consumption caused by the use of the EGR. (Mollenhauer et al. 2010, 71-72)

When using EGR systems the amount of soot in the cylinder can rise. The wear of the piston rings, especially the second, third and oil rings, is often increased. The total wear of various engine components can occur. (Kegl et al. 2013, 62)

The EGR system used in the latter experimental phase described in this thesis was a “high pressure EGR”. The system was equipped with an EGR cooler and the regulation of the EGR ratio was performed by an electronic valve controlled via an engine parameter controlling unit. The position of the EGR valve was determined for each load point separately.

A Testo 350 XL portable gas analyzer was used as an additional analyzer to enable calculating the actual exhaust gas recirculation percent (EGR %). Testo measured the amount of oxygen in the intake manifold and a Servomex Xentra 4900 analyzer was used to measure O_2, CO_2 and CO values from the exhaust pipe. Because the Testo and Servomex analyzers showed slightly different ambient oxygen levels, it was compensated in the EGR % calculation.

The EGR percentage was calculated using the following formula:

$$EGR\,\% = \frac{O_2\,amb.Testo - O_2\,in.manifold.Testo}{O_2\,amb.Servomex - O_2\,exh.gas.Servomex}$$

Explanation of terms:

O_2 amb.Testo = ambient oxygen % with Testo 350 XL portable gas analyzer

O_2 in.manifold.Testo = oxygen % from intake manifold with Testo 350 XL

O_2 amb.Servomex = ambient oxygen % with Servomex Xentra 4900 gas analyzer

O_2 exh.gas.Servomex = oxygen % from exhaust pipe with Servomex Xentra 4900

4 RESEARCH PROGRAM AND FACILITIES

4.1 Internal Combustion Engine Laboratory

The study was performed at the Internal Combustion Engine Laboratory in Turku University of Applied Sciences during the summer of 2014. The research engine was loaded using a Schenck Horiba W 400 eddy-current dynamometer. The controlling of the engine and dynamometer, as well as data logging was conducted by a LabVIEW based program, which used National Instruments PXI system hardware. The main measurement equipment used in this study is shown in Table 4.1.

Table 4.1. Measurement equipment of TUAS Engine Research Laboratory.

Measurement	Instrument
Temperature	Thermocouple K-Type
Pressure	Keller Piezoresistive pressure sensor
Air Flow	ABB Sensyflow FMT-700P
Fuel Mass Flow	Micro Motion CMF025M Coriolis flow meter
Smoke (FSN)	AVL 415 S
Particle Sensor	Pegasor PPS-M
Nitrous Oxide (NO_X)	Eco Physics CLD 700EI ht
Nitrocarbons (HC)	CAI HFID 300
Carbon Monoxide (CO), Carbon Dioxide (CO_2) and Oxygen (O_2)	Servomex Xentra 4900
Oxygen for EGR % calc.	Testo 350 XL

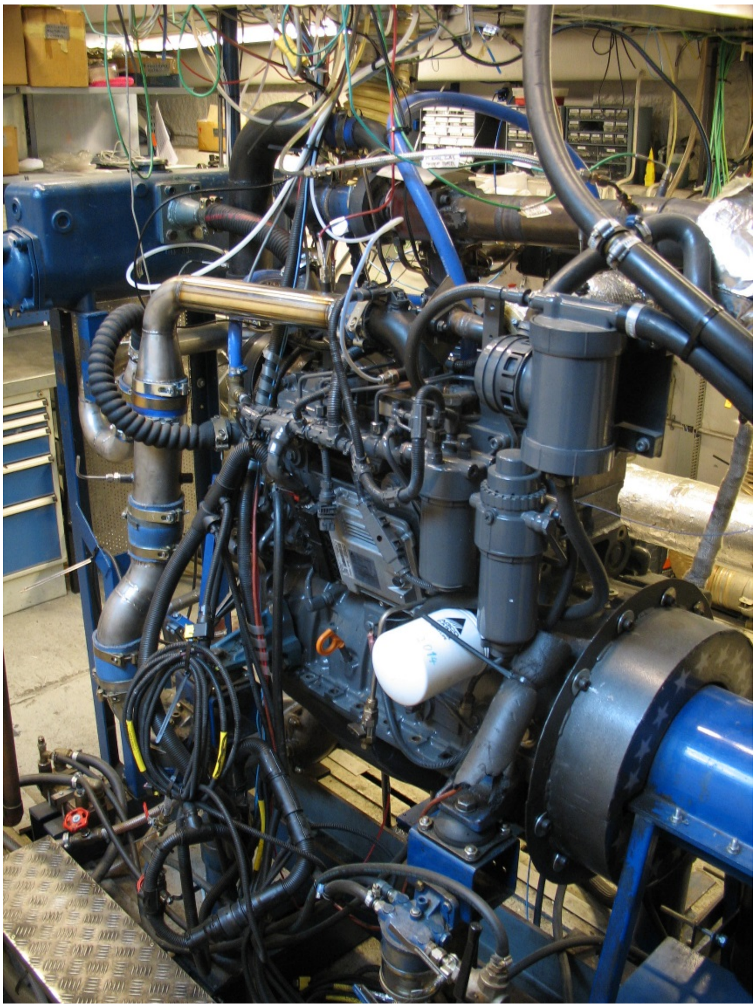
For measuring the cylinder pressure an AVL GU 22C cylinder pressure sensor was used along with an AVL IndiSet 642 indicating system. The results were analyzed with AVL IndiCom v2.3 combustion analysis software. With this equipment the cylinder pressure results were collected at 0.5 crank angle degree interval. The results were calculated from one work cycle of the engine.

The cylinder pressure measurements, as well as engine smoke measurements with an AVL 415 S sensor cold be performed only at steady state load points.

The software that enabled the adjustment of engine fuel injection parameters was provided by the engine manufacturer.

4.2 Research Engine

AGCO Power 44 AWI diesel engine was used as a research engine in this study, Picture 4.1.



Picture 4.1. AGCO Power 44 AWI research engine.

The engine has 4 cylinders with a displacement of 4.4 liters. The engine is turbocharged, intercooled, and intended for off-road use. The engine has a common rail fuel injection system, and is equipped with 4-valve cylinder head.

The engine in the standard form was designed to meet Stage 3B emission requirements. The specifications of the engine are shown in Table 4.2.

Table 4.2. Specifications of the research engine.

Engine	Agco Power
Type	44 AWI
Cylinder order	In-line 4 cyl.
Emission level	Stage 3B
Bore	108 mm
Stroke	120 mm
Displacement	4.4 dm^3
Fuel injection	Bosch Common Rail
Rated Power / Speed	99 kW / 2200 rpm
Maximum Torque / Speed	572 Nm/ 1500 rpm

The intercooler used in this study was equipped with an external water circulation, which had a valve controlled by an engine management program. The water flow was regulated so that the air temperature after the intercooler was constant during different measurements. Exhaust backpressure, intercooler backpressure and intake air pressure loss were all possible to adjust manually to a desired level.

In the second part of the study the engine was equipped with an external Exhaust Gas Recirculation system (eEGR). The amount of recirculation was adjusted by an EGR valve controlled with the engine's manufacturer software.

The common rail system of the engine was able to produce up to 1600 bar of fuel injection pressure. It was possible to use up to five different injections during one working cycle of the engine. The injection cycles are shown in Figure 4.1.

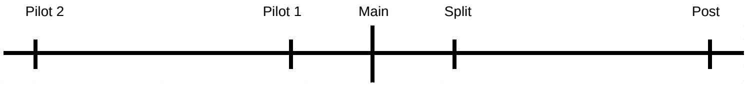


Figure 4.1. Separate injections of the common rail fuel injection system.

4.3 Fuels

In this study the total of three different fuels was used. For reference purposes normal summer grade diesel fuel oil was used (DFO DIF -5/15). The research fuels were Neste Oil’s NExBTL (100 %) and a mixture of NExBTL and normal summer grade diesel oil (50-50 % mix). The basic characteristics of the research fuels are presented in Table 4.3. More specific characteristics are shown in the appendix 1. All fuels were provided by Neste Oil.

Table 4.3. Characteristics of research fuels.

Fuel	Density kg/m^3	Net Heating Value MJ/kg	Cetane number
DFO (DIR -5/15)	837.4	42.956	53.2
NExBTL (100 %)	779.7	43.855	74.0
50-50 % -mix	808.6	43.448	63.3

As Table 4.3 shows NExBTL has quite high cetane number compared to the ordinary diesel fuel oil. The cetane number of the 50-50 % mix is quite close in the middle point of the fuels used for the blend.

The density of NExBTL is lower than the density of DFO. The density of the fuel mix is exactly in the middle point of DFO and NExBTL.

Research fuels were stored inside a container outside the laboratory. Each of the fuels were in their own 400 liter tank. The fuels were pumped from the storing tanks into a smaller tank inside the laboratory from where they were directed through a fuel flow meter into the engine. The laboratory tank was washed before another fuel was pumped into it.

The reference Diesel Fuel Oil was only used for reference purposes in steady state and transient measurements. All other research tests were performed using NExBTL or 50-50 % mix fuels.

4.4 Steady State Load Points and Transient Cycle

Six different steady state load points were used during the first part of the study. In the last part of the study a transient cycle was also used for research purposes of the engine. Steady state load points (marked with red color and named P1-P6), as well as the torque curve of the engine are presented in Table 4.4 and Figure 4.2.

Table 4.4. Six steady state load points.

Load point	Engine Speed (rpm)	Load (%)	Engine Torque (Nm)
1	1500	100	572
2	1300	75	417
3	1800	75	402
4	2200	50	215
5	1800	25	134
6	1300	25	139

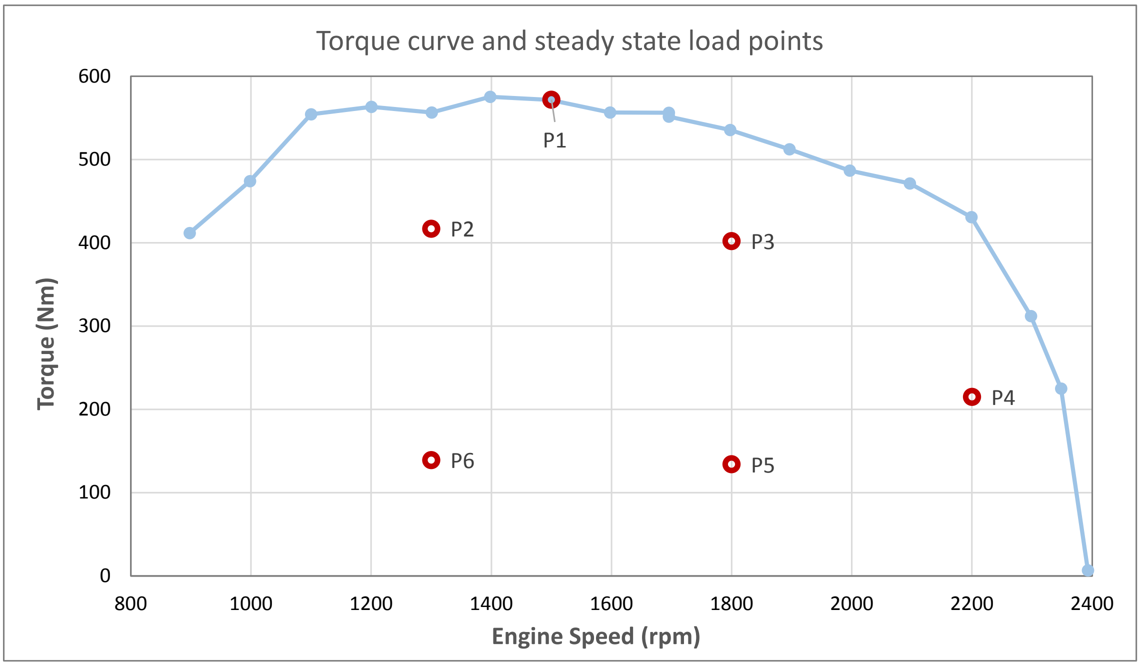


Figure 4.2. Steady state load points and torque curve of the research engine.

In the latter part of the study a nearly 16 minute transient cycle was also used. The transient cycle was run automatically via the engine and brake controlling program. During the transient cycle runs the eEGR system was disabled. The engine torque and speed profile of the transient cycle is shown in Figure 4.3.

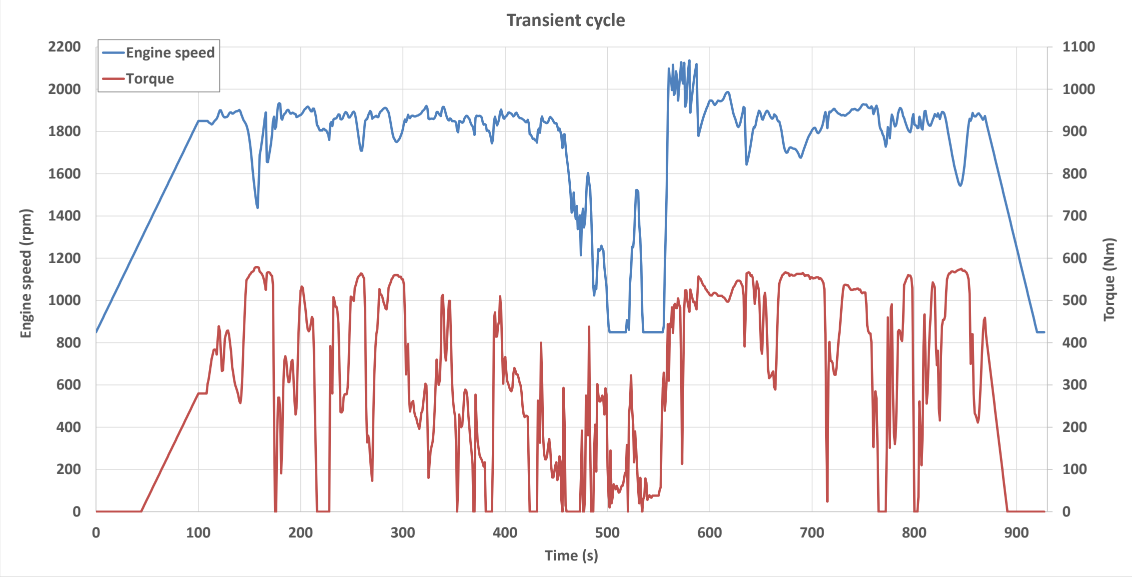


Figure 4.3. Engine torque and speed profile of the transient cycle.

4.5 Test Procedure

Before the beginning of each measurement the engine was warmed up. The oil and water temperature of the engine were above 80 °C before starting the measurements. The intake manifold temperature, exhaust back pressure, intercooler backpressure and intake air pressure lost were adjusted to constant values as precisely as possible at load point 1 (1500 rpm/572 Nm). The target values for these adjustments are shown in Table 4.5.

Table 4.5. Target values for adjustments at load point 1.

Intake manifold temperature	°C	47
Exhaust backpressure	mbar	150
Intercooler backpressure	mbar	50
Intake air pressure loss	mbar	20

In steady state measurements the engine was stabilized for the minimum of five minutes. After the engine was stabilized the measured values were collected with an engine data acquisition program, usually with a 60 second averaging. After the test runs were performed the engine was cooled down before shutoff.

In the transient cycle studies the engine was first warmed up. After this the engine control program was set to perform the transient cycle with a desired engine speed and torque values. The values were adjusted at a 1 second interval. The results were recorded automatically to a data acquisition program, from where they were acquired and processed further.

The cylinder pressure values and Filter Smoke Number values could not be recorded during the transient cycle measurements.

4.6 Research Program

The basic assumption for the study was that the use of pure NExBTL and 50-50 % mix would lower the NO_X emissions significantly and bringing NO_X back up to levels of DFO by optimizing fuel injection parameters would result in advantages in the fuel consumption.

The studies were started by performing reference test runs using normal diesel fuel oil (DFO). After this reference test runs with each research fuel were performed (NExBTL and 50-50 % mix). In these runs the fuel injection parameters of the engine were kept standard.

Next, the target was to perform the optimization of the engine fuel injection parameters. For this purpose the fuel injection parameter tabulation was performed with NExBTL fuel. The actual fuel injection parameter optimization was performed based on the tabulation using NExBTL and 50-50 % mix fuels. The following injection parameters were altered during the fuel injection parameter optimization: Main injection advance (Main 1), Common rail pressure, Pilot 1 injection advance, Pilot 1 injection quantity and disabling of Pilot 1 injection.

The steps for the optimization of each fuel injection parameter were determined by tabulation so that the NO_X result with the research fuels would not rise past the reference NO_X result with the diesel fuel oil. This resulted in the changes to be quite conservative.

In the second phase of the study the engine was equipped with an external Exhaust Gas Recirculation (eEGR). The tabulation for the basis of EGR tests was performed with the 50-50 % mix fuel. Two different EGR rates were chosen for the test runs performed with both research fuels. In the first option the EGR rates were lower than in the second option. After this the fuel injection parameters of the engine were optimized using smaller EGR rates.

In the last part of the steady state test runs, the check for reference values was performed with each fuel.

In the final part of this study transient tests were performed with DFO, NExBTL and 50-50 % mix fuel. In the transient cycle runs the EGR was disabled.

The research program is presented in Table 4.6 below.

Table 4.6. Experimental research program.

Test	**Fuel**	**Mode**
Reference	DFO, NExBTL, 50-50 % -mix	Steady-state
Tabulation of fuel injection parameters	NExBTL	Steady-state
Optimization of fuel injection parameters:	NExBTL, 50-50 % -mix	
* Main 1 advance + 1 °		
* Rail pressure + 10 Mpa		
* Pilot 1 advance 500 µs		
* Pilot 1 quantity 3 mg		
* Pilot 1 injection disabled		
* Main 1 advance - 1 °	50-50 % -mix	Steady-state
Tabulation of EGR-values		
EGR-tests:	NExBTL, 50-50 % -mix	
* EGR valve positions: 0-0-5-10-15-15 %		
* EGR valve positions: 0-5-10-15-20-20 %		
* EGR valve optimization (0-0-5-10-15-15 %)		
Checkup of reference	DFO, NExBTL, 50-50 % -mix	Steady-state
Transient tests	DFO, NExBTL, 50-50 % -mix	Transient

5 RESEARCH RESULTS OF FUEL INJECTION OPTIMIZATION

5.1 Reference Results

At first the engine was run using the three different fuels without any alternation to the fuel injection parameters. The objective was to determine the differences between the ordinary diesel fuel oil (DFO) compared to the two research fuels: pure NExBTL and 50 % - 50 % mixture of NExBTL and diesel fuel oil (50-50 % mix). These were also the reference results for all fuels.

5.1.1 Gaseous Emissions, Smoke, Fuel Consumption and Efficiency

The assumption was that the use of the research fuels would decrease the NO_X results significantly, and by performing fuel parameter optimization, the NO_X would be brought back to the base level of DFO and this would result in fuel consumption gains.

However, in this research the measured NO_X was quite similar while using different fuels. The 50-50 % mix produced the lowest NO_X results, between 1.9 (P2) and 6.7 % (P1) lower than that of DFO. Results of the nitrogen oxides with NExBTL were generally quite close to those measured with DFO, the biggest advance for NExBTL was 2.3 % in load point 5. This resulted in situation where there was not a lot of possibilities to optimize the fuel consumption, because the NO_X could not rise past the levels measured with the DFO.

In nearly all load points, the smoke of the engine was lowest when using 100 % NExBTL. Lack of aromatics in NExBTL causes smoke of pure NExBTL and 50-50 % fuel mix to be lower than DFO. (Sugiyama et al. 2011, 2)

In all load points, except load point 2, smoke numbers of NExBTL were between 30 (P6) and 50 % (P4) smaller than those of DFO. Smoke results with 50-50 % mix were also lower than those of DFO in nearly all load points. The greatest differences in smoke, in the favor of the research fuels, were measured at lower engine loads. Overall the smoke number results were quite low, and slight changes in the smoke number resulted in big differences in percentages.

The volumetric fuel flow was highest when using NExBTL, and lowest when using standard diesel. The results with DFO were 4.2-5.2 % lower than those of NExBTL. The results of 50-50 % mix were in between of these results. The results of diesel were 2.3-3.9 % lower than those of mixed fuel.

The lower volumetric heating value, due to the lower density of NExBTL and 50-50 % mix explains this trend. The density of NExBTL is about 7 % lower than the density of DFO and the density of 50-50 % mix is about 4 % lower than density of DFO. When inspecting specific fuel consumption (g/kWh) results, it was seen that engine used 1.2-2.4 % less NExBTL than DFO. On the contrary SFC results with 50-50 % mix were quite similar to those measured with DFO.

The efficiency of the engine was quite similar with DFO and NExBTL, but especially at higher loads using 50-50 % mix fuel resulted in slightly lower efficiency.

5.1.2 Cylinder Pressure

When examining the cylinder pressure results, it was seen that the differences in cylinder pressures were quite small. The biggest differences in the cylinder pressure, heat release and cumulative heat release results were seen at the lower loads, for this purpose results from load point 6 (1300 rpm/139 Nm) are shown from the reference test runs.

In the Figure 5.1 cylinder pressure results from load point 6 are presented. It can be seen that the 50-50 % mix resulted in slightly lower maximum curve at crank angles -20°…+20°.

Overall the highest cylinder maximum pressures were measured with DFO. Similar results were reported in Master Thesis by Michaela Hissa in University of

Vaasa 2014, where results from the engine runs with DFO, HVO and several other biofuels were examined. (Hissa 2014, 41, 46, 131)

The fuel injection parameters are shown in the left upper corner of the following figures.

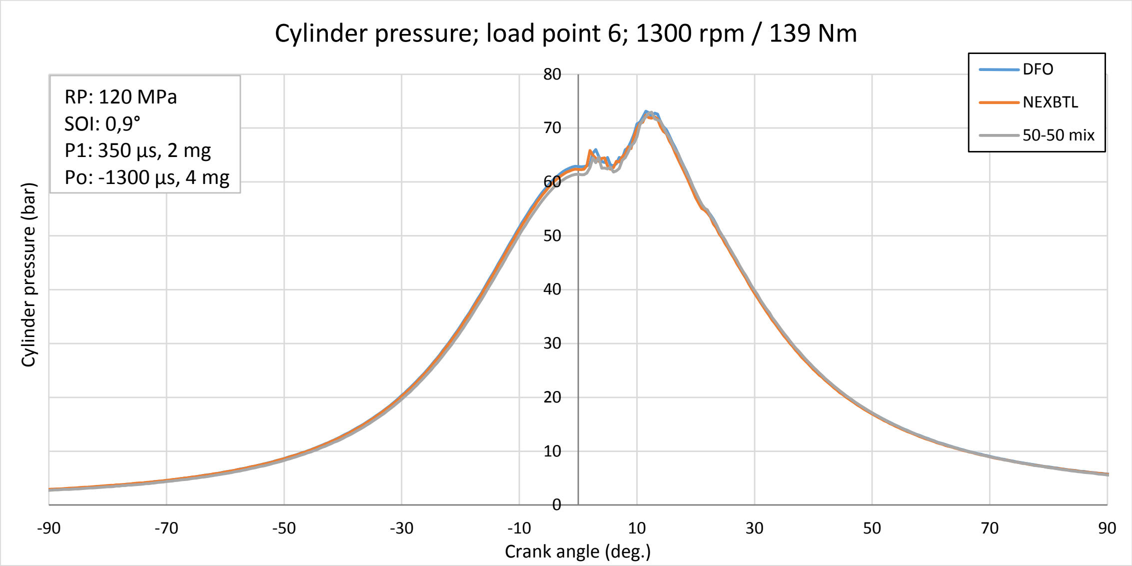


Figure 5.1. Cylinder pressure at load point 6.

5.1.3 Heat Release

The results of heat release from load point 6 are presented in Figure 5.2. In the picture the movement of the fuel injector needle is also seen. It can be seen that in this load point three separate injections were in use.

The results from the cylinder pressure measurements were at a 0.5 degree interval. Because all three fuels are after all quite close to each other in qualities, it is quite challenging to discover the differences in ignition delays.

Figure 5.2 shows that NExBTL seems to produce faster maximum peak of heat release from Pilot 1 ignition. The ignition delays for NExBTL and 50-50 % mix were 577 µs and for DFO 641 µs, the difference being only 0.5 degrees of crank angle. This is quite normal ignition delay for diesel engine, as it may vary between 300 and 800 µs (Mollenhauer et al. 2010, 67).

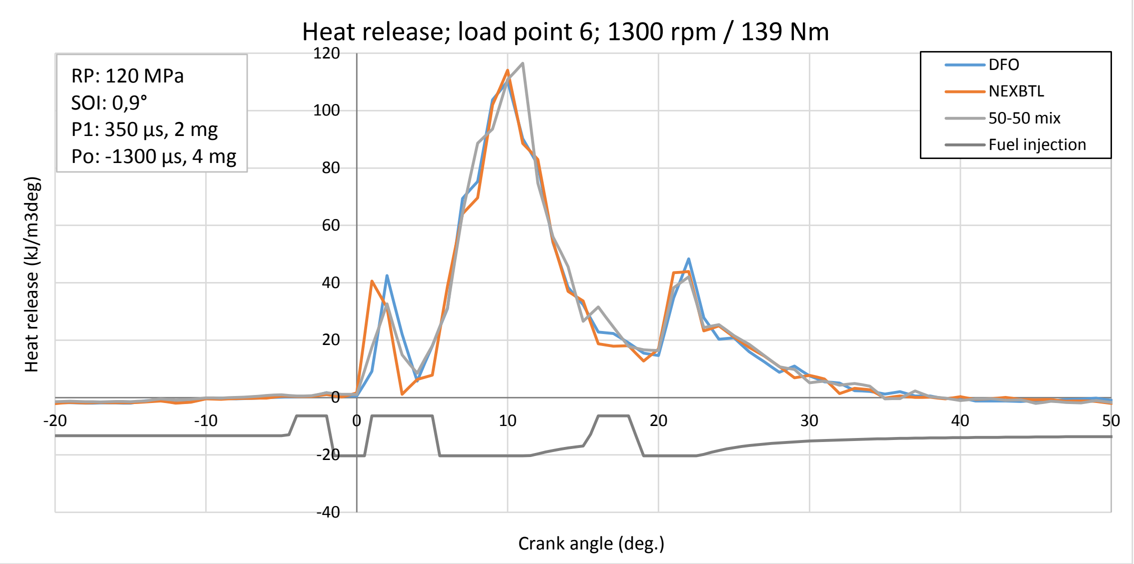


Figure 5.2. Heat release and injections in load point 6.

The maximum heat release was recorded with 50-50 % mix, slightly later than with other fuels, Figure 5.2. The maximum heat releases of DFO and NExBTL were quite similar to each other. Heat releases caused by post injection were quite equal with all three fuels.

Close to the starting of the ignition heat release and cumulative heat release curves dips into negative values, because of the injection of the fuel to the cylinder, Figures 5.2 and 5.3. The heat is committed to vaporization of the fuel and rise of cylinder pressure. (AVL 2003b, 66; Hissa 2014, 41)

In load points 3, 4 and 5 was seen that Pilot 1 injection resulted in several heat release peaks with all fuels. Most clearly the effect was visible in load point 5, where it can be seen that heat release curves even dips into negative range for DFO and NExBTL fuels, Figure 5.3. Overall the heat release curves were very unstable in these load points.

One explanation for this phenomenon can be that the cylinder pressure is measured from the hole made in cylinder head, which forms a slight pothole when the sensor is in place. This might result in irregularity in the cylinder pressure at the sensor at certain engine speeds and loads.

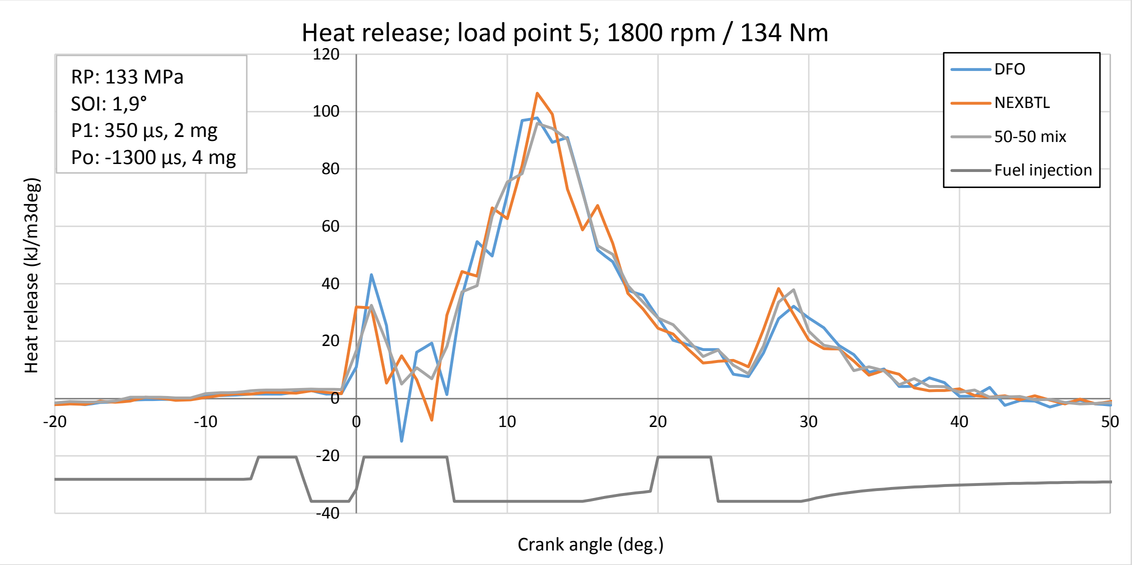


Figure 5.3. Heat release in load point 5.

5.1.4 Cumulative Heat Release

In the Figure 5.4 cumulative heat release in load point 6 is presented. Figure shows that the curves are quite similar until crank angle 10 degrees which is close to where the main injection heat release reaches its maximum. After this the cumulative heat release curve of the 50-50 % mix separates itself from the others to reach higher values. Similar trend was seen in all low load points at a different engine speeds (load points 4, 5 and 6).

The maximum value of cumulative heat release with 50-50 % mix in load point 6 (1115 kJ/m^3) was 4 % higher than that of DFO (1071 kJ/m^3). In five of six load points the fuel blend produced highest cumulative heat releases, with maximum difference to DFO 4.5 % in load point 4.

NExBTL resulted in lowest cumulative heat releases in all six load points. The greatest difference to those of DFO was 2 % in load point 6 (1051 kJ/m^3 vs 1071 kJ/m^3).

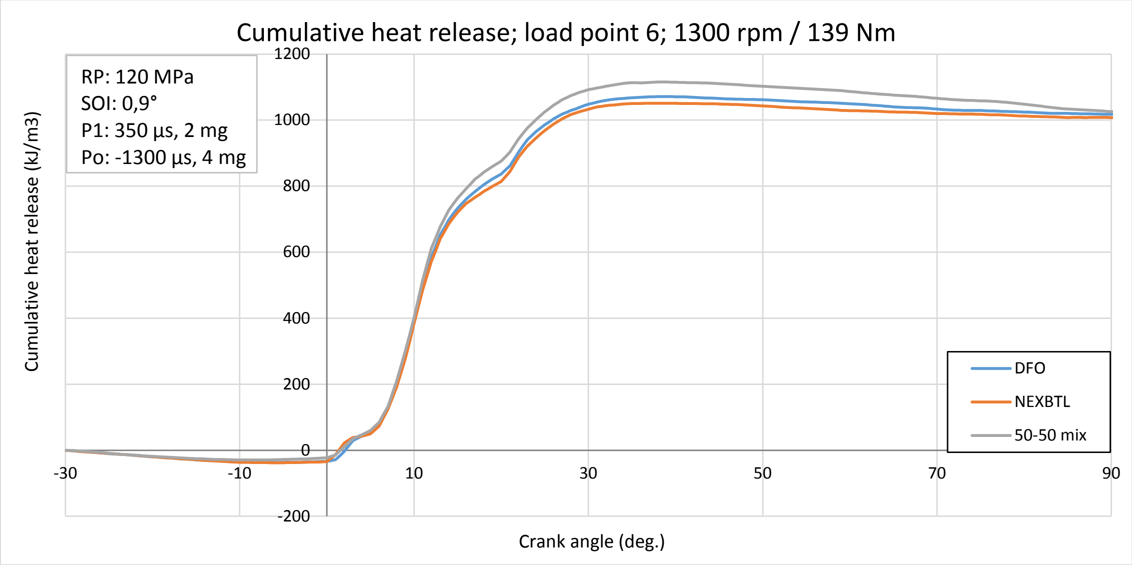


Figure 5.4. Cumulative heat release in load point 6.

5.1.5 Ignition Delay

The calculated fuel ignition delays are shown in Table 5.1. Because the interval of the data was 0.5 crank angle degrees, it is difficult to see great differences in ignition delays. As it can be seen from the table the ignition delays of DFO in load points 1, 5 and 6 are slightly longer than for the two research fuels. The difference is only 0.5 degrees of crank angle. However, this is quite logical as NExBTL and 50-50 % mix have higher octane number than standard DFO and thus ignites faster (Mollenhauer et al. 2010, 66).

Table 5.1. Calculated ignition delays in reference measurements.

	Ignition delay µs		
Test point	Fuel		
	DFO	NExBTL	50-50 %-mix
1	500.0	444.4	444.4
2	448.7	448.7	448.7
3	509.3	509.3	509.3
4	530.3	530.3	530.3
5	601.9	555.6	555.6
6	641.0	576.9	576.9

5.2 Main Injection Advance

Next, the advance of Main fuel injection was increased by one degree (+1°). This meant that the fuel was injected one degree of crank angle earlier to the engine than in the reference test runs. Other fuel injection parameters were kept constant at a reference level. However, because Pilot 1 and Post injection timings are in relation to Main injection, each injection started at a different crank angle degree than in the previous tests. The distances between each injection were kept same as in the reference tests. These test runs were performed only with NExBTL and 50-50 % mix research fuels.

5.2.1 Gaseous Emissions, Smoke, Fuel Consumption and Efficiency

Advancing the main injection timing by one crank angle degree increased NO_X results with the both research fuels from the reference levels. With NExBTL the values increased 1.7-8.2 %, when compared to the reference. The greatest change was recorded in load point 4. Runs performed with the fuel mix 50-50 % resulted in 3.0-6.5 % higher NO_X than the reference results for this fuel, with the biggest change in load point 6. Comparing the two research fuels to each other showed, that 50-50 % mix fuel produced lower nitrous oxide results than pure NExBTL. The nitrous oxide results of NExBTL were 1.7-5.4 % greater than those of 50-50 % mix, and the greatest difference was measured in load point 4.

Results for the exhaust smoke measured with optical meter were smaller with NExBTL, when compared to 50-50 % mix in these test runs. The results with pure NExBTL were about 20-40 % lower than those of the fuel blend. Comparing smoke results for both fuels to each fuel own reference, the tendency for slight decrease was seen in most load points.

Overall the smoke results were quite low and it was quite difficult to calculate precise percentages of changes, as changes of one decimal cause big difference in percentages.

The volumetric fuel consumption was lower when using fuel blend 50-50 % than NExBTL. The consumption was 1.9-3.5 % lower, with greatest difference in load point 6. Specific fuel consumption results (g/kWh) shows that the engine used between 0.3 and 1.5 % more 50-50 % fuel mix than NExBTL in all load points except point 6. This tendency is logical as the density of NExBTL is lower than density of fuel blend by 4 %. The fuel consumption results for both tested fuels were quite close to the base reference levels as the maximum differences were about 1 % for volumetric fuel consumption and SFC results.

The calculated efficiency of the engine was virtually same for the both research fuels. In load point 6 the efficiency of 50-50 % mix was 1.6 % higher than pure NExBTL. Comparing the results from test runs with altered Main injection timing to the reference results showed, that the efficiency of the engine was virtually same with both fuels as the differences at the greatest were about 1 %.

Out of the all fuel injection parameter changes this change was optimal for 50-50 % mix fuel. The NO_X results increased to the same level as with DFO without parameter changes. SFC and efficiency of the engine were slightly better than the base levels for 50-50 % mix fuel.

5.2.2 Cylinder Pressure

In the following figures the in-cylinder data is compared between the two research fuels NExBTL and 50-50 % mix. The fuel injection parameters are displayed in the left upper corner of the figures, and changed parameter is displayed in red color.

Advancing the Main injection did not have a great effect on the differences in cylinder pressures between two research fuels. The greatest differences were found in load points 1 and 2. The cylinder pressure results from load point 1 are presented in Figure 5.5. It can be seen that the 50-50 % mix produces a slightly higher maximum cylinder pressure of 136 bar, while the maximum cylinder pressure of NExBTL is 134 bar. The pressure curve of the fuel blend also stays longer at a higher level than that of NExBTL after the maximum pressure is reached.

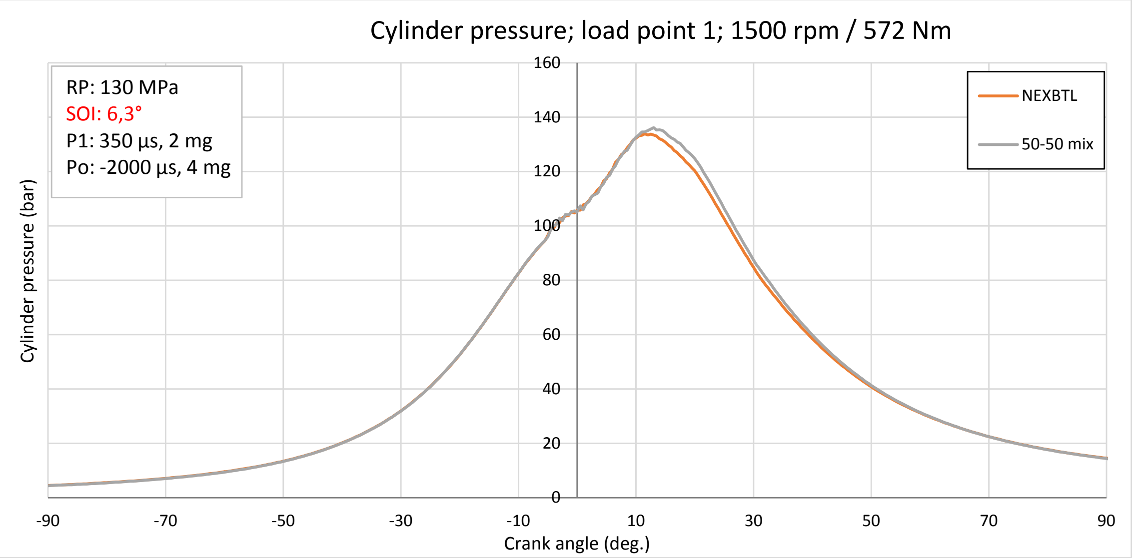


Figure 5.5. Cylinder pressure at load point 1, Main injection advance change +1°.

Advancing the start of the main injection produced higher cylinder pressure peaks than the reference results for each fuel. This was seen clearest at the higher loads (P1-P3).

5.2.3 Heat Release

Heat release curves were quite similar with the both fuels researched, except for load point 1, where the 50-50 % mix produced higher heat release between 8…23 degrees of crank angle, Figure 5.6.

The peak value of heat release was 5.4 % higher with 50-50 % mix fuel than that of NExBTL. Fuel blend produced also higher peak value of Pilot 1 heat release, although it can be seen that the ignition delay of 50-50 % mix was slightly longer than that of NExBTL, Figure 5.6.

In the load points 3, 4 and 5 the Pilot 1 injection resulted in several heat release peaks. Similarly to the reference test run results, the heat release curves in these load points were quite unstable.

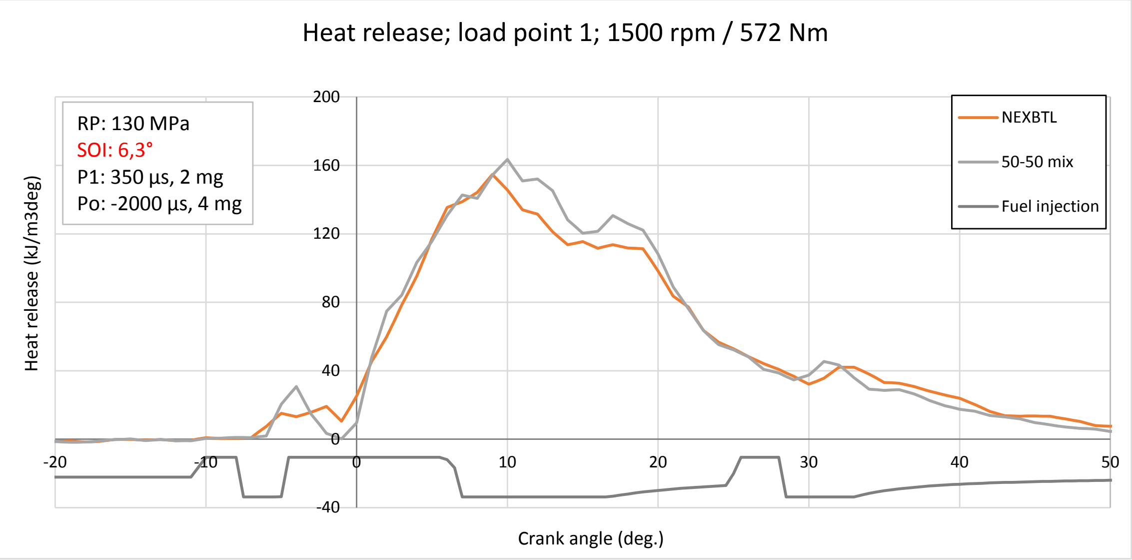


Figure 5.6. Heat release at load point 1, Main injection advance change +1°.

5.2.4 Cumulative heat release

As indicated in previous figures, the cumulative heat release of blended 50-50 % mix fuel was higher than that of NExBTL between 10 and 90 degrees of crank angle, Figure 5.7.

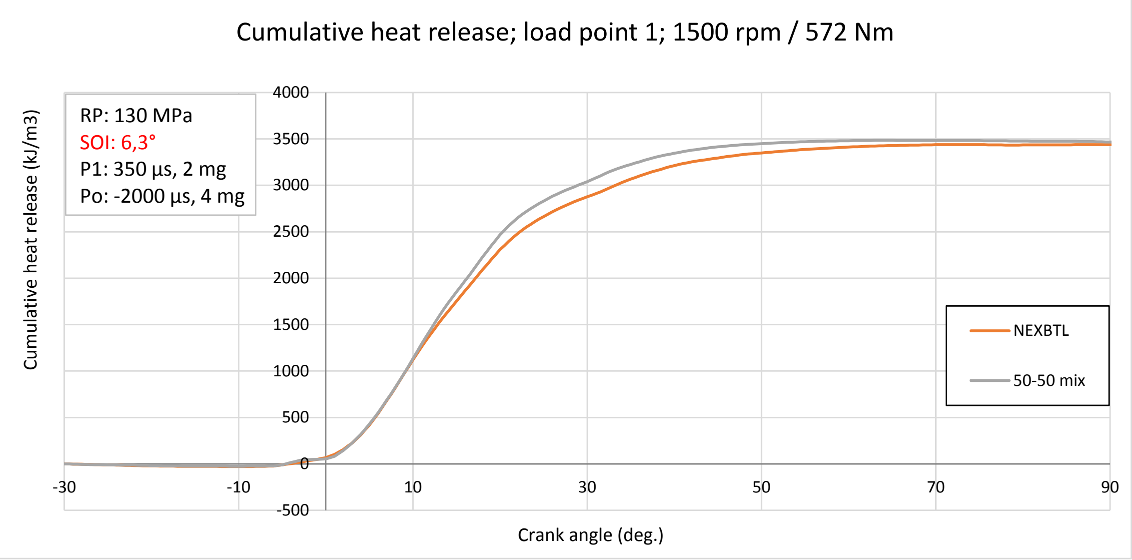


Figure 5.7. Cumulative heat release at load point 1, Main injection advance change +1°.

In these test runs the 50-50 % mix produced generally higher cumulative heat releases in all test point, except load point 2, where heat releases were quite similar, and NExBTL produced momentarily slightly higher results for some degrees of crank angle.

5.2.5 Ignition Delay

The ignition delays for NExBTL in these test runs were same as in the reference tests, despite alternation of the fuel injection advance. In two load points, 1 and 5, the ignition delay of 50-50 % mix was longer by approximately 50 µs, Table 5.2. This is still quite logical as the cetane number for the NExBTL is higher than cetane number of the fuel mix.

Table 5.2. Ignition delays, Main injection advance change +1°.

	Ignition delay µs						
	Fuel						
Test point	NExBTL: M1 Adv: +1 deg.	50-50 % -mix, M1 Adv: +1	diff. 50-50 % -mix-NExBTL	Ref. NExBTL	Ref. 50-50 % -mix	diff. NExBTL: test-ref.	diff. 50-50 %-mix: test-ref.
1	444.4	500.0	55.6	444.4	444.4	0.0	55.6
2	448.7	448.7	0.0	448.7	448.7	0.0	0.0
3	509.3	509.3	0.0	509.3	509.3	0.0	0.0
4	530.3	530.3	0.0	530.3	530.3	0.0	0.0
5	555.6	601.9	46.3	555.6	555.6	0.0	46.3
6	576.9	576.9	0.0	576.9	576.9	0.0	0.0

5.3 Common Rail Pressure

Next the common rail pressure was increased by 10 MPa from base level in each load point. All other fuel injection parameters were kept same as in the reference test runs. The test runs were performed with NExBTL and 50-50 % mix fuels.

5.3.1 Gaseous Emissions, Smoke, Fuel Consumption and Efficiency

The use of fuel blend 50-50 produced 1.4-6.8 % lower nitrous oxide results than use of pure NExBTL. The biggest difference was seen in load point 4. Comparing NO_X results to the reference results for both fuels it was seen, that rising the common rail pressure resulted in increased NO_X results in nearly all load points. For NExBTL nitrous oxide results were about 5 % higher at a maximum, in load points 3 and 5. For 50-50 % mix the NO_X results were approximately 4 % higher at a maximum in load point 6, but about 4 % lower in load point 4.

The smoke results of NExBTL were 10 to 40 % lower than those of blended fuel. When compared to its reference results, the smoke of NExBTL was quite similar, although in load point 2 smoke number was half of the reference result. The smoke of 50-50 % mix fuel was lower than the reference in all load points except load point 4, where it was identical to the reference. Overall the smoke numbers were quite small.

Measured volumetric fuel consumption was 1.2-2.5 % smaller for 50-50 % mix than for pure NExBTL, with the biggest difference in load point 2. SFC again was lower for NExBTL than for fuel blend by 0.8-1.8 %, with maximum difference in load point 6.

SFC and volumetric fuel consumption results for both NExBTL and 50-50 mix, were inside 1 % of the respective reference values, except in load point 6, where these test runs produced about 2 % lower results than the reference.

Efficiencies of the engine calculated from the results of these test runs were quite close for both measured fuels. In majority of the load points NExBTL produced slightly better efficiency than 50-50 % mix, with the differences in values less than 1 %. Comparing the efficiency of this NExBTL run to the reference result, it was seen that the differences were inside 1 %, except load point 6, where the value was 2.1 % higher than in the reference runs. Similar results were acquired using 50-50 % mix fuel, with only difference in load point 6, where 1.7 % higher efficiency was measured than in the reference test run.

5.3.2 Cylinder Pressure

Raised common rail pressure did not make great differences in the cylinder pressure curves for NExBTL and 50-50 % mix fuels when compared to each other. The differences in the maximum cylinder pressures for the two research fuels were 1.2 % at largest, Figure 5.8.

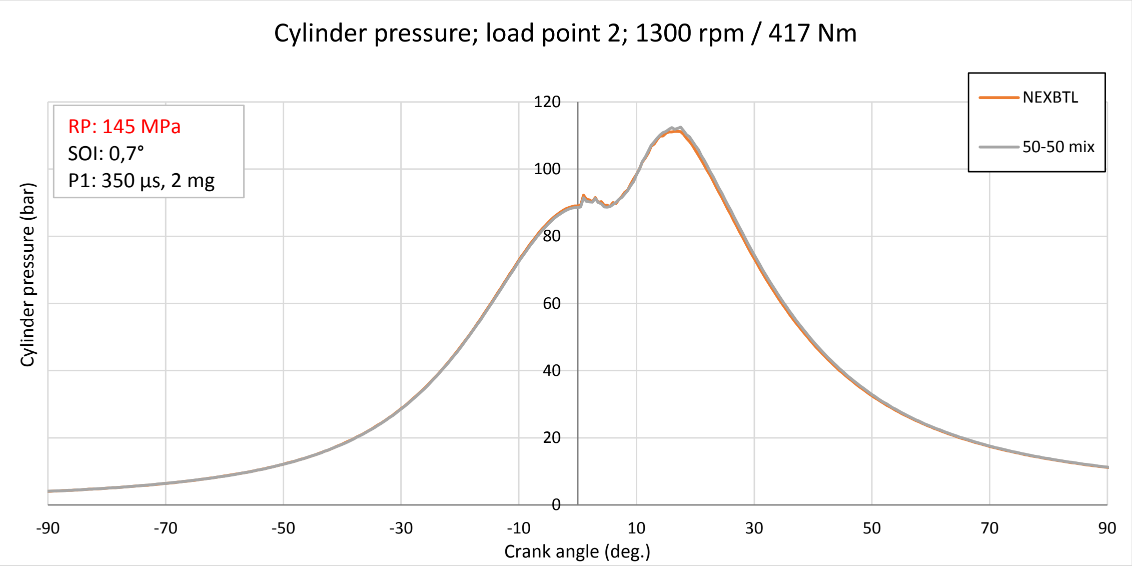


Figure 5.8. Cylinder pressure with raised common rail pressure in load point 2 (+10 MPa).

Increasing the fuel rail pressure by 10 MPa resulted in the slightly higher cylinder pressure results at higher loads (P1-P3) for both fuels, when compared to the reference results of each fuel.

5.3.3 Heat Release

Test runs performed with the increased common rail pressure did not produce significant differences between the two fuels in heat release curves. In load points 1 and 2 50-50 % mix produced slightly higher heat releases than NExBTL. In the rest of load points NExBTL produced higher maximum heat releases, Figure 5.9. The differences in the maximum heat release peaks were not significant, at the highest 9 % in load point 4. In load points 5 and 6 it was possible to see that NExBTL produced peak of Pilot 1 heat release earlier, Figure 5.9.

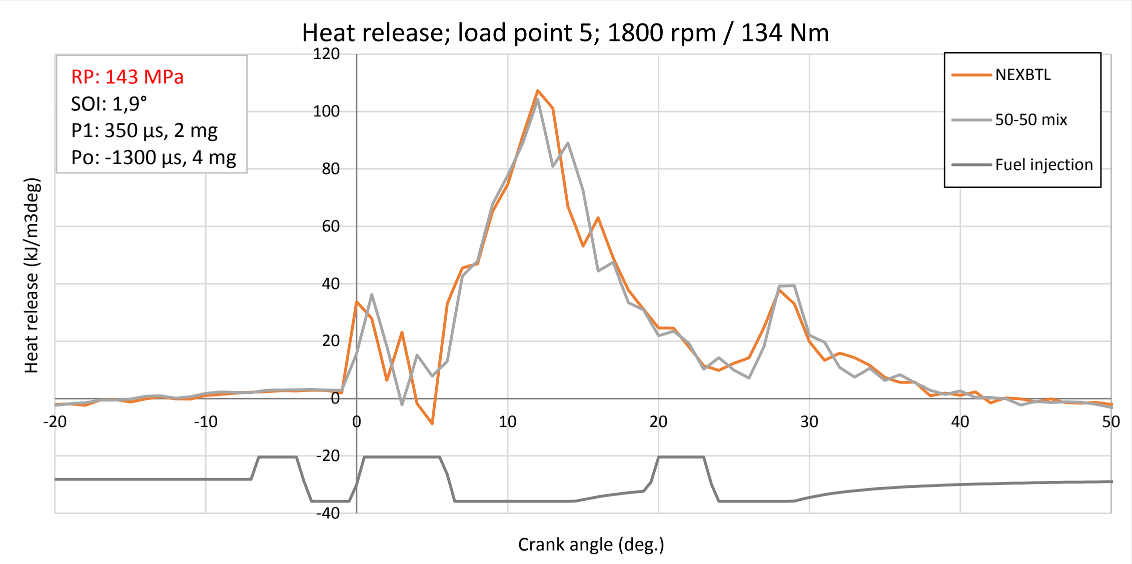


Figure 5.9. Heat release with raised common rail pressure in load point 5 (+10 MPa).

In load points 2, 3, 4 and 5 the Pilot 1 injection produced several heat release peaks. Figure 5.9 shows that heat release dips into negative range also after the Pilot 1 injection peak. Overall the heat release curves in load points 3, 4 and 5 were quite unstable for both tested fuels.

5.3.4 Cumulative Heat Release

Rising the common rail pressure did not produce significant differences in cumulative heat releases between NExBTL and 50-50 % mix. The greatest differences were seen in load point 2, Figure 5.10. In this load point the maximum of cumulative heat release of fuel blend was about 2.3 % higher than that of NExBTL.

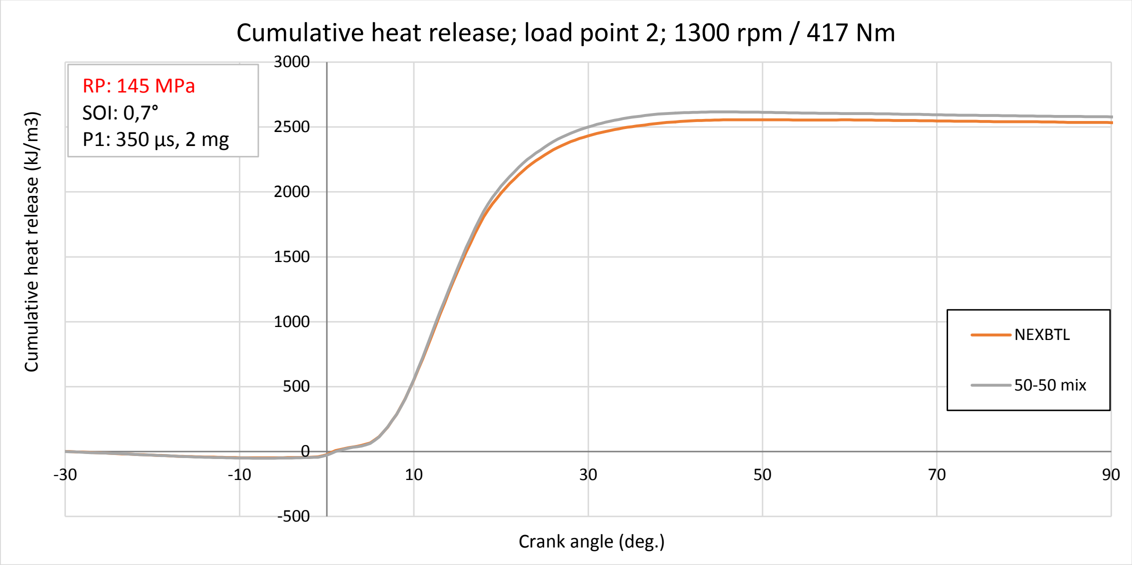


Figure 5.10. Cumulative heat release with raised common rail pressure in load point 2 (+10 MPa).

5.3.5 Ignition Delay

Ignition delays for these test runs can be seen in Table 5.3. As table shows the only difference noticed was that the ignition delay in load point 1 was shorter for NExBTL than for the 50-50 % fuel mixture. In this load point the ignition delay was also shorter than in the reference tests for NExBTL. The difference however, was only 0.5 degrees of crank angle, which was the minimum resolution for this measurement.

Table 5.3. Ignition delay in test runs with raised common rail pressure (+10 MPa).

	Ignition delay µs						
	Fuel						
Test point	NExBTL, RP: + 10 Mpa	50-50 %-mix, RP: +10 Mpa	diff. 50-50 % -mix-NExBTL	Ref. NExBTL	Ref. 50-50 % -mix	diff. NExBTL: test-ref.	diff. 50-50 %-mix: test-ref.
1	388.9	444.4	55.6	444.4	444.4	-55.6	0.0
2	448.7	448.7	0.0	448.7	448.7	0.0	0.0
3	509.3	509.3	0.0	509.3	509.3	0.0	0.0
4	530.3	530.3	0.0	530.3	530.3	0.0	0.0
5	555.6	555.6	0.0	555.6	555.6	0.0	0.0
6	576.9	576.9	0.0	576.9	576.9	0.0	0.0

5.4 Pilot Injection Advance

For the following test runs the Pilot 1 injection timing was changed from 350 microseconds to 500 microseconds. It meant that the Pilot 1 injection was farther (earlier) from the Main injection. The number indicates the time difference between the end of Pilot 1 injection and start of Main injection. All other fuel injection parameters were kept same as in the reference test runs.

5.4.1 Gaseous Emissions, Smoke, Fuel Consumption and Efficiency

Comparing the nitrous oxide results with the both research fuels in tests performed with advanced pilot injection showed that 50-50 % mix fuel produced 3.1-5.4 % lower results than NExBTL in all load points. The biggest difference was in load point 2. Compared to the reference results NExBTL produced higher NO_X in all load points except load points 1 and 6. The differences were however quite small, 1.5 % at a maximum in load point 1. Fuel blend of 50-50 % produced lower nitrous oxide results in all load points except load point 1, where NO_X was 1.1 % higher than the reference result. In other load points (2-6) the NO_X for 50-50 % mix was 1.4 to 2.5 % smaller than the reference results, with the greatest difference in load point 5.

Similarly to the previous results, lower smoke numbers were recorded with NExBTL. The results in these test runs were about 30-50 % lower for NExBTL than for 50-50 % mix. Overall the smoke numbers were quite low.

Specific fuel consumption figures were 1.8-2.3 % smaller for NExBTL than for 50-50 % mix. Volumetric fuel consumption on the contrary was 0.7-1.7 % lower for fuel mix than for NExBTL. Comparing fuel consumptions to the reference results for each fuel showed no significant changes, as the numbers were within about 1 % of each reference results.

The calculated efficiency of the engine was higher for NExBTL in each load point. The difference to 50-50 % fuel mix was 0.8-1.4 %, and the biggest difference was recorded in load point 6. The engine efficiency results with the both fuels, compared with the reference results of each fuel, were quite similar as the greatest differences were about 1 %.

Changing Pilot 1 injection advance from 350 µs to 500 µs, produced optimal results for the NExBTL as the NO_X results were slightly closer to the NO_X results of DFO. The difference however, was quite small. Simultaneously SFC and efficiency of the engine were slightly better than with the standard fuel injection parameters.

5.4.2 Cylinder Pressure

NExBTL produced slightly higher peaks of maximum cylinder pressure in all load points in the engine runs performed with changed Pilot 1 injection advance. In load point 5, Figure 5.11, it is clearly visible, that the cylinder pressure curve of NExBTL is higher than that of fuel blend between -30…30 degrees of crank angle. The difference between the maximum cylinder pressures in load point 5, for the two tested fuels was 2.6 % at peak values (82.1 bar vs 80.0 bar).

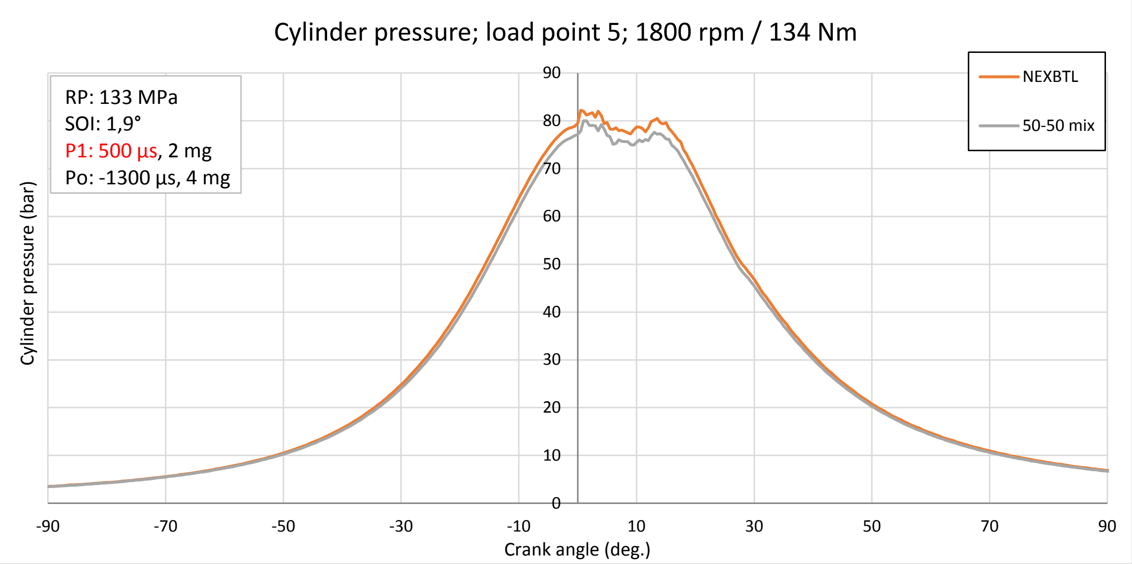


Figure 5.11. Cylinder pressure in load point 5, Pilot 1 advance 500 µs.

5.4.3 Heat Release

Heat release curves in the tests performed with earlier Pilot 1 timing were quite similar for NExBTL and 50-50 % mix fuels. The differences in heat releases were quite small. In load points 3 and 5, both at engine speed 1800 rpm (402 and 134 Nm), it can be seen that the heat release curves make one extra peak of heat release after the initial Pilot 1 peak before the heat release from Main injection, Figures 5.12 and 5.13.

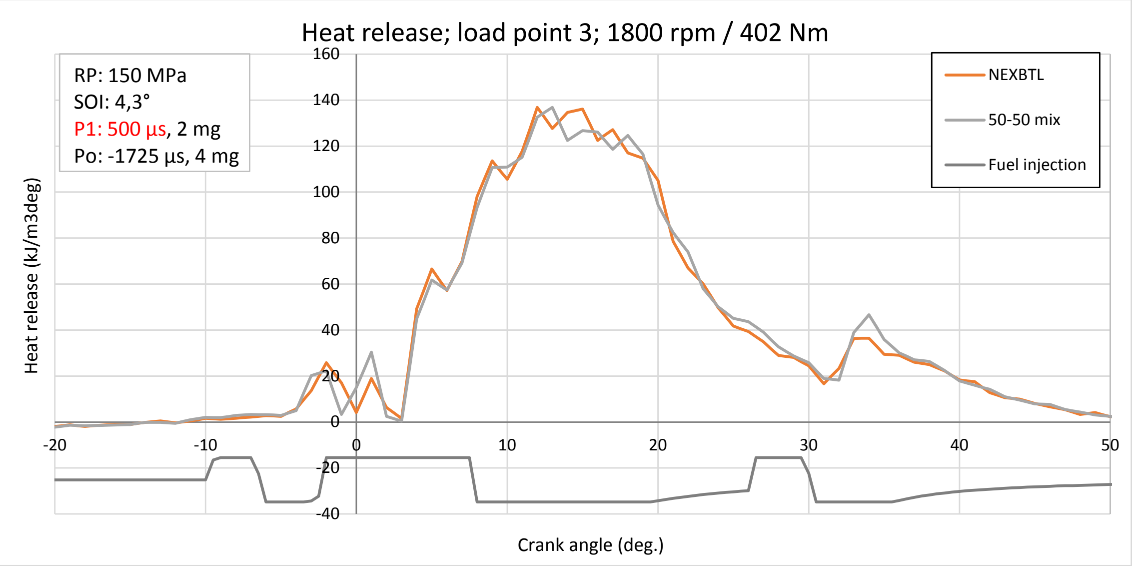


Figure 5.12. Heat release curve in load point 3, Pilot 1 advance 500 µs.

Tendency for a second peak of heat Pilot 1 heat release was also seen in load point 4 to a lesser degree.

Figure 5.13 shows that the heat release curve dips into negative range for 50-50 % mix fuel at approximately 5 degrees of crank angle. Overall in the load points 3 and 5 (engine speed 1800 rpm), the heat release curves were quite unstable. This is quite similar to the results recorded in the previous test runs.

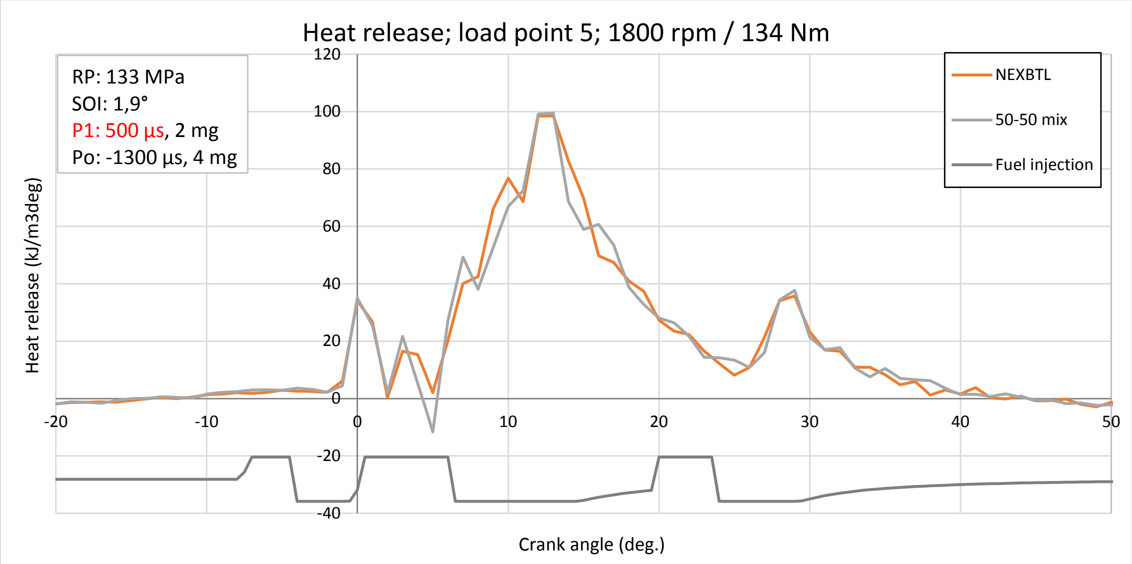


Figure 5.13. Heat release curve in load point 5, Pilot 1 advance 500 µs.

Increasing Pilot 1 injection advance from 300 to 500 µs produced higher peaks of pilot injection heat releases in load points 1 and 2 for both fuels, when compared to the reference results of each fuel.

5.4.4 Cumulative Heat Release

In most load points the cumulative heat release curves were quite similar for the both research fuels. In load point 5, cumulative heat release curve of NExBTL was slightly higher than for the 50-50 % mix, Figure 5.14. The difference in peak values was about 2 %.

In the cumulative heat release curve of load point 5, the start of Pilot 1, Main and Post injections can be clearly seen from the shape of the curve.

In load point 6, on the contrary, the cumulative heat release curve of 50-50 mix was about 2 % higher than that of NExBTL at the maximum value.

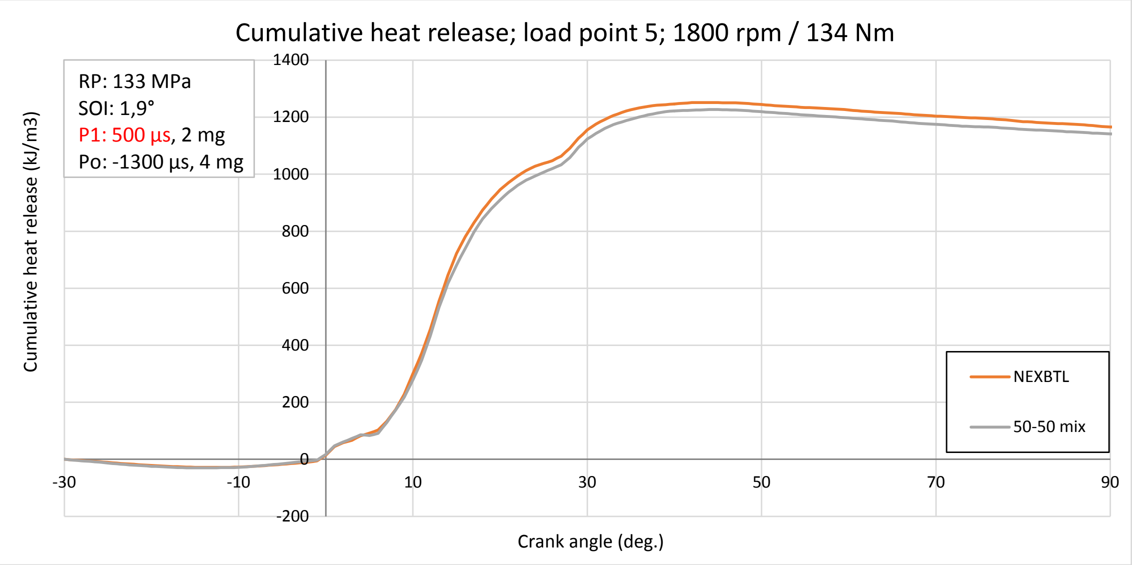


Figure 5.14. Cumulative heat release in load point 5, Pilot 1 advance 500 µs.

5.4.5 Ignition Delay

No differences in the ignition delays between the two test fuels were seen in the test runs performed with earlier Pilot 1 timing, Table 5.4.

Advancing the timing of Pilot 1 injection did however affect the ignition delay when compared to the reference results. In load points 3, 5 and 6 the ignition delays in these test runs were longer, and in load point 4 the delay was shorter. The differences were same with the both research fuels.

Table 5.4. Ignition delays, Pilot 1 advance 500 µs.

	Ignition delay µs						
	Fuel						
Test point	NExBTL, Pil1 Adv: 500 µs	50-50 %-mix, Pil1 Adv: 500 µs	diff. 50-50 % -mix-NExBTL	Ref. NExBTL	Ref. 50-50 % -mix	diff. NExBTL: test-ref.	diff. 50-50 %-mix: test-ref.
1	444.4	444.4	0.0	444.4	444.4	0.0	0.0
2	448.7	448.7	0.0	448.7	448.7	0.0	0.0
3	555.6	555.6	0.0	509.3	509.3	46.3	46.3
4	492.4	492.4	0.0	530.3	530.3	-37.9	-37.9
5	601.9	601.9	0.0	555.6	555.6	46.3	46.3
6	641.0	641.0	0.0	576.9	576.9	64.1	64.1

5.5 Pilot Injection Quantity

Next the fuel injection quantity was increased from 2 milligrams to 3 milligrams. The Pilot 1 injection advance was returned to 350 microseconds and all other fuel injection parameters were kept constant, similar to reference tests.

5.5.1 Gaseous Emissions, Smoke, Fuel Consumption and Efficiency

Similarly to the results from the previous test runs the 50-50 % mix fuel produced lower nitrous oxide results than pure NExBTL. The differences were between 1.6 and 6.9 %, with the biggest difference recorded in load point 4. In load points 1-4 the NO_X results for 50-50 % mix were more than 5 % lower than those of NExBTL.

When comparing results from the test runs with increased pilot injection to the reference results for NExBTL it can be seen, that in load points 2-6 reference NO_X was 1.8-3.9 % smaller than in this test runs. The biggest difference was in load point 4. In load point 1 NO_X result was 2.6 % lower than the reference result.

For 50-50 % mix fuel the NO_X results were quite similar to the reference with exception of load point 6, where the reference NO_X was 3.0 % smaller. In all other load points the nitrous oxide results were about 1.5 % of the reference results.

The smoke results in these tests followed previous trend, where NExBTL produced smaller smoke by 30-50 % than blended fuel. Increase in Pilot 1 injection resulted in lower smoke in load point 2 for the both fuels when comparing to each reference results. Smoke number for NExBTL was half of the reference result and for 50-50 % mix fuel the reduction was around 30 %. Still overall all the smoke numbers were on a quite low level.

Similarly to the previous results, NExBTL produced smaller SFC than 50-50 % mix by 1.7-3.1 % (load points 1 and 5 respectively). On the contrary the blended fuel produced smaller volumetric fuel consumption than NExBTL in all load points, except load point 5. The volumetric fuel consumption of fuel blend was smaller by a maximum of 1.7 % in load point 1.

Slightly lower fuel consumption results of NExBTL can be seen at lower engine loads (load points 4-6) when compared to the reference results. The SFC in this test run was 1.7 % and volumetric fuel consumption 1.1 % lower than reference results in load point 5.

SFC and volumetric fuel consumption results for fuel blend were quite close to reference results in all load points.

Efficiency of the engine was higher when using NExBTL than 50-50 % mix. Efficiency results with blended fuel were 0.8-2.2 % smaller than results with pure NExBTL. The biggest difference was recorded in load point 5. Comparing to the reference results NExBTL produced better efficiency at the lower engine loads (P4-P6), with maximum difference 1.7 % in load point 5. Blended 50-50 % mix fuel did not produce similar performance in efficiency when compared to its reference.

5.5.2 Cylinder Pressure

Increasing the Pilot 1 quantity by one milligram did not affect the cylinder pressures greatly when comparing the results of the two research fuels with each other. In Figure 5.15 is presented results from load point 5, where the maximum cylinder pressure of NExBTL was higher. In the test runs performed with increased Pilot 1 injection quantity pure NExBTL produced higher cylinder pressures in all load points, the biggest difference in maximum pressures was about 3 %.

Increase in Pilot 1 quantity produced higher cylinder pressure peak values for NExBTL in all load points when compared to results with reference fuel injection parameters.

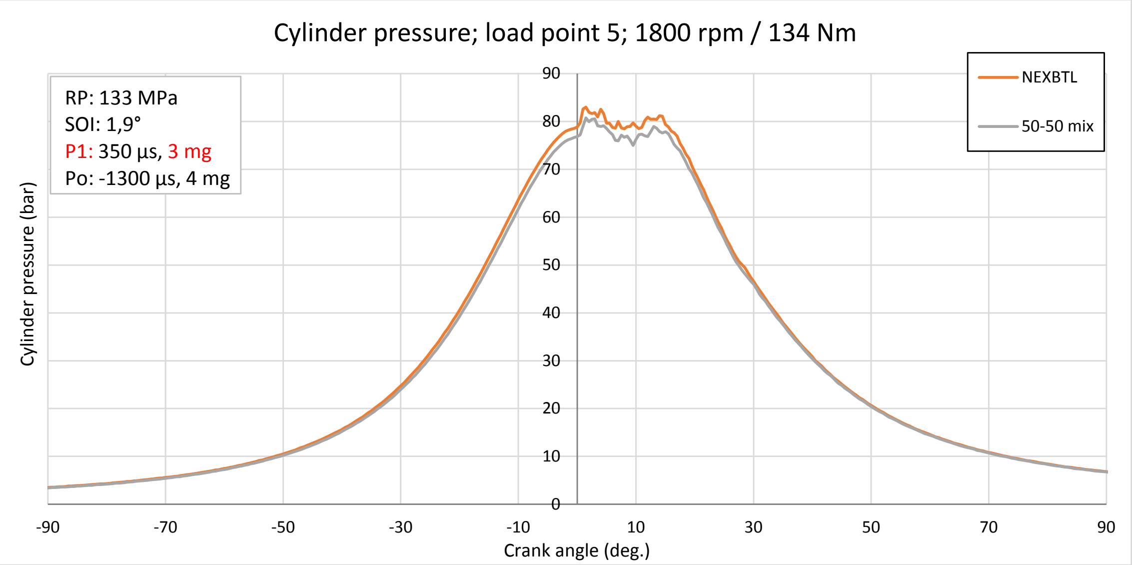


Figure 5.15. Cylinder pressure in load point 5, Pilot 1 quantity 3 mg.

5.5.3 Heat Release

Comparing heat releases of the two research fuels, it was observed that NExBTL produced higher peak heat release rate values than 50-50 % mix. In load points with lower engine torque (P4, 5 and 6) it was noticed that pure NExBTL produced higher Pilot 1 peak value than fuel blend, Figure 5.16.

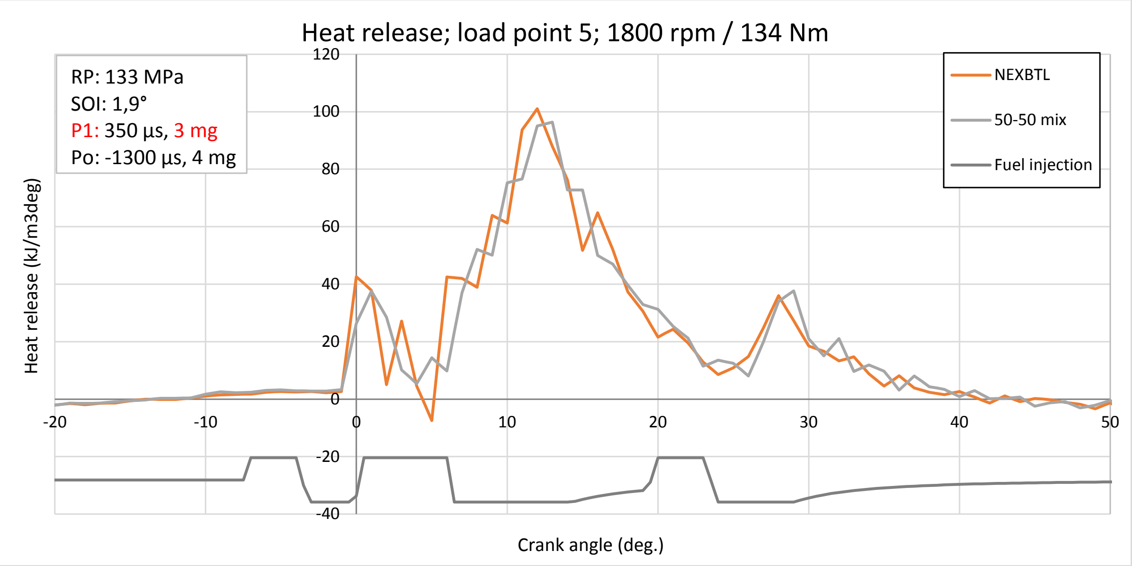


Figure 5.16. Heat release in load point 5 with pilot injection of 3 mg.

Figure 5.16 (load point 5) shows that both NExBTL and 50-50 % mix fuels produced quite unstable heat release values. Especially NExBTL produced two peaks of Pilot 1 injection heat release. Similar tendency was seen in load point 3 (engine speed also 1800 rpm) and to a lesser degree in load point 4 (engine speed 2200 rpm).

5.5.4 Cumulative Heat Release

Cumulative heat releases did not differ greatly between the two research fuels. The greatest difference in maximum cumulative heat release values was seen in load point 3, where the difference was about 2 %, Figure 5.17.

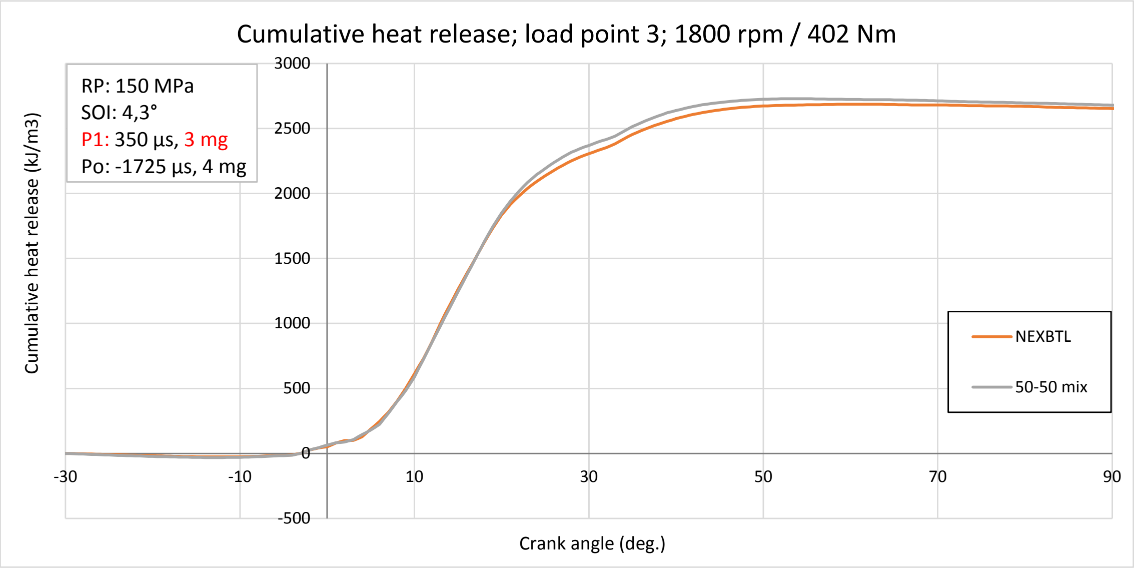


Figure 5.17. Cumulative heat release in load point 3 with pilot injection of 3 mg.

5.5.5 Ignition Delay

With the exception of load point 1 the ignition delays were similar between the two research fuels, Table 5.5. In load point 1 NExBTL ignited faster by 56 µs (0.5 crank angle degree).

When compared to the reference test runs increasing of Pilot 1 injection slowed ignition with both fuels in load points 4, 5 and 6, which have lower engine torque. Fuel blend did produce slower ignition in load point 1.

Table 5.5. Ignition delays, Pilot injection quantity 3 mg.

	Ignition delay µs						
	Fuel						
Load point	NExBTL, Pil1 qty: 3 mg	50-50 %-mix, Pil1 qty: 3 mg	diff. 50-50 % -mix-NExBTL	Ref. NExBTL	Ref. 50-50 % -mix	diff. NExBTL: test-ref.	diff. 50-50 %-mix: test-ref.
1	444.4	500.0	55.6	444.4	444.4	0.0	55.6
2	448.7	448.7	0.0	448.7	448.7	0.0	0.0
3	509.3	509.3	0.0	509.3	509.3	0.0	0.0
4	568.2	568.2	0.0	530.3	530.3	37.9	37.9
5	601.9	601.9	0.0	555.6	555.6	46.3	46.3
6	576.9	576.9	0.0	576.9	576.9	0.0	0.0

5.6 Pilot Injection Off

Next the Pilot 1 injection was disabled to see how this would affect the results of the engine. However it was seen from the in-cylinder measurements presented later, that disabling the Pilot 1 injection still caused the injector to perform two phased injection, which can be seen in injector needle movement and in the in-cylinder results for some load points. The quantity of the Pilot 1 injection was set to zero, but the engine management program still opened the injector for 80 µs. The injector closed between the pilot and the main injections for only 0.5 crank angle degrees. It is debatable whether fuel was injected into the cylinder at this point or not. This two phased injector movement however may have had effect on some inconsistencies seen in heat release results.

5.6.1 Gaseous Emissions, Smoke, Fuel Consumption and Efficiency

With disabled pilot injection 50-50 % mix fuel produced smaller nitrous oxides results than NExBTL, similarly to the previous test runs. NO_X results for blended fuel were up to 8.7 % smaller than NExBTL in load point 1. In other load points the 50-50 % mix produced 1.0-4.5 % lower NO_X results than pure NExBTL.

When the nitrous oxides results of NExBTL in this test run were compared to the reference results, only significant differences were seen in load points 5 and 6, where NO_X results with no pilot injection were 7.1 and 5.9 % lower than the reference respectively. These load points had lower engine torques.

Similar results were seen with 50-50 % mix fuel, as only significant differences in NO_X were seen at the lower engine loads, load points 4, 5 and 6. The nitrous oxides results in these load points from runs without pilot injection were 3.0 %, 10.1 % and 5.0 % lower than the reference results for this fuel.

With Pilot 1 injection disabled smoke results of NExBTL were lower than those of 50-50 % mix only in load points 1, 4 and 5. In other load points the results were either same or slightly higher (P2) than for blended fuel.

Compared to the reference results, the smoke numbers of NExBTL were slightly smaller in test runs with no pilot injection. The only exception was load point 3, where smoke was slightly higher than the reference. Smoke results for 50-50 % mix were in all load points 20-40 % smaller than in the reference test runs.

SFC results with pure NExBTL were 1.4-2.2 % smaller than with 50-50 % mix fuel, with the biggest difference in load point 1. Simultaneously volumetric fuel consumption with blended fuel was 1.0-2.0 % smaller than with NExBTL with the pilot injection disabled.

With the exception of load point 4, SFC and volumetric fuel consumption in the reference test runs were slightly smaller than in the test runs with no Pilot 1 injection for the both research fuels.

In other load points than 5 and 6, NExBTL had slightly better engine efficiency than 50-50 % mix. Compared to the reference results for each fuel, the only slight difference in engine efficiency in these test runs was seen in load point 6 for NExBTL, where disabling the pilot injection led to 1.3 % smaller engine efficiency.

5.6.2 Cylinder Pressure

In the test runs performed with no Pilot 1 injection NExBTL produced slightly higher maximum cylinder pressures than fuel blend. The difference in the maximum pressures was about 3 % at the highest.

In the load point 3 the Main injection was two phased, and produced one extra peak after start of the ignition, Figure 5.18.

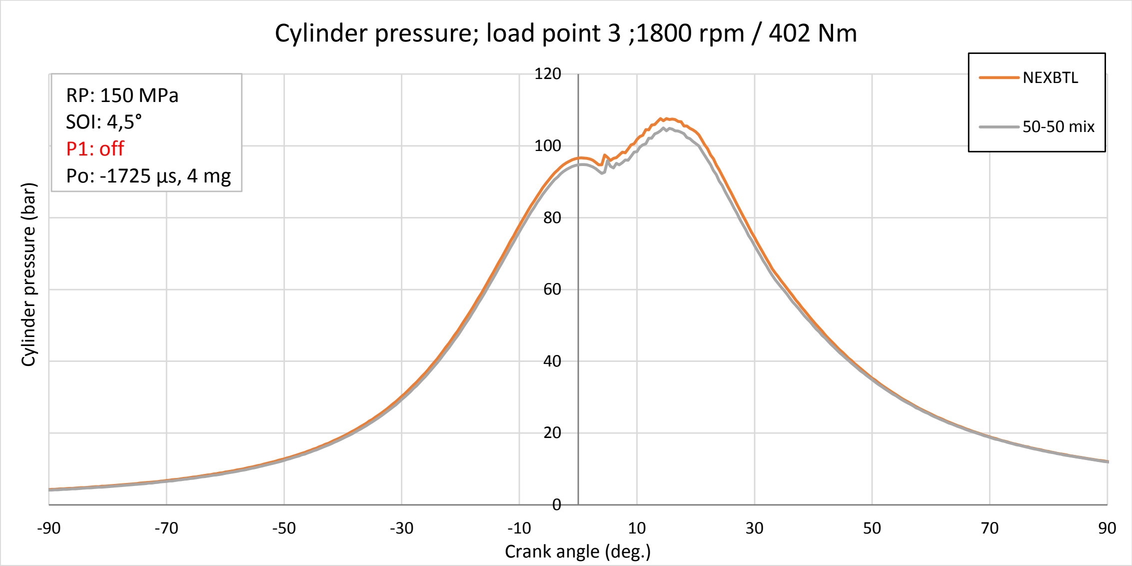


Figure 5.18. Cylinder pressure in load point 3 with pilot injection off.

Disabling the pilot fuel injection resulted in lower maximum cylinder pressures in all load points for 50-50 % mix fuel, when compared to the base results of this fuel. For NExBTL similar tendency was seen only in the lower engine loads, load points 4-6, when compared to the results of NExBTL test runs with no injection parameter changes.

5.6.3 Heat Release

It was seen from the injection needle movement measurements that the injection was two phased in every load point, even though the Pilot 1 injection was disabled, Figure 5.19.

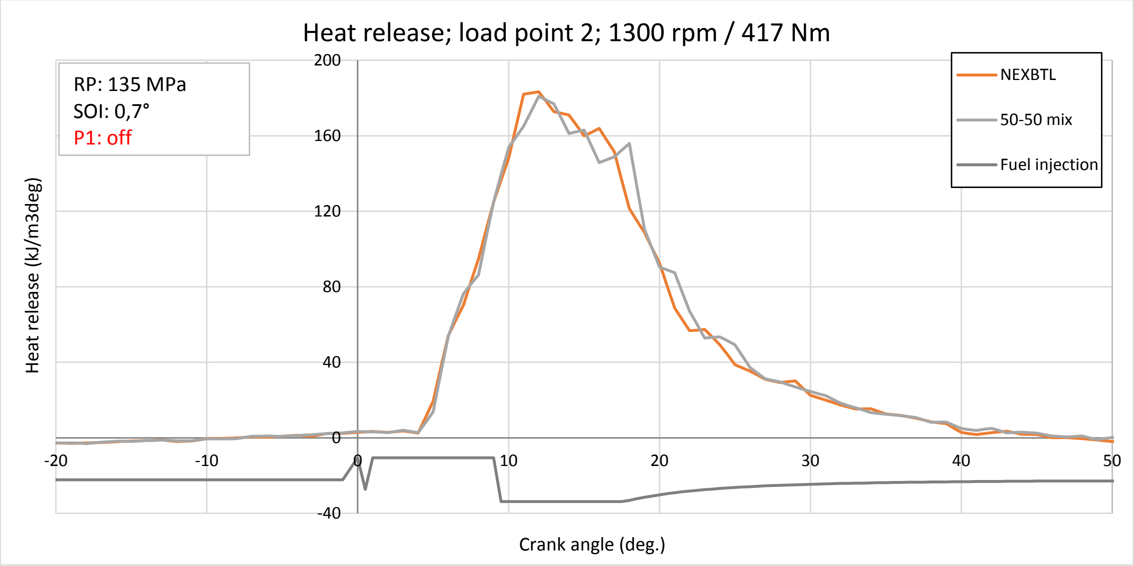


Figure 5.19. Heat release in load point 2 with no pilot injection.

In the load points 4 and 5 the heat release curves have clearly two phases with the both research fuels, Figure 5.20. As the figure below shows, first the heat release peak of the premixed combustion phase occurs. In this phase the nearly flammable fuel-air mix, which was formed during ignition delay, combusts rapidly and results in a high peak of heat release. (Heywood 1988, 505-506)

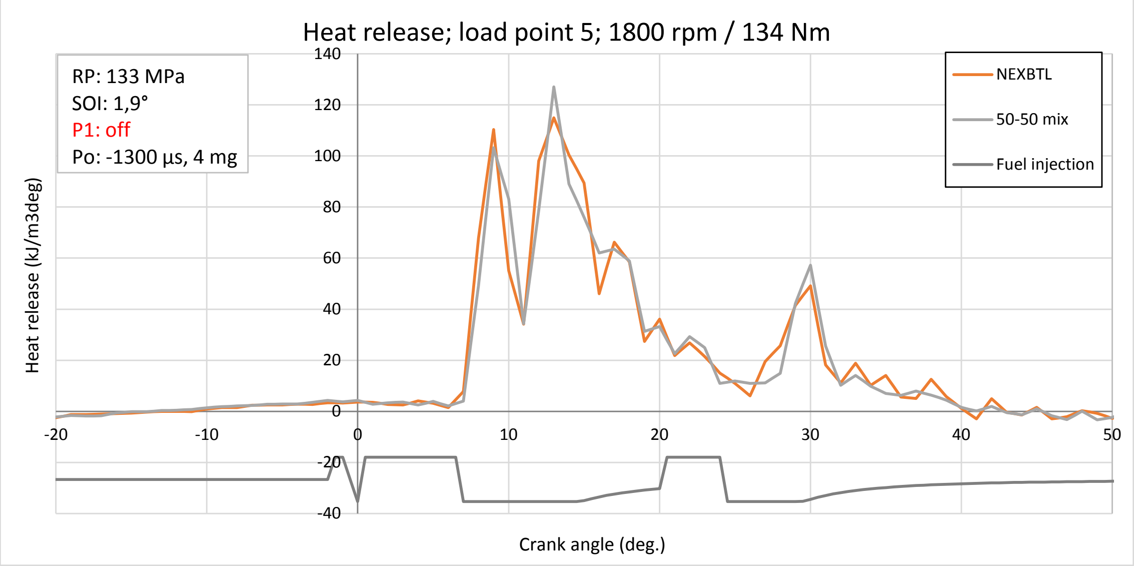


Figure 5.20. Heat release in load point 5 with no pilot injection.

After the premixed combustion phase the heat release curves of both fuels dipped vastly, before new heat release peak was developed. The heat release curves differ greatly of the heat release curves measured in the previous test runs of this study.

In load point 6 the peak premixed combustion phase heat release occurred earlier for NExBTL than for blended 50-50 % mix, Figure 5.21. Figure also shows that the NExBTL produced initial heat release faster than blended fuel.

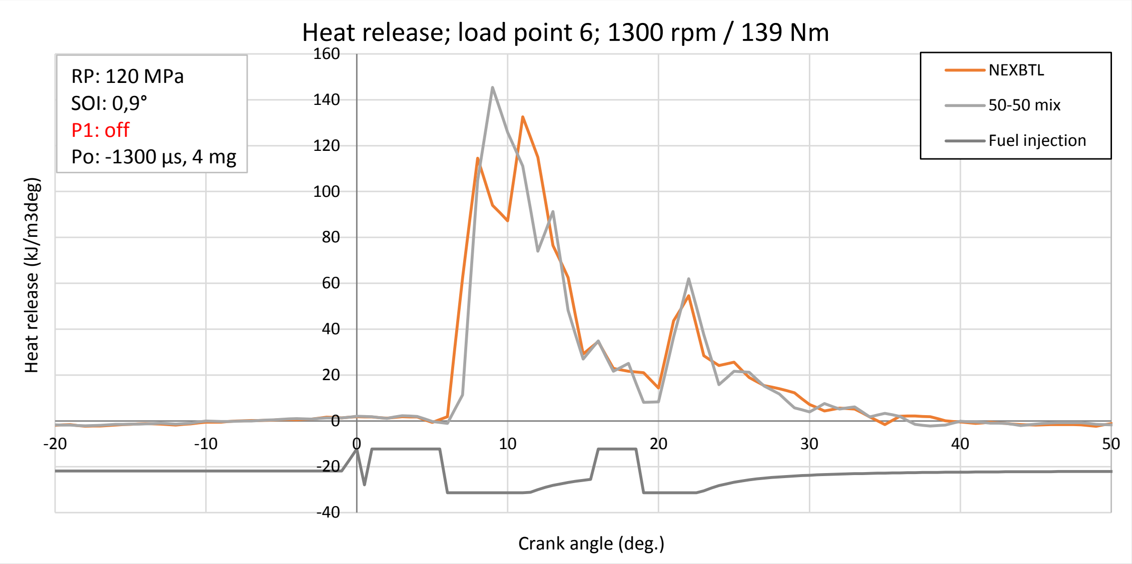


Figure 5.21. Heat release in load point 6 with no pilot injection.

Overall the maximum heat release rates were quite close between the two fuels at the load points 1, 2 and 3. However at the load points 4, 5 and 6, with lower engine torques, the 50-50 % mix produced higher maximum heat release values. The difference at the highest was about 10 % in load point 5, Figure 5.20.

Disabling pilot injection produced significantly higher heat release peaks at the lower load range (P5-P6) for both fuels, when compared to the reference results of each fuel.

5.6.4 Cumulative Heat Release

With disabled pilot injection high heat release peaks of premixed combustion phases were recorded in load points 4-6 for both fuels, which can be also seen in cumulative heat release curves, Figure 5.22. As the figure shows, the cumulative heat release of NExBTL was greater than that of 50-50 % mix by 5 % at the maximum value. The difference is quite significant, considering that the maximum heat release value of fuel blend was higher at the same load point, and heat release of NExBTL did dip down at the beginning of the combustion.

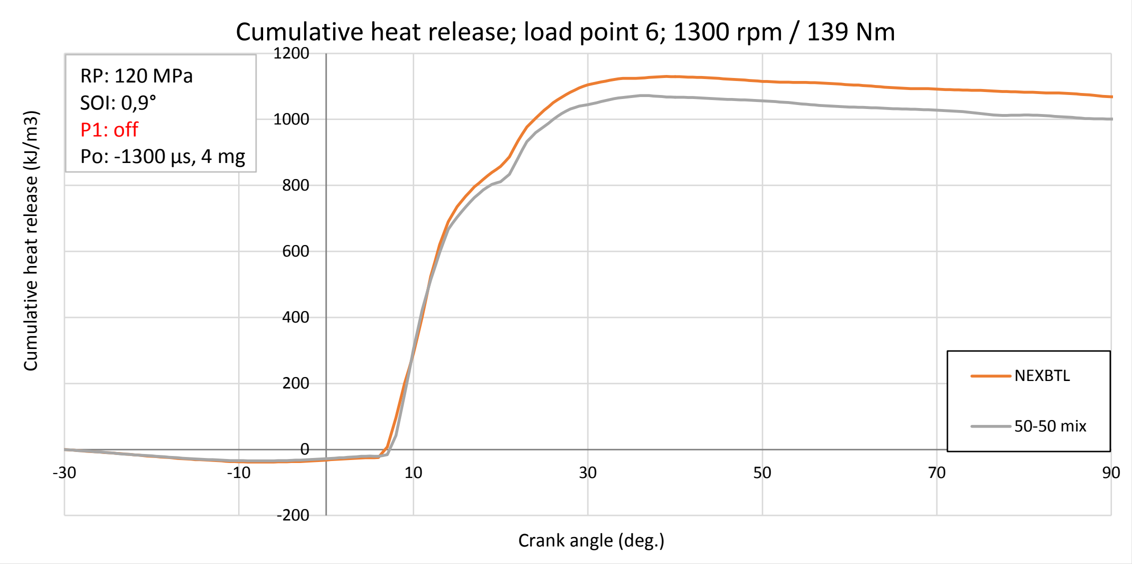


Figure 5.22. Cumulative heat release in load point 6 with no pilot injection.

It is noticeable that in the load point 6 the maximum cumulative heat release value of NExBTL was 7.0 % higher than the base reference level of NExBTL. On the contrary, maximum result of the blended fuel was 3.9 % lower than its maximum reference result.

5.6.5 Ignition Delay

Ignition delays in the test runs with no pilot injection were a lot slower when calculated similarly to the ignition delays in the previous test runs. Determining this proved to be challenging, as runs with no pilot injection actually had slight movement of injector needle directly before the main injection by error. The duration of false pilot injection was only 80 µs compared to 290 µs of Pilot 1 injection duration in the reference runs. It is debatable whether or how much fuel was injected at this injection.

Initially the ignition delays were calculated similarly to previous delay results, where the beginning of the injection was determined to start immediately after the injector is opened for the first time. In this case the ignition delay appeared to be a lot longer than in the reference results in all load points and for both fuels. The differences to the reference were between 130 and 320 µs, for fuel blend, and between 130 and 256 µs for NExBTL.

However, when heat release curves without pilot injection were compared to the reference curves it seemed that in reality the ignition delays were longer only in load points 5 and 6. On this account the calculation of the ignition delays was altered so, that the beginning of true injection was decided to occur at the main injection. The results from these calculations are presented in Table 5.6. However these results should be observed critically as it is not known if some fuel was injected into cylinder during false pilot injection.

Table 5.6. Ignition delays with no pilot injection.

	Ignition delay µs (counted from beginnig of main injection)						
	Fuel						
Load point	NExBTL, Pil 1 off	50-50 %-mix, Pil1 off	diff. 50-50 % -mix-NExBTL	Ref. NExBTL	Ref. 50-50 % -mix	diff. NExBTL: test-ref.	diff. 50-50 %-mix: test-ref.
1	444.4	444.4	0.0	444.4	444.4	0.0	0.0
2	448.7	448.7	0.0	448.7	448.7	0.0	0.0
3	509.3	509.3	0.0	509.3	509.3	0.0	0.0
4	492.4	492.4	0.0	530.3	530.3	-37.9	-37.9
5	601.9	648.1	46.3	555.6	555.6	46.3	92.6
6	705.1	769.2	64.1	576.9	576.9	128.2	192.3

The table shows that NExBTL resulted in faster ignition than fuel blend in load points 5 and 6. This is quite logical as the NExBTL has higher cetane number.

When compared to the reference results, the ignition delays without pilot injection were longer in load points 5 and 6. In load point 4 the ignition delays without pilot injection seemed to be slightly faster than in the reference test runs.

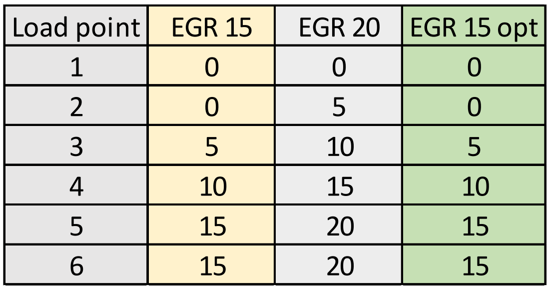
6 RESEARCH RESULTS WITH EGR SYSTEM

Next step in the study was to equip the engine with an external cooled exhaust gas recirculation (eEGR) system. The EGR valve was controlled externally by the engine management system. First the EGR valve positions were tabulated for each load point using 50-50 % mix fuel. Tabulation was performed at 10-15-20-25-30 percentages. From these test runs two different EGR position parameter sets were selected. One setting was with lower EGR valve openings, abbreviated *EGR 15* (as maximum opening for EGR valve in these parameters was 15 %), and another setting was abbreviated to *EGR 20* (maximum opening of EGR valve 20 %). At the higher engine loads (load points 1-3), EGR valve was either closed or only slightly open (5 %). Biggest openings of the valve were in load points 5 and 6, where speed and load of the engine were lower.

After these test runs, the engine fuel injection parameters were optimized using EGR 15 exhaust gas recirculation parameters. These test runs and engine parameters used were abbreviated *EGR 15 opt*.

The EGR valve positions used are presented in Table 6.1. It is noticeable that the values displayed in this table are EGR valve positions and not actual EGR percentages. Also the EGR valve was not completely sealed when closed, and some EGR circulation still occurred with EGR valve position 0 %, due to the high pressure in exhaust manifold.

Table 6.1. EGR valve positions for EGR test runs.



Load point	EGR 15	EGR 20	EGR 15 opt
1	0	0	0
2	0	5	0
3	5	10	5
4	10	15	10
5	15	20	15
6	15	20	15

6.1 Lower EGR Valve Positions

The lower EGR valve position parameters were abbreviated *EGR 15*, as the maximum percentage of the valve opening was 15 % in load points 5 and 6, Table 6.1. In these parameters the EGR valve was closed at load points 1 and 2, where engine load was high.

The calculated EGR % are presented in Table 6.2. As table shows, small amount of exhaust gas circulated even with closed EGR valve, load points 1 and 2. Highest EGR % was recorded at load point 5, with EGR valve opening of 15 % and engine speed of 1800 rpm.

Table 6.2 Calculated EGR % with EGR 15 parameters.

	Calculated EGR %		EGR-valve opening %
Load point	Fuel		
	NExBTL	50-50 %-mix	
1	2.0	1.3	0
2	0.8	0.7	0
3	8.1	6.9	5
4	13.6	13.6	10
5	25.2	25.2	15
6	17.5	17.3	15

For unknown reason the main injection advance in load point 6 of these test runs, differed from the reference test runs. In the reference test runs the main injection advance at P6 was one crankshaft degree. The timing value in EGR 15 runs was about 2.4 crankshaft degrees. This means that the injections in load point 6 were earlier than in other EGR test runs. Luckily, in EGR 15 test runs the main injection advance was same for both tested fuels, and it did not affect comparability between them.

6.1.1 Gaseous Emissions, Smoke, Fuel Consumption and Efficiency

In the test runs performed with lower EGR valve openings (EGR 15), NExBTL produced smaller results of nitrous oxides than 50-50 % mix in all load points.

The differences were between 4.6 (P4) and 10.0 % (P1). This trend differed from previous NO_X results measured in the reference and fuel injection optimization test runs, where 50-50 % mix produced generally smaller NO_X results than NExBTL. The greatest differences in nitrous oxides were recorded in load points 1 and 2, where EGR valve was closed and only small exhaust gas recirculation occurred, Table 6.2. In other load points NO_X results of NExBTL were about 5 % smaller than the results measured with blended fuel.

Compared to the reference results EGR 15 parameters produced clearly lower NO_X results for the both research fuels. For NExBTL the specific NO_X results (g/kWh), from test runs with EGR 15 parameters, were between 23 (P2) and 55 (P5 and P6) % smaller than in the reference test runs. Similarly for 50-50 % mix fuel specific NO_X results were between 12 (P1) and 52 (P6) % smaller than the reference results. The biggest advances for NO_X were recorded with the biggest EGR valve openings in load points 5 and 6 with both fuels. However, it is noticeable that for unknown reason the injection advance in load point 6 of these test runs was earlier than in the reference test runs. Because of this the results in load point 6 are not directly comparable to the reference.

It is noticeable that specific NO_X results from load points 1 and 2 were clearly smaller than in the reference test runs, despite the fact that EGR valve was closed. EGR valve was not completely sealed and some exhaust gas circulated also in these load points. Also the modifications made to accommodate EGR system to the engine altered slightly the exhaust manifold system of the engine. Air mass flow, in load points 1 and 2 of test runs with EGR 15 parameters, was about 5-7 % smaller for NExBTL and about 2-5 % smaller for 50-50 % mix than the reference air mass flow.

Apart from load point 1, NExBTL produced smaller smoke results than 50-50 % mix in all load points of test runs performed with EGR 15 parameters. The smoke numbers of NExBTL were between 15 (P2) and 40 (P4 and P5) % smaller than the results of fuel blend in load points 2-6.

Compared to the reference smoke numbers, both research fuels produced clearly bigger smoke numbers in EGR 15 test runs, which is quite natural for exhaust gas recirculation system, as the air mass flow of the engine decreases. Increase in these test runs was between 60-65 % for NExBTL and 45-66 % for 50-50 % mix.

Specific fuel consumption for both research fuels was quite similar in EGR 15 test runs, as the differences were only about 1 % at a maximum. Volumetric fuel consumption with blended fuel was 2.9 (P3) to 4.8 (P6) % smaller than with NExBTL.

Compared to the reference results of the two fuels, both SFC and volumetric fuel consumption were smaller in load points 4-6, where bigger EGR circulation was used. The greatest advantage in fuel consumption was measured in load point 5, where results with EGR 15 parameters were up to 5.7 % (SFC) and 4.8 % (volumetric fuel consumption) smaller than the reference results of NExBTL. Similar numbers for 50-50 % mix fuel were 5.7 % (SFC) and 5.9 % (volumetric fuel consumption).

When comparing calculated engine efficiency for both fuels in EGR 15 test runs, it was seen that 50-50 % mix produced slightly higher efficiency results in all load points, with the difference of 2 % in load point 6. Compared to the base results of each fuel it was seen that best efficiencies were recorded in load points with the biggest EGR valve openings (load points 4-6). The greatest difference of engines efficiency was measured in load point 5, where the reference results for both fuels were 5.7 % lower than the results with EGR 15 parameters.

6.1.2 Cylinder Pressure

EGR 15 test runs did not show great differences in cylinder pressure curves between the two research fuels. The greatest differences were recorded in load points 1 and 2, at about 1.5 %. In these load points NExBTL produced higher peak values of cylinder pressure the highest being 128.3 bar, Figure 6.1.

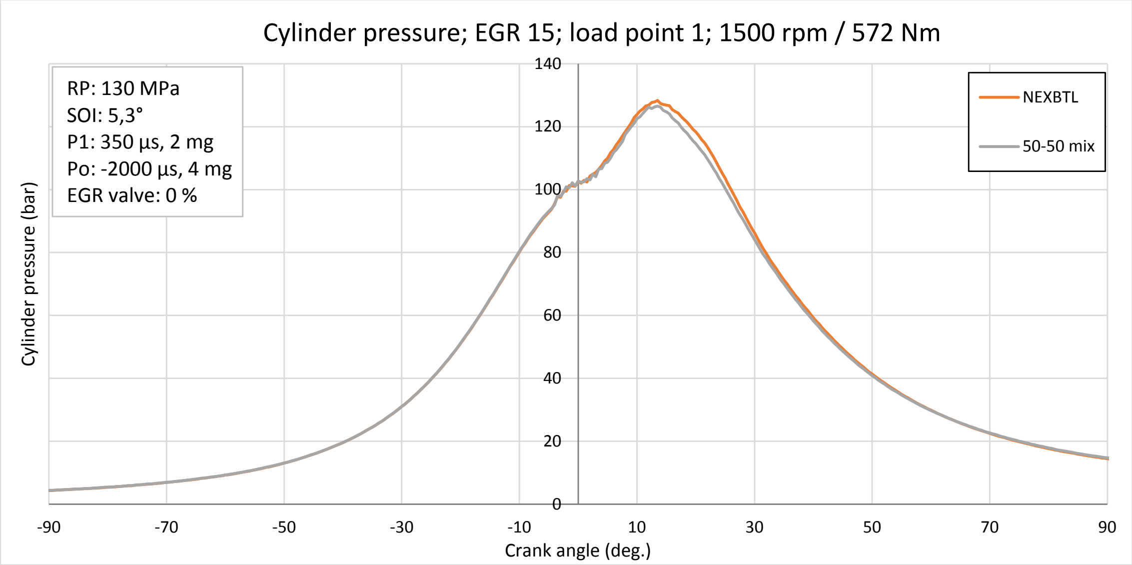


Figure 6.1. Cylinder pressure in load point 1, EGR 15 parameters.

6.1.3 Heat Release

With EGR 15 exhaust gas recirculation parameters heat release curves for 50-50 % mix fuel did decrease faster after main injection heat release, than for pure NExBTL, in load points 1 and 2, Figure 6.2. In these points EGR valve was closed but some amount of exhaust gas still circulated to the intake manifold of the engine.

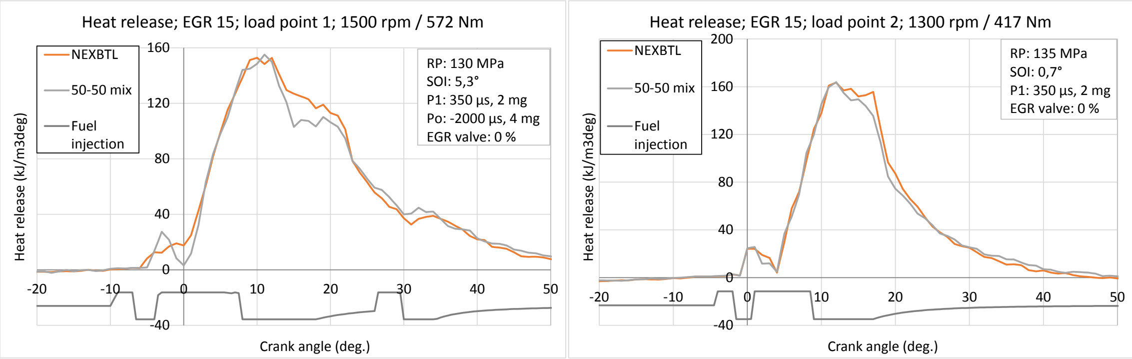


Figure 6.2. Heat releases in load points 1 and 2, EGR 15 parameters.

In the load points 3, 4 and 5 pilot injection produced several heat release peaks, similarly to the previous test runs. In these load points the heat release curves were again quite unstable, Figure 6.3.

The peak heat release of NExBTL was 6.6 % lower than 50-50 % mix fuel in load point 4. In load point 5, on the contrary, peak release of fuel blend was 5.8 % lower than that of pure NExBTL.

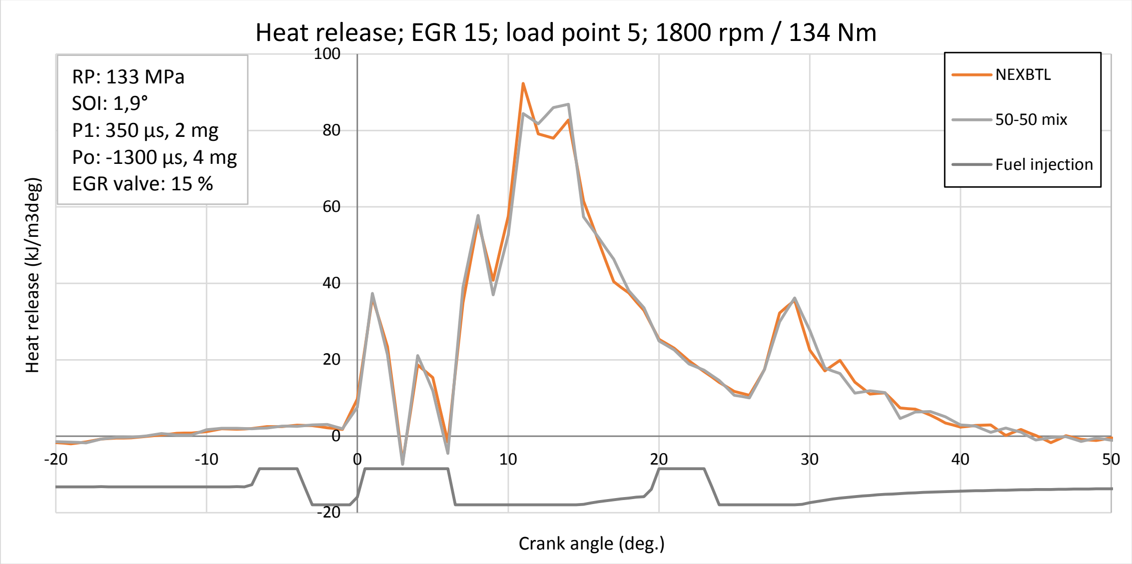


Figure 6.3. Heat release in load point 5, EGR 15 parameters.

6.1.4 Cumulative Heat Release

The differences in heat release curves presented in Figure 6.2 can also be clearly seen in cumulative heat releases at the same load points 1 and 2, Figure 6.4. The cumulative heat releases of 50-50 % mix fuel were lower than those of NExBTL between crank angle degrees of 15 to 70.

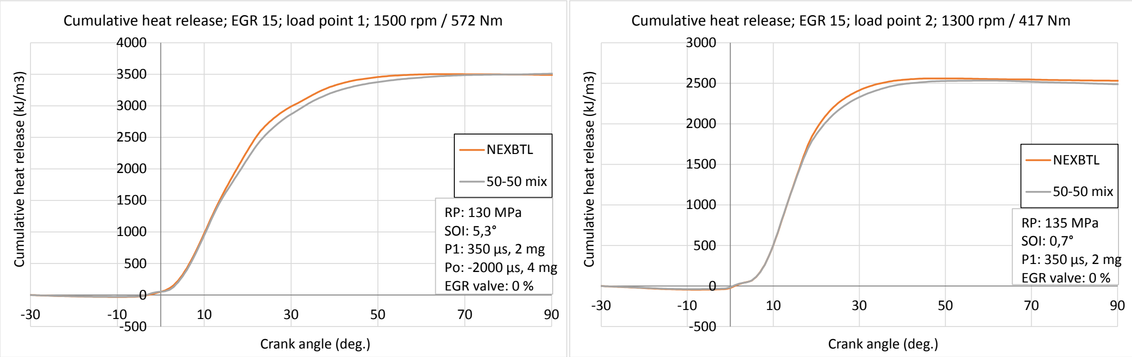


Figure 6.4. Cumulative heat release in load points 1 and 2, EGR 15 parameters.

With EGR 15 parameters no significant changes in maximum values of cumulative heat releases were recorded between the two research fuels. The greatest difference was measured at load point 6, where maximum peak of cumulative heat release of NExBTL was 1022 kJ/m^3, which was about 1 % smaller than peak of cumulative heat release of 50-50 % mix (1032 kJ/m^3).

6.1.5 Ignition Delay

With the exception of load point 1, no differences in ignition delays were recorded between the two research fuels, Table 6.3. At load point 1 NExBTL produced faster ignition than 50-50 % mix by 56 µs.

Table 6.3. Ignition delay with EGR 15 parameters.

	Ignition delay µs						
	Fuel						
Load point	NExBTL, EGR 15 %	50-50 %-mix, EGR 15 %	diff. 50-50 % -mix-NExBTL	Ref. NExBTL	Ref. 50-50 % -mix	diff. NExBTL: test-ref.	diff. 50-50 %-mix: test-ref.
1	500.0	555.6	55.6	444.4	444.4	55.6	111.1
2	448.7	448.7	0.0	448.7	448.7	0.0	0.0
3	555.6	555.6	0.0	509.3	509.3	46.3	46.3
4	568.2	568.2	0.0	530.3	530.3	37.9	37.9
5	601.9	601.9	0.0	555.6	555.6	46.3	46.3
6	641.0	641.0	0.0	576.9	576.9	64.1	64.1

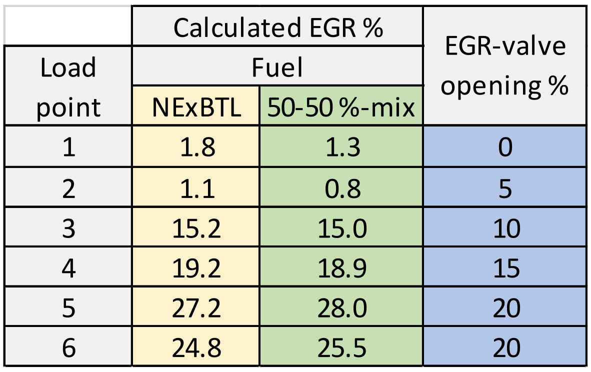
When compared to the reference ignition delay results of each fuel, it can be seen that with the exception of load point 2, use of EGR system resulted in slower ignition. Particularly big difference of 111 µs was recorded for 50-50 % mix at load point 1.

6.2 Higher EGR Valve Positions

The higher settings of the EGR valve positions were abbreviated *EGR 20*, as the maximum opening of the EGR valve in load points 5 and 6 was 20 %, Table 6.4. With these EGR valve settings the valve was shut only in load point 1.

The calculated EGR rates are shown in Table 6.4. As table shows, the EGR % was even higher at load point 1, where EGR valve was closed, than in load point 2, where EGR valve was opened 5 %.

Table 6.4. EGR valve opening and calculated EGR % with EGR 20 parameters.



Load point	Calculated EGR %		EGR-valve opening %
	Fuel		
	NExBTL	50-50 %-mix	
1	1.8	1.3	0
2	1.1	0.8	5
3	15.2	15.0	10
4	19.2	18.9	15
5	27.2	28.0	20
6	24.8	25.5	20

6.2.1 Gaseous Emissions, Smoke, Fuel Consumption and Efficiency

Similarly to the test results from EGR 15 test runs, using of EGR 20 parameters resulted in lower nitrous oxide results for NExBTL than for 50-50 % mix. The values measured with NExBTL were between 2.4 (P3) to 4.9 (P1 and P6) % lower than with 50-50 % mix. Unexpectedly the greatest differences in NO_X results were recorded with EGR valve shut (P1) and at the maximum opening of the valve (P6).

Compared to the reference results, NO_X results with both fuels were significantly lower. Nitrous oxides of NExBTL were between 25 (P1 and P2) and 73 (P6) % lower than the reference levels with the same fuel. For blended 50-50 % mix the NO_X results were between 15 (P1) and 71 (P6) % lower than the base values.

Out of the two research fuels, the NExBTL produced lower smoke numbers than 50-50 % mix in all load points, except P2 where numbers were same. The smoke results of NExBTL were lower by 13-44 % than the results of fuel mix in load points 1 and 3-6.

As expected the smoke numbers were significantly higher in EGR 20 test runs than in the reference test runs. The base values of NExBTL were between 29 (P2) and 82 (P1 and P6) % lower than NExBTL results in these test runs. For blended fuel, reference smoke levels were between 17 (P2) and 82 (P4 and P6) % lower than results from the test runs with EGR 20 parameters.

Specific fuel consumptions of both fuels were quite close to each other, as the differences were about 1 % at a maximum. Volumetric fuel flow of 50-50 % mix was smaller than that of NExBTL by 2.3 (P3) to 4.1 (P6).

Compared to the reference results of each fuel it was seen than specific fuel consumptions and volumetric fuel flows in EGR 20 test runs were lower in load points 4-6. SFC and volumetric fuel flow of NExBTL were about 4 % smaller at a maximum in load point 5 than the base result. For 50-50 % mix the difference to the reference in same load point was about 6 %.

The calculated efficiency of the engine was slightly higher for 50-50 % mix than for NExBTL. The difference however was only 1 % at a maximum. In load points 4-6, where EGR valve openings were the biggest, the efficiency of the engine was higher in EGR 20 test runs than in reference test runs with both fuels. The biggest differences were measured in load point 5, where the base result of NExBTL was 4.4 % lower than the result with EGR 20 parameters. For blended fuel the difference to the reference was even larger at 5.9 %

6.2.2 Cylinder Pressure

Differences in the cylinder pressure curves between the two research fuels were quite minimal. The biggest difference was recorded in load point 4, Figure 6.5. Overall the cylinder pressure curves were quite similar.

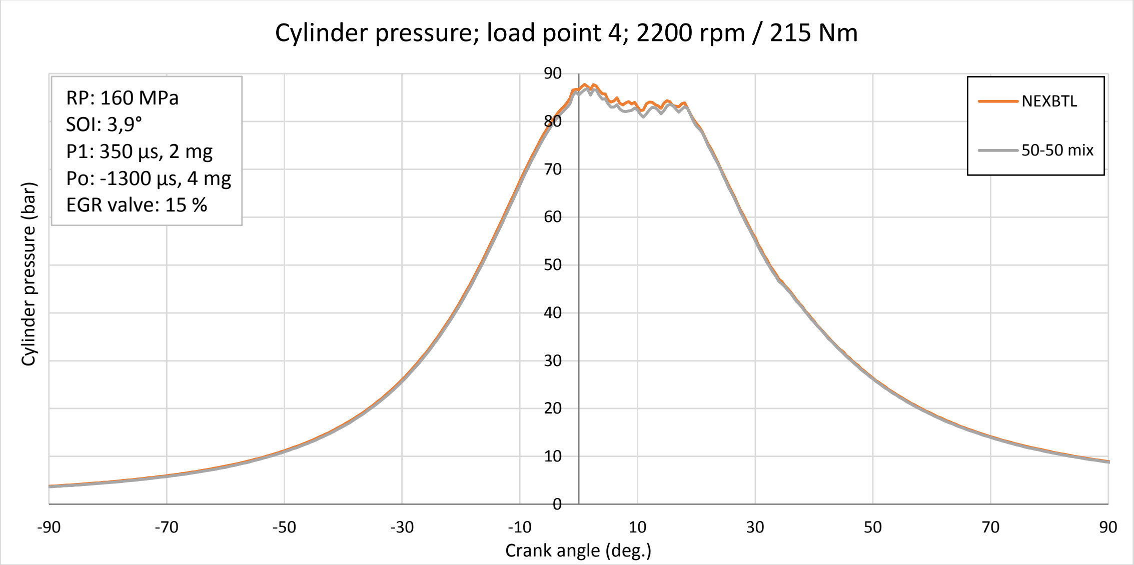


Figure 6.5. Cylinder pressure in load point 4, EGR 20 parameters.

6.2.3 Heat Release

Contrary to the heat release results recorded with the EGR 15 parameters, no significant differences between heat release curves of the two research fuels were recorded in load points 1 and 2, Figure 6.6. The heat release curves in all six load points were quite close to each other.

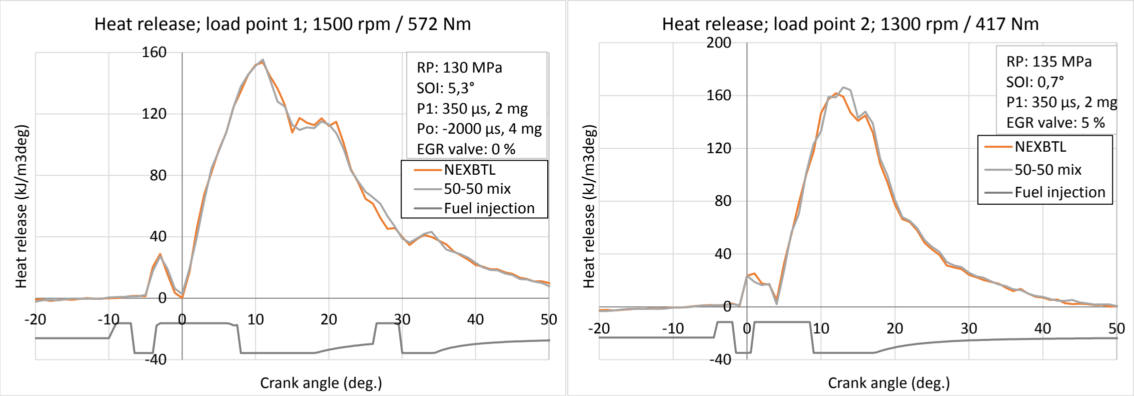


Figure 6.6. Heat releases in load points 1 and 2, EGR 20 parameters.

Similarly to the previous test runs, the heat release curves in load points 3, 4 and 5 produced several Pilot 1 heat release peaks and were in general quite unstable.

The greatest difference in peak values of heat release were measured in load point 5, where the difference was 4.8 %, Figure 6.7.

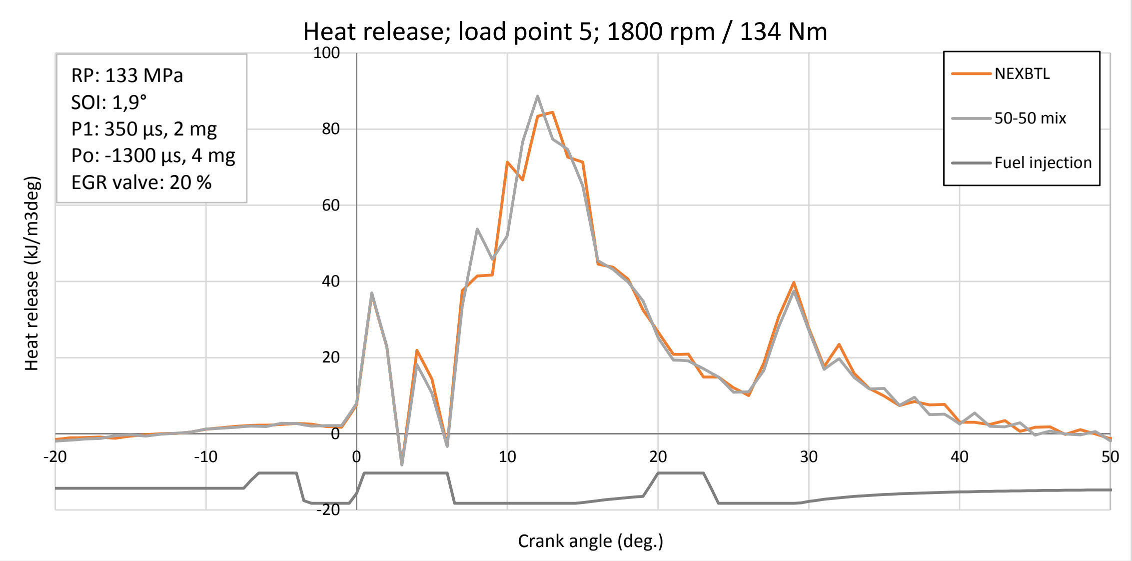


Figure 6.7. Heat release in load point 5, EGR 20 parameters.

6.2.4 Cumulative Heat Release

Apart from load points 2 and 5, the cumulative heat release curves of the test runs with larger EGR valve settings were virtually identical. In load point 2 the maximum value of cumulative heat release of NExBTL was 2.0 % smaller than that of 50-50 % mix (2510 vs. 2562 kJ/m^3). In load point 5 on the contrary, the difference was 2.3 % in favor of NExBTL, with the maximum values of 1184 (NExBTL) and 1156 kJ/m^3 (50-50 % mix), Figure 6.8.

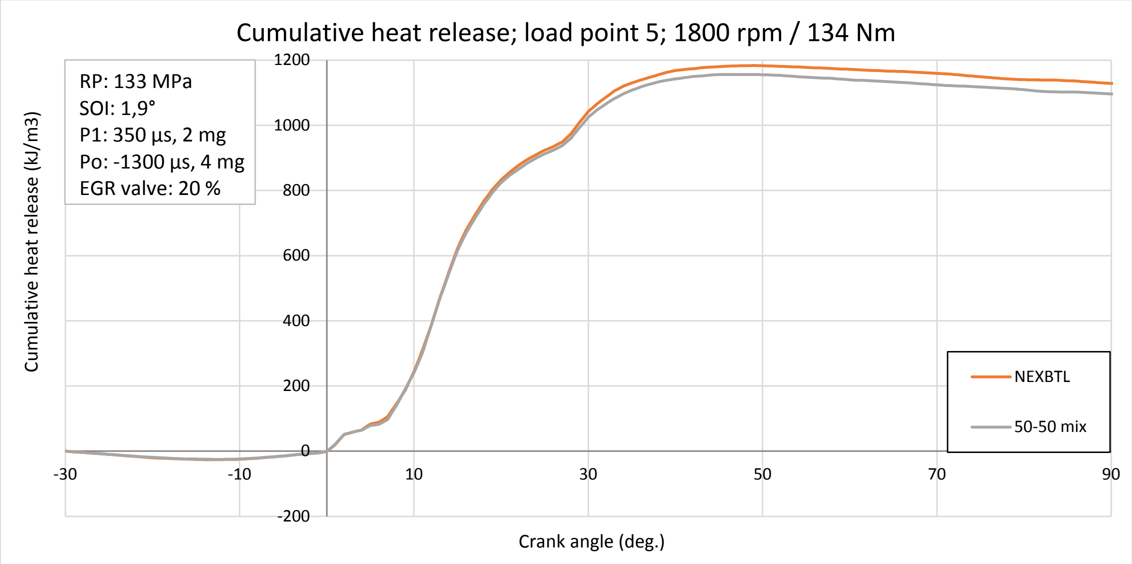


Figure 6.8. Cumulative heat release in load point 5, EGR 20 parameters.

6.2.5 Ignition Delay

When using larger EGR 20 parameters no difference in ignition delays were seen between the two research fuels, Table 6.5. On the other hand, when compared to the reference values for both fuels, use of EGR did slow ignition in load points 1, 5 and 6. The differences were same for both fuels and the biggest difference to base level was 111 µs in load point 1.

Table 6.5. Ignition delays with EGR 20 parameters.

	Ignition delay µs						
	Fuel						
Load point	NExBTL, EGR 15 %	50-50 %-mix, EGR 15 %	diff. 50-50 % -mix-NExBTL	Ref. NExBTL	Ref. 50-50 % -mix	diff. NExBTL: test-ref.	diff. 50-50 %-mix: test-ref.
1	555.6	555.6	0.0	444.4	444.4	111.1	111.1
2	448.7	448.7	0.0	448.7	448.7	0.0	0.0
3	509.3	509.3	0.0	509.3	509.3	0.0	0.0
4	530.3	530.3	0.0	530.3	530.3	0.0	0.0
5	648.1	648.1	0.0	555.6	555.6	92.6	92.6
6	641.0	641.0	0.0	576.9	576.9	64.1	64.1

When compared to the values from the test runs performed with EGR 15 parameters (Figure 6.2.) it can be seen that in load point 2 and 6 the ignition delays were same for both fuels. In load point 1, where EGR valve was closed in both EGR parameters, the only difference was measured with NExBTL, where with EGR 20 parameters the ignition was slightly faster. In load points 3 and 4 the ignition was faster with EGR 20 parameters despite larger exhaust gas recirculation. In load point 5 the values measured with larger EGR valve opening resulted in slower ignition than with lesser EGR valve opening parameters.

6.3 Lower EGR Valve Positions and Optimized Fuel Injection Parameters

In the following test runs the EGR valve positions at each load point were returned to the lower EGR 15 parameters. Simultaneously the fuel injection parameters were optimized so, that the nitrous oxide results, decreased by the use of EGR, increased close to the values measured with diesel fuel oil in reference runs. The objective was to improve the fuel economy and efficiency of the engine. Modified fuel injection parameters are presented in Table 6.6 and the modifications of parameters are highlighted in red colour.

Table 6.6. Optimized fuel injection parameters, EGR 15 opt parameters

		Load point 1		Load point 2		Load point 3		Load point 4		Load point 5		Load point 6	
		REF	EGR 15 OPT	REF	EGR 15 OPT	REF	EGR 15 OPT	REF	EGR 15 OPT	REF	EGR 15 OPT	REF	EGR 15 OPT
Rail pressure	MPa	130	130	135	135	150	150	160	160	130	130	120	120
Injection advance M1	° crankshaft	5.3	5.4	0.7	0.7	4.5	7.0	4.0	8.5	1.9	9.0	0.9	9.0
Injection timing P1	µs	350	350	350	350	350	350	350	550	350	500	350	550
Injection timing P0	° crankshaft	-2000	-2000	-	-	-1725	-1725	-1300	-1300	-1300	-1300	-1300	-1300
Injection quantity M1	mg	92.5	94.2	70.3	71.0	64.5	64.2	37.5	35.2	20.6	17.8	23.6	22.7
Injection quantity P1	mg	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Injection quantity P0	mg	4.0	4.0	0.0	0.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0

The fuel injection parameters were optimized by altering the injection timing of Main 1 and Pilot 1 injections. As the EGR valve was closed in load points 1 and 2, the optimization was done in load points 3-6. As Table 6.6 shows, the Main 1 injection advance was increased, which means that the fuel was injected earlier into the cylinder than in the reference test runs. The injection was advanced by 2.6 degrees (P3), 4.6 degrees (P4), 7.4 degrees (P5) and 8.4 degrees (P6). The Pilot 1 timing was increased in load points 4-6, which means the pilot injection in these points was injected earlier than in the reference runs. In P4 and P6 Pilot 1 injection timing was increased from 350 to 550 µs and in P5 from 350 to 500 µs.

EGR valve openings and calculated EGR % are shown in Table 6.7 below.

Table 6.7. EGR valve opening and calculated EGR % with EGR 15 opt parameters.

	Calculated EGR %		EGR-valve opening %
Load point	Fuel		
	NExBTL	50-50 %-mix	
1	2.0	1.2	0
2	1.3	0.6	0
3	8.4	7.2	5
4	13.7	13.7	10
5	26.2	25.8	15
6	18.6	17.5	15

6.3.1 Gaseous Emissions, Smoke, Fuel Consumption and Efficiency

Advancing the beginning of the main fuel injection in load points 3-6 resulted in differences in NO_X results of the two fuels to vanish. In these load points NExBTL produced only 3 % smaller NO_X results than 50-50 % mix at a maximum (in P3), when before the fuel injection advance optimization the difference was up to 6 %. Overall the greatest difference in nitrous oxides results was measured in load point 1, where NExBTL produced 5.6 % smaller result than the fuel mix.

The optimization of the fuel injection advances brought NO_X clearly closer to reference results of each fuel. In optimized load points 3-6, nitrous oxides measured with EGR 15 opt parameters were 13 % for NExBTL and 11 % for 50-50 % mix smaller at a maximum. In load points 1 and 2, where no optimization was done, the NO_X results were quite similar to the results of EGR 15 test runs.

Similarly to the results from previous test runs pure NExBTL produced lower smoke number results than 50-50 % mix. The numbers of NExBTL were 16 (P1) to 47 % (P4) smaller. Compared to the results from the reference tests EGR 15 opt parameters produced significantly higher smoke numbers for both research fuels.

Specific fuel consumption was quite similar for both fuels and volumetric fuel consumption of 50-50 % mix was lower than with NExBTL. The volumetric values of blended fuel were smaller by 2.2 (P3) to 4.2 (P6) %.

Both SFC and volumetric fuel consumption did improve with optimized timing of the fuel injections. At a maximum, in load point 5, SFC and volumetric fuel consumption measured with both fuels were up to 8 % lower in the EGR 15 opt test runs than the reference results. Without fuel injection parameter optimization the results were about 4 % and 6 % lower than the reference figures, for NExBTL and 50-50 % mix respectively.

Similar improvements were seen in calculated efficiency of the engine. Similarly to the previous test runs, the maximum difference in efficiency of the engine was measured in load point 5. The reference engine efficiencies were about 8 % lower for both research fuels in load point 5. Without the injection parameter optimization the same differences to reference were about 4 and 6 % for NExBTL and 50-50 % mix respectively.

6.3.2 Cylinder Pressure

Cylinder pressure of NExBTL was higher than 50-50 % mix in all load points in the test runs performed with optimized EGR 15 parameters. The greatest difference in maximum cylinder pressures was measured in load point 6, Figure 6.9. The difference in peak values was 3.5 % (79.4 vs. 76.6 bar).

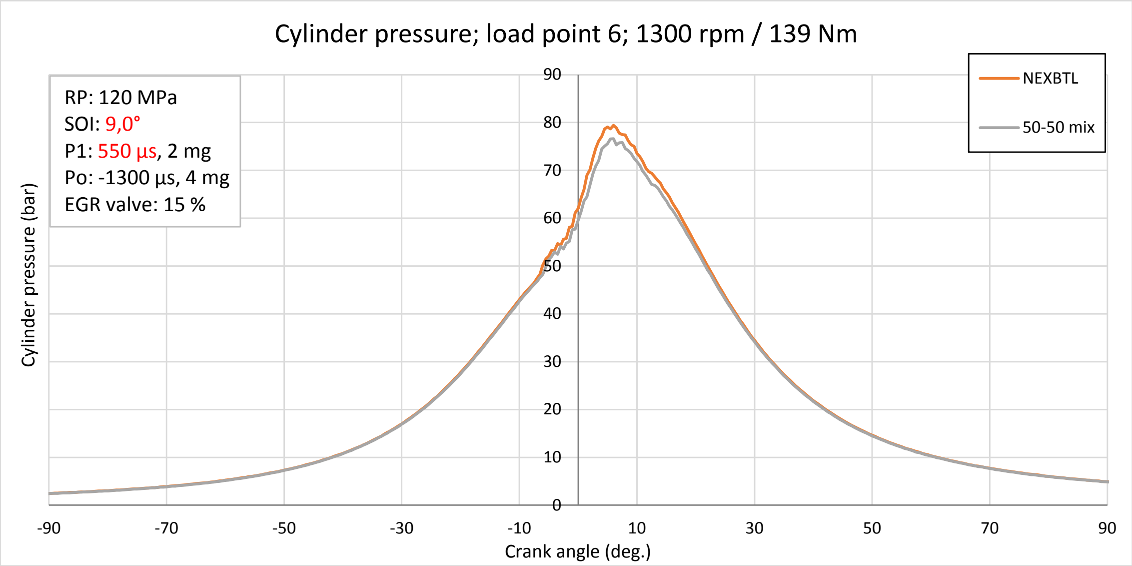


Figure 6.9. Cylinder pressures in load point 6, EGR 15 opt parameters.

6.3.3 Heat Release

In load points 1 and 2, where the fuel injection parameters were not altered, the heat release curves between the two research fuels were quite similar. In these load points the EGR valve was also closed.

Similarly to the previous test runs, in load points 3, 4 and 5 the pilot injection produced several heat release peaks, Figure 6.10. Also the heat release curves at these load points were quite unstable. This trend was also similar to the results of the previous test runs.

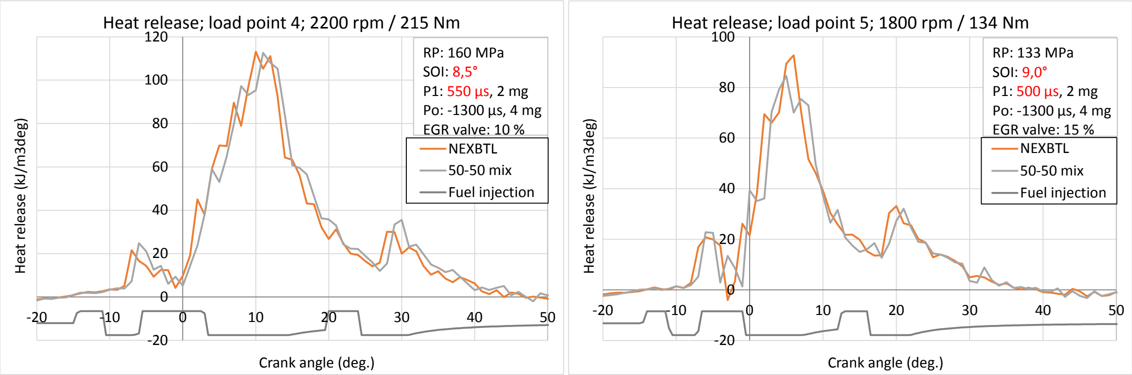


Figure 6.10. Heat releases in load points 4 and 5, EGR 15 opt parameters.

In load points 4, 5 and 6 it was clearly seen that NExBTL produced faster ignition than 50-50 % mix, Figure 6.10 and 6.11. The greatest ignition delay difference of 128 µs was measured in load point 6. These results were quite logical as NExBTL has higher cetane number than 50-50 % mix.

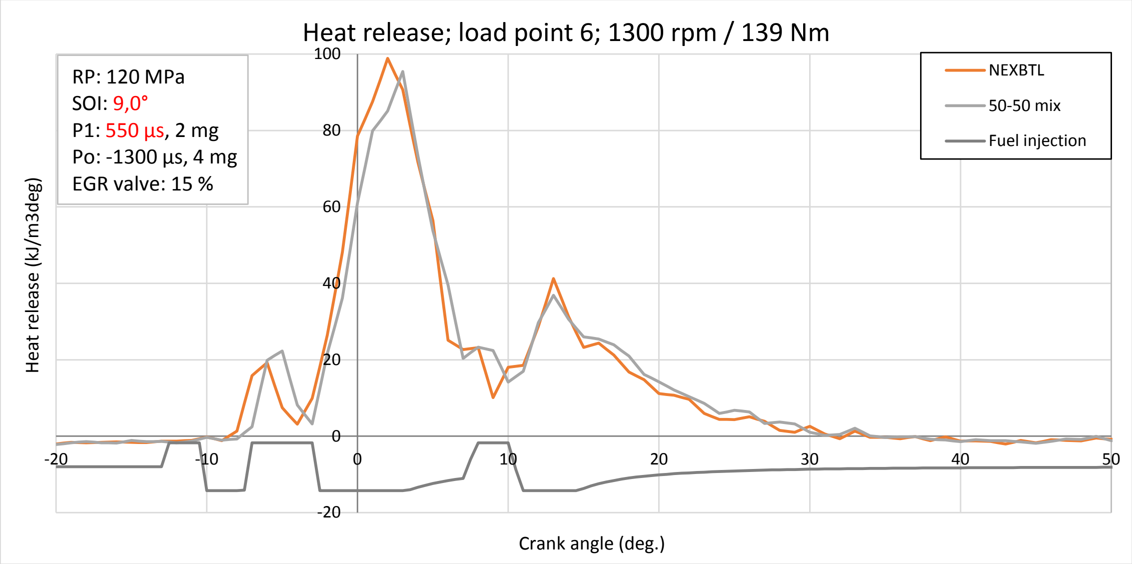


Figure 6.11. Heat release in load point 6, EGR 15 opt parameters.

The greatest difference in peak heat release values was measured in load point 5, Figure 6.10. In this load point the peak heat release value of fuel blend was 8.8 % lower than similar value of NExBTL (84.6 vs. 92.7 kJ/m^{3}deg).

6.3.4 Cumulative Heat Release

Cumulative heat release curves in the first three load points (P1-P3) were quite equal for both fuels. In load point 4 blended 50-50 % fuel mix produced slightly higher peak value of cumulative heat release. On the contrary the greatest difference in peak values of cumulative heat release was recorded in load point 5, Figure 6.12. The peak value of blended fuel was 4.4 % smaller than the peak value of NExBTL (1142 vs. 1091 kJ/m^3).

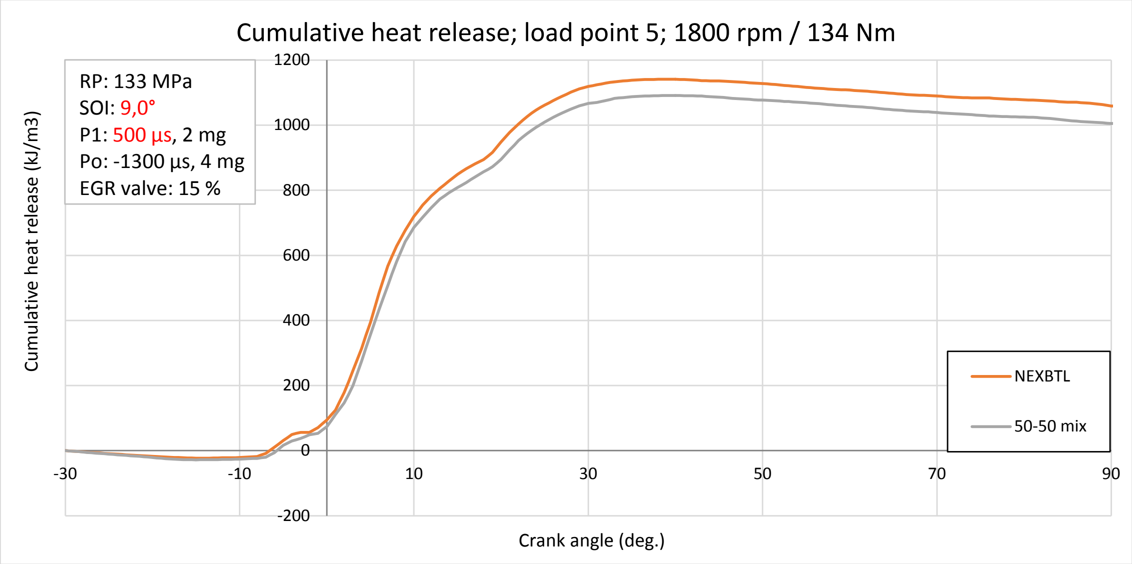


Figure 6.12. Cumulative heat release in load point 5, EGR 15 opt parameters.

It can be clearly seen in the cumulative heat release curves from load point 6 that NExBTL ignited faster and produced heat release rates earlier than blended fuel, Figure 6.13.

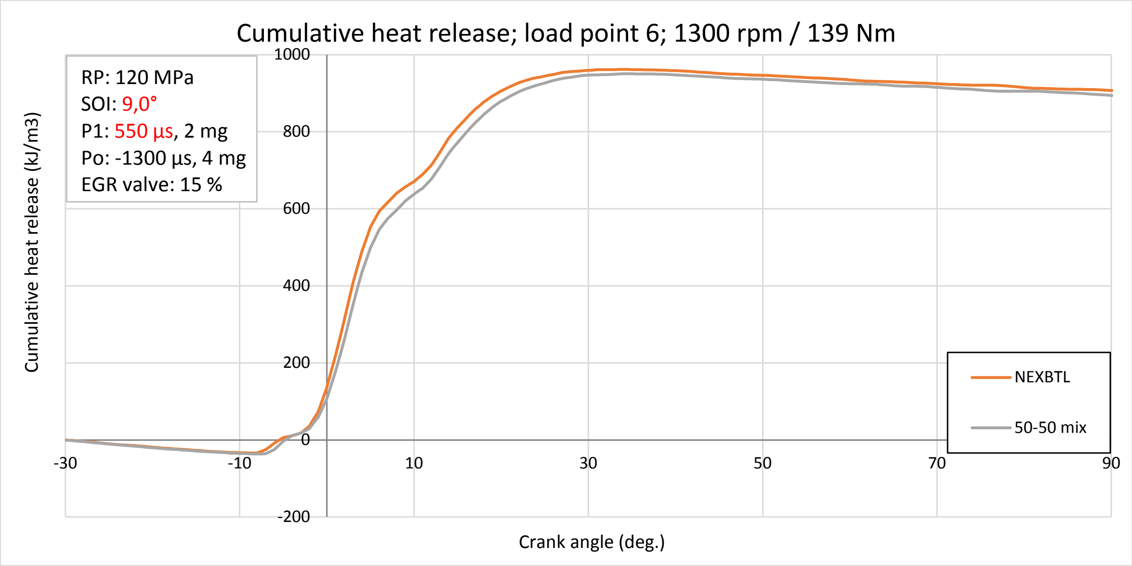


Figure 6.13. Cumulative heat release in load point 6, EGR 15 opt parameters.

6.3.5 Ignition Delay

NExBTL produced faster heat release results than 50-50 % mix in load points 4, 5 and 6, Table 6.8. The biggest difference of 128 µs was recorded in load point 6, with biggest EGR valve opening.

Compared to the reference ignition delay results it was seen that with NExBTL the ignition delays were slightly longer in load points 1, 3, 5 and 6 when using EGR 15 opt parameters.

EGR 15 opt parameters resulted in longer ignition delays for 50-50 % fuel mixture at all load points, except load point 2, when comparing results to the reference results of this fuel. Especially in the load points 5 and 6, where biggest EGR valve opening values were used, the difference in ignition delays was significant.

Table 6.8. Ignition delays with EGR 15 opt parameters.

	Ignition delay µs						
	Fuel						
Load point	NExBTL, EGR 15 %	50-50 %-mix, EGR 15 %	diff. 50-50 %-mix-NExBTL	Ref. NExBTL	Ref. 50-50 %-mix	diff. NExBTL: test-ref.	diff. 50-50 %-mix: test-ref.
1	500.0	500.0	0.0	444.4	444.4	55.6	55.6
2	448.7	448.7	0.0	448.7	448.7	0.0	0.0
3	555.6	555.6	0.0	509.3	509.3	46.3	46.3
4	530.3	606.1	75.8	530.3	530.3	0.0	75.8
5	601.9	694.4	92.6	555.6	555.6	46.3	138.9
6	641.0	769.2	128.2	576.9	576.9	64.1	192.3

6.3.6 Summary of In-Cylinder Results

When comparing in-cylinder results with three different EGR parameters, the greatest differences were seen at load points 3-6, where the engine fuel injection and EGR parameters differed the most.

The highest peak values of cylinder pressure in these load points were recorded with EGR 15 opt parameters for both fuels, where beginning of fuel injection was advanced, Figures 6.14 and 6.15. In load points 3 and 4 the reference cylinder pressure was only slightly above the results from the test runs performed with EGR 15 and EGR 20 parameters.

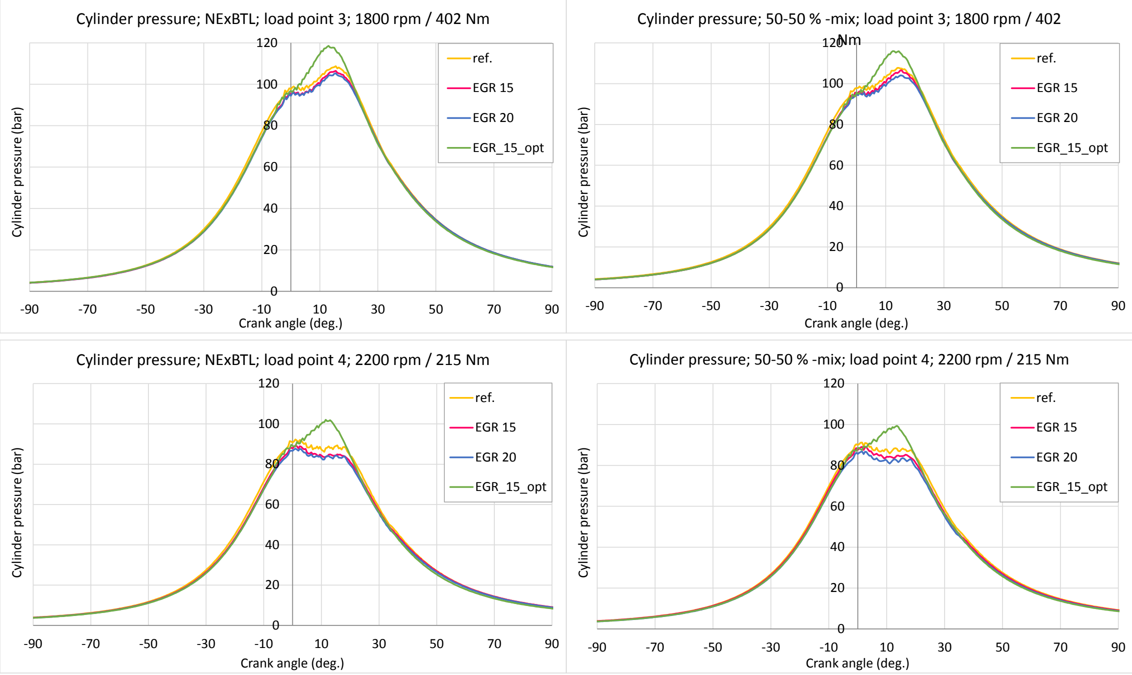


Figure 6.14. Cylinder pressures from EGR test runs in load points 3 and 4.

In load points 5 and 6 the use of the exhaust gas recirculation dropped the cylinder pressures considerably with both research fuels. With advanced beginning of the fuel injection (EGR 15 opt parameters) the maximum cylinder pressures rose above the reference values, Figure 6.15.

In load points 3-6 it was clearly seen that heat was released earlier in the results of the EGR 15 opt parameters with the both fuels, Figures 6.16 and 6.17. This was result from advanced beginning of the fuel injections. Similarly to the previous test run results, the heat releases curves from load points 3-5 were quite unstable.

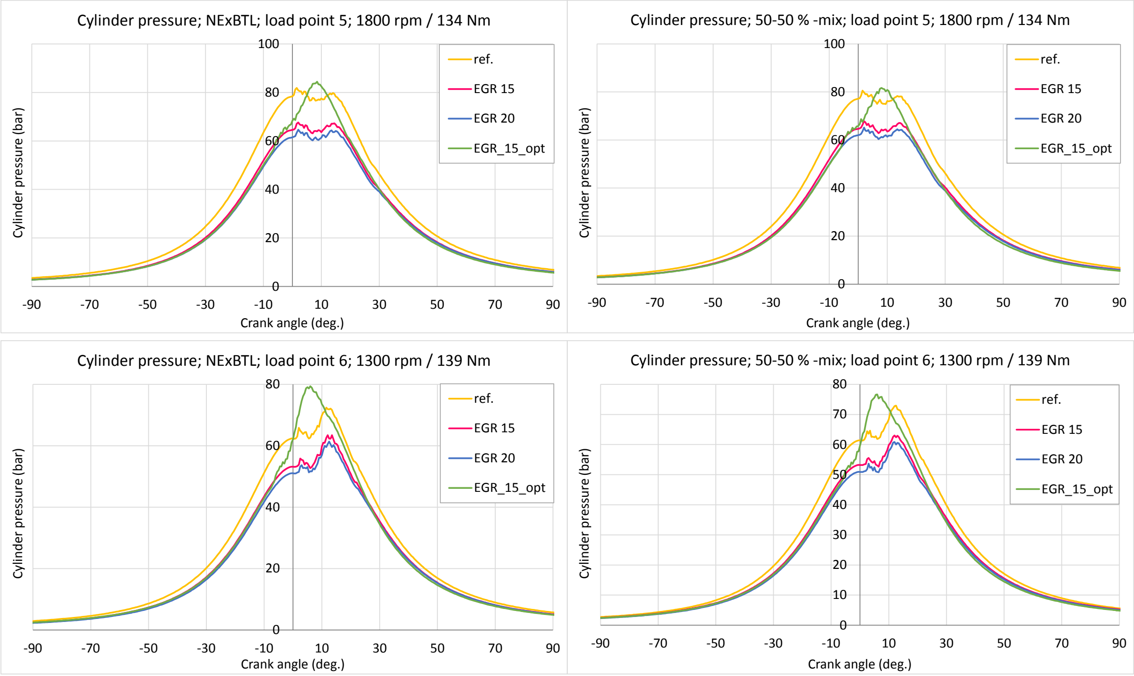


Figure 6.15. Cylinder pressures from EGR test runs in load points 5 and 6.

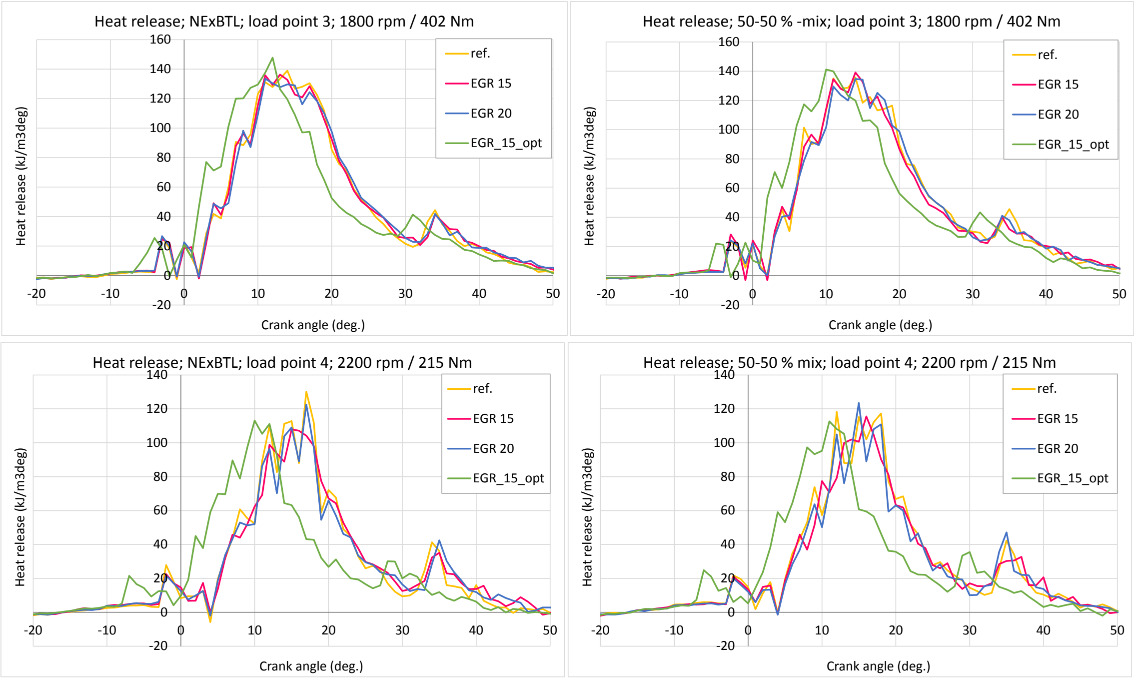


Figure 6.16. Heat releases from EGR test runs in load points 3 and 4.

In load points 5 and 6 the peak heat release values from reference test runs were highest with both fuels tested, Figure 6.17.

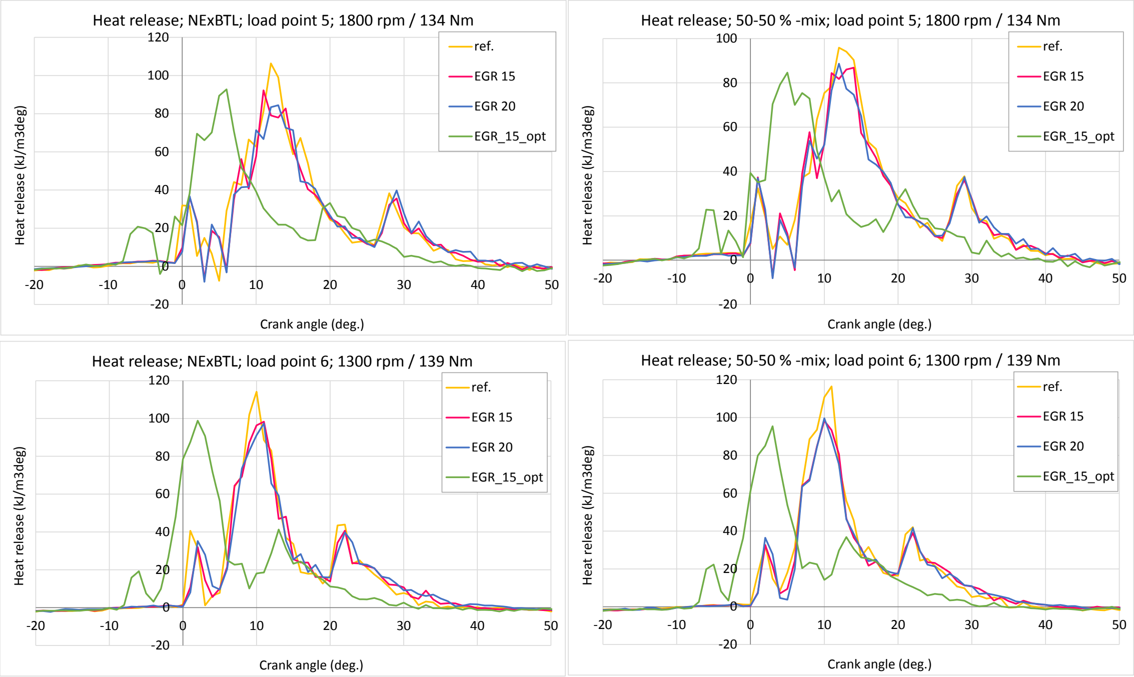


Figure 6.17. Heat releases from EGR test runs in load points 5 and 6.

Cumulative heat release results from test runs performed with EGR 15 opt parameters were overall lowest in load points 3-6 with both research fuels, Figures 6.18 and 6.19.

In load points 5 and 6 the reference cumulative heat releases measured with 50-50 % fuel mix were significantly higher than the results from the test runs with EGR 15 and EGR 20 parameters when using the same fuel, Figure 6.19. With NExBTL the difference between the results of NExBTL reference and the EGR 15 and 20 were not as significant as with fuel blend, as the reference cumulative heat releases of NExBTL were lower than 50-50 % mix at these load points.

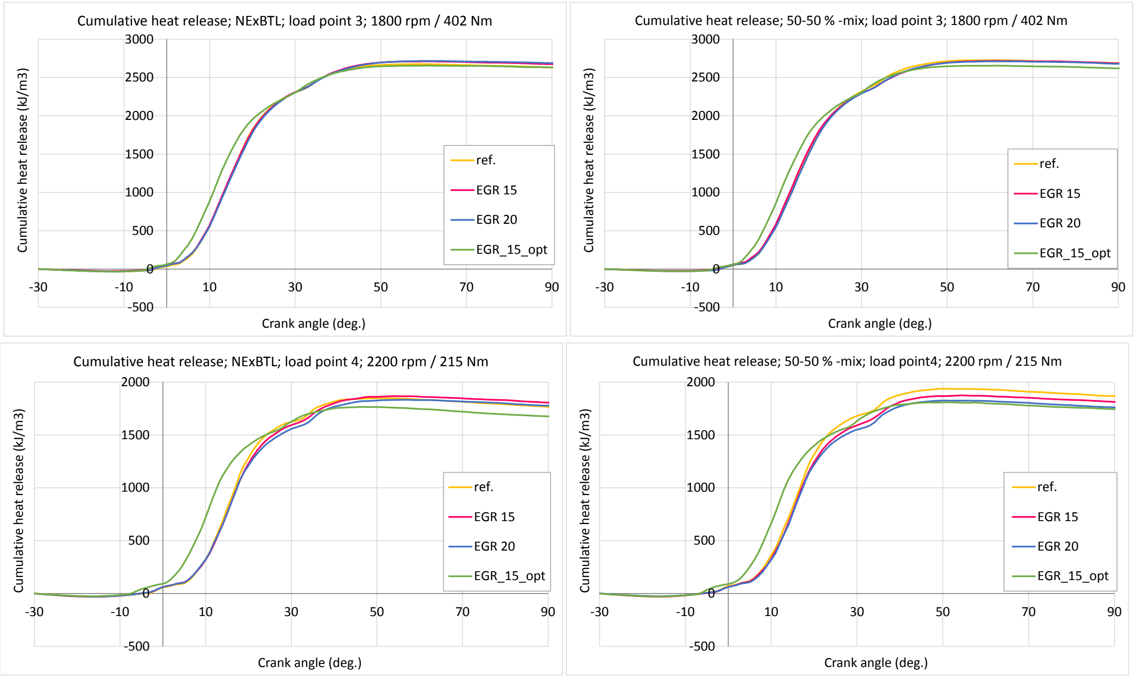


Figure 6.18. Cumulative heat releases from EGR test runs in load points 3 and 4.

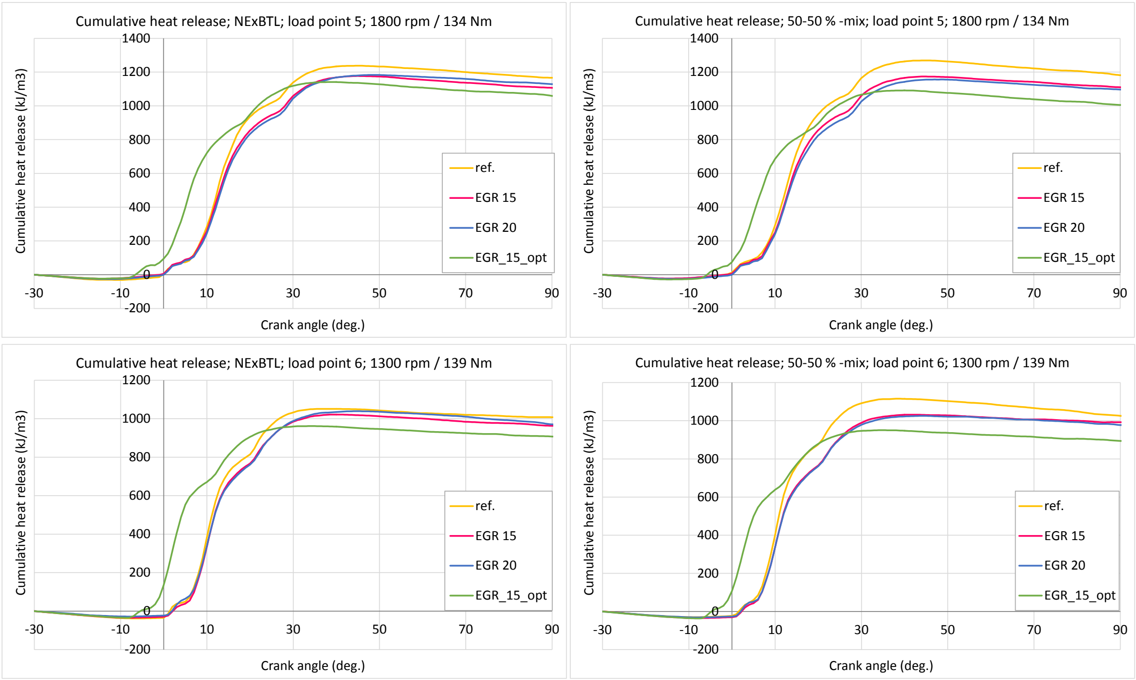


Figure 6.19. Cumulative heat releases from EGR test runs in load points 5 and 6.

7 RESULTS OF TRANCIENT CYCLE

As the last part of the research matrix a nearly 16 minute long transient cycle was run with DFO and both research fuels. The cylinder pressure data was not possible to collect from the transient cycle runs. Also smoke number results were not possible to measure from these runs. For the transient test runs the EGR system was disabled.

The main results of the transient test cycle are presented in Table 7.1 below.

Table 7.1. Results of the transient test cycle.

Fuel	NO_X	Engine efficiency	SFC	Total fuel consumption
	g/kWh	%	g/kWh	liters
DFO	6.6	37.0	226.5	4.4
NExBTL	6.6	37.3	220.2	4.6
50-50 % -mix	6.5	37.2	222.7	4.5

Virtually no difference in nitrous oxide results were measured in the transient cycle between DFO and the two research fuels. All fuels produced NO_X results within 0.1 g/kWh of each other. Pure NExBTL and blended 50-50 % mix produced slightly better results of engine efficiency. Similarly to the steady state results the biggest SFC was measured with diesel. Total fuel consumption on the other hand was 0.2 liters smaller with diesel fuel oil than with NExBTL. Total fuel consumption of 50-50 % mix was in between of DFO and NExBTL results. This is quite logical as diesel has highest density of the three fuels. The density of 50-50 % mix is naturally in the middle of densities of NExBTL and DFO.

Overall the results measured in transient test cycles of the three fuels were quite close to each other. Results were also quite logical when compared to the previous steady state results of all three fuels.

8 COMPARISON OF EXPERIMENTAL RESULTS TO LITERATURE AND OTHER STUDIES

In this paragraph the results from the experimental test runs performed are compared to the theoretical information and findings from other similar studies. The comparison to the theory focuses on the main phenomenon in engine parameter optimization, and their effects on engine performance and in-cylinder results.

As previously described, the assumption of this study was, that pure NExBTL and blended 50-50 % mix would produce lower NO_X results than the standard diesel fuel oil. With optimization of the fuel injection parameters, with the two research fuels, the NO_X results would be brought back up at each load point, close to the results measured with DFO. Thus the fuel injection parameter optimization concentrated mainly on increasing the NO_X, which same time usually results in gains in fuel consumption of the engine and lower smoke and particle emissions. As the initial gains in nitrous oxides with the research fuels compared with DFO were quite modest, the optimization steps of each parameter were therefore quite minor.

8.1 Fuel Injection Advance

Advancing the start of the fuel injection produces higher maximum value of cylinder pressure and produces earlier heat release. Earlier fuel injection results in higher local and maximum temperatures in cylinder, which lead to increase in NO_X. With the later injection more of the fuel burns during the later period of expansion stroke, where the temperature decreases and that is why the maximum temperature in the cylinder is lower. (Hsu 2002, 64-69)

Earlier fuel injection also produces longer ignition delay and higher initial peak of heat release. The relative cylinder efficiency of the earlier injection is higher which results in better fuel consumption. In the case of later fuel injection more fuel is burned closer to the end of the expansion cycle and thus the soot generated during this period has less time to burn off, which results in higher smoke/PM results. (Heywood 1988, 562; Hsu 2002, 64-69)

In the results from the experimental test runs, performed with advanced timing of the main fuel injection, several phenomenon similar to the theoretical statements were noticed. The NO_X results increased and the smoke decreased. Virtually no changes were seen in the fuel consumption results.

Advancing the beginning of the main fuel injection did result in higher maximum cylinder pressures in all load points for both research fuels, as stated in the theory. The difference in cylinder pressures can be seen from Figure 8.1 (NExBTL, P2).

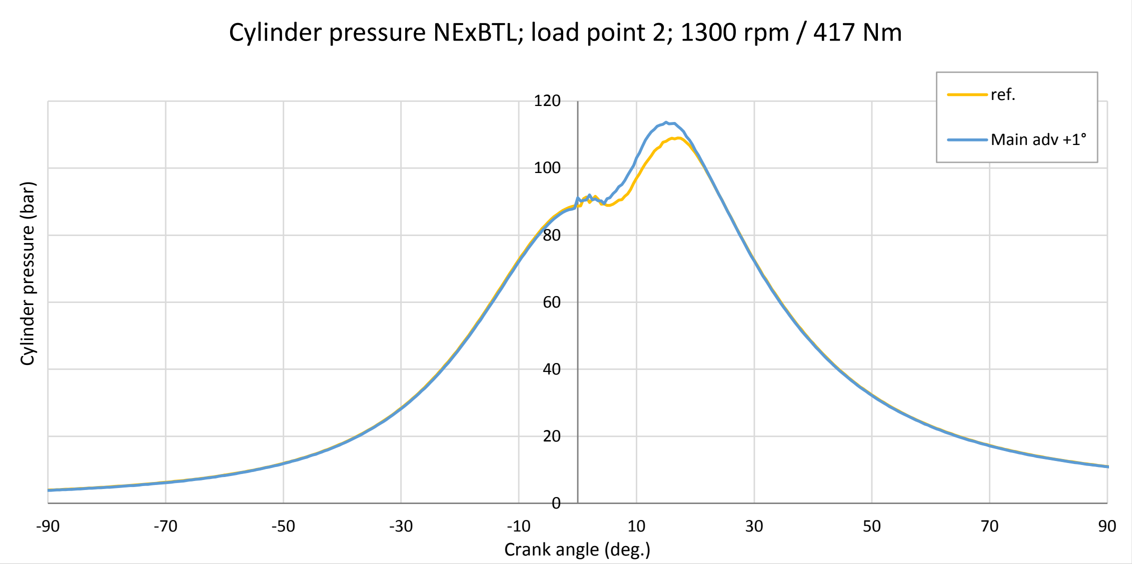


Figure 8.1. Cylinder pressure with reference and advanced main injection for NExBTL.

The heat release curve did shift to earlier crank angle values with earlier fuel injection timing in all load points with the both research fuels. Clearly higher initial peak of heat release was not widely detected. The shift of heat release curve is shown in Figure 8.2 (NExBTL, P2).

Slight increase in ignition delay was measured only with 50-50 % fuel mix in load points 1 and 5.

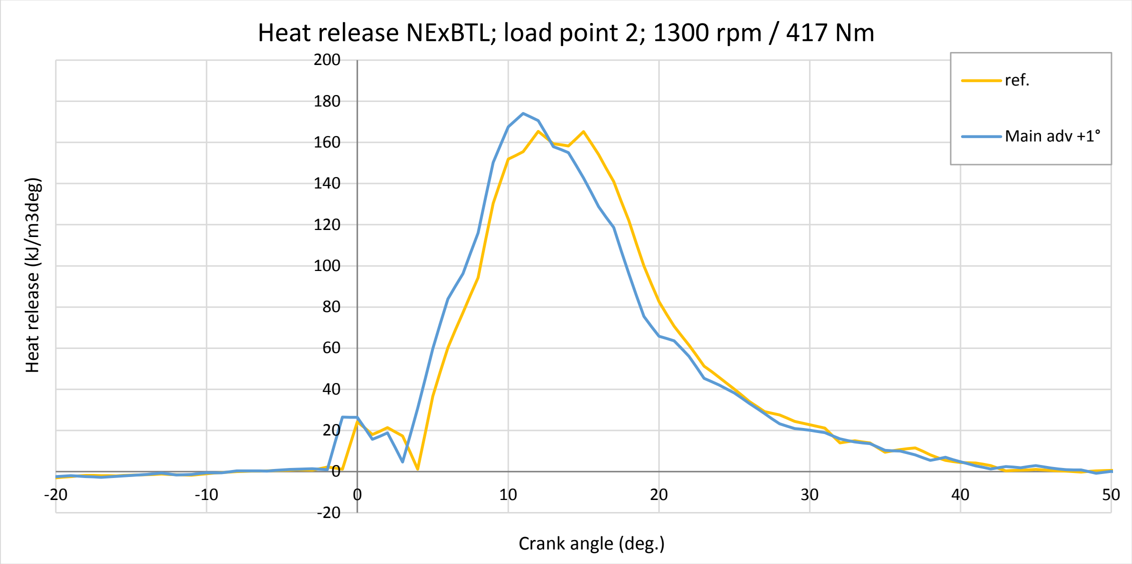


Figure 8.2. Shifted heat release with advanced timing of main injection for NExBTL.

8.2 Injection Pressure

Increasing fuel injection pressure results in better mixing of fuel and air in cylinder. The fuel spray atomization increases and this leads to faster mixing and burning, which can also be seen in faster heat release. The local peak temperatures in the cylinder rise and this leads to increases in NO_X. The biggest advantages of higher fuel injection pressure are seen in lesser smoke, due to the better mixing of air and fuel. Gains in fuel consumption are seen, especially at later fuel injection timings. Increasing the injection pressure also often results in higher initial peaks of heat release. (Heywood 1988, 560-562; Hsu 2002, 43-44; Mollenhauer et al. 2010, 451-452)

When inspecting results from test runs performed with higher fuel injection pressures, it was seen that NO_X did rise with increase in pressure, similarly to the theory. However, in this case higher fuel injection did not result in big advantages for smoke or fuel consumption.

The maximum cylinder pressure was slightly higher with increased fuel injection pressure in nearly all load points with both research fuels. Example of this is shown for NExBTL in Figure 8.3.

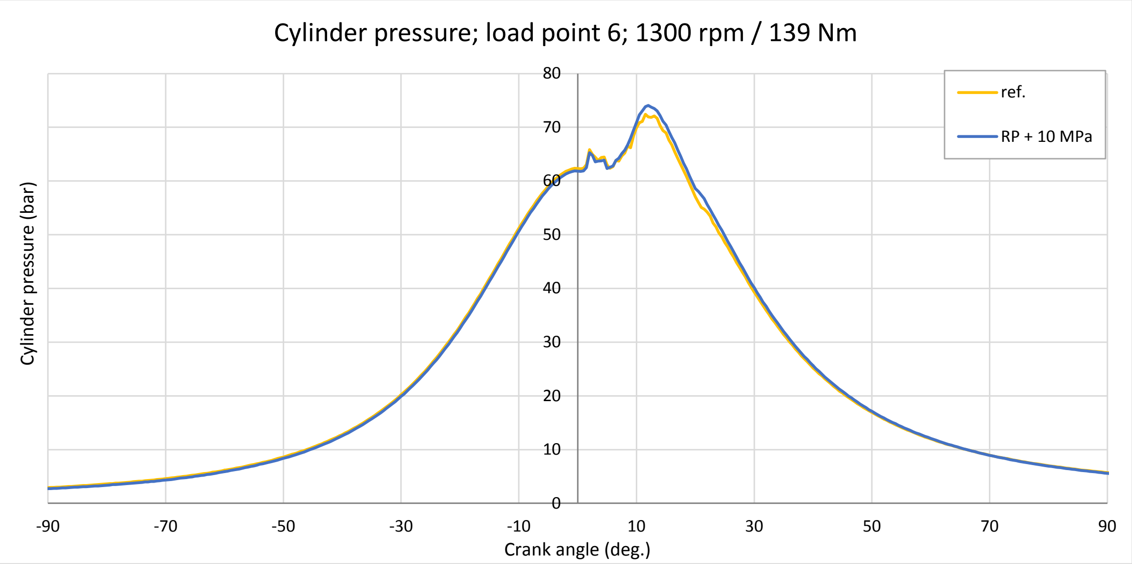


Figure 8.3. Cylinder pressure with standard and higher fuel injection pressure for NExBTL.

Higher initial peaks of heat release were not widely measured. In some load points faster heat release was seen with higher fuel injection pressure. For NExBTL this can be seen in load point 6 in Figure 8.4.

Similarly to theoretical statement virtually no changes in ignition delays were seen when fuel injection pressure was increased.

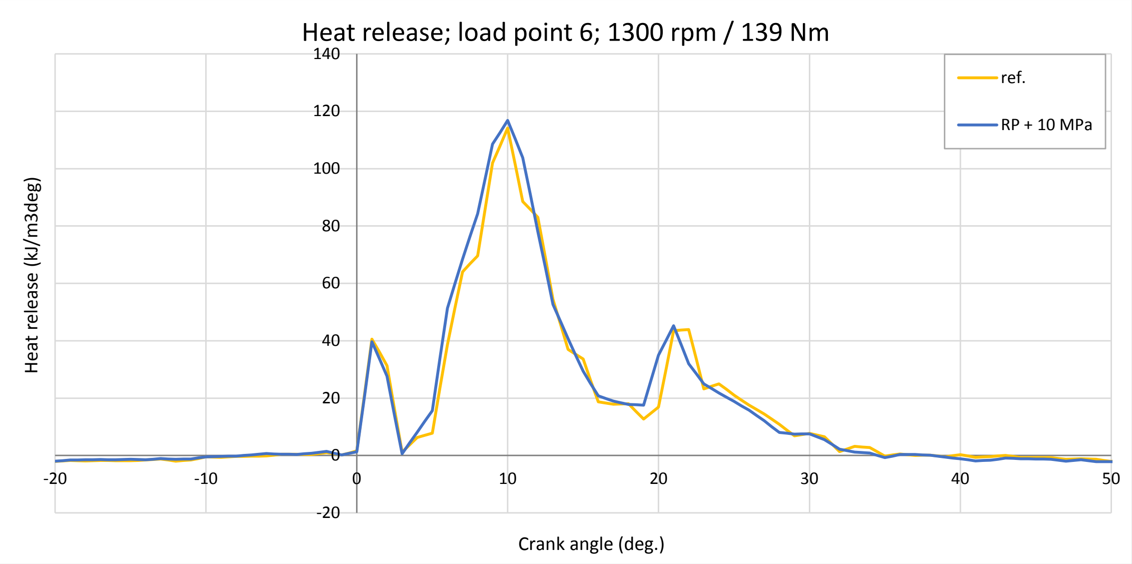


Figure 8.4. Heat release with standard and higher fuel injection pressure for NExBTL.

8.3 Pilot Injection

Pilot injection has been widely used to reduce combustion noise in the diesel engines. Usually the use of the pilot injection increases pressure and temperature in cylinder before the actual main injection, which shortens the ignition delay time of the main injection. Ignition peak of the cylinder pressure with no pilot injection is later than with activated pilot injection. Larger quantity of pilot injection usually results in faster ignition. Use of pilot injection can minimize high heat release peak of premixed combustion phase. (Heywood 1988, 505-506; Mollenhauer et al. 2010, 453-454)

Changes in the peak of the cylinder pressures were seen clearest in load point 6, Figure 8.5. As it can be seen from the test run with NExBTL, the rise of the cylinder pressure starts clearly later when pilot injection is deactivated.

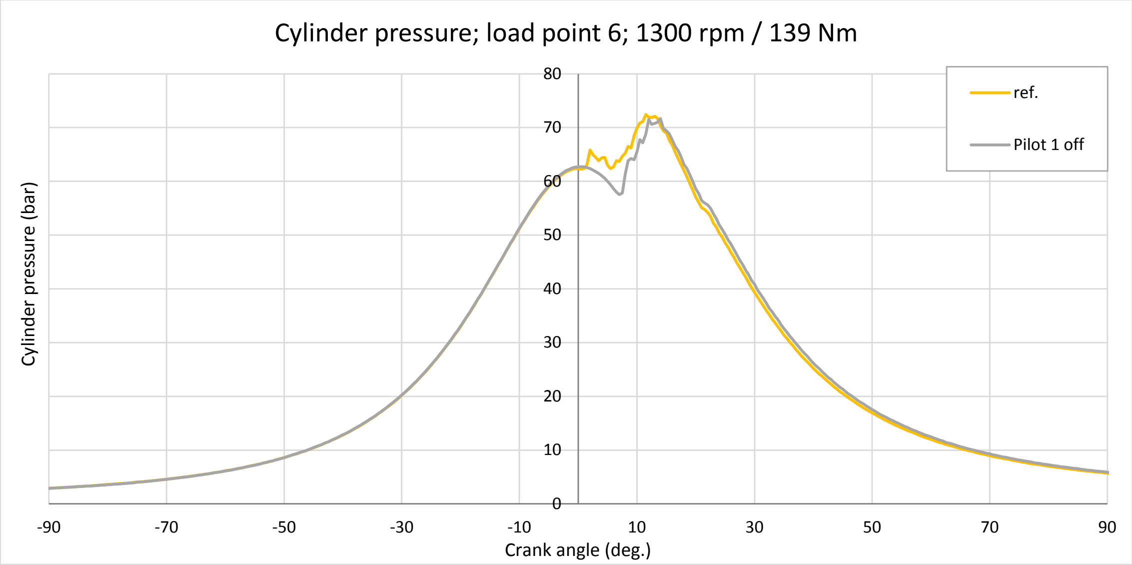


Figure 8.5. Cylinder pressure with pilot injection activated and deactivated for NExBTL.

Similarly to the theory the ignition delays were shorter when pilot injection was in use, but only at the lower engine loads in P5 and P6. Determining the beginning of the actual injection proved to be challenging as it was not clear whether small portion of pilot injection was in use after all by an error.

As Figure 8.6 shows the heat releases without pilot injection were quite different in load point 6 for NExBTL. With deactivated Pilot 1 injection the increase in heat release did start later than in reference. At this load point the heat release peak of premixed combustion phase can be clearly seen when the pilot injection is deactivated.

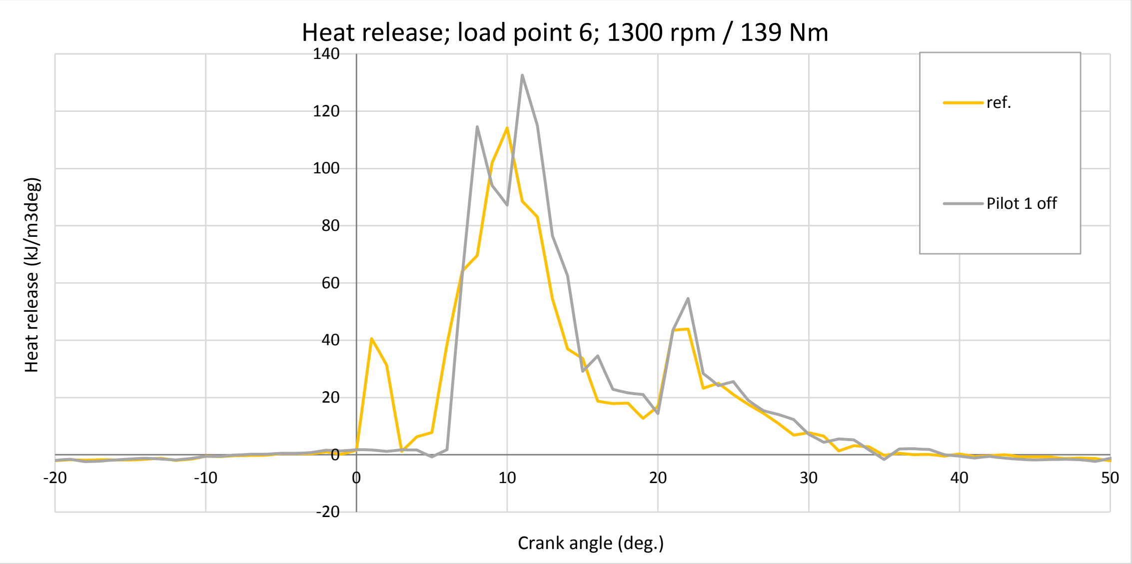


Figure 8.6. Heat release with pilot injection activated and deactivated with NExBTL in load point 6.

In load points 1 and 2 the heat releases with no pilot injection and reference did start at approximately same time for the main injections, when observed from heat release curves, Figure 8.7.

Generally the peaks of heat release were higher with deactivated pilot injection in all load points for both fuels compared.

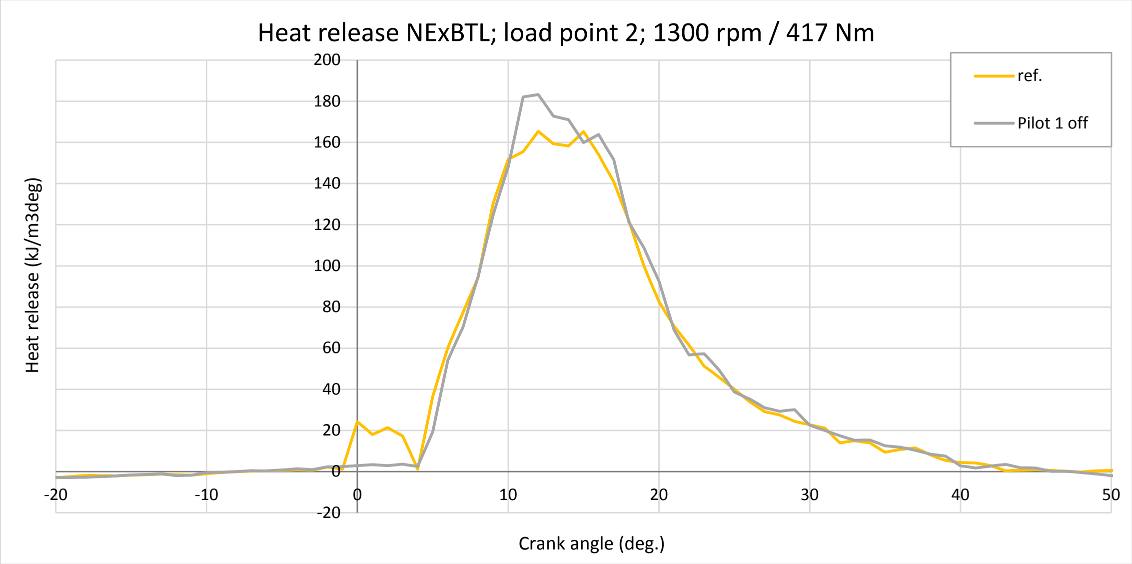


Figure 8.7. Heat release with pilot injection activated and deactivated with NExBTL in load point 2.

8.4 Comparison with Other Studies

Results presented in this thesis were compared to the results from several studies. The most notable of these studies were Master Thesis of Michaela Hissa (University of Vaasa 2014) and SAE publications by Sugiyama et al. (2011) and Aaltola et al. (2008). In these studies HVO fuel was compared with DFO and in some cases with HVO-DFO blends and bio-diesels. The comparison to this study is possible as NExBTL is HVO based fuel.

The engine used in the Master Thesis of Hissa was quite similar to the engine used in this thesis. Sugiyama et al. used an EGR equipped modern common rail injection passenger car engine in engine and chassis dynamometer (displacement 2.2 litres). Heavy duty direct injection diesel engine was used in research by Aaltola et al.

8.4.1 Heat Release, Ignition Delay and Cylinder Pressure

Sugiyama et al. reported that due to the higher cetane number of HVO, the ignition delay was clearly shorter than with DFO in all load conditions when the pilot injection was not in use. The difference was especially visible under low engine loads, because the gas temperatures in the cylinder at the start of the combustion were lower. The differences declines as the gas temperature rises with increase in the engine torque. (Sugiyama et al. 2011, 6)

When the pilot injection was enabled in studies by Sugiyama et al., the benefits of high cetane number of HVO diminished, and almost no difference was seen in the ignition delays and heat release curves of HVO and DFO. This was due to the increase in gas temperatures in the cylinder at the start of the combustion, caused by pilot injection. (Sugiyama et al. 2011, 7-8)

Similarly to the results from studies by Sugiyama et al. no significant differences in ignition delays were seen between NExBTL and DFO in this study. Pilot injection was in use when comparisons between DFO, pure NExBTL and 50-50 % fuel blend were made. It is debatable whether differences in ignition delay, heat release and cylinder pressure between these fuels would have been more visible if the comparison tests would be performed also without pilot injection.

When pilot injection was off, in comparison test runs of NExBTL and 50-50 % mix, the ignition delay differences increased in load points 5 and 6, with lower engine loads. These results were similar to the results of Sugiyama et al. However it was debatable whether in test runs of this study small amount of pilot injection was in use after all.

Similarly to the results presented in the Master Thesis of Michaela Hissa, where pilot injection was also in use, the results from this study showed that diesel produced higher peaks of cylinder pressure than NExBTL/HVO in all load points. Also in both researches the cylinder pressures were quite unstable at higher engine speeds and low engine loads. As a result of this the derived heat release curves were quite unstable in these load points. (Hissa 2014, 41, 46, 51-52, 131)

8.4.2 Nitrous Oxides and Smoke

Sugiyama et al. reported that when pilot injection was not used, HVO decreased the nitrous oxide results when compared to DFO. This was due to the shorter ignition delay of HVO, because of the higher cetane number. In the test runs by Sugiyama et al. performed with pilot injection no decrease in NO_X was observed. Aaltola et al. reported that with default settings of the engine NO_X decreased about 5 % on an average when using HVO. (Aaltola et al. 2008, 5-6; Sugiyama et al. 2011, 6-7)

The NO_X results presented in the thesis of Hissa were lower with HVO than with DFO in all loads at the intermediate engine speed (1500 rpm) and at higher loads at rated engine speed (2100 rpm). The pilot injection was in use in these load points. (Hissa 2014, 56)

In the results of this study NO_X of NExBTL was lower than that of DFO only in load points 3-6 in the runs with standard fuel injection parameters. The difference was about 2 % at a maximum. Load point 3 had quite high engine torque and load points 4-6 were with lower engine loads at a various engine speeds. With the reference fuel injection parameters the pilot injection was in use in all load points.

The reductions in nitrous oxides measured in this study were not as high as in some of the previous studies. It is debatable whether NO_X reduction would be higher without the use of the pilot injection, as these test runs were not performed with DFO.

The smoke results in all studies proved to have similar trend, as HVO/NExBTL generally produced clearly lower smoke numbers than DFO. This was due to the lack of aromatics in the HVO fuel. Similarly to results in several studies, the results of this study showed smoke reductions of over 30 %. (Aaltola et al. 2008, 5-6; Sugiyama et al. 2011, 7-8, 10; Hissa 2014, 54)

Study by Happonen et al. showed that addition of oxygenate to HVO fuel could reduce particle emission further without significantly effecting the nitrous oxides results. Results of up to 25 % reduction in particulate mass were seen with addition of DNPE (di-n-pentyl ether) to HVO with the maximum increase in NO_X of 5 %. However, several problems need to be resolved before wide use of this technique could be possible. (Happonen et al. 2013, 385)

8.4.3 Fuel Consumption

Fuel consumption in the experimental results of this study compared to the results from studies by Aaltola et al. and Hissa were similar, as in all three studies gravimetric fuel consumption with HVO/NExBTL was about 2-3 % lower than with DFO. Simultaneously volumetric fuel consumption of HVO/NExBTL did increase from the results of DFO. This was due to the HVO having lower volumetric heating value than diesel. (Aaltola et al. 2008, 2-6; Hissa 2014, 138, 150)

9 CONCLUSIONS

The following conclusions can be made from the results of this research:

- The greatest benefits of using NExBTL and fuel blend of 50-50 % were seen in the reduced smoke numbers in all load points compared to the standard DFO. Benefit in smoke was due to the lack of aromatics in NExBTL. Fuel mix of 50-50 % showed also clear benefits in smoke numbers when compared to DFO.
- Pure NExBTL produced quite similar results of nitrous oxides compared to DFO. Fuel blend of 50-50 % showed lowest NO_X results of all three fuels. The difference to DFO in these load points was about 2 % at a maximum.
- Use of NExBTL lowered the gravimetric fuel consumption compared to DFO, but simultaneously volumetric fuel consumption was higher. The fuel consumption results of fuel blend were in between of pure NExBTL and DFO. This was due to the lower volumetric heating value of NExBTL.
- Only slightly shorter ignition delays were seen with pure NExBTL compared to the two other fuels. Possibly this was because the use of the pilot injection in comparison test runs with DFO diminished benefits of higher cetane number of NExBTL.
- Due to the low reduction of nitrous oxides with NExBTL and 50-50 % mix, no significant gains in fuel consumption was achieved with fuel injection parameter optimization. The objective was to keep NO_X at the level of DFO.
- Use of the EGR to reduce nitrous oxides was beneficial with both research fuels, as the standard smoke number results of these fuels were significantly lower when compared to DFO. In the EGR runs NExBTL produced lower NO_X than 50-50 % fuel blend. However, the use of the EGR increased smoke numbers quite significantly even with NExBTL.
- When the fuel injection parameters of the EGR engine using NExBTL and 50-50 % mix were optimized, fuel consumption gains of up to 8 % compared to reference results with DFO were recorded. In this situation

however, smoke numbers were significantly higher than the reference results.

10 SUMMARY

The emissions of off-road diesel engines have been limited widely by the legislation for the last 20…25 years. The legislation guides manufacturers to produce engines with less emissions. Simultaneously it is estimated that oil reserves of the world are running out. This leads to situation where the greatest challenges in diesel engine development are in decreasing of nitrous oxides (NO_X), smoke and particulate matter (PM) and fuel consumption. To improve greenhouse gas emissions and sustainability, a direction towards use of bio and renewable fuels has been taken.

Finnish oil and refining company Neste Oil has developed a renewable fuel called NExBTL. The fuel is produced by Hydrotreatening of Vegetable Oils (HVO) and method can be used also for animal fats. The NExBTL has similar chemical properties to fossil diesel but has among other things, higher cetane number and does not include aromates. It can be blended to fossil diesel up to all proportions.

In this thesis the results from the test runs with pure NExBTL were compared to the results of test runs with standard diesel and fuel blend of the two (50-50 % mix). First, fuels were run with standard fuel injection parameters to determine base performance of each fuel at six steady state load points. After this the fuel injection parameter optimizations were performed with NExBTL and 50-50 % fuel mix at same load points. In the next phase of the study the engine was equipped with exhaust gas recirculation (EGR) system and ran in steady state load points with two different EGR valve settings and additionally with altered fuel injection parameters. In the final part of the study the engine was used in transient cycle.

The results of this study showed several benefits of using NExBTL and 50-50 % mix in off-road diesel engine. Biggest benefits of using NExBTL and fuel blend were seen in reduced smoke numbers in all load points compared to the standard DFO. Benefit in smoke was due to the lack of aromatics in NExBTL. Fuel mix of 50-50 % showed also clear benefits in smoke numbers compared to DFO.

Pure NExBTL produced quite similar results of nitrous oxides compared to DFO. Fuel blend of 50-50 % showed lowest NO_X results of the three fuels. The differences in NO_X between fuels were however quite small.

Gravimetric fuel consumption of NExBTL was slightly lower than that of DFO. Simultaneously the volumetric fuel consumption of NExBTL did increase from the results of DFO. This was due to the lower volumetric heating value of NExBTL compared to diesel. Fuel consumption results of 50-50 % mix were generally between results of NExBTL and DFO.

No significant differences in the in-cylinder results between three fuels were observed in this study. The ignition delay of NExBTL was slightly shorter in some load points compared to other fuels. It is possible that the use of pilot injection before the actual main injection diminished great benefits from higher cetane number of NExBTL.

Because reduction of nitrous oxides with NExBTL and 50-50 % mix compared to DFO was quite low, no significant gains in fuel consumptions were achieved with the fuel injection parameter optimization. The objective was to keep NO_X at the same level to DFO.

When exhaust gas recirculation system was in use nitrous oxides were reduced significantly when compared to the reference results. The reduction was seen with both NExBTL and 50-50 % mix, but NExBTL produced lowest nitrous oxide results of the two fuels. The use of the EGR is more beneficial with two research fuels then with standard diesel due to the lower base level of smoke. However, use of EGR increased smoke numbers quite rapidly even with NExBTL.

When fuel injection parameters of the EGR engine using NExBTL and 50-50 % mix were optimized, fuel consumption gains of up to 8 % were recorded. Smoke numbers in this situation were however significantly higher than the reference figures.

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Appendix 1

Fuel characteristics.

Kesädiesel (-5/-15), fossiilinen				**100% NExBTL**			**50/50-seos**		
Standardi	Mitattu suure	Arvo	Yksikkö	Mitattu suure	Arvo	Yksikkö	Mitattu suure	Arvo	Yksikkö
ENISO12185	TIHEYS	837	kg/m3	TIHEYS	779.7	kg/m3	TIHEYS	808.55	kg/m3
ASTMD7689	SAME-TARKKA	-5.1	°C	SAME-TARKKA	-37	°C			
EN116	CFPP	-20	°C	CFPP	-42	°C			
ENISO3104	VISKO40°C	3.45	mm2/s	VISKO40°C	2.892	mm2/s	VISKO40°C	3.178	mm2/s
ENISO20846	RIKKI	6.6	mg/kg	RIKKI	<1	mg/kg	RIKKI	3.3	mg/kg
ASTMD5291	VETY	13.9	wt-%	VETY	15.2	wt-%	VETY	14.6	wt-%
ENISO2719	LEIM-PM	68.5	°C	LEIM-PM	76.5	°C			
ASTMD6890	SETLUKU-IQT	53.2		SETLUKU-IQT	74		SETLUKU-IQT	63.3	
ASTMD4809	TEH LÄMPÖARVO	43.0	MJ/kg	TEH LÄMPÖARVO	43.855	MJ/kg	TEH LÄMPÖARVO	43.448	MJ/kg
ASTMD4809	TEH LÄMPÖARVO	36.0	MJ/l	TEH LÄMPÖARVO	34.195	MJ/l	TEH LÄMPÖARVO	35.119	MJ/l
ENISO3405	TIS- TA	179	°C	TIS- TA	201.8	°C	TIS- TA	185.2	°C
ENISO3405	TIS-05	208	°C	TIS-05	249.6	°C	TIS-05	224.1	°C
ENISO3405	TIS-10	222	°C	TIS-10	260.8	°C	TIS-10	241	°C
ENISO3405	TIS-20	243	°C	TIS-20	268.8	°C	TIS-20	257	°C
ENISO3405	TIS-30	261	°C	TIS-30	272.7	°C	TIS-30	267.8	°C
ENISO3405	TIS-40	277	°C	TIS-40	275.3	°C	TIS-40	275.5	°C
ENISO3405	TIS-50	291	°C	TIS-50	277.4	°C	TIS-50	281.4	°C
ENISO3405	TIS-60	303	°C	TIS-60	279.5	°C	TIS-60	286.8	°C
ENISO3405	TIS-70	314	°C	TIS-70	281.8	°C	TIS-70	293.5	°C
ENISO3405	TIS-80	327	°C	TIS-80	285	°C	TIS-80	302.4	°C
ENISO3405	TIS-90	342	°C	TIS-90	289.5	°C	TIS-90	320.3	°C
ENISO3405	TIS-95	352	°C	TIS-95	294.3	°C	TIS-95	338.4	°C
ENISO3405	TIS-TL	357	°C	TIS-TL	303.9	°C	TIS-TL	348.6	°C
EN12916	AROM-DI	1.3	wt-%	AROM-DI	<0,1	wt-%	AROM-DI	0.65	wt-%
EN12916	AROM-TRI	0.13	wt-%	AROM-TRI	<0,10	wt-%	AROM-TRI	0.065	wt-%
EN12916	AROM-DI+TRI	1.4	wt-%	AROM-DI+TRI	<0,1	wt-%	AROM-DI+TRI	0.7	wt-%
EN12916	AROM-kokonais	17.9	wt-%	AROM-MONO	<0,2	wt-%	AROM-MONO	8.95	wt-%
ASTMD4809	KAL LÄMPÖARVO	45.9	MJ/kg	AROM-LC	<0,2	wt-%			
				HFRR	333	µm/60°C			
				TUHKA	<0,001	wt-%			
				HIILTOJ10%-MCR	<0,01	wt-%			

			DIESEL REF					
Engine & environment	Load point		1	2	3	4	5	6
	Date & time	yyyy-mm-dd	2014-04-25	2014-04-25	2014-04-25	2014-04-25	2014-04-25	2014-04-25
	Atmospheric pressure	kPa	102.20	102.20	102.20	102.20	102.20	102.10
	Relative humidity	%	10.00	9.17	9.33	8.85	9.20	10.00
	Room temperature	oC	28.38	29.70	30.13	30.49	29.70	28.50
	Engine speed	1/min	1497.81	1301.22	1797.84	2199.23	1797.85	1300.94
	Engine torque	Nm	572.33	417.64	402.71	217.83	135.71	140.76
	Engine pow er	kW	90	57	76	50	26	19
	BMEP	bar	16.4	11.9	11.5	6.2	3.9	4.0
	SFC	g/kWh	210	210	216	258	274	246
Specific emissions	Lambda		1.49	1.89	1.97	2.98	4.12	3.67
	NOx left	g/kWh	7.72	8.58	7.02	6.85	6.75	8.25
	HC left	g/kWh	0.09	0.07	0.10	0.24	0.39	0.30
	CO left	g/kWh	0.12	0.09	0.16	0.51	0.69	0.31
	NOx sensor 1	g/kWh	8.24	9.06	7.55	7.44	7.02	8.38
	NOx sensor 2	g/kWh	8.18	8.92	7.51	7.41	7.09	8.35
	Smoke	FSN	0.031	0.009	0.013	0.027	0.025	0.015
WinEEM	Rail pressure	Mpa	129.99	134.83	148.10	159.80	133.41	119.14
	Injection timing M1	o crankshaft	5.31	0.70	4.45	3.90	1.91	0.90
	Injection timing P1	µs	350.00	350.00	350.00	350.00	350.00	350.00
	Injection timing P0	µs	-2000.00	0.00	-1725.00	-1300.00	-1300.00	-1300.00
	Injection quantity M1	mg	93.20	71.18	65.44	38.48	21.41	23.39
	Injection quantity P1	mg	2.00	2.00	2.00	2.00	2.00	2.00
	Injection quantity P0	mg	4.00	0.00	4.00	4.00	4.00	4.00
	Injection duration M1	µs	1358.38	1079.98	974.33	691.93	584.83	572.97
	Injection duration P1	µs	288.50	284.42	275.18	269.20	286.00	297.85
	Injection duration P0	µs	359.07	0.00	333.62	320.10	347.93	367.52
Temperature	T Before compressor	oC	25.41	26.24	25.76	25.68	25.22	25.25
	T After compressor	oC	128.21	112.25	120.16	113.99	93.29	63.42
	T Intake manifold	oC	46.75	41.60	48.50	50.51	39.60	29.39
	T Before turbine	oC	597.86	467.32	498.49	399.64	283.83	257.79
	T After turbine	oC	482.01	367.21	398.15	303.92	204.75	207.36
	T Fuel	oC	35.66	35.49	36.15	37.51	36.65	35.64
	T Oil	oC	110.58	106.03	109.15	108.57	102.56	97.56
	T Engine coolant	oC	85.41	82.45	83.30	81.28	79.83	79.28
	T After Charge Air Cooler	oC	43.09	36.93	45.40	47.81	35.35	22.33
Pressure	P Before compressor	bar,abs	1.00	1.00	1.00	0.99	1.00	1.01
	P After compressor	bar,abs	2.24	1.98	2.17	2.06	1.80	1.41
	P Intake manifold	bar,abs	2.19	1.94	2.12	1.98	1.75	1.38
	P Before turbine	bar,abs	2.58	2.25	2.77	3.00	2.44	1.69
	P After turbine	bar,abs	1.17	1.11	1.20	1.23	1.13	1.06
	Oil pressure	bar,rel	3.23	3.11	3.83	4.24	4.21	3.60
	Intake air depressure	mbar,rel	22	18	26	31	23	15
	Exhaust backpressure	mbar,rel	148	86	182	211	106	36
	Cooler backpressure	mbar, rel	47.205	47.625	57.742	86.602	49.864	28.875
Mass flow	Air	kg/s	0.11	0.09	0.13	0.16	0.12	0.07
	Air flow	kg/h	406.35	327.83	469.69	560.45	419.64	251.39
	Fuel flow	g/s	5.22	3.31	4.56	3.59	1.95	1.31
	Fuel flow	L/s	0.01	0.00	0.01	0.00	0.00	0.00
	Fuel flow	L/h	22.46	14.25	19.59	15.44	8.36	5.63
	Efficiency	%	40.00	39.98	38.73	32.52	30.58	34.10
Exhaust gas	HC, C1 w et	ppm	41.24	24.55	31.19	43.71	48.62	46.86
	NO	ppm	1273.67	1095.50	826.37	427.72	277.75	439.03
	NOX	ppm	1314.50	1143.33	868.32	465.97	309.43	471.93
	CO, dry	ppm	28.93	16.47	27.87	48.82	44.06	24.87
	CO2, dry	%	9.82	7.67	7.24	4.76	3.32	3.73
	O2, dry	%	7.34	10.22	10.79	14.16	16.19	15.59
	Smoke	FSN	0.03	0.01	0.01	0.03	0.03	0.02
	NOX sensor 1	ppm	1279.23	1122.52	871.17	482.65	310.95	461.72
	O2 sensor 1	%	6.56	9.53	9.98	13.27	15.22	14.58
	NOX sensor 2	ppm	1270.38	1104.41	866.02	480.78	314.06	459.79
	O2 sensor 2	%	6.46	9.32	9.89	13.29	15.36	14.71

Appendix 3

			NExBTL REF					
Engine & environment	Load point		1	2	3	4	5	6
	Date & time	yyyy-mm-dd	2014-04-30	2014-04-30	2014-04-30	2014-04-30	2014-04-30	2014-04-30
	Atmospheric pressure	kPa	100.50	100.50	100.50	100.50	100.50	100.50
	Relative humidity	%	14.32	14.00	13.00	12.22	13.00	13.00
	Room temperature	oC	23.54	24.95	25.83	26.40	25.80	24.70
	Engine speed	1/min	1497.46	1300.07	1797.44	2198.76	1797.29	1299.92
	Engine torque	Nm	571.30	416.67	401.89	217.01	134.91	139.98
	Engine power	kW	90	57	76	50	25	19
	BMEP	bar	16.3	11.9	11.5	6.2	3.9	4.0
	SFC	g/kWh	205	205	212	252	270	243
Specific emissions	Lambda		1.48	1.86	1.95	2.97	4.04	3.59
	NOx left	g/kWh	7.81	8.63	6.91	6.73	6.60	8.10
	HC left	g/kWh	0.09	0.05	0.08	0.19	0.28	0.18
	CO left	g/kWh	0.12	0.08	0.16	0.45	0.56	0.26
	NOx sensor 1	g/kWh	8.25	8.99	7.31	7.19	6.76	8.11
	NOx sensor 2	g/kWh	8.16	8.83	7.26	7.17	6.80	8.07
	Smoke	FSN	0.020	0.010	0.007	0.013	0.013	0.011
WinEEM	Rail pressure	Mpa	128.66	134.83	149.51	159.99	132.64	119.33
	Injection timing M1	o crankshaft	5.30	0.70	4.26	3.90	1.91	0.90
	Injection timing P1	µs	350.00	350.00	350.00	350.00	350.00	350.00
	Injection timing P0	µs	-2000.00	0.00	-1700.00	-1300.00	-1300.00	-1300.00
	Injection quantity M1	mg	92.46	70.30	64.50	37.45	20.61	23.57
	Injection quantity P1	mg	2.00	2.00	2.00	2.00	2.00	2.00
	Injection quantity P0	mg	4.00	0.00	4.00	4.00	4.00	4.00
	Injection duration M1	µs	1344.55	1073.22	965.62	680.90	579.27	574.13
	Injection duration P1	µs	288.05	283.72	275.52	269.60	286.93	296.70
	Injection duration P0	µs	357.92	0.00	334.15	320.32	348.70	366.38
Temperature	T Before compressor	oC	21.54	22.11	21.53	21.49	21.26	21.53
	T After compressor	oC	124.94	107.50	116.66	110.39	89.56	60.51
	T Intake manifold	oC	46.67	39.39	47.50	49.36	39.41	29.00
	T Before turbine	oC	599.33	469.45	501.31	403.92	291.16	265.05
	T After turbine	oC	482.28	369.84	400.06	307.87	212.58	214.47
	T Fuel	oC	34.33	34.62	34.92	35.94	35.52	34.81
	T Oil	oC	108.05	104.65	108.42	108.00	102.26	96.79
	T Engine coolant	oC	84.89	82.02	82.79	81.01	79.51	78.83
	T After Charge Air Cooler	oC	43.28	34.76	44.67	47.05	35.29	22.15
Pressure	P Before compressor	bar,abs	0.98	0.99	0.98	0.97	0.98	0.99
	P After compressor	bar,abs	2.22	1.95	2.16	2.05	1.78	1.40
	P Intake manifold	bar,abs	2.18	1.91	2.11	1.97	1.74	1.37
	P Before turbine	bar,abs	2.56	2.22	2.76	2.99	2.41	1.67
	P After turbine	bar,abs	1.15	1.09	1.19	1.22	1.11	1.04
	Oil pressure	bar,rel	3.31	3.16	3.86	4.25	4.22	3.63
	Intake air depressure	mbar,rel	21	18	26	31	23	15
	Exhaust backpressure	mbar,rel	146	86	184	213	108	37
	Cooler backpressure	mbar, rel	41.238	42.332	55.201	84.075	47.399	29.283
Mass flow	Air	kg/s	0.11	0.09	0.13	0.16	0.12	0.07
	Air flow	kg/h	405.56	324.27	467.96	558.62	414.85	248.35
	Fuel flow	g/s	5.09	3.23	4.45	3.49	1.91	1.29
	Fuel flow	L/s	0.01	0.00	0.01	0.00	0.00	0.00
	Fuel flow	L/h	23.51	14.91	20.55	16.12	8.81	5.94
	Efficiency	%	40.1	40.1	38.8	32.6	30.4	33.8
Exhaust gas	HC, C1 wet	ppm	39.87	18.48	26.14	34.88	34.91	28.83
	NO	ppm	1237.50	1064.00	782.92	403.20	263.23	424.30
	NOX	ppm	1296.83	1129.17	836.82	448.48	297.68	458.23
	CO, dry	ppm	29.87	14.74	28.24	42.54	36.43	21.28
	CO2, dry	%	9.44	7.37	6.96	4.57	3.21	3.64
	O2, dry	%	7.40	10.26	10.87	14.21	16.20	15.58
	Smoke	FSN	0.02	0.01	0.01	0.01	0.01	0.01
	NOX sensor 1	ppm	1253.90	1095.80	827.43	457.15	295.07	442.08
	O2 sensor 1	%	6.50	9.43	9.92	13.15	15.08	14.42
	NOX sensor 2	ppm	1240.36	1075.42	821.68	455.70	296.66	439.64
	O2 sensor 2	%	6.47	9.28	9.90	13.26	15.29	14.61

			50 - 50 MIX REF					
Engine & environment	Load point		1	2	3	4	5	6
	Date & time	yyyy-mm-dd	2014-05-21	2014-05-21	2014-05-21	2014-05-21	2014-05-21	2014-05-21
	Atmospheric pressure	kPa	101.30	101.30	101.30	101.30	101.30	101.30
	Relative humidity	%	19.12	19.00	18.03	18.00	19.00	20.05
	Room temperature	oC	33.28	33.90	34.20	34.10	33.40	32.40
	Engine speed	1/min	1498.26	1302.34	1798.30	2199.51	1798.24	1301.98
	Engine torque	Nm	573.16	418.58	403.41	218.49	136.43	141.25
	Engine power	kW	90	57	76	50	26	19
	BMEP	bar	16.4	12.0	11.5	6.2	3.9	4.0
	SFC	g/kWh	209	209	215	254	272	246
Specific emissions	Lambda		1.43	1.82	1.93	2.92	3.97	3.50
	NOx left	g/kWh	7.20	8.42	6.78	6.58	6.58	7.94
	HC left	g/kWh	0.09	0.06	0.09	0.22	0.34	0.26
	CO left	g/kWh	0.19	0.10	0.19	0.50	0.62	0.31
	NOx sensor 1	g/kWh	7.51	8.65	7.06	6.93	6.65	7.86
	NOx sensor 2	g/kWh	7.40	8.45	6.99	6.90	6.69	7.81
	Smoke	FSN	0.046	0.012	0.012	0.020	0.019	0.016
WinEEM	Rail pressure	Mpa	129.63	134.58	148.54	159.90	133.33	119.30
	Injection timing M1	o crankshaft	5.30	0.72	4.30	3.90	1.93	0.90
	Injection timing P1	µs	350.00	350.00	350.00	350.00	350.00	350.00
	Injection timing P0	µs	-2000.00	0.00	-1740.00	-1300.00	-1300.00	-1300.00
	Injection quantity M1	mg	93.90	71.55	65.96	38.86	21.33	23.47
	Injection quantity P1	mg	2.00	2.00	2.00	2.00	2.00	2.00
	Injection quantity P0	mg	4.00	0.00	4.00	4.00	4.00	4.00
	Injection duration M1	µs	1371.97	1087.77	978.77	695.02	583.45	574.58
	Injection duration P1	µs	288.63	284.35	275.43	269.48	286.07	297.05
	Injection duration P0	µs	359.28	0.00	334.47	321.00	348.35	366.88
Temperature	T Before compressor	oC	30.21	30.95	30.27	29.78	29.60	29.45
	T After compressor	oC	134.18	117.65	126.36	119.23	97.89	66.98
	T Intake manifold	oC	47.88	42.91	49.91	52.54	41.87	30.57
	T Before turbine	oC	610.77	473.18	503.70	403.40	288.25	262.06
	T After turbine	oC	493.17	372.39	400.91	305.85	208.71	212.29
	T Fuel	oC	35.54	35.81	36.46	37.00	36.43	35.83
	T Oil	oC	111.48	106.66	109.01	108.74	102.70	97.33
	T Engine coolant	oC	86.10	83.32	83.57	81.64	80.29	79.41
	T After Charge Air Cooler	oC	1339.72	1339.72	1339.72	1339.72	1339.72	1339.72
Pressure	P Before compressor	bar,abs	0.99	1.00	0.99	0.98	0.99	1.00
	P After compressor	bar,abs	2.23	1.97	2.17	2.05	1.78	1.39
	P Intake manifold	bar,abs	2.18	1.92	2.11	1.97	1.73	1.36
	P Before turbine	bar,abs	2.55	2.23	2.77	2.99	2.41	1.66
	P After turbine	bar,abs	1.16	1.10	1.20	1.22	1.12	1.05
	Oil pressure	bar,rel	3.18	3.08	3.82	4.23	4.19	3.59
	Intake air depressure	mbar,rel	21	17	25	30	22	15
	Exhaust backpressure	mbar,rel	151	87	182	207	104	34
	Cooler backpressure	mbar, rel	57.486	49.665	59.208	85.679	47.198	28.103
Mass flow	Air	kg/s	0.11	0.09	0.13	0.15	0.11	0.07
	Air flow	kg/h	399.98	321.69	468.89	554.53	412.37	246.37
	Fuel flow	g/s	5.23	3.31	4.54	3.55	1.94	1.32
	Fuel flow	L/s	0.0	0.0	0.0	0.0	0.0	0.0
	Fuel flow	L/h	23.3	14.7	20.2	15.8	8.6	5.9
	Efficiency	%	39.6	39.7	38.5	32.6	30.5	33.7
Exhaust gas	HC, C1 wet	ppm	38.75	21.61	28.84	40.61	43.85	42.27
	NO	ppm	1167.83	1053.67	767.92	397.57	265.05	414.75
	NOX	ppm	1206.83	1102.50	812.67	436.85	296.82	448.53
	CO, dry	ppm	45.54	18.86	33.07	48.83	40.82	25.96
	CO2, dry	%	9.99	7.73	7.22	4.75	3.33	3.78
	O2, dry	%	6.92	9.98	10.68	14.14	16.19	15.53
	Smoke	FSN	0.05	0.01	0.01	0.02	0.02	0.02
	NOX sensor 1	ppm	1139.92	1046.00	784.60	436.47	288.05	424.67
	O2 sensor 1	%	6.06	9.06	9.67	12.99	14.96	14.29
	NOX sensor 2	ppm	1122.89	1022.70	777.31	434.67	290.06	422.03
	O2 sensor 2	%	5.94	8.90	9.62	13.06	15.12	14.44

			NExBTL Main 1 Adv +1 deg.					
Engine & environment	Load point		1	2	3	4	5	6
	Date & time	yyyy-mm-dd	2014-05-14	2014-05-14	2014-05-14	2014-05-14	2014-05-14	2014-05-14
	Atmospheric pressure	kPa	101.17	101.20	101.20	101.20	101.20	101.30
	Relative humidity	%	13.00	12.23	12.00	12.00	12.00	13.00
	Room temperature	oC	25.88	27.55	28.01	28.22	27.19	25.82
	Engine speed	1/min	1497.73	1300.43	1797.50	2199.01	1797.53	1300.23
	Engine torque	Nm	571.09	416.58	401.79	217.04	135.03	140.10
	Engine pow er	kW	90	57	76	50	25	19
	BMEP	bar	16.3	11.9	11.5	6.2	3.9	4.0
	SFC	g/kWh	205	205	211	249	271	245
Specific emissions	Lambda		1.46	1.85	1.96	2.97	3.99	3.52
	NOx left	g/kWh	7.94	8.90	7.33	7.29	7.08	8.61
	HC left	g/kWh	0.09	0.06	0.08	0.19	0.26	0.19
	CO left	g/kWh	0.15	0.08	0.16	0.39	0.47	0.23
	NOx sensor 1	g/kWh	8.36	9.27	7.78	7.79	7.26	8.63
	NOx sensor 2	g/kWh	8.28	9.10	7.72	7.74	7.32	8.59
	Smoke	FSN	0.025	0.004	0.010	0.011	0.012	0.009
WinEEM	Rail pressure	Mpa	130.63	134.96	148.43	160.04	132.80	118.93
	Injection timing M1	o crankshaft	6.30	1.70	5.30	4.90	2.90	1.90
	Injection timing P1	µs	350.00	350.00	350.00	350.00	350.00	350.00
	Injection timing P0	µs	-2000.00	0.00	-1718.00	-1300.00	-1300.00	-1300.00
	Injection quantity M1	mg	92.52	70.42	64.65	37.46	20.47	23.40
	Injection quantity P1	mg	2.00	2.00	2.00	2.00	2.00	2.00
	Injection quantity P0	mg	4.00	0.00	4.00	4.00	4.00	4.00
	Injection duration M1	µs	1353.93	1072.80	962.53	681.52	574.68	570.70
	Injection duration P1	µs	288.33	283.57	275.52	269.38	286.75	297.28
	Injection duration P0	µs	358.75	0.00	334.03	320.18	349.20	366.82
Temperature	T Before compressor	oC	23.50	24.43	23.92	23.70	23.09	23.18
	T After compressor	oC	126.53	109.10	118.69	112.02	90.31	60.33
	T Intake manifold	oC	49.24	41.67	49.39	51.21	40.18	28.54
	T Before turbine	oC	600.53	468.41	497.63	399.33	287.06	261.09
	T After turbine	oC	485.56	370.44	397.60	303.82	209.25	211.96
	T Fuel	oC	34.44	34.90	35.30	35.77	35.65	34.73
	T Oil	oC	110.21	105.01	108.58	108.33	101.65	96.35
	T Engine coolant	oC	85.09	82.18	83.00	81.23	79.70	78.85
Pressure	P Before compressor	bar,abs	0.99	0.99	0.99	0.98	0.99	1.00
	P After compressor	bar,abs	2.23	1.95	2.17	2.06	1.78	1.39
	P Intake manifold	bar,abs	2.18	1.90	2.11	1.97	1.73	1.36
	P Before turbine	bar,abs	2.55	2.21	2.76	2.99	2.40	1.66
	P After turbine	bar,abs	1.16	1.10	1.19	1.22	1.11	1.05
	Oil pressure	bar,rel	3.23	3.12	3.83	4.24	4.22	3.64
	Intake air depressure	mbar,rel	21	18	26	30	22	15
	Exhaust backpressure	mbar,rel	147	84	182	209	103	34
	Cooler backpressure	mbar, rel	49.717	48.749	59.232	89.486	50.355	28.893
Mass flow	Air	kg/s	0.11	0.09	0.13	0.15	0.11	0.07
	Air flow	kg/h	400.22	321.03	468.57	554.23	411.90	246.60
	Fuel flow	g/s	5.10	3.23	4.43	3.46	1.92	1.30
	Fuel flow	L/s	0.0065	0.0041	0.0057	0.0044	0.0025	0.0017
	Fuel flow	L/h	23.54	14.90	20.48	15.99	8.84	6.00
	Efficiency	%	40.1	40.1	38.9	32.9	30.3	33.5
Exhaust gas	HC, C1 w et	ppm	39.19	19.73	25.39	34.15	33.15	30.21
	NO	ppm	1305.67	1136.50	849.02	450.67	293.08	459.52
	NOX	ppm	1347.50	1188.17	893.52	491.43	323.97	491.90
	CO, dry	ppm	36.61	16.06	27.33	37.78	30.85	18.97
	CO2, dry	%	9.56	7.47	6.99	4.59	3.24	3.67
	O2, dry	%	7.34	10.22	10.91	14.29	16.26	15.63
	Smoke	FSN	0.03	0.00	0.01	0.01	0.01	0.01
	NOX sensor 1	ppm	1297.12	1151.15	886.02	501.23	320.88	474.95
	O2 sensor 1	%	6.43	9.35	9.94	13.19	15.09	14.46
	NOX sensor 2	ppm	1284.59	1130.60	879.44	498.29	323.64	472.82
	O2 sensor 2	%	6.36	9.19	9.89	13.27	15.30	14.61

			50 - 50 % MIX Main 1 Adv +1 deg.					
Engine & environment	Load point		1	2	3	4	5	6
	Date & time	yyyy-mm-dd	2014-05-22	2014-05-22	2014-05-22	2014-05-22	2014-05-22	2014-05-22
	Atmospheric pressure	kPa	101.63	101.60	101.60	101.62	101.60	101.70
	Relative humidity	%	27.73	25.00	24.00	22.00	22.00	23.00
	Room temperature	oC	28.99	30.89	31.76	32.70	32.36	31.30
	Engine speed	1/min	1497.92	1301.43	1798.06	2199.49	1798.23	1301.69
	Engine torque	Nm	572.07	417.55	402.68	218.04	136.10	141.16
	Engine power	kW	90	57	76	50	26	19
	BMEP	bar	16.3	11.9	11.5	6.2	3.9	4.0
	SFC	g/kWh	207	207	214	252	272	244
Specific emissions	Lambda		1.46	1.84	1.93	2.97	3.98	3.53
	NOx left	g/kWh	7.66	8.67	7.00	6.90	6.88	8.46
	HC left	g/kWh	0.09	0.06	0.09	0.21	0.32	0.24
	CO left	g/kWh	0.17	0.09	0.19	0.45	0.52	0.26
	NOx sensor 1	g/kWh	8.28	9.20	7.57	7.48	7.13	8.59
	NOx sensor 2	g/kWh	8.15	8.99	7.51	7.43	7.16	8.54
	Smoke	FSN	0.043	0.007	0.012	0.020	0.018	0.014
WinEEM	Rail pressure	Mpa	128.45	134.73	148.76	160.12	133.34	119.07
	Injection timing M1	o crankshaft	6.30	1.70	5.30	4.90	2.90	1.90
	Injection timing P1	µs	350.00	350.00	350.00	350.00	350.00	350.00
	Injection timing P0	µs	-2000.00	0.00	-1730.00	-1300.00	-1300.00	-1300.00
	Injection quantity M1	mg	93.23	70.84	65.18	38.27	20.91	23.34
	Injection quantity P1	mg	2.00	2.00	2.00	2.00	2.00	2.00
	Injection quantity P0	mg	4.00	0.00	4.00	4.00	4.00	4.00
	Injection duration M1	µs	1355.08	1079.97	971.05	690.07	580.00	571.77
	Injection duration P1	µs	287.90	284.45	275.65	269.52	286.27	297.65
	Injection duration P0	µs	358.25	0.00	334.30	320.38	348.42	367.57
Temperature	T Before compressor	oC	27.71	28.23	28.65	29.03	29.35	29.42
	T After compressor	oC	130.81	113.62	124.01	117.76	96.63	66.52
	T Intake manifold	oC	47.76	43.19	50.03	50.62	41.01	30.98
	T Before turbine	oC	604.52	471.62	501.87	401.06	288.51	262.42
	T After turbine	oC	488.78	372.82	400.76	304.94	210.38	213.51
	T Fuel	oC	35.53	35.81	36.12	37.39	36.84	35.78
	T Oil	oC	109.81	105.51	108.75	108.73	102.58	97.63
	T Engine coolant	oC	85.48	82.78	83.57	81.90	80.27	79.40
Pressure	P Before compressor	bar,abs	1.00	1.00	0.99	0.99	1.00	1.00
	P After compressor	bar,abs	2.23	1.96	2.17	2.05	1.77	1.39
	P Intake manifold	bar,abs	2.18	1.91	2.11	1.96	1.72	1.35
	P Before turbine	bar,abs	2.56	2.22	2.77	3.00	2.40	1.66
	P After turbine	bar,abs	1.16	1.10	1.20	1.23	1.12	1.05
	Oil pressure	bar,rel	3.22	3.11	3.82	4.22	4.19	3.57
	Intake air depressure	mbar,rel	20	16	25	29	21	14
	Exhaust backpressure	mbar,rel	148	86	182	209	105	35
	Cooler backpressure	mbar, rel	50.84	53.587	63.179	92.021	52.045	34.927
Mass flow	Air	kg/s	0.11	0.09	0.13	0.15	0.11	0.07
	Air flow	kg/h	402.11	321.14	466.40	556.85	411.55	246.04
	Fuel flow	g/s	5.16	3.27	4.51	3.51	1.94	1.30
	Fuel flow	L/s	0.0064	0.0040	0.0056	0.0043	0.0024	0.0016
	Fuel flow	L/h	22.99	14.57	20.09	15.62	8.62	5.80
	Efficiency	%	40.0	40.0	38.7	32.9	30.5	34.0
Exhaust gas	HC, C1 wet	ppm	39.41	20.28	29.20	38.35	41.19	39.22
	NO	ppm	1199.33	1063.00	778.98	411.72	277.68	442.23
	NOX	ppm	1235.00	1108.50	821.07	447.63	306.27	472.67
	CO, dry	ppm	42.03	16.42	33.86	43.14	34.45	21.41
	CO2, dry	%	9.76	7.61	7.12	4.67	3.30	3.74
	O2, dry	%	7.11	10.05	10.72	14.17	16.17	15.53
	Smoke	FSN	0.04	0.01	0.01	0.02	0.02	0.01
	NOX sensor 1	ppm	1211.15	1086.00	823.02	460.05	304.68	459.00
	O2 sensor 1	%	6.23	9.19	9.73	13.02	14.97	14.30
	NOX sensor 2	ppm	1192.72	1061.60	816.41	456.90	306.29	456.37
	O2 sensor 2	%	6.17	9.04	9.70	13.13	15.14	14.46

			NExBTL Rail Pressure +10 Mpa					
Engine & environment	Load point		1	2	3	4	5	6
	Date & time	yyyy-mm-dd	2014-05-14	2014-05-14	2014-05-14	2014-05-14	2014-05-14	2014-05-14
	Atmospheric pressure	kPa	101.30	101.30	101.40	101.40	101.40	101.40
	Relative humidity	%	12.00	10.82	11.00	11.00	12.00	12.00
	Room temperature	oC	27.69	27.84	29.50	29.79	28.91	27.68
	Engine speed	1/min	1497.70	1300.87	1797.73	2199.15	1797.74	1300.73
	Engine torque	Nm	571.84	417.20	402.39	217.62	135.57	140.58
	Engine pow er	kW	90	57	76	50	26	19
	BMEP	bar	16.3	11.9	11.5	6.2	3.9	4.0
	SFC	g/kWh	205	205	212	250	269	238
Specific emissions	Lambda		1.46	1.85	1.94	2.94	4.00	3.62
	NOx left	g/kWh	7.74	8.83	7.28	6.86	6.91	8.40
	HC left	g/kWh	0.08	0.06	0.08	0.18	0.27	0.18
	CO left	g/kWh	0.14	0.07	0.15	0.44	0.52	0.25
	NOx sensor 1	g/kWh	8.21	9.21	7.75	7.29	7.06	8.41
	NOx sensor 2	g/kWh	8.13	9.05	7.70	7.24	7.11	8.34
	Smoke	FSN	0.023	0.005	0.006	0.012	0.011	0.010
WinEEM	Rail pressure	Mpa	141.82	143.92	160.16	160.03	141.73	125.31
	Injection timing M1	o crankshaft	5.30	0.70	4.30	3.90	1.90	0.90
	Injection timing P1	µs	350.00	350.00	350.00	350.00	350.00	350.00
	Injection timing P0	µs	-2000.00	0.00	-1700.00	-1300.00	-1300.00	-1300.00
	Injection quantity M1	mg	97.87	72.05	64.43	37.66	21.09	18.11
	Injection quantity P1	mg	2.00	2.00	2.00	2.00	2.00	2.00
	Injection quantity P0	mg	4.00	0.00	4.00	4.00	4.00	4.00
	Injection duration M1	µs	1297.80	1046.70	935.33	684.52	561.53	559.30
	Injection duration P1	µs	279.87	277.48	268.43	269.42	279.70	292.58
	Injection duration P0	µs	345.62	0.00	322.40	320.28	338.42	358.15
Temperature	T Before compressor	oC	24.59	25.15	24.91	24.76	24.52	24.62
	T After compressor	oC	127.98	110.58	120.10	113.49	92.07	62.24
	T Intake manifold	oC	48.60	42.00	51.91	54.55	42.56	30.42
	T Before turbine	oC	602.54	470.37	502.21	404.98	289.84	262.61
	T After turbine	oC	486.79	371.58	401.20	309.17	211.81	213.07
	T Fuel	oC	34.96	35.10	35.65	36.42	35.80	34.81
	T Oil	oC	110.86	105.33	109.34	108.59	102.39	96.87
	T Engine coolant	oC	85.21	82.28	83.28	81.41	79.80	79.39
Pressure	P Before compressor	bar,abs	0.99	1.00	0.99	0.98	0.99	1.00
	P After compressor	bar,abs	2.23	1.96	2.17	2.06	1.78	1.39
	P Intake manifold	bar,abs	2.18	1.92	2.11	1.97	1.73	1.36
	P Before turbine	bar,abs	2.56	2.22	2.76	2.98	2.40	1.67
	P After turbine	bar,abs	1.16	1.10	1.19	1.22	1.12	1.05
	Oil pressure	bar,rel	3.20	3.12	3.80	4.23	4.20	3.62
	Intake air depressure	mbar,rel	21	17	26	30	22	15
	Exhaust backpressure	mbar,rel	147	85	179	207	103	34
	Cooler backpressure	mbar, rel	47.659	45.474	59.995	88.595	49.778	29.247
Mass flow	Air	kg/s	0.11	0.09	0.13	0.15	0.11	0.07
	Air flow	kg/h	401.49	322.12	466.51	551.44	410.79	246.39
	Fuel flow	g/s	5.12	3.24	4.45	3.48	1.91	1.26
	Fuel flow	L/s	0.0066	0.0042	0.0057	0.0045	0.0024	0.0016
	Fuel flow	L/h	23.62	14.96	20.56	16.07	8.80	5.84
	Efficiency	%	40.0	40.0	38.8	32.8	30.5	34.5
Exhaust gas	HC, C1 w et	ppm	36.83	20.38	27.16	33.54	34.33	28.88
	NO	ppm	1278.17	1130.50	853.10	428.33	287.77	452.87
	NOX	ppm	1321.00	1183.00	898.48	468.97	319.47	485.90
	CO, dry	ppm	33.45	13.69	26.51	42.22	34.15	20.18
	CO2, dry	%	9.66	7.52	7.09	4.67	3.28	3.69
	O2, dry	%	7.33	10.23	10.86	14.24	16.25	15.64
	Smoke	FSN	0.02	0.01	0.01	0.01	0.01	0.01
	NOX sensor 1	ppm	1278.85	1148.42	892.78	475.63	315.08	467.85
	O2 sensor 1	%	6.36	9.33	9.86	13.23	15.09	14.45
	NOX sensor 2	ppm	1266.12	1128.96	887.37	472.52	317.41	464.28
	O2 sensor 2	%	6.29	9.16	9.79	13.20	15.25	14.60

			50-50 % MIX Rail Pressure +10 Mpa					
Engine & environment	Load point		1	2	3	4	5	6
	Date & time	yyyy-mm-dd	2014-05-22	2014-05-22	2014-05-22	2014-05-22	2014-05-22	2014-05-22
	Atmospheric pressure	kPa	101.70	101.70	101.74	101.80	101.80	101.80
	Relative humidity	%	15.00	14.00	15.00	15.00	16.00	17.00
	Room temperature	oC	33.90	34.50	34.80	34.80	34.11	32.50
	Engine speed	1/min	1498.07	1301.75	1798.02	2199.46	1798.15	1301.77
	Engine torque	Nm	572.95	418.19	403.19	218.38	136.39	141.58
	Engine power	kW	90	57	76	50	26	19
	BMEP	bar	16.4	12.0	11.5	6.2	3.9	4.0
	SFC	g/kWh	208	207	214	255	271	242
Specific emissions	Lambda		1.44	1.84	1.93	2.92	3.99	3.56
	NOx left	g/kWh	7.46	8.71	6.95	6.39	6.65	8.25
	HC left	g/kWh	0.09	0.06	0.09	0.21	0.34	0.26
	CO left	g/kWh	0.15	0.08	0.16	0.48	0.57	0.27
	NOx sensor 1	g/kWh	8.00	9.10	7.41	6.87	6.86	8.38
	NOx sensor 2	g/kWh	7.88	9.01	7.36	6.84	6.89	8.31
	Smoke	FSN	0.033	0.007	0.010	0.020	0.016	0.011
WinEEM	Rail pressure	Mpa	138.39	145.11	159.34	159.91	142.98	128.96
	Injection timing M1	o crankshaft	5.30	0.72	4.30	3.90	1.92	0.90
	Injection timing P1	µs	350.00	350.00	350.00	350.00	350.00	350.00
	Injection timing P0	µs	-2000.00	0.00	-1730.00	-1300.00	-1300.00	-1300.00
	Injection quantity M1	mg	97.38	71.66	64.56	37.86	21.46	17.96
	Injection quantity P1	mg	2.00	2.00	2.00	2.00	2.00	2.00
	Injection quantity P0	mg	4.00	0.00	4.00	4.00	4.00	4.00
	Injection duration M1	µs	1299.23	1038.30	938.40	684.02	563.25	552.20
	Injection duration P1	µs	280.68	277.18	268.65	269.42	278.90	289.57
	Injection duration P0	µs	346.82	0.00	323.08	320.80	336.78	353.57
Temperature	T Before compressor	oC	30.94	30.61	30.48	30.32	29.87	29.53
	T After compressor	oC	134.40	116.30	126.03	119.27	97.39	66.74
	T Intake manifold	oC	48.26	41.98	48.92	50.74	40.93	30.38
	T Before turbine	oC	605.23	467.86	500.15	402.92	287.05	259.07
	T After turbine	oC	489.65	368.50	399.01	306.59	208.42	210.09
	T Fuel	oC	36.00	36.09	36.95	37.59	37.05	36.16
	T Oil	oC	110.97	105.23	108.86	108.71	102.59	97.64
	T Engine coolant	oC	86.16	82.91	83.80	81.75	80.33	79.60
Pressure	P Before compressor	bar,abs	1.00	1.00	0.99	0.99	1.00	1.00
	P After compressor	bar,abs	2.21	1.95	2.16	2.05	1.77	1.38
	P Intake manifold	bar,abs	2.17	1.91	2.10	1.96	1.73	1.36
	P Before turbine	bar,abs	2.55	2.23	2.77	3.00	2.41	1.66
	P After turbine	bar,abs	1.16	1.10	1.20	1.23	1.12	1.05
	Oil pressure	bar,rel	3.19	3.12	3.81	4.22	4.19	3.56
	Intake air depressure	mbar,rel	19	16	24	29	22	15
	Exhaust backpressure	mbar,rel	148	85	181	208	103	34
	Cooler backpressure	mbar, rel	45.261	43.498	55.653	83.839	47.318	25.645
Mass flow	Air	kg/s	0.11	0.09	0.13	0.15	0.11	0.07
	Air flow	kg/h	399.16	322.23	467.22	555.92	412.45	246.43
	Fuel flow	g/s	5.20	3.28	4.52	3.56	1.93	1.30
	Fuel flow	L/s	0.0064	0.0041	0.0056	0.0044	0.0024	0.0016
	Fuel flow	L/h	23.13	14.59	20.12	15.84	8.61	5.77
	Efficiency	%	39.8	40.0	38.7	32.5	30.6	34.3
Exhaust gas	HC, C1 wet	ppm	38.36	21.96	28.64	39.06	42.90	41.43
	NO	ppm	1238.00	1113.33	806.13	392.92	273.95	441.15
	NOX	ppm	1275.17	1164.00	847.43	429.37	304.08	473.33
	CO, dry	ppm	36.11	15.70	27.33	46.62	37.45	22.50
	CO2, dry	%	9.85	7.64	7.15	4.72	3.31	3.74
	O2, dry	%	7.10	10.14	10.80	14.20	16.22	15.60
	Smoke	FSN	0.03	0.01	0.01	0.02	0.02	0.01
	NOX sensor 1	ppm	1242.68	1127.00	839.47	438.40	301.77	461.00
	O2 sensor 1	%	6.17	9.29	9.84	13.16	14.97	14.33
	NOX sensor 2	ppm	1224.84	1116.10	834.83	436.57	303.23	457.05
	O2 sensor 2	%	6.10	9.07	9.72	13.11	15.17	14.51

			NExBTL , Pil 1 timing 500 µs					
Engine & environment	Load point		1	2	3	4	5	6
	Date & time	yyyy-mm-dd	2014-05-15	2014-05-15	2014-05-15	2014-05-15	2014-05-15	2014-05-15
	Atmospheric pressure	kPa	102.90	102.90	102.80	102.80	102.80	102.80
	Relative humidity	%	11.00	11.00	10.00	10.00	10.00	11.00
	Room temperature	oC	25.35	27.50	28.12	28.30	27.50	26.20
	Engine speed	1/min	1497.52	1300.24	1797.56	2198.76	1797.54	1300.39
	Engine torque	Nm	571.58	417.16	402.35	217.47	135.37	140.39
	Engine pow er	kW	90	57	76	50	25	19
	BMEP	bar	16.3	11.9	11.5	6.2	3.9	4.0
	SFC	g/kWh	205	205	212	250	270	241
Specific emissions	Lambda		1.48	1.88	1.96	3.00	4.07	3.66
	NOx left	g/kWh	7.69	8.74	6.98	6.82	6.63	8.07
	HC left	g/kWh	0.08	0.05	0.08	0.20	0.30	0.20
	CO left	g/kWh	0.12	0.07	0.16	0.44	0.53	0.25
	NOx sensor 1	g/kWh	8.19	9.17	7.42	7.29	6.81	8.10
	NOx sensor 2	g/kWh	8.09	9.02	7.36	7.25	6.86	8.06
	Smoke	FSN	0.023	0.007	0.008	0.012	0.014	0.009
WinEEM	Rail pressure	Mpa	129.22	134.93	148.93	159.94	133.03	118.72
	Injection timing M1	o crankshaft	5.27	0.60	4.23	3.90	1.93	0.90
	Injection timing P1	µs	500.00	500.00	500.00	500.00	500.00	500.00
	Injection timing P0	µs	-2000.00	0.00	-1720.00	-1300.00	-1300.00	-1300.00
	Injection quantity M1	mg	91.62	69.11	64.42	37.19	20.84	23.13
	Injection quantity P1	mg	2.00	2.00	2.00	2.00	2.00	2.00
	Injection quantity P0	mg	4.00	0.00	4.00	4.00	4.00	4.00
	Injection duration M1	µs	1338.35	1061.18	965.37	681.18	577.28	569.20
	Injection duration P1	µs	288.38	284.22	275.62	269.27	287.03	297.57
	Injection duration P0	µs	358.32	0.00	334.30	320.13	348.87	367.23
Temperature	T Before compressor	oC	23.03	24.12	23.95	23.43	23.08	23.12
	T After compressor	oC	125.06	108.77	118.13	110.87	90.65	61.62
	T Intake manifold	oC	48.22	41.46	49.37	50.61	40.36	29.16
	T Before turbine	oC	598.13	464.74	498.35	399.39	288.06	260.32
	T After turbine	oC	483.06	366.40	397.89	304.69	209.81	209.93
	T Fuel	oC	34.59	34.66	35.05	35.92	35.68	34.85
	T Oil	oC	109.22	104.09	108.40	108.20	102.11	96.66
	T Engine coolant	oC	84.99	82.23	83.01	81.01	79.65	79.03
Pressure	P Before compressor	bar,abs	1.01	1.01	1.00	1.00	1.01	1.01
	P After compressor	bar,abs	2.25	1.98	2.19	2.07	1.81	1.42
	P Intake manifold	bar,abs	2.20	1.94	2.13	1.98	1.76	1.39
	P Before turbine	bar,abs	2.58	2.25	2.79	3.01	2.45	1.71
	P After turbine	bar,abs	1.18	1.11	1.21	1.24	1.13	1.06
	Oil pressure	bar,rel	3.27	3.15	3.83	4.24	4.20	3.62
	Intake air depressure	mbar,rel	22	18	25	30	22	15
	Exhaust backpressure	mbar,rel	148	84	183	211	106	36
	Cooler backpressure	mbar, rel	46.785	46.668	59.156	87.975	50.438	28.618
Mass flow	Air	kg/s	0.11	0.09	0.13	0.16	0.12	0.07
	Air flow	kg/h	406.74	327.39	470.96	560.94	418.97	252.88
	Fuel flow	g/s	5.10	3.23	4.46	3.48	1.91	1.28
	Fuel flow	L/s	0.0065	0.0041	0.0057	0.0045	0.0024	0.0016
	Fuel flow	L/h	23.53	14.92	20.60	16.05	8.82	5.92
	Efficiency	%	40.1	40.1	38.7	32.8	30.4	34.0
Exhaust gas	HC, C1 w et	ppm	35.51	19.21	25.77	35.55	36.90	30.92
	NO	ppm	1258.33	1102.00	813.57	421.52	272.32	424.40
	NOX	ppm	1290.17	1149.50	852.85	458.00	301.03	453.65
	CO, dry	ppm	29.09	13.08	27.66	41.27	34.05	19.79
	CO2, dry	%	9.36	7.27	6.85	4.52	3.16	3.54
	O2, dry	%	7.55	10.45	11.02	14.35	16.32	15.75
	Smoke	FSN	0.02	0.01	0.01	0.01	0.01	0.01
	NOX sensor 1	ppm	1260.13	1124.35	848.45	468.50	299.23	439.27
	O2 sensor 1	%	6.64	9.54	10.02	13.25	15.16	14.57
	NOX sensor 2	ppm	1243.68	1105.99	842.13	465.59	301.51	436.85
	O2 sensor 2	%	6.58	9.42	10.00	13.36	15.38	14.77

			50-50 % MIX, Pil 1 timing 500 µs					
Engine & environment	Load point		1	2	3	4	5	6
	Date & time	yyyy-mm-dd	2014-05-23	2014-05-23	2014-05-23	2014-05-23	2014-05-23	2014-05-23
	Atmospheric pressure	kPa	101.70	101.70	101.70	101.70	101.70	101.70
	Relative humidity	%	29.00	25.00	24.00	23.00	24.78	25.00
	Room temperature	oC	30.07	32.77	33.27	33.75	32.22	31.83
	Engine speed	1/min	1497.78	1300.85	1797.87	2199.33	1797.96	1301.13
	Engine torque	Nm	572.32	417.72	402.80	218.20	136.20	141.14
	Engine power	kW	90	57	76	50	26	19
	BMEP	bar	16.4	11.9	11.5	6.2	3.9	4.0
	SFC	g/kWh	209	208	216	255	275	247
Specific emissions	Lambda		1.44	1.83	1.92	2.92	3.94	3.49
	NOx left	g/kWh	7.28	8.26	6.66	6.48	6.41	7.82
	HC left	g/kWh	24.25	30.35	33.11	58.66	84.79	67.63
	CO left	g/kWh	0.15	0.09	0.16	0.48	0.62	0.29
	NOx sensor 1	g/kWh	7.76	8.61	7.04	6.90	6.56	7.87
	NOx sensor 2	g/kWh	7.66	8.44	6.98	6.85	6.62	7.83
	Smoke	FSN	0.044	0.010	0.012	0.022	0.020	0.015
WinEEM	Rail pressure	Mpa	130.00	134.65	146.39	159.94	133.06	118.74
	Injection timing M1	o crankshaft	5.29	0.70	4.30	3.90	1.90	0.90
	Injection timing P1	µs	500.00	500.00	500.00	500.00	500.00	500.00
	Injection timing P0	µs	-2000.00	0.00	-1700.00	-1300.00	-1300.00	-1300.00
	Injection quantity M1	mg	92.54	69.61	64.53	37.32	20.69	23.06
	Injection quantity P1	mg	2.00	2.00	2.00	2.00	2.00	2.00
	Injection quantity P0	mg	4.00	0.00	4.00	4.00	4.00	4.00
	Injection duration M1	µs	1353.08	1064.67	967.43	682.32	578.32	568.12
	Injection duration P1	µs	288.62	284.32	275.67	269.63	286.52	297.35
	Injection duration P0	µs	358.57	0.00	334.50	320.92	349.35	367.12
Temperature	T Before compressor	oC	29.65	30.83	31.00	30.96	30.16	30.29
	T After compressor	oC	133.11	116.91	126.66	120.03	97.81	67.67
	T Intake manifold	oC	48.58	43.51	49.82	51.17	40.83	30.98
	T Before turbine	oC	608.88	473.92	505.61	403.49	287.56	261.45
	T After turbine	oC	492.39	373.96	403.31	306.97	208.57	212.02
	T Fuel	oC	35.40	36.05	36.31	37.10	36.57	35.90
	T Oil	oC	109.09	105.61	108.93	108.60	102.36	97.52
	T Engine coolant	oC	85.82	83.01	83.86	81.84	80.40	79.72
Pressure	P Before compressor	bar,abs	1.00	1.00	0.99	0.99	1.00	1.00
	P After compressor	bar,abs	2.21	1.95	2.15	2.04	1.77	1.38
	P Intake manifold	bar,abs	2.17	1.91	2.10	1.96	1.72	1.35
	P Before turbine	bar,abs	2.55	2.23	2.76	2.99	2.41	1.66
	P After turbine	bar,abs	1.16	1.10	1.20	1.23	1.12	1.05
	Oil pressure	bar,rel	3.24	3.10	3.81	4.23	4.19	3.57
	Intake air depressure	mbar,rel	21	17	24	29	21	14
	Exhaust backpressure	mbar,rel	147	87	183	210	105	35
	Cooler backpressure	mbar, rel	42.087	43.556	54.298	83.885	46.564	29.276
Mass flow	Air	kg/s	0.11	0.09	0.13	0.15	0.11	0.07
	Air flow	kg/h	401.27	321.44	468.17	556.14	412.64	246.26
	Fuel flow	g/s	5.22	3.29	4.55	3.56	1.96	1.32
	Fuel flow	L/s	0.0065	0.0041	0.0056	0.0044	0.0024	0.0016
	Fuel flow	L/h	23.23	14.67	20.27	15.85	8.72	5.88
	Efficiency	%	39.6	39.7	38.3	32.5	30.1	33.5
Exhaust gas	HC, C1 wet	ppm	10816.79	10816.79	10816.79	10816.79	10816.79	10816.79
	NO	ppm	1143.67	1017.67	743.75	385.17	253.97	403.83
	NOX	ppm	1169.00	1051.33	776.07	418.70	281.63	432.10
	CO, dry	ppm	37.05	16.31	27.63	46.40	41.21	24.32
	CO2, dry	%	9.88	7.68	7.23	4.75	3.31	3.76
	O2, dry	%	7.10	10.13	10.79	14.25	16.32	15.66
	Smoke	FSN	0.04	0.01	0.01	0.02	0.02	0.02
	NOX sensor 1	ppm	1128.00	1009.97	760.32	421.80	276.13	415.42
	O2 sensor 1	%	6.15	9.08	9.65	12.98	14.96	14.27
	NOX sensor 2	ppm	1112.20	990.23	753.71	419.17	278.63	413.46
	O2 sensor 2	%	6.08	8.94	9.60	13.03	15.11	14.44

			NExBTL, Pil1 qty 3 mg					
Engine & environment	Load point		1	2	3	4	5	6
	Date & time	yyyy-mm-dd	2014-05-15	2014-05-15	2014-05-15	2014-05-15	2014-05-15	2014-05-15
	Atmospheric pressure	kPa	102.80	102.80	102.80	102.80	102.80	102.80
	Relative humidity	%	9.00	9.00	9.00	9.00	10.00	11.00
	Room temperature	oC	29.35	29.83	29.90	29.90	28.39	26.40
	Engine speed	1/min	1497.85	1300.63	1797.60	2199.07	1797.57	1300.51
	Engine torque	Nm	572.37	417.32	402.58	217.71	135.76	140.81
	Engine pow er	kW	90	57	76	50	26	19
	BMEP	bar	16.4	11.9	11.5	6.2	3.9	4.0
	SFC	g/kWh	205	205	211	249	266	240
Specific emissions	Lambda		1.47	1.86	1.96	2.99	4.12	3.67
	NOx left	g/kWh	7.61	8.79	7.08	7.01	6.81	8.32
	HC left	g/kWh	0.08	0.06	0.08	0.19	0.28	0.21
	CO left	g/kWh	0.13	0.07	0.15	0.39	0.48	0.24
	NOx sensor 1	g/kWh	8.02	9.15	7.50	7.47	6.98	8.38
	NOx sensor 2	g/kWh	7.92	8.97	7.44	7.42	7.04	8.33
	Smoke	FSN	0.025	0.005	0.007	0.012	0.012	0.008
WinEEM	Rail pressure	Mpa	130.54	134.62	148.16	159.76	132.89	119.19
	Injection timing M1	o crankshaft	5.32	0.70	4.37	3.90	1.92	0.90
	Injection timing P1	µs	350.00	350.00	350.00	350.00	350.00	350.00
	Injection timing P0	µs	-2000.00	0.00	-1700.00	-1300.00	-1300.00	-1300.00
	Injection quantity M1	mg	92.00	69.64	64.02	36.80	19.60	22.46
	Injection quantity P1	mg	3.00	3.00	3.00	3.00	3.00	3.00
	Injection quantity P0	mg	4.00	0.00	4.00	4.00	4.00	4.00
	Injection duration M1	µs	1353.70	1069.28	960.82	677.25	565.30	559.30
	Injection duration P1	µs	311.32	305.82	294.73	286.53	308.97	322.35
	Injection duration P0	µs	359.42	0.00	334.13	320.03	349.15	366.33
Temperature	T Before compressor	oC	25.26	25.35	25.02	24.62	23.82	23.38
	T After compressor	oC	127.30	110.23	119.29	112.34	91.01	61.39
	T Intake manifold	oC	48.87	43.48	50.45	52.69	39.87	28.32
	T Before turbine	oC	602.06	469.07	498.87	400.82	286.34	258.41
	T After turbine	oC	487.26	370.99	398.91	305.78	208.40	208.39
	T Fuel	oC	34.67	34.82	35.69	36.04	35.61	34.68
	T Oil	oC	111.77	106.05	109.18	108.37	101.75	96.03
	T Engine coolant	oC	85.34	82.27	83.19	81.20	79.87	78.79
Pressure	P Before compressor	bar,abs	1.01	1.01	1.00	1.00	1.01	1.01
	P After compressor	bar,abs	2.25	1.98	2.19	2.08	1.80	1.42
	P Intake manifold	bar,abs	2.20	1.93	2.13	1.99	1.75	1.39
	P Before turbine	bar,abs	2.57	2.25	2.78	3.01	2.44	1.70
	P After turbine	bar,abs	1.18	1.11	1.21	1.24	1.13	1.06
	Oil pressure	bar,rel	3.17	3.09	3.80	4.23	4.21	3.65
	Intake air depressure	mbar,rel	21	17	25	30	22	15
	Exhaust backpressure	mbar,rel	150	86	183	209	104	35
	Cooler backpressure	mbar, rel	50.844	48.222	61.631	89.083	48.691	28.702
Mass flow	Air	kg/s	0.11	0.09	0.13	0.16	0.12	0.07
	Air flow	kg/h	404.67	324.41	469.06	558.57	418.59	252.80
	Fuel flow	g/s	5.11	3.24	4.45	3.47	1.89	1.28
	Fuel flow	L/s	0.0066	0.0042	0.0057	0.0045	0.0024	0.0016
	Fuel flow	L/h	23.59	14.94	20.52	16.04	8.71	5.90
	Efficiency	%	40.1	40.0	38.9	32.9	30.9	34.2
Exhaust gas	HC, C1 w et	ppm	37.57	19.98	25.41	34.49	35.43	32.15
	NO	ppm	1271.33	1135.00	835.38	439.03	281.12	438.68
	NOX	ppm	1305.50	1181.50	875.05	476.53	311.12	469.45
	CO, dry	ppm	32.00	13.59	25.99	36.83	30.63	19.32
	CO2, dry	%	9.54	7.39	6.90	4.54	3.16	3.54
	O2, dry	%	7.39	10.33	10.99	14.33	16.33	15.78
	Smoke	FSN	0.03	0.01	0.01	0.01	0.01	0.01
	NOX sensor 1	ppm	1259.62	1145.58	867.83	485.43	308.38	455.97
	O2 sensor 1	%	6.48	9.46	10.01	13.26	15.22	14.61
	NOX sensor 2	ppm	1243.31	1123.15	860.63	482.07	311.31	453.41
	O2 sensor 2	%	6.38	9.28	9.95	13.33	15.40	14.78

			50-50 % MIX, Pil1 qty 3 mg					
Engine & environment	Load point		1	2	3	4	5	6
	Date & time	yyyy-mm-dd	2014-05-23	2014-05-23	2014-05-23	2014-05-23	2014-05-23	2014-05-23
	Atmospheric pressure	kPa	101.70	101.70	101.70	101.70	101.70	101.70
	Relative humidity	%	22.00	20.00	20.00	20.00	21.00	24.00
	Room temperature	oC	33.76	34.96	35.11	35.10	34.30	32.93
	Engine speed	1/min	1498.04	1301.76	1798.00	2199.44	1798.20	1301.77
	Engine torque	Nm	572.94	418.16	403.25	218.45	136.43	141.59
	Engine power	kW	90	57	76	50	26	19
	BMEP	bar	16.4	12.0	11.5	6.2	3.9	4.0
	SFC	g/kWh	209	210	217	254	274	246
Specific emissions	Lambda		1.44	1.81	1.92	2.92	3.92	3.48
	NOx left	g/kWh	7.22	8.33	6.69	6.55	6.65	8.19
	HC left	g/kWh	24.11	30.27	33.07	58.47	84.15	67.23
	CO left	g/kWh	0.17	0.09	0.16	0.42	0.50	0.28
	NOx sensor 1	g/kWh	7.62	8.63	7.05	6.96	6.79	8.19
	NOx sensor 2	g/kWh	7.50	8.45	6.99	6.92	6.84	8.13
	Smoke	FSN	0.046	0.008	0.013	0.021	0.018	0.013
WinEEM	Rail pressure	Mpa	129.79	135.20	146.87	160.20	131.69	118.71
	Injection timing M1	o crankshaft	5.31	0.70	4.30	3.90	1.90	0.90
	Injection timing P1	µs	350.00	350.00	350.00	350.00	350.00	350.00
	Injection timing P0	µs	-2000.00	0.00	-1720.00	-1300.00	-1300.00	-1300.00
	Injection quantity M1	mg	92.25	69.76	63.89	36.85	19.62	22.17
	Injection quantity P1	mg	3.00	3.00	3.00	3.00	3.00	3.00
	Injection quantity P0	mg	4.00	0.00	4.00	4.00	4.00	4.00
	Injection duration M1	µs	1349.27	1064.33	961.18	681.38	567.40	555.58
	Injection duration P1	µs	310.80	305.63	294.80	286.53	308.48	323.45
	Injection duration P0	µs	358.88	0.00	333.87	320.70	348.82	367.47
Temperature	T Before compressor	oC	32.28	32.58	32.20	31.76	31.52	31.32
	T After compressor	oC	136.06	118.53	127.92	120.71	98.73	68.20
	T Intake manifold	oC	48.23	42.34	49.66	50.70	41.16	30.85
	T Before turbine	oC	608.80	471.40	504.36	402.45	286.76	259.44
	T After turbine	oC	492.15	371.83	402.11	305.93	208.14	210.17
	T Fuel	oC	36.16	36.18	36.48	37.24	36.66	36.16
	T Oil	oC	110.87	106.18	109.08	108.77	102.54	97.21
	T Engine coolant	oC	86.24	83.20	84.06	82.05	80.57	79.80
Pressure	P Before compressor	bar,abs	1.00	1.00	0.99	0.99	1.00	1.00
	P After compressor	bar,abs	2.21	1.95	2.15	2.04	1.76	1.38
	P Intake manifold	bar,abs	2.16	1.90	2.10	1.95	1.71	1.35
	P Before turbine	bar,abs	2.55	2.23	2.76	3.00	2.40	1.65
	P After turbine	bar,abs	1.17	1.10	1.20	1.23	1.12	1.05
	Oil pressure	bar,rel	3.19	3.09	3.80	4.22	4.18	3.59
	Intake air depressure	mbar,rel	20	16	24	28	21	14
	Exhaust backpressure	mbar,rel	148	87	182	209	103	34
	Cooler backpressure	mbar, rel	45.87	46.226	54.947	91.369	47.509	29.506
Mass flow	Air	kg/s	0.11	0.09	0.13	0.15	0.11	0.07
	Air flow	kg/h	399.55	321.05	468.12	555.03	410.20	245.69
	Fuel flow	g/s	5.21	3.32	4.57	3.55	1.96	1.32
	Fuel flow	L/s	0.0064	0.0041	0.0057	0.0044	0.0024	0.0016
	Fuel flow	L/h	23.18	14.78	20.35	15.82	8.72	5.88
	Efficiency	%	39.7	39.5	38.2	32.6	30.2	33.6
Exhaust gas	HC, C1 wet	ppm	10816.79	10816.79	10816.79	10816.79	10816.79	10816.79
	NO	ppm	1164.50	1047.83	759.37	397.48	270.28	426.15
	NOX	ppm	1193.00	1084.33	793.33	430.05	298.27	456.18
	CO, dry	ppm	40.70	17.00	28.29	41.14	33.55	23.57
	CO2, dry	%	9.97	7.71	7.25	4.76	3.33	3.76
	O2, dry	%	7.11	10.17	10.79	14.26	16.31	15.67
	Smoke	FSN	0.05	0.01	0.01	0.02	0.02	0.01
	NOX sensor 1	ppm	1139.02	1036.23	775.00	432.85	292.18	436.00
	O2 sensor 1	%	6.06	9.09	9.63	12.99	14.99	14.24
	NOX sensor 2	ppm	1121.89	1015.56	768.20	430.16	294.40	432.73
	O2 sensor 2	%	5.96	8.93	9.59	13.03	15.10	14.44

			NExBTL, Pil 1 off					
Engine & environment	Load point		1	2	3	4	5	6
	Date & time	yyyy-mm-dd	2014-05-16	2014-05-16	2014-05-16	2014-05-16	2014-05-16	2014-05-16
	Atmospheric pressure	kPa	102.30	102.30	102.30	102.30	102.30	102.30
	Relative humidity	%	23.57	20.65	21.00	20.00	21.00	22.00
	Room temperature	oC	24.78	25.76	26.89	27.30	26.79	25.94
	Engine speed	1/min	1497.56	1300.15	1797.38	2198.84	1797.35	1300.06
	Engine torque	Nm	571.38	416.81	402.01	217.19	135.19	140.27
	Engine pow er	kW	90	57	76	50	25	19
	BMEP	bar	16.3	11.9	11.5	6.2	3.9	4.0
	SFC	g/kWh	205	206	212	250	272	246
Specific emissions	Lambda		1.47	1.87	1.96	2.99	4.06	3.54
	NOx left	g/kWh	7.75	8.63	7.09	6.68	6.13	7.62
	HC left	g/kWh	0.08	0.05	0.07	0.18	0.29	0.16
	CO left	g/kWh	0.12	0.08	0.14	0.53	0.90	0.37
	NOx sensor 1	g/kWh	8.19	9.02	7.45	7.12	6.33	7.69
	NOx sensor 2	g/kWh	8.10	8.85	7.40	7.07	6.41	7.65
	Smoke	FSN	0.019	0.008	0.009	0.010	0.011	0.010
WinEEM	Rail pressure	Mpa	130.62	134.83	149.46	160.09	134.88	120.79
	Injection timing M1	o crankshaft	5.46	0.80	4.30	3.90	1.91	0.90
	Injection timing P1	µs	0.00	0.00	0.00	0.00	0.00	0.00
	Injection timing P0	µs	-2000.00	0.00	-1730.00	-1300.00	-1300.00	-1300.00
	Injection quantity M1	mg	97.01	75.69	67.31	36.02	24.97	27.09
	Injection quantity P1	mg	0.00	0.00	0.00	0.00	0.00	0.00
	Injection quantity P0	mg	4.00	0.00	4.00	4.00	4.00	4.00
	Injection duration M1	µs	1401.35	1124.67	992.05	668.27	622.45	630.05
	Injection duration P1	µs	80.00	80.00	80.00	80.00	80.00	80.00
	Injection duration P0	µs	357.58	0.00	333.93	320.15	345.37	363.75
Temperature	T Before compressor	oC	22.47	23.17	22.97	22.72	22.65	22.91
	T After compressor	oC	124.76	108.95	117.26	110.33	91.40	60.68
	T Intake manifold	oC	48.38	42.43	49.52	50.70	40.64	30.00
	T Before turbine	oC	600.86	469.47	500.85	401.56	291.90	265.07
	T After turbine	oC	486.75	371.11	400.94	307.13	212.93	215.98
	T Fuel	oC	34.06	34.33	34.79	35.57	35.36	34.72
	T Oil	oC	108.97	104.69	108.04	107.95	102.21	97.26
	T Engine coolant	oC	84.96	82.10	82.95	81.01	79.64	78.81
Pressure	P Before compressor	bar,abs	1.00	1.01	1.00	0.99	1.00	1.01
	P After compressor	bar,abs	2.24	1.99	2.18	2.07	1.82	1.41
	P Intake manifold	bar,abs	2.20	1.94	2.13	1.98	1.77	1.38
	P Before turbine	bar,abs	2.57	2.25	2.78	3.00	2.46	1.68
	P After turbine	bar,abs	1.17	1.11	1.21	1.23	1.13	1.06
	Oil pressure	bar,rel	3.26	3.13	3.84	4.23	4.19	3.60
	Intake air depressure	mbar,rel	21	18	26	30	23	15
	Exhaust backpressure	mbar,rel	147	86	182	211	108	36
	Cooler backpressure	mbar, rel	46.342	46.445	58.321	88.673	50.164	29.448
Mass flow	Air	kg/s	0.11	0.09	0.13	0.16	0.12	0.07
	Air flow	kg/h	405.34	327.02	470.50	559.68	420.64	248.69
	Fuel flow	g/s	5.11	3.24	4.46	3.47	1.92	1.31
	Fuel flow	L/s	0.0066	0.0042	0.0057	0.0045	0.0025	0.0017
	Fuel flow	L/h	23.58	14.96	20.61	16.02	8.89	6.03
	Efficiency	%	40.0	39.9	38.7	32.9	30.2	33.3
Exhaust gas	HC, C1 w et	ppm	37.29	17.49	23.08	33.36	36.52	25.93
	NO	ppm	1222.33	1055.50	798.42	395.12	237.50	387.10
	NOX	ppm	1259.00	1100.17	834.97	434.32	267.10	421.25
	CO, dry	ppm	27.76	14.50	24.59	49.88	57.55	30.24
	CO2, dry	%	9.49	7.35	6.94	4.56	3.20	3.66
	O2, dry	%	7.30	10.24	10.84	14.21	16.20	15.53
	Smoke	FSN	0.02	0.01	0.01	0.01	0.01	0.01
	NOX sensor 1	ppm	1213.88	1069.25	818.00	441.00	266.03	407.78
	O2 sensor 1	%	6.48	9.44	9.93	13.17	15.11	14.40
	NOX sensor 2	ppm	1200.32	1048.75	813.00	438.00	269.30	406.00
	O2 sensor 2	%	6.40	9.27	9.89	13.24	15.28	14.56

			50-50 %, Pil 1 off					
Engine & environment	Load point		1	2	3	4	5	6
	Date & time	yyyy-mm-dd	2014-05-23	2014-05-23	2014-05-23	2014-05-23	2014-05-23	2014-05-23
	Atmospheric pressure	kPa	101.67	101.61	101.60	101.60	101.60	101.60
	Relative humidity	%	21.00	21.00	21.00	21.90	21.68	22.00
	Room temperature	oC	34.82	35.29	35.20	35.10	34.90	33.90
	Engine speed	1/min	1498.37	1302.29	1798.22	2199.76	1798.36	1302.28
	Engine torque	Nm	573.21	418.76	403.82	218.86	136.88	141.85
	Engine pow er	kW	90	57	76	50	26	19
	BMEP	bar	16.4	12.0	11.5	6.3	3.9	4.1
	SFC	g/kWh	210	210	216	253	273	247
Specific emissions	Lambda		1.42	1.82	1.92	2.94	3.95	3.47
	NOx left	g/kWh	7.07	8.24	6.79	6.38	5.91	7.54
	HC left	g/kWh	24.03	30.36	33.04	58.54	84.32	67.36
	CO left	g/kWh	0.15	0.09	0.16	0.57	1.15	0.46
	NOx sensor 1	g/kWh	7.45	8.57	7.14	6.77	6.01	7.55
	NOx sensor 2	g/kWh	7.34	8.40	7.08	6.73	6.10	7.51
	Smoke	FSN	0.035	0.007	0.009	0.016	0.014	0.010
WinEEM	Rail pressure	Mpa	129.82	134.61	149.35	159.78	135.75	120.68
	Injection timing M1	o crankshaft	5.28	0.80	4.39	3.90	1.90	0.90
	Injection timing P1	µs	0.00	0.00	0.00	0.00	0.00	0.00
	Injection timing P0	µs	-2000.00	0.00	-1722.00	-1300.00	-1300.00	-1300.00
	Injection quantity M1	mg	97.88	75.56	67.17	36.07	24.69	27.15
	Injection quantity P1	mg	0.00	0.00	0.00	0.00	0.00	0.00
	Injection quantity P0	mg	4.00	0.00	4.00	4.00	4.00	4.00
	Injection duration M1	µs	1414.63	1129.88	994.17	666.82	616.75	632.12
	Injection duration P1	µs	80.00	80.00	80.00	80.00	80.00	80.00
	Injection duration P0	µs	357.62	0.00	334.33	319.90	346.22	364.23
Temperature	T Before compressor	oC	32.56	32.59	32.33	31.99	31.96	31.86
	T After compressor	oC	136.02	119.10	127.91	121.10	99.60	69.23
	T Intake manifold	oC	48.26	42.32	48.97	49.96	40.03	30.34
	T Before turbine	oC	611.75	471.93	501.68	398.65	286.56	258.85
	T After turbine	oC	495.67	372.42	399.89	302.03	207.90	209.14
	T Fuel	oC	36.02	36.20	36.35	37.14	36.81	36.07
	T Oil	oC	111.38	106.56	109.42	108.86	102.74	97.88
	T Engine coolant	oC	86.45	83.33	84.19	82.04	80.45	79.82
Pressure	P Before compressor	bar,abs	1.00	1.00	0.99	0.99	1.00	1.00
	P After compressor	bar,abs	2.21	1.95	2.15	2.04	1.76	1.38
	P Intake manifold	bar,abs	2.16	1.91	2.09	1.95	1.72	1.35
	P Before turbine	bar,abs	2.54	2.23	2.76	3.00	2.41	1.66
	P After turbine	bar,abs	1.17	1.10	1.20	1.22	1.12	1.05
	Oil pressure	bar,rel	3.17	3.08	3.79	4.22	4.18	3.56
	Intake air depressure	mbar,rel	19	15	23	28	20	13
	Exhaust backpressure	mbar,rel	149	88	181	208	104	35
	Cooler backpressure	mbar, rel	46.86	44.709	53.478	88.291	46.179	27.433
Mass flow	Air	kg/s	0.11	0.09	0.13	0.15	0.11	0.07
	Air flow	kg/h	398.36	322.63	468.54	556.88	412.44	246.71
	Fuel flow	g/s	5.24	3.33	4.56	3.55	1.96	1.33
	Fuel flow	L/s	0.0065	0.0041	0.0056	0.0044	0.0024	0.0016
	Fuel flow	L/h	23.33	14.81	20.29	15.80	8.71	5.92
	Efficiency	%	39.5	39.5	38.4	32.7	30.3	33.5
Exhaust gas	HC, C1 w et	ppm	10816.79	10816.79	10816.79	10816.79	10816.79	10816.79
	NO	ppm	1151.00	1025.33	766.90	379.03	231.28	391.25
	NOX	ppm	1177.33	1063.50	801.85	413.88	263.52	422.82
	CO, dry	ppm	36.74	17.03	28.75	55.55	76.27	38.16
	CO2, dry	%	10.09	7.74	7.25	4.76	3.34	3.80
	O2, dry	%	6.98	10.14	10.79	14.27	16.28	15.61
	Smoke	FSN	0.04	0.01	0.01	0.02	0.01	0.01
	NOX sensor 1	ppm	1121.75	1019.40	780.73	415.52	256.85	403.80
	O2 sensor 1	%	5.96	9.06	9.61	12.97	14.93	14.22
	NOX sensor 2	ppm	1103.92	998.89	774.54	413.41	260.70	401.97
	O2 sensor 2	%	5.83	8.89	9.55	13.02	15.06	14.37

			NExBTL, EGR 15 %-parameters					
Engine & environment	Load point		1	2	3	4	5	6
	Date & time	yyyy-mm-dd	2014-08-27	2014-08-27	2014-08-27	2014-08-27	2014-08-27	2014-08-27
	Atmospheric pressure	kPa	99.60	99.60	99.60	99.60	99.60	99.60
	Relative humidity	%	28.03	27.00	26.00	25.10	26.00	27.00
	Room temperature	oC	29.82	30.67	31.65	31.80	31.01	30.13
	Engine speed	1/min	1497.88	1301.57	1797.88	2199.29	1798.04	1301.76
	Engine torque	Nm	572.12	417.58	402.74	217.99	136.07	141.06
	Engine power	kW	90	57	76	50	26	19
	BMEP	bar	16.3	11.9	11.5	6.2	3.9	4.0
	SFC	g/kWh	208	208	213	245	255	241
Specific emissions	Lambda		1.38	1.71	1.83	2.53	2.77	2.36
	NOx left	g/kWh	5.71	6.61	5.16	3.87	2.96	3.68
	HC left	g/kWh	0.07	0.06	0.08	0.16	0.22	0.14
	CO left	g/kWh	0.29	0.10	0.18	0.44	0.55	0.32
	NOx sensor 1	g/kWh	6.04	6.87	5.46	4.11	2.96	3.68
	NOx sensor 2	g/kWh	6.00	6.78	5.44	4.12	3.04	3.69
	Smoke	FSN	0.124	0.011	0.019	0.033	0.035	0.031
	Testo O2	%	20.71	20.92	20.13	19.96	19.28	19.63
EGR	EGR-valve position	%	0	0	5	10	15	15
	EGR	%	2.0	0.8	8.1	13.6	25.2	17.5
WinEEM	Rail pressure	Mpa	129.98	134.78	148.67	160.23	132.01	118.46
	Injection timing M1	o crankshaft	5.42	0.71	4.51	3.90	1.91	2.42
	Injection timing P1	µs	350.00	350.00	350.00	350.00	350.00	350.00
	Injection timing P0	µs	-2000.00	0.00	-1782.00	-1300.00	-1300.00	-1300.00
	Injection quantity M1	mg	94.54	71.62	65.65	36.99	19.19	22.90
	Injection quantity P1	mg	2.00	2.00	2.00	2.00	2.00	2.00
	Injection quantity P0	mg	4.00	0.00	4.00	4.00	4.00	4.00
	Injection duration M1	µs	1378.25	1086.08	976.93	678.22	563.98	566.67
	Injection duration P1	µs	288.40	284.42	275.47	269.33	288.03	298.25
	Injection duration P0	µs	358.78	0.00	334.53	320.15	350.57	368.28
Temperature	T Before compressor	oC	27.22	27.83	27.79	27.54	27.75	28.04
	T After compressor	oC	133.49	112.88	124.94	117.04	77.76	53.62
	T Intake manifold	oC	47.49	42.17	50.23	52.25	47.12	56.01
	T Before turbine	oC	629.30	493.86	521.82	412.19	318.99	294.53
	T After turbine	oC	509.60	394.55	417.71	314.80	255.69	255.51
	T Fuel	oC	35.95	36.05	36.30	37.10	36.91	36.24
	T Oil	oC	109.94	105.66	109.31	108.68	102.22	97.44
	T Engine coolant	oC	86.00	82.82	83.91	81.82	80.06	79.58
	T After Charge Air Cooler	oC	43.74	36.58	47.03	46.23	27.06	20.80
Pressure	P Before compressor	bar,abs	0.98	0.98	0.98	0.98	0.99	0.99
	P After compressor	bar,abs	2.20	1.89	2.14	2.03	1.51	1.22
	P Intake manifold	bar,abs	2.14	1.84	2.07	1.96	1.47	1.19
	P Before turbine	bar,abs	2.49	2.13	2.67	2.73	1.81	1.36
	P After turbine	bar,abs	1.14	1.08	1.17	1.16	1.05	1.01
	Oil pressure	bar,rel	3.22	3.10	3.78	4.21	4.24	3.62
	Intake air depressure	mbar,rel	14	11	18	20	10	7
	Exhaust backpressure	mbar,rel	142	81	173	167	52	16
	Cooler backpressure	mbar, rel	50.745	51.144	64.3	77.835	40.581	26.079
Mass flow	Air	kg/s	0.11	0.08	0.12	0.13	0.08	0.05
	Air flow	kg/h	385.91	302.93	442.24	464.66	271.12	164.14
	Fuel flow	g/s	5.19	3.29	4.50	3.42	1.82	1.29
	Fuel flow	L/s	0.0067	0.0042	0.0058	0.0044	0.0023	0.0017
	Fuel flow	L/h	23.9	15.2	20.8	15.8	8.4	5.9
	Efficiency	%	39.5	39.4	38.5	33.5	32.2	34.0
Exhaust gas	HC, C1, wet	ppm	32.53	21.37	26.11	35.65	42.41	33.58
	NO	ppm	933.33	859.35	605.42	266.45	168.73	277.75
	NOX	ppm	956.33	888.58	632.42	297.18	198.08	305.28
	CO, dry	ppm	73.45	19.62	33.18	51.07	55.30	39.55
	CO2, dry	%	10.31	8.13	7.57	5.34	4.74	5.47
	O2, dry	%	6.18	9.19	9.97	13.13	13.98	12.95
	Smoke	FSN	0.12	0.01	0.02	0.03	0.03	0.03
	NOX sensor 1	ppm	913.28	848.80	617.75	296.92	187.13	286.63
	O2 sensor 1	%	5.43	8.35	9.05	12.05	12.88	11.77
	NOX sensor 2	ppm	907.45	837.18	615.30	297.93	192.55	287.23
	O2 sensor 2	%	5.29	8.16	8.93	12.00	12.84	11.77

			50-50 % MIX, EGR 15 %-parameters					
Engine & environment	Load point		1	2	3	4	5	6
	Date & time	yyyy-mm-dd	2014-08-14	2014-08-14	2014-08-14	2014-08-14	2014-08-14	2014-08-14
	Atmospheric pressure	kPa	99.90	99.90	99.90	99.90	100.00	99.95
	Relative humidity	%	41.50	33.57	30.00	29.98	29.08	30.00
	Room temperature	oC	27.31	30.16	31.88	32.25	31.81	30.81
	Engine speed	1/min	1497.88	1301.63	1797.97	2199.43	1798.04	1301.59
	Engine torque	Nm	572.14	417.51	402.62	218.24	136.13	141.00
	Engine power	kW	90	57	76	50	26	19
	BMEP	bar	16.4	11.9	11.5	6.2	3.9	4.0
	SFC	g/kWh	209	208	215	245	257	239
Specific emissions	Lambda		1.41	1.73	1.84	2.55	2.80	2.43
	NOx left	g/kWh	6.34	7.08	5.42	4.05	3.15	3.90
	HC left	g/kWh	0.07	0.06	0.08	0.20	0.27	0.20
	CO left	g/kWh	0.24	0.09	0.15	0.47	0.57	0.34
	NOx sensor 1	g/kWh	6.68	7.32	5.74	4.23	3.12	3.91
	NOx sensor 2	g/kWh	6.62	7.18	5.70	4.27	3.23	3.93
	Smoke	FSN	0.108	0.013	0.022	0.055	0.056	0.044
	Testo O2	%	20.83	20.93	20.26	19.98	19.32	19.68
EGR	EGR-valve position	%	0	0	5	10	15	15
	EGR	%	1.3	0.7	6.9	13.6	25.2	17.3
WinEEM	Rail pressure	Mpa	130.09	134.90	150.24	159.81	130.63	117.71
	Injection timing M1	o crankshaft	5.36	0.70	4.56	3.90	1.91	2.32
	Injection timing P1	µs	350.00	350.00	350.00	350.00	350.00	350.00
	Injection timing P0	µs	-2000.00	0.00	-1750.00	-1300.00	-1300.00	-1300.00
	Injection quantity M1	mg	93.94	71.48	65.95	37.34	19.53	22.74
	Injection quantity P1	mg	2.00	2.00	2.00	2.00	2.00	2.00
	Injection quantity P0	mg	4.00	0.00	4.00	4.00	4.00	4.00
	Injection duration M1	µs	1363.23	1085.28	979.55	679.22	566.05	564.15
	Injection duration P1	µs	287.87	284.18	275.65	269.23	287.88	298.17
	Injection duration P0	µs	358.05	0.00	334.27	320.58	350.43	368.20
Temperature	T Before compressor	oC	27.09	28.32	28.63	29.29	29.08	28.65
	T After compressor	oC	133.22	111.31	124.92	118.17	78.76	54.12
	T Intake manifold	oC	47.83	41.52	50.78	50.75	47.31	56.42
	T Before turbine	oC	630.65	499.96	527.59	410.50	318.65	293.16
	T After turbine	oC	509.64	401.20	423.20	312.57	255.61	253.52
	T Fuel	oC	34.80	36.30	37.03	38.13	37.42	36.56
	T Oil	oC	106.14	104.16	108.60	108.30	102.27	96.79
	T Engine coolant	oC	85.39	82.79	83.80	82.31	80.13	79.59
	T After Charge Air Cooler	oC	44.93	36.68	47.98	44.91	27.71	21.01
Pressure	P Before compressor	bar,abs	0.98	0.99	0.98	0.98	0.99	0.99
	P After compressor	bar,abs	2.20	1.88	2.13	2.02	1.50	1.22
	P Intake manifold	bar,abs	2.15	1.83	2.07	1.95	1.46	1.19
	P Before turbine	bar,abs	2.51	2.11	2.66	2.72	1.81	1.37
	P After turbine	bar,abs	1.14	1.08	1.17	1.16	1.05	1.02
	Oil pressure	bar,rel	3.36	3.15	3.81	4.23	4.25	3.65
	Intake air depressure	mbar,rel	15	12	19	20	12	8
	Exhaust backpressure	mbar,rel	140	79	172	162	51	17
	Cooler backpressure	mbar, rel	43.698	51.468	60.072	69.953	35.379	22.691
Mass flow	Air	kg/s	0.11	0.08	0.12	0.13	0.08	0.05
	Air flow	kg/h	393.63	304.45	444.23	466.54	272.97	165.63
	Fuel flow	g/s	5.21	3.29	4.53	3.42	1.83	1.28
	Fuel flow	L/s	0.0064	0.0041	0.0056	0.0042	0.0023	0.0016
	Fuel flow	L/h	23.2	14.7	20.2	15.2	8.1	5.7
	Efficiency	%	39.6	39.8	38.5	33.8	32.3	34.7
Exhaust gas	HC, C1, wet	ppm	33.66	22.40	27.35	43.05	51.66	46.02
	NO	ppm	975.67	893.17	624.35	272.45	176.88	287.53
	NOX	ppm	997.50	922.83	649.60	303.22	206.02	316.13
	CO, dry	ppm	61.35	19.11	27.04	54.35	56.99	41.94
	CO2, dry	%	10.31	8.25	7.70	5.37	4.80	5.50
	O2, dry	%	6.40	9.18	9.97	13.21	14.05	13.07
	Smoke	FSN	0.11	0.01	0.02	0.06	0.06	0.04
	NOX sensor 1	ppm	945.67	873.93	632.80	297.20	193.00	296.98
	O2 sensor 1	%	5.59	8.34	8.99	12.06	12.91	11.87
	NOX sensor 2	ppm	936.93	857.62	628.83	299.83	199.40	298.72
	O2 sensor 2	%	5.51	8.19	8.92	12.06	12.89	11.87

			NExBTL, EGR 20 %-parameters					
Engine & environment	Load point		1	2	3	4	5	6
	Date & time	yyyy-mm-dd	2014-08-27	2014-08-27	2014-08-27	2014-08-27	2014-08-27	2014-08-27
	Atmospheric pressure	kPa	99.50	99.50	99.50	99.55	99.50	99.59
	Relative humidity	%	34.32	31.00	29.00	28.00	29.00	31.00
	Room temperature	oC	26.72	28.51	29.73	30.10	29.30	28.20
	Engine speed	1/min	1497.67	1300.72	1797.60	2199.11	1797.82	1301.85
	Engine torque	Nm	571.07	416.41	401.63	216.93	135.20	141.49
	Engine power	kW	90	57	76	50	25	19
	BMEP	bar	16.3	11.9	11.5	6.2	3.9	4.0
	SFC	g/kWh	208	207	214	245	259	241
Specific emissions	Lambda		1.39	1.71	1.69	2.30	2.45	2.10
	NOx left	g/kWh	5.79	6.52	3.65	2.95	2.26	2.21
	HC left	g/kWh	0.06	0.05	0.07	0.15	0.21	0.13
	CO left	g/kWh	0.28	0.10	0.19	0.45	0.58	0.38
	NOx sensor 1	g/kWh	6.17	6.79	3.78	3.08	2.25	2.20
	NOx sensor 2	g/kWh	6.16	6.71	3.79	3.13	2.36	2.25
	Smoke	FSN	0.108	0.014	0.049	0.062	0.053	0.060
	Testo O2	%	20.75	20.88	19.22	19.38	18.9	18.77
EGR	EGR-valve position	%	0	5	10	15	20	20
	EGR	%	1.8	1.1	15.2	19.2	27.2	24.8
WinEEM	Rail pressure	Mpa	130.04	134.90	148.09	159.76	130.67	119.06
	Injection timing M1	o crankshaft	5.37	0.70	4.51	3.90	1.96	0.90
	Injection timing P1	µs	350.00	350.00	350.00	350.00	350.00	350.00
	Injection timing P0	µs	-2000.00	0.00	-1748.00	-1300.00	-1300.00	-1300.00
	Injection quantity M1	mg	93.90	70.98	65.72	36.31	18.80	23.27
	Injection quantity P1	mg	2.00	2.00	2.00	2.00	2.00	2.00
	Injection quantity P0	mg	4.00	0.00	4.00	4.00	4.00	4.00
	Injection duration M1	µs	1367.35	1080.62	978.20	672.77	560.43	570.97
	Injection duration P1	µs	288.30	283.93	275.53	269.50	288.70	297.40
	Injection duration P0	µs	358.28	0.00	334.42	320.65	351.48	366.73
Temperature	T Before compressor	oC	25.19	26.27	26.30	26.30	26.50	26.71
	T After compressor	oC	130.84	110.38	124.45	114.17	71.87	49.38
	T Intake manifold	oC	46.49	40.48	50.05	58.85	60.61	63.77
	T Before turbine	oC	629.68	493.19	535.97	420.84	332.52	312.42
	T After turbine	oC	510.57	395.05	428.54	324.72	273.09	272.91
	T Fuel	oC	34.93	35.76	36.18	37.46	36.80	35.91
	T Oil	oC	109.87	105.52	109.18	108.73	102.25	96.15
	T Engine coolant	oC	85.63	82.70	84.16	82.49	80.62	79.53
	T After Charge Air Cooler	oC	42.22	34.02	42.97	41.01	24.31	19.41
Pressure	P Before compressor	bar,abs	0.98	0.98	0.98	0.98	0.99	0.99
	P After compressor	bar,abs	2.19	1.88	2.13	2.01	1.45	1.19
	P Intake manifold	bar,abs	2.14	1.84	2.08	1.94	1.41	1.17
	P Before turbine	bar,abs	2.49	2.11	2.56	2.56	1.69	1.31
	P After turbine	bar,abs	1.14	1.08	1.15	1.14	1.04	1.01
	Oil pressure	bar,rel	3.22	3.10	3.78	4.21	4.24	3.68
	Intake air depressure	mbar,rel	14	11	16	17	9	7
	Exhaust backpressure	mbar,rel	145	81	152	139	43	12
	Cooler backpressure	mbar, rel	48.925	46.969	59.28	73.004	38.466	23.047
Mass flow	Air	kg/s	0.11	0.08	0.11	0.12	0.07	0.04
	Air flow	kg/h	386.95	301.01	408.68	421.28	241.40	146.32
	Fuel flow	g/s	5.18	3.26	4.50	3.39	1.83	1.29
	Fuel flow	L/s	0.0066	0.0042	0.0058	0.0044	0.0023	0.0017
	Fuel flow	L/h	23.9	15.0	20.8	15.7	8.4	6.0
	Efficiency	%	39.5	39.7	38.3	33.6	31.7	34.0
Exhaust gas	HC, C1, wet	ppm	28.62	20.09	26.88	35.77	44.13	34.33
	NO	ppm	930.83	843.18	459.02	218.92	139.97	179.68
	NOX	ppm	950.67	869.05	479.68	247.27	167.78	204.22
	CO, dry	ppm	70.64	19.57	38.48	57.60	65.43	53.81
	CO2, dry	%	10.25	8.13	8.24	5.87	5.35	6.25
	O2, dry	%	6.25	9.14	9.03	12.35	13.07	11.80
	Smoke	FSN	0.11	0.01	0.05	0.06	0.05	0.06
	NOX sensor 1	ppm	914.45	832.00	456.00	242.00	157.00	189.95
	O2 sensor 1	%	5.63	8.37	8.20	11.32	12.04	10.64
	NOX sensor 2	ppm	912.27	821.80	458.30	245.40	164.30	194.72
	O2 sensor 2	%	5.51	8.19	8.06	11.22	11.94	10.66

			50-50 % MIX, EGR 20 %-parameters					
Engine & environment	Load point		1	2	3	4	5	6
	Date & time	yyyy-mm-dd	2014-08-14	2014-08-14	2014-08-14	2014-08-14	2014-08-14	2014-08-14
	Atmospheric pressure	kPa	99.90	99.90	99.90	99.90	100.00	99.91
	Relative humidity	%	30.00	29.00	28.00	28.52	30.00	32.00
	Room temperature	oC	31.23	32.00	32.79	32.44	31.50	30.62
	Engine speed	1/min	1497.94	1301.55	1797.78	2199.26	1797.80	1301.31
	Engine torque	Nm	572.62	417.86	402.86	218.05	136.07	141.00
	Engine power	kW	90	57	76	50	26	19
	BMEP	bar	16.4	11.9	11.5	6.2	3.9	4.0
	SFC	g/kWh	210	208	216	246	256	241
Specific emissions	Lambda		1.40	1.71	1.68	2.30	2.47	2.12
	NOx left	g/kWh	6.09	6.73	3.73	3.04	2.36	2.32
	HC left	g/kWh	0.08	0.06	0.08	0.17	0.24	0.17
	CO left	g/kWh	0.27	0.10	0.20	0.47	0.60	0.40
	NOx sensor 1	g/kWh	6.38	6.94	3.89	3.14	2.33	2.29
	NOx sensor 2	g/kWh	6.33	6.83	3.90	3.18	2.42	2.35
	Smoke	FSN	0.124	0.014	0.063	0.110	0.084	0.088
	Testo O2	%	20.83	20.92	19.25	19.42	18.86	18.74
EGR	EGR-valve position	%	0	5	10	15	20	20
	EGR	%	1.3	0.8	15.0	18.9	28.0	25.5
WinEEM	Rail pressure	Mpa	130.10	134.62	148.87	159.72	131.68	118.61
	Injection timing M1	o crankshaft	5.36	0.70	4.39	3.90	1.91	0.90
	Injection timing P1	µs	350.00	350.00	350.00	350.00	350.00	350.00
	Injection timing P0	µs	-2000.00	0.00	-1300.00	-1300.00	-1300.00	-1300.00
	Injection quantity M1	mg	93.86	71.40	65.16	37.14	19.45	23.05
	Injection quantity P1	mg	2.00	2.00	2.00	2.00	2.00	2.00
	Injection quantity P0	mg	4.00	0.00	4.00	4.00	4.00	4.00
	Injection duration M1	µs	1362.70	1086.37	973.98	680.12	565.08	566.72
	Injection duration P1	µs	288.48	284.63	275.33	269.43	288.02	297.85
	Injection duration P0	µs	358.82	0.00	334.47	320.83	350.62	367.82
Temperature	T Before compressor	oC	28.85	28.73	28.78	28.62	28.55	28.70
	T After compressor	oC	135.06	111.84	126.39	115.63	73.35	51.27
	T Intake manifold	oC	47.09	41.37	50.86	59.54	63.41	67.11
	T Before turbine	oC	626.81	496.01	537.56	424.40	334.89	312.68
	T After turbine	oC	502.96	396.03	427.64	327.73	274.83	272.52
	T Fuel	oC	36.21	36.34	37.12	38.16	37.44	36.65
	T Oil	oC	109.60	105.76	109.33	108.50	102.06	96.98
	T Engine coolant	oC	85.92	82.88	84.33	81.98	80.26	79.65
	T After Charge Air Cooler	oC	43.82	35.78	44.06	41.77	25.83	20.93
Pressure	P Before compressor	bar,abs	0.98	0.99	0.98	0.98	0.99	0.99
	P After compressor	bar,abs	2.19	1.86	2.12	1.99	1.44	1.18
	P Intake manifold	bar,abs	2.15	1.82	2.07	1.92	1.40	1.16
	P Before turbine	bar,abs	2.51	2.10	2.55	2.54	1.68	1.31
	P After turbine	bar,abs	1.14	1.08	1.15	1.14	1.04	1.01
	Oil pressure	bar,rel	3.23	3.10	3.79	4.23	4.26	3.65
	Intake air depressure	mbar,rel	15	11	17	17	10	7
	Exhaust backpressure	mbar,rel	144	81	150	137	41	13
	Cooler backpressure	mbar, rel	44.15	39.834	49.871	63.613	31.399	19.847
Mass flow	Air	kg/s	0.11	0.08	0.11	0.12	0.07	0.04
	Air flow	kg/h	391.42	301.56	409.22	420.52	240.53	145.69
	Fuel flow	g/s	5.23	3.29	4.56	3.43	1.82	1.29
	Fuel flow	L/s	0.0065	0.0041	0.0056	0.0042	0.0023	0.0016
	Fuel flow	L/h	23.3	14.7	20.3	15.3	8.1	5.7
	Efficiency	%	39.5	39.8	38.3	33.7	32.4	34.4
Exhaust gas	HC, C1, wet	ppm	36.90	23.82	31.39	40.74	52.89	45.78
	NO	ppm	989.33	884.53	479.55	231.53	149.12	188.48
	NOX	ppm	995.50	899.28	490.75	254.65	175.28	212.55
	CO, dry	ppm	66.78	21.43	41.21	60.97	68.20	56.38
	CO2, dry	%	10.34	8.33	8.43	6.03	5.49	6.39
	O2, dry	%	6.43	9.16	9.06	12.34	13.08	11.85
	Smoke	FSN	0.12	0.01	0.06	0.11	0.08	0.09
	NOX sensor 1	ppm	939.37	848.83	467.02	245.23	162.15	195.73
	O2 sensor 1	%	5.56	8.25	8.06	11.22	11.91	10.61
	NOX sensor 2	ppm	931.53	835.85	468.21	248.46	168.61	200.13
	O2 sensor 2	%	5.44	8.08	7.95	11.14	11.87	10.63

			NExBTL, EGR 15 % opt -parameters					
Engine & environment	Load point		1	2	3	4	5	6
	Date & time	yyyy-mm-dd	2014-08-28	2014-08-28	2014-08-28	2014-08-28	2014-08-28	2014-08-28
	Atmospheric pressure	kPa	100.20	100.20	100.20	100.20	100.20	100.20
	Relative humidity	%	35.05	32.00	30.00	29.00	30.88	32.00
	Room temperature	oC	26.59	27.97	29.19	29.70	28.80	27.90
	Engine speed	1/min	1497.56	1300.57	1797.60	2199.05	1797.79	1299.28
	Engine torque	Nm	571.38	416.81	402.02	217.22	135.34	141.46
	Engine power	kW	90	57	76	50	25	19
	BMEP	bar	16.3	11.9	11.5	6.2	3.9	4.0
	SFC	g/kWh	207	207	210	240	249	238
Specific emissions	Lambda		1.39	1.74	1.86	2.58	2.79	2.37
	NOx left	g/kWh	5.77	6.82	6.27	6.04	5.74	7.21
	HC left	g/kWh	0.06	0.06	0.08	0.15	0.19	0.12
	CO left	g/kWh	0.25	0.09	0.17	0.26	0.27	0.18
	NOx sensor 1	g/kWh	6.17	7.04	6.63	6.40	5.84	7.27
	NOx sensor 2	g/kWh	6.15	6.94	6.60	6.31	5.81	7.19
	Smoke	FSN	0.099	0.011	0.019	0.016	0.023	0.025
	Testo O2	%	20.75	20.9	20.16	20.01	19.26	19.57
EGR	EGR-valve position	%	0	0	5	10	15	15
	EGR	%	2.0	1.3	8.4	13.7	26.2	18.6
WinEEM	Rail pressure	Mpa	131.62	134.79	148.30	160.23	129.80	118.11
	Injection timing M1	o crankshaft	5.40	0.70	7.10	8.60	9.30	9.30
	Injection timing P1	µs	350.00	350.00	350.00	550.00	500.00	550.00
	Injection timing P0	µs	-2000.00	0.00	-1707.00	-1300.00	-1300.00	-1300.00
	Injection quantity M1	mg	94.25	71.00	64.23	35.17	17.81	22.68
	Injection quantity P1	mg	2.00	2.00	2.00	2.00	2.00	2.00
	Injection quantity P0	mg	4.00	0.00	4.00	4.00	4.00	4.00
	Injection duration M1	µs	1364.97	1080.50	963.85	663.18	551.07	559.15
	Injection duration P1	µs	287.98	284.35	275.80	269.82	289.90	298.10
	Injection duration P0	µs	357.77	0.00	334.37	320.48	352.73	368.07
Temperature	T Before compressor	oC	24.62	25.54	25.61	25.99	25.87	26.16
	T After compressor	oC	129.70	110.07	120.96	112.48	71.70	49.71
	T Intake manifold	oC	47.64	40.99	48.50	49.88	44.01	53.50
	T Before turbine	oC	630.07	489.54	504.84	391.28	299.78	281.52
	T After turbine	oC	512.54	391.33	403.72	297.04	241.35	243.44
	T Fuel	oC	35.10	35.44	36.05	36.95	36.62	35.92
	T Oil	oC	110.04	105.12	108.85	108.59	102.44	96.81
	T Engine coolant	oC	85.67	82.50	83.41	81.46	79.88	79.24
	T After Charge Air Cooler	oC	43.43	35.59	45.30	44.02	25.46	19.57
Pressure	P Before compressor	bar,abs	0.99	0.99	0.98	0.98	0.99	1.00
	P After compressor	bar,abs	2.20	1.91	2.13	2.01	1.47	1.21
	P Intake manifold	bar,abs	2.15	1.86	2.07	1.93	1.43	1.19
	P Before turbine	bar,abs	2.49	2.14	2.67	2.70	1.76	1.35
	P After turbine	bar,abs	1.15	1.08	1.17	1.16	1.05	1.02
	Oil pressure	bar,rel	3.22	3.12	3.81	4.22	4.24	3.64
	Intake air depressure	mbar,rel	14	11	18	19	10	7
	Exhaust backpressure	mbar,rel	145	82	171	160	49	15
	Cooler backpressure	mbar, rel	48.066	50.405	62.532	75.095	38.203	24.838
Mass flow	Air	kg/s	0.11	0.08	0.12	0.13	0.07	0.05
	Air flow	kg/h	387.39	305.50	443.38	462.79	265.00	162.48
	Fuel flow	g/s	5.16	3.26	4.42	3.33	1.77	1.27
	Fuel flow	L/s	0.0066	0.0042	0.0057	0.0043	0.0023	0.0016
	Fuel flow	L/h	23.8	15.1	20.4	15.4	8.2	5.9
	Efficiency	%	39.6	39.7	39.1	34.3	32.9	34.5
Exhaust gas	HC, C1, wet	ppm	28.36	21.56	27.29	33.37	36.58	28.95
	NO	ppm	913.50	861.78	729.58	427.05	355.38	567.03
	NOX	ppm	946.33	895.20	757.18	458.22	384.40	595.57
	CO, dry	ppm	64.20	18.90	31.30	30.55	27.89	22.83
	CO2, dry	%	10.30	7.99	7.36	5.18	4.67	5.44
	O2, dry	%	6.19	9.34	10.21	13.26	14.01	12.90
	Smoke	FSN	0.10	0.01	0.02	0.02	0.02	0.03
	NOX sensor 1	ppm	912.00	849.60	740.02	457.87	370.63	565.13
	O2 sensor 1	%	5.58	8.55	9.31	12.21	12.93	11.76
	NOX sensor 2	ppm	908.70	838.11	736.78	451.63	368.98	558.76
	O2 sensor 2	%	5.39	8.34	9.16	12.20	12.90	11.76

			50-50 % MIX, EGR 15 % opt -parameters					
Engine & environment	Load point		1	2	3	4	5	6
	Date & time	yyyy-mm-dd	2014-08-18	2014-08-18	2014-08-18	2014-08-18	2014-08-18	2014-08-18
	Atmospheric pressure	kPa	99.30	99.30	99.30	99.30	99.40	99.40
	Relative humidity	%	39.00	34.00	31.88	31.08	31.00	33.00
	Room temperature	oC	27.74	29.90	31.14	31.10	29.85	28.42
	Engine speed	1/min	1497.92	1301.37	1797.74	2199.10	1797.78	1301.37
	Engine torque	Nm	571.93	417.49	402.62	217.89	135.83	140.85
	Engine power	kW	90	57	76	50	26	19
	BMEP	bar	16.3	11.9	11.5	6.2	3.9	4.0
	SFC	g/kWh	209	208	213	240	251	237
Specific emissions	Lambda		1.39	1.72	1.84	2.57	2.77	2.39
	NOx left	g/kWh	6.11	7.09	6.47	6.09	5.84	7.26
	HC left	g/kWh	0.07	0.06	0.08	0.16	0.23	0.18
	CO left	g/kWh	0.27	0.10	0.16	0.28	0.32	0.21
	NOx sensor 1	g/kWh	6.42	7.27	6.73	6.42	5.91	7.22
	NOx sensor 2	g/kWh	6.35	7.16	6.69	6.33	5.89	7.16
	Smoke	FSN	0.118	0.015	0.027	0.030	0.029	0.037
	Testo O2	%	20.87	20.97	20.26	19.99	19.26	19.65
EGR	EGR-valve position	%	0	0	5	10	15	15
	EGR	%	1.2	0.6	7.2	13.7	25.8	17.5
WinEEM	Rail pressure	Mpa	130.36	135.17	146.63	159.84	135.31	117.88
	Injection timing M1	o crankshaft	5.35	0.70	6.90	8.40	8.90	8.90
	Injection timing P1	µs	350.00	350.00	350.00	550.00	500.00	550.00
	Injection timing P0	µs	-2000.00	0.00	-1682.00	-1300.00	-1300.00	-1300.00
	Injection quantity M1	mg	93.77	70.91	63.99	36.12	18.60	22.64
	Injection quantity P1	mg	2.00	2.00	2.00	2.00	2.00	2.00
	Injection quantity P0	mg	4.00	0.00	4.00	4.00	4.00	4.00
	Injection duration M1	µs	1359.70	1079.13	960.47	670.83	549.77	562.80
	Injection duration P1	µs	287.53	283.53	275.63	269.52	284.98	299.13
	Injection duration P0	µs	357.55	0.00	333.53	320.08	345.97	368.70
Temperature	T Before compressor	oC	25.79	26.80	26.90	26.79	26.89	26.67
	T After compressor	oC	132.03	110.55	122.84	113.14	72.23	50.45
	T Intake manifold	oC	47.51	42.11	50.77	52.46	44.89	55.54
	T Before turbine	oC	637.37	503.96	518.04	402.57	307.18	289.23
	T After turbine	oC	514.43	403.89	413.77	307.08	247.89	250.92
	T Fuel	oC	35.35	36.20	36.64	37.82	36.91	36.10
	T Oil	oC	109.47	105.32	109.17	108.64	101.59	97.40
	T Engine coolant	oC	85.52	82.82	83.70	81.48	79.95	79.47
	T After Charge Air Cooler	oC	44.26	37.24	47.87	46.76	26.91	20.68
Pressure	P Before compressor	bar,abs	0.98	0.98	0.97	0.97	0.98	0.99
	P After compressor	bar,abs	2.19	1.87	2.11	1.98	1.45	1.20
	P Intake manifold	bar,abs	2.14	1.83	2.05	1.91	1.41	1.17
	P Before turbine	bar,abs	2.49	2.11	2.65	2.67	1.74	1.34
	P After turbine	bar,abs	1.14	1.07	1.16	1.15	1.04	1.01
	Oil pressure	bar,rel	3.24	3.12	3.80	4.23	4.27	3.62
	Intake air depressure	mbar,rel	15	11	19	19	11	8
	Exhaust backpressure	mbar,rel	144	81	170	157	46	15
	Cooler backpressure	mbar, rel	48.548	47.479	60.751	72.362	38.03	25.069
Mass flow	Air	kg/s	0.11	0.08	0.12	0.13	0.07	0.04
	Air flow	kg/h	387.03	302.82	441.85	459.35	263.50	161.62
	Fuel flow	g/s	5.22	3.29	4.48	3.34	1.78	1.27
	Fuel flow	L/s	0.0065	0.0041	0.0055	0.0041	0.0022	0.0016
	Fuel flow	L/h	23.2	14.7	20.0	14.9	7.9	5.6
	Efficiency	%	39.6	39.8	38.9	34.6	33.0	34.9
Exhaust gas	HC, C1, wet	ppm	30.85	24.16	26.25	35.80	45.96	42.22
	NO	ppm	962.33	899.33	740.33	426.10	358.33	559.97
	NOX	ppm	985.83	928.83	774.03	461.25	393.57	598.65
	CO, dry	ppm	68.89	20.94	29.92	33.24	33.24	26.99
	CO2, dry	%	10.49	8.36	7.67	5.40	4.86	5.61
	O2, dry	%	6.30	9.17	10.11	13.23	14.01	12.96
	Smoke	FSN	0.12	0.02	0.03	0.03	0.03	0.04
	NOX sensor 1	ppm	930.30	871.22	740.82	456.78	376.40	558.78
	O2 sensor 1	%	5.49	8.29	9.13	12.05	12.83	11.76
	NOX sensor 2	ppm	919.57	857.70	736.75	450.02	375.09	554.27
	O2 sensor 2	%	5.36	8.12	9.00	12.04	12.81	11.72