# THE EFFECT OF EXHAUST GAS RECIRCULATION ON PARTICULATE MATTER EMISSIONS FROM A COMPRESSION-IGNITION, NATURAL GAS FUELLED ENGINE

By

Thomas Willem Brakel

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Department of Mechanical Engineering

The University of British Columbia
Vancouver, Canada

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## Abstract

A mini-dilution tunnel was designed and built to measure particulate matter (PM) emissions from a single-cylinder research engine (SCRE) based on the Cummins ISX 400 series. The SCRE relies on the high-pressure direct injection of natural gas, pilot ignited with diesel fuel for combustion. Two methods were used for PM measurements: pre-weighed filters and a tapered element oscillating microbalance (TEOM).

A repeatability study was conducted to determine the experimental error associated with PM measurements and to compare results from pre-weighed filters with those taken using a TEOM. The PM emission rate uncertainty was determined to be at maximum 29%, with 10-12% due to measurement uncertainty and the remainder due to poor engine repeatability. PM emission rates from the TEOM showed excellent correlation with measurements using pre-weighed filters by applying a correction factor of 1.43.

The second part of this work was to examine the effect of replacement exhaust gas recirculation (EGR) on particulate emissions. EGR is primarily used in engines to reduce the formation of oxides of nitrogen ($NO_x$). The drawback of using high EGR flow rates is a deterioration in combustion and an increase in the amount of unburned species (HC, CO, PM) that are formed. The results show the PM penalty is negligible for EGR rates up to 15% and that increasing the exhaust pressure significantly affects PM and CO emissions. It was also found that increasing the amount of diesel pilot at 800 RPM 75% load with 17% EGR significantly increases PM and CO emissions.

# Table of Contents

# List of Figures

# List of Tables

# Nomenclature

| | | |
|---|---|---|
| A/F | = | Overall air–to–fuel ratio |
| AVG | = | Average value (mean) |
| BP | = | Back pressure (exhaust) |
| CNG | = | Compressed natural gas |
| CO | = | Carbon monoxide |
| $CO_2$ | = | Carbon dioxide |
| COV | = | Coefficient of variation (standard deviation/mean) |
| DPW | = | Diesel (pilot) pulse width |
| EGR | = | Exhaust gas recirculation |
| GRIT | = | Gas relative injection timing (between pilot and natural gas injection) |
| HPDI | = | High pressure direct injection |
| IMEP | = | Indicated mean effective pressure |
| GSOI | = | (Natural) gas start of injection |
| $NO_x$ | = | Oxides of nitrogen (NO, $NO_2$,...) |
| PM | = | Particulate matter |
| PSOI | = | Pilot start of injection (diesel) |
| Q | = | Mass flow rate of indicated species |
| SCRE | = | Single cylinder research engine |
| TEOM | = | Tapered element oscillating microbalance |
| THC | = | Total hydrocarbons |
| UBC | = | University of British Columbia |
| $\rho$ | = | Density of the indicated species |

## Acknowledgments

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# Chapter 1: Introduction

The diesel engine is widely used in the power generation and transportation industries. The advantages of this engine over its spark-ignited counterpart are mainly greater efficiency and higher torque at low speeds. These benefits do not come without cost; diesel engines emit significantly higher amounts of particulate matter (PM) and oxides of nitrogen ($NO_x$).

One system that preserves the performance benefits of the Diesel cycle while reducing these harmful emissions is the high-pressure direct injection (HPDI) of natural gas with a diesel pilot [1]. This injection process is being developed by Westport Innovations. The HPDI system is a retrofit for a diesel engine that replaces the fuel injection system. Instead of using entirely diesel, only a small amount (~5% of fuel energy) is initially injected at high pressure into the cylinder. The pilot spray of diesel autoignites and is followed by the injection of high-pressure natural gas, which subsequently undergoes combustion and performs expansion work on the piston. The natural gas uses the diesel pilot as an ignition source. Initial results [2] have shown a significant reduction of $NO_x$, $CO_2$, and PM while maintaining high thermal efficiency.

## 1.1 Particulate Matter

Diesel exhaust particulate matter (PM) consists of: highly agglomerated solid carbonaceous material, ash, volatile organic and sulphur compounds [3]. Solid carbon is formed in locally fuel-rich regions inside the cylinder, but subsequently much of it is oxidized. The remainder is exhausted in the form of particle agglomerates. These particles vary in size, shape and chemical composition. The typical composition of PM from a heavy-duty diesel engine is given in Figure 1-1. The HPDI system with natural gas is expected to have a much lower sulphate fraction since the main source of sulphur is diesel fuel. Fuel and oil contributions are likely to be different, as well as the variation with speed and load.

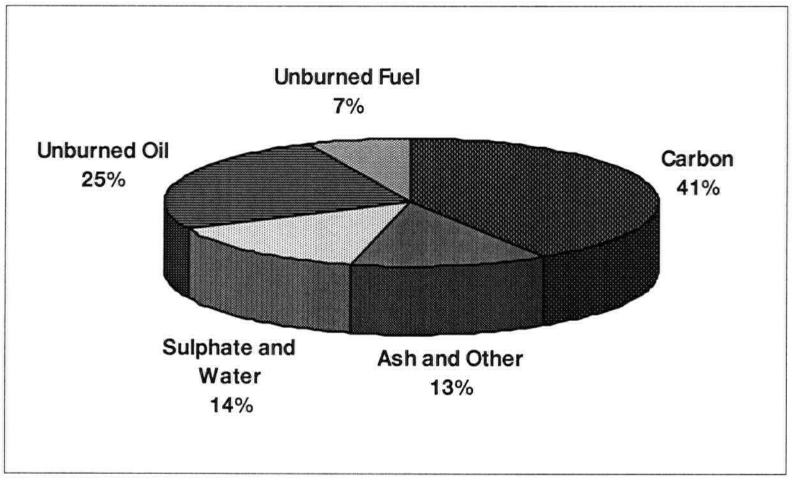


**Figure 1-1: Typical composition of heavy-duty diesel engine PM from Kittelson [3]**

Particle growth is a dynamic process [4], initiated by the formation of small nuclei in the cylinder immediately after combustion has occurred. As these particles travel out the exhaust line they grow as hydrocarbon molecules condense. This process is driven by the fact that the exhaust is being cooled by heat loss and mixing with ambient air. Clearly, the measurement will be affected by the proximity to the exhaust manifold, which motivates the use of a dilution system to simulate the process of particles leaving the exhaust manifold and being emitted into the atmosphere.

## 1.2 Dilution Systems

In 1972 the US Environmental Protection Agency (EPA) defined a full-flow constant volume sampling process required for PM measurements of heavy-duty diesel engines. This apparatus dilutes the entire exhaust coming out of the vehicle engine, and a portion of diluted exhaust is drawn through a pair of Teflon filters. The EPA defines PM as the mass collected on a filter from exhaust that has been diluted and cooled to 52°C or below [5]. The systems necessary for these EPA tests are extremely large, cumbersome, expensive and are limited to a range of engine sizes. This led to the use of mini or micro dilution systems, which are more compact but sample only a small amount of the total exhaust stream. A significant amount of work was done on their validation in the 1980s. Of significant importance, MacDonald *et al.* [6] looked at the effects of different dilution ratios and filter temperatures on PM measurements using a mini-dilution tunnel. This effect was within their experimental error over relatively large dilution ratio ranges, approximately a 10% reduction in PM mass for a change in dilution ratio from 10 to 30. This was also later confirmed by Lapuerta *et al.* [7] who reported a decrease in PM mass of 25% when changing the dilution ratio from 5 to 25. Kayes and Hochgreb [8] suggest using a dilution ration between 13-18 to obtain the maximum PM emission while minimizing variability.

The other important parameter is the temperature of the diluted exhaust as it reaches the primary filter ("filter temperature"). Again, EPA test procedures require this temperature not to exceed 52°C [5]. The sensitivity of mass measurements to temperature was investigated initially by MacDonald *et al.* [6] and subsequently by Khalek *et al.* [9]. MacDonald *et al.* found a 35% decrease in filter mass when the filter temperature was changed from 35°C to 100°C. Khalek *et al.* reported a similar decrease in mass measurements.

Previous research at UBC/Westport by Baribeau [10] has already been performed on a six-cylinder version of the same engine used in the present study. However, the dilution tunnel was a commercial system built by Sierra Instruments, which may contribute to differences in measurements. A literature search on PM emissions from natural gas engines was performed. Information was available on spark-ignited engines with negligible PM emissions. There was no other data available on compression-ignition natural gas engine particulate matter at the time of this study.

### 1.3 Exhaust-Gas Recirculation (EGR)

One method of reducing the $NO_x$ emissions from an internal combustion engine is to recirculate a portion of the exhaust gas into the inlet air charge. The most recent comprehensive work involving EGR on diesel engines was completed by Ladommatos *et al.* [11]. They determined the principal mechanism in $NO_x$ reduction was lowering the flame temperature inside the cylinder by replacing $O_2$ with (primarily) $CO_2$ and $H_2O$. They clearly showed the effectiveness of EGR in reducing $NO_x$ emissions from the engine they tested.

They also showed that high amounts of EGR lead to a favourable environment for the formation of unburned hydrocarbons and particulate matter. Since the overall flame temperature is being lowered by the dilution of oxygen, there is less heat available to oxidize hydrocarbon particles. This "$NO_x$ – PM tradeoff" for diesel engines is well known [11] and similar behaviour is expected for the HPDI system with EGR. Previous research at UBC by McTaggart-Cowan [12] has already investigated the capabilities of EGR to reduce $NO_x$ emissions. The PM emission results described here complement the earlier results on $NO_x$ for the HPDI engine with EGR.

## 1.4 Project goals and objectives

The objectives of this work were:

1) *To design and construct a mini-dilution tunnel to measure PM from the UBC SCRE.*
2) *To determine the repeatability of PM measurements using TEOM and filter sampling methods.*
3) *To perform a baseline study of the PM emission rate from the SCRE using a "four corners" approach.*
4) *To examine the effects of EGR on PM emission rates from the SCRE.*

# Chapter 2: Experimental Apparatus

## 2.1 Dilution System

The mini-dilution tunnel in Figure 2.1 was the system used for all PM measurements described in this document. Appendix A has detailed information for each device (mass flow controller, pressure sensor, etc.) as well as dimensions for all piping used. This system was developed since the SCRE required a dilution tunnel for particulate measurements. The main design issues were filter loading, stable flow rates and accurate flow control. An iterative process was used to optimize each of these criteria. The sample flow rate was set to approximately 20 SLPM to keep the pressure difference across the filters below 1 psid. In the experiments performed, dilution ratios between 9-15 were used, which produced an appropriate mass of particulate on the filters. If the mass deposition rate is very high, the pressure drop across the filters will increase rapidly, changing the pressure within the dilution system. If the rate is very low, sampling times have to be longer. Mass flow controllers were installed to compensate for pressure fluctuations in the dilution tunnel. The sample tube was heated keeping the filter temperature between 43-50°C but never exceeding the upper limit of 52°C. The sampling period varied, depending on whether or not pre-weighed Teflon filters were used, but were typically 5 or 10 minutes in duration.

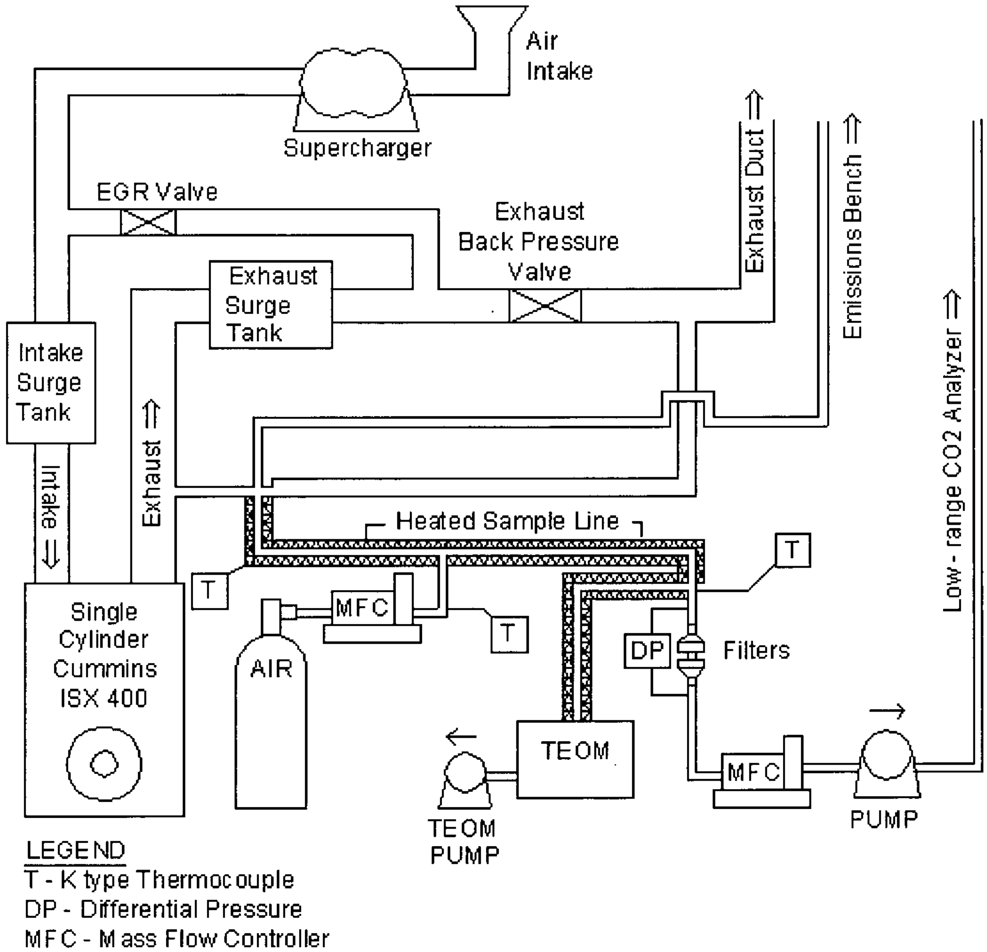


**Figure 2-1: Schematic of dilution system**

The dilution system inlet is connected to the main exhaust line approximately 75 cm from the manifold. This inlet is also connected to the main exhaust duct, past the back pressure valve, to maintain the sampled exhaust close to atmospheric pressure. During sampling, the pump draws exhaust into the mixing region. It is then combined with approximately 10-15 times (by mass) the amount of dilution air, controlled by a mass flow controller. The exhaust and dilution air have one meter to travel with a Reynold's number of 2000. The resulting mixture either passes through the filter holders or is drawn into the tapered element oscillating microbalance (TEOM). Proper mixing was confirmed by taking $CO_2$ measurements at the TEOM and filter outlets. The diluted exhaust (sampled air) is filtered and passes through a second mass flow controller to measure the total sample flow. This air stream then passes through the pump. On the pressure side of the pump, there is a line that leads to the $CO_2$ analyzer to measure the diluted sample $CO_2$ concentration in order to calculate the dilution ratio. The outlet of the pump is reconnected to the exhaust duct that expels the gases to the outside of the building.

### 2.2 Single-Cylinder Research Engine (SCRE)

The engine used in these tests is a modified Cummins ISX 400 series heavy-duty diesel engine. Figure 2-2 shows the engine and test cell before the emissions and dilution system were installed. The engine was modified by Cummins Inc. to operate with one cylinder. The alterations included installing dummy injectors, blocking the intake and exhaust ports, and removing the piston rings from the non-firing pistons. These pistons were also drilled through to reduce compression in the unused cylinders, with the removed mass being replaced by lead in the wrist pin to maintain the engine balance. The modifications did not include any other changes to the internal workings of the engine – the fuel rails, internal air intake manifold, cam shafts and timing, firing cylinder piston, etc. are all the same as for a production engine. The actual specifications for the SCRE are given in Table 2-1.

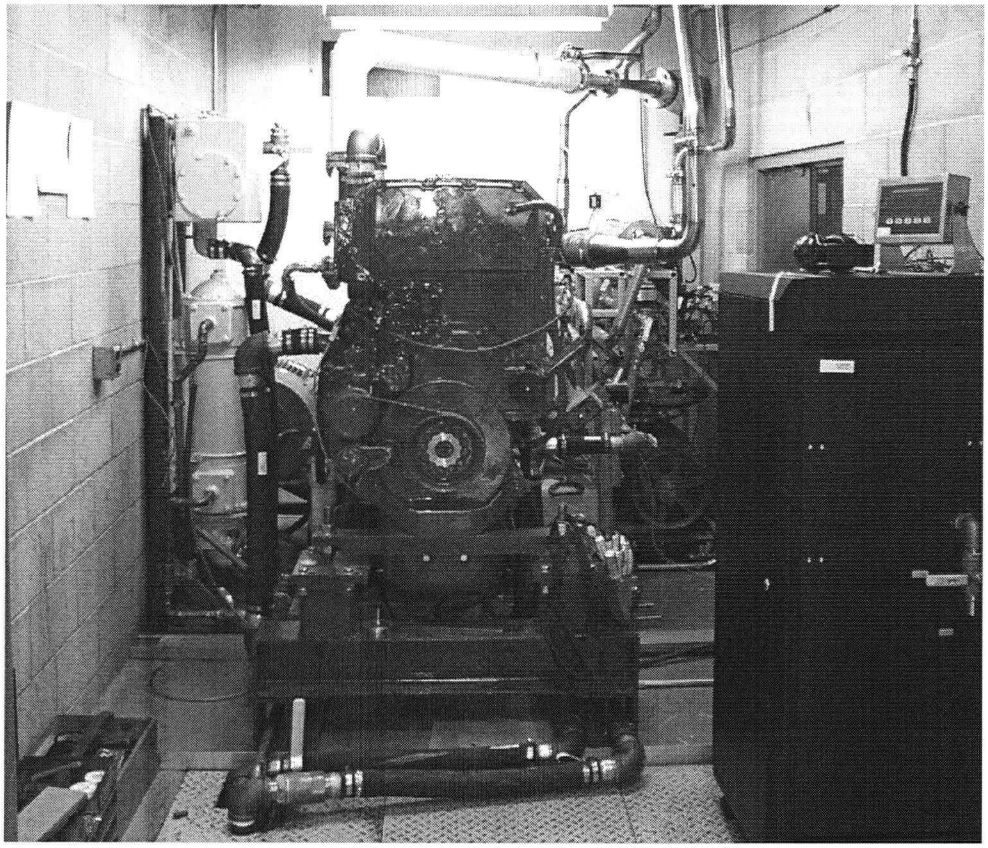

**Figure 2-2: SCRE and test cell**

| | |
|---|---|
| Engine Type | four-stroke, inline, supercharged, aftercooled |
| Displacement/cylinder | 2.5 L |
| Compression ratio | 19:1 |
| Bore | 137 mm |
| Stroke | 169 mm |
| Connecting rod Length | 261.5 mm |
| Rated power | 300 kW @ 1800 RPM |
| Rated torque | 1966 Nm @ 1200 RPM |

**Table 2-1: Cummins ISX SCRE specifications**

### 2.2.1 *HPDI Injector*

The injector used in this work was designed by Westport Innovations. The details of its operation and design are presented in the patents by Touchette [13] and Ouellette [14]. Two internal fueling rails are used to supply the fuels (diesel and natural gas) to the injector, while the hydraulic/mechanical control of the diesel injector is replaced by electronic control for the HPDI system. A detailed schematic can not be presented since it is proprietary information. The diagram in Figure 2-3 shows a cam actuated injector, similar to the Westport HPDI injector. The HPDI injection is a two-stage process through separate fuel ports. Diesel fuel is initially injected at high pressure, followed by the injection of high-pressure natural gas. The absolute and relative timing of the two injections affect the efficiency and emissions of the engine. The injection timing is controlled via a proprietary controller with software developed by Westport Innovations.

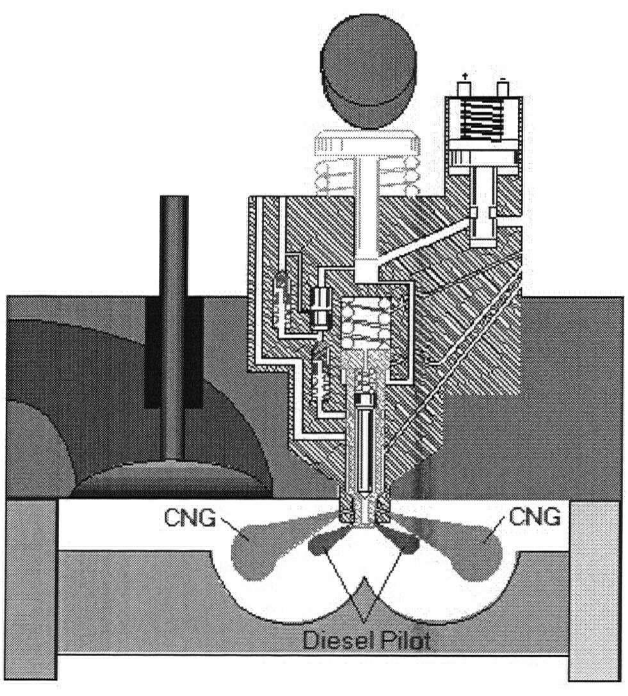


**Figure 2-3: Schematic of Westport HPDI injector**

The injection of diesel begins precisely at the time specified by the pilot start of injection (PSOI), relative to top dead center (TDC). However, the reservoir beneath the lower intensifier is filled with diesel for the duration of the pilot pulse width (DPW) prior to the PSOI. The DPW refers to the time the reservoir beneath the lower intensifier has to fill with diesel. The timing specified by the PSOI corresponds to the lifting of the pilot needle and thereby injecting diesel. Setting the gas relative injection timing (GRIT) controls the delay until natural gas injection. The GRIT specifies the time lapse after the PSOI to the beginning of natural gas injection. The duration of the natural gas injection lasts for the time specified by the gas pulse width (GPW). Here the GPW corresponds to the duration the gas needle is lifted and CNG is being injected into the cylinder. All of these parameters are set in values of milliseconds. The sequence of events during injection is summarized in Figure 2-4. The timing used in the performed experiments is given on page 26. The specifications of the injector used in this work are given in Table 2-2.

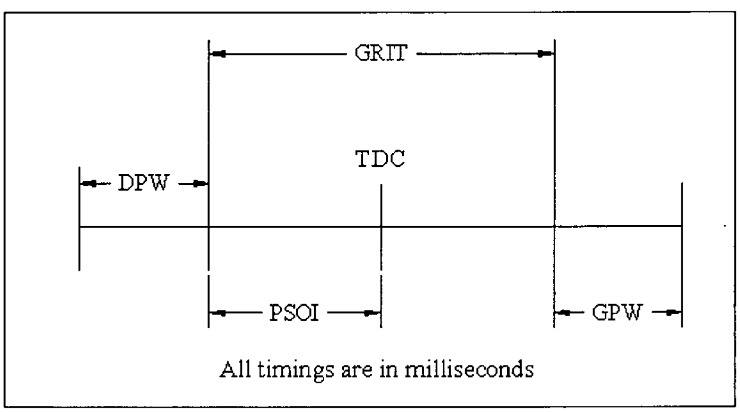


**Figure 2-4: Summary of HPDI Injection Process**

| | |
|---|---|
| Model Number | J31 |
| Body Number | 053 |
| Number of Gas holes | 8 |
| Gas hole size | 0.72mm |
| Gas Injection Angle | 18° from firedeck |
| Number of Pilot Holes | 7 |
| Pilot Hole Size | 0.12mm |
| Pilot Injection Angle | 18° from firedeck |

**Table 2-2: HPDI injector specifications**

### *2.2.2 Engine Operation*

Since the SCRE operates with only one cylinder firing the torque output can be insufficient to overcome internal friction. A 30 kW electric motor was also connected to provide additional power. This arrangement still does not enable operation over the entire ISX 400 range. Figure 2-5 is an engine map that shows the test conditions the SCRE can operate at compared to the six-cylinder version. At high speed and load, the supercharger limits the operating time due to overheating. This limitation was the reason for selecting 1400 RPM 85 % load as the high-speed high-load condition.

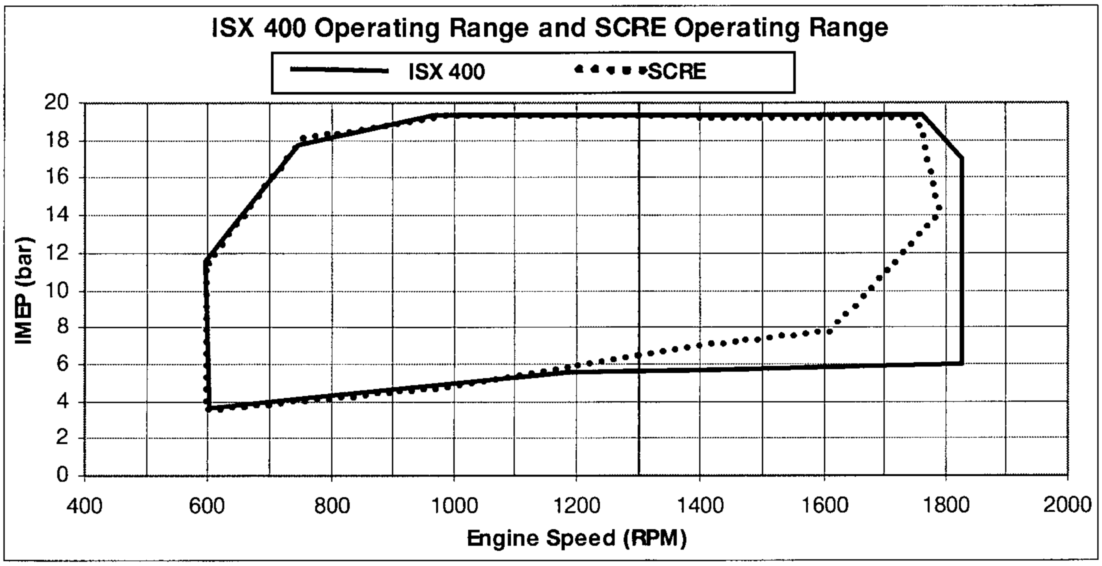


**Figure 2-5: Engine map of SCRE**

The procedure for setting the engine at a given speed/load combination was performed as follows. Before engine operation, the supply pressure of natural gas was set at 19 MPa. After 30 minutes of warm-up, the specific injection timing was entered, followed by ensuring enough torque is being supplied by the vector drive to overcome friction. The gas pulse width (GPW) was then entered into the controller. The natural gas flow rate is constantly measured and displayed on the data acquisition system. The GPW was set to ensure the CNG flow rate is as close as possible to the target. The diesel pressure was approximately 0.5 MPa greater than the CNG pressure. The airflow rate was obtained by setting the speed of a motor attached to a Lysholm screw compressor. Once a desired operating condition was set, a period of 7-10 minutes was allowed for the engine to stabilize before sampling. McTaggart-Cowan [15] provides a detailed discussion of the SCRE operation and instrumentation.

### *2.2.3 EGR Operation*

For EGR operation the exhaust pressure was set approximately 10-20 kPa greater than the intake manifold pressure by closing the back pressure valve. Opening the EGR valve allowed a portion of the exhaust gas to recirculate into the intake. Obtaining the same back pressure and EGR combination proved to be challenging for the two following reasons. The back pressure would begin to increase only when the back pressure valve was approximately 80% closed, and also opening the EGR valve lowered the exhaust back pressure. A detailed discussion of EGR operation is presented in Appendix H.

In most cases, intake $CO_2$ measurements were taken before and after each EGR sampling period to confirm a consistent EGR rate. The experiments performed were based on replacement EGR only. A portion of the intake air was replaced with exhaust gas, and thus lowering the oxygen concentration in the cylinder. The EGR flow rate was calculated using the following relations:

$$\%EGR = \frac{\dot{m}_{egr}}{\dot{m}_{freshair} + \dot{m}_{egr}} \times 100 = \left( \frac{[CO_2]_{Intake} - 0.030}{[CO_2]_{Exhaust} - 0.030} \right) \times \frac{MW_{exhaustgas}}{MW_{manifoldair}} \times 100 \quad (2.1)$$

Here $[CO_2]$ represents the $CO_2$ concentrations, $MW$ is the molecular weight of the intake and exhaust gases. The ambient air $CO_2$ concentration was assumed to be 300 ppm. The actual value is slightly higher (380 ppm), however the effect on the calculated EGR rate is only slight decrease of 0.1-0.2%. Recalculating all EGR rates was not performed for this reason.

### 2.2.4 *Diesel Flow Measurement*

The diesel mass flow rate accounts for approximately 5% of the total fuel energy. The method used for measuring the diesel flow rate was based on the "pail and scale" technique, whereby a scale measures the mass of diesel in a small reservoir and the decrease over time is recorded. A linear regression of the mass was used to calculate the diesel fuel consumption. Appendix I gives a detailed description of the calculation procedure and difficulties that arise when calculating the diesel mass flow rate. Fluctuations occur when the diesel was warming up during engine start-up or when the engine cell door was opened, which skewed the diesel mass data. Also, a period of at least 7-8 minutes is required for sufficient accuracy. If the diesel mass data had high variability for that period, additional test data was pooled. This provided data for a longer time span, but the diesel flow rate was assumed constant over this period. The uncertainty in diesel flow measurements is approximately 5-10% at 1400 and 1600 RPM. For tests performed at 800 RPM the error can be as high as 20%, but may be even higher.

## 2.3 Measurement Techniques

There were two methods used for measuring PM emitted from the SCRE. They are both based on gravimetric analysis – i.e., measurement of the mass of PM deposited on a filter. In either case the following formula was used to calculate the emission rate of PM:

$$Q_{PM} = \left( \frac{m_{PM}}{m_{EXHAUST}} \right) Q_{ENGINE} \tag{2.2}$$

$Q_{PM}$ is the emission rate of PM in g/hr, given by the concentration of PM in the sampled air stream multiplied by the engine exhaust flow rate ($Q_{ENGINE}$). The engine exhaust flow rate is given by the sum of the natural gas, diesel and inlet air mass flows. The mass of particulate is either taken from a linear regression from the TEOM output data (see Appendix C) or the difference in Teflon filter weights before and after being exposed to diluted exhaust.

The mass of exhaust being sampled, is given by:

$$m_{EXHAUST} = \frac{V_{SAMPLE} \rho t}{DR} \tag{2.3}$$

The volumetric flow rate of diluted exhaust ($V_{SAMPLE}$) is set by a mass flow controller. For measurements taken with the TEOM, this flow rate is constant at 3.0 SLPM. The dilution ratio was calculated by measuring the sample $CO_2$ concentration and comparing it to the engine exhaust $CO_2$ level, as explained in section 2.3.1. The density of air ($\rho$) used in the above calculation was 1.293g/L (air @ 1atm, 0°C) as specified in the Omega operating manual for the mass flow controllers. Since the exhaust is diluted by at least 10 times and is primarily composed of $N_2$ (~70%), no correction factor was deemed necessary since the mixture closely resembles air. The sampling time ($t$) was recorded with the TEOM and data acquisition computers.

### *2.3.1 Dilution Ratio Determination*

The PM emission rate was measured from diluted exhaust. In order to calculate the actual emission rate, the amount the exhaust was diluted needs to be determined. The dilution ratio ($DR$) is defined as:

$$DR = \frac{Q_{SAMPLED}}{Q_{EXHAUST}} \tag{2.4}$$

This is simply the mass flow rate of the sampled air through the filters/TEOM ($Q_{SAMPLED}$) divided by the mass flow rate of exhaust into the dilution tunnel ($Q_{EXHAUST}$).

There are two methods for performing this calculation. It is possible to measure these flow rates and/or use conservation of mass to calculate the unknown quantities directly. However, the flow rate of raw exhaust coming from the engine is generally difficult to measure. This is due to the fact it is at high-temperature, contains particulates and is pulsating since it is driven by a single-cylinder engine. To obtain the exhaust flow rate one might simply subtract the dilution air flow rate from the sampled flow rate, except these two values are typically 10 times greater than the exhaust flow. Hence, this method would lead to an unacceptably high experimental error (~25%). Obtaining the dilution ratio from mass flow rates was calculated but was used for verification purposes only.

It is shown in Appendix D that the dilution ratio can be related by measuring the gas composition before and after dilution. The relationship in terms of wet $CO_2$ concentrations is given by:

$$DR = \frac{([CO_2]_{EXHAUST} - [CO_2]_{DILUTION})}{([CO_2]_{SAMPLED} - [CO_2]_{DILUTION})} \qquad (2.5)$$

Here, $[CO_2]_{EXHAUST}$ is the concentration of the raw engine exhaust, $[CO_2]_{DILUTION}$ is the bottled air which is known (500 ppm), and $[CO_2]_{SAMPLED}$ is the diluted exhaust. The $CO_2$ measurements were performed by non-dispersive infrared (NDIR) analyzers which operate on a dry basis only. The calculation needs to be corrected for water loss and this is presented in Appendix D. The use of exhaust gas analysis enables a direct comparison between the raw exhaust and diluted exhaust streams, reducing the uncertainty of the dilution ratio measurement.

### *2.3.2 Pre-Weighed Filters*

This method involves the use of pre-weighed Teflon membrane filters of 47mm diameter and 2μm mesh size to collect PM. The filters were pre-weighed using a Sartorius M3P scale that measures the weight with an accuracy of 0.001 mg, although actual weight measurements varied over approximately 0.010 mg. The PM weights that were measured were at least 0.2 mg, implying the mass measurements should be accurate within 5%. Filters were conditioned for at least 48 hours in the weighing room to match the humidity conditions prior to being weighed. The weighing room is a controlled environment at 20°C and 50% relative humidity. After the filters were weighed they were numbered and placed in a clear case ready for use.

The pre-weighed, numbered filters were then loaded into a Pall-Gelman stainless steel filter holder and inserted into the diluted exhaust air stream for a known time period. The complete sampling procedure is presented in Appendix E. Once the sampling period was over, the filters were removed and placed in the same filter cases. They were later brought to the weighing room to be conditioned again, prior to final weighing. The filters were reweighed at least 48 hours after being left in the weighing room. The difference of the initial and final mass gives the amount of PM deposited over the sampling period. Steady state tests were performed to give average emission rates.

### *2.3.3 TEOM*

The other method to obtain PM measurements involved the use of a tapered element oscillating microbalance (TEOM) built by Rupprecht and Patashnick, which automates the weighing procedure. Figure 2-6 is a schematic is of the TEOM. A filter cartridge is attached to the end of a mass transducer that outputs the total accumulated PM mass in real time. The mass transducer operates on a slightly different principle than most other weighing devices. The heart of the device consists of a hollow tapered element that is clamped at one end and free to vibrate at the other end. For a more detailed discussion of operation and optimization of use of this device for particulate measurements see Okrent [16].

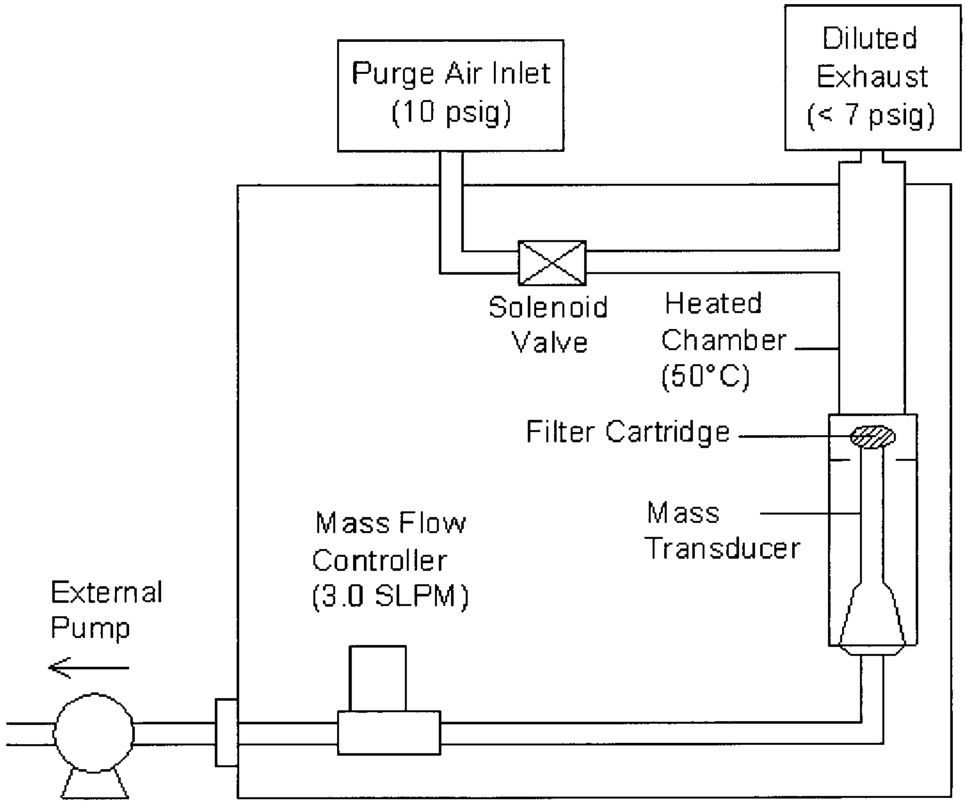


**Figure 2-6: Simplified schematic of the TEOM**

An exchangeable filter cartridge is placed on the tip of the free end of the tapered element. The sample stream of diluted exhaust is drawn through this filter and down the tapered element. The chamber leading to the mass transducer is held at a constant temperature of 50°C. The mass flow is held constant at 3.0 SLPM by a mass flow controller. The tapered element vibrates precisely at its natural frequency. An electronic control sensor detects this vibration and using a positive feedback loop adds electrical energy to the system to overcome friction. A gain control circuit maintains the vibration at constant amplitude, while a precision counter measures the frequency of oscillations with 0.42 second sampling period. As more particulate is collected on the filter, the mass of the element increases, which in turn lowers the natural frequency of vibration. This change in frequency can be related to the total mass of PM collected on the filter.

The tapered element is in essence a hollow cantilever beam with an associated spring constant and mass. In a spring mass system it can be shown the frequency is given by:

$$f = \sqrt{\frac{K}{M}} \tag{2.6}$$

Here f is the frequency of oscillations, K is the spring constant and M is the mass of the cantilever. In actual operation, the TEOM monitor always measures the entire mass of the system using:

$$M = \frac{K}{f^2} \tag{2.7}$$

The output from the TEOM was loaded into a spreadsheet and a linear regression was used to calculate the average emission rate. Appendix C presents actual data obtained with the TEOM and the method used to calculate the accumulated PM mass. Measurements were taken simultaneously using the TEOM and Teflon filters to compare emission rates. When only the TEOM was used for measurements, blank filters were inserted into the filter holders. The same operating procedure was used with flows adjusted to account for the additional TEOM flow. Appendix F presents the operating procedure when the only the TEOM was used.

### *2.3.4 Measurement Uncertainty*

The error for these experiments is defined in terms of two separate effects. First, there is the uncertainty related to the calculation and measurement of the PM emission rate. The second source is the variability of the emission rate due to the engine itself. Under proper operating conditions, McTaggart-Cowan [12] showed repeatability in gaseous emissions to 5%, except CO and total hydrocarbons that were repeatable to within 10%.

The calculation for the PM emission rate was given by:

$$Q_{PM} = \left( \frac{m_{PM}}{m_{EXHAUST}} \right) Q_{ENGINE}$$

with

$$m_{EXHAUST} = \left( \frac{V_{SAMPLE}}{DR} \right) \rho t$$

and the DR given by:

$$DR = \frac{([CO_2]_{EXHAUST} - [CO_2]_{DILUTION})}{([CO_2]_{SAMPLE} - [CO_2]_{DILUTION})}$$

The uncertainty for $Q_{ENGINE}$ comes from the uncertainty of the flow meters used to obtain the sum of the intake air, CNG and diesel flow rates. A turbine flow meter was used to measure the airflow rate, which is accurate to 3%. The airflow is around 40 - 50 times the total inlet fuel flow rate. Hence, the CNG and diesel flow rates do not significantly contribute to the measurement uncertainty, but they do affect the engine repeatability.

The mass of PM accumulated ($m_{PM}$) was taken from either Teflon filter weights or a regression analysis of the TEOM output. Both of these processes are assumed to have a maximum uncertainty of 5%.

The mass of sampled exhaust ($m_{EXHAUST}$) has two components. The dilution ratio (*DR*) contributes uncertainty from the $CO_2$ measurements. The analyzers are accurate to 1.5% of full-scale. In the experiments performed, this becomes at maximum 6% for the sampled $CO_2$ concentration ($[CO_2]_{SAMPLE}$) and 4% for the engine $CO_2$ concentration ($[CO_2]_{EXHAUST}$). The dilution ratio is believed to be accurate within 10% since it is not unlikely for bias to be present in both analyzers. The other parameters in the $m_{EXHAUST}$ equation are the sampled volume flow rate ($V_{SAMPLE}$), the density ($\rho$) and the sampling time ($t$). The data acquisition computer keeps track of the sampling time with high accuracy and the density of the mixture is assumed to be the same as air; both of these uncertainties are negligible. The mass flow controllers ensure sampled air ($V_{SAMPLE}$) is accurate within 3% of the set flow rate, according to the operating manual. All uncertainties are summarized in Table 2-3.

If the error is assumed to be random and all of these values are combined, the experimental error due to measurement will be at maximum 12%. The actual uncertainty was calculated based on experimental results presented in Section 3.3.

| VARIABLE | DESCRIPTION | METHOD OF MEASUREMENT | MAX ERROR |
|---|---|---|---|
| $Q_{ENGINE}$ | **Total engine exhaust flow rate** | **Intake air – turbine flow meter; CNG, Diesel negligible.** | **3%** |
| $m_{PM}$ | **PM mass obtained from TEOM/filters** | **Total error from balance (filters) or linear regression from TEOM data.** | **5%** |
| $m_{EXHAUST}$ | **mass of exhaust sampled** | **via parameters (V, ρ, t, DR) below** | **11%** |
| $V_{SAMPLE}$ | volumetric flow rate at STP for sampled stream | Omega mass flow controller | 3% |
| $\rho$ | diluted exhaust density (air) | Specified by Omega operating manual | <1% |
| $t$ | sample duration | Computer / Stopwatch | <1% |
| $[CO_2]_{EXHAUST}$ | exhaust $CO_2$ concentration | Beckman NDIR $CO_2$ Analyzer (0-20%) | 4% |
| $[CO_2]_{SAMPLE}$ | diluted exhaust (sampled) air | California Analytical NDIR $CO_2$ Analyzer (0-2%) | 6% |
| $[CO_2]_{DILUTION}$ | dilution air $CO_2$ concentration | Praxair Medical Air, certified 500 ppm | < 1% |

**Table 2-3: Experimental uncertainties in PM calculations**

# Chapter 3: Results and Discussion

## 3.1 Overview

The results show four important features of this work. First, it was necessary to validate the calculated emission rates by taking PM measurements simultaneously using the TEOM and pre-weighed filters. The calculated emission rates from both methods were then compared. Second, the repeatability of the PM emission rate of the SCRE at various speed and load conditions was determined using a "four corners" approach. Third, it was intended to identify sources of variability of the PM emission rate. The final objective was to show the effects of EGR rates up to 20% on PM emissions.

A summary of all experiments performed is given in Table 3-1. The operating conditions for these experiments are given in Table 3-2. The timing was selected based on previous experiments done by McTaggart-Cowan [12] that were optimized for $NO_x$ reduction. The same timing was used to obtain corresponding PM measurements. PM, CO, $CO_2$, $NO_x$, $O_2$ and THC emissions are summarized in Appendix B for all experiments. Significant variability existed in preliminary results, particularly with EGR, which motivated the experiments performed in section 3.5.

| Test Description | Method of Analysis | Operating Points |
|---|---|---|
| TEOM validation - HPDI with excess pilot fuel | TEOM and Teflon filter at all operating points | 800RPM/25% Load – 0, 10, 20 % EGR<br>800RPM/75% Load – 0, 10, 20 % EGR<br>1600RPM/40% Load – 0, 10, 20 % EGR |
| Repeatability and EGR Tests - HPDI with ~5% pilot fuel | TEOM at all operating points. Filter measurements taken at (vi) for verification. | 800RPM/25% Load – 0, 10, 20 % EGR<br>800RPM/75% Load – 0, 10, 20 % EGR<br>1600RPM/40% Load – 0, 10, 20 % EGR<br>1400RPM/85% Load – 0, 10, 20 % EGR |
| Back pressure and diesel pulse width tests – HPDI with ~5% pilot fuel | TEOM at all operating points | 800RPM/25% Load – DPW = 0.7, 1.1, 0.6, 1.0 (0 and 15% EGR); BP = 11, 31, 10, 39 kPa<br>800RPM/75% Load – DPW = 0.7, 1.1, 0.6, 1.0 (0 and 17% EGR); BP = 11, 70, 10, 59 kPa<br>1600RPM/40% Load – DPW = 0.7, 1.1, 0.6, 1.0 (0 and 17% EGR); BP = 12, 106, 12, 104 kPa<br>1400RPM/85% Load – DPW = 0.7, 1.1, 0.6, 1.0 (0 and 13% EGR); BP = 11, 152, 14, 158 kPa |

**Table 3-1: Summary of experiments**

| Operating Point | CNG Flow (kg/hr) | CNG Pressure (MPa) | Pilot Flow (kg/hr) | Air Flow (kg/hr) | PSOI (ms) | DPW (ms) | GRIT (ms) | IMEP (bar) | BP (kPa) |
|---|---|---|---|---|---|---|---|---|---|
| 800RPM 25% load (excess pilot) | 1.2 | 19.0 | 0.80 | 72 | -2.0 | 0.65 | 1.8 | 5.5 | 10 |
| 800RPM 75% load (excess pilot) | 2.9 | 19.0 | 0.60 | 90 | -2.0 | 0.65 | 1.8 | 11.4 | 10 |
| 1600RPM 40% load (excess pilot) | 3.6 | 19.0 | 0.60 | 215 | -2.2 | 0.65 | 1.8 | 8.5 | 10 |
| 800RPM 25% load | 1.2 | 19.0 | 0.15 | 72 | -2.0 | 0.7 | 1.8 | 5.5 | 10 |
| 800RPM 75% load | 2.9 | 19.0 | 0.15 | 90 | -2.0 | 0.7 | 1.8 | 11.4 | 10 |
| 1600RPM 40% load | 3.6 | 19.0 | 0.31 | 215 | -2.2 | 0.7 | 1.8 | 8.5 | 10 |
| 1400RPM 85% load | 6.3 | 19.0 | 0.30 | 275 | -2.7 | 0.7 | 1.8 | 14.8 | 10 |

**Table 3-2: Engine parameters for operating conditions**

## 3.2 TEOM Validation

The first set of experiments was performed with leaking injector seals. This caused excess diesel to be forced into the natural gas line, resulting in over-fueling the engine. The measurements taken with excess diesel being injected were used only to compare TEOM and pre-weighed filter measurements. All emissions were constant during each testing period.

The TEOM gives an online, real time measurement of PM mass. This device requires less sampling time and is more convenient to use than weighing filters. TEOM measurements were compared with the results from pre-weighed filters taken at the same time. The results are shown in Figure 3-1. All emission data for the excess diesel tests is presented in Appendix B starting on page 76.

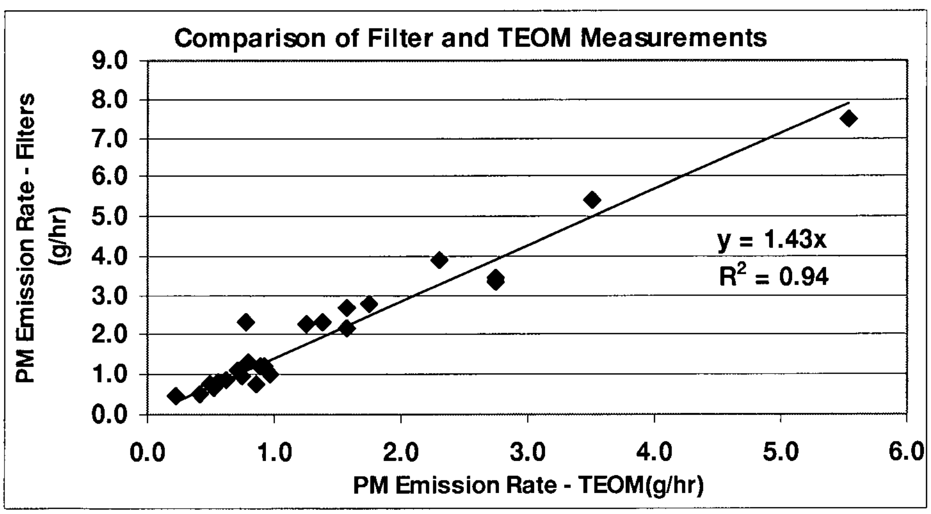


**Figure 3-1: Correlation of TEOM Data with Filters**

The comparison shows a significant offset between filter and TEOM measurements. This gives excellent agreement, with a $R^2$ value of 0.94, but the 43% correction is relatively high for measurements that are supposed to be the same quantity.

This is not unexpected since Green *et al.* [17] showed TEOM measurements underestimated $PM_{10}$ measurements by 15-30% versus other gravimetric techniques. Ayers *et al.* [18] also found their TEOM under measured $PM_{2.5}$ results by at least 30%. In both cases the authors reported the cause of this bias due to the volatilization of PM in the heated sampling environment of the TEOM.

### 3.3 Repeatability Study

A preliminary repeatability study was conducted to obtain baseline measurements from the SCRE. All results show noticeable day to day variation but provide a reasonable estimate of the emission rate at each test point. In most cases the emission rate was repeatable within 15% on the same day. The results are shown in Figure 3-2 through Figure 3-5. The emission rates have been normalized by the total fuel flow rate to account for variations in fuel flow. At higher load conditions (Figure 3-3 and Figure 3-5) there is higher day to day variability in PM. The error bars are calculated using the uncertainty from section 2.3.4, with an additional 10% for engine variation.

All results at 1400 RPM 85% load have insufficient airflow. A pressure relief valve located after the supercharger was set at a value lower than the boost pressure the engine required. Hence, approximately 20% of the airflow was diverted and did not enter the intake manifold. This was the only condition where the boost pressure exceeded the pressure relief valve setting, all other operating conditions were not affected.

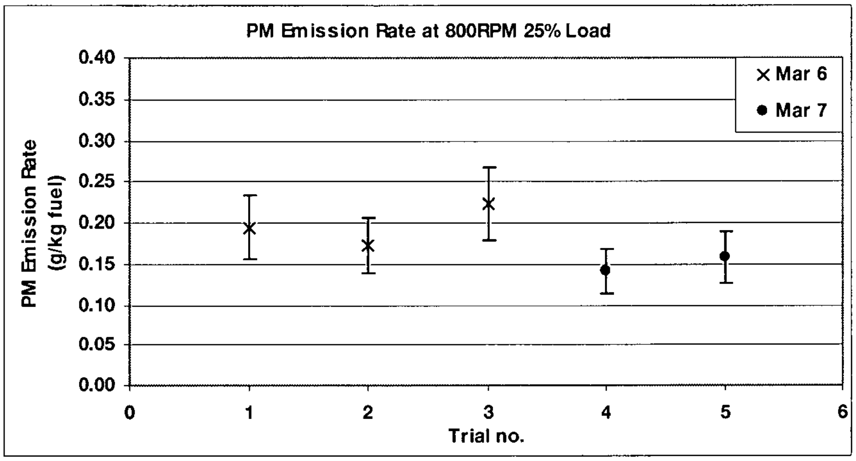


**Figure 3-2: Repetability Results at low-speed low-load**

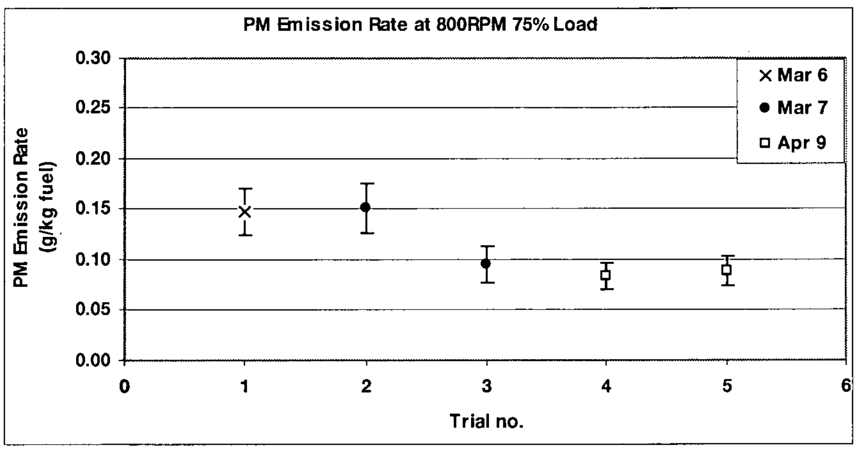


**Figure 3-3: Repetability Results at low-speed high-load**

The normalized emission rate at 1400 RPM 85% load is approximately three times the emission rate at 1600 RPM 40% load. This is due to the fact that only 80% of the intended airflow was being supplied to the engine as described earlier.

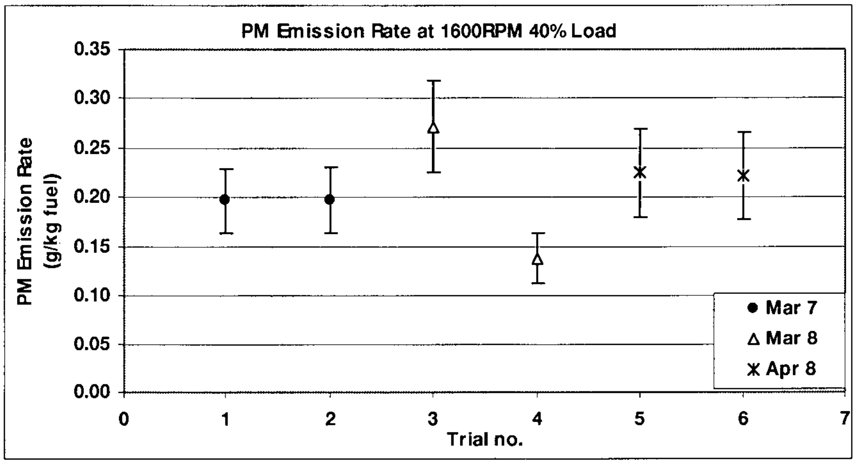


**Figure 3-4: Repeatability Results at high-speed low-load**

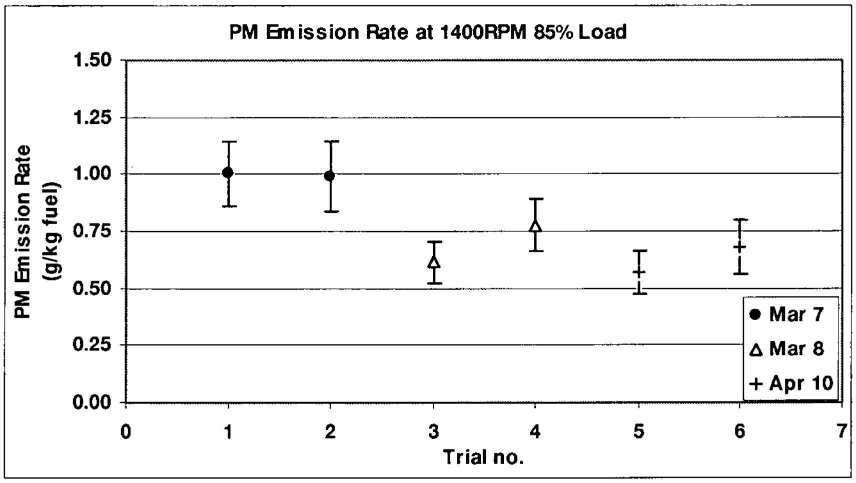


**Figure 3-5: Repeatability Results at mid-speed high-load**

One factor that may affect the PM emission rate is the variation in the relative humidity (RH) that changes the water content of the intake air. Table 3-3 summarizes the RH for the various test days. RH was not recorded prior to March 6.

| Date: | Mar 6 | Mar 7 | Mar 8 | Apr 8 | Apr 9 | Apr 10 |
|---|---|---|---|---|---|---|
| RH (%): | 32% | 33% | 35% | 45% | 50% | 55% |

**Table 3-3: Summary of relative humidity**

PM and all gaseous emissions are summarized in Table 3-4 with the average (AVG) and coefficient of variation (COV). The COV represents a measure of experimental error since it is the standard deviation normalized by the mean. These values are considered the actual experimental error associated with PM measurements from the SCRE. Results were included from tests were included under operating conditions specified in Table 3-2, without EGR.

| | 800 RPM 25% Load | | 800 RPM 75% Load | | 1600 RPM 40% Load | | 1400 RPM 85% Load | |
|---|---|---|---|---|---|---|---|---|
| | AVG | COV | AVG | COV | AVG | COV | AVG | COV |
| Diesel Flow(kg/hr) | 0.16 | 0.051 | 0.17 | 0.060 | 0.30 | 0.080 | 0.3 | 0.048 |
| CNG Flow(kg/hr) | 1.20 | 0.041 | 2.92 | 0.005 | 3.77 | 0.024 | 6.24 | 0.015 |
| Air Flow(kg/hr) | 72.6 | 0.010 | 91.6 | 0.017 | 213.2 | 0.012 | 275.9 | 0.007 |
| Exhaust Flow(kg/hr) | 74.0 | 0.010 | 94.7 | 0.017 | 217.3 | 0.012 | 282.5 | 0.007 |
| | | | | | | | | |
| CO (g/hr) | 4.9 | 0.359 | 72.8 | 0.104 | 26.4 | 0.082 | 187.4 | 0.156 |
| $CO_2$ (kg/hr) | 3.7 | 0.039 | 8.8 | 0.014 | 11.3 | 0.032 | 23.3 | 0.015 |
| $NO_x$ (g/hr) | 140.1 | 0.076 | 199.5 | 0.042 | 120.0 | 0.044 | 264.7 | 0.031 |
| $O_2$ (kg/hr) | 11.6 | 0.026 | 8.9 | 0.033 | 33.6 | 0.030 | 32.1 | 0.021 |
| tHC (g/hr,C1) | 14.7 | 0.084 | 14.0 | 0.131 | 67.7 | 0.070 | 57.2 | 0.056 |
| PM (g/hr) - TEOM | 0.24 | 0.202 | 0.35 | 0.294 | 0.8 | 0.205 | 5.2 | 0.252 |
| | | | | | | | | |
| CO (g/kg fuel) | 3.6 | 0.361 | 23.5 | 0.103 | 6.4 | 0.077 | 29.1 | 0.164 |
| $CO_2$ (kg/kg fuel) | 2.7 | 0.052 | 2.8 | 0.011 | 2.7 | 0.025 | 3.6 | 0.018 |
| $NO_x$ (g/kg fuel) | 103.5 | 0.083 | 64.4 | 0.039 | 29.0 | 0.040 | 41.0 | 0.023 |
| $O_2$ (g/kg fuel) | 8.6 | 0.042 | 2.9 | 0.034 | 8.1 | 0.033 | 5.0 | 0.026 |
| tHC (g/kg fuel,C1) | 10.8 | 0.065 | 4.5 | 0.133 | 16.4 | 0.072 | 8.9 | 0.060 |
| PM (g/kg fuel) - TEOM | 0.18 | 0.208 | 0.11 | 0.290 | 0.20 | 0.207 | 0.8 | 0.253 |

**Table 3-4: PM and gaseous baseline emissions of the SCRE**

## 3.4 Comparison with Six Cylinder ISX 400

The following data is presented with results by Baribeau [10] from the six cylinder ISX 400. The conditions are slightly different but all results have been normalized by total fuel flow. This comparison is intended to be an order of magnitude analysis only. The results from both engines are presented in Table 3-5. The operating conditions are slightly different, but there is reasonable agreement with the PM emission rate at low-speed high-load (SCRE 800 RPM 75% load / ISX 984 RPM 84%) and high-speed low-load (SCRE 1600 RPM 40% load / ISX 1800 RPM 18%), which are the most similar conditions. The only large discrepancy is the $NO_x$ emissions from the SCRE, which are significantly higher at all points.

| Engine Parameters | SCRE | | | | ISX 400 | | | |
|---|---|---|---|---|---|---|---|---|
| Speed | 800 | 800 | 1600 | 1400 | 600 | 984 | 1800 | 1668 |
| Load (%) | 25 | 75 | 40 | 85 | 0 | 84 | 18 | 95 |
| PSOI(ms) | -2 | -2 | -2.2 | -2.7 | -0.55 | -1 | -2.1 | -1.7 |
| Diesel Flow (kg/hr) | 0.16 | 0.17 | 0.30 | 0.29 | 0.47 | 1.09 | 1.82 | 1.88 |
| CNG Flow (kg/hr) | 1.20 | 2.91 | 3.77 | 6.24 | 1.56 | 28.7 | 12.65 | 60.26 |
| Air Flow (kg/hr) | 72.6 | 91.6 | 213.2 | 275.9 | N/A | N/A | N/A | N/A |
| CO (g/kg fuel) | 3.6 | 23.5 | 6.4 | 29.1 | 14.4 | 9.0 | 11.3 | 4.0 |
| $CO_2$ (kg/kg fuel) | 2.7 | 2.8 | 2.7 | 3.6 | 3.1 | 2.7 | 2.7 | 2.7 |
| $NO_x$ (g/kg fuel) | 103.5 | 64.4 | 29.0 | 41.0 | 44.2 | 21.1 | 19.3 | 8.9 |
| $O_2$ (g/kg fuel) | 8.6 | 2.9 | 8.1 | 5.0 | 30.0 | 3.0 | 13.9 | 3.3 |
| tHC (g/kg fuel) | 10.8 | 4.5 | 16.4 | 8.9 | 22.4 | 2.3 | 17.1 | 2.6 |
| PM (g/kg fuel) | 0.18 | 0.11 | 0.20 | 0.80 | 0.81 | 0.12 | 0.60 | 0.09 |

**Table 3-5: Comparison of SCRE and six-cylinder ISX 400**

## 3.5 Sources of Variability

Tests were performed in order to account for some of the variability in the measured PM emissions. The effects of changing the diesel pulse width (with and without EGR) and the exhaust back pressure were investigated. The tests are summarized in Table 3-6.

| Operating Point (speed/load) | DPW – no EGR BP =10kPa (ms [kg/hr]) | Back Pressure DPW = 0.7ms (kPa) | DPW with EGR BP = variable (ms [kg/hr]) | EGR for DPW test (%) |
|---|---|---|---|---|
| 800RPM 25% load | 0.7 [0.15], 1.1 [0.22], 0.6 [0.14], 1.0 [0.18] | 11, 31, 10, 39 | 0.7 [0.15], 1.1 [0.22], 0.6 [0.14], 1.0 [0.18] | 15 |
| 800RPM 75% load | 0.7 [0.16], 1.1 [0.20], 0.6 [0.15], 1.0 [0.18] | 11, 70, 10, 59 | 0.7 [0.16], 1.1 [0.20], 0.6 [0.15], 1.0 [0.18] | 17 |
| 1600RPM 40% load | 0.7 [0.28], 1.1 [0.37], 0.6 [0.25],1.0 [0.33] | 12, 106, 12, 104 | 0.7 [0.28], 1.1 [0.37], 0.6 [0.25],1.0 [0.33] | 17 |
| 1400RPM 85% load | 0.7 [0.29], 1.1 [0.34], 0.6 [0.28],1.0 [0.32] | 11, 152, 14, 158 | 0.7 [0.29], 1.1 [0.34], 0.6 [0.28],1.0 [0.32] | 13 |

**Table 3-6: Summary of variability test parameters**

In order to confirm if back pressure effects were due to the dilution system, as opposed to changing engine conditions, the normalized CO emission rates have been plotted as well since both emissions are products of incomplete combustion. The correlation between PM and CO emissions is high only at 800 RPM 75% load as shown in Figure 3-7. In some cases, the correlation depends on which day the data was collected. The correlations between CO and PM along with the correlation coefficients are given in Figure 3-6 through Figure 3-9. It should be noted the CO analyzer used has a range of 0 to 1% (0-10000 ppm) and CO levels at low load were under 200 ppm.

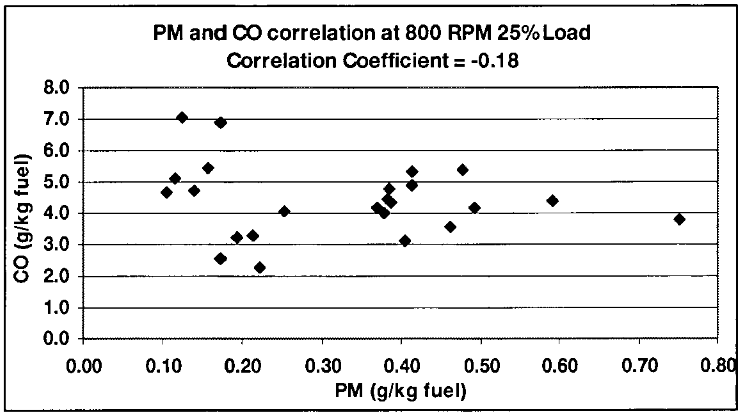


**Figure 3-6: PM/CO correlation at low-speed low-load**

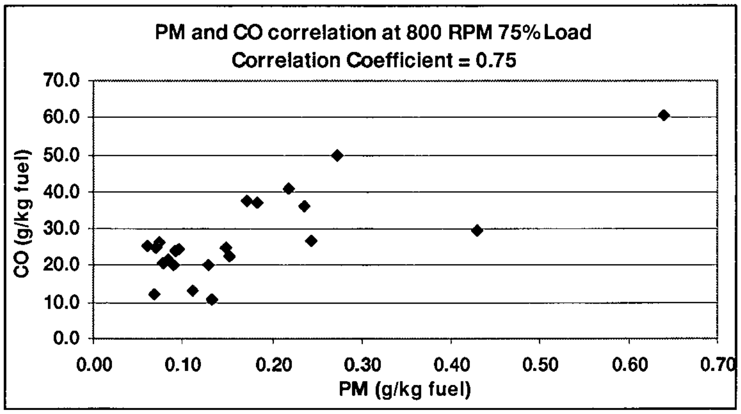


**Figure 3-7: PM/CO correlation at low-speed high-load**

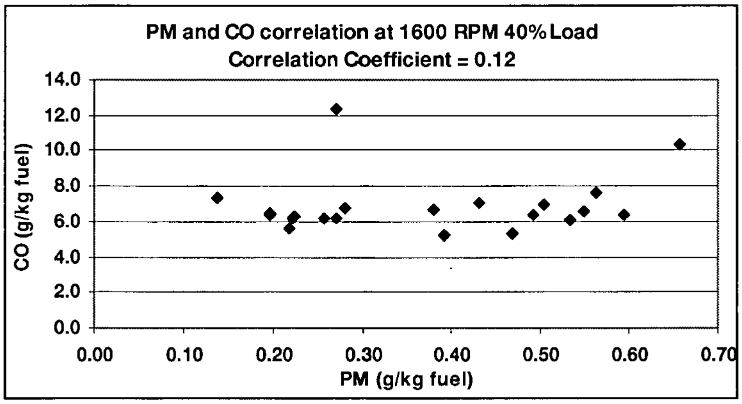


**Figure 3-8 : PM/CO correlation at high-speed low-load**

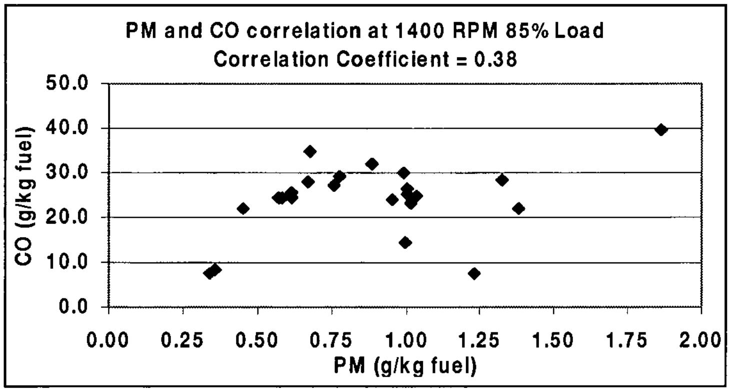


**Figure 3-9: PM/CO correlation at mid-speed high-load**

The tests at 800 RPM 25% load were performed with excessive engine cooling causing the engine oil to be 40°C lower than usual. The absolute values of these tests were not considered, they are only used for relative comparison. Tests performed at other conditions were not significantly affected and were included in other sections. The location of all corresponding emission data can be found in Table 3-7. The relationship between diesel flow and pulse width is presented in Appendix I. Since significant error is associated with the diesel flow rate measurement itself, the results are presented with the corresponding diesel pulse width setting.

| Speed/ Load | Table | Page No. |
|---|---|---|
| 800 RPM/25% | Table 4-3 | 60 |
| 800 RPM/75% | Table 4-8 | 65 |
| 1600 RPM/40% | Table 4-12 | 69 |
| 1400 RPM/85% | Table 4-16 | 73 |

**Table 3-7: Location of variability emissions Data in Appendix B**

### *3.5.1 Diesel Pulse Width Tests (no EGR)*

The following tests were performed by starting at a typical DPW setting (0.7), then changing to a high value (1.1), then changing down to a low value (0.6) and finally to a high value (1.0). The emission rates are plotted in the order they were measured in.

At 800 RPM 25% load, there is a lower total exhaust flow at a lower temperature than the other test points. This means there is less flow past the sample tube. Also, the $CO_2$ emission rate is the lowest concentration compared to other operating conditions, which means the uncertainty in the dilution ratio will be higher. Both of these factors make it difficult to determine any significant effects at low-speed low-load. Figure 3-10 shows a slight decrease with increasing DPW, although this is may be due to fluctuations in the CO analyzer.

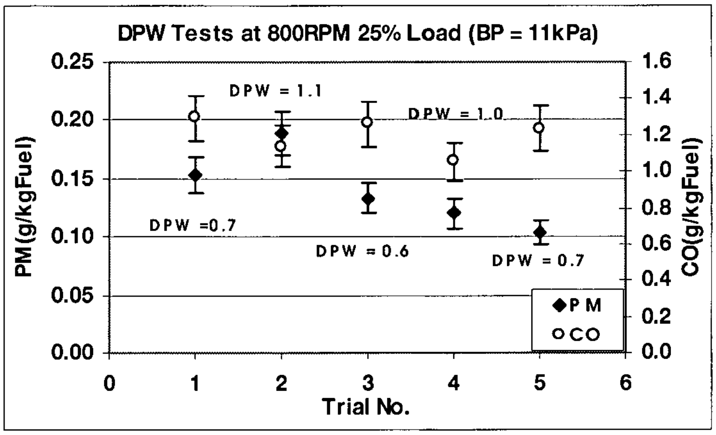


**Figure 3-10: The effect of diesel pulse width at low-speed low-load**

Slight effects of DPW on PM and CO are found at 800 RPM high load as shown in Figure 3-11. However, the change in emission rates is within experimental error so no conclusion can be drawn.

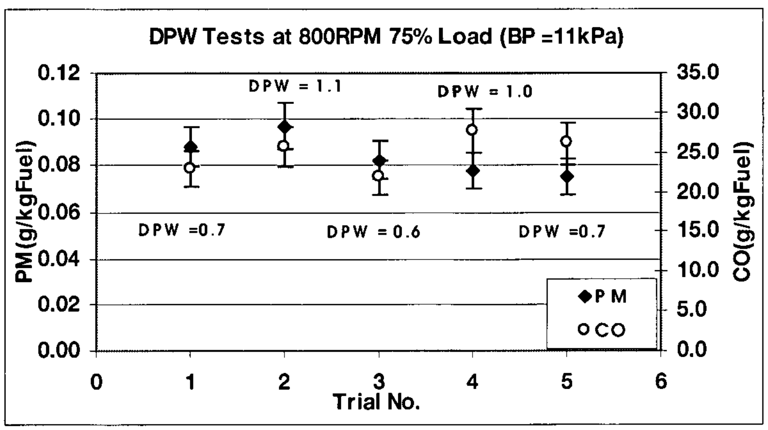


**Figure 3-11: The effect of diesel pulse width at low-speed high-load**

The tests performed at 1600 RPM 40% load were biased due to water found in the sampling tube upstream of the TEOM. This is believed to be the cause of the decaying trend in the PM emission rate shown in Figure 3-12. The emission rate at trial 5 corresponds to the mean value obtained in previous experiments. Since the CO remains constant it is likely there was little change in the PM emission rate.

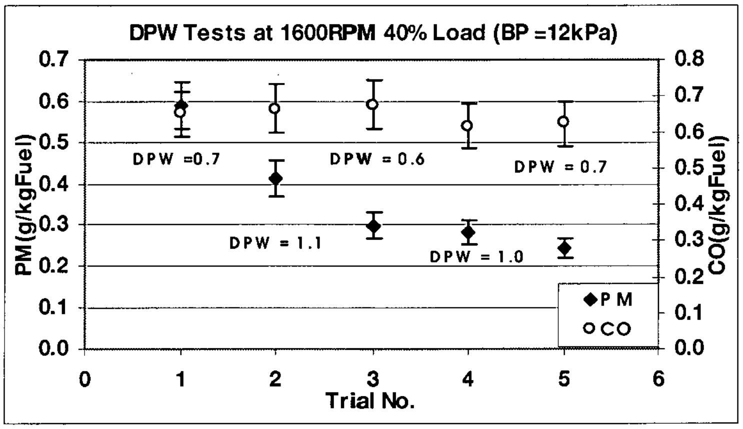


**Figure 3-12: The effect of diesel pulse width at high-speed low-load**

Figure 3-13 shows an increase in PM and CO when the DPW was changed from 0.7 to 1.1 ms at 1400 RPM 85% load. However, the emissions remain constant afterwards. The DPW may affect both PM and CO as shown at 800 RPM high load but it is not definite since the variation is around the same magnitude as the uncertainty.

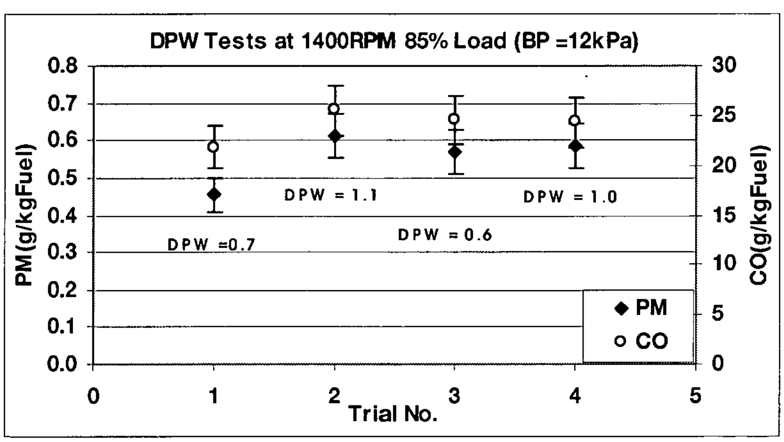


**Figure 3-13: The effect of diesel pulse width at mid-speed high-load**

### *3.5.2 Diesel Pulse Width Tests (with EGR)*

Tests were performed in the same manner as described in the previous section, except with approximately 15% EGR. Slight fluctuations in CO and PM are shown at 800 RPM 25% load in Figure 3-14, but are within experimental uncertainty.

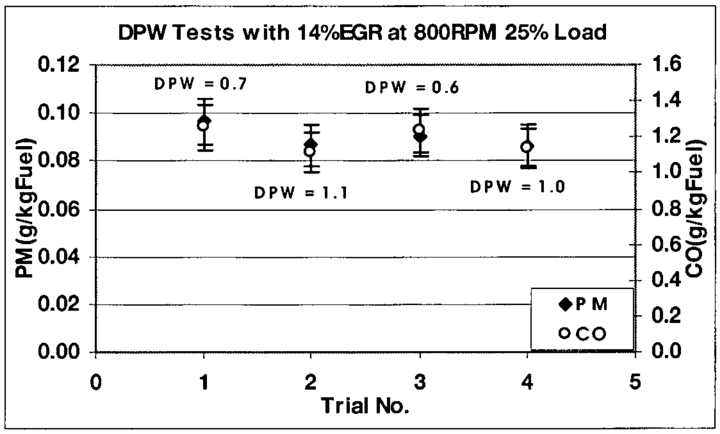


**Figure 3-14: The effect of diesel pulse width at low-speed low-load with EGR**

At higher load, increasing the DPW produces higher amounts of CO and PM. The diesel flow rate changes from 0.15 to 0.20 kg/hr, which is a difference of 30% of the pilot fuel flow rate. The CO and PM emission rates are increased by approximately the same amount.

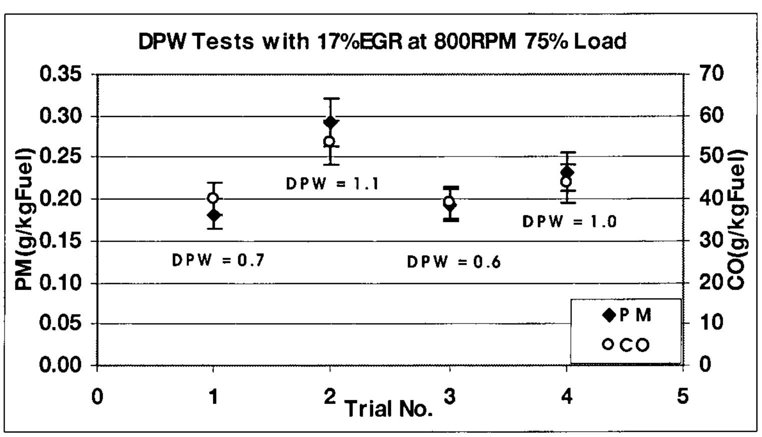


**Figure 3-15: The effect of diesel pulse width at low-speed high-load with EGR**

No significant change can be found at either 1600 RPM 40% load or 1400 RPM 85% load with EGR, as shown in Figure 3-16 and Figure 3-17.

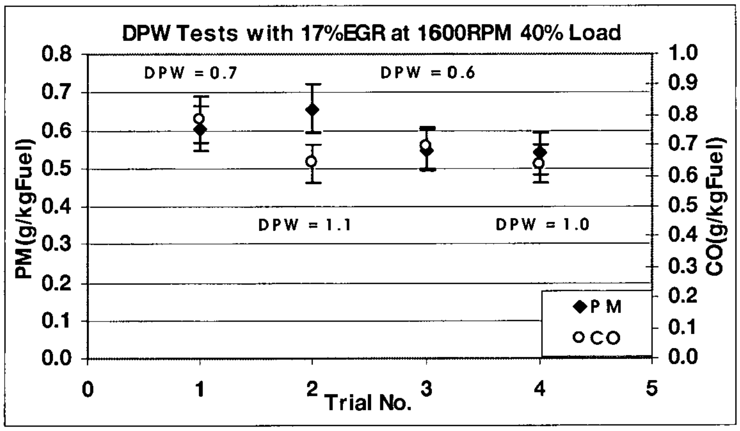


**Figure 3-16: The effect of diesel pulse width at high-speed low-load with EGR**

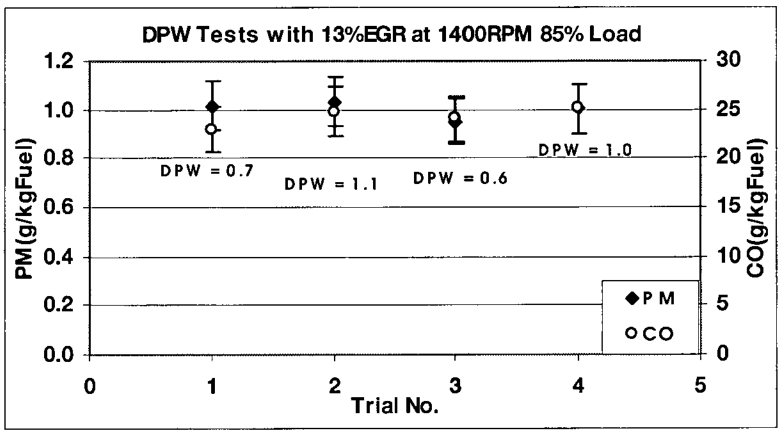


**Figure 3-17: The effect of diesel pulse width at mid-speed high-load with EGR**

### *3.5.3 Back Pressure Tests (no EGR)*

The effect of back pressure was examined since a significant back pressure is required for EGR operation. It is imperative to differentiate between the effects of back pressure alone versus EGR. At low-speed low-load there is an increase in PM and CO emissions with increasing back pressure as shown in Figure 3-18.

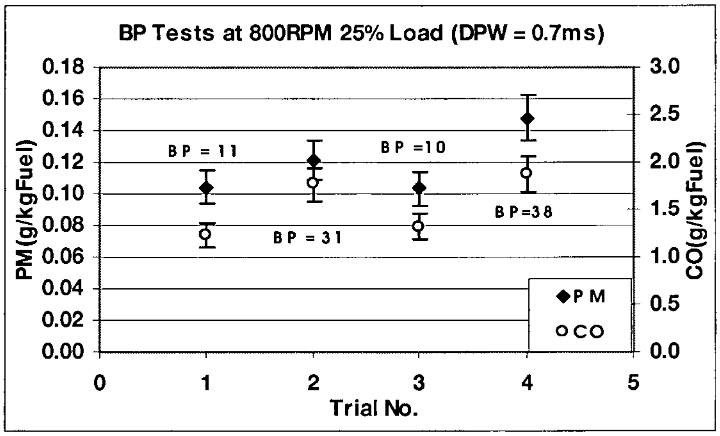


**Figure 3-18: The effect of back pressure at low-speed low-load**

At 800 RPM 75% load and 1600 RPM 40% load the CO and PM emission rates diverge with increasing back pressure, as shown in Figure 3-19 and Figure 3-20. The normalized CO rates are reduced by approximately half when the engine is operating with a higher back pressure. These figures also clearly show an increase in PM with back pressure. At 800 RPM 75% load it appears there may be a transition region that the back pressure must exceed (~65kPa) to affect the PM emission rate.

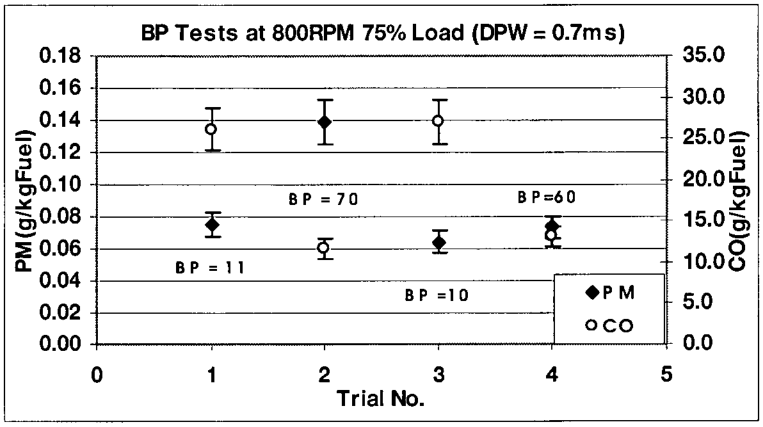


**Figure 3-19: The effect of back pressure at low-speed high-load**

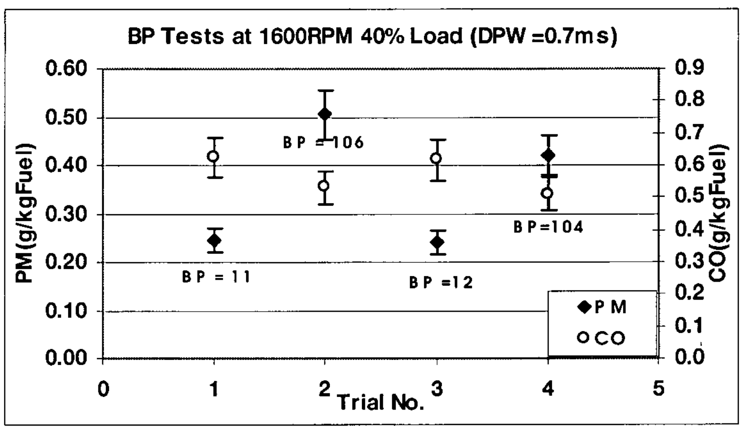


**Figure 3-20: The effect of back pressure at high-speed low-load**

Figure 3-21 shows at 1400 RPM 85% load the opposite trend in PM occurs compared to the previous two cases. Increasing back pressure tends to suppress the formation of CO and PM at this operating condition. It is possible the reversal in the PM trend is due to higher exhaust temperatures caused by increasing the exhaust pressure. Appendix B shows the exhaust temperatures for all experiments. It is possible that having the exhaust temperature higher allows more hydrocarbons to oxidize or inhibits condensation reactions from occurring. For example, at 1400 RPM 85% load the temperature increased from 380°C (10 kPa) up to a value of approximately 470°C at (150 kPa).

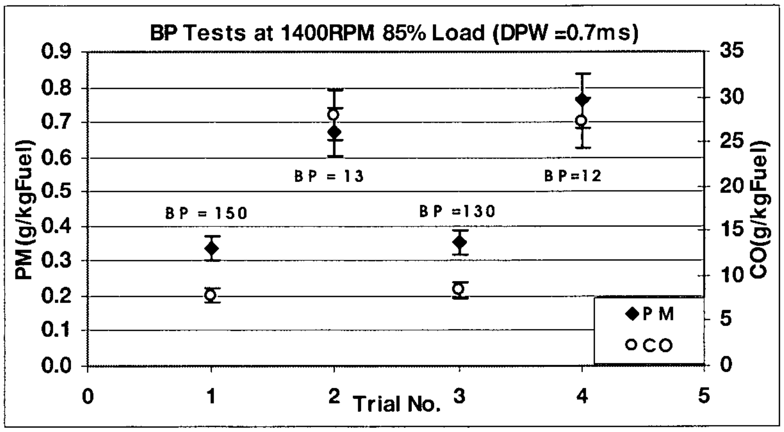


**Figure 3-21: The effect of back pressure at mid-speed high-load**

Heywood [4] states the oxidation rate of CO can be considered negligible below 600°C, which implies the engine conditions must have been changing since the CO concentration will be constant after the gas passes the exhaust valve.

### *3.5.4 Effects on In-Cylinder Pressure*

The diesel pulse width or exhaust back pressure did not significantly (at least 10% change) affect the IMEP, heat release rate, peak cylinder pressure or peak cylinder pressure location. All high speed data is presented in Appendix J. There are small differences in the heat release curves but it is difficult to discern if these are due to noise in the high speed data or actual changes in combustion. Increasing the back pressure caused an increase in the work required during the exhaust stroke (pumping loop).

### *3.5.5 Exclusion of Data Points (Outliers)*

From the previous results it was determined that the exhaust back pressure definitely affects the PM emission rate and the amount of diesel injected has more subtle effects. It was also found that moisture in the sampling apparatus can lead to an overestimate of the PM emission rate. Data was excluded from the baseline and EGR results if it was significantly different than the expected value due to any of the following reasons:

- The back pressure for non-EGR tests was outside of 8-15kPa.
- The diesel pulse width was set outside of 0.6 - 0.7 ms.
- The tests performed were within 30 sampling minutes since the first test on that day and the emission rate was exaggerated due to condensation in the dilution system piping.
- The emission rate recorded by the TEOM was not constant within 5%.

Data points that were excluded were shaded in light gray in Appendix B to show they were deemed outliers.

## 3.6 The Effect of Exhaust Gas Recirculation

Experiments were performed to show the change in PM emissions when using exhaust gas recirculation to reduce $NO_x$ levels from the engine. The same operating points were tested as in section 3.3, with EGR rates up to approximately 22%. The emission summaries are located in Appendix B.

### *3.6.1 Particulate and $NO_x$ Emissions*

Results were compared over different sampling days to show the effect of EGR on $NO_x$ and PM emissions. The emission rates (normalized by total fuel flow) for $NO_x$ and PM are plotted in Figure 3-22 through Figure 3-25. In all cases a linear decrease in $NO_x$ was observed as previously shown by McTaggart-Cowan [12]. $NO_x$ emissions were not affected by higher back pressure, but as shown in section 3.5.3, PM emissions showed a large sensitivity to changes in back pressure.

At 800 RPM 25% load there is little effect of EGR on particulate emissions, as shown in Figure 3-22. However, a slight increase in PM is observed at 10% EGR, followed by a slight decrease at EGR levels of 20%.

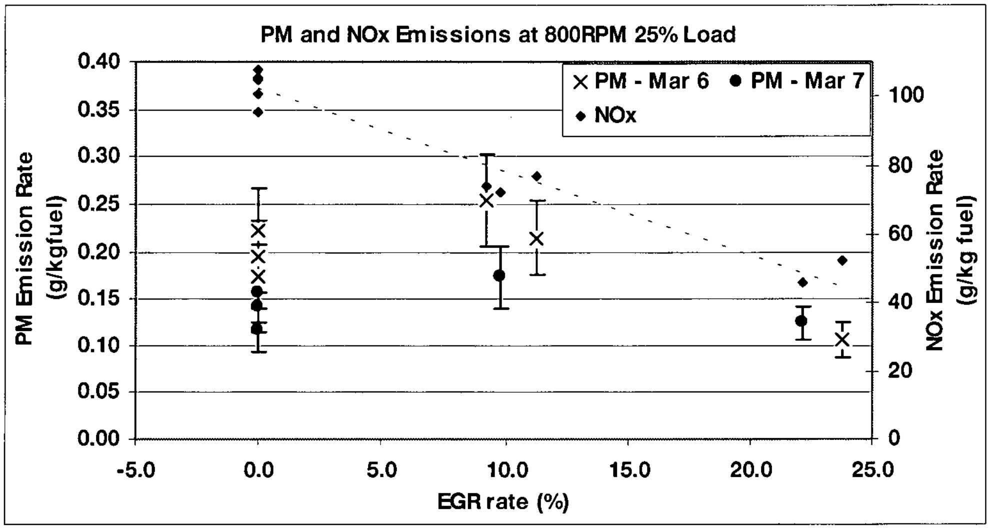


**Figure 3-22: The effect of EGR at low-speed low-load**

At 800 RPM 75% load the PM emission rate increases with higher EGR rates as shown in Figure 3-23. This is partly due to the fact that the back pressure has increased from approximately 10 kPa to 50 kPa, which increases the particulate emission (0.13 g/kg fuel) without EGR as shown in Figure 3-19 from the previous section. Hence, it is believed the PM emission rate is not significantly increasing due to EGR itself until operating at rates greater than 15%.

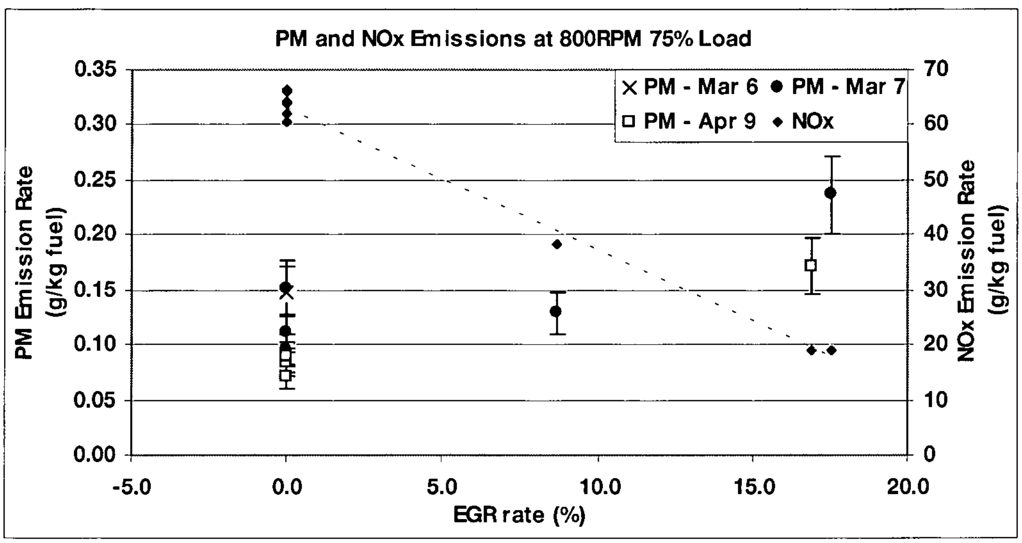


**Figure 3-23: The effect of EGR at low-speed high-load**

At 1600 RPM 40% load and 1400 RPM 85% load an increase in PM with EGR is visible, but again a major portion is due to applying back pressure. Emission rates of 0.5 g/kg fuel were found at 1600 RPM 40% load with 105 kPa of back pressure without EGR. This implies only a slight increase even at EGR rates of 20%.

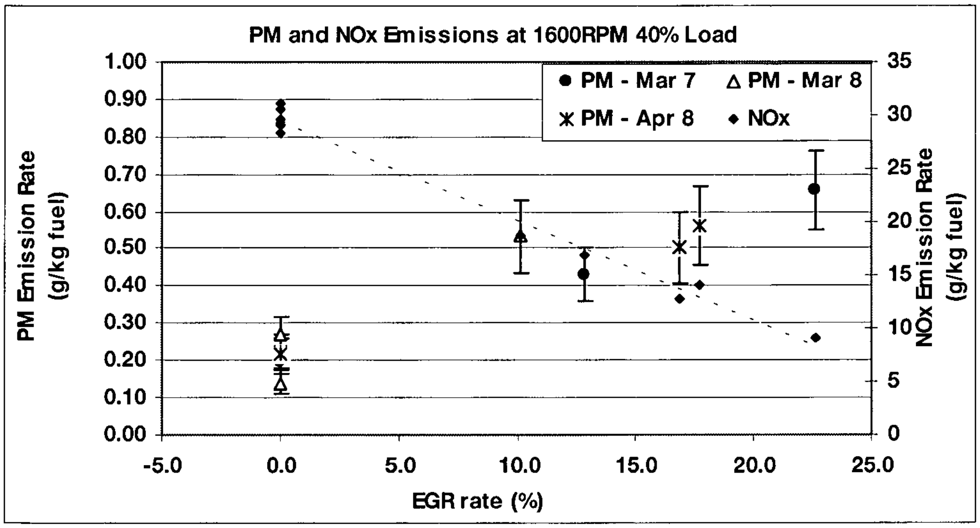


**Figure 3-24: The effect of EGR at high-speed low-load**

At 1400 RPM 85% load there appears to be a more pronounced increase in PM emissions with increasing EGR. There is insufficient air in the cylinder due to the pressure relief valve opening. This explains the high CO emissions were measured at this condition. The increase in PM with EGR is visible but is not excessive as shown in Figure 3-25.

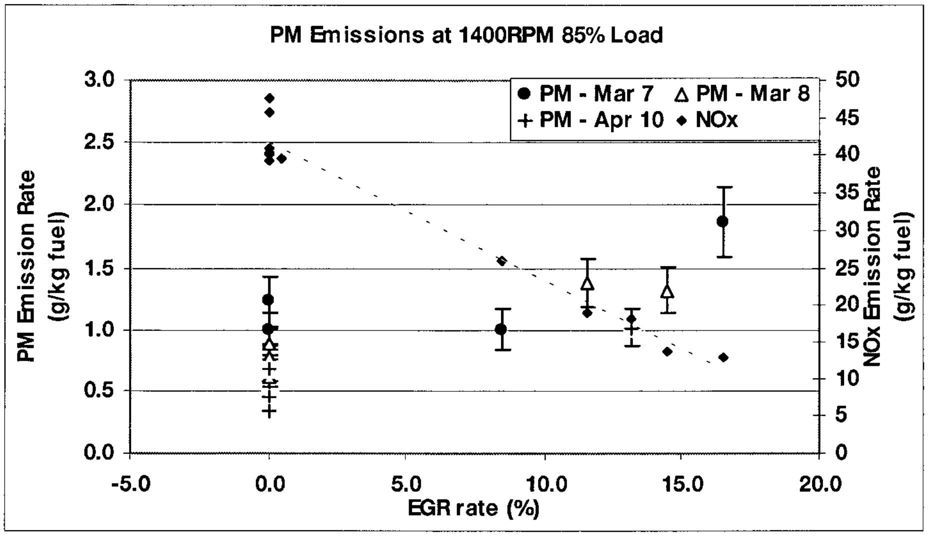


Figure 3-25: The effect of EGR at mid-speed high-load

### *3.6.2 In-Cylinder Pressure*

One of the concerns when operating at higher EGR rates is reducing engine performance. Figure 3-26 through Figure 3-28 show no significant changes in IMEP, peak cylinder pressure and peak cylinder pressure location. The results were taken from the same day but similar trends exist in other trials. A summary of high-speed data is presented in Appendix J, for each sampling period.

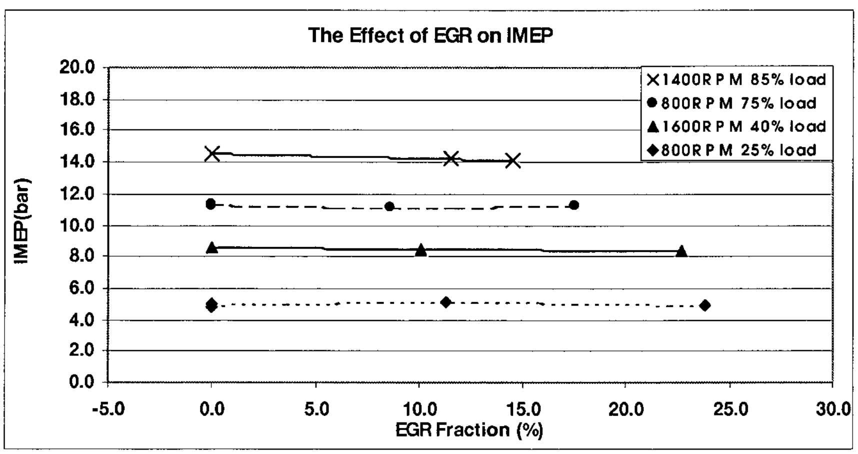


Figure 3-26: IMEP variation with EGR

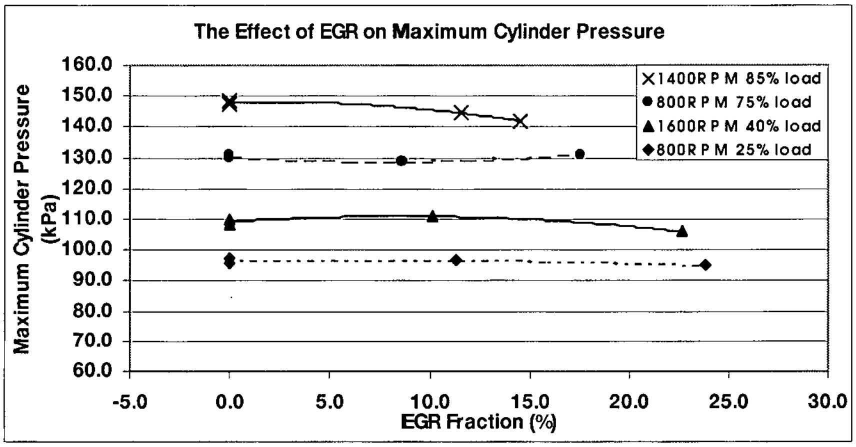


**Figure 3-27: Peak cylinder pressure variation with EGR**

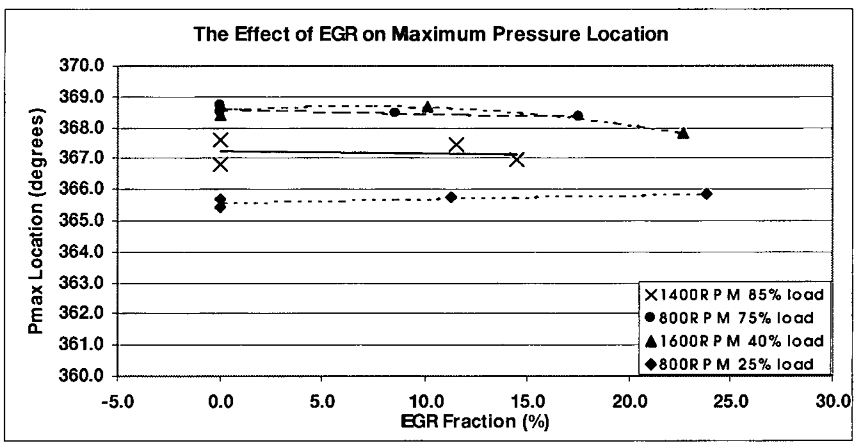


**Figure 3-28: Peak cylinder pressure location variation with EGR**

The only measurement that showed a significant change due to EGR was the rate of heat release. Increasing the amount of EGR delays the heat release within the cylinder, which results in later burning with less time to oxidize particulates.

At 800 RPM 25% load the heat release occurs later and within a shorter time interval as shown in Figure 3-29. It should be pointed out that the integrated heat release is lower for 22% EGR, but the maximum rate is higher. This may explain the decrease in PM at EGR rates of 20%.

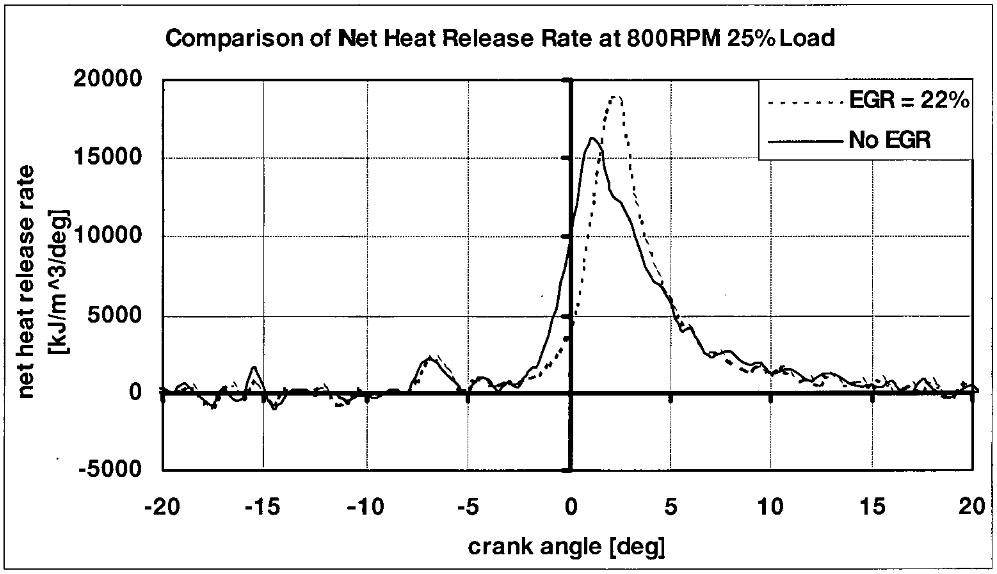


**Figure 3-29: The effect of EGR on heat release at low-speed low-load**

At 800 RPM 75% load a two-stage process is observed without EGR, as shown in Figure 3-30. EGR delays the heat release rate and occurs at a higher rate in a shorter time, but the effect is not as pronounced as at 25% load.

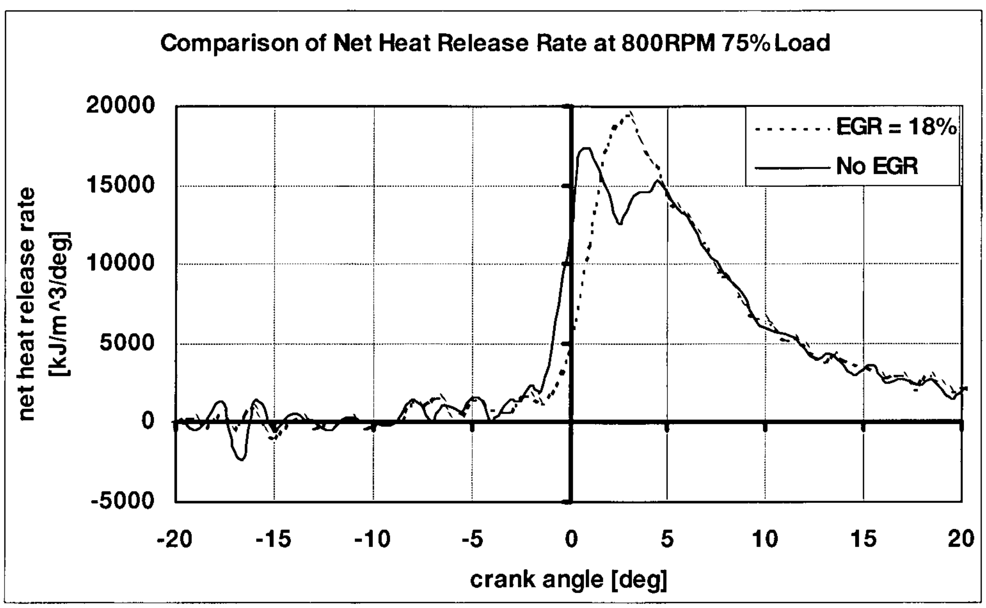


**Figure 3-30: The effect of EGR on heat release at low-speed high-load**

At 1600 RPM 40% load and 1400 85% load there is only a slight effect of EGR, the heat release rate is only slightly delayed as shown in Figure 3-31 and Figure 3-32.

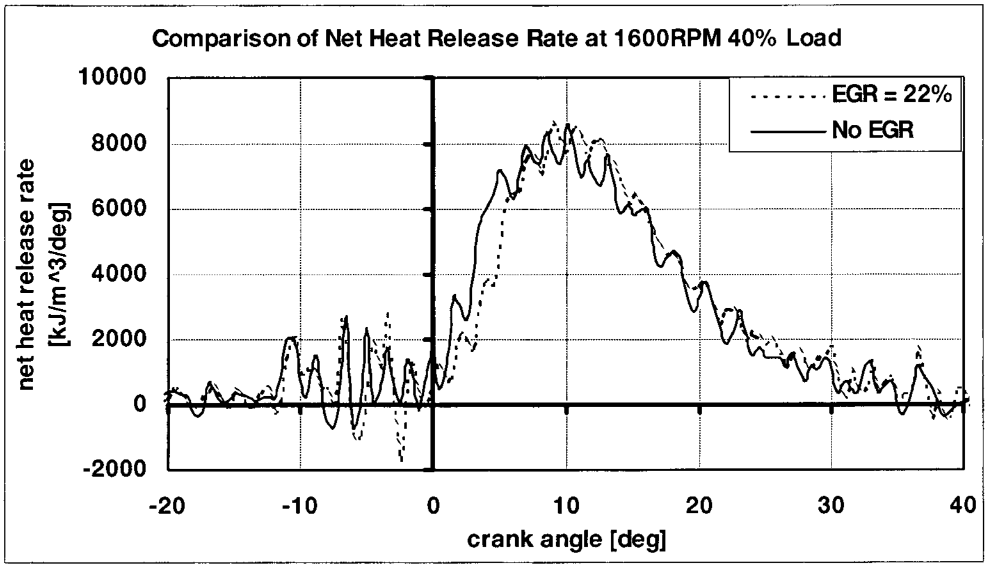


**Figure 3-31: The effect of EGR on heat release at high-speed low-load**

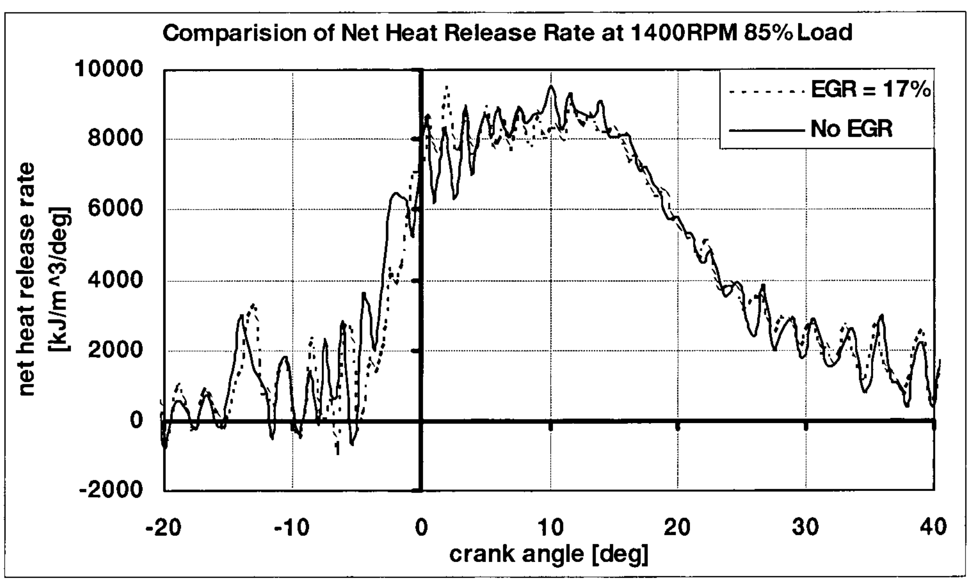


**Figure 3-32: The effect of EGR on heat release at mid-speed high-load**

# Chapter 4: Conclusions and Future Work

## 4.1 Conclusions

The primary goal of this work was to design and construct a suitable mini-dilution system capable of measuring particulate emissions. This was successfully completed and it was shown the overall accuracy of PM emission rates is between 20 and 29%, depending on the operating condition. The measurement uncertainty was calculated to be at maximum 12%, implying the remainder of variability is attributed to the engine itself.

The TEOM can be used to reduce sampling time and provide a real-time PM measurement. The PM emission rate from the TEOM can be corrected by multiplying values by 1.43 to correspond with those taken using pre-weighed Teflon filters.

At 800 RPM 75% load with EGR it was shown that there was a definite correlation between DPW and CO/PM emissions. These effects of the DPW are likely present, although to a much lesser extent, when operating at other conditions. Increasing the back pressure alone tends to increase PM emissions, except at 1400 RPM high load. More experiments are needed to quantify these effects. However, the HPDI system with EGR does not show a large increase in PM emissions, even at EGR rates of 15% if the back pressure effects are considered.

## 4.2 Recommendations for Future Work

The addition of the mini-dilution tunnel was the first stage for further PM research endeavours. The most important recommendation is to determine an appropriate exhaust back pressure for all test points. The values from the turbocharger inlet (of the ISX 400) need to be measured and recorded. The back pressure needs to be specified precisely, so it can be set at a given value during operation of the SCRE.

There are still numerous other parameters that can be tested with the current equipment. For example, the PM emission rate at various timings could be explored, especially at different EGR rates. The other interesting parameter to investigate is changing the duration of the diesel pulse width, at different conditions. For optimizing an EGR engine it would be desirable to know when the PM penalty appears. In section 3.6, PM emission rates increased with EGR at every condition except low-speed low-load. There is likely a transition region where these effects change from negligible to fairly significant. Knowing where this transition occurs would be invaluable to minimize emissions.

To improve the accuracy of measurements there are several improvements that would be worthwhile. A more accurate measurement of the diesel flow rate would be valuable, particularly for lower speeds. The correlation between the TEOM data and pre-weighed filters should be verified. This may be important since the comparison tests were performed with excess diesel leaking into the engine. The correction factor may be different if running at normal HPDI conditions.

Finally, there are some more technical additions that would be worthwhile. One is the addition of a Scanning Mobility Particle Sizer. There has been a lot of concern that the PM emitted from the natural gas engine may be significantly higher in the ultra-fine size range. These ultra-fine particles are believed to be more hazardous to human health due to their ability to penetrate the lungs and enter the pulmonary system. Knowing the particle size distribution would be interesting from an academic standpoint but may be a genuine concern should the emission rate of ultra-fine particles be relatively high.

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# Appendix A: Description of Apparatus

| Device | Manufacturer | Description / Model | Comments/Other |
|---|---|---|---|
| Thermocouple | Omega Inc. | K- type | KMQSS-125-U-6 (0-1000K) |
| Mass Flow Controller | Omega Inc. | FMA-1928 | 0 – 50SLPM (±1.5% full scale) |
| Pressure Sensor | Autotran Inc | 601D - 015 (D = differential) | 0-1psid 0-5VDC output |
| Filter Holder | Pall-Gelman | 2220 | Stainless steel 47mm filter holder |
| Teflon Filters | Pall | Teflo 47mm, 2μm mesh - RJP2047 | 99.99% Aerosol retention (ASTM D2986-71) |
| TEOM | Rupprecht and Patashnick | 1105 | |
| TEOM filters | Rupprecht and Patashnick | exchangeable filter cartridges | Pallflex TX40 TEOM filters |
| Scale | Sartorius GmbH | Model no. M3P | range = 0 – 3000mg |
| Pump | Thomas Industries | Diaphragm Pump: 2737BM370 | rated flow: 180LPM |
| Air Supply | Praxair Inc. | Medical Air<br>$O_2$ = 19.5 –23.5%<br>$CO_2$ = 500ppm<br>CO < 10ppm<br>$NO_x$ < 2.5 ppm<br>$SO_2$ < 5ppm | Balance $N_2$ and certified:<br>HC (condensed): none<br>$H_2O$ (condensed): none |

**Table 4-1: Detailed description of dilution tunnel components**

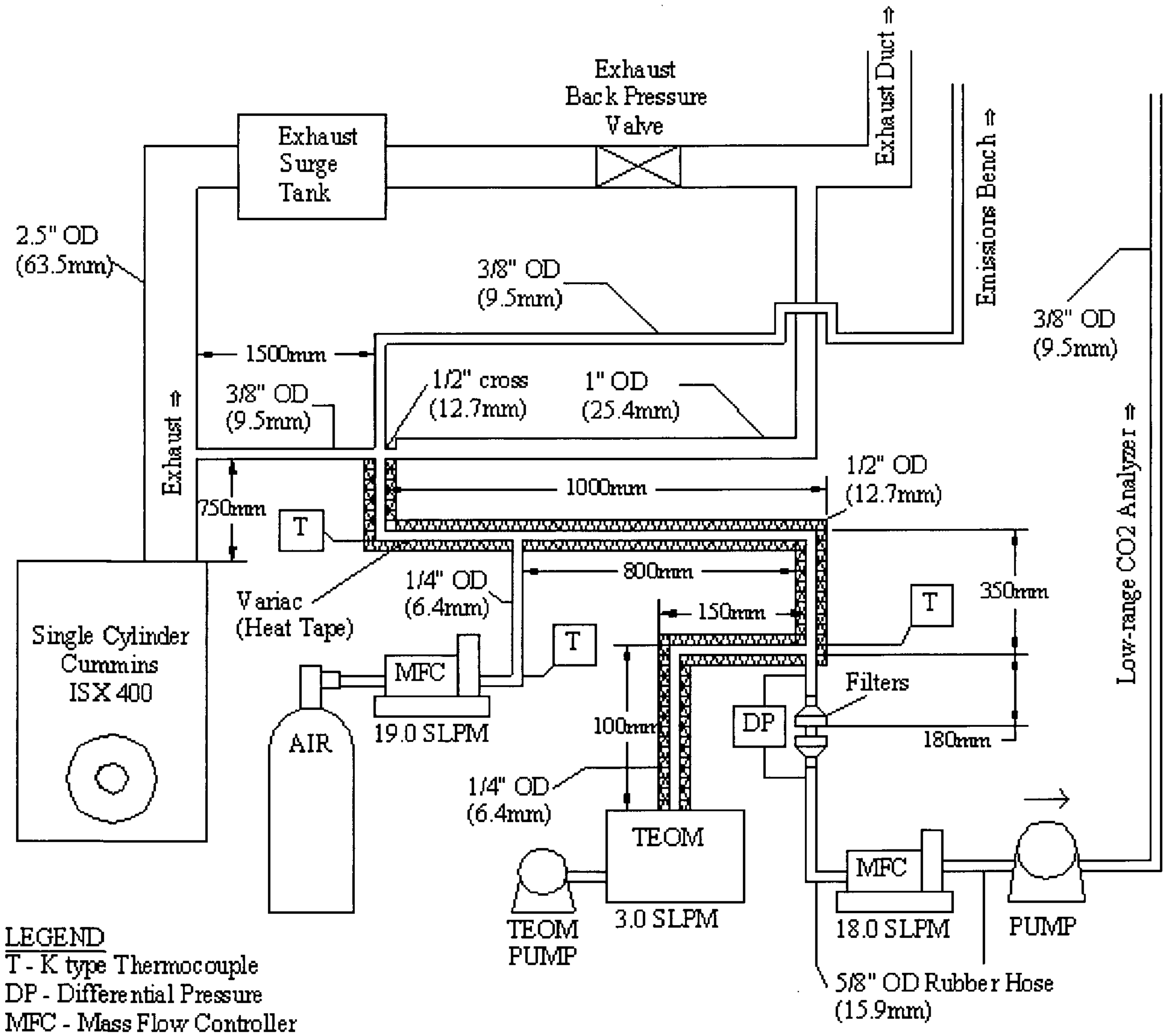



**Figure 4-1: Detailed Schematic of Dilution System**

# Appendix B: Experimental Results

Note: (i) Negative nmHC indicates malfunction of the $CH_4$ analyzer.

(ii) *Air to fuel ratio = Air Flow / (CNG Flow + Diesel Flow)*

| Label: | A5 | A8 | A10 | A25 | A28 | A29 | | |
|---|---|---|---|---|---|---|---|---|
| Date: | 6-Mar-02 | 6-Mar-02 | 6-Mar-02 | 7-Mar-02 | 7-Mar-02 | 7-Mar-02 | | |
| Time: | 12:24:34 | 15:16:05 | 15:59:31 | 14:06:02 | 14:47:30 | 14:55:26 | AVG | COV |
| **Engine Parameters** | | | | | | | | |
| Speed(RPM) | 799.4 | 790.8 | 797.5 | 805.0 | 799.7 | 800.2 | 798.5 | 0.006 |
| Load(%) | 25 | 25 | 25 | 25 | 25 | 25 | 25.0 | 0.000 |
| Indicated Power (kW) | 8.4 | 8.0 | 8.4 | 8.8 | 8.0 | 8.6 | 8.3 | 0.041 |
| IMEP (bar) | 5.1 | 4.8 | 5.1 | 5.2 | 4.8 | 5.2 | 5.0 | 0.036 |
| Pmax(bar) | 96.1 | 96.0 | 97.1 | 96.4 | 94.2 | 96.2 | 96.0 | 0.011 |
| Pmax location (degrees) | 365.9 | 365.5 | 365.7 | 365.8 | 365.9 | 365.9 | 365.7 | 0.000 |
| Diesel Flow(kg/hr) | 0.16 | 0.17 | 0.17 | 0.15 | 0.15 | 0.21 | 0.16 | 0.051 |
| CNG Flow(kg/hr) | 1.24 | 1.16 | 1.22 | 1.23 | 1.13 | 1.11 | 1.20 | 0.041 |
| Air Flow(kg/hr) | 71.8 | 71.9 | 72.7 | 73.4 | 73.3 | 73.4 | 72.6 | 0.010 |
| Exhaust Flow(kg/hr) | 73.2 | 73.2 | 74.1 | 74.8 | 74.6 | 74.7 | 74.0 | 0.010 |
| Exhaust Back Pressure (kPa) | 14.3 | 14.2 | 10.2 | 9.6 | 10.7 | 10.8 | 11.8 | 0.192 |
| EGR Fraction(%) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | N/A |
| **Exhaust Emission Flows** | | | | | | | | |
| CO (g/hr) | 4.54 | 3.36 | 3.17 | 6.51 | 6.98 | 6.74 | 4.9 | 0.359 |
| $CO_2$ (kg/hr) | 3.78 | 3.59 | 3.73 | 3.78 | 3.45 | 3.73 | 3.7 | 0.039 |
| $NO_x$ (g/hr) | 147.8 | 142.4 | 148.9 | 138.9 | 122.4 | 137.8 | 140.1 | 0.076 |
| $O_2$ (kg/hr) | 11.2 | 11.6 | 11.6 | 11.6 | 12.1 | 11.8 | 11.6 | 0.026 |
| $CH_4$ (g/hr) | 5.97 | 6.75 | 6.51 | 54.50 | 41.90 | 53.69 | 23.1 | 1.008 |
| nmHC (g/hr,C1) | 10.23 | 7.06 | 6.86 | -40.25 | -26.15 | -38.98 | -8.4 | -2.743 |
| tHC (g/hr,C1) | 16.20 | 13.82 | 13.37 | 14.25 | 15.74 | 14.71 | 14.7 | 0.084 |
| PM (g/hr) - TEOM | 0.27 | 0.23 | 0.31 | 0.19 | 0.20 | 0.15 | 0.24 | 0.202 |
| **Exhaust Emission Flows/Fuel** | | | | | | | | |
| CO (g/kg fuel) | 3.24 | 2.46 | 2.41 | 4.92 | 5.11 | 4.86 | 3.6 | 0.361 |
| $CO_2$ (kg/kg fuel) | 2.69 | 2.63 | 2.83 | 2.86 | 2.52 | 2.69 | 2.7 | 0.052 |
| $NO_x$ (g/kg fuel) | 105.4 | 104.3 | 113.2 | 105.0 | 89.6 | 99.4 | 103.5 | 0.083 |
| $O_2$ (g/kg fuel) | 8.00 | 8.49 | 8.83 | 8.80 | 8.83 | 8.53 | 8.6 | 0.042 |
| $CH_4$ (g/kg fuel) | 4.26 | 4.94 | 4.95 | 41.18 | 30.65 | 38.73 | 17.2 | 1.017 |
| nmHC (g/kg fuel,C1) | 7.30 | 5.17 | 5.21 | -30.41 | -19.13 | -28.12 | -6.4 | -2.712 |
| tHC (g/kg fuel,C1) | 11.55 | 10.11 | 10.16 | 10.77 | 11.52 | 10.61 | 10.8 | 0.065 |
| PM (g/kg fuel) - TEOM | 0.19 | 0.17 | 0.23 | 0.15 | 0.15 | 0.11 | 0.18 | 0.208 |

**Table 4-2: 800 RPM 25% load baseline emissions**

| Label: | E1 | E2 | E3 | E4 | E5 | E6 |
|---|---|---|---|---|---|---|
| Date: | 10-Apr-02 | 10-Apr-02 | 10-Apr-02 | 10-Apr-02 | 10-Apr-02 | 10-Apr-02 |
| Time: | 12:29:19 | 12:35:02 | 12:42:23 | 12:49:00 | 12:56:29 | 13:04:01 |
| **Engine Parameters** | | | | | | |
| Speed(RPM) | 809.0 | 808.3 | 805.2 | 805.3 | 802.9 | 797.5 |
| Load(%) | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| Indicated Power (kW) | 8.8 | 8.7 | 8.1 | 8.4 | 8.2 | 8.4 |
| IMEP (bar) | 5.25 | 5.20 | 4.80 | 4.98 | 4.88 | 5.04 |
| Pmax(bar) | 97.11 | 96.90 | 95.30 | 95.72 | 95.34 | 97.12 |
| Pmax location (degrees) | 366.0 | 365.9 | 365.7 | 365.9 | 366.0 | 365.8 |
| Diesel Flow(kg/hr) | 0.155 | 0.241 | 0.136 | 0.170 | 0.146 | 0.147 |
| CNG Flow(kg/hr) | 1.23 | 1.21 | 1.20 | 1.19 | 1.17 | 1.16 |
| Air Flow(kg/hr) | 73.4 | 73.5 | 73.5 | 73.7 | 73.8 | 73.2 |
| Exhaust Flow(kg/hr) | 74.7 | 74.9 | 74.9 | 75.1 | 75.1 | 74.5 |
| Exhaust Back Pressure (kPa) | 11.9 | 11.3 | 11.5 | 11.2 | 11.1 | 31.1 |
| EGR Fraction(%) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Exhaust Emission Flows** | | | | | | |
| CO (g/hr) | 6.1 | 5.5 | 5.6 | 4.8 | 5.3 | 7.0 |
| $CO_2$ (kg/hr) | 3.9 | 4.0 | 3.7 | 3.8 | 3.6 | 3.4 |
| $NO_x$ (g/hr) | 139.7 | 142.0 | 129.1 | 132.7 | 125.2 | 118.3 |
| $O_2$ (kg/hr) | 11.5 | 11.5 | 11.8 | 11.7 | 12.0 | 12.1 |
| $CH_4$ (g/hr) | 4.7 | 4.5 | 4.8 | 4.4 | 4.7 | 7.6 |
| nmHC (g/hr,C1) | 8.5 | 8.1 | 8.4 | 7.7 | 8.4 | 13.5 |
| tHC (g/hr,C1) | 13.2 | 12.6 | 13.2 | 12.0 | 13.1 | 21.1 |
| PM (g/hr) - TEOM [corrected] | 0.818 | 1.093 | 0.658 | 0.626 | 0.499 | 0.539 |
| **Exhaust Emission Flows/Fuel** | | | | | | |
| CO (g/kg fuel) | 4.42 | 3.77 | 4.17 | 3.54 | 3.99 | 5.35 |
| $CO_2$ (kg/kg fuel) | 2.78 | 2.74 | 2.75 | 2.83 | 2.76 | 2.61 |
| $NO_x$ (g/kg fuel) | 100.80 | 97.65 | 96.44 | 97.78 | 95.14 | 90.52 |
| $O_2$ (g/kg fuel) | 8.32 | 7.90 | 8.82 | 8.63 | 9.09 | 9.27 |
| $CH_4$ (g/kg fuel) | 3.40 | 3.08 | 3.58 | 3.20 | 3.58 | 5.84 |
| nmHC (g/kg fuel,C1) | 6.10 | 5.57 | 6.30 | 5.66 | 6.38 | 10.30 |
| tHC (g/kg fuel,C1) | 9.50 | 8.65 | 9.88 | 8.87 | 9.96 | 16.13 |
| PM (g/kg fuel) - TEOM [corrected] | 0.59 | 0.75 | 0.49 | 0.46 | 0.38 | 0.41 |
| **Dilution System Parameters** | | | | | | |
| Exhaust Temp - manifold (C) | 228.3 | 230.0 | 219.5 | 220.6 | 212.9 | 227.3 |
| Exhaust Temp - sample inlet (C) | 167.5 | 162.4 | 158.5 | 155.0 | 153.2 | 168.0 |
| Dilution Air Temp (C) | 14.6 | 16.2 | 16.2 | 16.3 | 16.6 | 16.4 |
| Filter Temp (C) | 43.9 | 42.5 | 41.3 | 40.4 | 39.8 | 39.2 |
| Sample $CO_2$ (%) | 0.33 | 0.33 | 0.29 | 0.29 | 0.28 | 0.27 |
| Dilution Ratio - $CO_2$ | 11.7 | 12.3 | 13.0 | 13.4 | 13.5 | 13.4 |

**Table 4-3: 800 RPM 25% load – BP/DPW data summaries (I)**

| Label: | E7 | E8 | E9 | E10 | E11 | E12 | E13 |
|---|---|---|---|---|---|---|---|
| Date: | 10-Apr-02 | 10-Apr-02 | 10-Apr-02 | 10-Apr-02 | 10-Apr-02 | 10-Apr-02 | 10-Apr-02 |
| Time: | 13:11:28 | 13:18:54 | 13:33:57 | 13:41:19 | 13:48:22 | 13:55:41 | 14:08:14 |
| **Engine Parameters** | | | | | | | |
| Speed(RPM) | 797.0 | 793.4 | 800.1 | 798.9 | 798.6 | 799.7 | 801.4 |
| Load(%) | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| Indicated Power (kW) | 8.3 | 7.8 | 10.0 | 10.2 | 9.8 | 10.2 | 10.0 |
| IMEP (bar) | 4.99 | 4.75 | 5.99 | 6.11 | 5.91 | 6.13 | 6.00 |
| Pmax(bar) | 96.47 | 95.29 | 99.98 | 100.52 | 99.83 | 100.07 | 99.41 |
| Pmax location (degrees) | 365.8 | 365.9 | 366.2 | 366.4 | 366.3 | 366.4 | 366.2 |
| Diesel Flow(kg/hr) | 0.158 | 0.142 | 0.129 | 0.205 | 0.145 | 0.178 | 0.137 |
| CNG Flow(kg/hr) | 1.15 | 1.13 | 1.40 | 1.41 | 1.42 | 1.42 | 1.43 |
| Air Flow(kg/hr) | 73.7 | 73.1 | 60.4 | 60.0 | 59.9 | 59.8 | 72.8 |
| Exhaust Flow(kg/hr) | 75.0 | 74.4 | 61.9 | 61.6 | 61.4 | 61.4 | 74.4 |
| Exhaust Back Pressure (kPa) | 10.1 | 38.8 | 26.9 | 27.2 | 27.3 | 27.4 | 12.3 |
| EGR Fraction(%) | 0.0 | 0.0 | 14.9 | 14.2 | 14.9 | 14.3 | 0.0 |
| **Exhaust Emission Flows** | | | | | | | |
| CO (g/hr) | 5.4 | 6.9 | 7.5 | 7.0 | 7.4 | 7.2 | 4.9 |
| $CO_2$ (kg/hr) | 3.6 | 3.2 | 4.3 | 4.5 | 4.2 | 4.4 | 4.4 |
| $NO_x$ (g/hr) | 124.4 | 108.2 | 84.1 | 86.9 | 80.5 | 78.9 | 151.2 |
| $O_2$ (kg/hr) | 12.1 | 12.3 | 8.2 | 7.9 | 8.1 | 7.9 | 10.8 |
| $CH_4$ (g/hr) | 5.2 | 8.0 | 9.5 | 9.3 | 9.9 | 11.0 | 4.0 |
| nmHC (g/hr,C1) | 9.2 | 13.5 | 15.6 | 14.8 | 15.9 | 17.2 | 7.1 |
| tHC (g/hr,C1) | 14.4 | 21.5 | 25.1 | 24.1 | 25.8 | 28.3 | 11.1 |
| PM (g/hr) - TEOM [corrected] | 0.484 | 0.610 | 0.631 | 0.625 | 0.600 | 0.612 | 0.633 |
| **Exhaust Emission Flows/Fuel** | | | | | | | |
| CO (g/kg fuel) | 4.15 | 5.40 | 4.90 | 4.35 | 4.76 | 4.47 | 3.11 |
| $CO_2$ (kg/kg fuel) | 2.73 | 2.53 | 2.79 | 2.77 | 2.72 | 2.76 | 2.82 |
| $NO_x$ (g/kg fuel) | 95.05 | 84.74 | 54.96 | 53.95 | 51.60 | 49.26 | 96.51 |
| $O_2$ (g/kg fuel) | 9.22 | 9.66 | 5.35 | 4.91 | 5.19 | 4.94 | 6.91 |
| $CH_4$ (g/kg fuel) | 3.95 | 6.24 | 6.19 | 5.74 | 6.37 | 6.89 | 2.57 |
| nmHC (g/kg fuel,C1) | 7.04 | 10.59 | 10.20 | 9.21 | 10.19 | 10.76 | 4.50 |
| tHC (g/kg fuel,C1) | 10.99 | 16.84 | 16.40 | 14.95 | 16.56 | 17.65 | 7.07 |
| PM (g/kg fuel) - TEOM [corrected] | 0.37 | 0.48 | 0.41 | 0.39 | 0.38 | 0.38 | 0.40 |
| **Dilution System Parameters** | | | | | | | |
| Exhaust Temp - manifold (C) | 212.4 | 229.5 | 258.9 | 265.6 | 259.0 | 266.6 | 250.9 |
| Exhaust Temp - sample inlet (C) | 159.8 | 168.9 | 183.9 | 194.5 | 196.6 | 197.0 | 178.2 |
| Dilution Air Temp (C) | 16.5 | 16.6 | 16.8 | 17.5 | 17.5 | 17.4 | 17.2 |
| Filter Temp (C) | 38.9 | 38.6 | 38.1 | 38.4 | 38.7 | 39.0 | 39.3 |
| Sample $CO_2$ (%) | 0.27 | 0.25 | 0.40 | 0.41 | 0.38 | 0.40 | 0.34 |
| Dilution Ratio - $CO_2$ | 13.6 | 14.1 | 12.7 | 13.1 | 13.3 | 13.1 | 13.2 |

**Table 4-4: 800 RPM 25% load – BP/DPW data summaries (II)**

| Label: | A5 | A6 | A7 | A8 | A9 |
|---|---|---|---|---|---|
| Date: | 6-Mar-02 | 6-Mar-02 | 6-Mar-02 | 6-Mar-02 | 6-Mar-02 |
| Time: | 12:24:34 | 12:47:31 | 15:07:01 | 15:16:05 | 15:45:07 |
| **Engine Parameters** | | | | | |
| Speed(RPM) | 799.4 | 795.5 | 785.3 | 790.8 | 791.7 |
| Load(%) | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| Indicated Power (kW) | 8.4 | 8.3 | 8.0 | 8.0 | 8.4 |
| IMEP (bar) | 5.1 | 5.0 | 4.9 | 4.8 | 5.1 |
| Pmax(bar) | 96.1 | 95.4 | 95.2 | 96.0 | 96.8 |
| Pmax location (degrees) | 365.9 | 365.6 | 365.9 | 365.5 | 365.7 |
| Diesel Flow(kg/hr) | 0.158 | 0.158 | 0.165 | 0.165 | 0.165 |
| CNG Flow(kg/hr) | 1.24 | 1.21 | 1.15 | 1.16 | 1.20 |
| Air Flow(kg/hr) | 71.8 | 64.1 | 56.4 | 71.9 | 63.1 |
| Exhaust Flow(kg/hr) | 73.2 | 65.5 | 57.7 | 73.2 | 64.5 |
| Exhaust Back Pressure (kPa) | 14.3 | 23.1 | 27.2 | 14.2 | 23.2 |
| EGR Fraction(%) | 0.0 | 9.2 | 23.8 | 0.0 | 11.3 |
| **Exhaust Emission Flows** | | | | | |
| CO (g/hr) | 4.54 | 5.56 | 6.11 | 3.36 | 4.48 |
| $CO_2$ (kg/hr) | 3.8 | 3.6 | 3.5 | 3.6 | 3.7 |
| $NO_x$ (g/hr) | 147.77 | 100.79 | 68.61 | 142.41 | 105.32 |
| $O_2$ (kg/hr) | 11.21 | 9.72 | 8.19 | 11.59 | 9.50 |
| $CH_4$ (g/hr) | 5.97 | 8.96 | 13.13 | 6.75 | 9.19 |
| nmHC (g/hr,C1) | 10.23 | 15.02 | 8.69 | 7.06 | 10.79 |
| tHC (g/hr,C1) | 16.20 | 23.98 | 21.82 | 13.82 | 19.98 |
| PM (g/hr) - TEOM [corrected] | 0.27 | 0.35 | 0.14 | 0.23 | 0.29 |
| **Exhaust Emission Flows/Fuel** | | | | | |
| CO (g/kg fuel) | 3.24 | 4.07 | 4.64 | 2.54 | 3.28 |
| $CO_2$ (kg/kg fuel) | 2.69 | 2.64 | 2.67 | 2.71 | 2.69 |
| $NO_x$ (g/kg fuel) | 105.37 | 73.79 | 52.14 | 107.59 | 77.04 |
| $O_2$ (g/kg fuel) | 8.00 | 7.11 | 6.22 | 8.76 | 6.95 |
| $CH_4$ (g/kg fuel) | 4.26 | 6.56 | 9.98 | 5.10 | 6.72 |
| nmHC (g/kg fuel,C1) | 7.30 | 11.00 | 6.60 | 5.34 | 7.89 |
| tHC (g/kg fuel,C1) | 11.55 | 17.55 | 16.58 | 10.44 | 14.62 |
| PM (g/kg fuel) - TEOM [corrected] | 0.19 | 0.25 | 0.11 | 0.17 | 0.21 |
| **Dilution System Parameters** | | | | | |
| Exhaust Temp - manifold (C) | 239.5 | 245.6 | 243.4 | 231.6 | 246.4 |
| Exhaust Temp - sample inlet (C) | 194.2 | 182.2 | 182.0 | 166.2 | 181.2 |
| Dilution Air Temp (C) | 10.3 | 12.7 | 13.4 | 13.0 | 12.7 |
| Filter Temp (C) | 37.8 | 37.0 | 43.1 | 41.3 | 37.0 |
| Sample $CO_2$ (%) | 0.31 | 0.32 | 0.39 | 0.31 | 0.35 |
| Dilution Ratio – $CO_2$ | 12.9 | 12.9 | 11.4 | 12.0 | 12.2 |

**Table 4-5: Data summaries for 800 RPM 25% load tests (I)**

| Label: | A10 | A25 | A26 | A27 | A28 | A29 |
|---|---|---|---|---|---|---|
| Date: | 6-Mar-02 | 7-Mar-02 | 7-Mar-02 | 7-Mar-02 | 7-Mar-02 | 7-Mar-02 |
| Time: | 15:59:31 | 14:06:02 | 14:23:31 | 14:35:00 | 14:47:30 | 14:55:26 |
| **Engine Parameters** | | | | | | |
| Speed(RPM) | 797.5 | 805.0 | 797.1 | 795.2 | 799.7 | 800.2 |
| Load(%) | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 | 25.0 |
| Indicated Power (kW) | 8.4 | 8.8 | 8.3 | 34.1 | 8.0 | 8.6 |
| IMEP (bar) | 5.1 | 5.2 | 4.99 | 20.6 | 4.8 | 5.2 |
| Pmax(bar) | 97.1 | 96.4 | 96.33 | 95.5 | 94.2 | 96.2 |
| Pmax location (degrees) | 365.7 | 365.8 | 366.0 | 390.5 | 365.9 | 365.9 |
| Diesel Flow(kg/hr) | 0.165 | 0.149 | 0.166 | 0.149 | 0.149 | 0.208 |
| CNG Flow(kg/hr) | 1.22 | 1.23 | 1.15 | 1.14 | 1.13 | 1.11 |
| Air Flow(kg/hr) | 72.7 | 73.4 | 57.1 | 65.5 | 73.3 | 73.4 |
| Exhaust Flow(kg/hr) | 74.1 | 74.8 | 58.4 | 66.8 | 74.6 | 74.7 |
| Exhaust Back Pressure (kPa) | 10.2 | 9.6 | 27.0 | 36.1 | 10.7 | 10.8 |
| EGR Fraction(%) | 0.0 | 0.0 | 22.1 | 9.8 | 0.0 | 0.0 |
| **Exhaust Emission Flows** | | | | | | |
| CO (g/hr) | 3.17 | 6.51 | 9.3 | 8.91 | 6.98 | 6.74 |
| $CO_2$ (kg/hr) | 3.7 | 3.8 | 3.5 | 3.4 | 3.4 | 3.7 |
| $NO_x$ (g/hr) | 148.94 | 138.91 | 60.2 | 93.07 | 122.44 | 137.76 |
| $O_2$ (kg/hr) | 11.62 | 11.65 | 8.3 | 10.40 | 12.07 | 11.82 |
| $CH_4$ (g/hr) | 6.51 | 54.50 | 5.4 | 24.80 | 41.90 | 53.69 |
| nmHC (g/hr,C1) | 6.86 | -40.25 | 26.2 | 1.14 | -26.15 | -38.98 |
| tHC (g/hr,C1) | 13.37 | 14.25 | 31.6 | 25.94 | 15.74 | 14.71 |
| PM (g/hr) - TEOM [corrected] | 0.31 | 0.19 | 0.164 | 0.22 | 0.20 | 0.15 |
| **Exhaust Emission Flows/Fuel** | | | | | | |
| CO (g/kg fuel) | 2.29 | 4.72 | 7.03 | 6.89 | 5.45 | 5.11 |
| $CO_2$ (kg/kg fuel) | 2.69 | 2.74 | 2.68 | 2.60 | 2.69 | 2.83 |
| $NO_x$ (g/kg fuel) | 107.44 | 100.66 | 45.71 | 71.97 | 95.49 | 104.55 |
| $O_2$ (g/kg fuel) | 8.38 | 8.44 | 6.29 | 8.04 | 9.41 | 8.97 |
| $CH_4$ (g/kg fuel) | 4.70 | 39.49 | 4.10 | 19.18 | 32.67 | 40.75 |
| nmHC (g/kg fuel,C1) | 4.95 | -29.16 | 19.93 | 0.88 | -20.40 | -29.59 |
| tHC (g/kg fuel,C1) | 9.64 | 10.33 | 24.03 | 20.06 | 12.28 | 11.16 |
| PM (g/kg fuel) - TEOM [corrected] | 0.22 | 0.14 | 0.12 | 0.17 | 0.16 | 0.12 |
| **Dilution System Parameters** | | | | | | |
| Exhaust Temp - manifold (C) | 236.7 | 233.3 | 230.7 | 239.5 | 219.0 | 225.0 |
| Exhaust Temp - sample inlet (C) | 163.2 | 193.1 | 181.0 | 182.5 | 165.9 | 158.8 |
| Dilution Air Temp (C) | 13.1 | 12.4 | 13.7 | 14.2 | 14.6 | 14.2 |
| Filter Temp (C) | 37.1 | 38.5 | 36.8 | 36.8 | 37.0 | 36.9 |
| Sample $CO_2$ (%) | 0.31 | 0.33 | 0.57 | 0.33 | 0.30 | 0.31 |
| Dilution Ratio – $CO_2$ | 12.2 | 11.7 | 7.5 | 11.6 | 11.7 | 12.2 |

**Table 4-6: Data summaries for 800 RPM 25% load tests (II)**

| | A1 | A4 | A20 | A24 | C3 | C13 | A23 | | |
|---|---|---|---|---|---|---|---|---|---|
| Date: | 6-Mar-02 | 6-Mar-02 | 7-Mar-02 | 7-Mar-02 | 9-Apr-02 | 9-Apr-02 | 7-Mar-02 | | |
| Time: | 11:18:17 | 12:10:02 | 12:53:49 | 13:51:00 | 10:23:51 | 12:02:18 | 13:42:00 | AVG | COV |
| **Engine Parameters** | | | | | | | | | |
| Speed(RPM) | 802.5 | 801.5 | 810.5 | 810.1 | 805.9 | 805.4 | 808.1 | 806.7 | 0.005 |
| Load(%) | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 0.000 |
| Indicated Power (kW) | 24.1 | 19.0 | 19.0 | 19.2 | 19.1 | 18.9 | 19.1 | 19.1 | 0.006 |
| IMEP (bar) | 14.4 | 11.4 | 11.3 | 11.4 | 11.4 | 11.3 | 11.4 | 11.4 | 0.006 |
| Pmax(bar) | 131.7 | 130.8 | 129.9 | 131.1 | 129.6 | 129.7 | 130.8 | 130.2 | 0.005 |
| Pmax location (degrees) | 371.5 | 368.4 | 368.7 | 368.5 | 368.5 | 368.5 | 368.5 | 368.5 | 0.000 |
| Diesel Flow(kg/hr) | 0.17 | 0.17 | 0.18 | 0.18 | 0.16 | 0.16 | 0.18 | 0.17 | 0.060 |
| CNG Flow(kg/hr) | 2.94 | 2.91 | 2.89 | 2.92 | 2.92 | 2.93 | 2.90 | 2.9 | 0.005 |
| Air Flow(kg/hr) | 91.3 | 91.0 | 92.1 | 93.4 | 89.2 | 92.3 | 92.8 | 91.6 | 0.017 |
| Exhaust Flow(kg/hr) | 94.4 | 94.1 | 95.2 | 96.6 | 92.3 | 95.3 | 95.9 | 94.7 | 0.017 |
| Exhaust Back Pressure (kPa) | 10.9 | 11.5 | 11.3 | 12.7 | 10.4 | 13.1 | **48.2** | 11.8 | 0.092 |
| EGR Fraction(%) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | N/A |
| **Exhaust Emission Flows** | | | | | | | | | |
| CO (g/hr) | 82.9 | 77.4 | 70.2 | 76.7 | 67.0 | 62.3 | 40.28 | 72.8 | 0.104 |
| $CO_2$ (kg/hr) | 8.83 | 8.75 | 8.84 | 8.91 | 8.57 | 8.75 | 8.90 | 8.8 | 0.014 |
| $NO_x$ (g/hr) | 208.06 | 203.89 | 205.82 | 200.72 | 191.13 | 187.24 | 198.21 | 199.5 | 0.042 |
| $O_2$ (kg/hr) | 8.59 | 8.65 | 9.00 | 9.16 | 8.88 | 9.37 | 9.09 | 8.9 | 0.033 |
| $CH_4$ (g/hr) | 5.78 | 5.90 | 92.95 | 88.25 | 3.80 | 4.32 | 86.55 | 33.5 | 1.321 |
| nmHC (g/hr,C1) | 9.34 | 10.83 | -81.46 | -73.81 | 9.35 | 8.71 | -70.42 | -19.5 | -2.312 |
| tHC (g/hr,C1) | 15.12 | 16.73 | 11.49 | 14.44 | 13.15 | 13.03 | 16.13 | 14.0 | 0.131 |
| PM (g/hr) - TEOM | 0.76 | 0.46 | 0.47 | 0.30 | 0.26 | 0.27 | 0.34 | 0.35 | 0.294 |
| **Exhaust Emission Flows/Fuel** | | | | | | | | | |
| CO (g/kg fuel) | 26.62 | 25.08 | 22.49 | 24.86 | 21.84 | 20.11 | 12.93 | 23.5 | 0.103 |
| $CO_2$ (kg/kg fuel) | 2.83 | 2.84 | 2.83 | 2.89 | 2.79 | 2.82 | 2.86 | 2.8 | 0.011 |
| $NO_x$ (g/kg fuel) | 66.77 | 66.08 | 65.88 | 65.04 | 62.26 | 60.41 | 63.65 | 64.4 | 0.039 |
| $O_2$ (g/kg fuel) | 2.76 | 2.80 | 2.88 | 2.97 | 2.89 | 3.02 | 2.92 | 2.9 | 0.034 |
| $CH_4$ (g/kg fuel) | 1.86 | 1.91 | 29.75 | 28.60 | 1.24 | 1.39 | 27.79 | 10.8 | 1.320 |
| nmHC (g/kg fuel,C1) | 3.00 | 3.51 | -26.07 | -23.92 | 3.05 | 2.81 | -22.61 | -6.3 | -2.316 |
| tHC (g/kg fuel,C1) | 4.85 | 5.42 | 3.68 | 4.68 | 4.28 | 4.20 | 5.18 | 4.5 | 0.133 |
| PM (g/kg fuel) - TEOM | 0.24 | 0.15 | 0.15 | 0.10 | 0.08 | 0.09 | 0.11 | 0.11 | 0.290 |

**Table 4-7: 800 RPM 75% load baseline emissions**

| Label: | C1 | C2 | C3 | C4 | C5 | C6 | C7 |
|---|---|---|---|---|---|---|---|
| Date: | 9-Apr-02 | 9-Apr-02 | 9-Apr-02 | 9-Apr-02 | 9-Apr-02 | 9-Apr-02 | 9-Apr-02 |
| Time: | 10:23:51 | 10:34:31 | 10:42:28 | 10:49:30 | 10:55:53 | 11:03:18 | 11:10:07 |
| **Engine Parameters** | | | | | | | |
| Speed(RPM) | 805.9 | 805.1 | 804.5 | 804.9 | 804.7 | 800.8 | 806.5 |
| Load(%) | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 |
| Indicated Power (kW) | 19.1 | 19.2 | 18.9 | 19.2 | 19.1 | 19.1 | 19.1 |
| IMEP (bar) | 11.4 | 11.4 | 11.3 | 11.4 | 11.4 | 11.4 | 11.4 |
| Pmax(bar) | 129.6 | 129.9 | 129.0 | 129.7 | 129.4 | 130.6 | 129.6 |
| Pmax location (degrees) | 368.5 | 368.5 | 368.5 | 368.3 | 368.5 | 368.5 | 368.5 |
| Diesel Flow(kg/hr) | 0.164 | 0.176 | 0.150 | 0.157 | 0.163 | 0.158 | 0.176 |
| CNG Flow(kg/hr) | 2.92 | 2.92 | 2.93 | 2.91 | 2.93 | 2.91 | 2.93 |
| Air Flow(kg/hr) | 89.2 | 89.5 | 89.4 | 89.5 | 89.4 | 87.9 | 89.4 |
| Exhaust Flow(kg/hr) | 92.3 | 92.5 | 92.5 | 92.6 | 92.5 | 91.0 | 92.5 |
| Exhaust Back Pressure (kPa) | 10.4 | 10.7 | 10.7 | 10.8 | 10.8 | 69.9 | 10.1 |
| EGR Fraction(%) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Exhaust Emission Flows** | | | | | | | |
| CO (g/hr) | 67.04 | 74.66 | 63.98 | 80.80 | 76.43 | 33.74 | 79.23 |
| $CO_2$ (kg/hr) | 8.57 | 8.62 | 8.53 | 8.62 | 8.62 | 8.46 | 8.65 |
| $NO_x$ (g/hr) | 191.13 | 190.64 | 191.31 | 188.29 | 187.34 | 185.35 | 188.47 |
| $O_2$ (kg/hr) | 8.88 | 8.89 | 8.99 | 8.92 | 8.87 | 8.81 | 8.84 |
| $CH_4$ (g/hr) | 3.80 | 3.99 | 3.87 | 3.95 | 3.98 | 6.06 | 3.91 |
| nmHC (g/hr,C1) | 9.35 | 9.91 | 9.45 | 9.68 | 9.00 | 11.88 | 8.46 |
| tHC (g/hr,C1) | 13.15 | 13.90 | 13.32 | 13.63 | 12.98 | 17.94 | 12.37 |
| PM (g/hr) - TEOM [corrected] | 0.26 | 0.28 | 0.24 | 0.23 | 0.22 | 0.40 | 0.19 |
| **Exhaust Emission Flows/Fuel** | | | | | | | |
| CO (g/kg fuel) | 21.76 | 24.15 | 20.75 | 26.34 | 24.71 | 11.01 | 25.47 |
| $CO_2$ (kg/kg fuel) | 2.78 | 2.79 | 2.77 | 2.81 | 2.79 | 2.76 | 2.78 |
| $NO_x$ (g/kg fuel) | 62.02 | 61.65 | 62.06 | 61.38 | 60.57 | 60.47 | 60.58 |
| $O_2$ (g/kg fuel) | 2.88 | 2.88 | 2.92 | 2.91 | 2.87 | 2.87 | 2.84 |
| $CH_4$ (g/kg fuel) | 1.23 | 1.29 | 1.26 | 1.29 | 1.29 | 1.98 | 1.26 |
| nmHC (g/kg fuel,C1) | 3.03 | 3.21 | 3.06 | 3.15 | 2.91 | 3.88 | 2.72 |
| tHC (g/kg fuel,C1) | 4.27 | 4.50 | 4.32 | 4.44 | 4.20 | 5.85 | 3.98 |
| PM (g/kg fuel) - TEOM [corrected] | 0.08 | 0.09 | 0.08 | 0.07 | 0.07 | 0.13 | 0.06 |
| **Dilution System Parameters** | | | | | | | |
| Exhaust Temp - manifold (C) | 372.7 | 375.2 | 371.2 | 374.5 | 374.4 | 420.2 | 376.2 |
| Exhaust Temp - sample inlet (C) | 181.8 | 226.8 | 236.2 | 238.9 | 241.0 | 304.3 | 278.2 |
| Dilution Air Temp (C) | 21.5 | 20.6 | 19.2 | 17.5 | 16.0 | 15.1 | 13.6 |
| Filter Temp (C) | 46.0 | 44.3 | 42.1 | 40.6 | 39.3 | 38.0 | 37.5 |
| Sample $CO_2$ (%) | 0.51 | 0.47 | 0.43 | 0.49 | 0.47 | 0.30 | 0.52 |
| Dilution Ratio - $CO_2$ | 12.9 | 14.1 | 15.3 | 13.5 | 14.0 | 23.6 | 12.8 |

**Table 4-8: 800 RPM 75% load – BP/DPW emissions (I)**

| Label: | C8 | C9 | C10 | C11 | C12 | C13 |
|---|---|---|---|---|---|---|
| Date: | 9-Apr-02 | 9-Apr-02 | 9-Apr-02 | 9-Apr-02 | 9-Apr-02 | 9-Apr-02 |
| Time: | 11:18:58 | 11:33:09 | 11:39:35 | 11:46:33 | 11:53:43 | 12:02:18 |
| **Engine Parameters** | | | | | | |
| Speed(RPM) | 804.2 | 802.1 | 802.2 | 800.8 | 800.8 | 805.4 |
| Load(%) | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 |
| Indicated Power (kW) | 19.1 | 18.8 | 18.7 | 18.6 | 18.8 | 18.9 |
| IMEP (bar) | 11.4 | 11.3 | 11.2 | 11.1 | 11.2 | 11.3 |
| Pmax(bar) | 130.0 | 128.4 | 127.8 | 128.7 | 128.4 | 129.7 |
| Pmax location (degrees) | 368.6 | 368.5 | 368.5 | 368.4 | 368.4 | 368.5 |
| Diesel Flow(kg/hr) | 0.170 | 0.181 | 0.210 | 0.172 | 0.189 | 0.157 |
| CNG Flow(kg/hr) | 2.92 | 2.91 | 2.89 | 2.92 | 2.91 | 2.93 |
| Air Flow(kg/hr) | 88.3 | 73.6 | 73.4 | 73.5 | 73.6 | 92.3 |
| Exhaust Flow(kg/hr) | 91.4 | 76.6 | 76.5 | 76.6 | 76.7 | 95.3 |
| Exhaust Back Pressure (kPa) | 58.5 | 72.0 | 72.7 | 72.5 | 72.6 | 13.1 |
| EGR Fraction(%) | 0.0 | 16.9 | 16.7 | 16.9 | 16.8 | 0.0 |
| **Exhaust Emission Flows** | | | | | | |
| CO (g/hr) | 38.45 | 116.12 | 154.91 | 113.94 | 127.07 | 62.35 |
| $CO_2$ (kg/hr) | 8.56 | 8.29 | 8.38 | 8.26 | 8.32 | 8.75 |
| $NO_x$ (g/hr) | 186.30 | 59.01 | 54.75 | 55.40 | 56.79 | 187.24 |
| $O_2$ (kg/hr) | 8.78 | 5.63 | 5.47 | 5.64 | 5.59 | 9.37 |
| $CH_4$ (g/hr) | 5.40 | 9.76 | 10.22 | 9.95 | 9.77 | 4.32 |
| nmHC (g/hr,C1) | 10.42 | 15.77 | 17.03 | 16.47 | 16.00 | 8.71 |
| tHC (g/hr,C1) | 15.82 | 25.53 | 27.25 | 26.42 | 25.77 | 13.03 |
| PM (g/hr) - TEOM [corrected] | 0.21 | 0.53 | 0.84 | 0.56 | 0.68 | 0.27 |
| **Exhaust Emission Flows/Fuel** | | | | | | |
| CO (g/kg fuel) | 12.42 | 37.62 | 49.92 | 36.90 | 41.04 | 20.21 |
| $CO_2$ (kg/kg fuel) | 2.77 | 2.68 | 2.70 | 2.68 | 2.69 | 2.83 |
| $NO_x$ (g/kg fuel) | 60.20 | 19.12 | 17.64 | 17.94 | 18.34 | 60.69 |
| $O_2$ (g/kg fuel) | 2.84 | 1.82 | 1.76 | 1.83 | 1.80 | 3.04 |
| $CH_4$ (g/kg fuel) | 1.75 | 3.16 | 3.29 | 3.22 | 3.16 | 1.40 |
| nmHC (g/kg fuel,C1) | 3.37 | 5.11 | 5.49 | 5.33 | 5.17 | 2.82 |
| tHC (g/kg fuel,C1) | 5.11 | 8.27 | 8.78 | 8.56 | 8.32 | 4.22 |
| PM (g/kg fuel) - TEOM [corrected] | 0.07 | 0.17 | 0.27 | 0.18 | 0.22 | 0.09 |
| **Dilution System Parameters** | | | | | | |
| Exhaust Temp - manifold (C) | 414.2 | 423.0 | 427.8 | 423.0 | 425.7 | 370.5 |
| Exhaust Temp - sample inlet (C) | 302.8 | 328.7 | 334.3 | 334.4 | 334.2 | 281.4 |
| Dilution Air Temp (C) | 12.7 | 11.2 | 12.1 | 12.5 | 12.5 | 11.9 |
| Filter Temp (C) | 37.3 | 37.2 | 38.1 | 39.0 | 40.1 | 40.6 |
| Sample $CO_2$ (%) | 0.51 | 0.62 | 0.62 | 0.62 | 0.63 | 0.55 |
| Dilution Ratio - $CO_2$ | 13.1 | 12.2 | 12.2 | 12.0 | 11.9 | 11.7 |

**Table 4-9: 800 RPM 75% load – BP/DPW emissions (II)**

| Label: | A1 | A2 | A3 | A4 | A20 | A21 | A22 | A23 | A24 |
|---|---|---|---|---|---|---|---|---|---|
| Date: | 6-Mar-02 | 6-Mar-02 | 6-Mar-02 | 6-Mar-02 | 7-Mar-02 | 7-Mar-02 | 7-Mar-02 | 7-Mar-02 | 7-Mar-02 |
| Time: | 11:18:17 | 11:36:30 | 11:52:09 | 12:10:02 | 12:53:49 | 13:16:59 | 13:30:30 | 13:42:00 | 13:51:00 |
| **Engine Parameters** | | | | | | | | | |
| Speed(RPM) | 802.5 | 798.7 | 798.8 | 801.5 | 810.5 | 806.6 | 806.4 | 808.1 | 810.1 |
| Load(%) | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 | 75.0 |
| Indicated Power (kW) | 24.1 | 18.5 | 18.8 | 19.0 | 19.0 | 18.7 | 18.9 | 19.1 | 19.2 |
| IMEP (bar) | 14.4 | 11.1 | 11.3 | 11.4 | 11.3 | 11.1 | 11.3 | 11.4 | 11.4 |
| Pmax(bar) | 131.7 | 127.2 | 128.3 | 130.8 | 129.9 | 128.8 | 131.1 | 130.8 | 131.1 |
| Pmax location (degrees) | 371.5 | 368.4 | 368.4 | 368.4 | 368.7 | 368.5 | 368.4 | 368.5 | 368.5 |
| Diesel Flow(kg/hr) | 0.17 | 0.17 | 0.17 | 0.17 | 0.21 | 0.21 | 0.21 | 0.21 | 0.21 |
| CNG Flow(kg/hr) | 2.94 | 2.91 | 2.95 | 2.91 | 2.89 | 2.88 | 2.90 | 2.90 | 2.92 |
| Air Flow(kg/hr) | 91.3 | 74.0 | 80.3 | 91.0 | 92.1 | 82.0 | 76.7 | 92.8 | 93.4 |
| Exhaust Flow(kg/hr) | 94.4 | 77.1 | 83.4 | 94.1 | 95.2 | 85.1 | 79.8 | 95.9 | 96.6 |
| Exhaust Back Pressure (kPa) | 10.9 | 53.6 | 51.5 | 11.5 | 11.3 | 77.6 | 66.9 | 48.2 | 12.7 |
| EGR Fraction(%) | 0.0 | 16.5 | 8.8 | 0.0 | 0.0 | 8.7 | 17.5 | 0.0 | 0.0 |
| **Exhaust Emission Flows** | | | | | | | | | |
| CO (g/hr) | 82.94 | 187.10 | 92.44 | 77.38 | 70.25 | 62.48 | 112.70 | 40.28 | 76.71 |
| $CO_2$ (kg/hr) | 8.83 | 8.59 | 8.59 | 8.75 | 8.84 | 8.57 | 8.60 | 8.90 | 8.91 |
| $NO_x$ (g/hr) | 208.06 | 59.97 | 117.49 | 203.89 | 205.82 | 118.10 | 59.57 | 198.21 | 200.72 |
| $O_2$ (kg/hr) | 8.59 | 4.80 | 6.36 | 8.65 | 9.00 | 7.01 | 5.67 | 9.09 | 9.16 |
| $CH_4$ (g/hr) | 5.78 | 10.70 | 8.62 | 5.90 | 92.95 | 31.84 | -10.25 | 86.55 | 88.25 |
| nmHC (g/hr,C1) | 9.34 | 16.66 | 14.29 | 10.83 | -81.46 | -7.91 | 37.50 | -70.42 | -73.81 |
| tHC (g/hr,C1) | 15.12 | 27.36 | 22.91 | 16.73 | 11.49 | 23.93 | 27.25 | 16.13 | 14.44 |
| PM (g/hr) - TEOM [corrected] | 0.76 | 1.97 | 1.34 | 0.46 | 0.47 | 0.40 | 0.74 | 0.34 | 0.30 |
| **Exhaust Emission Flows/Fuel** | | | | | | | | | |
| CO (g/kg fuel) | 26.62 | 60.64 | 29.59 | 25.07 | 22.65 | 20.19 | 36.19 | 12.93 | 24.50 |
| $CO_2$ (kg/kg fuel) | 2.83 | 2.78 | 2.75 | 2.84 | 2.85 | 2.77 | 2.76 | 2.86 | 2.85 |
| $NO_x$ (g/kg fuel) | 66.77 | 19.44 | 37.61 | 66.07 | 66.37 | 38.17 | 19.13 | 63.64 | 64.12 |
| $O_2$ (g/kg fuel) | 2.76 | 1.55 | 2.04 | 2.80 | 2.90 | 2.27 | 1.82 | 2.92 | 2.93 |
| $CH_4$ (g/kg fuel) | 1.86 | 3.47 | 2.76 | 1.91 | 29.97 | 10.29 | -3.29 | 27.79 | 28.19 |
| nmHC (g/kg fuel,C1) | 3.00 | 5.40 | 4.57 | 3.51 | -26.27 | -2.56 | 12.04 | -22.61 | -23.58 |
| tHC (g/kg fuel,C1) | 4.85 | 8.87 | 7.33 | 5.42 | 3.71 | 7.73 | 8.75 | 5.18 | 4.61 |
| PM (g/kg fuel) - TEOM [corrected] | 0.24 | 0.64 | 0.43 | 0.15 | 0.15 | 0.13 | 0.24 | 0.11 | 0.10 |
| **Dilution System Parameters** | | | | | | | | | |
| Exhaust Temp - manifold (C) | 388.7 | 431.1 | 431.0 | 388.3 | 381.7 | 440.4 | 417.5 | 411.0 | 384.2 |
| Exhaust Temp - sample inlet (C) | 266.8 | 328.5 | 328.9 | 270.3 | 223.5 | 345.3 | 333.5 | 322.0 | 281.9 |
| Dilution Air Temp (C) | 11.8 | 9.3 | 9.4 | 9.9 | 11.7 | 9.8 | 10.3 | 10.5 | 11.1 |
| Filter Temp (C) | 37.5 | 35.8 | 36.2 | 37.7 | 40.5 | 36.9 | 36.4 | 37.0 | 38.2 |
| Sample $CO_2$ (%) | 0.57 | 0.64 | 0.58 | 0.53 | 0.46 | 0.53 | 0.57 | 0.50 | 0.57 |
| Dilution Ratio - $CO_2$ | 11.4 | 12.1 | 12.4 | 12.5 | 14.6 | 13.3 | 13.3 | 13.3 | 11.4 |

**Table 4-10: Data Summaries for 800 RPM 75% load tests**

| Label: | A11 | A14 | A127 | A133 | B5 | B7 | A135 | | |
|---|---|---|---|---|---|---|---|---|---|
| Date: | 7-Mar-02 | 7-Mar-02 | 8-Mar-02 | 8-Mar-02 | 8-Apr-02 | 8-Apr-02 | 8-Mar-02 | | |
| Time: | 10:17:27 | 11:03:01 | 14:16:44 | 15:14:31 | 14:03:47 | 14:23:24 | 15:27:46 | AVG | COV |
| **Engine Parameters** | | | | | | | | | |
| Speed(RPM) | 1613.7 | 1610.3 | 1611.0 | 1599.7 | 1611.8 | 1613.5 | 1605.6 | 1610.0 | 0.003 |
| Load(%) | 40.0 | 40.0 | 40.0 | 40.0 | 40.0 | 40.0 | 40.0 | 40.0 | 0.000 |
| Indicated Power (kW) | 28.2 | 28.4 | 28.7 | 28.4 | 27.4 | 27.2 | 28.7 | 28.1 | 0.021 |
| IMEP (bar) | 8.4 | 8.5 | 8.6 | 8.5 | 8.17 | 8.10 | 8.59 | 8.37 | 0.023 |
| Pmax(bar) | 106.6 | 105.7 | 109.8 | 108.6 | 106.48 | 106.26 | 108.77 | 107.2 | 0.015 |
| Pmax location (degrees) | 368.3 | 368.1 | 368.4 | 368.7 | 367.9 | 367.6 | 367.1 | 368.2 | 0.001 |
| Diesel Flow(kg/hr) | 0.32 | 0.32 | 0.26 | 0.32 | 0.30 | 0.31 | **0.46** | 0.30 | 0.080 |
| CNG Flow(kg/hr) | 3.83 | 3.84 | 3.84 | 3.82 | 3.67 | 3.64 | 3.77 | 3.8 | 0.024 |
| Air Flow(kg/hr) | 212.1 | 210.0 | 217.5 | 214.9 | 212.4 | 212.4 | 215.3 | 213.2 | 0.012 |
| Exhaust Flow(kg/hr) | 216.3 | 214.2 | 221.6 | 219.1 | 216.4 | 216.4 | 219.5 | 217.3 | 0.012 |
| Exhaust Back Pressure (kPa) | 11.1 | 11.3 | 10.9 | 11.7 | 11.8 | 11.8 | 11.6 | 11.4 | 0.035 |
| EGR Fraction(%) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | N/A |
| **Exhaust Emission Flows** | | | | | | | | | |
| CO (g/hr) | 26.98 | 26.52 | 25.40 | 30.33 | 24.8 | 24.4 | 31.7 | 26.4 | 0.082 |
| $CO_2$ (kg/hr) | 11.32 | 11.72 | 11.43 | 11.60 | 10.9 | 10.9 | 12.0 | 11.3 | 0.032 |
| $NO_x$ (g/hr) | 129.20 | 123.00 | 118.78 | 117.29 | 115.7 | 115.9 | 11.9 | 120.0 | 0.044 |
| $O_2$ (kg/hr) | 32.83 | 32.01 | 34.79 | 34.26 | 33.8 | 33.9 | 125.4 | 33.6 | 0.030 |
| $CH_4$ (g/hr) | 18.34 | -56.02 | 29.98 | 30.34 | 20.2 | 19.6 | 34.1 | 10.4 | 3.169 |
| nmHC (g/hr,C1) | 47.07 | 116.91 | 40.17 | 44.56 | 48.8 | 46.4 | 30.6 | 57.3 | 0.512 |
| tHC (g/hr,C1) | 65.41 | 60.89 | 70.15 | 74.90 | 68.9 | 66.0 | 45.5 | 67.7 | 0.070 |
| PM (g/hr) - TEOM | 0.82 | 0.82 | 1.11 | 0.57 | 0.891 | 0.876 | 76.1 | 0.8 | 0.205 |
| **Exhaust Emission Flows/Fuel** | | | | | | | | | |
| CO (g/kg fuel) | 6.49 | 6.36 | 6.13 | 7.29 | 6.06 | 5.93 | 7.75 | 6.4 | 0.077 |
| $CO_2$ (kg/kg fuel) | 2.72 | 2.81 | 2.76 | 2.79 | 2.65 | 2.65 | 2.92 | 2.7 | 0.025 |
| $NO_x$ (g/kg fuel) | 31.09 | 29.49 | 28.66 | 28.20 | 28.25 | 28.17 | 2.91 | 29.0 | 0.040 |
| $O_2$ (g/kg fuel) | 7.90 | 7.68 | 8.40 | 8.24 | 8.26 | 8.23 | 30.61 | 8.1 | 0.033 |
| $CH_4$ (g/kg fuel) | 4.41 | -13.43 | 7.24 | 7.30 | 4.93 | 4.77 | 8.32 | 2.5 | 3.127 |
| nmHC (g/kg fuel,C1) | 11.33 | 28.04 | 9.69 | 10.71 | 11.91 | 11.28 | 7.48 | 13.8 | 0.506 |
| tHC (g/kg fuel,C1) | 15.74 | 14.60 | 16.93 | 18.01 | 16.83 | 16.04 | 11.10 | 16.4 | 0.072 |
| PM (g/kg fuel) - TEOM | 0.20 | 0.20 | 0.27 | 0.14 | 0.22 | 0.21 | 18.58 | 0.20 | 0.207 |

**Table 4-11: 1600 RPM 40% load baseline emissions**

| Label: | B1 | B2 | B3 | B4 | B5 | B6 |
|---|---|---|---|---|---|---|
| Date: | 4/8/02 | 4/8/02 | 4/8/02 | 4/8/02 | 4/8/02 | 4/8/02 |
| Time: | 13:27:23 | 13:31:39 | 13:41:56 | 13:53:09 | 14:03:47 | 14:15:04 |
| **Engine Parameters** | | | | | | |
| Speed(RPM) | 1608.6 | 1618.1 | 1620.0 | 1614.8 | 1611.8 | 1562.1 |
| Load(%) | 40.0 | 40.0 | 40.0 | 40.0 | 40.0 | |
| Indicated Power (kW) | 28.1 | 27.6 | 27.6 | 27.7 | 27.4 | 34.8 |
| IMEP (bar) | 8.39 | 8.18 | 8.18 | 8.22 | 8.17 | 10.68 |
| Pmax(bar) | 107.19 | 106.62 | 106.62 | 107.10 | 106.48 | 110.77 |
| Pmax location (degrees) | 368.0 | 368.0 | 368.0 | 367.9 | 367.9 | 370.1 |
| Diesel Flow(kg/hr) | 0.27 | 0.32 | 0.25 | 0.36 | 0.30 | 0.28 |
| CNG Flow(kg/hr) | 3.67 | 3.67 | 3.65 | 3.64 | 3.67 | 3.57 |
| Air Flow(kg/hr) | 213.1 | 212.7 | 212.8 | 212.5 | 212.4 | 210.6 |
| Exhaust Flow(kg/hr) | 217.0 | 216.7 | 216.7 | 216.5 | 216.4 | 214.4 |
| Exhaust Back Pressure (kPa) | 11.9 | 11.7 | 11.8 | 11.8 | 11.8 | 106.3 |
| EGR Fraction(%) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Exhaust Emission Flows** | | | | | | |
| CO (g/hr) | 25.7 | 26.5 | 26.3 | 24.8 | 24.8 | 20.3 |
| $CO_2$ (kg/hr) | 10.8 | 10.9 | 10.7 | 11.0 | 10.9 | 10.7 |
| $NO_x$ (g/hr) | 114.8 | 115.6 | 112.0 | 118.0 | 115.7 | 125.8 |
| $O_2$ (kg/hr) | 33.9 | 33.8 | 34.1 | 33.7 | 33.8 | 33.7 |
| $CH_4$ (g/hr) | 21.3 | 21.5 | 21.3 | 20.1 | 20.2 | 13.1 |
| nmHC (g/hr,C1) | 47.1 | 48.6 | 50.8 | 49.0 | 48.8 | 36.4 |
| tHC (g/hr,C1) | 68.3 | 70.0 | 72.1 | 69.1 | 68.9 | 49.5 |
| PM (g/hr) - TEOM [corrected] | 2.161 | 1.510 | 1.093 | 1.032 | 0.891 | 1.800 |
| **Exhaust Emission Flows/Fuel** | | | | | | |
| CO (g/kg fuel) | 6.53 | 6.66 | 6.76 | 6.19 | 6.26 | 5.27 |
| $CO_2$ (kg/kg fuel) | 2.74 | 2.73 | 2.74 | 2.76 | 2.74 | 2.78 |
| $NO_x$ (g/kg fuel) | 29.15 | 29.01 | 28.72 | 29.51 | 29.17 | 32.69 |
| $O_2$ (g/kg fuel) | 8.62 | 8.49 | 8.73 | 8.42 | 8.54 | 8.75 |
| $CH_4$ (g/kg fuel) | 5.39 | 5.39 | 5.46 | 5.03 | 5.09 | 3.42 |
| nmHC (g/kg fuel,C1) | 11.95 | 12.19 | 13.03 | 12.24 | 12.30 | 9.45 |
| tHC (g/kg fuel,C1) | 17.34 | 17.58 | 18.49 | 17.27 | 17.39 | 12.87 |
| PM (g/kg fuel) - TEOM [corrected] | 0.55 | 0.38 | 0.28 | 0.26 | 0.22 | 0.47 |
| **Dilution System Parameters** | | | | | | |
| Exhaust Temp - manifold (C) | 275.0 | 277.5 | 273.6 | 277.6 | 274.1 | 315.4 |
| Exhaust Temp - sample inlet (C) | 178.5 | 194.8 | 200.4 | 201.2 | 201.9 | 260.4 |
| Dilution Air Temp (C) | 15.5 | 16.2 | 14.9 | 12.2 | 11.2 | 9.0 |
| Filter Temp (C) | 42.2 | 40.8 | 39.7 | 39.2 | 39.1 | 38.5 |
| Sample $CO_2$ (%) | 0.43 | 0.31 | 0.28 | 0.32 | 0.31 | 0.29 |
| Dilution Ratio - $CO_2$ | 8.5 | 12.3 | 13.4 | 12.0 | 12.2 | 13.3 |

**Table 4-12: 1600 RPM 40% load – BP/DPW test emissions (I)**

| Label: | B7 | B8 | B9 | B10 | B11 | B12 | B13 |
|---|---|---|---|---|---|---|---|
| Date: | 4/8/02 | 4/8/02 | 4/8/02 | 4/8/02 | 4/8/02 | 4/8/02 | 4/8/02 |
| Time: | 14:23:24 | 14:32:56 | 15:06:44 | 15:17:18 | 15:25:42 | 15:34:43 | 15:51:09 |
| **Engine Parameters** | | | | | | | |
| Speed(RPM) | 1613.5 | 1578.9 | 1573.5 | 1595.3 | 1597.2 | 1595.9 | 1606.8 |
| Load(%) | 40.0 | 40.0 | 40.0 | 40.0 | 40.0 | 40.0 | 40.0 |
| Indicated Power (kW) | 27.2 | 27.1 | 26.6 | 27.5 | 27.6 | 27.6 | 29.5 |
| IMEP (bar) | 8.10 | 8.23 | 8.11 | 8.26 | 8.29 | 8.29 | 8.80 |
| Pmax(bar) | 106.26 | 109.92 | 107.34 | 108.33 | 106.49 | 106.75 | 95.64 |
| Pmax location (degrees) | 367.6 | 367.8 | 369.4 | 368.1 | 369.1 | 368.8 | 370.0 |
| Diesel Flow(kg/hr) | 0.31 | 0.27 | 0.27 | 0.38 | 0.32 | 0.36 | 0.30 |
| CNG Flow(kg/hr) | 3.64 | 3.63 | 3.58 | 3.64 | 3.70 | 3.65 | 3.61 |
| Air Flow(kg/hr) | 212.4 | 210.9 | 166.7 | 166.3 | 166.2 | 166.2 | 185.3 |
| Exhaust Flow(kg/hr) | 216.4 | 214.8 | 170.5 | 170.4 | 170.3 | 170.2 | 189.2 |
| Exhaust Back Pressure (kPa) | 11.8 | 103.9 | 131.7 | 132.7 | 133.1 | 133.1 | 11.0 |
| EGR Fraction(%) | 0.0 | 0.0 | 17.7 | 16.7 | 16.9 | 16.6 | 0.0 |
| **Exhaust Emission Flows** | | | | | | | |
| CO (g/hr) | 24.4 | 20.2 | 29.3 | 25.6 | 27.8 | 25.7 | 22.1 |
| $CO_2$ (kg/hr) | 10.9 | 10.9 | 10.4 | 11.0 | 10.9 | 11.0 | 11.0 |
| $NO_x$ (g/hr) | 115.9 | 126.3 | 54.0 | 53.3 | 51.2 | 52.1 | 119.4 |
| $O_2$ (kg/hr) | 33.9 | 33.5 | 24.3 | 23.6 | 23.7 | 23.6 | 28.0 |
| $CH_4$ (g/hr) | 19.6 | 13.2 | 37.7 | 36.5 | 38.6 | 37.1 | 14.4 |
| nmHC (g/hr,C1) | 46.4 | 37.6 | 73.6 | 70.7 | 75.4 | 71.9 | 37.7 |
| tHC (g/hr,C1) | 66.0 | 50.9 | 111.4 | 107.2 | 114.0 | 109.1 | 52.1 |
| PM (g/hr) - TEOM [corrected] | 0.876 | 1.524 | 2.163 | 2.385 | 2.022 | 1.970 | 0.852 |
| **Exhaust Emission Flows/Fuel** | | | | | | | |
| CO (g/kg fuel) | 6.18 | 5.20 | 7.62 | 6.37 | 6.91 | 6.40 | 5.63 |
| $CO_2$ (kg/kg fuel) | 2.75 | 2.81 | 2.70 | 2.74 | 2.70 | 2.74 | 2.80 |
| $NO_x$ (g/kg fuel) | 29.33 | 32.45 | 14.04 | 13.27 | 12.71 | 13.00 | 30.50 |
| $O_2$ (g/kg fuel) | 8.57 | 8.62 | 6.33 | 5.89 | 5.89 | 5.90 | 7.14 |
| $CH_4$ (g/kg fuel) | 4.96 | 3.40 | 9.82 | 9.08 | 9.58 | 9.27 | 3.68 |
| nmHC (g/kg fuel,C1) | 11.74 | 9.66 | 19.16 | 17.60 | 18.74 | 17.94 | 9.62 |
| tHC (g/kg fuel,C1) | 16.70 | 13.07 | 28.98 | 26.67 | 28.32 | 27.21 | 13.31 |
| PM (g/kg fuel) - TEOM [corrected] | 0.22 | 0.39 | 0.56 | 0.59 | 0.50 | 0.49 | 0.22 |
| **Dilution System Parameters** | | | | | | | |
| Exhaust Temp - manifold (C) | 273.4 | 320.0 | 331.1 | 342.4 | 341.2 | 341.4 | 305.3 |
| Exhaust Temp - sample inlet (C) | 232.0 | 267.1 | 283.5 | 291.6 | 293.5 | 293.7 | 240.4 |
| Dilution Air Temp (C) | 10.4 | 8.2 | 4.2 | 4.9 | 4.9 | 4.4 | 5.2 |
| Filter Temp (C) | 38.9 | 38.8 | 35.8 | 36.9 | 37.6 | 38.2 | 39.3 |
| Sample $CO_2$ (%) | 0.31 | 0.30 | 0.35 | 0.36 | 0.36 | 0.36 | 0.34 |
| Dilution Ratio - $CO_2$ | 12.1 | 12.9 | 13.2 | 13.1 | 13.3 | 13.2 | 12.7 |

**Table 4-13: 1600 RPM 40% load – BP/DPW test emissions (II)**

| Label: | A11 | A12 | A13 | A14 | A127 | A129 | A131 | A133 |
|---|---|---|---|---|---|---|---|---|
| Date: | 7-Mar-02 | 7-Mar-02 | 7-Mar-02 | 7-Mar-02 | 8-Mar-02 | 8-Mar-02 | 8-Mar-02 | 8-Mar-02 |
| Time: | 10:17:27 | 10:33:02 | 10:47:06 | 11:03:01 | 14:16:44 | 14:33:59 | 14:56:22 | 15:14:31 |
| **Engine Parameters** | | | | | | | | |
| Speed(RPM) | 1613.7 | 1598.6 | 1602.6 | 1610.3 | 1611.0 | 1599.4 | 1600.8 | 1599.7 |
| Load(%) | 40.0 | 40.0 | 40.0 | 40.0 | 40.0 | 40.0 | 40.0 | 40.0 |
| Indicated Power (kW) | 28.2 | 28.4 | 28.1 | 28.4 | 28.7 | 28.2 | 27.7 | 28.4 |
| IMEP (bar) | 8.4 | 8.5 | 8.4 | 8.5 | 8.6 | 8.5 | 8.3 | 8.5 |
| Pmax(bar) | 106.6 | 107.4 | 105.6 | 105.7 | 109.8 | 111.0 | 105.9 | 108.6 |
| Pmax location (degrees) | 368.3 | 369.2 | 369.5 | 368.1 | 368.4 | 368.7 | 367.8 | 368.7 |
| Diesel Flow(kg/hr) | 0.32 | 0.32 | 0.32 | 0.32 | 0.26 | 0.31 | 0.31 | 0.32 |
| CNG Flow(kg/hr) | 3.83 | 3.85 | 3.82 | 3.84 | 3.84 | 3.80 | 3.79 | 3.82 |
| Air Flow(kg/hr) | 212.1 | 178.8 | 157.4 | 210.0 | 217.5 | 189.3 | 157.9 | 214.9 |
| Exhaust Flow(kg/hr) | 216.3 | 182.9 | 161.5 | 214.2 | 221.6 | 193.4 | 162.0 | 219.1 |
| Exhaust Back Pressure (kPa) | 11.1 | 119.5 | 124.7 | 11.3 | 10.9 | 125.2 | 130.5 | 11.7 |
| EGR Fraction(%) | 0.0 | 12.8 | 22.6 | 0.0 | 0.0 | 10.1 | 22.7 | 0.0 |
| **Exhaust Emission Flows** | | | | | | | | |
| CO (g/hr) | 26.98 | 29.29 | 42.65 | 26.52 | 25.40 | 25.01 | 50.51 | 30.33 |
| $CO_2$ (kg/hr) | 11.32 | 11.17 | 11.22 | 11.72 | 11.43 | 11.17 | 11.11 | 11.60 |
| $NO_x$ (g/hr) | 129.20 | 70.01 | 37.24 | 123.00 | 118.78 | 77.26 | 34.75 | 117.29 |
| $O_2$ (kg/hr) | 32.83 | 25.54 | 20.68 | 32.01 | 34.79 | 28.81 | 22.07 | 34.26 |
| $CH_4$ (g/hr) | 18.34 | 15.69 | -81.26 | -56.02 | 29.98 | 26.33 | 22.58 | 30.34 |
| nmHC (g/hr,C1) | 47.07 | 78.93 | 235.59 | 116.91 | 40.17 | 59.49 | 171.83 | 44.56 |
| tHC (g/hr,C1) | 65.41 | 94.62 | 154.32 | 60.89 | 70.15 | 85.82 | 194.40 | 74.90 |
| PM (g/hr) - TEOM [corrected] | 0.82 | 1.80 | 2.72 | 0.82 | 1.11 | 2.19 | 1.11 | 0.57 |
| **Exhaust Emission Flows/Fuel** | | | | | | | | |
| CO (g/kg fuel) | 6.49 | 7.02 | 10.29 | 6.38 | 6.20 | 6.08 | 12.33 | 7.33 |
| $NO_x$ (g/kg fuel) | 31.09 | 16.79 | 8.99 | 29.58 | 29.01 | 18.78 | 8.48 | 28.35 |
| $O_2$ (g/kg fuel) | 7.90 | 6.12 | 4.99 | 7.70 | 8.50 | 7.01 | 5.39 | 8.28 |
| $CH_4$ (g/kg fuel) | 4.41 | 3.76 | -19.61 | -13.47 | 7.32 | 6.40 | 5.51 | 7.33 |
| nmHC (g/kg fuel,C1) | 11.33 | 18.93 | 56.85 | 28.11 | 9.81 | 14.46 | 41.94 | 10.77 |
| tHC (g/kg fuel,C1) | 15.74 | 22.69 | 37.24 | 14.64 | 17.13 | 20.86 | 47.45 | 18.10 |
| PM (g/kg fuel) - TEOM [corrected] | 0.20 | 0.43 | 0.66 | 0.20 | 0.27 | 0.53 | 0.27 | 0.14 |
| **Dilution System Parameters** | | | | | | | | |
| Exhaust Temp - manifold (C) | 292.4 | 355.1 | 355.1 | 299.5 | 285.2 | 344.9 | 347.2 | 286.2 |
| Exhaust Temp - sample inlet (C) | 224.9 | 302.4 | 303.5 | 247.8 | 220.5 | 295.5 | 297.9 | 239.5 |
| Dilution Air Temp (C) | 15.6 | 12.0 | 11.3 | 11.4 | 14.4 | 11.5 | 7.8 | 10.4 |
| Filter Temp (C) | 45.8 | 41.5 | 39.6 | 39.8 | 43.7 | 41.5 | 39.6 | 39.9 |
| Sample $CO_2$ (%) | 0.44 | 0.44 | 0.48 | 0.42 | 0.42 | 0.36 | 0.40 | 0.34 |
| Dilution Ratio - $CO_2$ | 8.6 | 10.0 | 10.5 | 9.4 | 9.0 | 11.9 | 12.4 | 11.5 |

**Table 4-14: Data Summaries for 1600 RPM 40% load tests**

| Label: | A15 | A19 | A136 | A139 | D3 | D13 | A18 | A140 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Date: | 7-Mar-02 | 7-Mar-02 | 8-Mar-02 | 8-Mar-02 | 10-Apr-02 | 10-Apr-02 | 7-Mar-02 | 8-Mar-02 | | |
| Time: | 11:41:03 | 12:30:31 | 15:46:38 | 16:28:29 | 10:25:15 | 11:53:41 | 12:24:01 | 16:34:37 | AVG | COV |
| **Engine Parameters** | | | | | | | | | | |
| Speed(RPM) | 1406.3 | 1433.3 | 1397.7 | 1409.4 | 1405.7 | 1407.6 | 1415.6 | 1407.3 | 1410.0 | 0.009 |
| Load(%) | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 0.000 |
| Indicated Power (kW) | 42.3 | 43.0 | 42.3 | 42.6 | 42.0 | 42.4 | 42.1 | 42.3 | 42.4 | 0.008 |
| IMEP (bar) | 14.4 | 14.4 | 14.5 | 14.5 | 14.33 | 14.46 | 14.3 | 14.4 | 14.4 | 0.005 |
| Pmax(bar) | 146.5 | 145.0 | 148.4 | 147.6 | 147.19 | 144.44 | 145.0 | 147.7 | 146.5 | 0.010 |
| Pmax location (degrees) | 366.9 | 367.1 | 367.6 | 366.8 | 367.2 | 367.2 | 366.9 | 367.2 | 367.1 | 0.001 |
| Diesel Flow(kg/hr) | 0.28 | 0.28 | 0.30 | 0.31 | 0.29 | 0.30 | 0.28 | **0.41** | 0.3 | 0.048 |
| CNG Flow(kg/hr) | 6.26 | 6.39 | 6.11 | 6.19 | 6.21 | 6.30 | 6.08 | 6.06 | 6.2 | 0.015 |
| Air Flow(kg/hr) | 273.4 | 278.8 | 275.4 | 275.1 | 275.8 | 277.1 | 278.7 | 275.1 | 275.9 | 0.007 |
| Exhaust Flow(kg/hr) | 279.9 | 285.4 | 281.8 | 281.6 | 282.3 | 283.7 | 285.0 | 281.6 | 282.5 | 0.007 |
| Exhaust Back Pressure (kPa) | 10.6 | 11.7 | 11.0 | 12.4 | 11.4 | 5.2 | **123.2** | 12.3 | 10.4 | 0.254 |
| **Exhaust Emission Flows** | | | | | | | | | | |
| CO (g/hr) | 172.66 | 198.73 | 155.88 | 208.17 | 159.8 | 229.3 | 48.00 | 187.90 | 187.4 | 0.156 |
| $CO_2$ (kg/hr) | 23.05 | 23.78 | 23.02 | 23.64 | 23.2 | 23.0 | 24.29 | 23.64 | 23.3 | 0.015 |
| $NO_x$ (g/hr) | 261.24 | 267.49 | 259.89 | 255.36 | 279.3 | 265.1 | 290.79 | 265.38 | 264.7 | 0.031 |
| $O_2$ (kg/hr) | 31.41 | 31.73 | 33.24 | 32.36 | 31.6 | 32.1 | 31.39 | 32.51 | 32.1 | 0.021 |
| $CH_4$ (g/hr) | 5.34 | 6.31 | 39.76 | 41.37 | 21.3 | 23.7 | 24.76 | 41.56 | 23.0 | 0.678 |
| nmHC (g/hr,C1) | 54.99 | 52.52 | 18.81 | 17.44 | 30.8 | 30.9 | 8.96 | 15.14 | 34.2 | 0.472 |
| tHC (g/hr,C1) | 60.32 | 58.83 | 58.57 | 58.81 | 52.0 | 54.6 | 33.73 | 56.70 | 57.2 | 0.056 |
| PM (g/hr) - TEOM | 6.55 | 6.60 | 3.93 | 5.76 | 3.700 | 4.479 | 7.81 | 5.03 | 5.2 | 0.252 |
| **Exhaust Emission Flows/Fuel** | | | | | | | | | | |
| CO (g/kg fuel) | 26.76 | 30.54 | 24.14 | 32.67 | 24.39 | 35.87 | 7.36 | 28.49 | 29.1 | 0.164 |
| $CO_2$ (kg/kg fuel) | 3.57 | 3.66 | 3.57 | 3.71 | 3.53 | 3.60 | 3.73 | 3.58 | 3.6 | 0.018 |
| $NO_x$ (g/kg fuel) | 40.48 | 41.11 | 40.25 | 40.08 | 42.63 | 41.46 | 44.61 | 40.24 | 41.0 | 0.023 |
| $O_2$ (g/kg fuel) | 4.87 | 4.88 | 5.15 | 5.08 | 4.82 | 5.02 | 4.82 | 4.93 | 5.0 | 0.026 |
| $CH_4$ (g/kg fuel) | 0.83 | 0.97 | 6.16 | 6.49 | 3.25 | 3.70 | 3.80 | 6.30 | 3.6 | 0.683 |
| nmHC (g/kg fuel,C1) | 8.52 | 8.07 | 2.91 | 2.74 | 4.69 | 4.83 | 1.38 | 2.30 | 5.3 | 0.470 |
| tHC (g/kg fuel,C1) | 9.35 | 9.04 | 9.07 | 9.23 | 7.94 | 8.54 | 5.17 | 8.60 | 8.9 | 0.060 |
| PM (g/kg fuel) - TEOM | 1.02 | 1.01 | 0.61 | 0.90 | 0.56 | 0.70 | 1.20 | 0.76 | 0.8 | 0.253 |

**Table 4-15: 1400 RPM 85% load baseline emissions**

| Label: | D1 | D2 | D3 | D4 | D5 | D6 |
|---|---|---|---|---|---|---|
| Date: | 4/10/02 | 4/10/02 | 4/10/02 | 4/10/02 | 4/10/02 | 4/10/02 |
| Time: | 10:06:30 | 10:19:52 | 10:25:15 | 10:32:11 | 10:41:12 | 10:47:38 |
| **Engine Parameters** | | | | | | |
| Speed(RPM) | 1408.5 | 1406.1 | 1405.7 | 1404.5 | 1386.9 | 1405.1 |
| Load(%) | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 |
| Indicated Power (kW) | 42.2 | 41.9 | 42.0 | 41.9 | 41.0 | 42.3 |
| IMEP (bar) | 14.39 | 14.31 | 14.33 | 14.31 | 14.20 | 14.44 |
| Pmax(bar) | 147.62 | 146.80 | 147.19 | 147.03 | 147.33 | 146.80 |
| Pmax location (degrees) | 367.0 | 367.0 | 367.2 | 366.9 | 366.9 | 367.1 |
| Diesel Flow(kg/hr) | 0.28 | 0.34 | 0.29 | 0.33 | 0.30 | 0.30 |
| CNG Flow(kg/hr) | 6.18 | 6.18 | 6.21 | 6.13 | 6.07 | 6.25 |
| Air Flow(kg/hr) | 276.2 | 275.9 | 275.8 | 277.8 | 277.8 | 278.1 |
| Exhaust Flow(kg/hr) | 282.6 | 282.5 | 282.3 | 284.3 | 284.2 | 284.7 |
| Exhaust Back Pressure (kPa) | 11.1 | 11.4 | 11.4 | 11.4 | 151.6 | 13.7 |
| EGR Fraction(%) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Exhaust Emission Flows** | | | | | | |
| CO (g/hr) | 140.8 | 166.1 | 159.8 | 156.7 | 49.5 | 183.4 |
| $CO_2$ (kg/hr) | 22.6 | 23.2 | 23.2 | 23.4 | 24.3 | 23.8 |
| $NO_x$ (g/hr) | 255.9 | 276.0 | 279.3 | 284.0 | 303.2 | 285.8 |
| $O_2$ (kg/hr) | 32.4 | 31.7 | 31.6 | 31.8 | 30.9 | 31.2 |
| $CH_4$ (g/hr) | 23.7 | 22.0 | 21.3 | 20.9 | 13.6 | 18.8 |
| nmHC (g/hr,C1) | 38.8 | 33.2 | 30.8 | 30.1 | 21.7 | 26.7 |
| tHC (g/hr,C1) | 62.5 | 55.2 | 52.0 | 51.0 | 35.4 | 45.5 |
| PM (g/hr) - TEOM [corrected] | 2.930 | 3.991 | 3.700 | 3.773 | 2.155 | 4.401 |
| **Exhaust Emission Flows/Fuel** | | | | | | |
| CO (g/kg fuel) | 21.83 | 25.49 | 24.56 | 24.27 | 7.78 | 27.99 |
| $CO_2$ (kg/kg fuel) | 3.50 | 3.56 | 3.56 | 3.63 | 3.82 | 3.64 |
| $NO_x$ (g/kg fuel) | 39.66 | 42.34 | 42.93 | 43.98 | 47.59 | 43.61 |
| $O_2$ (g/kg fuel) | 5.03 | 4.86 | 4.86 | 4.93 | 4.85 | 4.76 |
| $CH_4$ (g/kg fuel) | 3.67 | 3.38 | 3.27 | 3.24 | 2.14 | 2.87 |
| nmHC (g/kg fuel,C1) | 6.02 | 5.09 | 4.73 | 4.66 | 3.41 | 4.08 |
| tHC (g/kg fuel,C1) | 9.69 | 8.47 | 8.00 | 7.90 | 5.55 | 6.94 |
| PM (g/kg fuel) - TEOM [corrected] | 0.45 | 0.61 | 0.57 | 0.58 | 0.34 | 0.67 |
| **Dilution System Parameters** | | | | | | |
| Exhaust Temp - manifold (C) | 376.0 | 388.1 | 387.8 | 388.2 | 468.2 | 398.6 |
| Exhaust Temp - sample inlet (C) | 241.5 | 270.1 | 274.7 | 275.9 | 383.1 | 343.3 |
| Dilution Air Temp (C) | 17.4 | 14.5 | 13.5 | 12.4 | 10.4 | 9.2 |
| Filter Temp (C) | 45.4 | 42.5 | 41.8 | 41.3 | 39.3 | 39.3 |
| Diff Pressure - filters (psid) | 0.9 | 0.9 | 0.9 | 0.9 | 1.0 | 1.0 |
| Sample $CO_2$ (%) | 0.45 | 0.43 | 0.41 | 0.40 | 0.36 | 0.38 |
| Dilution Ratio - $CO_2$ | 12.9 | 14.0 | 14.6 | 14.9 | 18.0 | 16.4 |

**Table 4-16: 1400 RPM 85% load – BP/DPW test emissions (I)**

| Label: | D7 | D8 | D9 | D10 | D11 | D12 | D13 |
|---|---|---|---|---|---|---|---|
| Date: | 4/10/02 | 4/10/02 | 4/10/02 | 4/10/02 | 4/10/02 | 4/10/02 | 4/10/02 |
| Time: | 10:54:57 | 11:03:00 | 11:23:31 | 11:28:43 | 11:34:34 | 11:41:08 | 11:53:41 |
| **Engine Parameters** | | | | | | | |
| Speed(RPM) | 1393.3 | 1404.2 | 1386.2 | 1387.3 | 1387.0 | 1388.2 | 1407.6 |
| Load(%) | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 |
| Indicated Power (kW) | 41.2 | 42.1 | 40.5 | 40.5 | 40.4 | 40.8 | 42.4 |
| IMEP (bar) | 14.21 | 14.37 | 14.04 | 14.00 | 13.98 | 14.10 | 14.46 |
| Pmax(bar) | 146.77 | 146.21 | 143.26 | 143.89 | 143.13 | 143.02 | 144.44 |
| Pmax location (degrees) | 366.6 | 367.2 | 367.2 | 366.9 | 367.2 | 367.2 | 367.2 |
| Diesel Flow(kg/hr) | 0.28 | 0.31 | 0.28 | 0.34 | 0.27 | 0.32 | 0.30 |
| CNG Flow(kg/hr) | 6.11 | 6.21 | 6.09 | 6.06 | 6.11 | 6.10 | 6.30 |
| Air Flow(kg/hr) | 278.0 | 278.0 | 231.9 | 232.0 | 232.2 | 232.6 | 277.1 |
| Exhaust Flow(kg/hr) | 284.3 | 284.5 | 238.3 | 238.4 | 238.6 | 239.0 | 283.7 |
| Exhaust Back Pressure (kPa) | 127.8 | 12.4 | 143.0 | 142.5 | 142.2 | 141.6 | 5.2 |
| EGR Fraction(%) | 0.0 | 0.0 | 13.2 | 13.0 | 13.1 | 13.0 | 0.0 |
| **Exhaust Emission Flows** | | | | | | | |
| CO (g/hr) | 53.6 | 177.1 | 146.7 | 158.6 | 153.4 | 160.9 | 229.3 |
| $CO_2$ (kg/hr) | 24.7 | 23.8 | 24.1 | 24.3 | 24.2 | 24.4 | 23.0 |
| $NO_x$ (g/hr) | 303.1 | 285.0 | 116.2 | 115.0 | 113.6 | 113.3 | 265.1 |
| $O_2$ (kg/hr) | 30.4 | 31.3 | 20.7 | 20.4 | 20.6 | 20.5 | 32.1 |
| $CH_4$ (g/hr) | 12.2 | 19.5 | 19.7 | 19.7 | 19.9 | 19.7 | 23.7 |
| nmHC (g/hr,C1) | 18.4 | 28.4 | 29.1 | 27.9 | 29.0 | 28.2 | 30.9 |
| tHC (g/hr,C1) | 30.5 | 47.9 | 48.8 | 47.5 | 48.9 | 47.9 | 54.6 |
| PM (g/hr) - TEOM [corrected] | 2.265 | 4.958 | 6.487 | 6.612 | 6.070 | 6.429 | 4.479 |
| **Exhaust Emission Flows/Fuel** | | | | | | | |
| CO (g/kg fuel) | 8.38 | 27.19 | 23.00 | 24.79 | 24.04 | 25.09 | 34.77 |
| $CO_2$ (kg/kg fuel) | 3.86 | 3.66 | 3.78 | 3.80 | 3.80 | 3.80 | 3.49 |
| $NO_x$ (g/kg fuel) | 47.41 | 43.74 | 18.23 | 17.97 | 17.81 | 17.66 | 40.19 |
| $O_2$ (g/kg fuel) | 4.76 | 4.80 | 3.24 | 3.20 | 3.22 | 3.19 | 4.86 |
| $CH_4$ (g/kg fuel) | 1.90 | 2.99 | 3.09 | 3.08 | 3.11 | 3.07 | 3.59 |
| nmHC (g/kg fuel,C1) | 2.87 | 4.36 | 4.56 | 4.36 | 4.55 | 4.40 | 4.69 |
| tHC (g/kg fuel,C1) | 4.78 | 7.36 | 7.65 | 7.43 | 7.66 | 7.47 | 8.27 |
| PM (g/kg fuel) - TEOM [corrected] | 0.35 | 0.76 | 1.02 | 1.03 | 0.95 | 1.00 | 0.68 |
| **Dilution System Parameters** | | | | | | | |
| Exhaust Temp - manifold (C) | 457.0 | 395.5 | 473.6 | 476.4 | 474.0 | 476.6 | 399.4 |
| Exhaust Temp - sample inlet (C) | 376.6 | 331.7 | 401.2 | 403.8 | 403.2 | 404.1 | 318.2 |
| Dilution Air Temp (C) | 8.7 | 8.4 | 7.9 | 6.6 | 6.0 | 6.2 | 7.0 |
| Filter Temp (C) | 39.1 | 40.5 | 44.2 | 43.2 | 42.3 | 41.7 | 46.7 |
| Diff Pressure - filters (psid) | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Sample $CO_2$ (%) | 0.47 | 0.50 | 0.54 | 0.54 | 0.54 | 0.54 | 0.56 |
| Dilution Ratio - $CO_2$ | 13.2 | 12.1 | 13.4 | 13.4 | 13.5 | 13.4 | 10.3 |

**Table 4-17: 1400 RPM 85% load – BP/DPW test emissions (II)**

| Label: | A15 | A16 | A17 | A18 | A19 | A136 | A137 | A138 | A139 | A140 |
|---|---|---|---|---|---|---|---|---|---|---|
| Date: | 7-Mar-02 | 7-Mar-02 | 7-Mar-02 | 7-Mar-02 | 7-Mar-02 | 8-Mar-02 | 8-Mar-02 | 8-Mar-02 | 8-Mar-02 | 8-Mar-02 |
| Time: | 11:41:03 | 11:57:57 | 12:14:00 | 12:24:01 | 12:30:31 | 15:46:38 | 16:05:51 | 16:18:01 | 16:28:29 | 16:34:37 |
| **Engine Parameters** | | | | | | | | | | |
| Speed(RPM) | 1406.3 | 1409.0 | 1407.9 | 1415.6 | 1433.3 | 1397.7 | 1390.5 | 1390.5 | 1409.4 | 1407.3 |
| Load(%) | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 | 85.0 |
| Indicated Power (kW) | 42.3 | 41.7 | 41.4 | 42.1 | 43.0 | 42.3 | 40.8 | 41.1 | 42.6 | 42.3 |
| IMEP (bar) | 14.4 | 14.2 | 14.1 | 14.3 | 14.4 | 14.5 | 14.1 | 14.2 | 14.5 | 14.4 |
| Pmax(bar) | 146.5 | 144.6 | 142.9 | 145.0 | 145.0 | 148.4 | 141.9 | 144.5 | 147.6 | 147.7 |
| Pmax location (degrees) | 366.9 | 366.9 | 367.0 | 366.9 | 367.1 | 367.6 | 367.0 | 367.4 | 366.8 | 367.2 |
| Diesel Flow(kg/hr) | 0.28 | 0.28 | 0.28 | 0.28 | 0.28 | 0.30 | 0.32 | 0.31 | 0.31 | 0.41 |
| CNG Flow(kg/hr) | 6.26 | 6.19 | 6.23 | 6.08 | 6.39 | 6.11 | 6.16 | 6.11 | 6.19 | 6.06 |
| Air Flow(kg/hr) | 273.4 | 258.0 | 229.3 | 278.7 | 278.8 | 275.4 | 213.2 | 248.9 | 275.1 | 275.1 |
| Exhaust Flow(kg/hr) | 279.9 | 264.5 | 235.8 | 285.0 | 285.4 | 281.8 | 219.7 | 255.3 | 281.6 | 281.6 |
| Exhaust Back Pressure (kPa) | 10.6 | 144.2 | 142.5 | 123.2 | 11.7 | 11.0 | 142.2 | 145.6 | 12.4 | 12.3 |
| EGR Fraction(%) | 0.0 | 8.5 | 16.5 | 0.0 | 0.0 | 0.0 | 14.5 | 11.5 | 0.0 | 0.0 |
| **Exhaust Emission Flows** | | | | | | | | | | |
| CO (g/hr) | 172.66 | 92.88 | 258.89 | 48.00 | 198.73 | 155.88 | 183.33 | 140.30 | 208.17 | 187.90 |
| $CO_2$ (kg/hr) | 23.05 | 25.16 | 24.95 | 24.29 | 23.78 | 23.02 | 22.54 | 25.41 | 23.64 | 23.64 |
| $NO_x$ (g/hr) | 261.24 | 168.62 | 82.95 | 290.79 | 267.49 | 259.89 | 88.22 | 121.43 | 255.36 | 265.38 |
| $O_2$ (kg/hr) | 31.41 | 25.39 | 18.77 | 31.39 | 31.73 | 33.24 | 19.26 | 24.08 | 32.36 | 32.51 |
| $CH_4$ (g/hr) | 5.34 | -55.29 | -101.78 | 24.76 | 6.31 | 39.76 | 31.80 | 37.17 | 41.37 | 41.56 |
| nmHC (g/hr,C1) | 54.99 | 103.26 | 171.56 | 8.96 | 52.52 | 18.81 | 30.51 | 22.19 | 17.44 | 15.14 |
| tHC (g/hr,C1) | 60.32 | 47.97 | 69.78 | 33.73 | 58.83 | 58.57 | 62.30 | 59.36 | 58.81 | 56.70 |
| PM (g/hr) - TEOM [corrected] | 6.55 | 6.45 | 12.13 | 7.81 | 6.60 | 3.93 | 8.56 | 8.87 | 5.76 | 5.03 |
| **Exhaust Emission Flows/Fuel** | | | | | | | | | | |
| CO (g/kg fuel) | 26.42 | 14.35 | 39.79 | 7.55 | 29.80 | 24.30 | 28.27 | 21.87 | 31.99 | 29.04 |
| $CO_2$ (kg/kg fuel) | 3.53 | 3.89 | 3.83 | 3.82 | 3.57 | 3.59 | 3.48 | 3.96 | 3.63 | 3.65 |
| $NO_x$ (g/kg fuel) | 39.98 | 26.06 | 12.75 | 45.71 | 40.11 | 40.51 | 13.61 | 18.93 | 39.24 | 41.01 |
| $O_2$ (g/kg fuel) | 4.81 | 3.92 | 2.89 | 4.93 | 4.76 | 5.18 | 2.97 | 3.75 | 4.97 | 5.02 |
| $CH_4$ (g/kg fuel) | 0.82 | -8.55 | -15.64 | 3.89 | 0.95 | 6.20 | 4.90 | 5.79 | 6.36 | 6.42 |
| nmHC (g/kg fuel,C1) | 8.42 | 15.96 | 26.37 | 1.41 | 7.88 | 2.93 | 4.70 | 3.46 | 2.68 | 2.34 |
| tHC (g/kg fuel,C1) | 9.23 | 7.41 | 10.73 | 5.30 | 8.82 | 9.13 | 9.61 | 9.25 | 9.04 | 8.76 |
| PM (g/kg fuel) - TEOM [corrected] | 1.00 | 1.00 | 1.86 | 1.23 | 0.99 | 0.61 | 1.32 | 1.38 | 0.88 | 0.78 |
| **Dilution System Parameters** | | | | | | | | | | |
| Exhaust Temp - manifold (C) | 397.4 | 481.6 | 487.9 | 463.9 | 406.3 | 385.7 | 483.1 | 480.3 | 400.4 | 397.1 |
| Exhaust Temp - sample inlet (C) | 267.4 | 405.5 | 416.5 | 400.0 | 338.4 | 243.2 | 409.9 | 408.6 | 341.5 | 306.5 |
| Dilution Air Temp (C) | 14.8 | 9.7 | 8.1 | 8.1 | 9.0 | 9.7 | 5.8 | 6.1 | 6.5 | 7.1 |
| Filter Temp (C) | 42.9 | 41.8 | 36.9 | 36.7 | 38.8 | 44.0 | 38.0 | 36.0 | 39.2 | 41.5 |
| Sample $CO_2$ (%) | 0.67 | 0.42 | 0.57 | 0.49 | 0.51 | 0.61 | 0.67 | 0.65 | 0.61 | 0.61 |
| Dilution Ratio - $CO_2$ | 8.6 | 16.4 | 13.2 | 12.5 | 11.6 | 9.4 | 10.7 | 10.8 | 9.7 | 9.7 |

**Table 4-18: Data summaries for 1400 RPM 85% load tests**

| Label: | 071 | 073 | 075 | 077 | 079 | 081 | 083 | 087 |
|---|---|---|---|---|---|---|---|---|
| Date: | 16-Jan-02 | 16-Jan-02 | 16-Jan-02 | 16-Jan-02 | 18-Jan-02 | 18-Jan-02 | 18-Jan-02 | 18-Jan-02 |
| Time: | 9:37:25 | 10:03:19 | 10:19:51 | 10:39:10 | 13:57:38 | 14:30:36 | 14:51:15 | 15:07:59 |
| **Engine Parameters** | | | | | | | | |
| Speed(RPM) | 1607.5 | 1598.9 | 1601.7 | 1603.4 | 821.0 | 815.1 | 813.3 | 822.6 |
| Load(%) | 40.0 | 40.0 | 40.0 | 40.0 | 75.0 | 75.0 | 75.0 | 75.0 |
| Indicated Power (kW) | 26.9 | 27.2 | 26.8 | 27.5 | 19.6 | 18.7 | 18.1 | 19.1 |
| IMEP (bar) | 8.0 | 8.2 | 8.0 | 8.2 | 11.5 | 11.0 | 10.7 | 11.1 |
| Pmax(bar) | 107.4 | 106.0 | 102.1 | 106.3 | 130.0 | 126.9 | 125.9 | 129.4 |
| Pmax location (degrees) | 368.4 | 368.7 | 366.0 | 368.2 | 368.7 | 368.1 | 368.3 | 368.4 |
| Diesel Flow(kg/hr) | 0.54 | 0.61 | 0.62 | 0.63 | 0.58 | 0.63 | 0.62 | 0.61 |
| CNG Flow(kg/hr) | 3.60 | 3.65 | 3.68 | 3.69 | 2.84 | 2.74 | 2.69 | 2.74 |
| Air Flow(kg/hr) | 209.8 | 176.9 | 149.4 | 210.8 | 91.6 | 78.0 | 67.5 | 91.7 |
| Exhaust Flow(kg/hr) | 214.0 | 181.2 | 153.7 | 215.1 | 95.0 | 81.4 | 70.8 | 95.1 |
| Exhaust Back Pressure (kPa) | 11.8 | 115.0 | 123.8 | 10.3 | 11.7 | 51.6 | 55.7 | 10.9 |
| EGR Fraction(%) | 0.0 | 11.6 | 24.8 | 0.0 | 0.0 | 12.2 | 23.3 | 0.0 |
| **Exhaust Emission Flows** | | | | | | | | |
| CO (g/hr) | 34.57 | 41.04 | 74.93 | 38.41 | 147.05 | 153.98 | 310.94 | 106.47 |
| $CO_2$ (kg/hr) | 11.59 | 11.28 | 11.15 | 11.89 | 9.78 | 9.37 | 8.92 | 9.63 |
| $NO_x$ (g/hr) | 112.18 | 66.77 | 26.62 | 108.96 | 195.71 | 84.62 | 24.08 | 198.43 |
| $O_2$ (kg/hr) | 34.13 | 26.49 | 19.96 | 33.80 | 8.59 | 5.72 | 3.49 | 8.79 |
| $CH_4$ (g/hr) | -150.6 | -128.0 | -108.9 | -151.5 | 4.10 | 7.77 | 12.50 | 3.87 |
| nmHC (g/hr,C1) | 215.66 | 214.31 | 288.10 | 217.03 | 15.00 | 17.93 | 21.99 | 13.35 |
| tHC (g/hr,C1) | 64.97 | 86.28 | 179.17 | 65.44 | 19.10 | 25.70 | 34.50 | 17.21 |
| PM (g/hr) - TEOM | 2.31 | 3.51 | 2.74 | 1.57 | 0.41 | 0.96 | 2.74 | 0.23 |
| PM(g/hr) - filters | 3.91 | 5.43 | 3.32 | 2.69 | 0.49 | 1.00 | 3.46 | 0.44 |
| PM mass(mg) – filters | 0.52 | 0.86 | 0.61 | 0.36 | 0.15 | 0.24 | 0.39 | 0.15 |
| **Dilution System Parameters** | | | | | | | | |
| Exhaust Temp - manifold (C) | 294.4 | 359.5 | 357.3 | 296.3 | 406.7 | 440.9 | 427.1 | 398.0 |
| Exhaust Temp - sample inlet (C) | 213.0 | 304.4 | 304.9 | 226.2 | 245.5 | 337.3 | 333.1 | 258.1 |
| Dilution Air Temp (C) | 16.5 | 13.1 | 13.7 | 14.4 | 18.9 | 14.4 | 13.6 | 13.8 |
| Filter Temp (C) | 44.3 | 47.2 | 46.9 | 47.6 | 47.4 | 31.7 | 36.7 | 39.8 |
| Dilution Flow Rate (SLPM) | 18.3 | 18.3 | 18.3 | 18.3 | 17.8 | 17.8 | 17.8 | 17.6 |
| Total Flow Rate (SLPM) | 17.8 | 17.9 | 17.8 | 17.8 | 17.8 | 17.8 | 17.8 | 17.9 |
| Diff Pressure – filters (psid) | 0.5 | 0.4 | 0.4 | 0.4 | 0.4 | 0.5 | 0.7 | 0.4 |
| Sample $CO_2$ (%) | 0.39 | 0.44 | 0.50 | 0.40 | 0.72 | 0.80 | 0.72 | 0.78 |
| Dilution Ratio – $CO_2$ | 10.2 | 10.2 | 10.2 | 10.1 | 9.9 | 9.9 | 12.1 | 9.0 |
| Dilution Ratio – MFC | 8.3 | 8.0 | 8.2 | 8.3 | 6.9 | 7.0 | 6.9 | 6.4 |
| Duration (mins) | 15 | 15 | 15 | 15 | 15 | 10 | 5 | 15 |

**Table 4-19: Excess diesel tests with filter emission rates (I)**

| Label: | 089 | 091 | 093 | 095 | 099 | 101 | 103 | 105 | 107 |
|---|---|---|---|---|---|---|---|---|---|
| Date: | 21-Jan-02 | 21-Jan-02 | 21-Jan-02 | 21-Jan-02 | 22-Jan-02 | 22-Jan-02 | 22-Jan-02 | 22-Jan-02 | 22-Jan-02 |
| Time: | 13:20:32 | 13:42:34 | 14:09:28 | 14:28:04 | 9:42:08 | 10:17:44 | 10:38:32 | 10:54:16 | 11:09:04 |
| **Engine Parameters** | | | | | | | | | |
| Speed(RPM) | 803.8 | 803.2 | 805.2 | 810.1 | 1594.7 | 1595.8 | 1614.9 | 1609.9 | 1600.6 |
| Load(%) | 25.0 | 25.0 | 25.0 | 25.0 | 75.0 | 40.0 | 40.0 | 40.0 | 40.0 |
| Indicated Power (kW) | 10.9 | 11.0 | 11.0 | 11.0 | 40.9 | 27.2 | 27.3 | 27.7 | 27.3 |
| IMEP (bar) | 6.5 | 6.6 | 6.6 | 6.5 | 12.3 | 8.2 | 8.1 | 8.3 | 8.2 |
| Pmax(bar) | 101.8 | 100.4 | 97.0 | 101.5 | 124.0 | 110.1 | 104.9 | 107.8 | 109.2 |
| Pmax location (degrees) | 366.3 | 366.2 | 366.4 | 366.4 | 367.2 | 368.2 | 369.4 | 368.4 | 368.2 |
| Diesel Flow(kg/hr) | 0.73 | 0.78 | 0.85 | 0.87 | 0.36 | 1.15 | 0.85 | 0.76 | 0.77 |
| CNG Flow(kg/hr) | 1.22 | 1.18 | 1.21 | 1.20 | 5.92 | 3.54 | 3.59 | 3.66 | 3.56 |
| Air Flow(kg/hr) | 72.1 | 61.3 | 53.6 | 73.1 | 298.6 | 214.4 | 156.0 | 181.1 | 214.1 |
| Exhaust Flow(kg/hr) | 74.0 | 63.3 | 55.7 | 75.1 | 304.9 | 219.1 | 160.5 | 185.5 | 218.4 |
| Exhaust Back Pressure (kPa) | 12.6 | 25.8 | 23.7 | 10.5 | 12.6 | 11.3 | 116.6 | 114.2 | 11.2 |
| EGR Fraction(%) | 0.0 | 12.6 | 19.8 | 0.0 | 0.0 | 0.0 | 19.6 | 10.1 | 0.0 |
| **Exhaust Emission Flows** | | | | | | | | | |
| CO (g/hr) | 6.07 | 7.52 | 10.45 | 5.77 | 120.48 | 28.14 | 42.65 | 29.46 | 28.45 |
| $CO_2$ (kg/hr) | 5.62 | 5.44 | 5.51 | 5.65 | 25.06 | 12.32 | 12.05 | 12.36 | 12.50 |
| $NO_x$ (g/hr) | 175.34 | 94.40 | 44.39 | 168.38 | 187.68 | 126.07 | 42.74 | 79.71 | 125.21 |
| $O_2$ (kg/hr) | 10.33 | 7.97 | 5.99 | 10.69 | 38.68 | 35.61 | 21.74 | 27.50 | 35.37 |
| $CH_4$ (g/hr) | 4.20 | 7.57 | 10.59 | 4.16 | 25.91 | 21.29 | 44.56 | 27.40 | 20.32 |
| nmHC (g/hr,C1) | 9.71 | 14.98 | 19.49 | 10.08 | 59.21 | 45.40 | 82.51 | 54.32 | 42.77 |
| tHC (g/hr,C1) | 13.91 | 22.55 | 30.08 | 14.25 | 85.12 | 66.69 | 127.07 | 81.72 | 63.09 |
| PM (g/hr) - TEOM | 0.80 | 0.89 | 0.56 | 0.72 | 5.54 | 1.37 | 1.75 | 1.26 | 0.77 |
| PM(g/hr) - filters | 1.30 | 1.23 | 0.81 | 1.10 | 7.46 | 2.31 | 2.78 | 2.28 | 2.31 |
| PM mass(mg) - filters | 0.52 | 0.58 | 0.44 | 0.43 | 0.43 | 0.28 | 0.27 | 0.21 | 0.27 |
| Dilution System Parameters | | | | | | | | | |
| Exhaust Temp - manifold (C) | 293.1 | 303.6 | 315.7 | 290.4 | 401.8 | 285.3 | 364.0 | 365.2 | 288.3 |
| Exhaust Temp - sample inlet (C) | 184.3 | 224.7 | 228.2 | 199.8 | 282.5 | 210.7 | 308.2 | 309.7 | 236.0 |
| Dilution Air Temp (C) | 19.9 | 18.5 | 18.3 | 18.2 | 17.0 | 13.7 | 13.1 | 12.4 | 12.0 |
| Filter Temp (C) | 41.1 | 41.7 | 41.6 | 42.5 | 47.0 | 29.4 | 40.4 | 44.0 | 47.3 |
| Dilution Flow Rate (SLPM) | 17.6 | 17.6 | 17.6 | 17.6 | 18.2 | 18.2 | 18.3 | 18.3 | 18.2 |
| Total Flow Rate (SLPM) | 17.8 | 17.8 | 17.8 | 17.8 | 17.8 | 17.8 | 17.9 | 17.9 | 17.8 |
| Diff Pressure - filters (psid) | 0.3 | 0.3 | 0.4 | 0.4 | 0.5 | 0.4 | 0.4 | 0.4 | 0.4 |
| Sample $CO_2$ (%) | 0.55 | 0.62 | 0.71 | 0.54 | 0.53 | 0.38 | 0.46 | 0.42 | 0.37 |
| Dilution Ratio - $CO_2$ | 9.8 | 9.8 | 9.7 | 10.0 | 11.0 | 11.0 | 11.7 | 11.6 | 11.6 |
| Dilution Ratio - MFC | 6.5 | 6.5 | 6.5 | 6.5 | 8.0 | 8.0 | 8.2 | 8.0 | 8.0 |
| Duration (mins) | 15 | 15 | 15 | 15 | 10 | 15 | 9.5 | 10 | 15 |

**Table 4-20: Excess diesel tests with filter emission rates (II)**

| Label: | 109 | 111 | 113 | 115 | 119 | 121 | 123 | 125 |
|---|---|---|---|---|---|---|---|---|
| Date: | 23-Jan-02 | 23-Jan-02 | 23-Jan-02 | 23-Jan-02 | 24-Jan-02 | 24-Jan-02 | 24-Jan-02 | 24-Jan-02 |
| Time: | 10:22:31 | 10:49:50 | 11:15:46 | 11:32:34 | 10:03:58 | 10:25:05 | 10:42:57 | 10:54:05 |
| **Engine Parameters** | | | | | | | | |
| Speed(RPM) | 809.9 | 807.0 | 806.1 | 809.4 | 810.0 | 805.5 | 804.0 | 808.9 |
| Load(%) | 25.0 | 25.0 | 25.0 | 25.0 | 75.0 | 75.0 | 75.0 | 75.0 |
| Indicated Power (kW) | 11.0 | 11.3 | 11.3 | 11.2 | 20.1 | 19.4 | 19.0 | 20.1 |
| IMEP (bar) | 6.5 | 6.7 | 6.7 | 6.6 | 11.9 | 11.6 | 11.3 | 11.9 |
| Pmax(bar) | 101.5 | 99.1 | 100.9 | 102.6 | 136.8 | 131.7 | 132.1 | 134.9 |
| Pmax location (degrees) | 366.3 | 366.4 | 366.7 | 366.8 | 368.1 | 368.0 | 367.9 | 368.0 |
| Diesel Flow(kg/hr) | 0.75 | 0.85 | 0.89 | 0.89 | 0.60 | 0.59 | 0.61 | 0.63 |
| CNG Flow(kg/hr) | 1.19 | 1.21 | 1.20 | 1.19 | 2.91 | 2.89 | 2.87 | 2.91 |
| Air Flow(kg/hr) | 72.1 | 53.6 | 61.1 | 72.4 | 93.9 | 76.4 | 69.1 | 92.8 |
| Exhaust Flow(kg/hr) | 74.1 | 55.6 | 63.2 | 74.5 | 97.4 | 79.9 | 72.6 | 96.3 |
| Exhaust Back Pressure (kPa) | 10.5 | 24.0 | 25.5 | 10.5 | 11.8 | 55.6 | 59.1 | 9.7 |
| EGR Fraction(%) | 0.0 | 20.4 | 12.8 | 0.0 | 0.0 | 12.7 | 22.0 | 0.0 |
| **Exhaust Emission Flows** | | | | | | | | |
| CO (g/hr) | 7.89 | 12.06 | 9.67 | 8.69 | 172.70 | 273.18 | 489.52 | 209.42 |
| $CO_2$ (kg/hr) | 5.61 | 5.53 | 5.50 | 5.55 | 10.09 | 9.57 | 9.23 | 10.13 |
| $NO_x$ (g/hr) | 172.46 | 46.55 | 87.57 | 172.05 | 205.87 | 69.87 | 24.21 | 190.40 |
| $O_2$ (kg/hr) | 10.21 | 5.71 | 7.54 | 10.20 | 8.74 | 4.93 | 3.26 | 8.32 |
| $CH_4$ (g/hr) | 3.81 | 10.47 | 7.21 | 3.93 | 6.06 | 10.04 | 15.53 | 5.31 |
| nmHC (g/hr,C1) | 11.23 | 20.01 | 15.67 | 11.48 | 12.14 | 17.97 | 24.15 | 11.77 |
| tHC (g/hr,C1) | 15.03 | 30.48 | 22.88 | 15.41 | 18.21 | 28.01 | 39.68 | 17.07 |
| PM (g/hr) - TEOM | 0.91 | 0.62 | 0.50 | 0.75 | 0.52 | 1.58 | 7.03 | 0.85 |
| PM(g/hr) - filters | 1.24 | 0.84 | 0.78 | 0.98 | 0.67 | 2.18 | 6.60 | 0.78 |
| PM mass(mg) - filters | 0.41 | 0.38 | 0.30 | 0.36 | 0.15 | 0.45 | 0.41 | 0.23 |
| Dilution System Parameters | | | | | | | | |
| Exhaust Temp - manifold (C) | 292.0 | 317.1 | 309.4 | 291.6 | 406.2 | 452.1 | 437.3 | 409.8 |
| Exhaust Temp - sample inlet (C) | 187.7 | 229.5 | 228.9 | 198.9 | 262.0 | 348.2 | 342.4 | 273.9 |
| Dilution Air Temp (C) | 20.1 | 19.4 | 18.9 | 18.8 | 15.5 | 13.2 | 13.4 | 14.8 |
| Filter Temp (C) | 45.2 | 45.1 | 45.5 | 45.7 | 44.6 | 45.7 | 42.4 | 48.0 |
| Dilution Flow Rate (SLPM) | 18.2 | 18.2 | 18.2 | 18.1 | 19.0 | 18.9 | 19.0 | 18.1 |
| Total Flow Rate (SLPM) | 17.8 | 17.8 | 17.8 | 17.8 | 17.8 | 17.9 | 17.9 | 17.8 |
| Diff Pressure - filters (psid) | 0.4 | 0.3 | 0.3 | 0.4 | 0.4 | 0.6 | 0.4 | 0.5 |
| Sample $CO_2$ (%) | 0.46 | 0.59 | 0.53 | 0.50 | 0.79 | 0.87 | 0.47 | 0.70 |
| Dilution Ratio - $CO_2$ | 11.9 | 11.8 | 11.8 | 10.7 | 9.0 | 9.4 | 19.5 | 10.4 |
| Dilution Ratio - MFC | 8.0 | 8.0 | 8.0 | 7.6 | 11.2 | 10.5 | 14.0 | 7.7 |
| Duration (mins) | 15 | 15 | 15 | 15 | 10 | 8 | 4.5 | 15 |

**Table 4-21: Excess diesel tests with filter emission rates (III)**

# Appendix C: Analysis of TEOM Output

A typical TEOM plot is shown below, showing the total mass and mass rate. A constant emission rate and increasing total mass line is expected.

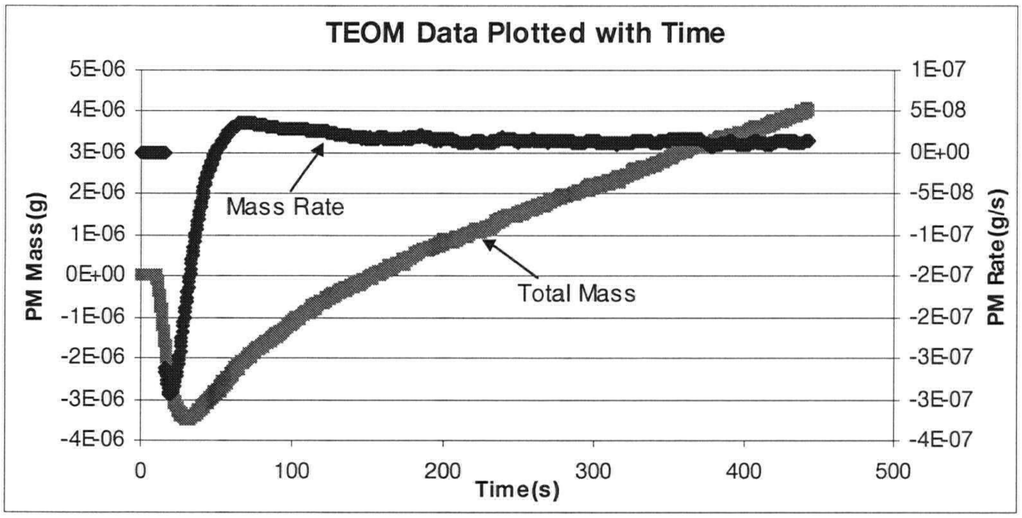
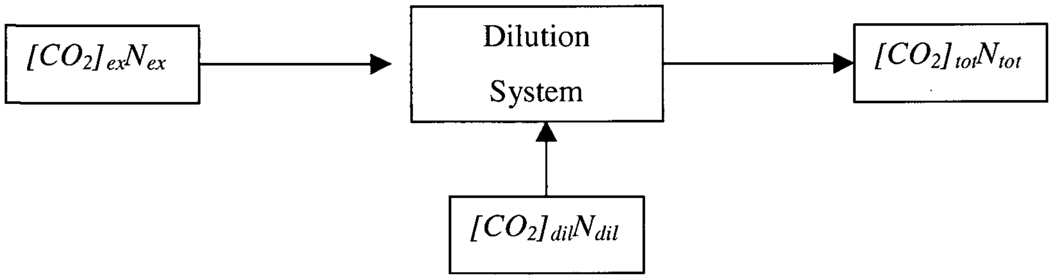



**Figure 4-2: Sample TEOM Output**

In all cases a linear regression was performed on the total mass data series. There is an initial period of approximately 60 seconds, where the output is unsteady, due to the adjustment of the TEOM to the different pressure source and the filter face to the exhaust humidity. This part of the data is omitted from the regression calculation. Once the regression is performed, the $R^2$ value is verified and expected to be greater than 0.98. This average rate is compared to the PM rate as measured on the graph for verification purposes. Once the PM emission rate is known, it can be multiplied by the duration of the sampling period to give the total mass collected.

# Appendix D: Derivation of Dilution Ratio Calculation

The flow of $CO_2$ through the dilution system is shown below:




Here, ex denotes exhaust (from engine), dil denotes dilution air and tot denotes the total sampled diluted exhaust. $[CO_2]$ is the $CO_2$ concentration in molar percent and $N$ represents the specified molar flow. By conservation of mass, the $CO_2$ into the system must equal the $CO_2$ out:

$$[CO_2]_{ex}N_{ex} + [CO_2]_{dil}N_{dil} = [CO_2]_{tot}N_{tot} \quad \text{(D-1)}$$

If we assume no chemical reactions are taking place the number of moles into the dilution system must be equal to the number out:

$$N_{ex} + N_{dil} = N_{tot} \quad \text{(D-2)}$$

We define the dilution ratio as the total exhaust flow divided by the raw exhaust flow into the dilution system: $DR = N_{tot}/N_{ex}$ (D-3)

Combining equations D-1 and D-2 into D-3 yield the following:

$$DR = \frac{[CO_2]_{ex,wet} - [CO_2]_{dil,wet}}{[CO_2]_{tot,wet} - [CO_2]_{dil,wet}} \quad \text{(D-4)}$$

Since the $CO_2$ concentrations are measured on a dry basis, the water loss must be accounted for, which is accomplished by using the following relations.

$$[CO_2]_{ex,wet} = [CO_2]_{ex,dry}(1-[H_2O]) \quad \text{(D-5)}$$

$$[CO_2]_{dil,wet} = [CO_2]_{dil,dry} \tag{D-6}$$

(there is no water in the dilution air)

Water in the diluted exhaust originates from the engine exhaust only. Since the dilution air contains no water the $CO_2$ concentration in the sampled air stream can be corrected by using the following apprOximation:

$$[CO_2]_{tot,wet} = [CO_2]_{tot,dry}\left(1 - \frac{[H_2O]_{ex}}{DR_{dry}}\right) \tag{D-7}$$

Note equation D-7 is essentially the same as D-5, however the water content has been diluted by an amount close to the dry dilution ratio (D-4 using dry values). The actual dilution ratio is found by substituting D-5, D-6, D-7 into D-4.

$$DR = \frac{[CO2]_{ex,dry}(1 - [H2O]_{ex}) - [CO_2]_{dil,dry}}{[CO_2]_{tot,dry}\left(1 - \frac{[H_2O]_{ex}}{DR_{dry}}\right) - [CO_2]_{dil,dry}} \tag{D-8}$$

# Appendix E: Sampling Procedure – Filters with TEOM

1. Before engine operation:
    - TEOM is turned on (with computer) to allow heating element to reach 50°C at least an hour before sampling. Ensure to start "teom-1105" program so warm-up procedure is initiated.
    - Purge air supply (TEOM) should be connected and set to 10 psig at bottle regulator.
    - Plug in mass flow controllers at least 30 minutes prior to operation.
    - Turn on heating tape at Variac to a value of 20 to heat up sample tube.

2. After engine has reached desired operating point:
    - Insert pre-weighed filters into filter holder, record number and engine conditions in logbook
    - Open TEOM purge air valve and plug in TEOM sample pump. Ensure flow rate is 3.0SLPM.
    - Open dilution air flow valve at sample line, ensure pressure is set to 10 psig at regulator

3. Rename low speed label field in data acquisition program to match the primary filter number with EGR rate if applicable. Begin low speed data collection, ensure sampling rate has been adjusted to record every 5-15 seconds.

4. Start TEOM sampling mode (ensure dilution air is on first), this should be sampling clean air with very little exhaust. TEOM pump must be plugged in.

5. Connect filter holder to bottom quick-connect joint only (to pump).

6. Turn on sample flow by opening large ball valve to exhaust duct and switching on sample pump. The filter holder should be drawing ambient air through the filters. Wait until mass flow controller connected to pump approaches setpoint value.

7. Open small ball valve (from dilution region) and allow any moisture to blow out (hold your breath). Connect other quick connect region and begin timing experiment at this point. This commences the sampling period for both the TEOM and filters.

8. Change $CO_2$ line source to PM (vs intake) and ensure $CO_2$ analyzer is receiving sufficient flow (check valves, pump, etc). Ensure dilution ratio is between 10 and 15, if it is not adjust dilution air mass flow controller, record adjustment in logbook.

9. At mid-point of sampling time
   - Make note of all data in logbook ("PM Tunnel Data"):
   - Capture high-speed data, change name to "Fast-xxx" where xxx is filter no.
   - Record any comments or concerns in lab book
   - Ensure low-speed data acquisition continues for remainder of sampling period

10. As soon as the sampling period expires:
    - Turn off sample pump
    - Close ball valve to exhaust duct
    - Close ball valve to filter holders
    - Remove filters
    - Return TEOM to "Initialization Mode"
    - Make note of stop time (TEOM and DAQ PCs)
    - Turn off dilution air
    - Place filters in appropriate cases and replace filters with unused pre-weighed filters for next point, return to step 2 when ready to begin sampling.

11. Otherwise shut down TEOM, unplug mass flow controller, proceed to engine shut down procedure.

# Appendix F: Operating Procedure – TEOM

1. Before engine operation:
   - TEOM is turned on (with computer) to allow heating element to reach 50°C at least an hour before sampling. Ensure to start "teom-1105" program so warm-up procedure is initiated.
   - Purge air supply (TEOM) should be connected and set to 10 psig at bottle regulator.
   - Plug in mass flow controllers at least 30 minutes prior to operation.
   - Turn on heating tape at Variac to a value of 20 to heat up sample tube.
   - Insert glass fiber filters into filter holder, these may need to be changed if heavy particulate emission are measured or used for an extended period.
   - Insert filter holder into quick connect joint at both ends

2. After engine has reached desired operating point:
   - Open TEOM purge air valve and plug in TEOM sample pump. Ensure flow rate is 3.0SLPM on TEOM data screen.
   - Open dilution air flow valve at sample line, ensure pressure is set to 10 psig at regulator

3. Rename low speed label field in data acquisition program to match the primary filter number with EGR rate if applicable. Begin low speed data collection, ensure sampling rate has been adjusted to record every 5-15 seconds.

4. Turn on sample flow by opening large ball valve to exhaust duct and switching on sample pump.

5. Change $CO_2$ line source to PM (vs intake) and ensure $CO_2$ analyzer is receiving sufficient flow (check valves, pump, etc). Ensure dilution ratio is between 10 and

15, if it is not adjust dilution air mass flow controller, note dilution ratio will be affected by TEOM flow as well (test run can be performed).

6. Start TEOM sampling mode (ensure dilution air is on first) by pressing F1 and entering a filename. A solenoid valve will click open, this starts the sampling period.

7. At mid-point of sampling time
   - Make note of all data in logbook ("PM Tunnel Data"):
   - Take high-speed data file
   - Record any comments or concerns in lab book
   - Ensure low-speed data acquisition continues for remainder of sampling period

8. As soon as the sampling period expires:
   - Stop TEOM sampling by pressing F2.
   - Press F3 and enter 'y' to return to initialization mode, this is necessary before starting to sample again.
   - Sample pump and dilution air can be left on if continuing to collect data

9. Set next operating point and return to step 2

10. Otherwise shut down TEOM, unplug mass flow controller, proceed to engine shut down procedure.

# Appendix G: List of Electronic Files

| Location/Filename(s) | Description |
|---|---|
| /Data/fastout.xls | template file required by high speed data processing routine |
| /Data/filter_weights.xls | data file containing filter weights, mass flow rates and experiment duration data. |
| /Data/High Speed Data Processing Routine.xls | self explanatory – author: G. McTaggart-Cowan |
| /Data/SCRE Emissions Spreadsheet.xls | self explanatory – author: S. Munshi |
| /Data/summary.xls | Excel file used to generate report from multiple data files. |
| /Data/template.xls | template file incorporating "SCRE Emission Sheet.xls" and "High Speed Data Processing Routine"used to calculate all PM emission rates. |
| /Data//Analyzed/071 – 125.xls | Results from experiments performed after Jan 1, 2002 until Feb 1, 2002 with excess diesel. Results used for TEOM vs Filters comparison |
| /Data//Analyzed/A1 – A30.xls | Baseline with TEOM and 5% diesel flow Mar 6-8 |
| /Data//Analyzed/B1 – B13.xls | BP and DPW study 1600RPM 40% load |
| /Data//Analyzed/C1 – C13.xls | BP and DPW study 800RPM 75% load |
| /Data//Analyzed/E1 – E13.xls | BP and DPW study 1400RPM 85% load |
| /Data//Analyzed/E1 – E13.xls | BP and DPW study 800RPM 25% load |
| /Data//Analyzed/A131 – A139.xls | Baseline points performed with TEOM and filters, Mar 8 (1600RPM 40% load) |
| /Data/raw/TEOM/"label".prn | TEOM output data fields |
| /Data/raw/ Files "label"-fast.csv | unprocessed high-speed data |
| /Data/raw/ Files "label"-slow.csv | unprocessed low-speed data (emissions, temperatures, pressures, etc.) |
| /Data/raw/015-125/ | all old raw data files for all experiments with corresponding label |
| /Data//Analyzed/Reports | reports/summaries generated on dates as labeled. |

## Appendix H: Engine Warm-up and Operating Procedure

The following list outlines the procedures used to achieve stable, repeatable operation of the SCRE with EGR over a range of operating conditions and EGR fractions. The following list refers to replacement EGR operation at fixed intake manifold temperature. Testing of other parameters will require some changes to these operating instructions. For non-EGR conditions the same procedure was used with low-range $CO_2$ connected to PM sampling outlet.

1) Let the engine reach full temperature by running at moderate speed and load (at least 95°C).

2) Set up the low-range $CO_2$ sensor for EGR operation. Turn the low-range selector valve (on the North outside wall of the test cell) to 'EGR'. Turn both handles on the $CO_2$ selector valves (inside the emissions bench, Cabinet 1, LHS) to 'low range'. Ensure that sample flow rate is 1 lpm (flow meter on RHS at back of cabinet) and that the drier flow rate (flow meter attached to back door of cabinet) is 2 lpm.

3) Determine the desired air and fuel flow rates and injection timing for the test point.

4) Adjust the supercharger speed, engine speed, engine load, and fuelling so that the engine is running under the desired conditions.

5) Adjust the back-pressure valve (using the control knob on the CP) until the BP reads 5-10 kPa above the intake manifold pressure.

6) Let the engine run for 5-10 minutes or until all the temperatures stop changing. Carefully monitor the intake air temperature.

7) Open the manual EGR valve (black handle, above the supercharger) so that EGR can flow to either the supercharger exhaust (handle to the left) or to the supercharger intake (handle to the right).

8) Open the remote EGR valve slowly. Watch the low-range $CO_2$ analyser output to detect when EGR flow starts. Adjust the EGR valve, supercharger speed and back-pressure valve to hold the manifold air pressure constant while adjusting the EGR fraction (displayed on the DAQ screen). Adjustments need to be made slowly, as the intake $CO_2$ sensor has a time delay of approximately 30 seconds.

9) During all adjustments, monitor the pressure trace and THC emissions.

10) Fine-tuning of the EGR flow rate is best achieved through stepwise adjustments of the supercharger (50 RPM) and the BP valve.

11) Once at the operating condition, let the engine run for about 5 minutes to allow all the readings to stabilise. Once low and high speed readings are taken, repeat steps 9-11 to get to the next desired operating condition.

12) To shut off the EGR system, reduce the opening of the EGR valve to 15-20%. Simultaneously (in stages) increase the supercharger speed and open the back-pressure valve so that the intake and exhaust manifold pressures are held approximately constant. Close the EGR valve the rest of the way, increase supercharger speed to reach the desired intake pressure, and adjust the back-pressure valve for the desired pressure.

13) Follow the standard procedures for adjusting the engine speed and load to reach the next desired operating condition. It is strongly recommended that the engine be run at a fixed (repeatability) point for at least 10 minutes between EGR test runs to purge all exhaust gases from the intake system and to ensure that the engine is operating in the expected manner.

# Appendix I: Diesel Flow Measurement

The mass of diesel in a reservoir was recorded with time to calculate diesel consumption. A linear regression was used to give the rate of decrease of fuel. Notice for even in the best case there is a large amount of noise in the data as shown in Figure 4-3. A regression analysis gives a range of 0.28 – 0.31 kg/hr for the slope at 95% confidence. The uncertainty of the diesel flow rate in this case would be within 10%.

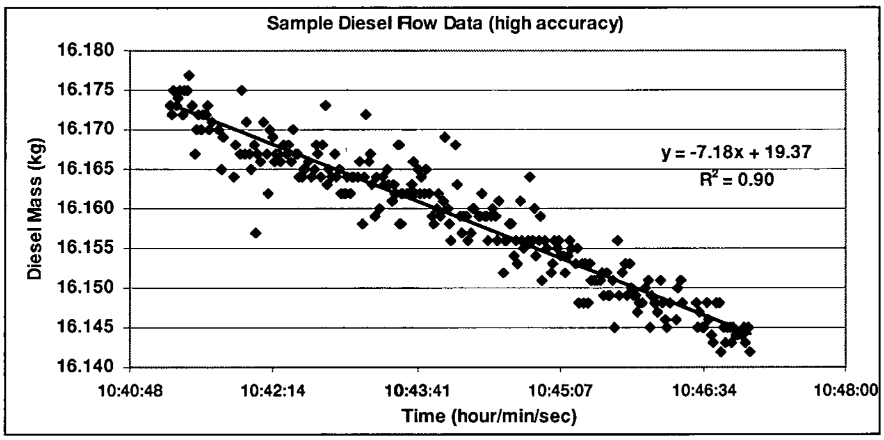



**Figure 4-3: Sample Diesel flow data - high accuracy**

A less ideal case is presented in Figure 4-4. The variability in this data is obviously higher.

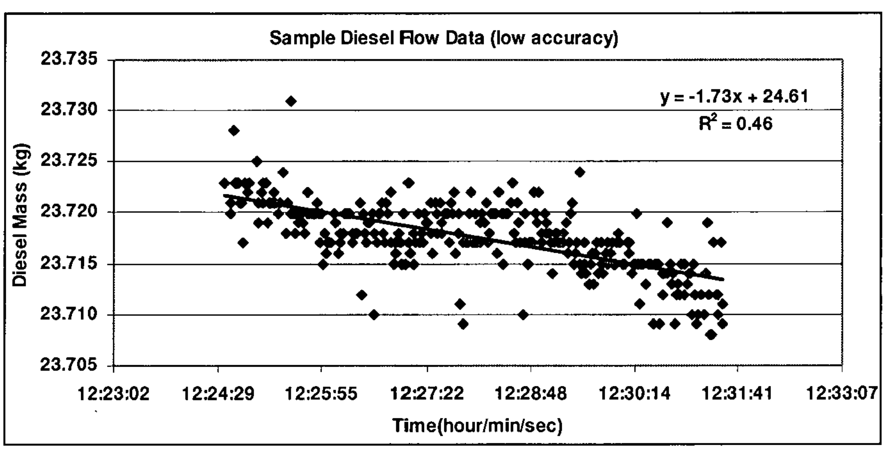



**Figure 4-4: Sample diesel flow data - low accuracy**

A regression analysis gives a range of 0.062 – 0.081 kg/hr for the slope at 95% confidence. The uncertainty of the diesel flow rate in this case would be 24%, however the true value should be around 0.15 kg/hr. In this situation, data from other sampling periods would be pooled and the diesel flow rate would be assumed constant over the entire interval. The error for this data set is likely to be 25% but could be even larger.

Figure 4-5 and Figure 4-6 the difficulty in discerning whether the actual diesel flow rate changes with pulse width or if it is purely excessive error in the calculation. At 800 RPM the diesel flow rate is unreliable with high variability. Hence, there is high scatter at various DPW values.

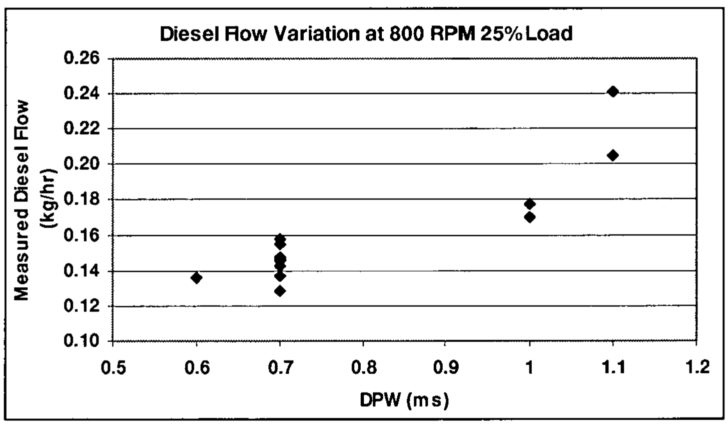



**Figure 4-5: Diesel Flow Measurements 800 RPM 25% Load**

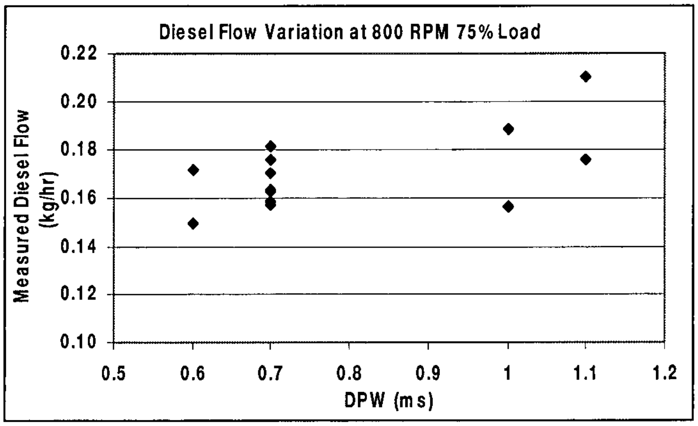



**Figure 4-6: Diesel Flow Measurements 800 RPM 75% Load**

At higher speeds, the same amount of scatter is present but represents less as a percentage of the total diesel flow rate, as shown in Figure 4-7 and Figure 4-8. For the following cases there is more confidence in the calculated diesel flow rate.

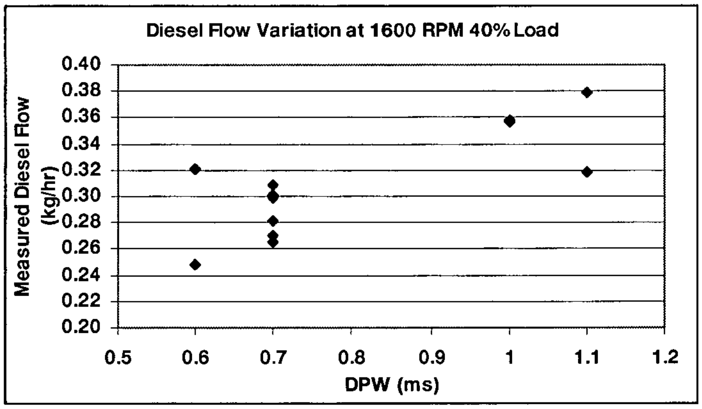



**Figure 4-7: Diesel Flow Measurements 1600 RPM 40% Load**

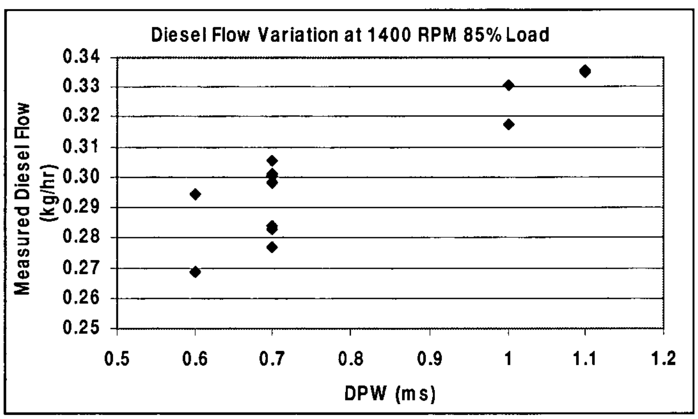



**Figure 4-8: Diesel Flow Measurements 1400 RPM 85% Load**

It is concluded the error in diesel flow measurements is around 20% at 800 RPM and 10% at the higher speeds.

## Appendix J: High-Speed Data Summaries

Attached is the high-speed data calculations for all samples. The pressure vs volume diagrams have been presented in log p vs V to emphasize the pumping loop. Graphs of the following in-cylinder pressure measurements are presented:

- pressure vs crank angle
- pressure vs volume
- heat release rate vs crank angle

All data is available with electronic submission on CD.

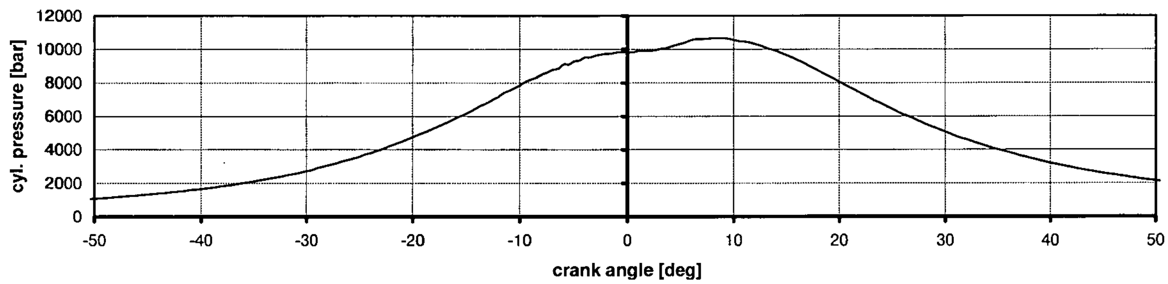
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 10660.71 |
| CA @ P_max [deg] | 8.0 |
| dP/dCA_max [bar/deg] | 398.067 |
| CA @ dP/dCA_max [deg] | -12.0 |
| IMEP [bar] | 801.67 |
| HHR_max [kJ/m^3/deg] | 9364.2 |
| IHR_max [kJ/m^3] | 142128.0 |
| 5% MFB [deg w.r.t TDC] | -5.0 |
| 10% MFB [deg w.r.t TDC] | 2.5 |
| 50% MFB [deg w.r.t TDC] | 10.0 |
| 90% MFB [deg w.r.t TDC] | 23.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.35 |
| poly-n compression corrected | 1.35 |
| poly-n expansion uncorrected | 1.31 |
| poly-n expansion corrected | 1.31 |

**Comments**

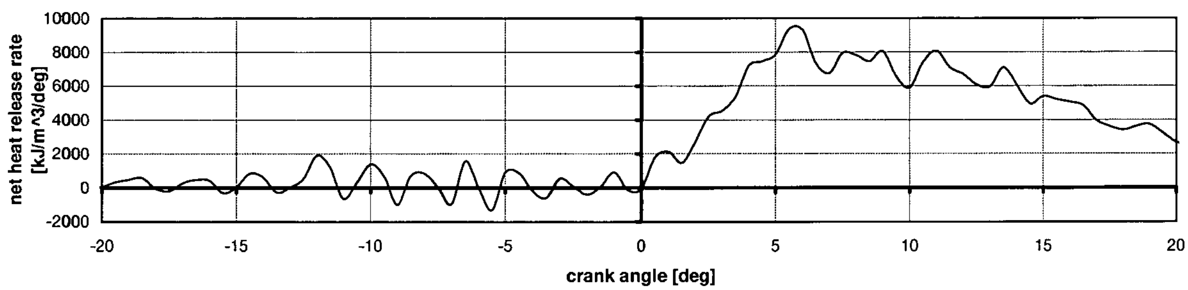
| Data Summary for filter: | 07.1 |
|---|---|
| Date: | 1/16/02 |
| Time: | 9:37:25 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1607.5 |
| Load-approx. (%) | 40.0 |
| Power (kW) | 26.9 |
| IMEP (bar) | 8.03 |
| Pmax(bar) | 107.40 |
| Pmax location (degrees) | 368.4 |
| Diesel Flow(kg/hr) | 0.54237 |
| CNG Flow(kg/hr) | 3.60 |
| Air Flow(kg/hr) | 209.8 |
| Exhaust Flow(kg/hr) | 214.0 |
| Exhaust Back Pressure (kPa) | 11.8 |
| EGR Fraction(%) | 0.0 |

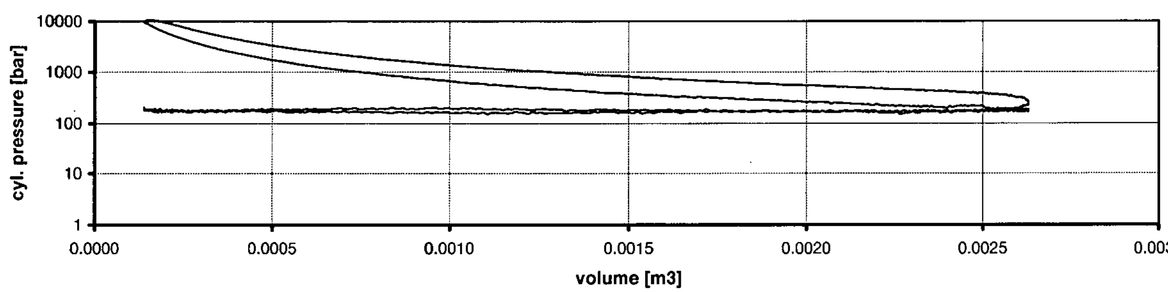
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume

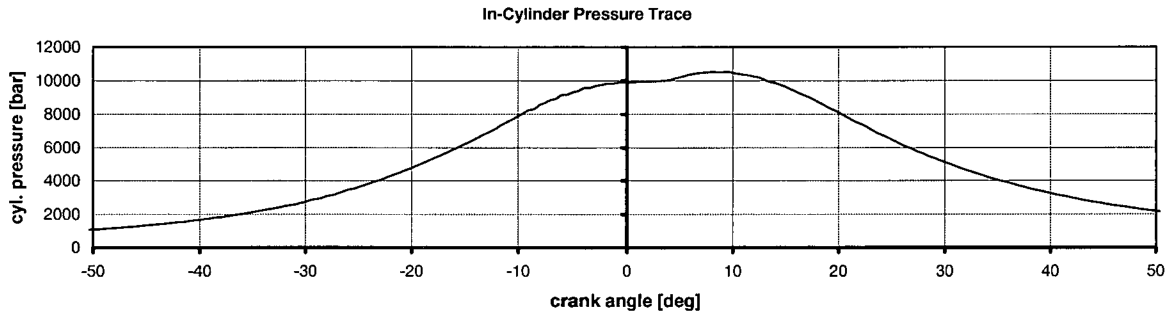


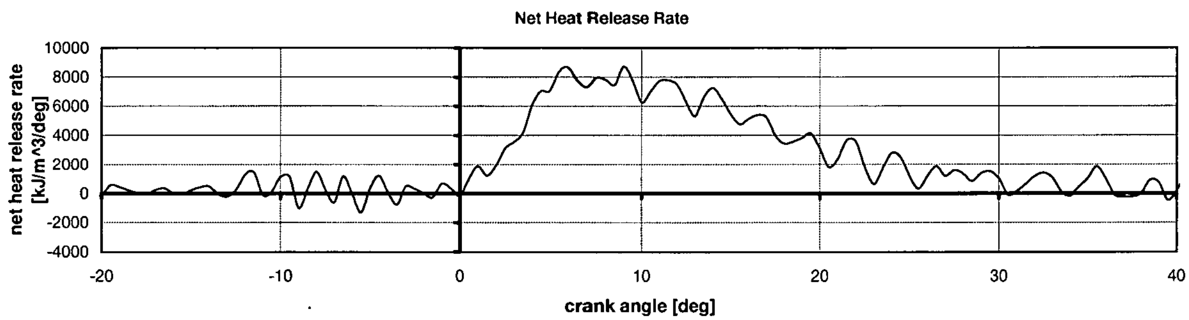
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 10532.12 |
| CA @ P_max [deg] | 9.5 |
| dP/dCA_max [bar/deg] | 382.558 |
| CA @ dP/dCA_max [deg] | -11.5 |
| IMEP [bar] | 816.40 |
| HHR_max [kJ/m^3/deg] | 8717.3 |
| IHR_max [kJ/m^3] | 145650.7 |
| 5% MFB [deg w.r.t TDC] | -1.0 |
| 10% MFB [deg w.r.t TDC] | 3.0 |
| 50% MFB [deg w.r.t TDC] | 11.0 |
| 90% MFB [deg w.r.t TDC] | 25.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.36 |
| poly-n compression corrected | 1.36 |
| poly-n expansion uncorrected | 1.29 |
| poly-n expansion corrected | 1.29 |

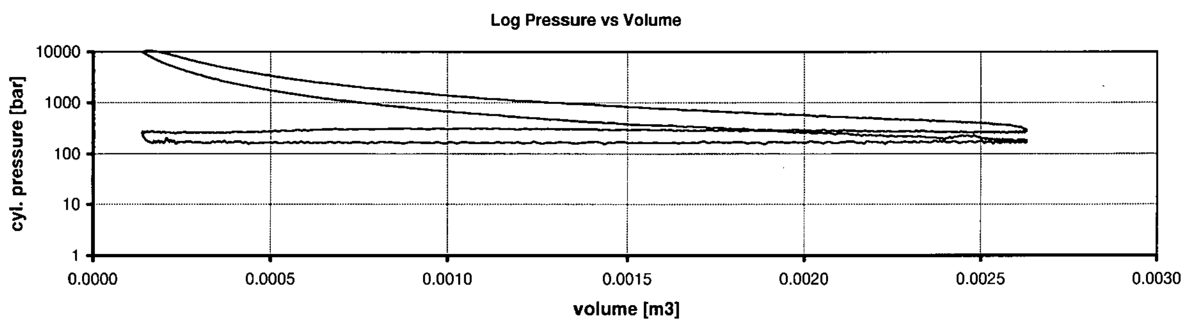
Comments

| | |
|---|---|
| Data Summary for filter: | 073 |
| Date: | 1/16/02 |
| Time: | 10:03:19 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1598.9 |
| Load - approx(%) | 40.0 |
| Power (kW) | 27.2 |
| IMEP (bar) | 8.17 |
| Pmax(bar) | 106.03 |
| Pmax location (degrees) | 368.7 |
| Diesel Flow(kg/hr) | 0.61279 |
| CNG Flow(kg/hr) | 3.65 |
| Air Flow(kg/hr) | 176.9 |
| Exhaust Flow(kg/hr) | 181.2 |
| Exhaust Back Pressure (kPa) | 115.0 |
| EGR Fraction(%) | 11.6 |



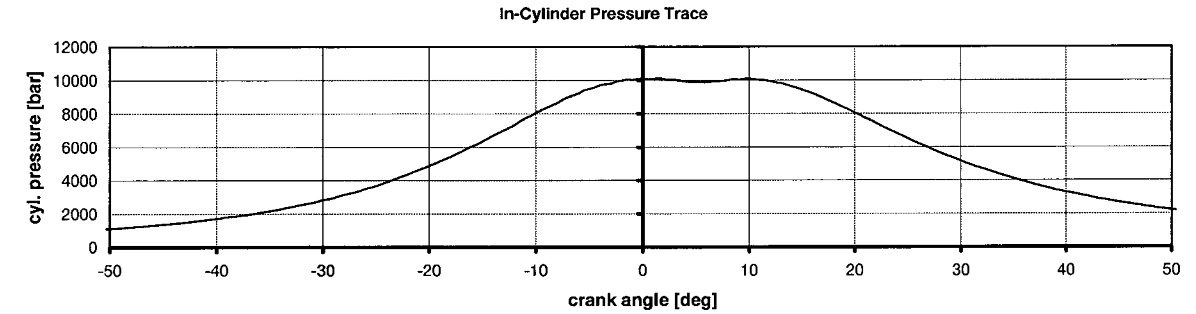



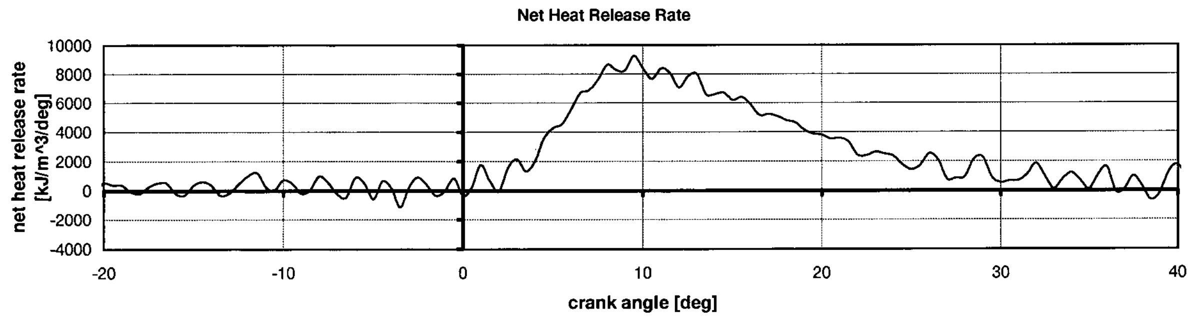
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 10108.53 |
| CA @ P_max [deg] | 1.5 |
| dP/dCA_max [bar/deg] | 379.112 |
| CA @ dP/dCA_max [deg] | -11.5 |
| IMEP [bar] | 801.04 |
| HHR_max [kJ/m^3/deg] | 9292.0 |
| IHR_max [kJ/m^3] | 146236.4 |
| 5% MFB [deg w.r.t TDC] | 0.5 |
| 10% MFB [deg w.r.t TDC] | 4.5 |
| 50% MFB [deg w.r.t TDC] | 12.5 |
| 90% MFB [deg w.r.t TDC] | 28.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.34 |
| poly-n compression corrected | 1.34 |
| poly-n expansion uncorrected | 1.29 |
| poly-n expansion corrected | 1.29 |

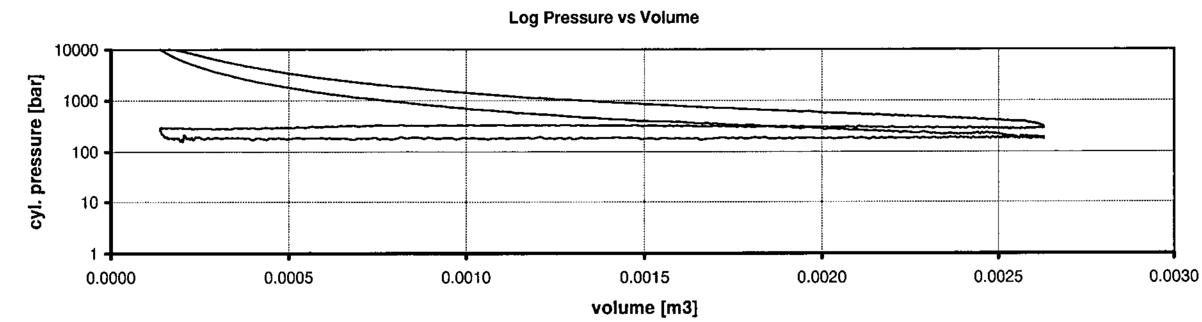
**Comments**

| | |
|---|---|
| Data Summary for filter: | 075 |
| Date: | 1/16/02 |
| Time: | 10:19:51 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1601.7 |
| Load - approx(%) | 40.0 |
| Power (kW) | 26.8 |
| IMEP (bar) | 8.02 |
| Pmax(bar) | 102.08 |
| Pmax location (degrees) | 366.0 |
| Diesel Flow(kg/hr) | 0.61991 |
| CNG Flow(kg/hr) | 3.68 |
| Air Flow(kg/hr) | 149.4 |
| Exhaust Flow(kg/hr) | 153.7 |
| Exhaust Back Pressure (kPa) | 123.8 |
| EGR Fraction(%) | 24.8 |



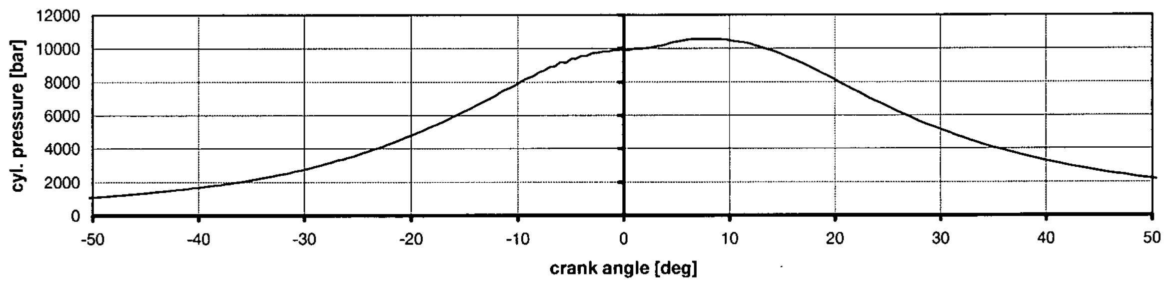
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 10553.73 |
| CA @ P_max [deg] | 8.0 |
| dP/dCA_max [bar/deg] | 396.344 |
| CA @ dP/dCA_max [deg] | -12.0 |
| IMEP [bar] | 821.63 |
| HHR_max [kJ/m^3/deg] | 8225.0 |
| IHR_max [kJ/m^3] | 148785.5 |
| 5% MFB [deg w.r.t TDC] | 0.0 |
| 10% MFB [deg w.r.t TDC] | 2.5 |
| 50% MFB [deg w.r.t TDC] | 11.0 |
| 90% MFB [deg w.r.t TDC] | 26.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.33 |
| poly-n compression corrected | 1.33 |
| poly-n expansion uncorrected | 1.28 |
| poly-n expansion corrected | 1.28 |

**Comments**

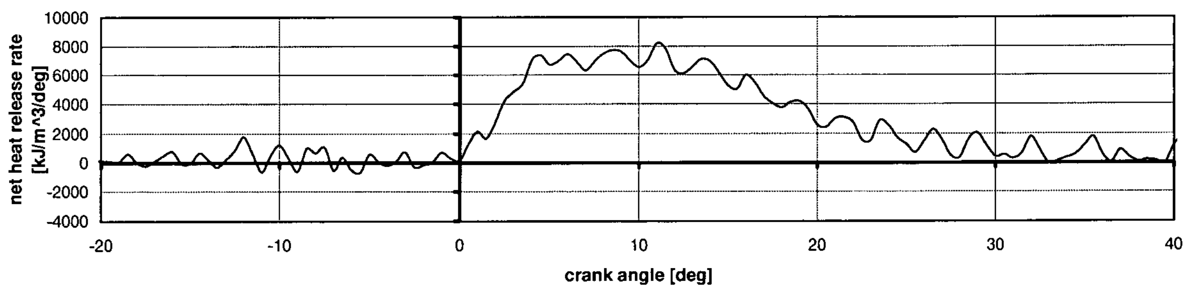
| | |
|---|---|
| Data Summary for filter: | 077 |
| Date: | 1/16/02 |
| Time: | 10:39:10 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1603.4 |
| Load(%) | 40.0 |
| Power (kW) | 27.5 |
| IMEP (bar) | 8.23 |
| Pmax(bar) | 106.31 |
| Pmax location (degrees) | 368.2 |
| Diesel Flow(kg/hr) | 0.63 |
| CNG Flow(kg/hr) | 3.69 |
| Air Flow(kg/hr) | 210.8 |
| Exhaust Flow(kg/hr) | 215.1 |
| Exhaust Back Pressure (kPa) | 10.3 |
| EGR Fraction(%) | 0.0 |

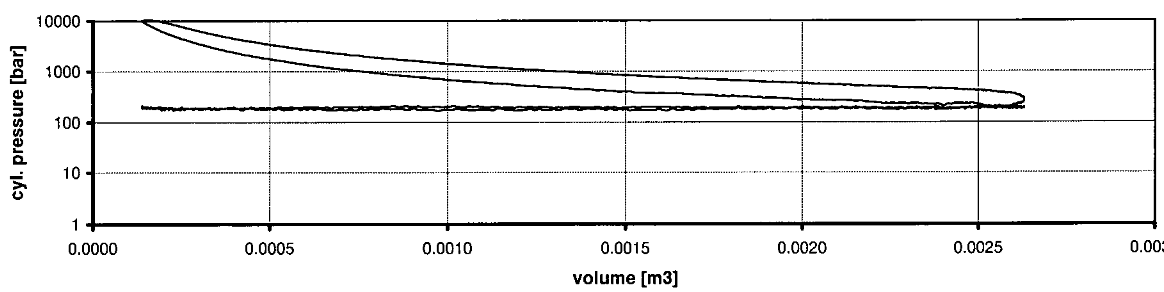
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume

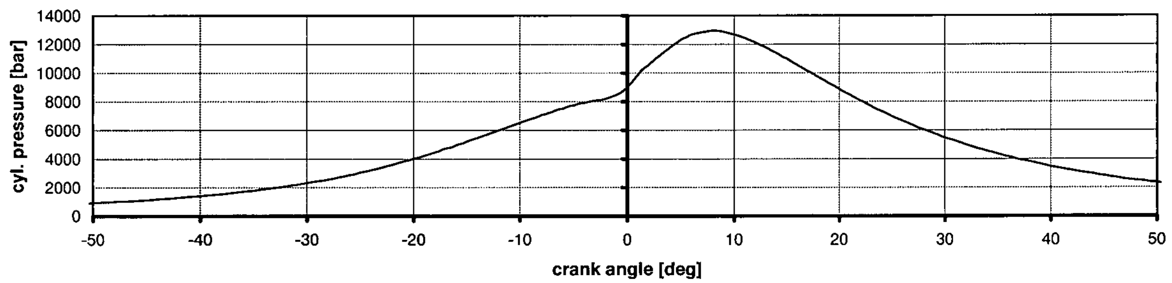


| | | Comments |
|---|---|---|
| Speed [RPM] | | |
| Torque [N-m] | | |
| Load [%] | | |
| P_max [deg] | 12931.37 | |
| CA @ P_max [deg] | 8.0 | |
| dP/dCA_max [bar/deg] | 877.127 | |
| CA @ dP/dCA_max [deg] | 0.5 | |
| IMEP [bar] | 1143.64 | |
| HHR_max [kJ/m^3/deg] | 16945.0 | |
| IHR_max [kJ/m^3] | 201930.9 | |
| 5% MFB [deg w.r.t TDC] | -1.5 | |
| 10% MFB [deg w.r.t TDC] | -0.5 | |
| 50% MFB [deg w.r.t TDC] | 5.0 | |
| 90% MFB [deg w.r.t TDC] | 21.5 | |
| Assumed poly-n during comprn. | 1.37 | |
| zero-level pr. offset [bar] | 0.000 | |
| poly-n compression uncorrected | 1.38 | |
| poly-n compression corrected | 1.38 | |
| poly-n expansion uncorrected | 1.35 | |
| poly-n expansion corrected | 1.35 | |

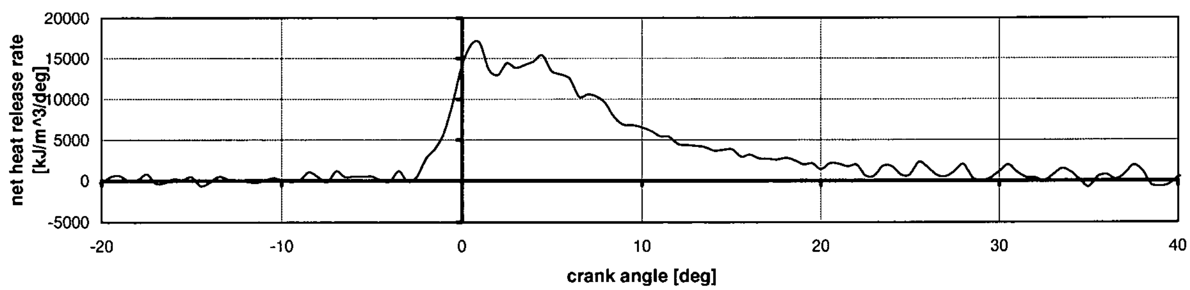
| Data Summary for filter: | 079 |
|---|---|
| Date: | 1/18/02 |
| Time: | 13:57:38 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 821.0 |
| Load(%) | 75.0 |
| Power (kW) | 19.6 |
| IMEP (bar) | 11.45 |
| Pmax(bar) | 129.99 |
| Pmax location (degrees) | 368.7 |
| Diesel Flow(kg/hr) | 0.58 |
| CNG Flow(kg/hr) | 2.84 |
| Air Flow(kg/hr) | 91.6 |
| Exhaust Flow(kg/hr) | 95.0 |
| Exhaust Back Pressure (kPa) | 11.7 |
| EGR Fraction(%) | 0.0 |

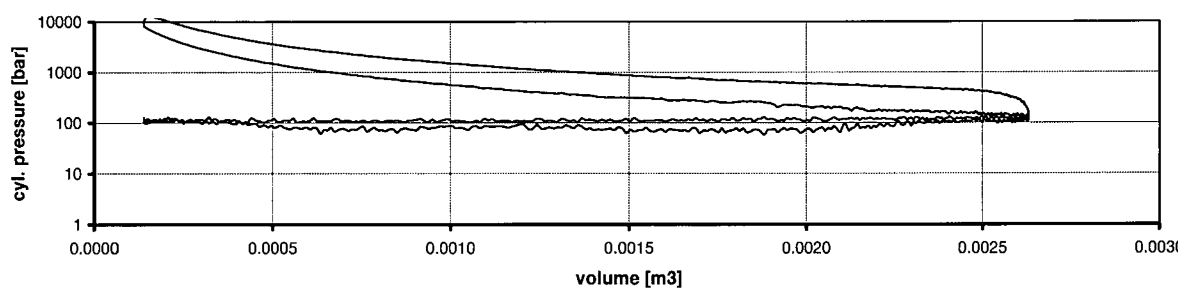
**In-Cylinder Pressure Trace**




**Net Heat Release Rate**




**Log Pressure vs Volume**



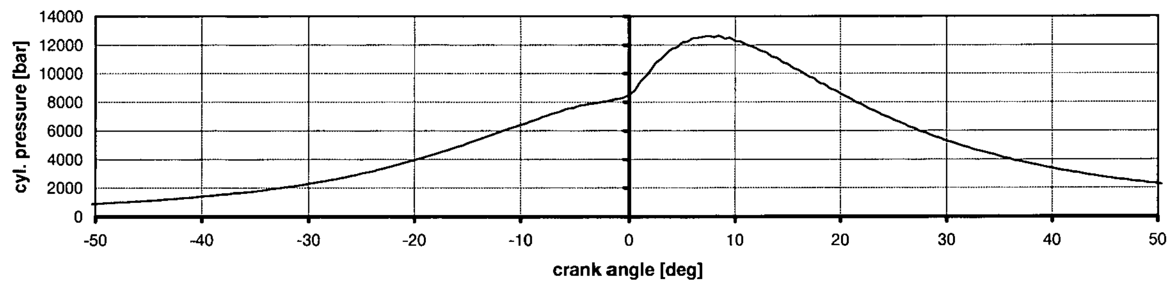
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 12642.40 |
| CA @ P_max [deg] | 7.5 |
| dP/dCA_max [bar/deg] | 947.779 |
| CA @ dP/dCA_max [deg] | 2.0 |
| IMEP [bar] | 1099.33 |
| HHR_max [kJ/m^3/deg] | 19461.5 |
| IHR_max [kJ/m^3] | 194264.4 |
| 5% MFB [deg w.r.t TDC] | -1.0 |
| 10% MFB [deg w.r.t TDC] | 0.0 |
| 50% MFB [deg w.r.t TDC] | 5.0 |
| 90% MFB [deg w.r.t TDC] | 22.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.35 |
| poly-n compression corrected | 1.35 |
| poly-n expansion uncorrected | 1.35 |
| poly-n expansion corrected | 1.35 |

**Comments**

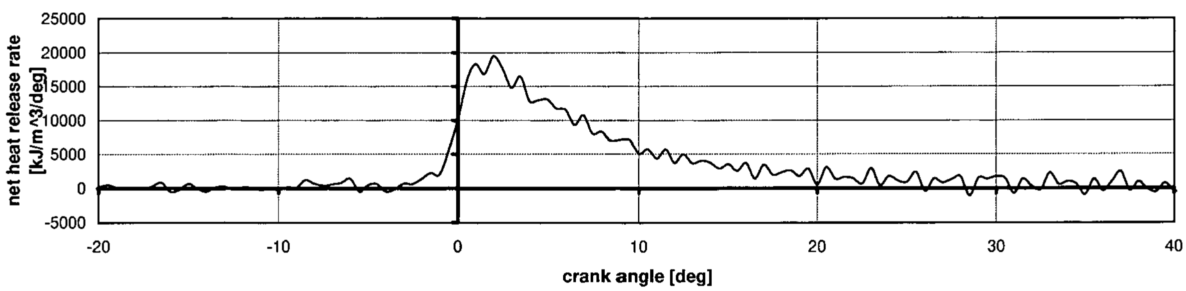
| | |
|---|---|
| Data Summary for filter: | 081 |
| Date: | 1/18/02 |
| Time: | 14:30:36 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 815.1 |
| Load(%) | 75.0 |
| Power (kW) | 18.7 |
| IMEP (bar) | 11.01 |
| Pmax(bar) | 126.85 |
| Pmax location (degrees) | 368.1 |
| Diesel Flow(kg/hr) | 0.63 |
| CNG Flow(kg/hr) | 2.74 |
| Air Flow(kg/hr) | 78.0 |
| Exhaust Flow(kg/hr) | 81.4 |
| Exhaust Back Pressure (kPa) | 51.6 |
| EGR Fraction(%) | 12.2 |

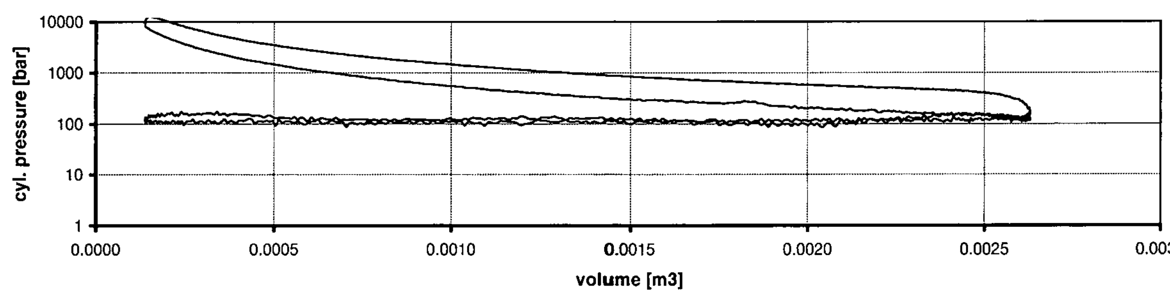
In-Cylinder Pressure Trace




Net Heat Release Rate



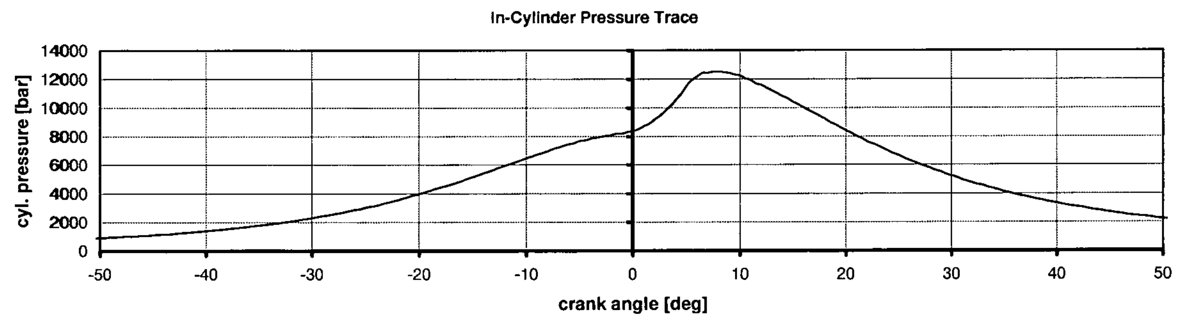

Log Pressure vs Volume

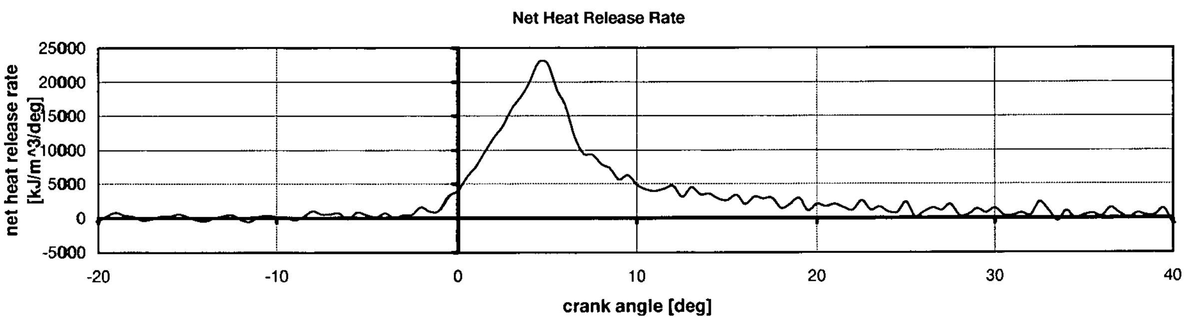


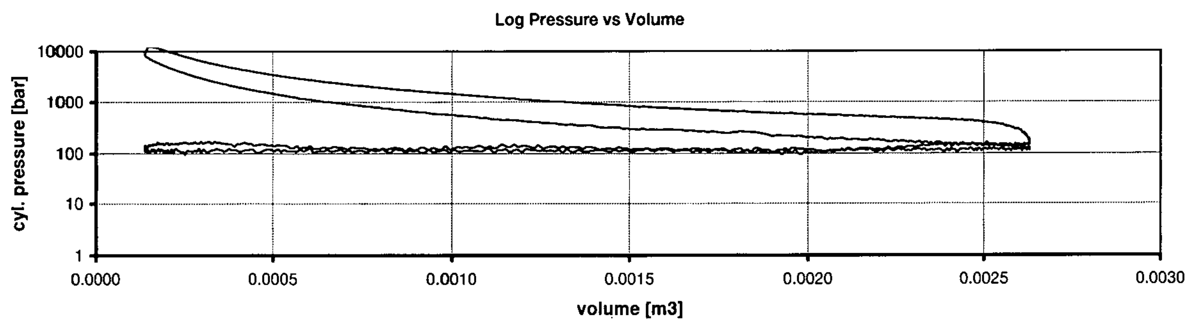
| | | Comments |
|---|---|---|
| Speed [RPM] | | |
| Torque [N-m] | | |
| Load [%] | | |
| P_max [deg] | 12524.71 | |
| CA @ P_max [deg] | 7.5 | |
| dP/dCA max [bar/deg] | 966.735 | |
| CA @ dP/dCA max [deg] | 4.5 | |
| IMEP [bar] | 1064.31 | |
| HHR max [kJ/m^3/deg] | 22878.0 | |
| IHR max [kJ/m^3] | 187628.5 | |
| 5% MFB [deg w.r.t TDC] | -0.5 | |
| 10% MFB [deg w.r.t TDC] | 1.0 | |
| 50% MFB [deg w.r.t TDC] | 5.5 | |
| 90% MFB [deg w.r.t TDC] | 23.5 | |
| Assumed poly-n during comprn. | 1.37 | |
| zero-level. pr. offset [bar] | 0.000 | |
| poly-n compression uncorrected | 1.37 | |
| poly-n compression corrected | 1.37 | |
| poly-n expansion uncorrected | 1.31 | |
| poly-n expansion corrected | 1.31 | |

| | |
|---|---|
| Data Summary for filter: | 083 |
| Date: | 1/18/02 |
| Time: | 14:51:15 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 813.3 |
| Load(%) | 75.0 |
| Power (kW) | 18.1 |
| IMEP (bar) | 10.66 |
| Pmax(bar) | 125.92 |
| Pmax location (degrees) | 368.3 |
| Diesel Flow(kg/hr) | 0.62 |
| CNG Flow(kg/hr) | 2.69 |
| Air Flow(kg/hr) | 67.5 |
| Exhaust Flow(kg/hr) | 70.8 |
| Exhaust Back Pressure (kPa) | 55.7 |
| EGR Fraction(%) | 23.3 |



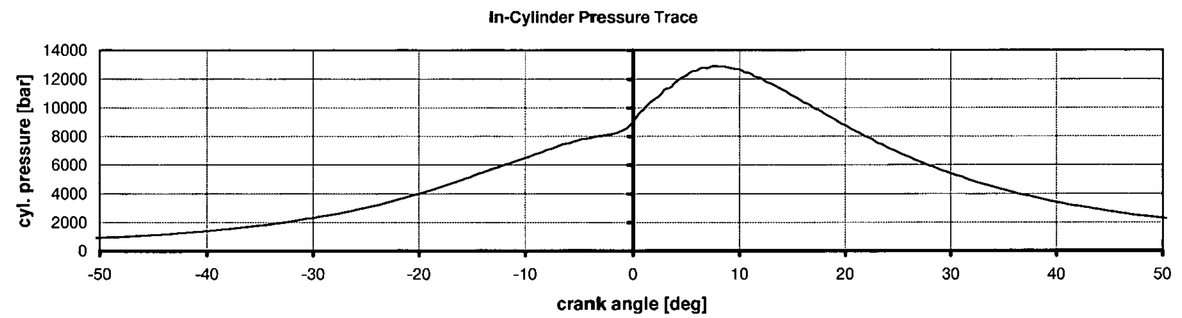



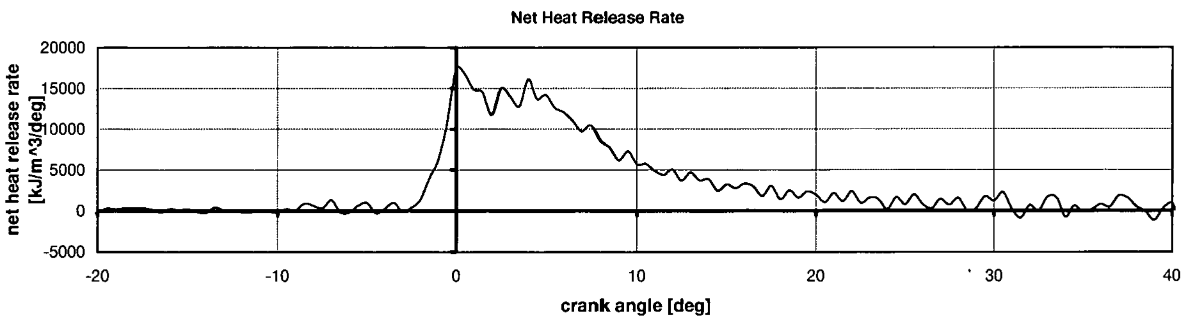
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 12887.84 |
| CA @ P_max [deg] | 7.5 |
| dP/dCA_max [bar/deg] | 944.333 |
| CA @ dP/dCA_max [deg] | 0.0 |
| IMEP [bar] | 1112.81 |
| HHR_max [kJ/m^3/deg] | 17487.6 |
| IHR_max [kJ/m^3] | 196396.8 |
| 5% MFB [deg w.r.t TDC] | -1.5 |
| 10% MFB [deg w.r.t TDC] | -0.5 |
| 50% MFB [deg w.r.t TDC] | 5.0 |
| 90% MFB [deg w.r.t TDC] | 21.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.36 |
| poly-n compression corrected | 1.36 |
| poly-n expansion uncorrected | 1.36 |
| poly-n expansion corrected | 1.36 |

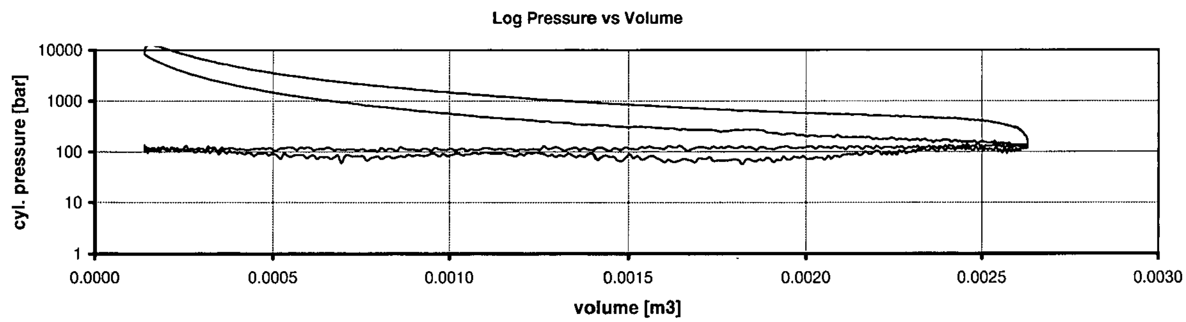
**Comments**

| | |
|---|---|
| Data Summary for filter: | 087 |
| Date: | 1/18/02 |
| Time: | 15:07:59 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 822.6 |
| Load(%) | 75.0 |
| Power (kW) | 19.1 |
| IMEP (bar) | 11.14 |
| Pmax(bar) | 129.45 |
| Pmax location (degrees) | 368.4 |
| Diesel Flow(kg/hr) | 0.61 |
| CNG Flow(kg/hr) | 2.74 |
| Air Flow(kg/hr) | 91.7 |
| Exhaust Flow(kg/hr) | 95.1 |
| Exhaust Back Pressure (kPa) | 10.9 |
| EGR Fraction(%) | 0.0 |



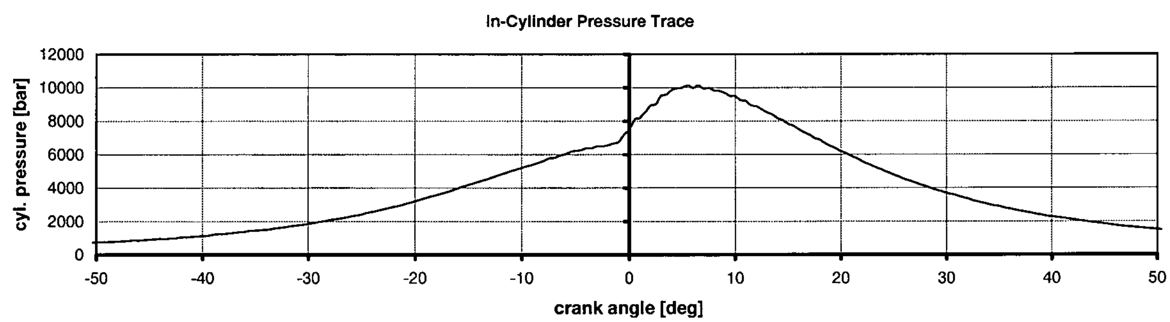



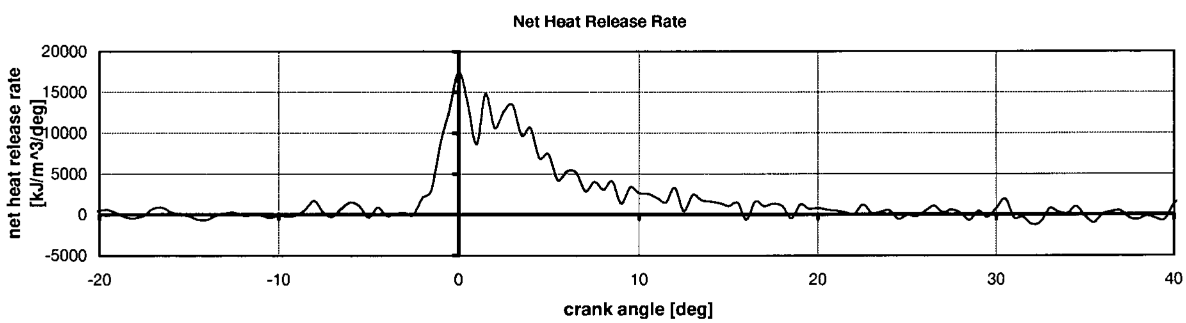
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 10130.87 |
| CA @ P_max [deg] | 6.5 |
| dP/dCA_max [bar/deg] | 940.886 |
| CA @ dP/dCA_max [deg] | 0.0 |
| IMEP [bar] | 652.08 |
| HHR_max [kJ/m^3/deg] | 17423.8 |
| IHR_max [kJ/m^3] | 113304.3 |
| 5% MFB [deg w.r.t TDC] | -2.0 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 2.5 |
| 90% MFB [deg w.r.t TDC] | 11.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.32 |
| poly-n compression corrected | 1.32 |
| poly-n expansion uncorrected | 1.37 |
| poly-n expansion corrected | 1.37 |

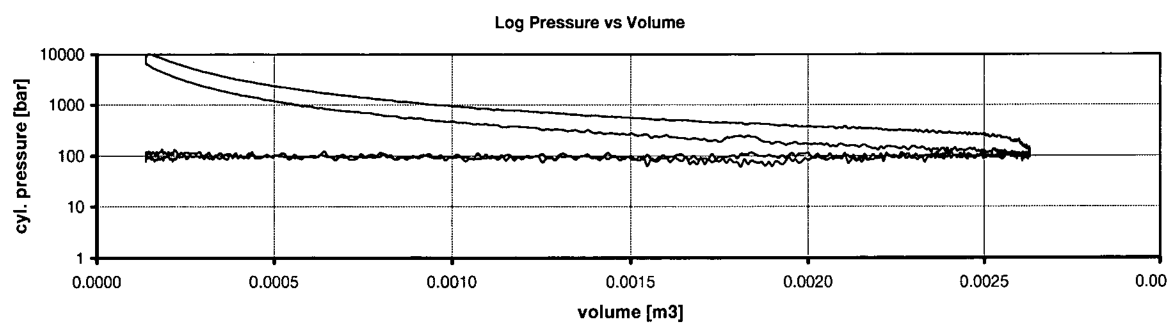
**Comments**

| | |
|---|---|
| Data Summary for filter: | 089 |
| Date: | 1/21/02 |
| Time: | 13:20:32 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 803.8 |
| Load(%) | |
| Power (kW) | 10.9 |
| IMEP (bar) | 6.53 |
| Pmax(bar) | 101.81 |
| Pmax location (degrees) | 366.3 |
| Diesel Flow(kg/hr) | 0.73 |
| CNG Flow(kg/hr) | 1.22 |
| Air Flow(kg/hr) | 72.1 |
| Exhaust Flow(kg/hr) | 74.0 |
| Exhaust Back Pressure (kPa) | 12.6 |
| EGR Fraction(%) | 0.0 |



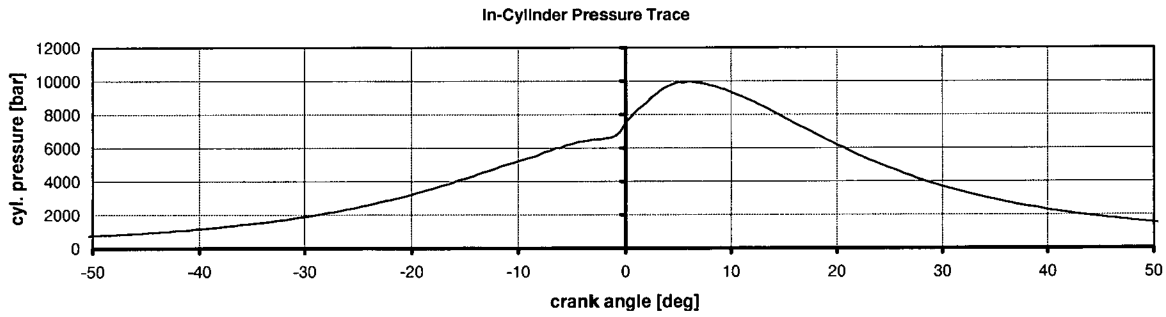



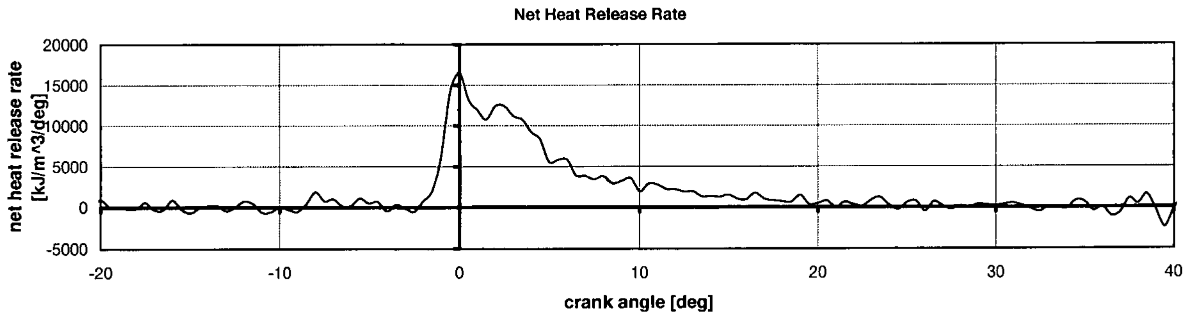
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 9971.47 |
| CA @ P max [deg] | 6.0 |
| dP/dCA max [bar/deg] | 894.359 |
| CA @ dP/dCA max [deg] | 0.0 |
| IMEP [bar] | 655.76 |
| HHR max [kJ/m^3/deg] | 16562.2 |
| IHR max [kJ/m^3] | 113960.4 |
| 5% MFB [deg w.r.t TDC] | -1.5 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 2.5 |
| 90% MFB [deg w.r.t TDC] | 13.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.29 |
| poly-n compression corrected | 1.29 |
| poly-n expansion uncorrected | 1.31 |
| poly-n expansion corrected | 1.31 |

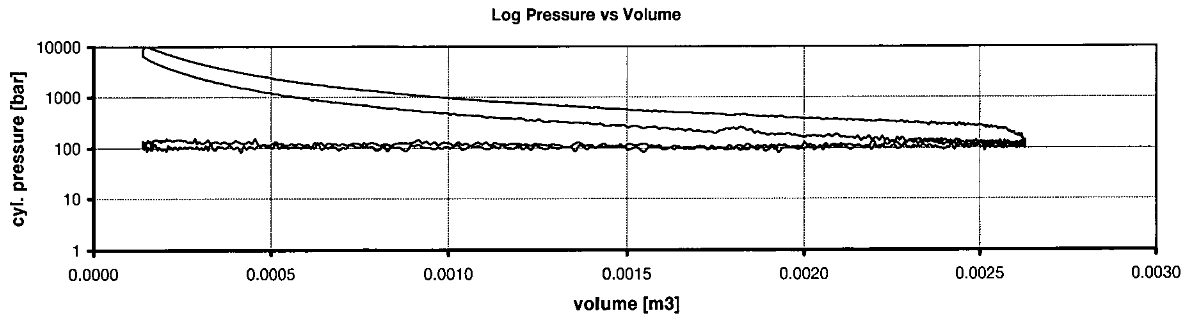
**Comments**

| | |
|---|---|
| Data Summary for filter: | 091 |
| Date: | 1/21/02 |
| Time: | 13:42:34 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 803.2 |
| Load(%) | 25.0 |
| Power (kW) | 11.0 |
| IMEP (bar) | 6.57 |
| Pmax(bar) | 100.42 |
| Pmax location (degrees) | 366.2 |
| Diesel Flow(kg/hr) | 0.78 |
| CNG Flow(kg/hr) | 1.18 |
| Air Flow(kg/hr) | 61.3 |
| Exhaust Flow(kg/hr) | 63.3 |
| Exhaust Back Pressure (kPa) | 25.8 |
| EGR Fraction(%) | 12.6 |



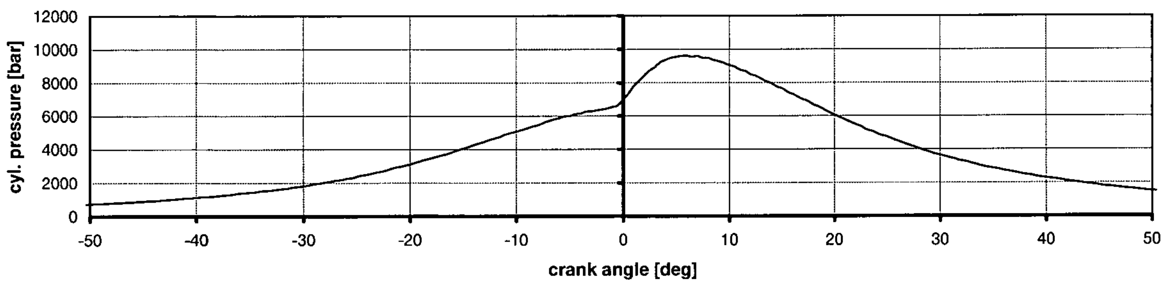
| Speed [RPM] | |
| --- | --- |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 9627.79 |
| CA @ P_max [deg] | 6.0 |
| dP/dCA_max [bar/deg] | 827.153 |
| CA @ dP/dCA_max [deg] | 0.5 |
| IMEP [bar] | 655.75 |
| HHR_max [kJ/m^3/deg] | 15646.2 |
| IHR_max [kJ/m^3] | 113727.2 |
| 5% MFB [deg w.r.t TDC] | -1.0 |
| 10% MFB [deg w.r.t TDC] | -0.5 |
| 50% MFB [deg w.r.t TDC] | 3.0 |
| 90% MFB [deg w.r.t TDC] | 15.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.34 |
| poly-n compression corrected | 1.34 |
| poly-n expansion uncorrected | 1.32 |
| poly-n expansion corrected | 1.32 |

**Comments**

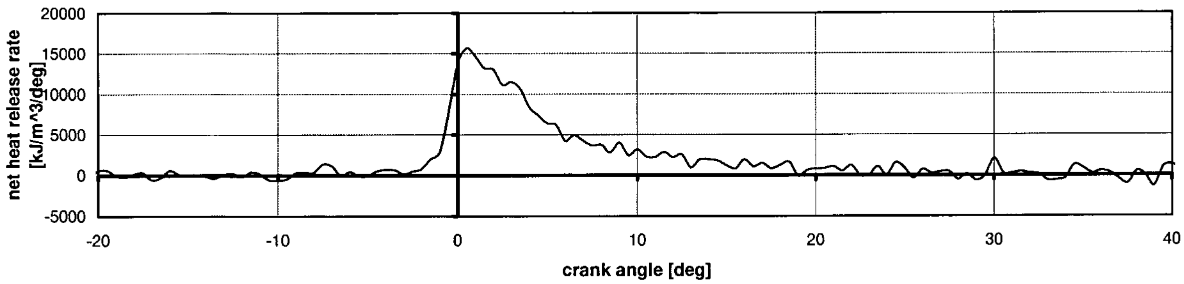
| Data Summary for filter: | 093 |
| --- | --- |
| Date: | 1/21/02 |
| Time: | 14:09:28 |

| Engine Parameters | Average |
| --- | --- |
| Speed(RPM) | 805.2 |
| Load(%) | 25.0 |
| Power (kW) | 11.0 |
| IMEP (bar) | 6.57 |
| Pmax(bar) | 97.02 |
| Pmax location (degrees) | 366.4 |
| Diesel Flow(kg/hr) | 0.85 |
| CNG Flow(kg/hr) | 1.21 |
| Air Flow(kg/hr) | 53.6 |
| Exhaust Flow(kg/hr) | 55.7 |
| Exhaust Back Pressure (kPa) | 23.7 |
| EGR Fraction(%) | 19.8 |

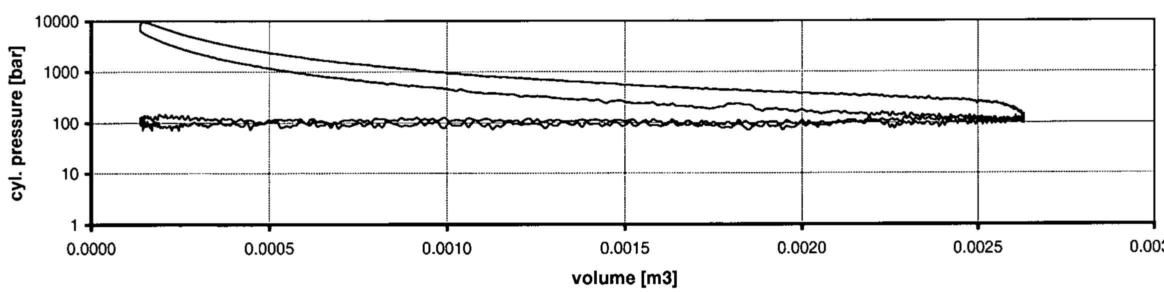
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume



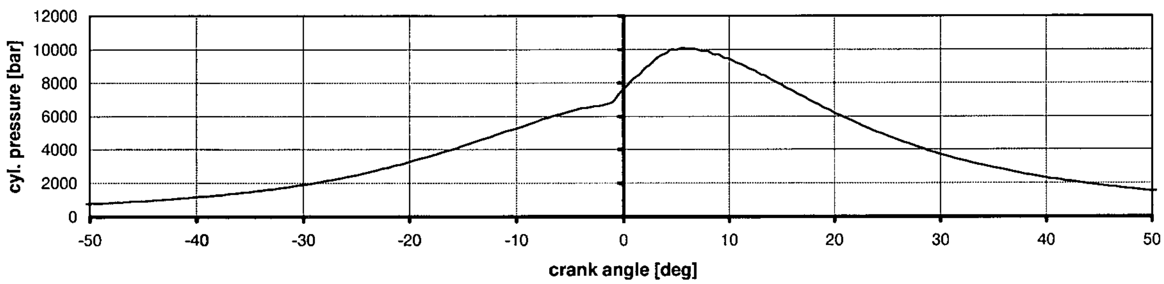
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 10092.62 |
| CA @ P_max [deg] | 5.5 |
| dP/dCA_max [bar/deg] | 746.161 |
| CA @ dP/dCA_max [deg] | -0.5 |
| IMEP [bar] | 648.20 |
| HHR_max [kJ/m^3/deg] | 13505.9 |
| IHR_max [kJ/m^3] | 113328.7 |
| 5% MFB [deg w.r.t TDC] | -2.0 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 2.5 |
| 90% MFB [deg w.r.t TDC] | 13.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.27 |
| poly-n compression corrected | 1.27 |
| poly-n expansion uncorrected | 1.30 |
| poly-n expansion corrected | 1.30 |

Comments

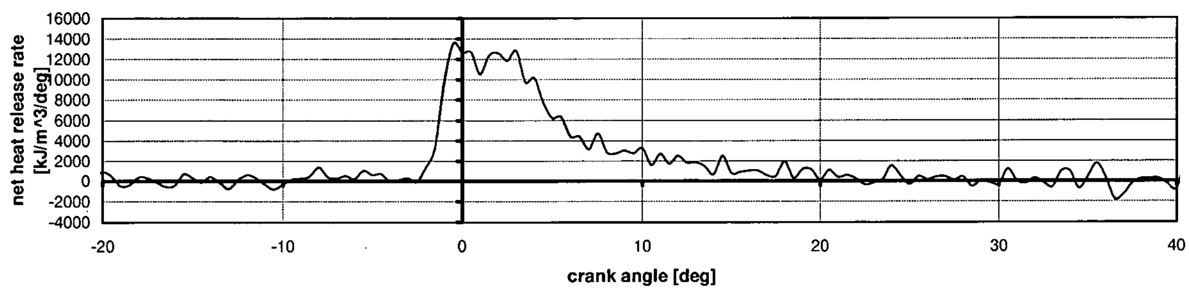
| | |
|---|---|
| Data Summary for filter: | 095 |
| Date: | 1/21/02 |
| Time: | 14:28:04 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 810.1 |
| Load(%) | 25.0 |
| Power (kW) | 11.0 |
| IMEP (bar) | 6.49 |
| Pmax(bar) | 101.49 |
| Pmax location (degrees) | 366.4 |
| Diesel Flow(kg/hr) | 0.87 |
| CNG Flow(kg/hr) | 1.20 |
| Air Flow(kg/hr) | 73.1 |
| Exhaust Flow(kg/hr) | 75.1 |
| Exhaust Back Pressure (kPa) | 10.5 |
| EGR Fraction(%) | 0.0 |

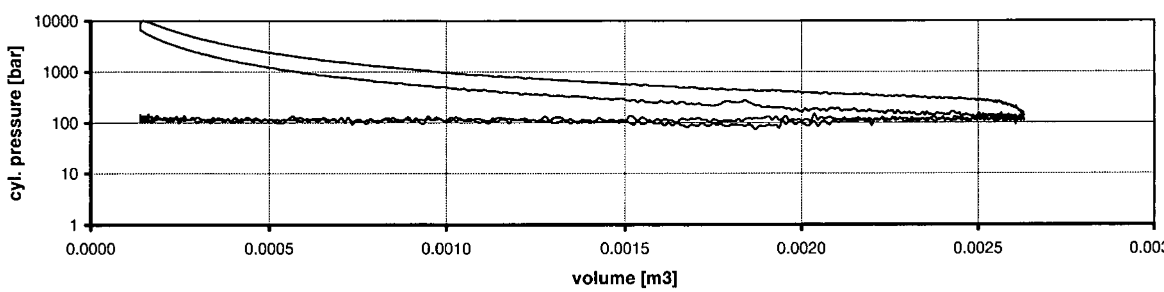
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume

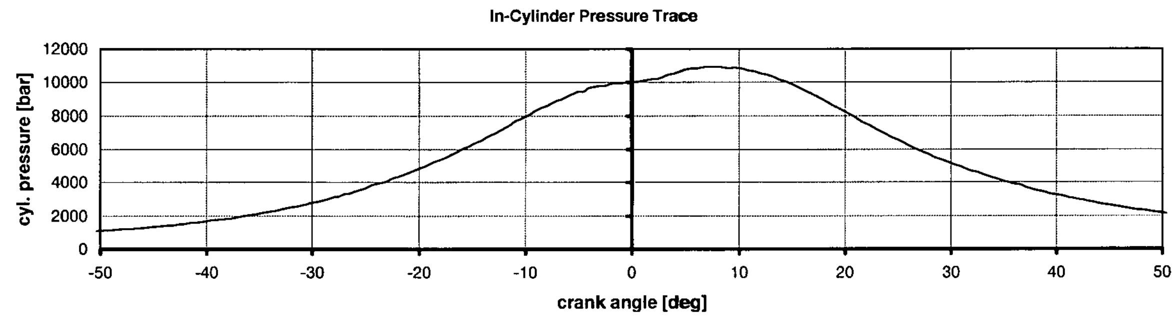


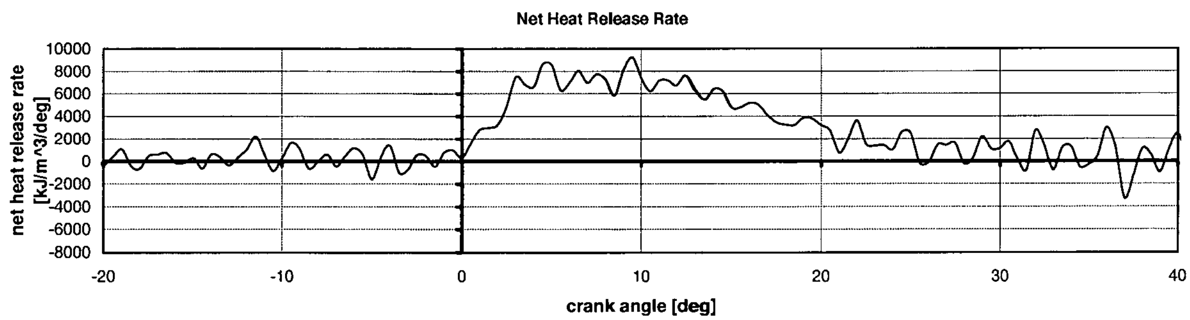
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 10930.08 |
| CA @ P max [deg] | 8.0 |
| dP/dCA max [bar/deg] | 418.746 |
| CA @ dP/dCA max [deg] | -11.5 |
| IMEP [bar] | 816.47 |
| HHR max [kJ/m^3/deg] | 9244.7 |
| IHR max [kJ/m^3] | 147306.1 |
| 5% MFB [deg w.r.t TDC] | -8.0 |
| 10% MFB [deg w.r.t TDC] | 2.0 |
| 50% MFB [deg w.r.t TDC] | 10.0 |
| 90% MFB [deg w.r.t TDC] | 24.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.31 |
| poly-n compression corrected | 1.31 |
| poly-n expansion uncorrected | 1.28 |
| poly-n expansion corrected | 1.28 |

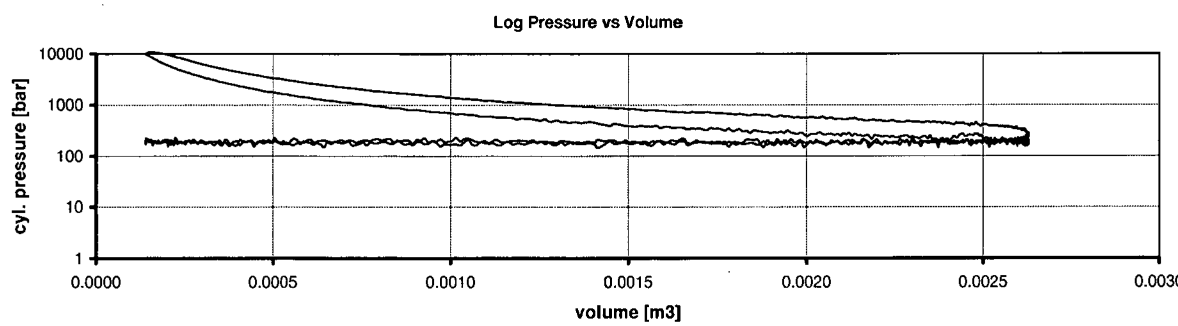
**Comments**

| | |
|---|---|
| Data Summary for filter: | 101 |
| Date: | 1/22/02 |
| Time: | 10:17:44 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1595.8 |
| Load(%) | 40.0 |
| Power (kW) | 27.2 |
| IMEP (bar) | 8.18 |
| Pmax(bar) | 110.11 |
| Pmax location (degrees) | 368.2 |
| Diesel Flow(kg/hr) | 1.15 |
| CNG Flow(kg/hr) | 3.54 |
| Air Flow(kg/hr) | 214.4 |
| Exhaust Flow(kg/hr) | 219.1 |
| Exhaust Back Pressure (kPa) | 11.3 |
| EGR Fraction(%) | 0.0 |



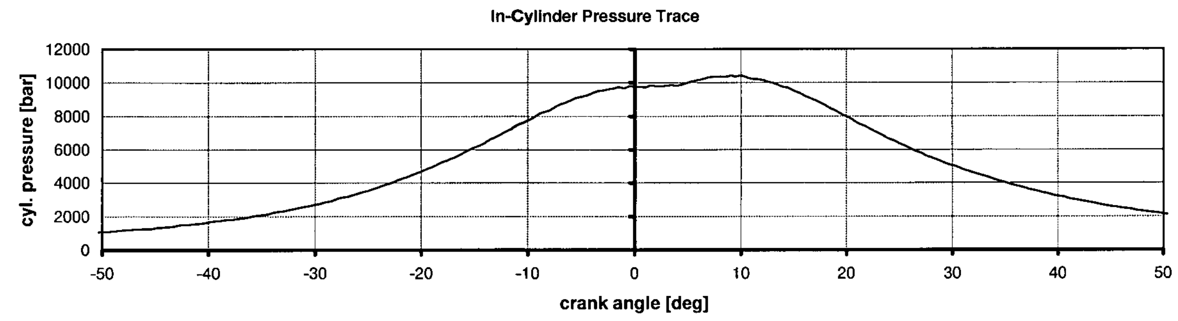



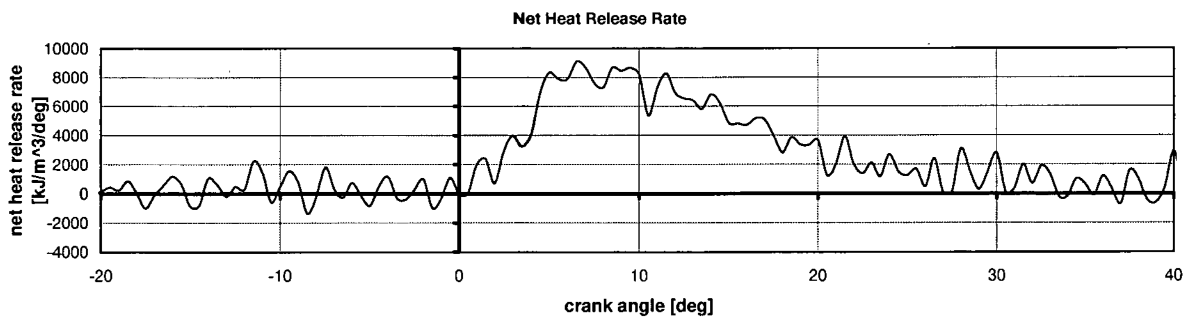
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 10413.07 |
| CA @ P max [deg] | 10.0 |
| dP/dCA max [bar/deg] | 408.407 |
| CA @ dP/dCA max [deg] | -11.5 |
| IMEP [bar] | 810.18 |
| HHR max [kJ/m^3/deg] | 9109.8 |
| IHR max [kJ/m^3] | 148646.3 |
| 5% MFB [deg w.r.t TDC] | -1.0 |
| 10% MFB [deg w.r.t TDC] | 3.0 |
| 50% MFB [deg w.r.t TDC] | 11.0 |
| 90% MFB [deg w.r.t TDC] | 29.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.33 |
| poly-n compression corrected | 1.33 |
| poly-n expansion uncorrected | 1.29 |
| poly-n expansion corrected | 1.29 |

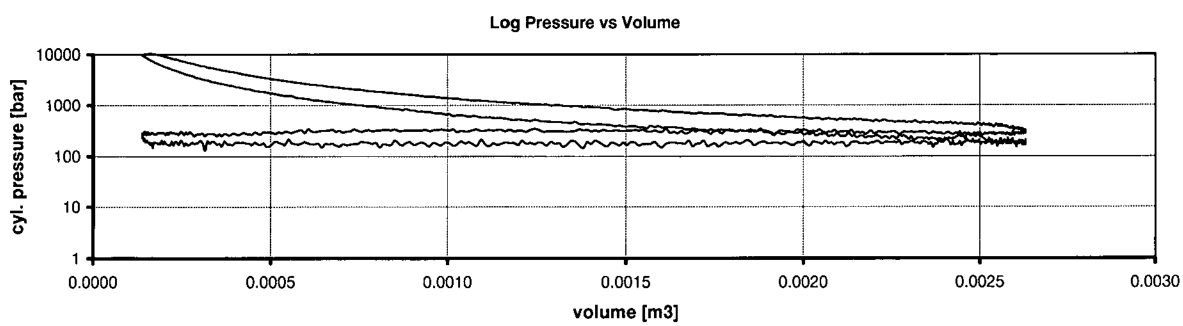
**Comments**

| | |
|---|---|
| Data Summary for filter: | 103 |
| Date: | 1/22/02 |
| Time: | 10:38:32 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1614.9 |
| Load(%) | 40.0 |
| Power (kW) | 27.3 |
| IMEP (bar) | 8.11 |
| Pmax(bar) | 104.85 |
| Pmax location (degrees) | 369.4 |
| Diesel Flow(kg/hr) | 0.85 |
| CNG Flow(kg/hr) | 3.59 |
| Air Flow(kg/hr) | 156.0 |
| Exhaust Flow(kg/hr) | 160.5 |
| Exhaust Back Pressure (kPa) | 116.6 |
| EGR Fraction(%) | 19.6 |



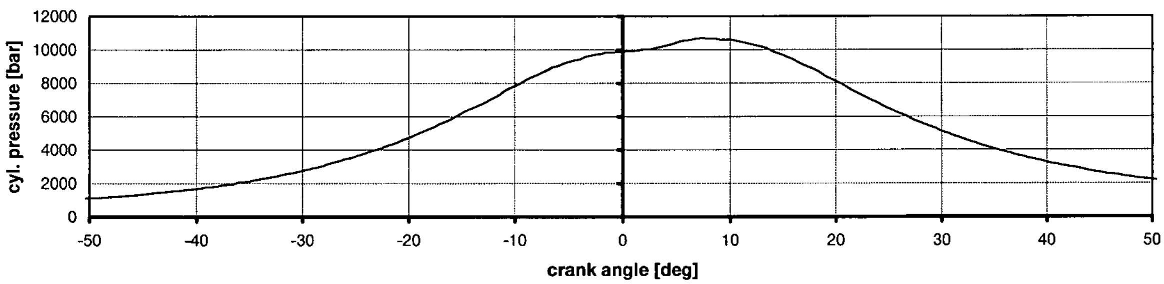
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 10688.65 |
| CA @ P max [deg] | 7.5 |
| dP/dCA max [bar/deg] | 406.683 |
| CA @ dP/dCA max [deg] | -11.5 |
| IMEP [bar] | 825.69 |
| HHR max [kJ/m^3/deg] | 8744.5 |
| IHR max [kJ/m^3] | 151805.9 |
| 5% MFB [deg w.r.t TDC] | -0.5 |
| 10% MFB [deg w.r.t TDC] | 2.5 |
| 50% MFB [deg w.r.t TDC] | 11.0 |
| 90% MFB [deg w.r.t TDC] | 28.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.27 |
| poly-n compression corrected | 1.27 |
| poly-n expansion uncorrected | 1.19 |
| poly-n expansion corrected | 1.19 |

**Comments**

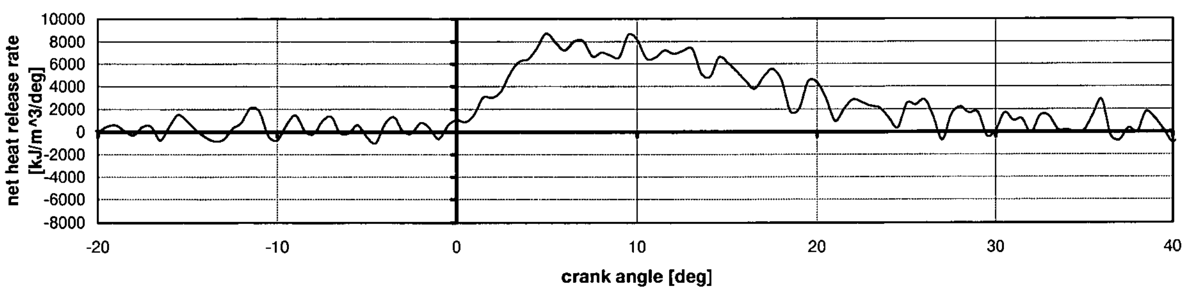
| | |
|---|---|
| Data Summary for filter: | 105 |
| Date: | 1/22/02 |
| Time: | 10:54:16 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1609.9 |
| Load(%) | 40.0 |
| Power (kW) | 27.7 |
| IMEP (bar) | 8.27 |
| Pmax(bar) | 107.78 |
| Pmax location (degrees) | 368.4 |
| Diesel Flow(kg/hr) | 0.76 |
| CNG Flow(kg/hr) | 3.66 |
| Air Flow(kg/hr) | 181.1 |
| Exhaust Flow(kg/hr) | 185.5 |
| Exhaust Back Pressure (kPa) | 114.2 |
| EGR Fraction(%) | 10.1 |

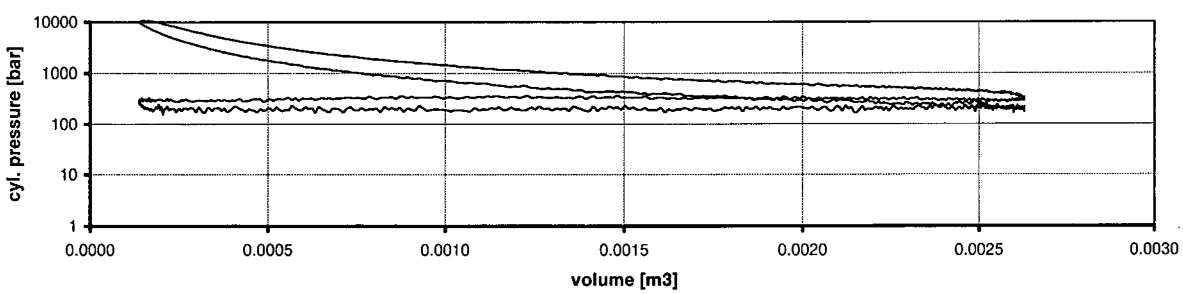
**In-Cylinder Pressure Trace**




**Net Heat Release Rate**




**Log Pressure vs Volume**

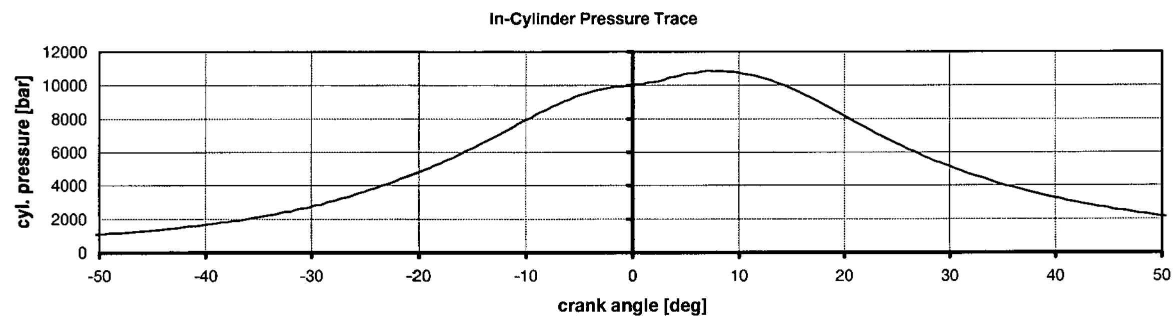


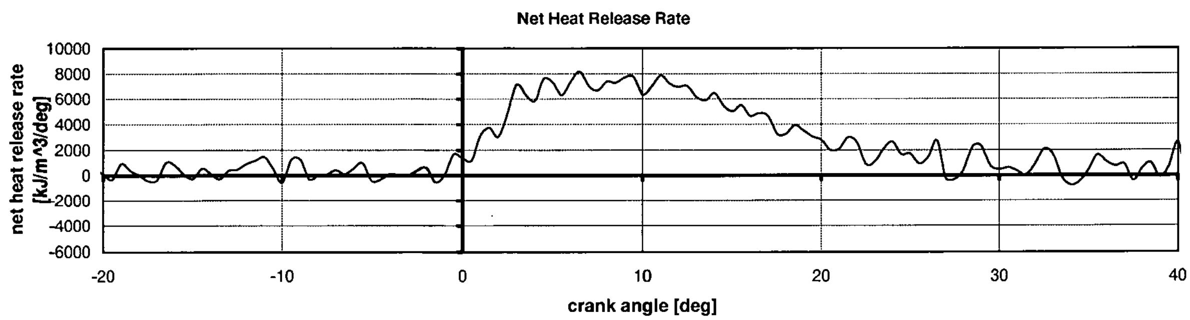
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 10842.38 |
| CA @ P max [deg] | 7.0 |
| dP/dCA max [bar/deg] | 384.281 |
| CA @ dP/dCA max [deg] | -11.0 |
| IMEP [bar] | 818.64 |
| HHR max [kJ/m^3/deg] | 8176.1 |
| IHR max [kJ/m^3] | 148707.6 |
| 5% MFB [deg w.r.t TDC] | -9.5 |
| 10% MFB [deg w.r.t TDC] | 1.5 |
| 50% MFB [deg w.r.t TDC] | 10.0 |
| 90% MFB [deg w.r.t TDC] | 25.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.33 |
| poly-n compression corrected | 1.33 |
| poly-n expansion uncorrected | 1.32 |
| poly-n expansion corrected | 1.32 |

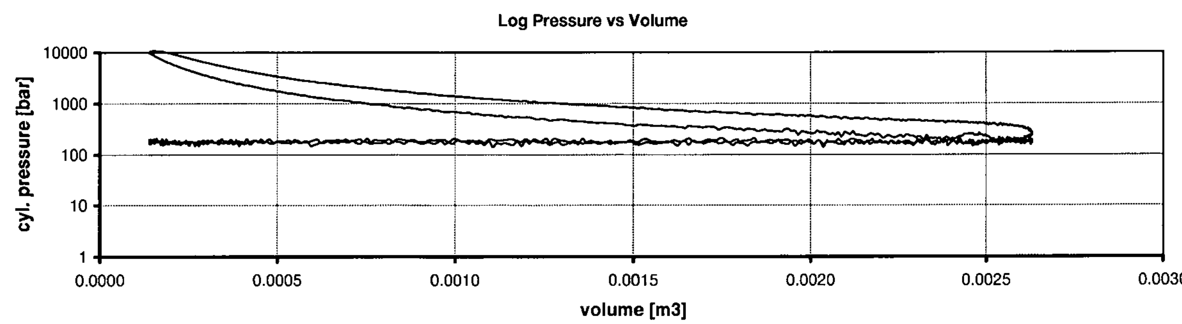
**Comments**

| | |
|---|---|
| Data Summary for filter: | 107 |
| Date: | 1/22/02 |
| Time: | 11:09:04 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1600.6 |
| Load(%) | 40.0 |
| Power (kW) | 27.3 |
| IMEP (bar) | 8.20 |
| Pmax(bar) | 109.22 |
| Pmax location (degrees) | 368.2 |
| Diesel Flow(kg/hr) | 0.77 |
| CNG Flow(kg/hr) | 3.56 |
| Air Flow(kg/hr) | 214.1 |
| Exhaust Flow(kg/hr) | 218.4 |
| Exhaust Back Pressure (kPa) | 11.2 |
| EGR Fraction(%) | 0.0 |



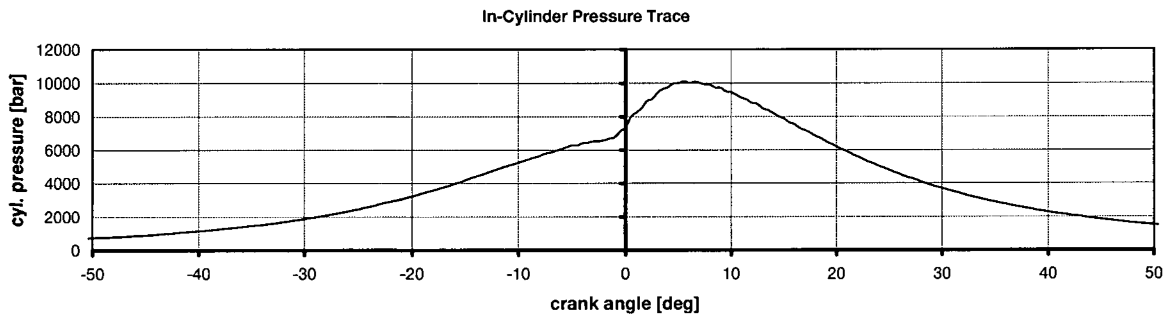



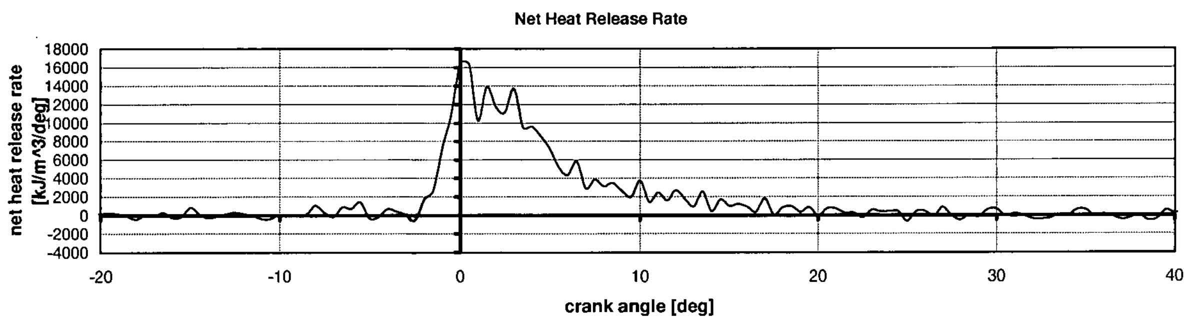
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 10116.31 |
| CA @ P max [deg] | 5.5 |
| dP/dCA max [bar/deg] | 887.466 |
| CA @ dP/dCA max [deg] | 0.0 |
| IMEP [bar] | 648.94 |
| HHR max [kJ/m^3/deg] | 16434.6 |
| IHR max [kJ/m^3] | 111722.5 |
| 5% MFB [deg w.r.t TDC] | -1.5 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 2.5 |
| 90% MFB [deg w.r.t TDC] | 11.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.32 |
| poly-n compression corrected | 1.32 |
| poly-n expansion uncorrected | 1.33 |
| poly-n expansion corrected | 1.33 |

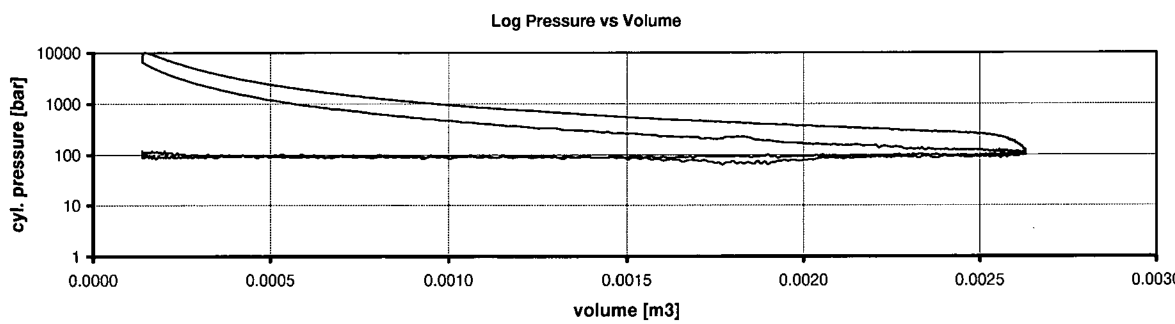
Comments

| | |
|---|---|
| Data Summary for filter: | 109 |
| Date: | 1/23/02 |
| Time: | 10:22:31 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 809.9 |
| Load(%) | 25.0 |
| Power (kW) | 11.0 |
| IMEP (bar) | 6.50 |
| Pmax(bar) | 101.47 |
| Pmax location (degrees) | 366.3 |
| Diesel Flow(kg/hr) | 0.75 |
| CNG Flow(kg/hr) | 1.19 |
| Air Flow(kg/hr) | 72.1 |
| Exhaust Flow(kg/hr) | 74.1 |
| Exhaust Back Pressure (kPa) | 10.5 |
| EGR Fraction(%) | 0.0 |



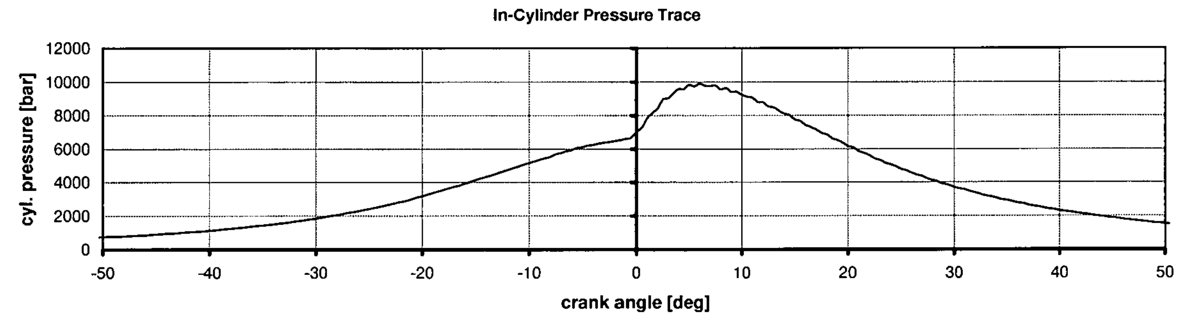



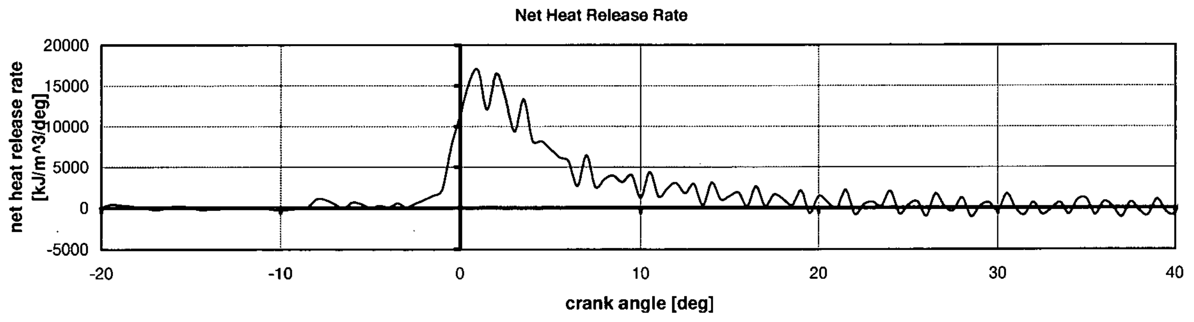
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 9896.74 |
| CA @ P max [deg] | 6.0 |
| dP/dCA max [bar/deg] | 877.127 |
| CA @ dP/dCA max [deg] | 1.0 |
| IMEP [bar] | 669.35 |
| HHR max [kJ/m^3/deg] | 16956.3 |
| IHR max [kJ/m^3] | 115792.6 |
| 5% MFB [deg w.r.t TDC] | -1.0 |
| 10% MFB [deg w.r.t TDC] | -0.5 |
| 50% MFB [deg w.r.t TDC] | 3.0 |
| 90% MFB [deg w.r.t TDC] | 14.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.33 |
| poly-n compression corrected | 1.33 |
| poly-n expansion uncorrected | 1.33 |
| poly-n expansion corrected | 1.33 |

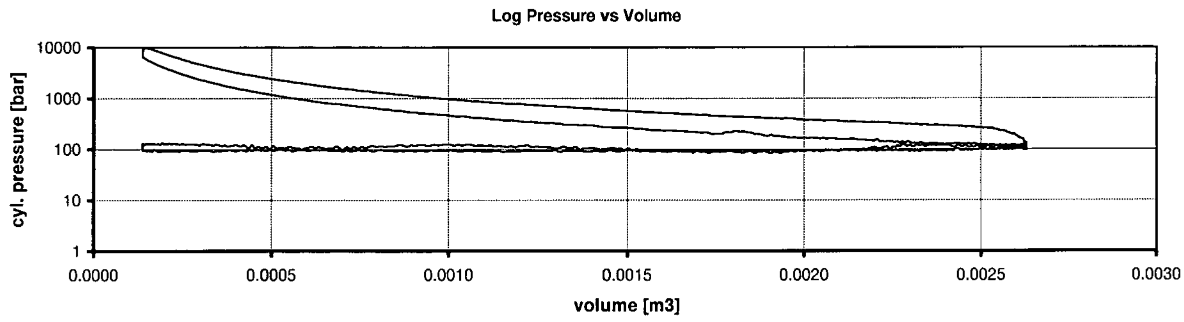
Comments

| | |
|---|---|
| Data Summary for filter: | 111 |
| Date: | 1/23/02 |
| Time: | 10:49:50 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 807.0 |
| Load(%) | 25.0 |
| Power (kW) | 11.3 |
| IMEP (bar) | 6.70 |
| Pmax(bar) | 99.09 |
| Pmax location (degrees) | 366.4 |
| Diesel Flow(kg/hr) | 0.85 |
| CNG Flow(kg/hr) | 1.21 |
| Air Flow(kg/hr) | 53.6 |
| Exhaust Flow(kg/hr) | 55.6 |
| Exhaust Back Pressure (kPa) | 24.0 |
| EGR Fraction(%) | 20.4 |



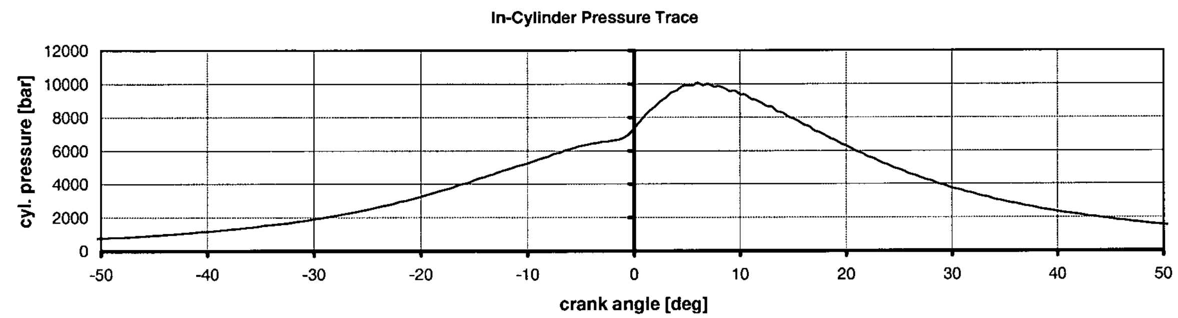



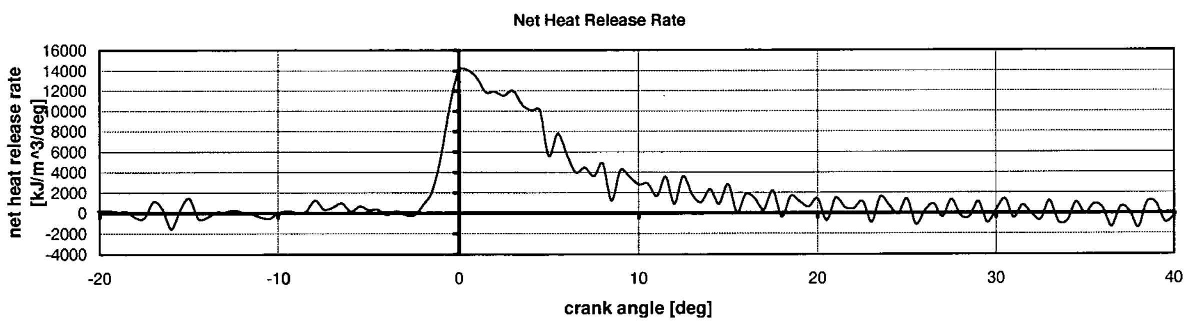
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 10078.11 |
| CA @ P_max [deg] | 6.0 |
| dP/dCA_max [bar/deg] | 758.223 |
| CA @ dP/dCA_max [deg] | 0.0 |
| IMEP [bar] | 669.12 |
| HHR_max [kJ/m^3/deg] | 14041.2 |
| IHR_max [kJ/m^3] | 115986.9 |
| 5% MFB [deg w.r.t TDC] | -1.5 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 3.0 |
| 90% MFB [deg w.r.t TDC] | 13.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.34 |
| poly-n compression corrected | 1.34 |
| poly-n expansion uncorrected | 1.33 |
| poly-n expansion corrected | 1.33 |

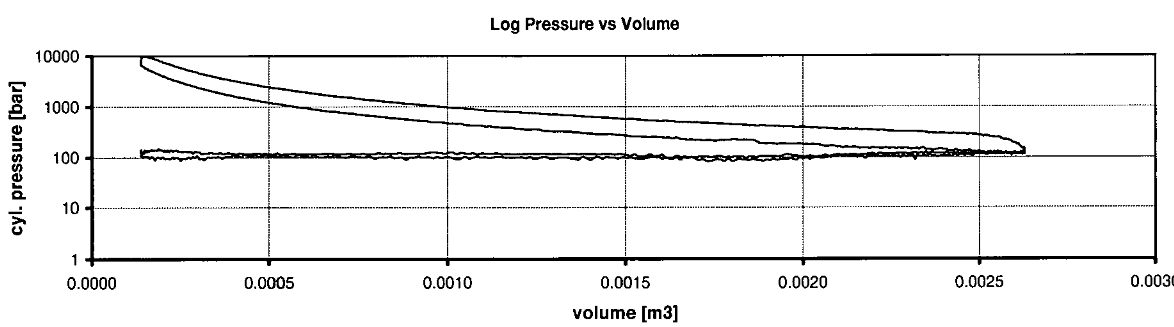
**Comments**

| | |
|---|---|
| Data Summary for filter: | 113 |
| Date: | 1/23/02 |
| Time: | 11:15:46 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 806.1 |
| Load(%) | 25.0 |
| Power (kW) | 11.3 |
| IMEP (bar) | 6.70 |
| Pmax(bar) | 100.90 |
| Pmax location (degrees) | 366.7 |
| Diesel Flow(kg/hr) | 0.89 |
| CNG Flow(kg/hr) | 1.20 |
| Air Flow(kg/hr) | 61.1 |
| Exhaust Flow(kg/hr) | 63.2 |
| Exhaust Back Pressure (kPa) | 25.5 |
| EGR Fraction(%) | 12.8 |



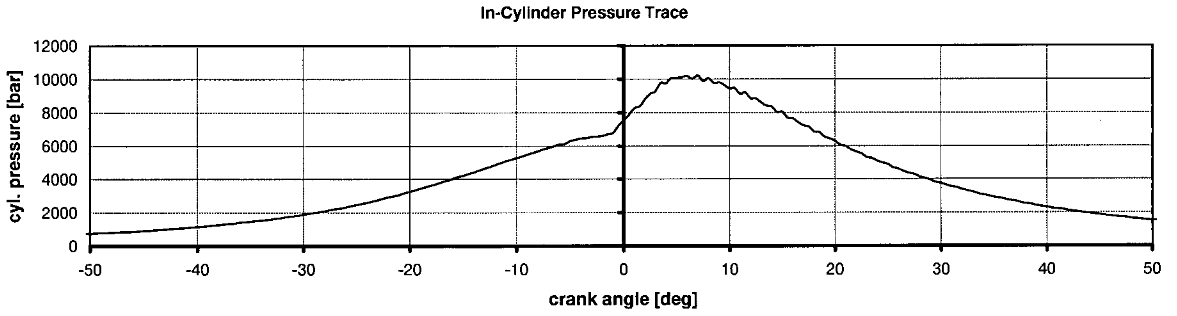



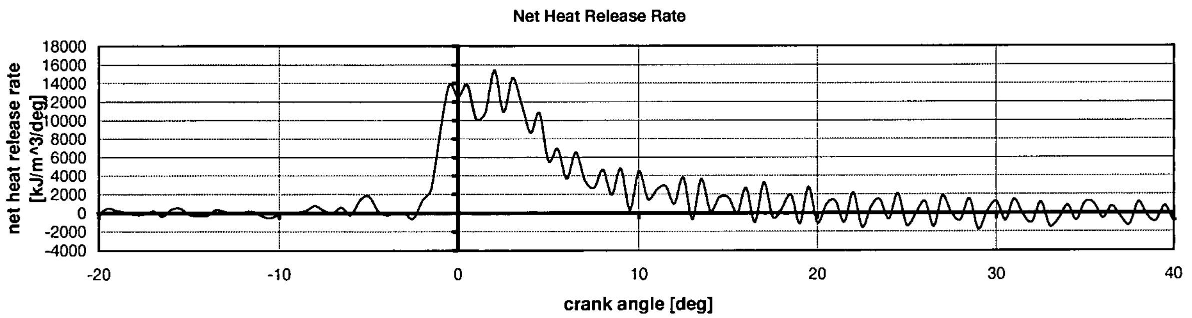
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 10230.76 |
| CA @ P_max [deg] | 7.0 |
| dP/dCA_max [bar/deg] | 761.670 |
| CA @ dP/dCA_max [deg] | -0.5 |
| IMEP [bar] | 662.79 |
| HHR_max [kJ/m^3/deg] | 15420.0 |
| IHR_max [kJ/m^3] | 114507.7 |
| 5% MFB [deg w.r.t TDC] | -1.5 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 2.5 |
| 90% MFB [deg w.r.t TDC] | 12.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.35 |
| poly-n compression corrected | 1.35 |
| poly-n expansion uncorrected | 1.33 |
| poly-n expansion corrected | 1.33 |

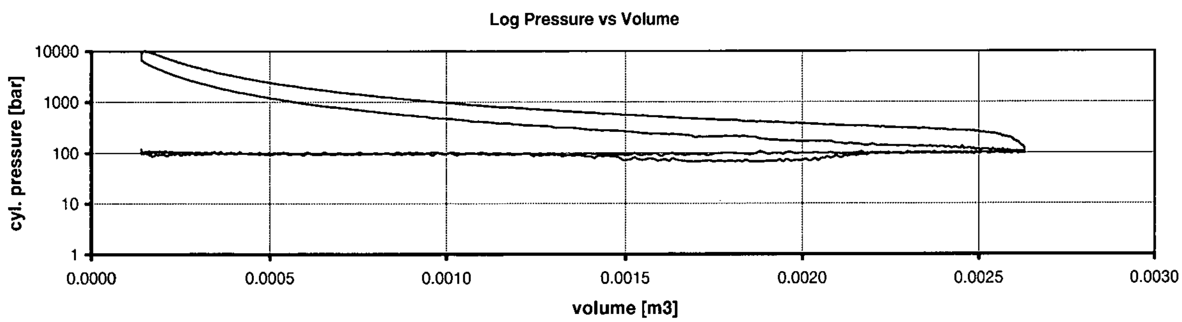
Comments

| Data Summary for filter: | 115 |
|---|---|
| Date: | 1/23/02 |
| Time: | 11:32:34 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 809.4 |
| Load(%) | |
| Power (kW) | 11.2 |
| IMEP (bar) | 6.64 |
| Pmax(bar) | 102.64 |
| Pmax location (degrees) | 366.8 |
| Diesel Flow(kg/hr) | 0.89 |
| CNG Flow(kg/hr) | 1.19 |
| Air Flow(kg/hr) | 72.4 |
| Exhaust Flow(kg/hr) | 74.5 |
| Exhaust Back Pressure (kPa) | 10.5 |
| EGR Fraction(%) | 0.0 |



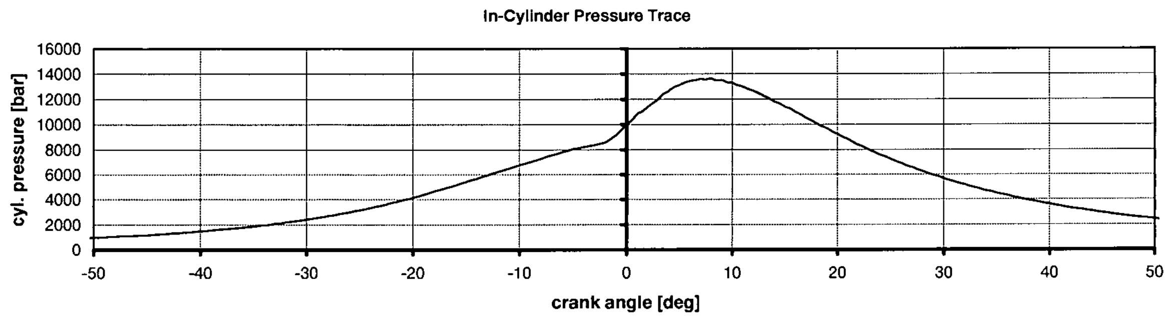



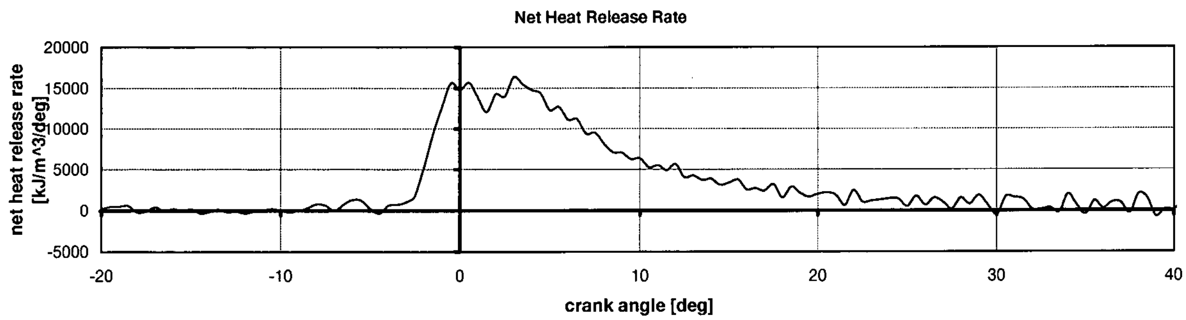
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 13638.64 |
| CA @ P_max [deg] | 8.0 |
| dP/dCA_max [bar/deg] | 865.064 |
| CA @ dP/dCA_max [deg] | -0.5 |
| IMEP [bar] | 1190.23 |
| HHR_max [kJ/m^3/deg] | 16406.6 |
| IHR_max [kJ/m^3] | 210962.7 |
| 5% MFB [deg w.r.t TDC] | -2.0 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 4.5 |
| 90% MFB [deg w.r.t TDC] | 23.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.34 |
| poly-n compression corrected | 1.34 |
| poly-n expansion uncorrected | 1.28 |
| poly-n expansion corrected | 1.28 |

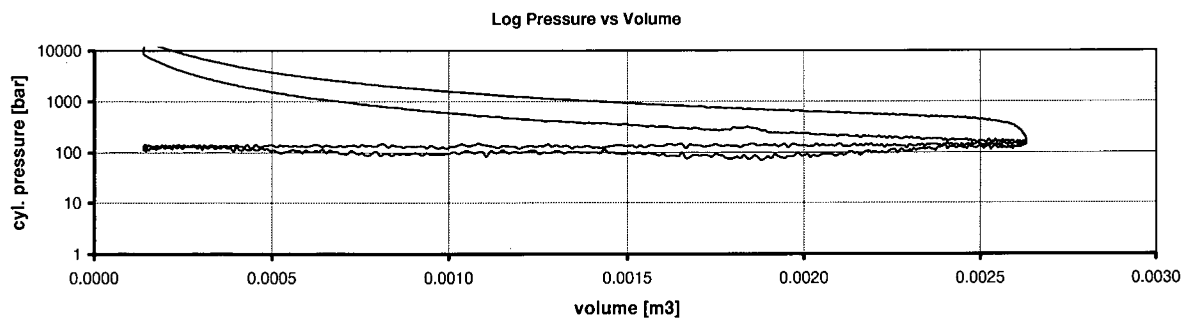
**Comments**

| | |
|---|---|
| Data Summary for filter: | 119 |
| Date: | 1/24/02 |
| Time: | 10:03:58 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 810.0 |
| Load(%) | 75.0 |
| Power (kW) | 20.1 |
| IMEP (bar) | 11.92 |
| Pmax(bar) | 136.80 |
| Pmax location (degrees) | 368.1 |
| Diesel Flow(kg/hr) | 0.60 |
| CNG Flow(kg/hr) | 2.91 |
| Air Flow(kg/hr) | 93.9 |
| Exhaust Flow(kg/hr) | 97.4 |
| Exhaust Back Pressure (kPa) | 11.8 |
| EGR Fraction(%) | 0.0 |



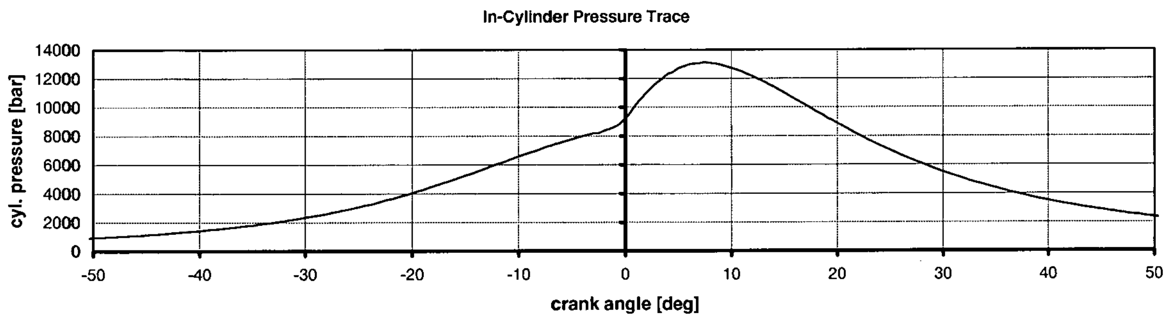



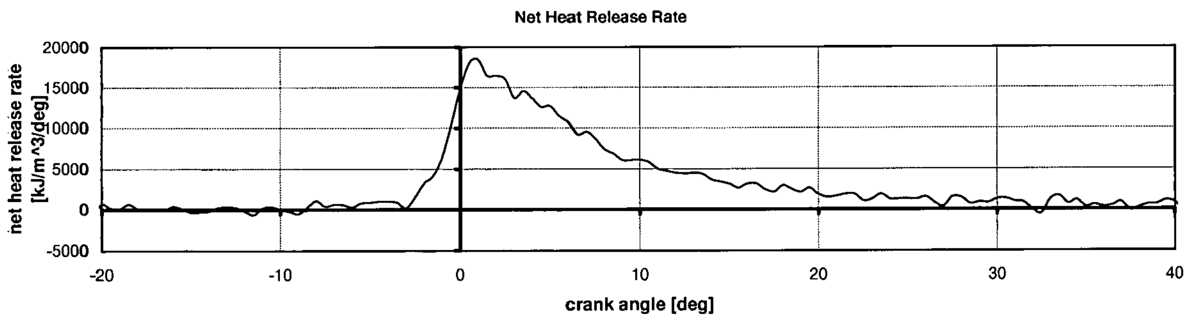
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 13109.55 |
| CA @ P_max [deg] | 7.5 |
| dP/dCA_max [bar/deg] | 954.672 |
| CA @ dP/dCA_max [deg] | 0.5 |
| IMEP [bar] | 1154.07 |
| HHR_max [kJ/m^3/deg] | 18504.8 |
| IHR_max [kJ/m^3] | 203218.9 |
| 5% MFB [deg w.r.t TDC] | -1.5 |
| 10% MFB [deg w.r.t TDC] | -0.5 |
| 50% MFB [deg w.r.t TDC] | 4.5 |
| 90% MFB [deg w.r.t TDC] | 23.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.33 |
| poly-n compression corrected | 1.33 |
| poly-n expansion uncorrected | 1.31 |
| poly-n expansion corrected | 1.31 |

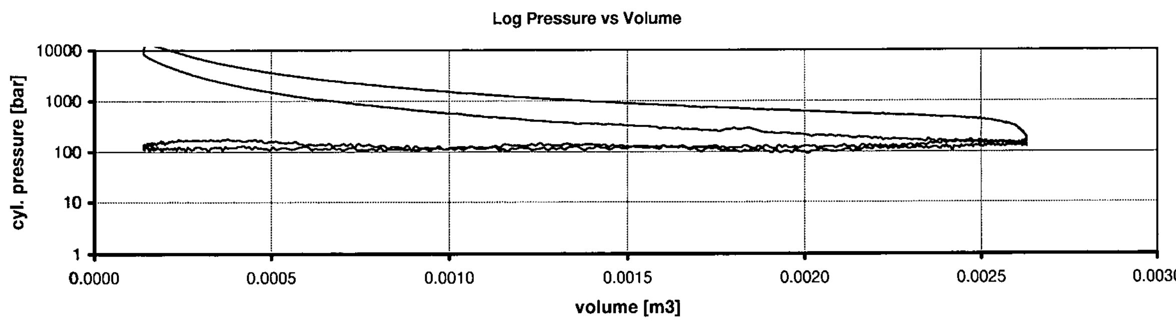
**Comments**

| | |
|---|---|
| Data Summary for filter: | 121 |
| Date: | 1/24/02 |
| Time: | 10:25:05 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 805.5 |
| Load(%) | 75.0 |
| Power (kW) | 19.4 |
| IMEP (bar) | 11.56 |
| Pmax(bar) | 131.66 |
| Pmax location (degrees) | 368.0 |
| Diesel Flow(kg/hr) | 0.59 |
| CNG Flow(kg/hr) | 2.89 |
| Air Flow(kg/hr) | 76.4 |
| Exhaust Flow(kg/hr) | 79.9 |
| Exhaust Back Pressure (kPa) | 55.6 |
| EGR Fraction(%) | 12.7 |



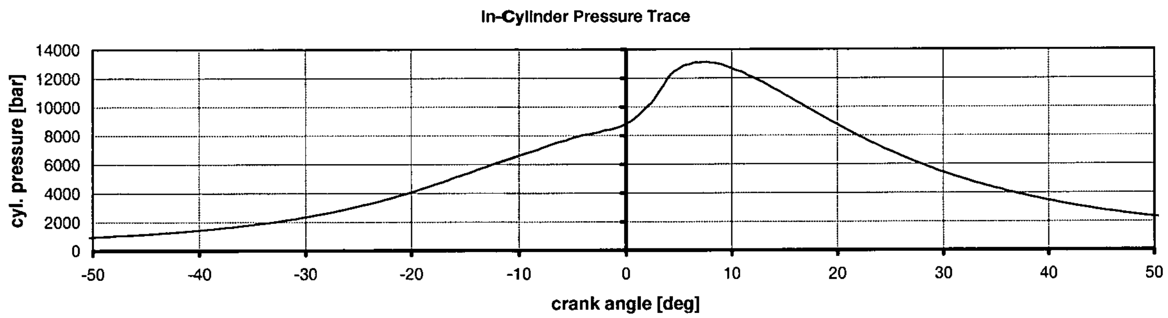



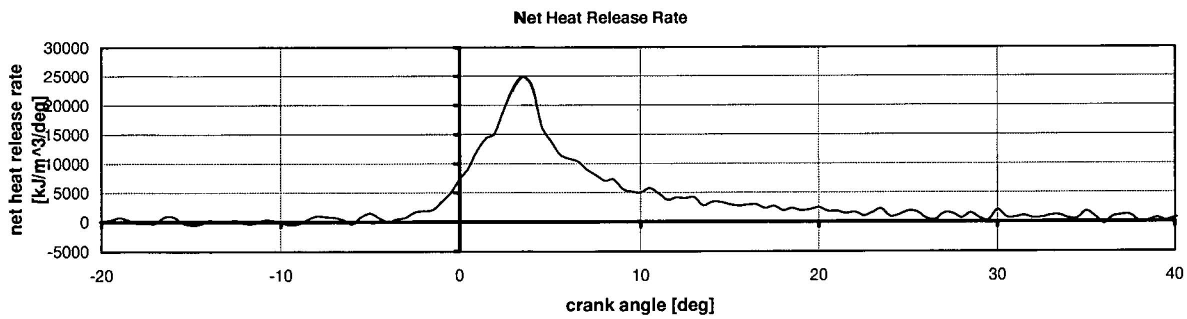
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 13122.32 |
| CA @ P_max [deg] | 7.5 |
| dP/dCA_max [bar/deg] | 1132.165 |
| CA @ dP/dCA_max [deg] | 3.5 |
| IMEP [bar] | 1131.28 |
| HHR_max [kJ/m^3/deg] | 24926.2 |
| IHR_max [kJ/m^3] | 199664.2 |
| 5% MFB [deg w.r.t TDC] | -1.0 |
| 10% MFB [deg w.r.t TDC] | 0.5 |
| 50% MFB [deg w.r.t TDC] | 4.5 |
| 90% MFB [deg w.r.t TDC] | 25.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.36 |
| poly-n compression corrected | 1.36 |
| poly-n expansion uncorrected | 1.32 |
| poly-n expansion corrected | 1.32 |

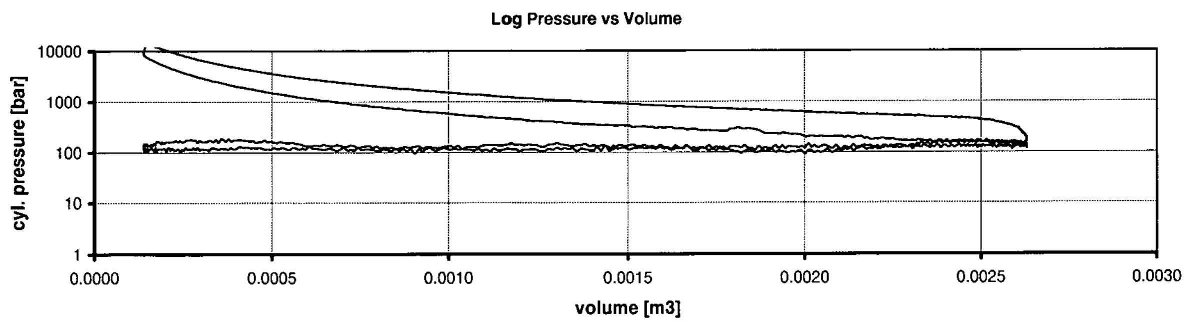
**Comments**

| Data Summary for filter: | 123 |
|---|---|
| Date: | 1/24/02 |
| Time: | 10:42:57 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 804.0 |
| Load(%) | 75.0 |
| Power (kW) | 19.0 |
| IMEP (bar) | 11.33 |
| Pmax(bar) | 132.05 |
| Pmax location (degrees) | 367.9 |
| Diesel Flow(kg/hr) | 0.61 |
| CNG Flow(kg/hr) | 2.87 |
| Air Flow(kg/hr) | 69.1 |
| Exhaust Flow(kg/hr) | 72.6 |
| Exhaust Back Pressure (kPa) | 59.1 |
| EGR Fraction(%) | 22.0 |



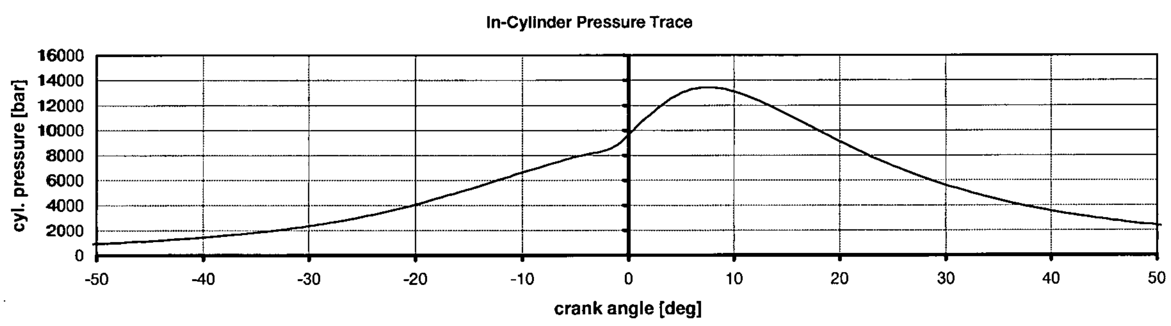



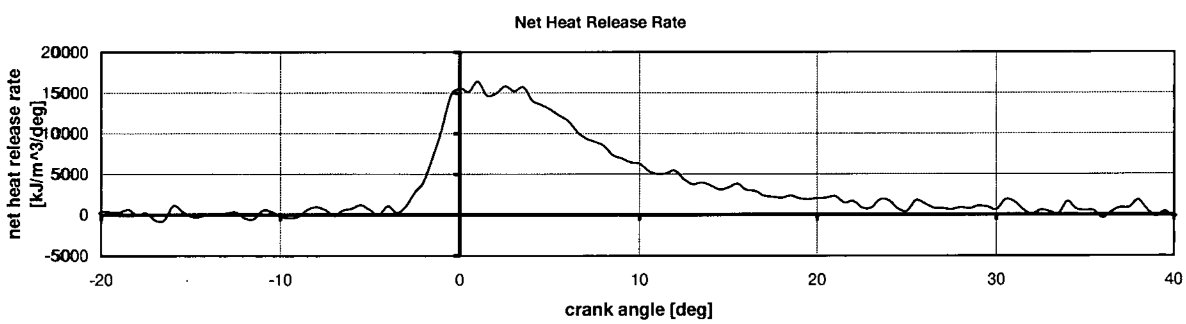
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 13438.79 |
| CA @ P max [deg] | 8.0 |
| dP/dCA max [bar/deg] | 839.215 |
| CA @ dP/dCA max [deg] | 0.0 |
| IMEP [bar] | 1188.61 |
| HHR max [kJ/m^3/deg] | 16453.2 |
| IHR max [kJ/m^3] | 208946.7 |
| 5% MFB [deg w.r.t TDC] | -2.0 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 4.5 |
| 90% MFB [deg w.r.t TDC] | 21.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.40 |
| poly-n compression corrected | 1.40 |
| poly-n expansion uncorrected | 1.33 |
| poly-n expansion corrected | 1.33 |

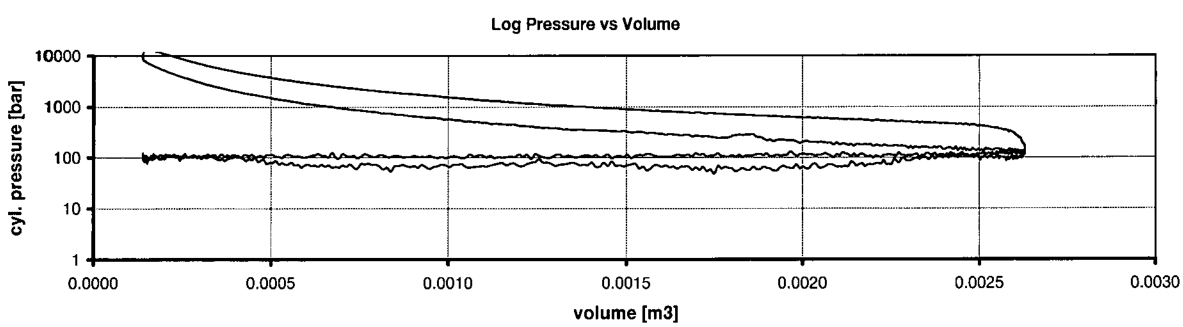
**Comments**

| | |
|---|---|
| Data Summary for filter: | 125 |
| Date: | 1/24/02 |
| Time: | 10:54:05 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 808.9 |
| Load(%) | 75.0 |
| Power (kW) | 20.1 |
| IMEP (bar) | 11.90 |
| Pmax(bar) | 134.89 |
| Pmax location (degrees) | 368.0 |
| Diesel Flow(kg/hr) | 0.63 |
| CNG Flow(kg/hr) | 2.91 |
| Air Flow(kg/hr) | 92.8 |
| Exhaust Flow(kg/hr) | 96.3 |
| Exhaust Back Pressure (kPa) | 9.7 |
| EGR Fraction(%) | 0.0 |



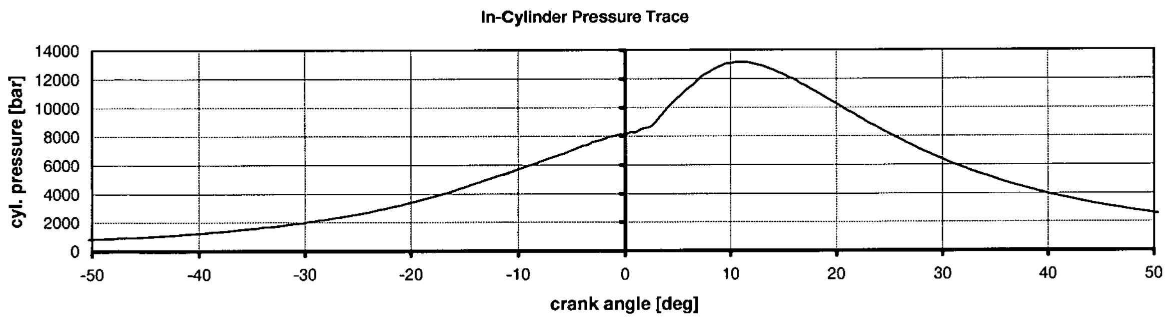



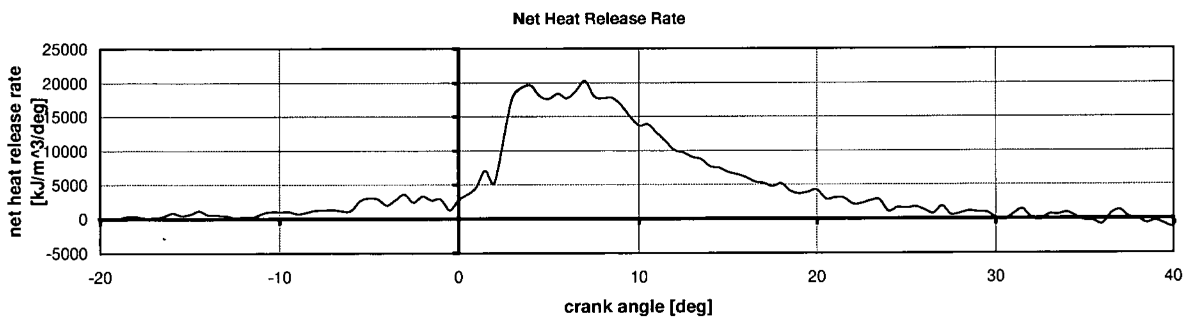
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 13143.63 |
| CA @ P_max [deg] | 11.0 |
| dP/dCA max [bar/deg] | 865.064 |
| CA @ dP/dCA max [deg] | 3.5 |
| IMEP [bar] | 1438.73 |
| HHR max [kJ/m^3/deg] | 20314.2 |
| IHR max [kJ/m^3] | 265458.0 |
| 5% MFB [deg w.r.t TDC] | -5.0 |
| 10% MFB [deg w.r.t TDC] | 0.0 |
| 50% MFB [deg w.r.t TDC] | 7.0 |
| 90% MFB [deg w.r.t TDC] | 17.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.26 |
| poly-n compression corrected | 1.26 |
| poly-n expansion uncorrected | 1.37 |
| poly-n expansion corrected | 1.37 |

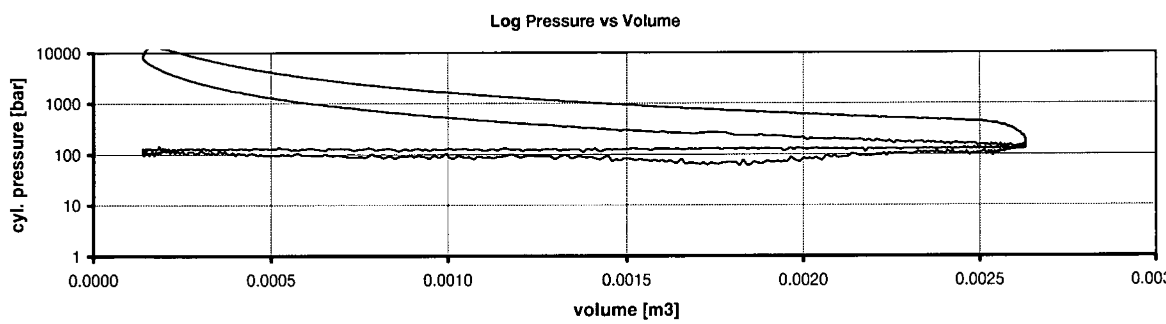
Comments

| | |
|---|---|
| Data Summary for filter: | A1 |
| Date: | 3/6/02 |
| Time: | 11:18:17 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 802.5 |
| Load(%) | 75.0 |
| Power (kW) | 24.1 |
| IMEP (bar) | 14.41 |
| Pmax(bar) | 131.68 |
| Pmax location (degrees) | 371.5 |
| Diesel Flow(kg/hr) | 0.17 |
| CNG Flow(kg/hr) | 2.94 |
| Air Flow(kg/hr) | 91.3 |
| Exhaust Flow(kg/hr) | 94.4 |
| Exhaust Back Pressure (kPa) | 10.9 |
| EGR Fraction(%) | 0.0 |



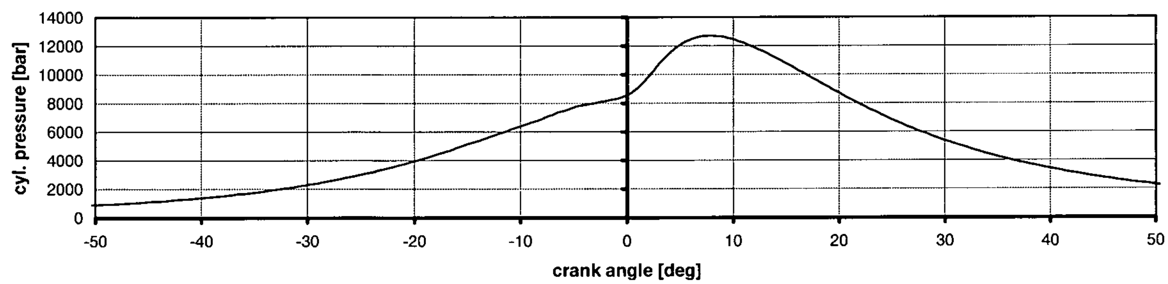
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 12707.67 |
| CA @ P max [deg] | 8.0 |
| dP/dCA max [bar/deg] | 877.127 |
| CA @ dP/dCA max [deg] | 2.5 |
| IMEP [bar] | 1112.91 |
| HHR max [kJ/m^3/deg] | 19188.0 |
| IHR max [kJ/m^3] | 196126.4 |
| 5% MFB [deg w.r.t TDC] | -1.0 |
| 10% MFB [deg w.r.t TDC] | 0.0 |
| 50% MFB [deg w.r.t TDC] | 5.0 |
| 90% MFB [deg w.r.t TDC] | 21.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.34 |
| poly-n compression corrected | 1.34 |
| poly-n expansion uncorrected | 1.31 |
| poly-n expansion corrected | 1.31 |

Comments

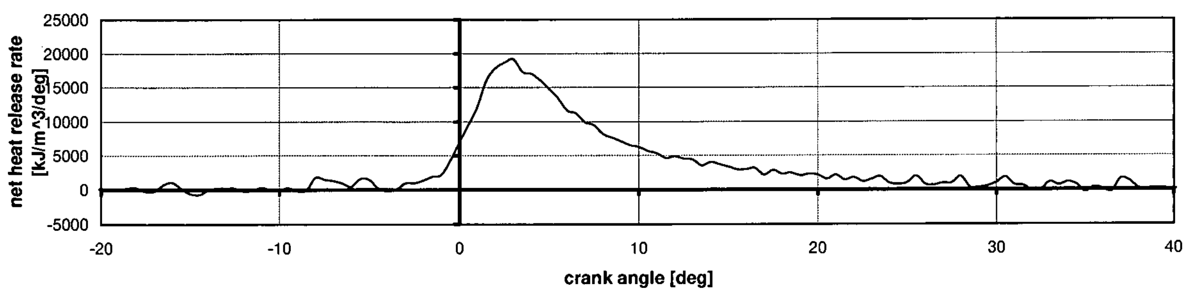
| | |
|---|---|
| Data Summary for filter: | A2 |
| Date: | 3/6/02 |
| Time: | 11:36:30 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 798.7 |
| Load(%) | 75.0 |
| Power (kW) | 18.5 |
| IMEP (bar) | 11.14 |
| Pmax(bar) | 127.20 |
| Pmax location (degrees) | 368.4 |
| Diesel Flow(kg/hr) | 0.17 |
| CNG Flow(kg/hr) | 2.91 |
| Air Flow(kg/hr) | 74.0 |
| Exhaust Flow(kg/hr) | 77.1 |
| Exhaust Back Pressure (kPa) | 53.6 |
| EGR Fraction(%) | 16.5 |

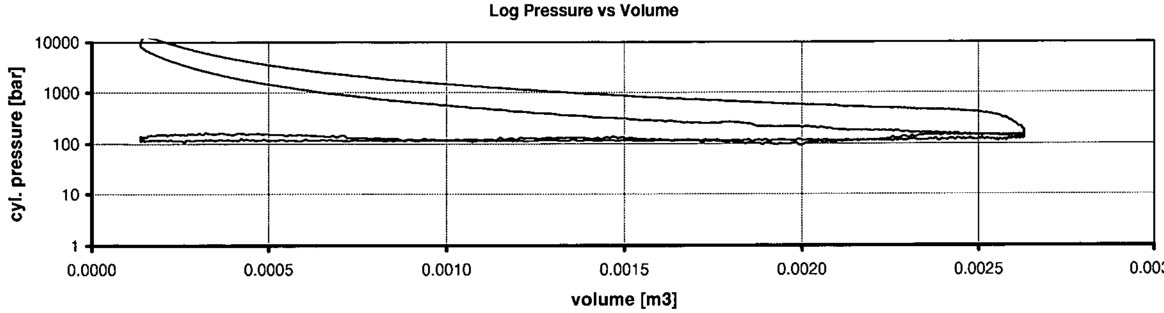
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume

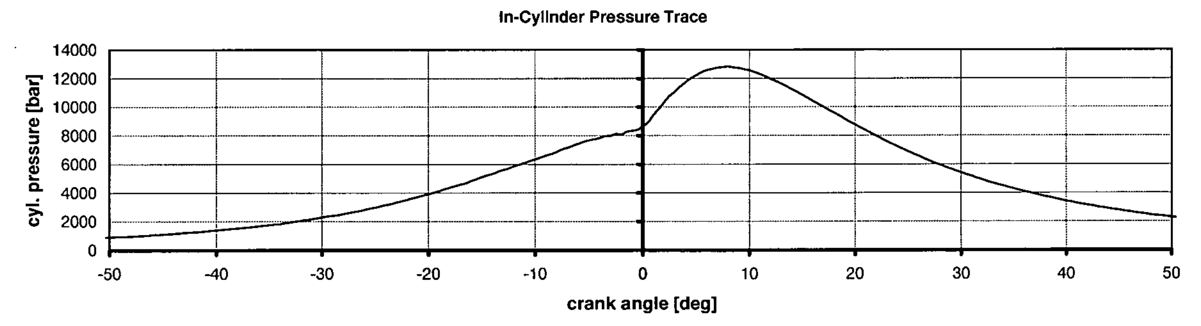


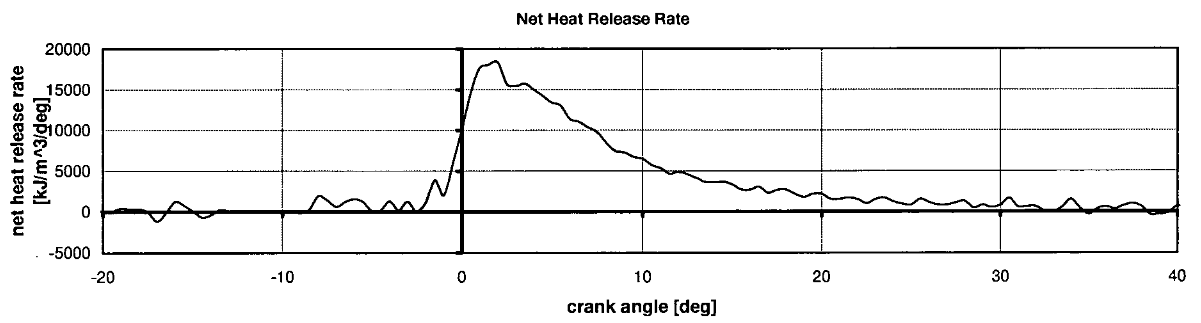
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 12823.35 |
| CA @ P max [deg] | 8.0 |
| dP/dCA max [bar/deg] | 906.422 |
| CA @ dP/dCA max [deg] | 1.0 |
| IMEP [bar] | 1127.32 |
| HHR max [kJ/m^3/deg] | 18423.7 |
| IHR max [kJ/m^3] | 197818.7 |
| 5% MFB [deg w.r.t TDC] | -1.5 |
| 10% MFB [deg w.r.t TDC] | 0.0 |
| 50% MFB [deg w.r.t TDC] | 5.0 |
| 90% MFB [deg w.r.t TDC] | 20.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.36 |
| poly-n compression corrected | 1.36 |
| poly-n expansion uncorrected | 1.33 |
| poly-n expansion corrected | 1.33 |

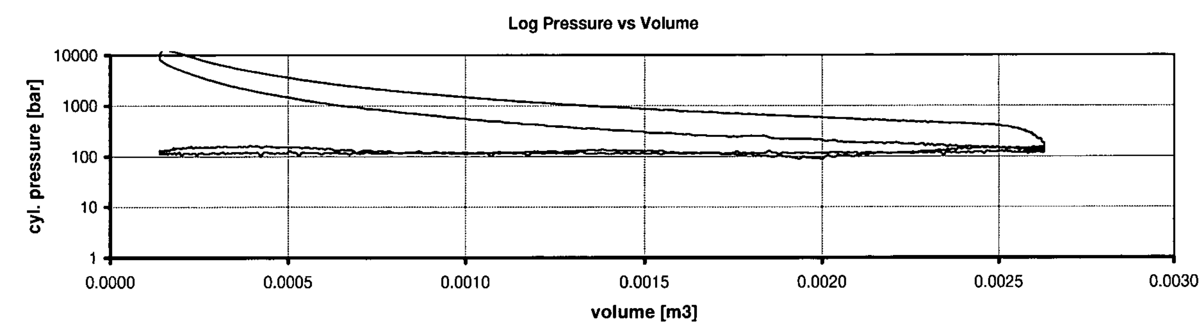
Comments

| | |
|---|---|
| Data Summary for filter: | A3 |
| Date: | 3/6/02 |
| Time: | 11:52:09 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 798.8 |
| Load(%) | 75.0 |
| Power (kW) | 18.8 |
| IMEP (bar) | 11.29 |
| Pmax(bar) | 128.32 |
| Pmax location (degrees) | 368.4 |
| Diesel Flow(kg/hr) | 0.17 |
| CNG Flow(kg/hr) | 2.95 |
| Air Flow(kg/hr) | 80.3 |
| Exhaust Flow(kg/hr) | 83.4 |
| Exhaust Back Pressure (kPa) | 51.5 |
| EGR Fraction(%) | 8.8 |



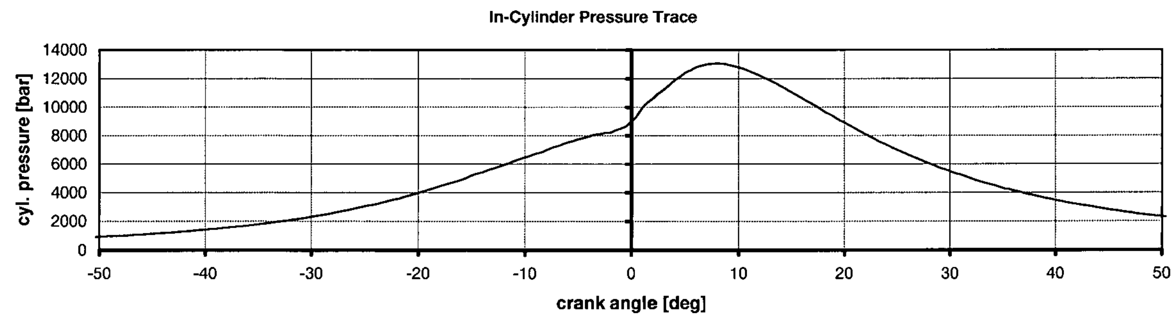



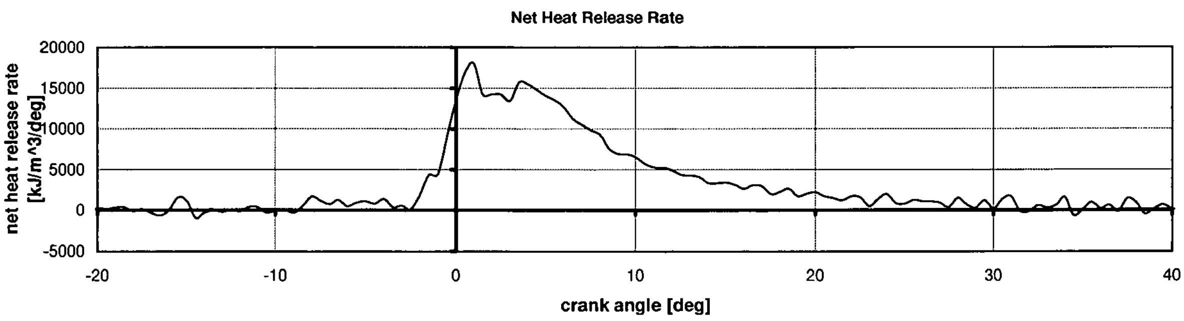
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 13051.66 |
| CA @ P max [deg] | 8.0 |
| dP/dCA max [bar/deg] | 927.100 |
| CA @ dP/dCA max [deg] | 1.0 |
| IMEP [bar] | 1138.87 |
| HHR max [kJ/m^3/deg] | 18065.5 |
| IHR max [kJ/m^3] | 200423.8 |
| 5% MFB [deg w.r.t TDC] | -2.0 |
| 10% MFB [deg w.r.t TDC] | -0.5 |
| 50% MFB [deg w.r.t TDC] | 5.0 |
| 90% MFB [deg w.r.t TDC] | 19.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.35 |
| poly-n compression corrected | 1.35 |
| poly-n expansion uncorrected | 1.32 |
| poly-n expansion corrected | 1.32 |

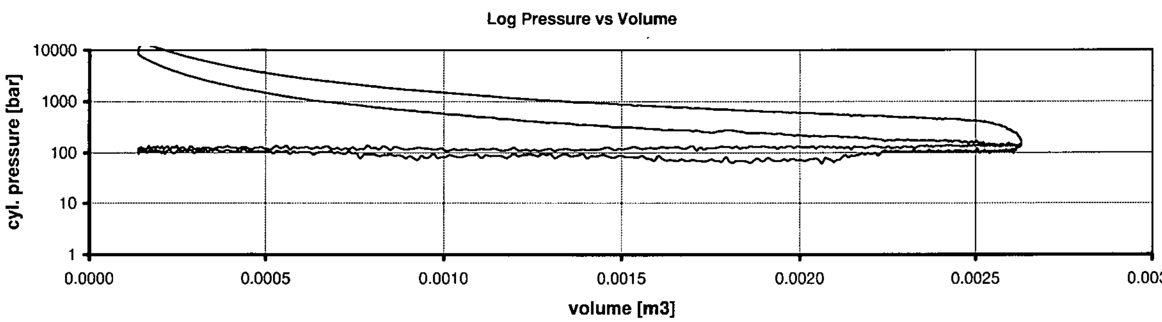
Comments

| | |
|---|---|
| Data Summary for filter: | A4 |
| Date: | 3/6/02 |
| Time: | 12:10:02 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 801.5 |
| Load(%) | 75.0 |
| Power (kW) | 19.0 |
| IMEP (bar) | 11.40 |
| Pmax(bar) | 130.79 |
| Pmax location (degrees) | 368.4 |
| Diesel Flow(kg/hr) | 0.17 |
| CNG Flow(kg/hr) | 2.91 |
| Air Flow(kg/hr) | 91.0 |
| Exhaust Flow(kg/hr) | 94.1 |
| Exhaust Back Pressure (kPa) | 11.5 |
| EGR Fraction(%) | 0.0 |



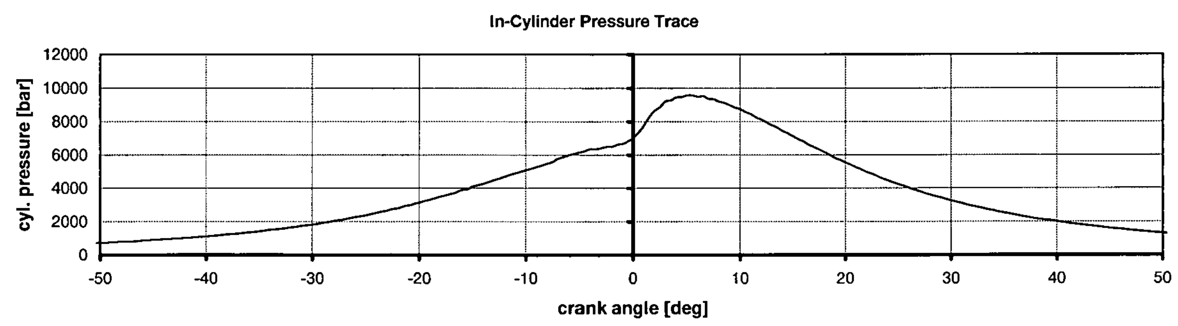



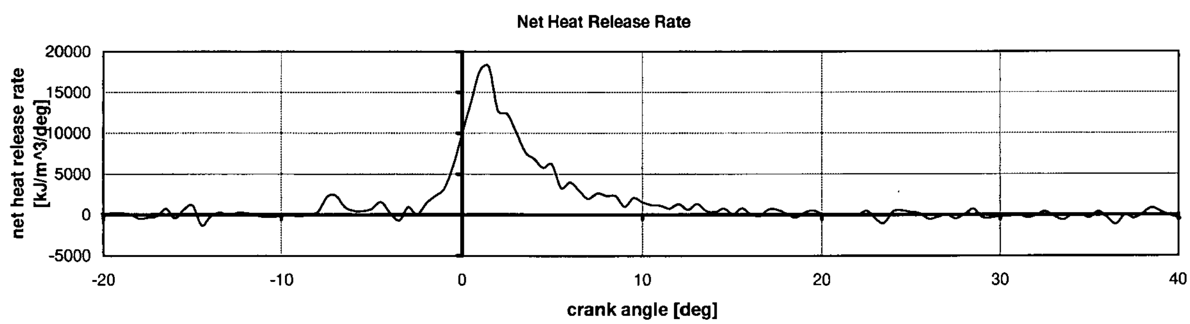
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 9571.13 |
| CA @ P_max [deg] | 5.5 |
| dP/dCA_max [bar/deg] | 918.484 |
| CA @ dP/dCA_max [deg] | 1.5 |
| IMEP [bar] | 505.24 |
| HHR_max [kJ/m^3/deg] | 18160.8 |
| IHR_max [kJ/m^3] | 89835.8 |
| 5% MFB [deg w.r.t TDC] | -5.0 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 1.5 |
| 90% MFB [deg w.r.t TDC] | 7.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.29 |
| poly-n compression corrected | 1.29 |
| poly-n expansion uncorrected | 1.34 |
| poly-n expansion corrected | 1.34 |

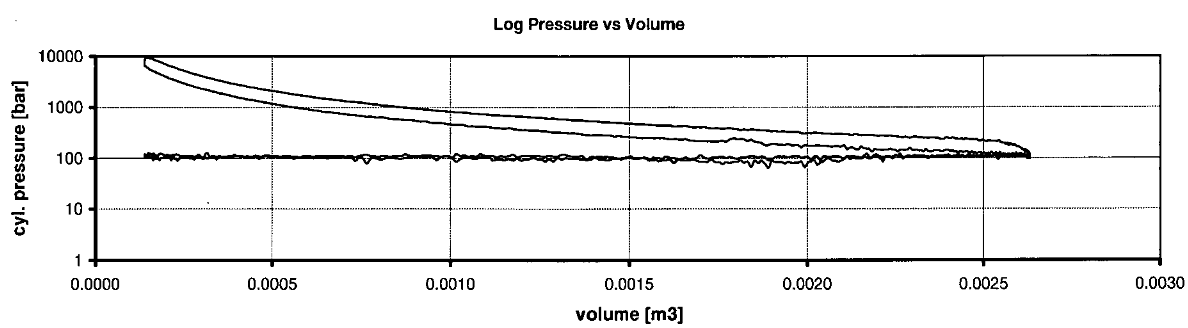
Comments

| Data Summary for filter: | A5 |
|---|---|
| Date: | 3/6/02 |
| Time: | 12:24:34 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 799.4 |
| Load(%) | 25.0 |
| Power (kW) | 8.4 |
| IMEP (bar) | 5.06 |
| Pmax(bar) | 96.14 |
| Pmax location (degrees) | 365.9 |
| Diesel Flow(kg/hr) | 0.16 |
| CNG Flow(kg/hr) | 1.24 |
| Air Flow(kg/hr) | 71.8 |
| Exhaust Flow(kg/hr) | 73.2 |
| Exhaust Back Pressure (kPa) | 14.3 |
| EGR Fraction(%) | 0.0 |



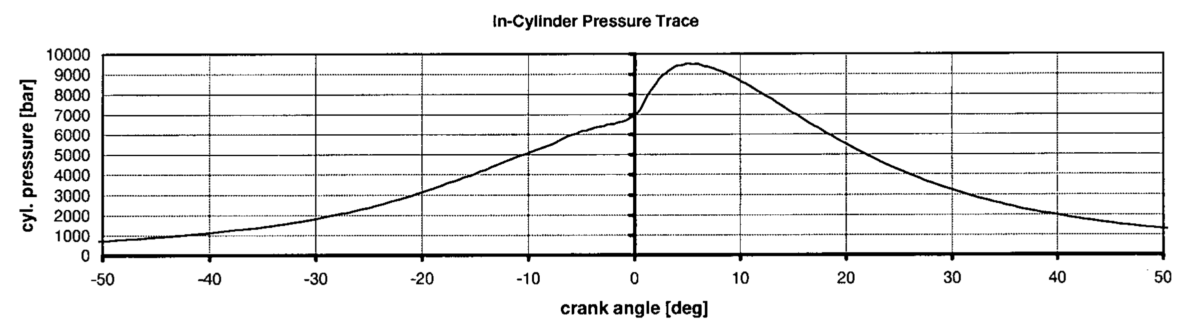



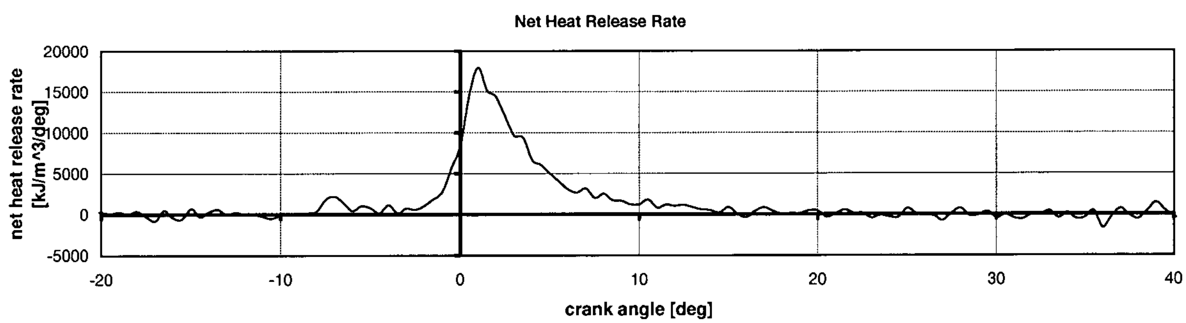
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 9519.50 |
| CA @ P max [deg] | 5.0 |
| dP/dCA max [bar/deg] | 932.270 |
| CA @ dP/dCA max [deg] | 1.0 |
| IMEP [bar] | 497.88 |
| HHR max [kJ/m^3/deg] | 17972.4 |
| IHR max [kJ/m^3] | 88180.6 |
| 5% MFB [deg w.r.t TDC] | -5.0 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 1.5 |
| 90% MFB [deg w.r.t TDC] | 7.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.30 |
| poly-n compression corrected | 1.30 |
| poly-n expansion uncorrected | 1.36 |
| poly-n expansion corrected | 1.36 |

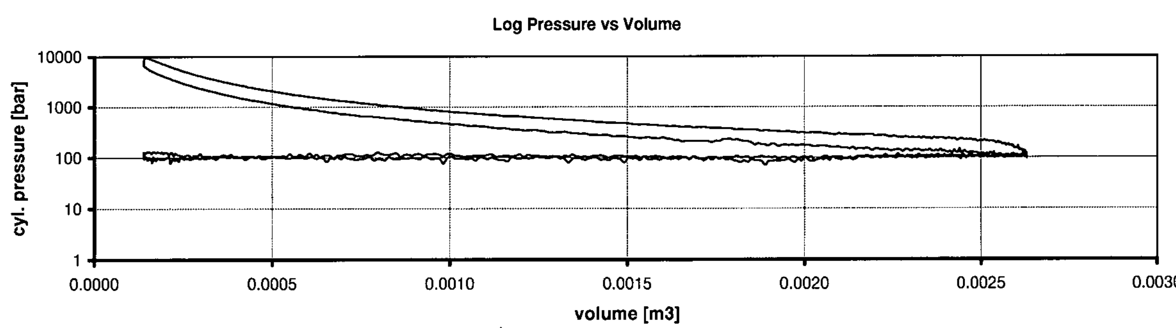
**Comments**

| | |
|---|---|
| Data Summary for filter: | A6 |
| Date: | 3/6/02 |
| Time: | 12:47:31 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 795.5 |
| Load - approx(%) | 25.0 |
| Power (kW) | 8.3 |
| IMEP (bar) | 4.99 |
| Pmax(bar) | 95.40 |
| Pmax location (degrees) | 365.6 |
| Diesel Flow(kg/hr) | 0.16 |
| CNG Flow(kg/hr) | 1.21 |
| Air Flow(kg/hr) | 64.1 |
| Exhaust Flow(kg/hr) | 65.5 |
| Exhaust Back Pressure (kPa) | 23.1 |
| EGR Fraction(%) | 9.2 |



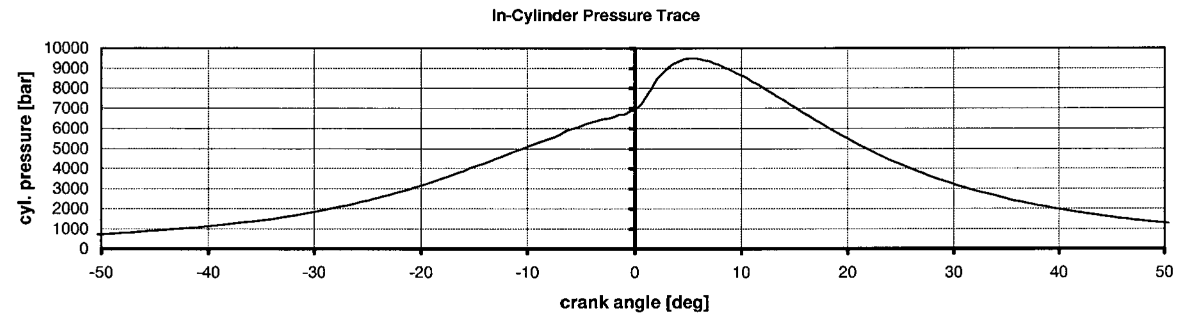



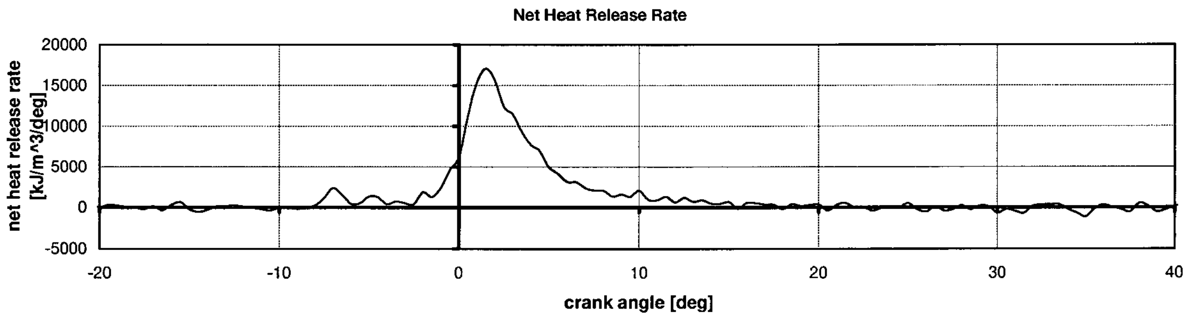
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 9480.36 |
| CA @ P_max [deg] | 5.5 |
| dP/dCA_max [bar/deg] | 863.341 |
| CA @ dP/dCA_max [deg] | 1.5 |
| IMEP [bar] | 488.97 |
| HHR_max [kJ/m^3/deg] | 17094.7 |
| IHR_max [kJ/m^3] | 87227.9 |
| 5% MFB [deg w.r.t TDC] | -5.0 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 1.5 |
| 90% MFB [deg w.r.t TDC] | 7.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.28 |
| poly-n compression corrected | 1.28 |
| poly-n expansion uncorrected | 1.35 |
| poly-n expansion corrected | 1.35 |

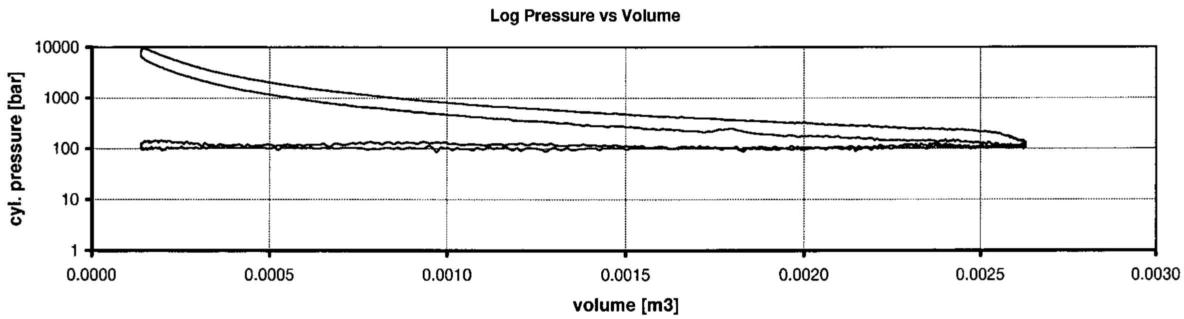
**Comments**

| | |
|---|---|
| Data Summary for filter: | A7 |
| Date: | 3/6/02 |
| Time: | 15:07:01 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 785.3 |
| Load - approx(%) | 25.0 |
| Power (kW) | 8.0 |
| IMEP (bar) | 4.90 |
| Pmax(bar) | 95.18 |
| Pmax location (degrees) | 365.9 |
| Diesel Flow(kg/hr) | 0.17 |
| CNG Flow(kg/hr) | 1.15 |
| Air Flow(kg/hr) | 56.4 |
| Exhaust Flow(kg/hr) | 57.7 |
| Exhaust Back Pressure (kPa) | 27.2 |
| EGR Fraction(%) | 23.8 |



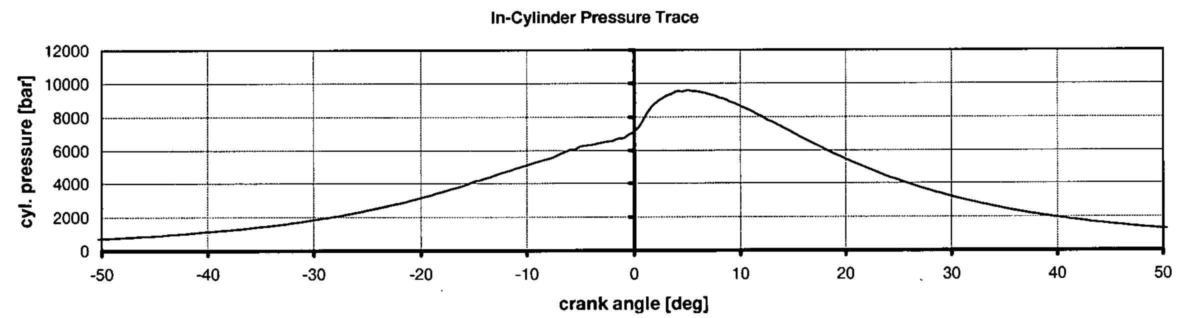



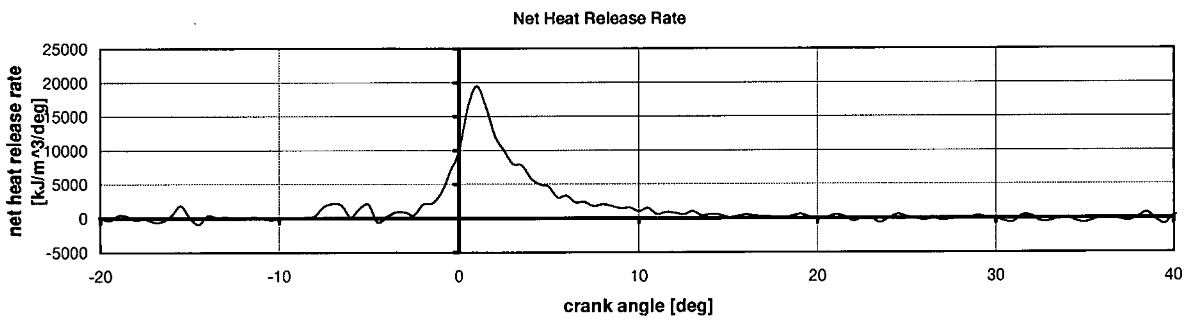
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 9583.31 |
| CA @ P max [deg] | 5.0 |
| dP/dCA max [bar/deg] | 1011.539 |
| CA @ dP/dCA max [deg] | 1.0 |
| IMEP [bar] | 482.89 |
| HHR max [kJ/m^3/deg] | 19463.9 |
| IHR max [kJ/m^3] | 86284.2 |
| 5% MFB [deg w.r.t TDC] | -6.0 |
| 10% MFB [deg w.r.t TDC] | -1.5 |
| 50% MFB [deg w.r.t TDC] | 1.0 |
| 90% MFB [deg w.r.t TDC] | 7.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.29 |
| poly-n compression corrected | 1.29 |
| poly-n expansion uncorrected | 1.36 |
| poly-n expansion corrected | 1.36 |

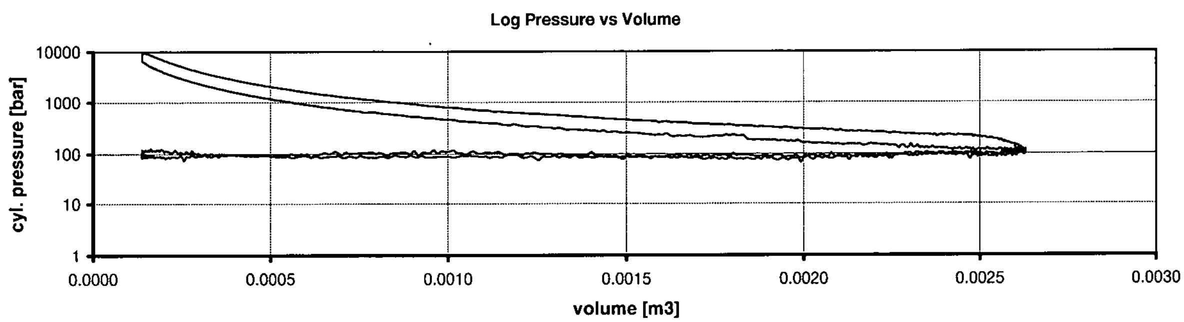
**Comments**

| | |
|---|---|
| Data Summary for filter: | A8 |
| Date: | 3/6/02 |
| Time: | 15:16:05 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 790.8 |
| Load - approx(%) | 25.0 |
| Power (kW) | 8.0 |
| IMEP (bar) | 4.84 |
| Pmax(bar) | 95.95 |
| Pmax location (degrees) | 365.5 |
| Diesel Flow(kg/hr) | 0.17 |
| CNG Flow(kg/hr) | 1.16 |
| Air Flow(kg/hr) | 71.9 |
| Exhaust Flow(kg/hr) | 73.2 |
| Exhaust Back Pressure (kPa) | 14.2 |
| EGR Fraction(%) | 0.0 |



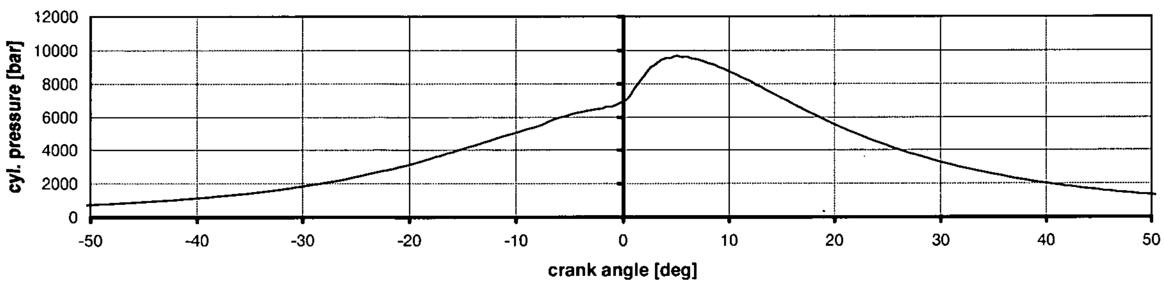
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 9667.43 |
| CA @ P_max [deg] | 5.0 |
| dP/dCA_max [bar/deg] | 921.931 |
| CA @ dP/dCA_max [deg] | 1.0 |
| IMEP [bar] | 510.66 |
| HHR_max [kJ/m^3/deg] | 17773.4 |
| IHR_max [kJ/m^3] | 90191.6 |
| 5% MFB [deg w.r.t TDC] | -4.5 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 1.5 |
| 90% MFB [deg w.r.t TDC] | 7.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.28 |
| poly-n compression corrected | 1.28 |
| poly-n expansion uncorrected | 1.32 |
| poly-n expansion corrected | 1.32 |

Comments

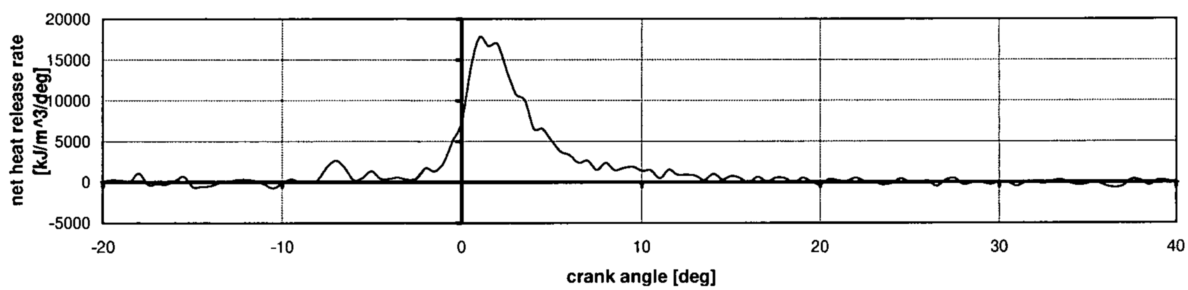
| | |
|---|---|
| Data Summary for filter: | A9 |
| Date: | 3/6/02 |
| Time: | 15:45:07 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 791.7 |
| Load - approx(%) | 25.0 |
| Power (kW) | 8.4 |
| IMEP (bar) | 5.11 |
| Pmax(bar) | 96.81 |
| Pmax location (degrees) | 365.7 |
| Diesel Flow(kg/hr) | 0.17 |
| CNG Flow(kg/hr) | 1.20 |
| Air Flow(kg/hr) | 63.1 |
| Exhaust Flow(kg/hr) | 64.5 |
| Exhaust Back Pressure (kPa) | 23.2 |
| EGR Fraction(%) | 11.3 |

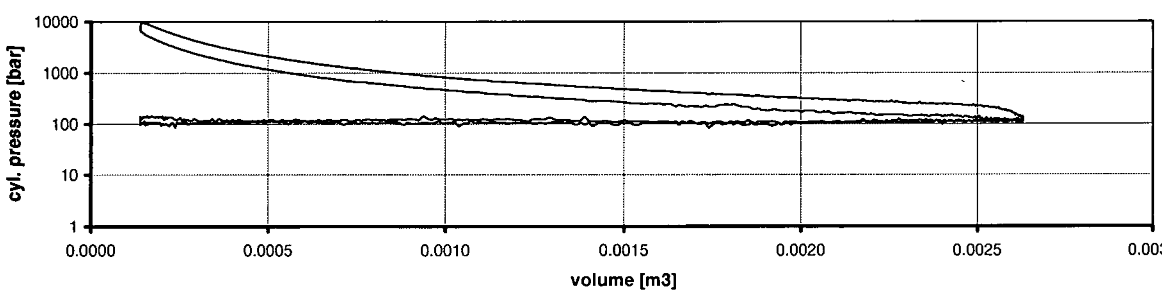
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume

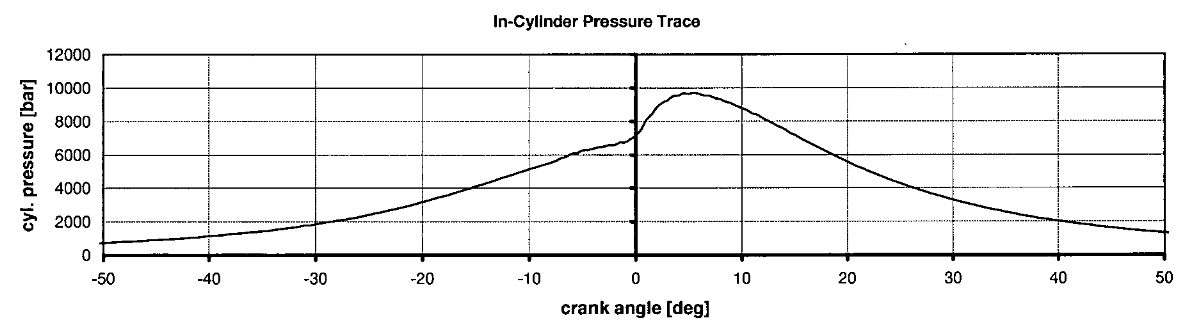


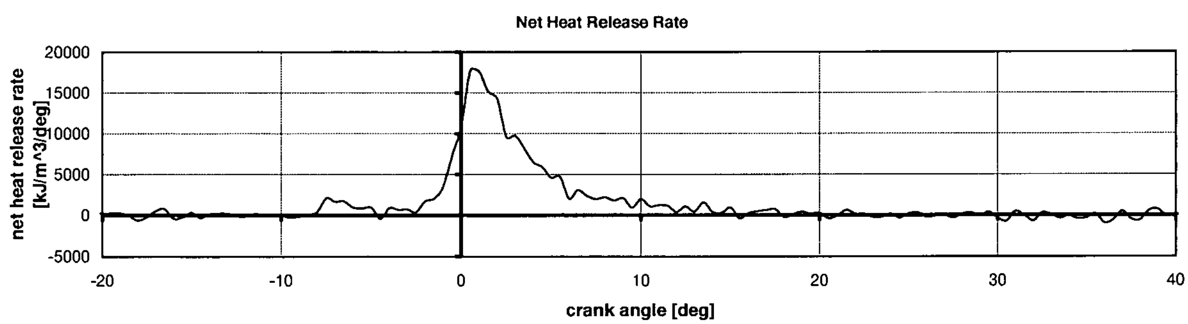
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 9692.32 |
| CA @ P max [deg] | 5.5 |
| dP/dCA max [bar/deg] | 937.440 |
| CA @ dP/dCA max [deg] | 0.5 |
| IMEP [bar] | 505.99 |
| HHR max [kJ/m^3/deg] | 17696.5 |
| IHR max [kJ/m^3] | 89622.6 |
| 5% MFB [deg w.r.t TDC] | -4.5 |
| 10% MFB [deg w.r.t TDC] | -1.5 |
| 50% MFB [deg w.r.t TDC] | 1.5 |
| 90% MFB [deg w.r.t TDC] | 7.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.28 |
| poly-n compression corrected | 1.28 |
| poly-n expansion uncorrected | 1.34 |
| poly-n expansion corrected | 1.34 |

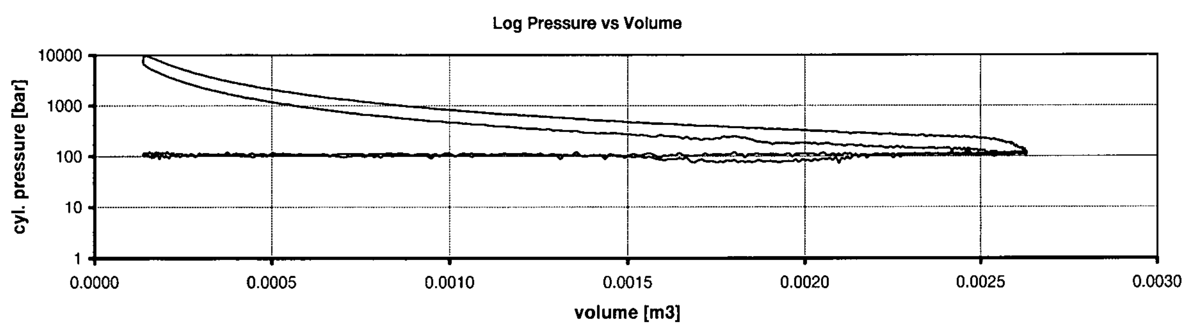
Comments

| Data Summary for filter: | A10 |
|---|---|
| Date: | 3/6/02 |
| Time: | 15:59:31 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 797.5 |
| Load - approx(%) | 25.0 |
| Power (kW) | 8.4 |
| IMEP (bar) | 5.07 |
| Pmax(bar) | 97.15 |
| Pmax location (degrees) | 365.7 |
| Diesel Flow(kg/hr) | 0.17 |
| CNG Flow(kg/hr) | 1.22 |
| Air Flow(kg/hr) | 72.7 |
| Exhaust Flow(kg/hr) | 74.1 |
| Exhaust Back Pressure (kPa) | 10.2 |
| EGR Fraction(%) | 0.0 |



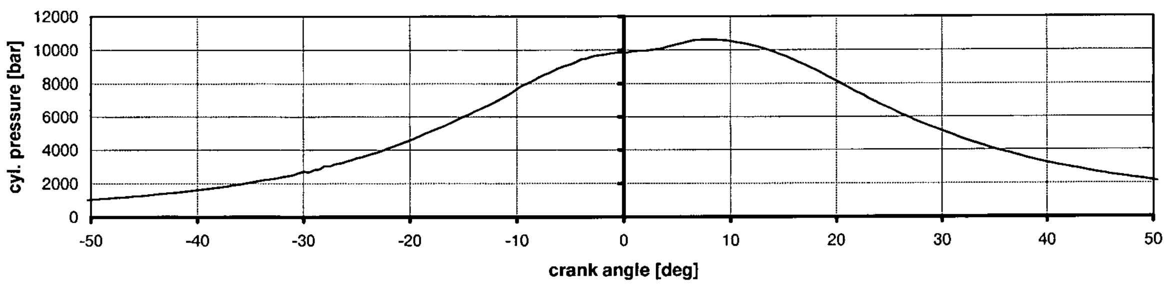
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 10596.23 |
| CA @ P max [deg] | 8.0 |
| dP/dCA max [bar/deg] | 422.193 |
| CA @ dP/dCA max [deg] | -10.5 |
| IMEP [bar] | 838.81 |
| HHR max [kJ/m^3/deg] | 8436.7 |
| IHR max [kJ/m^3] | 152283.0 |
| 5% MFB [deg w.r.t TDC] | -10.5 |
| 10% MFB [deg w.r.t TDC] | 0.5 |
| 50% MFB [deg w.r.t TDC] | 10.0 |
| 90% MFB [deg w.r.t TDC] | 23.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.36 |
| poly-n compression corrected | 1.36 |
| poly-n expansion uncorrected | 1.30 |
| poly-n expansion corrected | 1.30 |

**Comments**

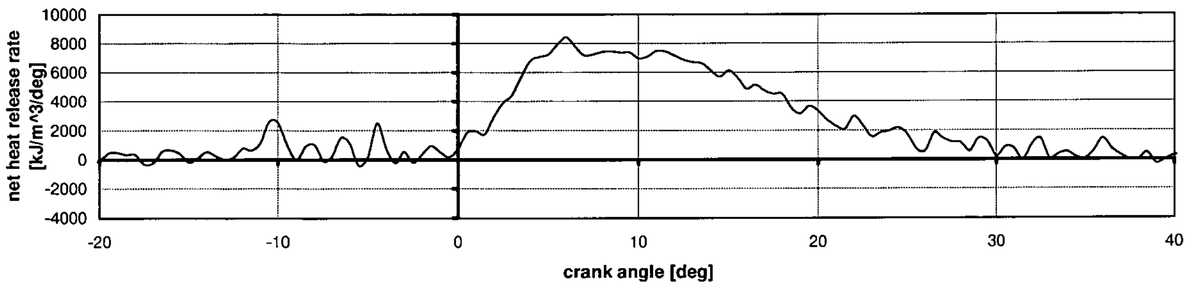
| | |
|---|---|
| Data Summary for filter: | A11 |
| Date: | 3/7/02 |
| Time: | 10:17:27 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1613.7 |
| Load - approx(%) | 40.0 |
| Power (kW) | 28.2 |
| IMEP (bar) | 8.40 |
| Pmax(bar) | 106.57 |
| Pmax location (degrees) | 368.3 |
| Diesel Flow(kg/hr) | 0.32 |
| CNG Flow(kg/hr) | 3.83 |
| Air Flow(kg/hr) | 212.1 |
| Exhaust Flow(kg/hr) | 216.3 |
| Exhaust Back Pressure (kPa) | 11.1 |
| EGR Fraction(%) | 0.0 |

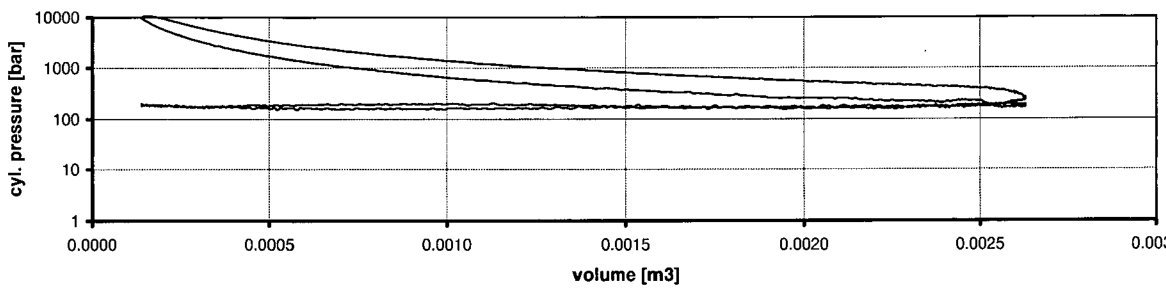
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume



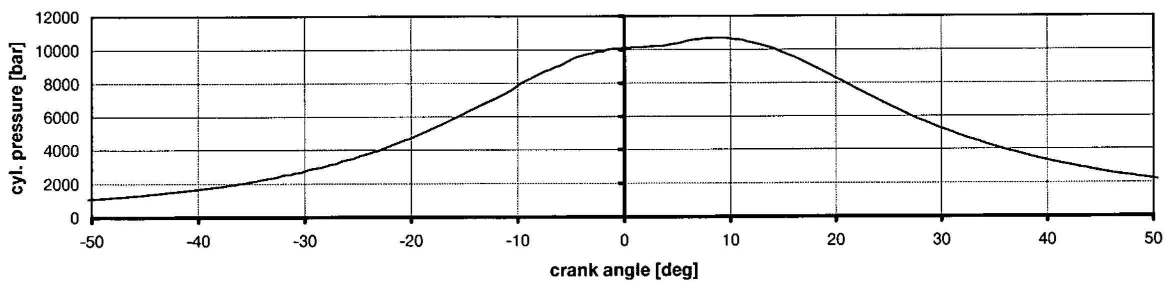
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 10701.11 |
| CA @ P_max [deg] | 8.5 |
| dP/dCA_max [bar/deg] | 417.023 |
| CA @ dP/dCA_max [deg] | -10.0 |
| IMEP [bar] | 850.45 |
| HHR_max [kJ/m^3/deg] | 8491.1 |
| IHR_max [kJ/m^3] | 152640.8 |
| 5% MFB [deg w.r.t TDC] | -6.0 |
| 10% MFB [deg w.r.t TDC] | 2.0 |
| 50% MFB [deg w.r.t TDC] | 10.5 |
| 90% MFB [deg w.r.t TDC] | 24.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.36 |
| poly-n compression corrected | 1.36 |
| poly-n expansion uncorrected | 1.30 |
| poly-n expansion corrected | 1.30 |

**Comments**

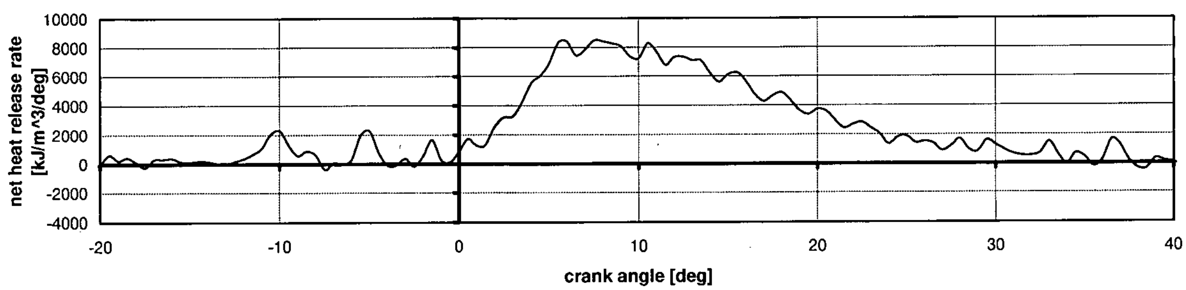
| Data Summary for filter: | A12 |
|---|---|
| Date: | 3/7/02 |
| Time: | 10:33:02 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1598.6 |
| Load - approx(%) | 40.0 |
| Power (kW) | 28.4 |
| IMEP (bar) | 8.52 |
| Pmax(bar) | 107.39 |
| Pmax location (degrees) | 369.2 |
| Diesel Flow(kg/hr) | 0.32 |
| CNG Flow(kg/hr) | 3.85 |
| Air Flow(kg/hr) | 178.8 |
| Exhaust Flow(kg/hr) | 182.9 |
| Exhaust Back Pressure (kPa) | 119.5 |
| EGR Fraction(%) | 12.8 |

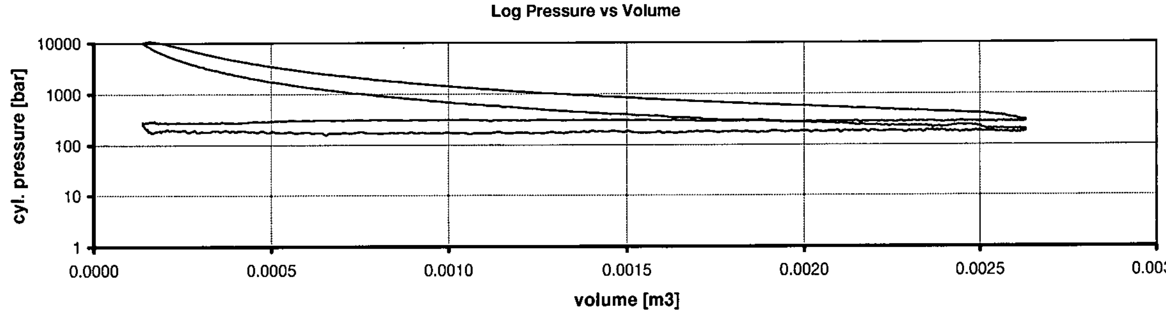
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume

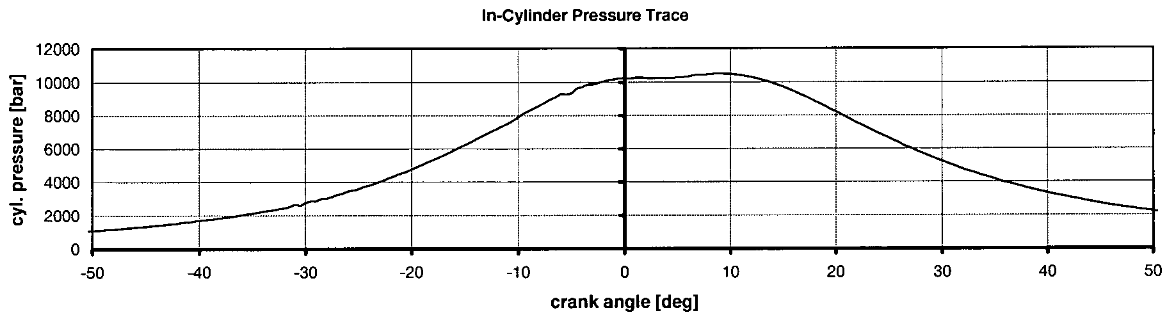


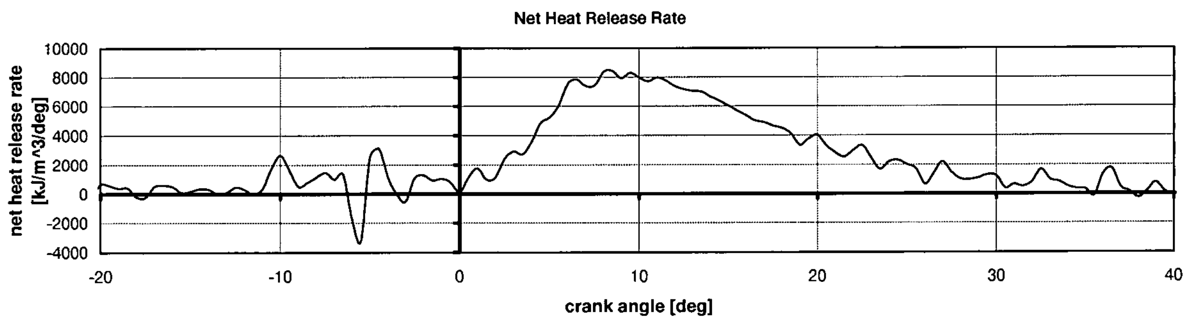
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 10509.33 |
| CA @ P_max [deg] | 8.5 |
| dP/dCA_max [bar/deg] | 434.255 |
| CA @ dP/dCA_max [deg] | -10.0 |
| IMEP [bar] | 839.08 |
| HHR_max [kJ/m^3/deg] | 8439.0 |
| IHR_max [kJ/m^3] | 152566.0 |
| 5% MFB [deg w.r.t TDC] | -9.5 |
| 10% MFB [deg w.r.t TDC] | 1.0 |
| 50% MFB [deg w.r.t TDC] | 11.0 |
| 90% MFB [deg w.r.t TDC] | 25.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.36 |
| poly-n compression corrected | 1.36 |
| poly-n expansion uncorrected | 1.32 |
| poly-n expansion corrected | 1.32 |

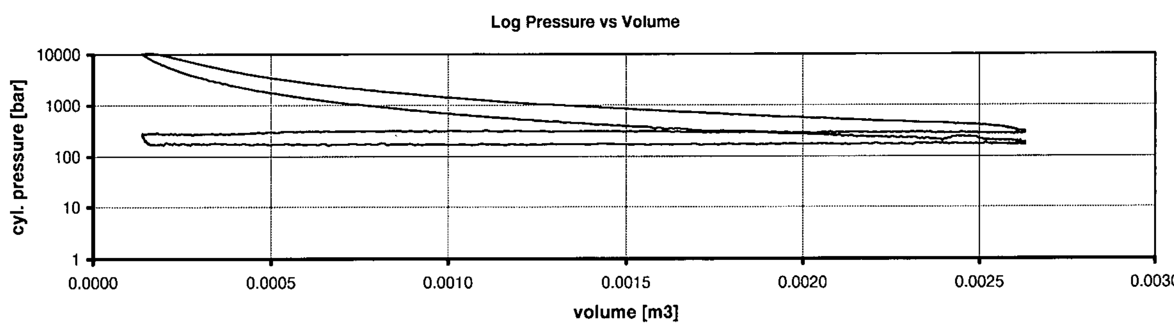
**Comments**

| | |
|---|---|
| Data Summary for filter: | A13 |
| Date: | 3/7/02 |
| Time: | 10:47:06 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1602.6 |
| Load - approx(%) | 40.0 |
| Power (kW) | 28.1 |
| IMEP (bar) | 8.40 |
| Pmax(bar) | 105.56 |
| Pmax location (degrees) | 369.5 |
| Diesel Flow(kg/hr) | 0.32 |
| CNG Flow(kg/hr) | 3.82 |
| Air Flow(kg/hr) | 157.4 |
| Exhaust Flow(kg/hr) | 161.5 |
| Exhaust Back Pressure (kPa) | 124.7 |
| EGR Fraction(%) | 22.6 |



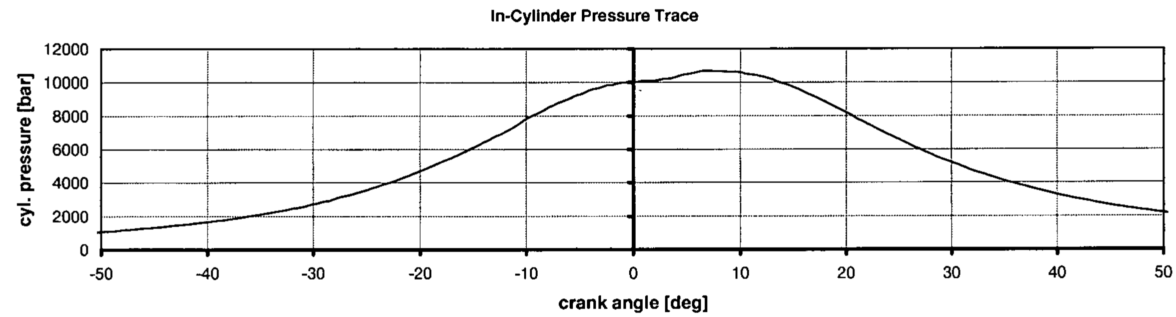



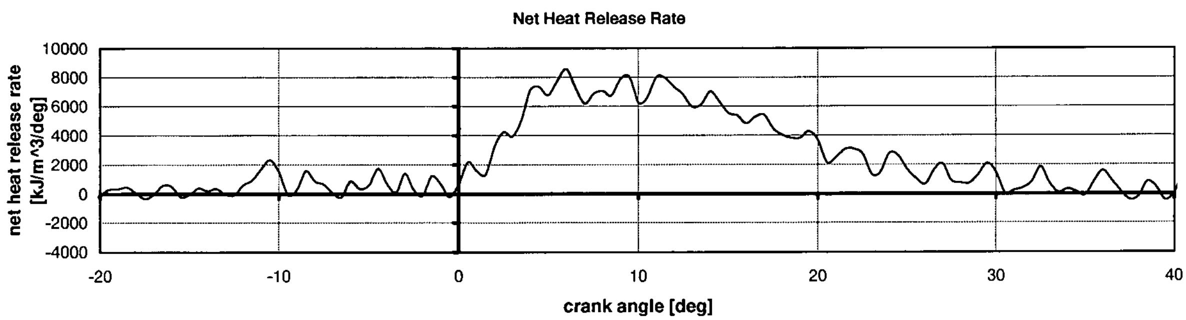
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 10676.23 |
| CA @ P_max [deg] | 6.5 |
| dP/dCA max [bar/deg] | 415.300 |
| CA @ dP/dCA max [deg] | -10.5 |
| IMEP [bar] | 838.05 |
| HHR max [kJ/m^3/deg] | 8566.2 |
| IHR max [kJ/m^3] | 151603.4 |
| 5% MFB [deg w.r.t TDC] | -8.0 |
| 10% MFB [deg w.r.t TDC] | 1.5 |
| 50% MFB [deg w.r.t TDC] | 10.5 |
| 90% MFB [deg w.r.t TDC] | 24.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.31 |
| poly-n compression corrected | 1.31 |
| poly-n expansion uncorrected | 1.30 |
| poly-n expansion corrected | 1.30 |

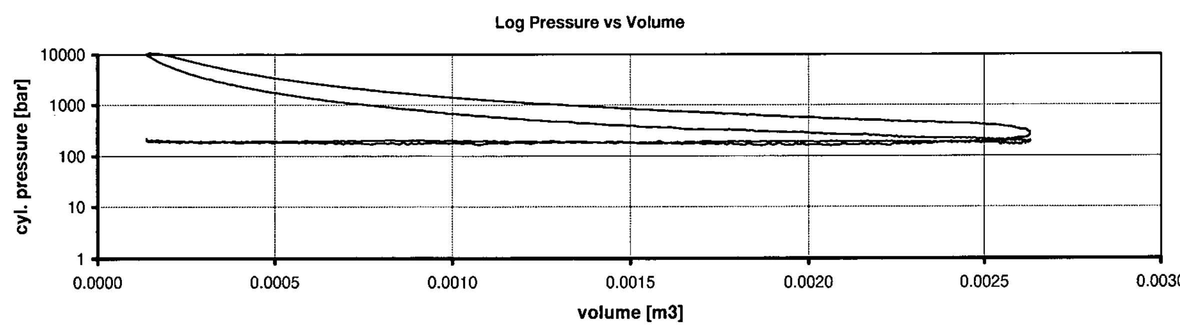
Comments

| | |
|---|---|
| Data Summary for filter: | B1 |
| Date: | 4/8/02 |
| Time: | 13:27:23 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1608.6 |
| Load - approx(%) | 40.0 |
| Power (kW) | 28.1 |
| IMEP (bar) | 8.39 |
| Pmax(bar) | 107.19 |
| Pmax location (degrees) | 368.0 |
| Diesel Flow(kg/hr) | 0.27 |
| CNG Flow(kg/hr) | 3.67 |
| Air Flow(kg/hr) | 213.1 |
| Exhaust Flow(kg/hr) | 217.0 |
| Exhaust Back Pressure (kPa) | 11.9 |
| EGR Fraction(%) | 0.0 |



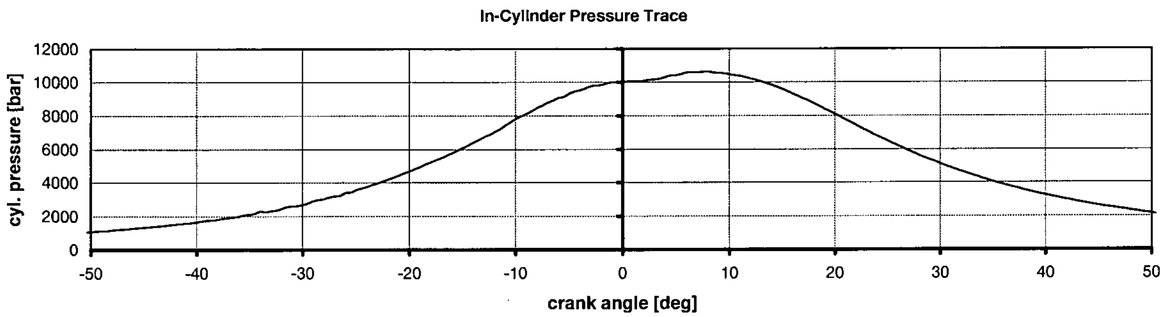



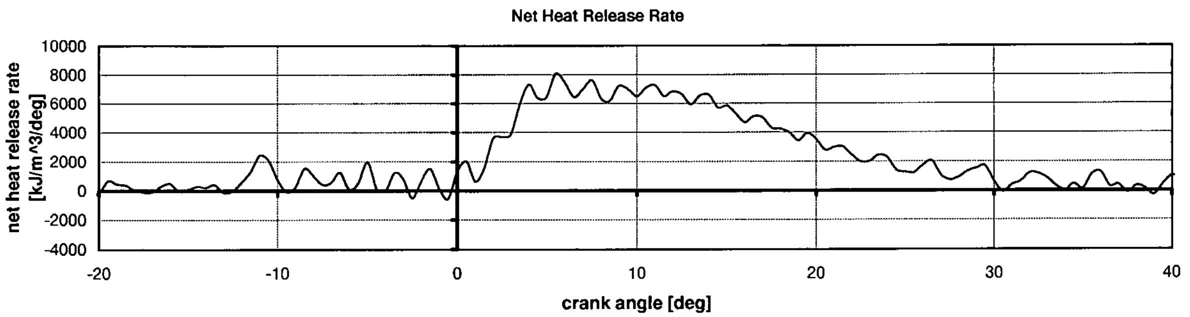
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 10632.76 |
| CA @ P_max [deg] | 8.0 |
| dP/dCA max [bar/deg] | 418.746 |
| CA @ dP/dCA max [deg] | -11.0 |
| IMEP [bar] | 816.89 |
| HHR max [kJ/m^3/deg] | 8058.0 |
| IHR max [kJ/m^3] | 146438.5 |
| 5% MFB [deg w.r.t TDC] | -7.5 |
| 10% MFB [deg w.r.t TDC] | 1.5 |
| 50% MFB [deg w.r.t TDC] | 10.5 |
| 90% MFB [deg w.r.t TDC] | 24.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.33 |
| poly-n compression corrected | 1.33 |
| poly-n expansion uncorrected | 1.30 |
| poly-n expansion corrected | 1.30 |

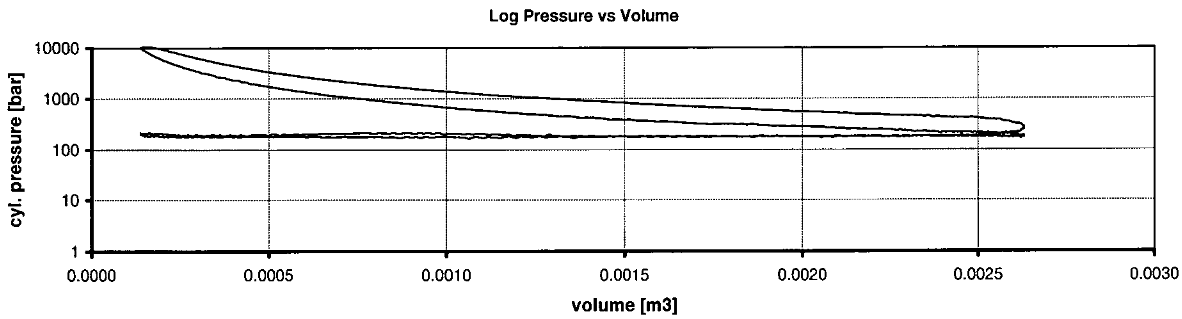
**Comments**

| Data Summary for filter: | B2 |
|---|---|
| Date: | 4/8/02 |
| Time: | 13:31:39 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1618.1 |
| Load - approx(%) | 40.0 |
| Power (kW) | 27.6 |
| IMEP (bar) | 8.18 |
| Pmax(bar) | 106.62 |
| Pmax location (degrees) | 368.0 |
| Diesel Flow(kg/hr) | 0.32 |
| CNG Flow(kg/hr) | 3.67 |
| Air Flow(kg/hr) | 212.7 |
| Exhaust Flow(kg/hr) | 216.7 |
| Exhaust Back Pressure (kPa) | 11.7 |
| EGR Fraction(%) | 0.0 |



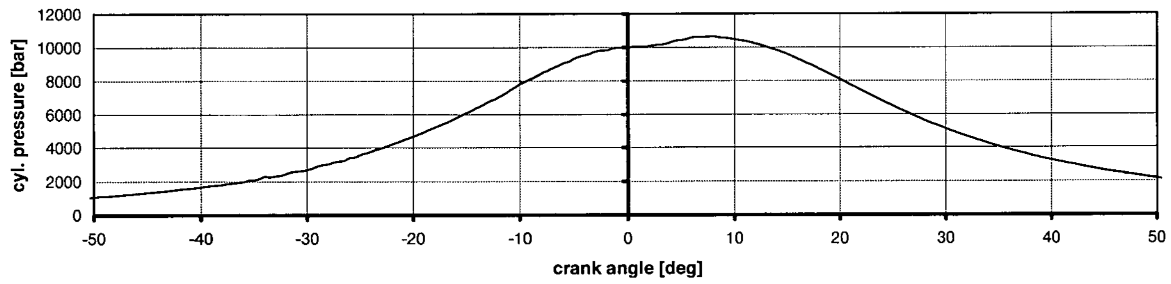
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 10632.80 |
| CA @ P_max [deg] | 8.0 |
| dP/dCA_max [bar/deg] | 418.746 |
| CA @ dP/dCA_max [deg] | -11.0 |
| IMEP [bar] | 816.89 |
| HHR_max [kJ/m^3/deg] | 8058.1 |
| IHR_max [kJ/m^3] | 146442.4 |
| 5% MFB [deg w.r.t TDC] | -7.5 |
| 10% MFB [deg w.r.t TDC] | 1.5 |
| 50% MFB [deg w.r.t TDC] | 10.5 |
| 90% MFB [deg w.r.t TDC] | 24.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.33 |
| poly-n compression corrected | 1.33 |
| poly-n expansion uncorrected | 1.30 |
| poly-n expansion corrected | 1.30 |

**Comments**

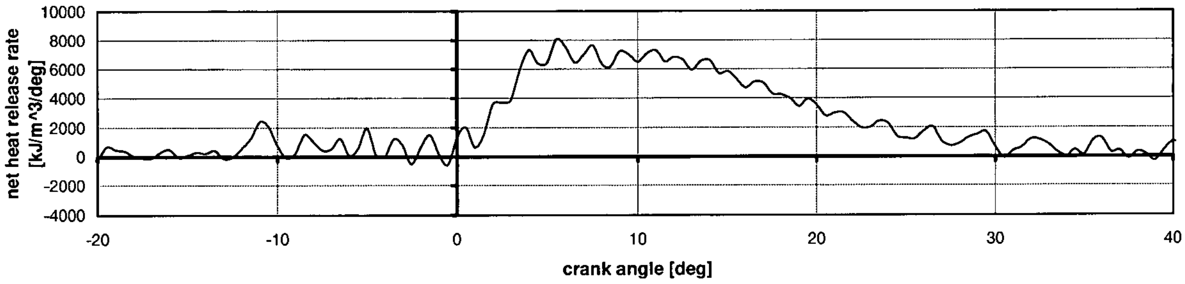
| | |
|---|---|
| Data Summary for filter: | B3 |
| Date: | 4/8/02 |
| Time: | 13:41:56 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1620.0 |
| Load - approx(%) | 40.0 |
| Power (kW) | 27.6 |
| IMEP (bar) | 8.18 |
| Pmax(bar) | 106.62 |
| Pmax location (degrees) | 368.0 |
| Diesel Flow(kg/hr) | 0.25 |
| CNG Flow(kg/hr) | 3.65 |
| Air Flow(kg/hr) | 212.8 |
| Exhaust Flow(kg/hr) | 216.7 |
| Exhaust Back Pressure (kPa) | 11.8 |
| EGR Fraction(%) | 0.0 |

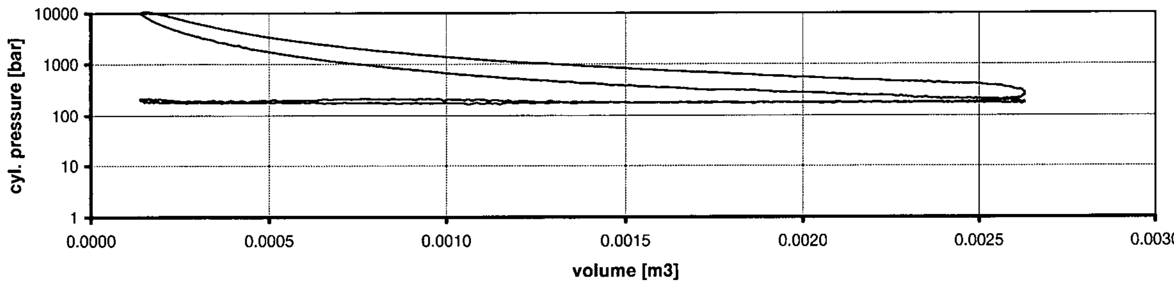
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume

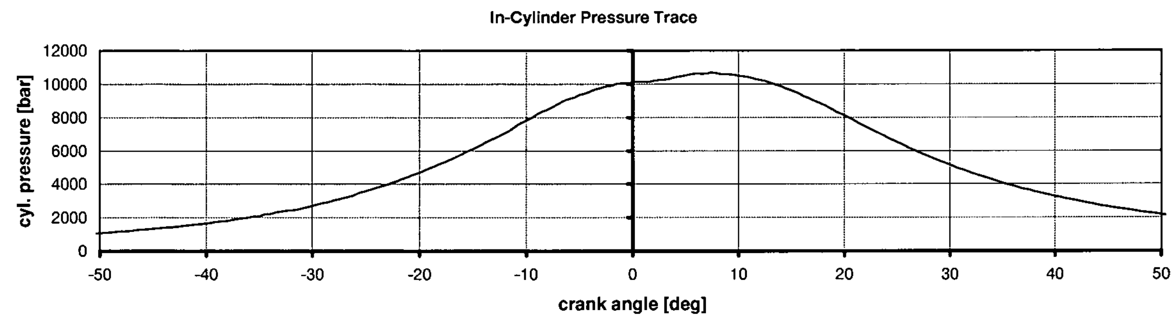


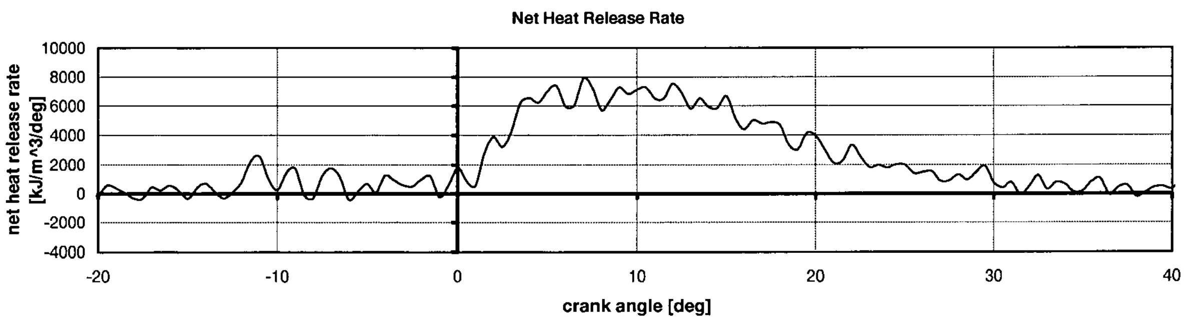
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 10691.37 |
| CA @ P max [deg] | 7.5 |
| dP/dCA max [bar/deg] | 429.086 |
| CA @ dP/dCA max [deg] | -11.0 |
| IMEP [bar] | 821.27 |
| HHR max [kJ/m^3/deg] | 7941.5 |
| IHR max [kJ/m^3] | 148012.3 |
| 5% MFB [deg w.r.t TDC] | -9.5 |
| 10% MFB [deg w.r.t TDC] | 0.5 |
| 50% MFB [deg w.r.t TDC] | 10.5 |
| 90% MFB [deg w.r.t TDC] | 24.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.34 |
| poly-n compression corrected | 1.34 |
| poly-n expansion uncorrected | 1.31 |
| poly-n expansion corrected | 1.31 |

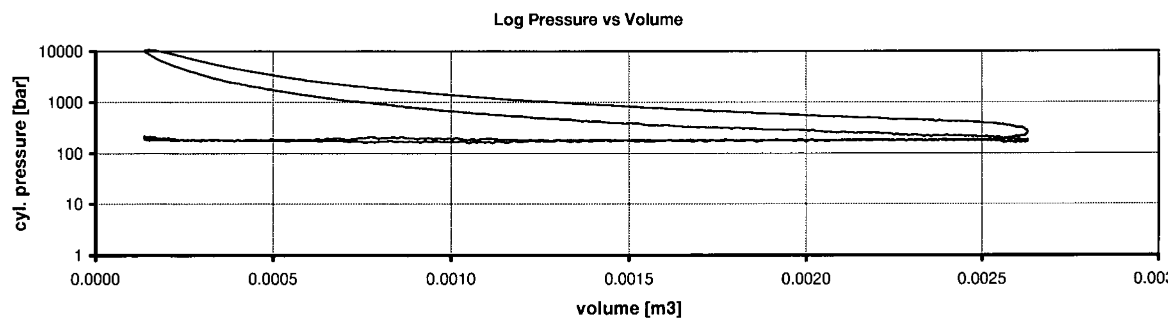
**Comments**

| Data Summary for filter: | B4 |
|---|---|
| Date: | 4/8/02 |
| Time: | 13:53:09 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1614.8 |
| Load - approx(%) | 40.0 |
| Power (kW) | 27.7 |
| IMEP (bar) | 8.22 |
| Pmax(bar) | 107.10 |
| Pmax location (degrees) | 367.9 |
| Diesel Flow(kg/hr) | 0.36 |
| CNG Flow(kg/hr) | 3.64 |
| Air Flow(kg/hr) | 212.5 |
| Exhaust Flow(kg/hr) | 216.5 |
| Exhaust Back Pressure (kPa) | 11.8 |
| EGR Fraction(%) | 0.0 |



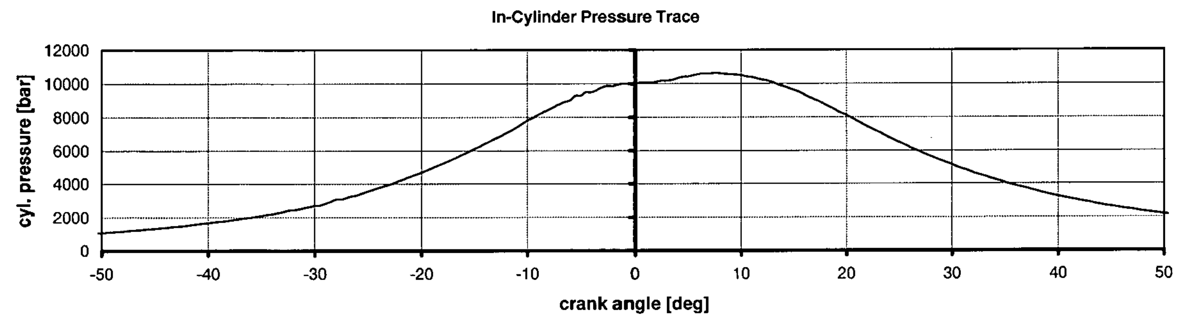



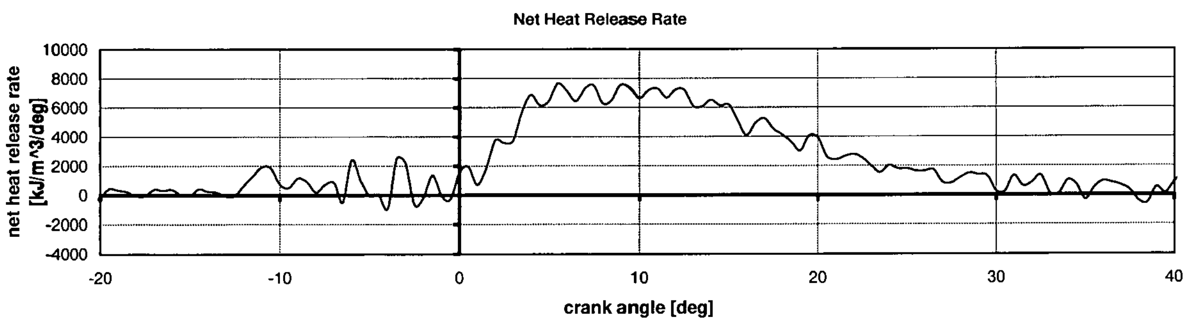
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 10615.56 |
| CA @ P max [deg] | 7.5 |
| dP/dCA max [bar/deg] | 398.067 |
| CA @ dP/dCA max [deg] | -11.0 |
| IMEP [bar] | 815.60 |
| HHR max [kJ/m^3/deg] | 7650.8 |
| IHR max [kJ/m^3] | 149512.2 |
| 5% MFB [deg w.r.t TDC] | -10.5 |
| 10% MFB [deg w.r.t TDC] | 0.5 |
| 50% MFB [deg w.r.t TDC] | 10.5 |
| 90% MFB [deg w.r.t TDC] | 24.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.33 |
| poly-n compression corrected | 1.33 |
| poly-n expansion uncorrected | 1.30 |
| poly-n expansion corrected | 1.30 |

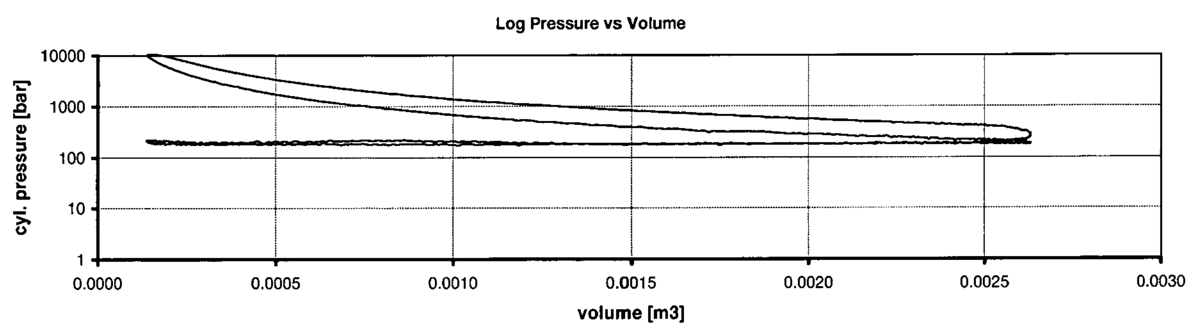
**Comments**

| | |
|---|---|
| Data Summary for filter: | B5 |
| Date: | 4/8/02 |
| Time: | 14:03:47 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1611.8 |
| Load - approx(%) | 40.0 |
| Power (kW) | 27.4 |
| IMEP (bar) | 8.17 |
| Pmax(bar) | 106.48 |
| Pmax location (degrees) | 367.9 |
| Diesel Flow(kg/hr) | 0.30 |
| CNG Flow(kg/hr) | 3.67 |
| Air Flow(kg/hr) | 212.4 |
| Exhaust Flow(kg/hr) | 216.4 |
| Exhaust Back Pressure (kPa) | 11.8 |
| EGR Fraction(%) | 0.0 |



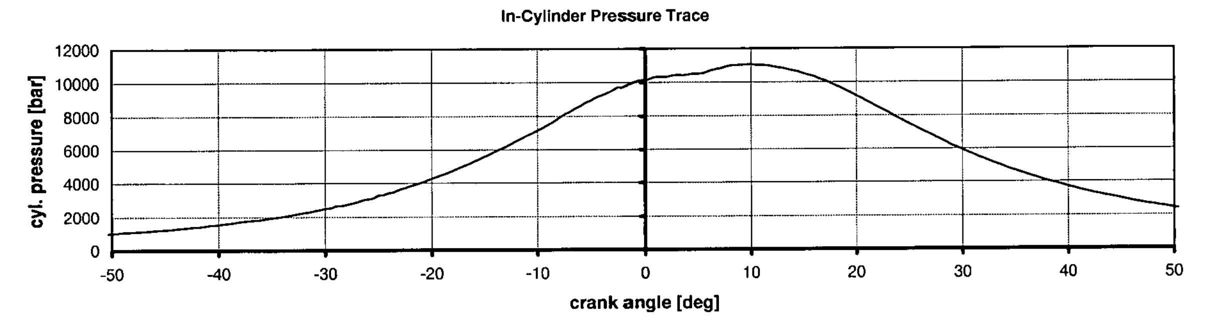



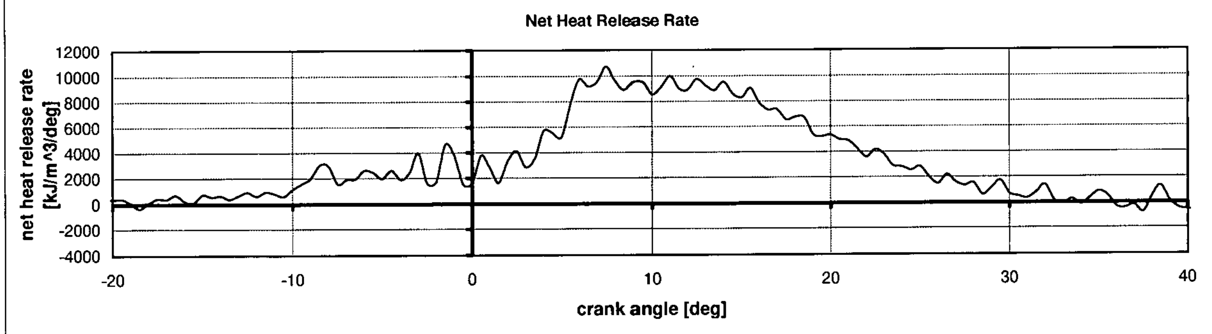
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 11044.34 |
| CA @ P max [deg] | 9.5 |
| dP/dCA max [bar/deg] | 415.300 |
| CA @ dP/dCA max [deg] | -8.5 |
| IMEP [bar] | 1067.05 |
| HHR max [kJ/m^3/deg] | 10729.7 |
| IHR max [kJ/m^3] | 201939.6 |
| 5% MFB [deg w.r.t TDC] | -8.0 |
| 10% MFB [deg w.r.t TDC] | -3.5 |
| 50% MFB [deg w.r.t TDC] | 10.5 |
| 90% MFB [deg w.r.t TDC] | 21.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.27 |
| poly-n compression corrected | 1.27 |
| poly-n expansion uncorrected | 1.38 |
| poly-n expansion corrected | 1.38 |

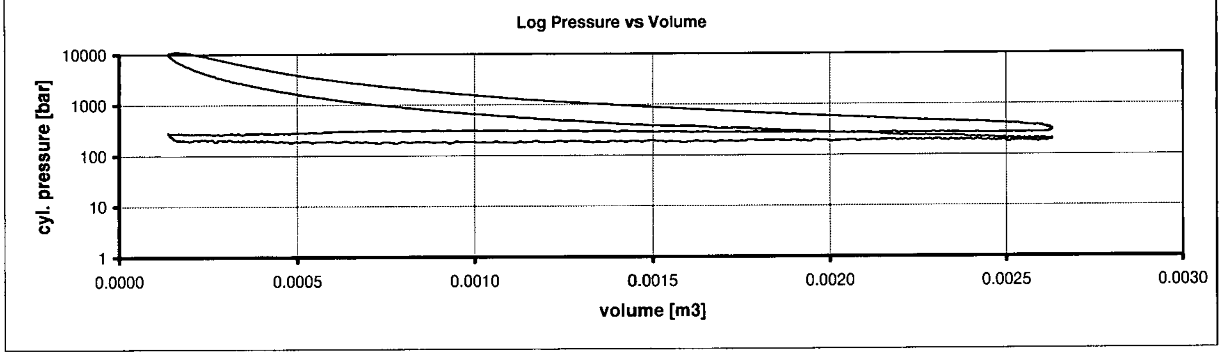
Comments

| Data Summary for filter: | B6 |
|---|---|
| Date: | 4/8/02 |
| Time: | 14:15:04 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1562.1 |
| Load - approx(%) | |
| Power (kW) | 34.8 |
| IMEP (bar) | 10.68 |
| Pmax(bar) | 110.77 |
| Pmax location (degrees) | 370.1 |
| Diesel Flow(kg/hr) | 0.28 |
| CNG Flow(kg/hr) | 3.57 |
| Air Flow(kg/hr) | 210.6 |
| Exhaust Flow(kg/hr) | 214.4 |
| Exhaust Back Pressure (kPa) | 106.3 |
| EGR Fraction(%) | 0.0 |



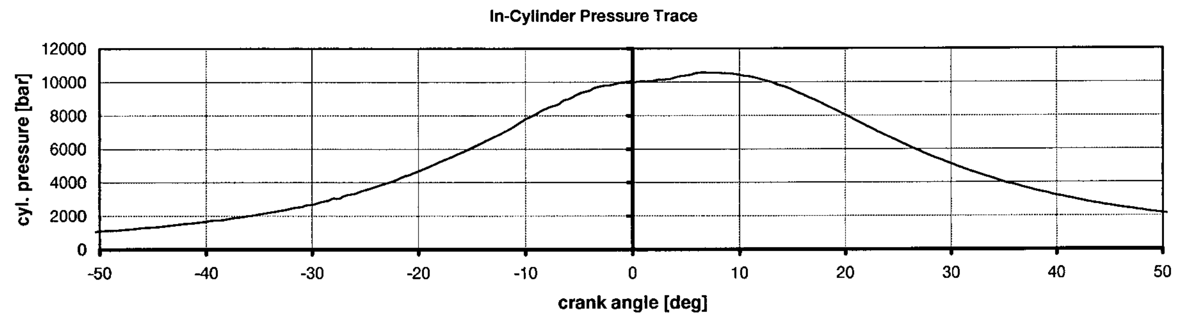



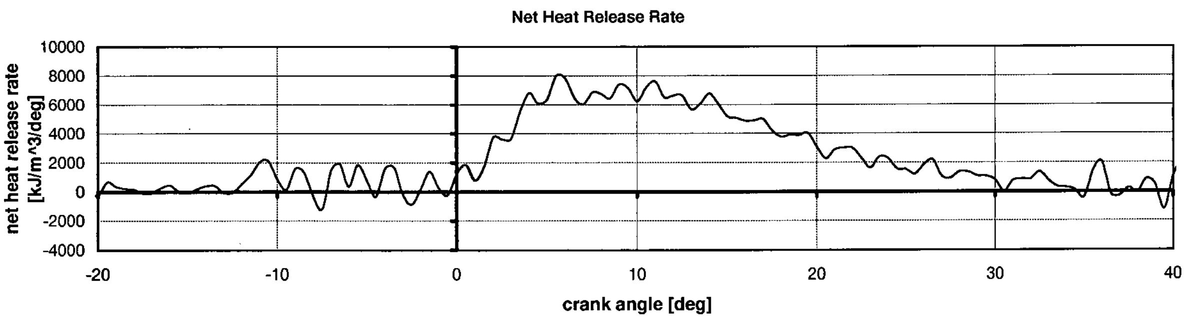
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 10575.64 |
| CA @ P_max [deg] | 6.5 |
| dP/dCA_max [bar/deg] | 404.960 |
| CA @ dP/dCA_max [deg] | -10.5 |
| IMEP [bar] | 809.37 |
| HHR_max [kJ/m^3/deg] | 8006.1 |
| IHR_max [kJ/m^3] | 146670.0 |
| 5% MFB [deg w.r.t TDC] | -9.0 |
| 10% MFB [deg w.r.t TDC] | 1.5 |
| 50% MFB [deg w.r.t TDC] | 10.5 |
| 90% MFB [deg w.r.t TDC] | 24.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.33 |
| poly-n compression corrected | 1.33 |
| poly-n expansion uncorrected | 1.30 |
| poly-n expansion corrected | 1.30 |

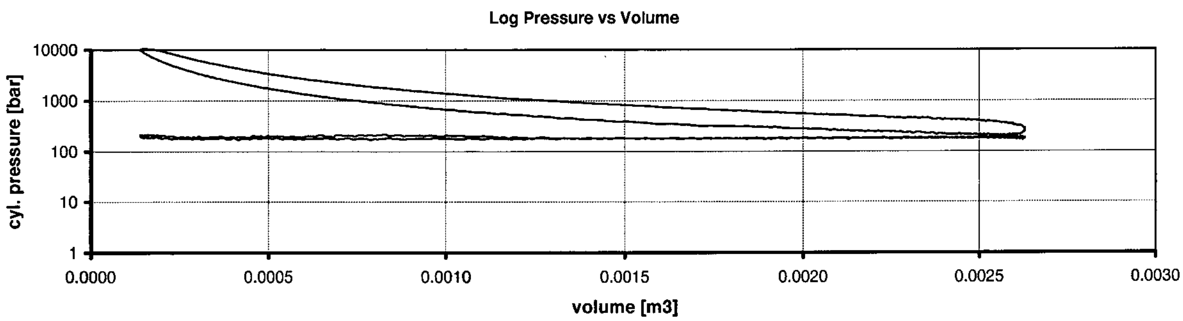
**Comments**

| | |
|---|---|
| Data Summary for filter: | B7 |
| Date: | 4/8/02 |
| Time: | 14:23:24 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1613.5 |
| Load - approx(%) | 40.0 |
| Power (kW) | 27.2 |
| IMEP (bar) | 8.10 |
| Pmax(bar) | 106.26 |
| Pmax location (degrees) | 367.6 |
| Diesel Flow(kg/hr) | 0.31 |
| CNG Flow(kg/hr) | 3.64 |
| Air Flow(kg/hr) | 212.4 |
| Exhaust Flow(kg/hr) | 216.4 |
| Exhaust Back Pressure (kPa) | 11.8 |
| EGR Fraction(%) | 0.0 |



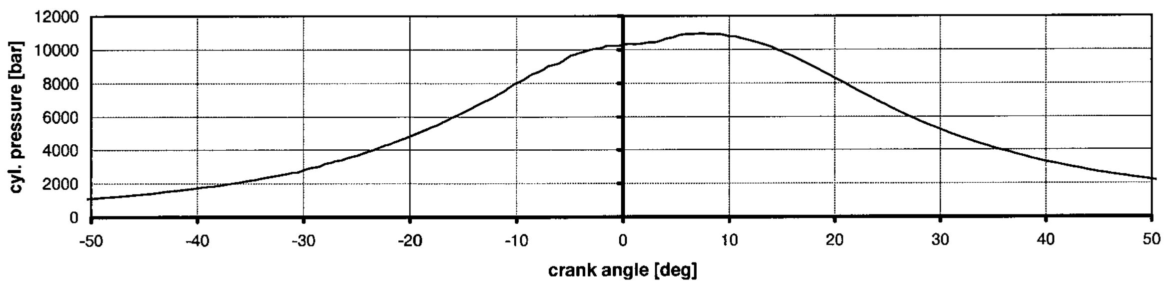
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 10960.93 |
| CA @ P_max [deg] | 7.5 |
| dP/dCA max [bar/deg] | 418.746 |
| CA @ dP/dCA max [deg] | -11.0 |
| IMEP [bar] | 821.69 |
| HHR max [kJ/m^3/deg] | 8234.3 |
| IHR max [kJ/m^3] | 147950.0 |
| 5% MFB [deg w.r.t TDC] | -6.0 |
| 10% MFB [deg w.r.t TDC] | 1.5 |
| 50% MFB [deg w.r.t TDC] | 10.5 |
| 90% MFB [deg w.r.t TDC] | 23.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.32 |
| poly-n compression corrected | 1.32 |
| poly-n expansion uncorrected | 1.30 |
| poly-n expansion corrected | 1.30 |

**Comments**

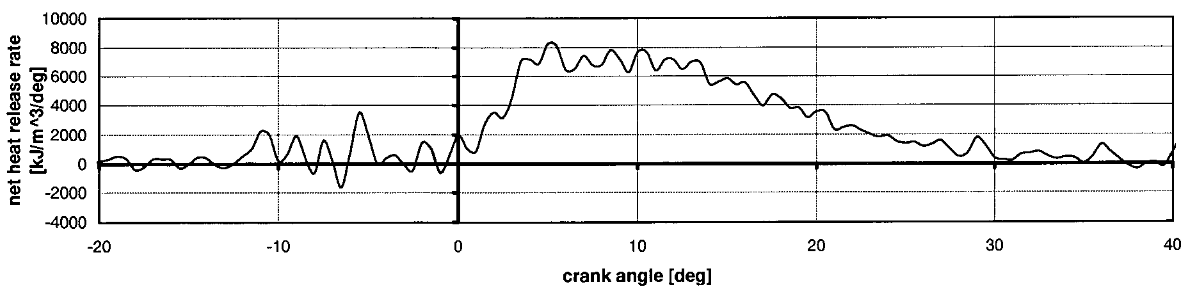
| | |
|---|---|
| Data Summary for filter: | B8 |
| Date: | 4/8/02 |
| Time: | 14:32:56 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1578.9 |
| Load - approx(%) | 40.0 |
| Power (kW) | 27.1 |
| IMEP (bar) | 8.23 |
| Pmax(bar) | 109.92 |
| Pmax location (degrees) | 367.8 |
| Diesel Flow(kg/hr) | 0.27 |
| CNG Flow(kg/hr) | 3.63 |
| Air Flow(kg/hr) | 210.9 |
| Exhaust Flow(kg/hr) | 214.8 |
| Exhaust Back Pressure (kPa) | 103.9 |
| EGR Fraction(%) | 0.0 |

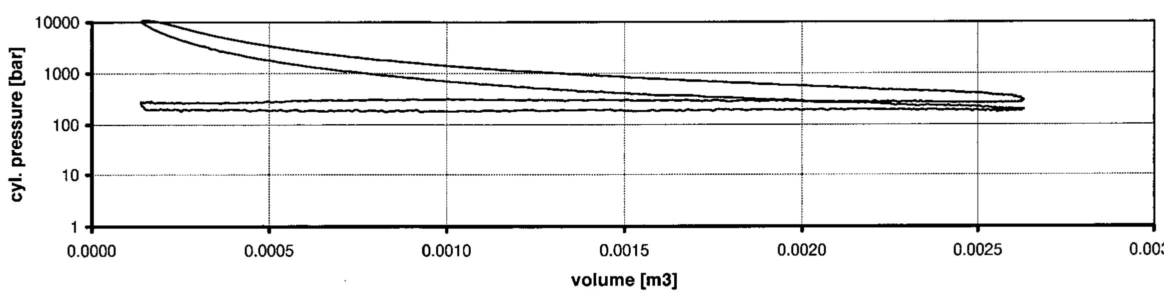
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume



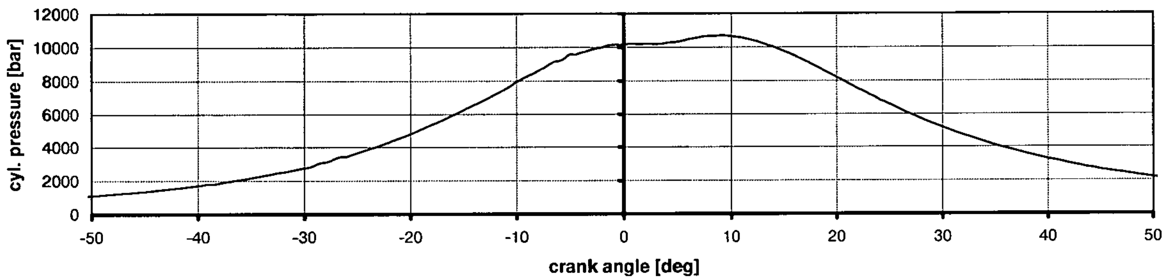
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 10689.62 |
| CA @ P max [deg] | 9.0 |
| dP/dCA max [bar/deg] | 418.746 |
| CA @ dP/dCA max [deg] | -10.5 |
| IMEP [bar] | 809.83 |
| HHR max [kJ/m^3/deg] | 9002.7 |
| IHR max [kJ/m^3] | 147222.2 |
| 5% MFB [deg w.r.t TDC] | -8.0 |
| 10% MFB [deg w.r.t TDC] | 2.0 |
| 50% MFB [deg w.r.t TDC] | 10.5 |
| 90% MFB [deg w.r.t TDC] | 24.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.33 |
| poly-n compression corrected | 1.33 |
| poly-n expansion uncorrected | 1.30 |
| poly-n expansion corrected | 1.30 |

**Comments**

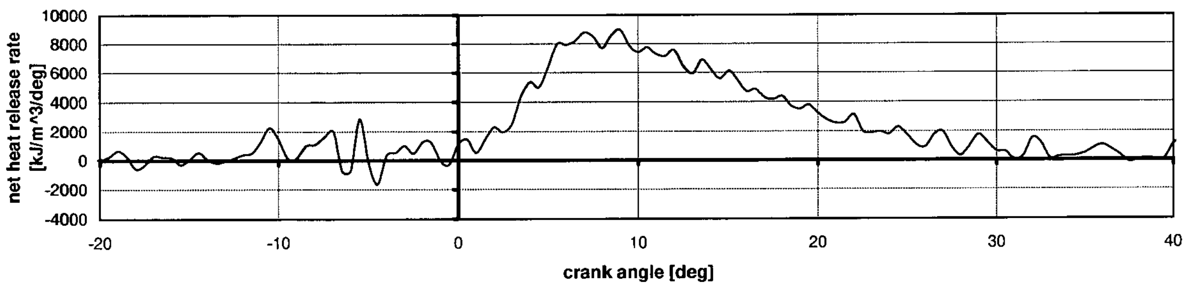
| | |
|---|---|
| Data Summary for filter: | B9 |
| Date: | 4/8/02 |
| Time: | 15:06:44 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1573.5 |
| Load - approx(%) | 40.0 |
| Power (kW) | 26.6 |
| IMEP (bar) | 8.11 |
| Pmax(bar) | 107.34 |
| Pmax location (degrees) | 369.4 |
| Diesel Flow(kg/hr) | 0.27 |
| CNG Flow(kg/hr) | 3.58 |
| Air Flow(kg/hr) | 166.7 |
| Exhaust Flow(kg/hr) | 170.5 |
| Exhaust Back Pressure (kPa) | 131.7 |
| EGR Fraction(%) | 17.7 |

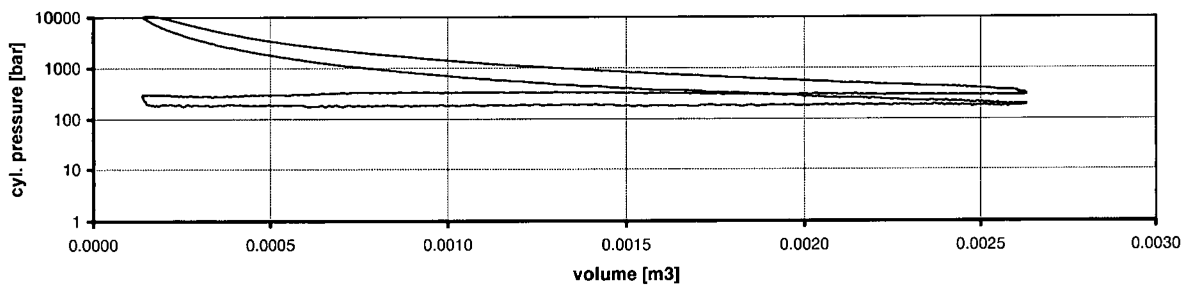
**In-Cylinder Pressure Trace**




**Net Heat Release Rate**




**Log Pressure vs Volume**

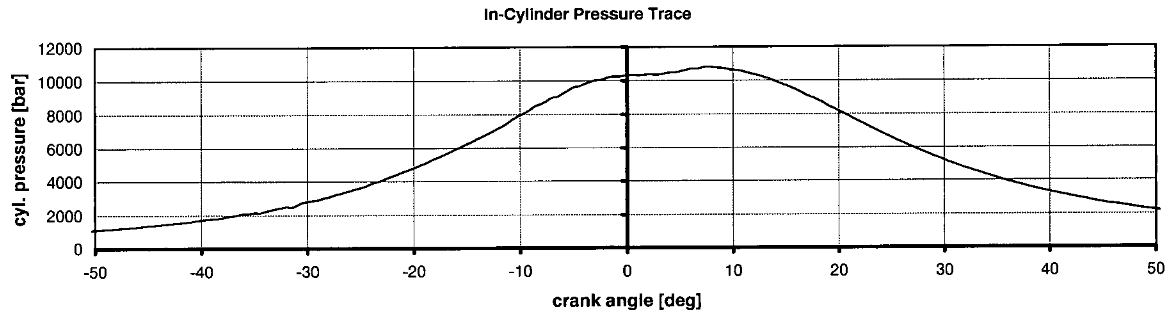


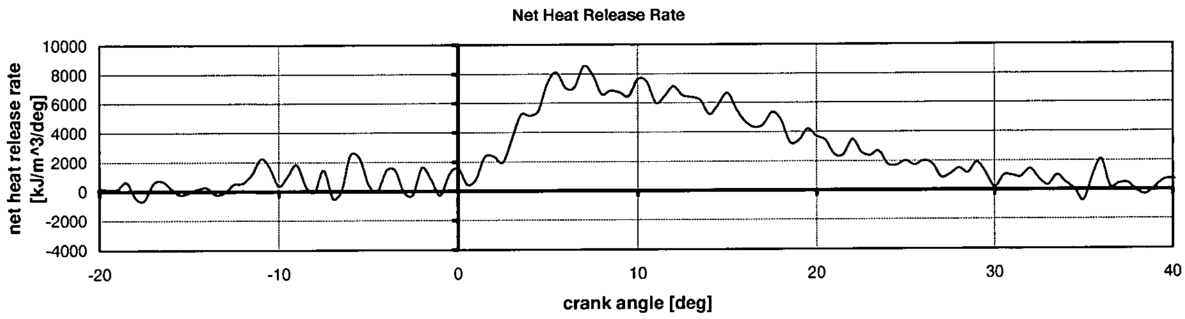
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 10800.41 |
| CA @ P_max [deg] | 7.5 |
| dP/dCA_max [bar/deg] | 418.746 |
| CA @ dP/dCA_max [deg] | -11.0 |
| IMEP [bar] | 825.43 |
| HHR_max [kJ/m^3/deg] | 8521.6 |
| IHR_max [kJ/m^3] | 150258.3 |
| 5% MFB [deg w.r.t TDC] | -9.0 |
| 10% MFB [deg w.r.t TDC] | 1.0 |
| 50% MFB [deg w.r.t TDC] | 11.0 |
| 90% MFB [deg w.r.t TDC] | 25.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.33 |
| poly-n compression corrected | 1.33 |
| poly-n expansion uncorrected | 1.28 |
| poly-n expansion corrected | 1.28 |

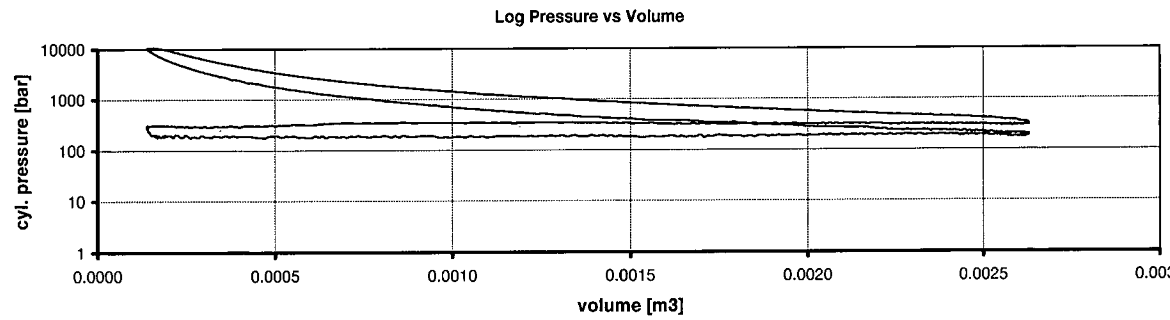
Comments

| | |
|---|---|
| Data Summary for filter: | B10 |
| Date: | 4/8/02 |
| Time: | 15:17:18 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1595.3 |
| Load - approx(%) | 40.0 |
| Power (kW) | 27.5 |
| IMEP (bar) | 8.26 |
| Pmax(bar) | 108.33 |
| Pmax location (degrees) | 368.1 |
| Diesel Flow(kg/hr) | 0.38 |
| CNG Flow(kg/hr) | 3.64 |
| Air Flow(kg/hr) | 166.3 |
| Exhaust Flow(kg/hr) | 170.4 |
| Exhaust Back Pressure (kPa) | 132.7 |
| EGR Fraction(%) | 16.7 |



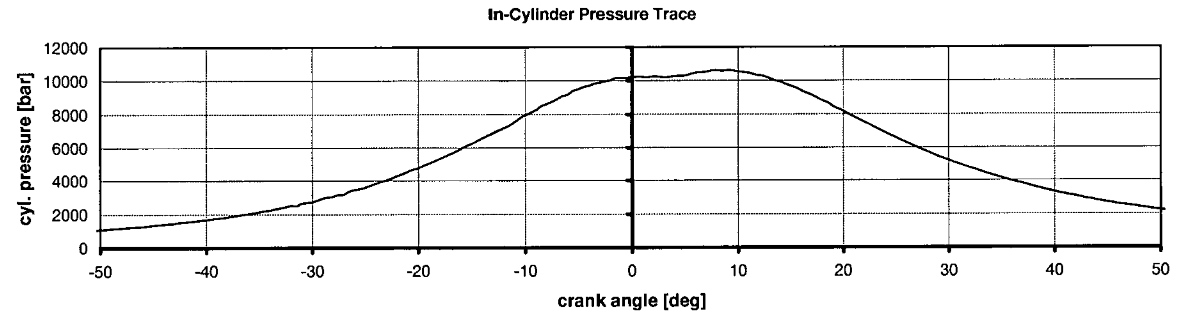



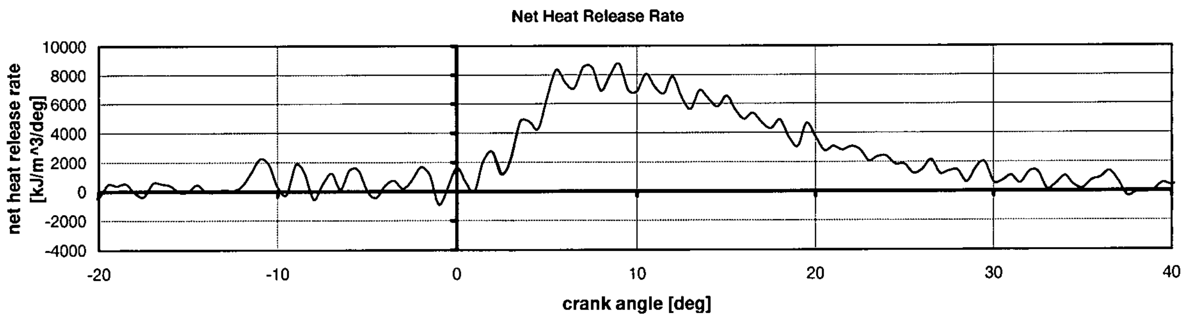
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 10602.66 |
| CA @ P max [deg] | 9.0 |
| dP/dCA max [bar/deg] | 417.023 |
| CA @ dP/dCA max [deg] | -11.0 |
| IMEP [bar] | 828.33 |
| HHR max [kJ/m^3/deg] | 8788.5 |
| IHR max [kJ/m^3] | 149638.8 |
| 5% MFB [deg w.r.t TDC] | -6.5 |
| 10% MFB [deg w.r.t TDC] | 2.5 |
| 50% MFB [deg w.r.t TDC] | 11.0 |
| 90% MFB [deg w.r.t TDC] | 25.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.33 |
| poly-n compression corrected | 1.33 |
| poly-n expansion uncorrected | 1.31 |
| poly-n expansion corrected | 1.31 |

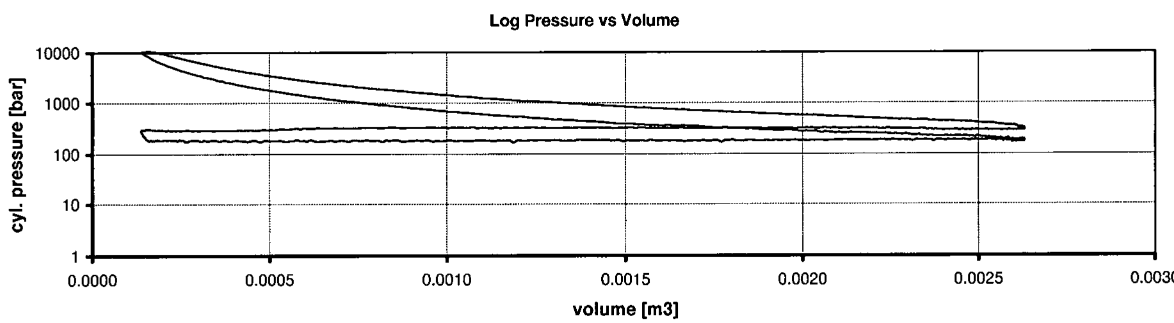
**Comments**

| Data Summary for filter: | B1,1 |
|---|---|
| Date: | 4/8/02 |
| Time: | 15:25:42 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1597.2 |
| Load - approx(%) | 40.0 |
| Power (kW) | 27.6 |
| IMEP (bar) | 8.29 |
| Pmax(bar) | 106.49 |
| Pmax location (degrees) | 369.1 |
| Diesel Flow(kg/hr) | 0.32 |
| CNG Flow(kg/hr) | 3.70 |
| Air Flow(kg/hr) | 166.2 |
| Exhaust Flow(kg/hr) | 170.3 |
| Exhaust Back Pressure (kPa) | 133.1 |
| EGR Fraction(%) | 16.9 |



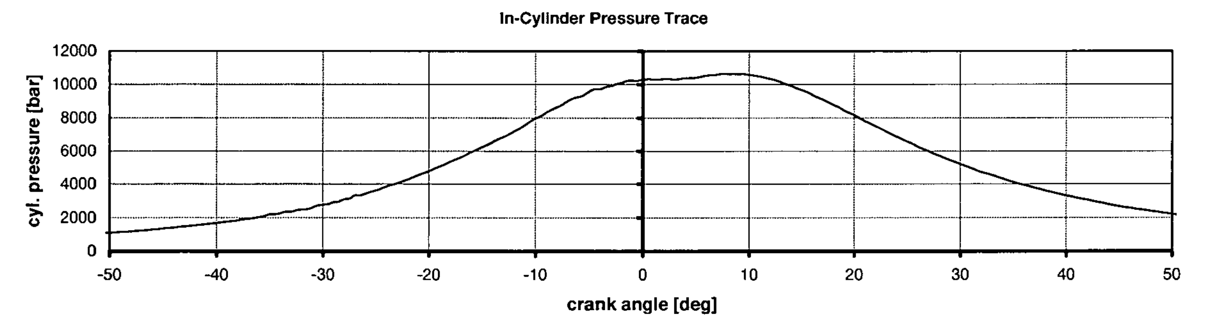



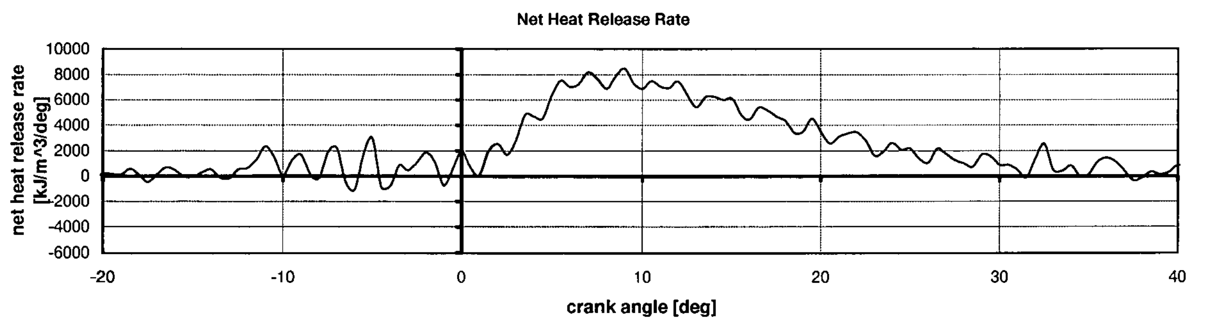



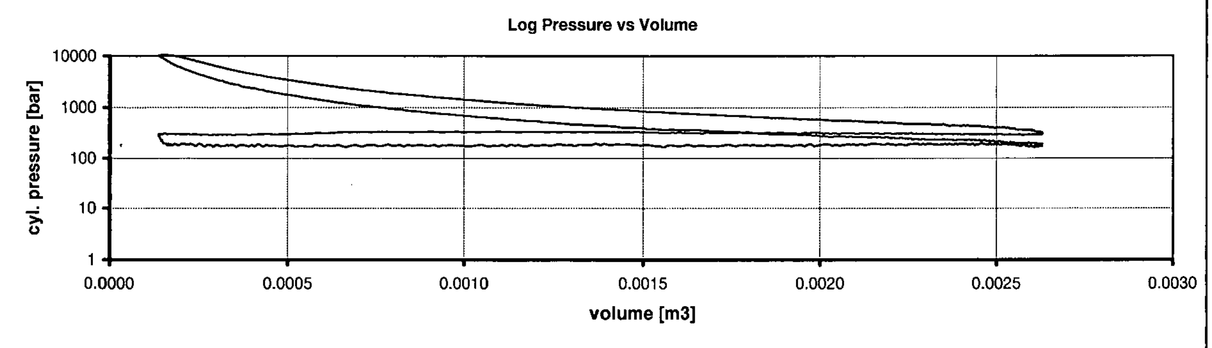
| | | Comments |
|---|---|---|
| Speed [RPM] | | |
| Torque [N-m] | | |
| Load [%] | | |
| P_max [deg] | 10635.55 | |
| CA @ P_max [deg] | 7.5 | |
| dP/dCA_max [bar/deg] | 422.193 | |
| CA @ dP/dCA_max [deg] | -11.0 | |
| IMEP [bar] | 828.21 | |
| HHR_max [kJ/m^3/deg] | 8478.2 | |
| IHR_max [kJ/m^3] | 151825.2 | |
| 5% MFB [deg w.r.t TDC] | -9.5 | |
| 10% MFB [deg w.r.t TDC] | 1.0 | |
| 50% MFB [deg w.r.t TDC] | 11.0 | |
| 90% MFB [deg w.r.t TDC] | 26.0 | |
| Assumed poly-n during comprn. | 1.37 | |
| zero-level. pr. offset [bar] | 0.000 | |
| poly-n compression uncorrected | 1.33 | |
| poly-n compression corrected | 1.33 | |
| poly-n expansion uncorrected | 1.31 | |
| poly-n expansion corrected | 1.31 | |

| Data Summary for filter: | B12 |
|---|---|
| Date: | 4/8/02 |
| Time: | 15:34:43 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1595.9 |
| Load - approx(%) | 40.0 |
| Power (kW) | 27.6 |
| IMEP (bar) | 8.29 |
| Pmax(bar) | 106.75 |
| Pmax location (degrees) | 368.8 |
| Diesel Flow(kg/hr) | 0.36 |
| CNG Flow(kg/hr) | 3.65 |
| Air Flow(kg/hr) | 166.2 |
| Exhaust Flow(kg/hr) | 170.2 |
| Exhaust Back Pressure (kPa) | 133.1 |
| EGR Fraction(%) | 16.6 |



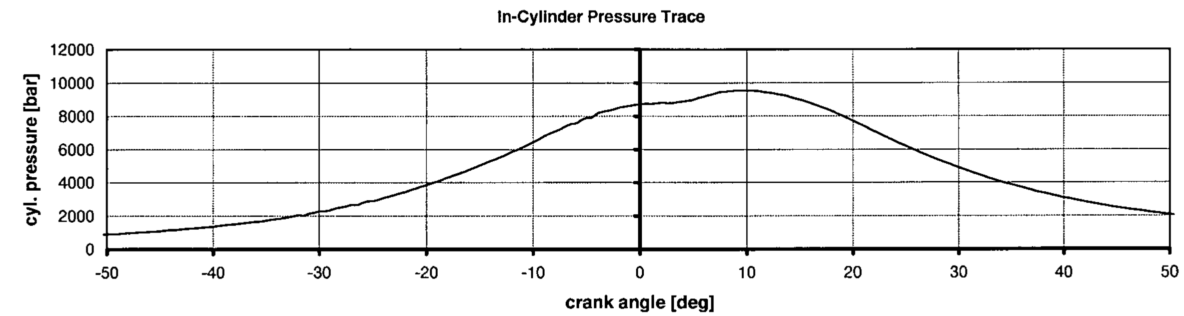



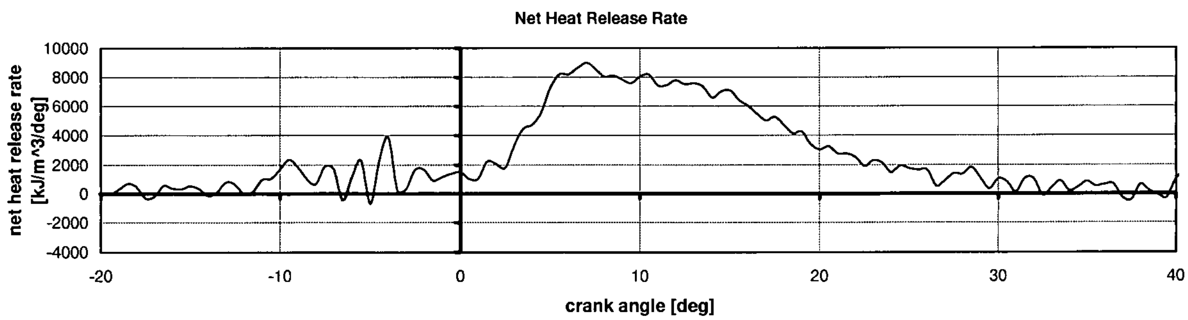
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 9531.03 |
| CA @ P_max [deg] | 9.5 |
| dP/dCA_max [bar/deg] | 361.879 |
| CA @ dP/dCA_max [deg] | -9.5 |
| IMEP [bar] | 878.76 |
| HHR_max [kJ/m^3/deg] | 9031.4 |
| IHR_max [kJ/m^3] | 161135.0 |
| 5% MFB [deg w.r.t TDC] | -9.5 |
| 10% MFB [deg w.r.t TDC] | -2.5 |
| 50% MFB [deg w.r.t TDC] | 10.0 |
| 90% MFB [deg w.r.t TDC] | 22.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.33 |
| poly-n compression corrected | 1.33 |
| poly-n expansion uncorrected | 1.31 |
| poly-n expansion corrected | 1.31 |

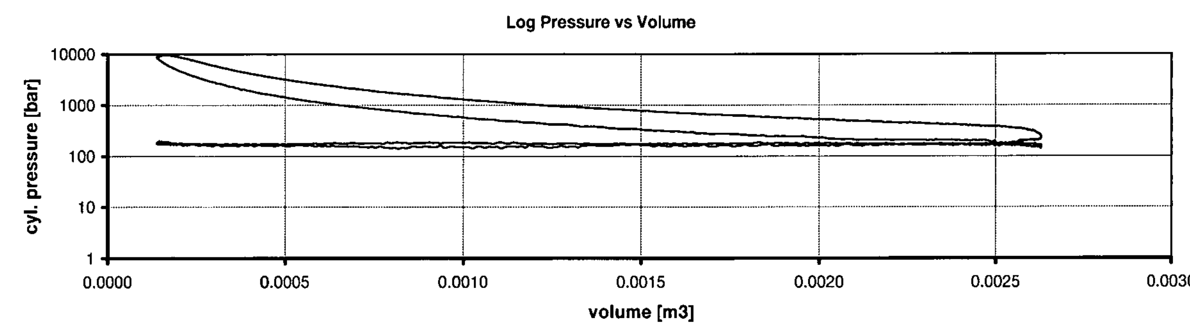
**Comments**

| | |
|---|---|
| Data Summary for filter: | B13 |
| Date: | 4/8/02 |
| Time: | 15:51:09 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1606.8 |
| Load - approx(%) | 40.0 |
| Power (kW) | 29.5 |
| IMEP (bar) | 8.80 |
| Pmax(bar) | 95.64 |
| Pmax location (degrees) | 370.0 |
| Diesel Flow(kg/hr) | 0.30 |
| CNG Flow(kg/hr) | 3.61 |
| Air Flow(kg/hr) | 185.3 |
| Exhaust Flow(kg/hr) | 189.2 |
| Exhaust Back Pressure (kPa) | 11.0 |
| EGR Fraction(%) | 0.0 |



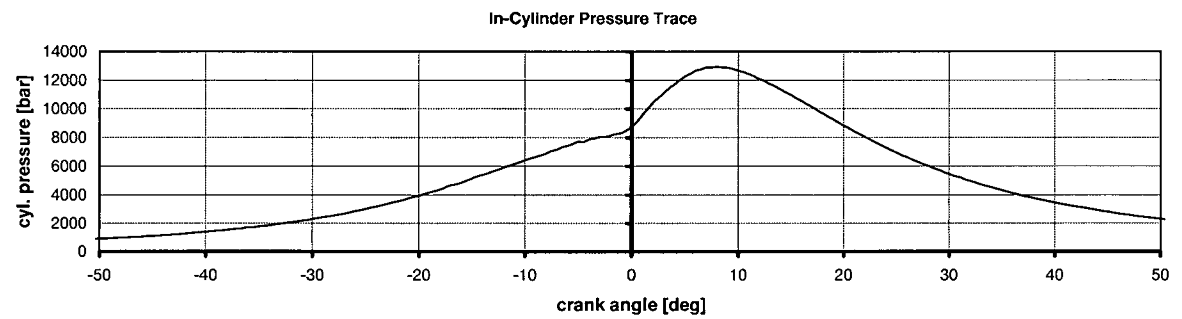



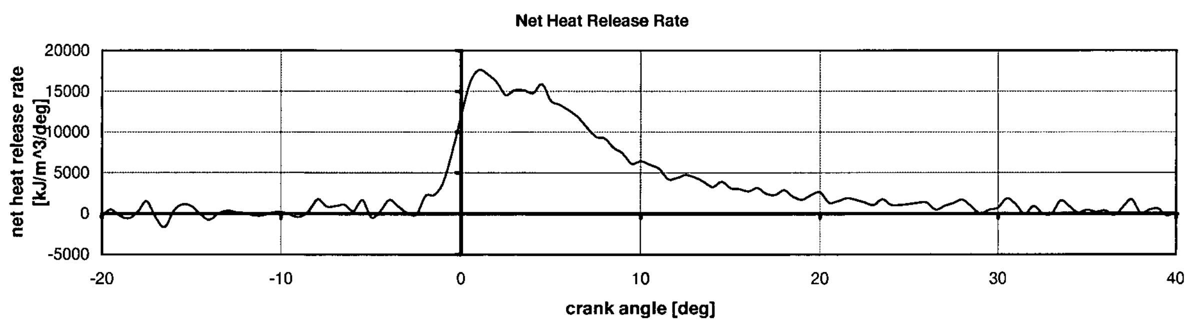
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 12947.39 |
| CA @ P_max [deg] | 8.0 |
| dP/dCA_max [bar/deg] | 906.422 |
| CA @ dP/dCA_max [deg] | 1.0 |
| IMEP [bar] | 1137.49 |
| HHR_max [kJ/m^3/deg] | 17653.9 |
| IHR_max [kJ/m^3] | 199383.6 |
| 5% MFB [deg w.r.t TDC] | -1.0 |
| 10% MFB [deg w.r.t TDC] | 0.0 |
| 50% MFB [deg w.r.t TDC] | 5.0 |
| 90% MFB [deg w.r.t TDC] | 20.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.34 |
| poly-n compression corrected | 1.34 |
| poly-n expansion uncorrected | 1.31 |
| poly-n expansion corrected | 1.31 |

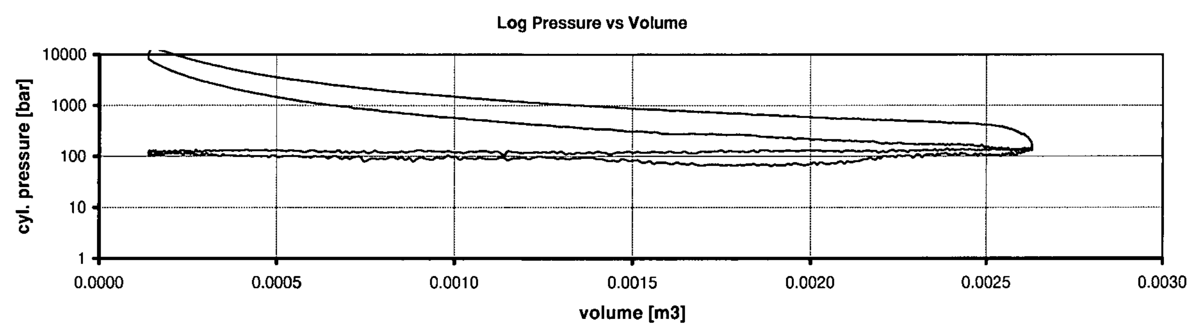
**Comments**

| Data Summary for filter: | C1 |
|---|---|
| Date: | 4/9/02 |
| Time: | 10:23:51 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 805.9 |
| Load - approx(%) | 75.0 |
| Power (kW) | 19.1 |
| IMEP (bar) | 11.39 |
| Pmax(bar) | 129.63 |
| Pmax location (degrees) | 368.5 |
| Diesel Flow(kg/hr) | 0.16 |
| CNG Flow(kg/hr) | 2.92 |
| Air Flow(kg/hr) | 89.2 |
| Exhaust Flow(kg/hr) | 92.3 |
| Exhaust Back Pressure (kPa) | 10.4 |
| EGR Fraction(%) | 0.0 |



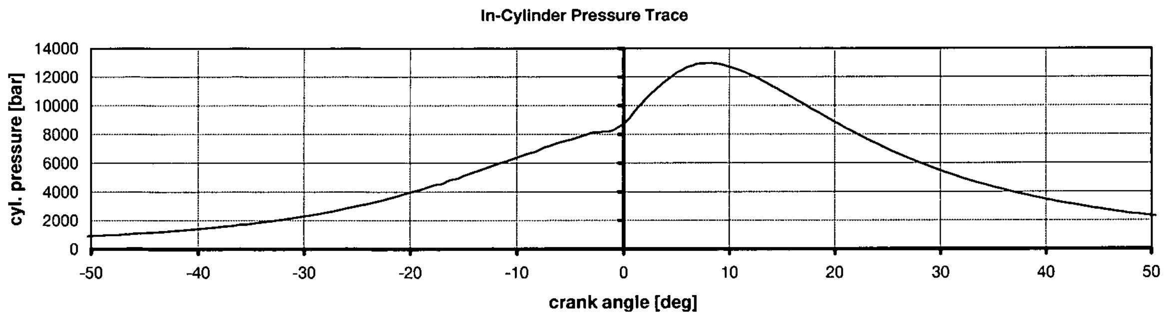



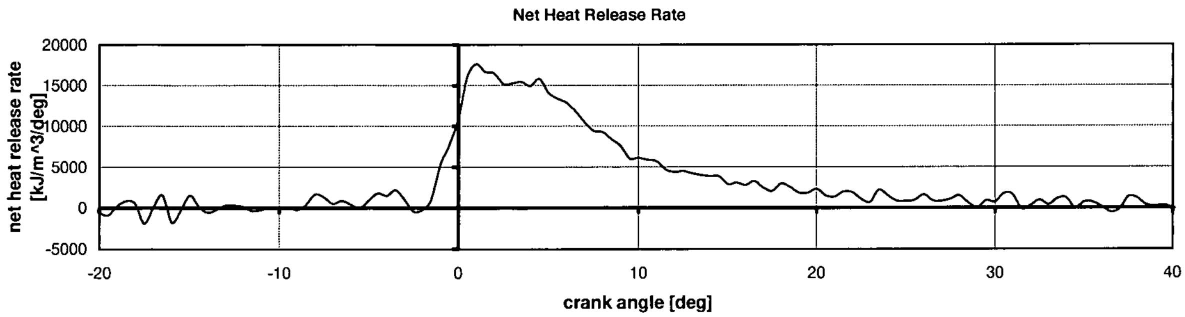
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 12962.57 |
| CA @ P_max [deg] | 8.0 |
| dP/dCA_max [bar/deg] | 904.698 |
| CA @ dP/dCA_max [deg] | 1.0 |
| IMEP [bar] | 1140.73 |
| HHR_max [kJ/m^3/deg] | 17621.2 |
| IHR_max [kJ/m^3] | 200728.6 |
| 5% MFB [deg w.r.t TDC] | -1.0 |
| 10% MFB [deg w.r.t TDC] | 0.0 |
| 50% MFB [deg w.r.t TDC] | 5.0 |
| 90% MFB [deg w.r.t TDC] | 20.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.32 |
| poly-n compression corrected | 1.32 |
| poly-n expansion uncorrected | 1.31 |
| poly-n expansion corrected | 1.31 |

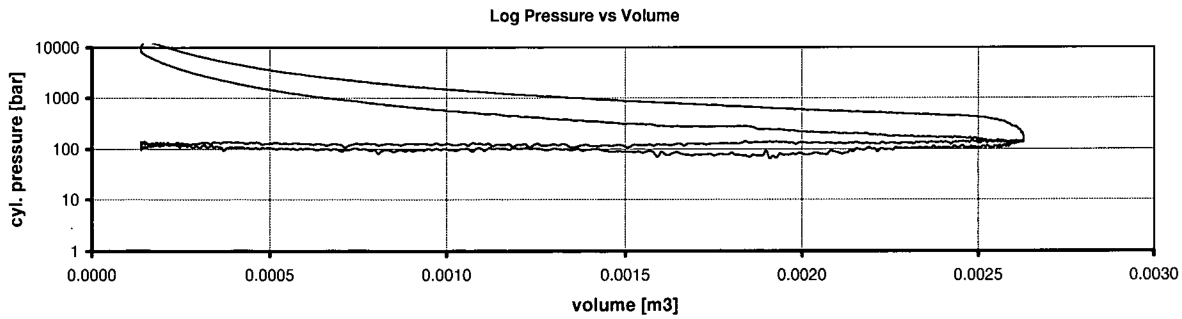
**Comments**

| | |
|---|---|
| Data Summary for filter: | C2 |
| Date: | 4/9/02 |
| Time: | 10:34:31 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 805.1 |
| Load - approx(%) | 75.0 |
| Power (kW) | 19.2 |
| IMEP (bar) | 11.42 |
| Pmax(bar) | 129.90 |
| Pmax location (degrees) | 368.5 |
| Diesel Flow(kg/hr) | 0.18 |
| CNG Flow(kg/hr) | 2.92 |
| Air Flow(kg/hr) | 89.5 |
| Exhaust Flow(kg/hr) | 92.5 |
| Exhaust Back Pressure (kPa) | 10.7 |
| EGR Fraction(%) | 0.0 |



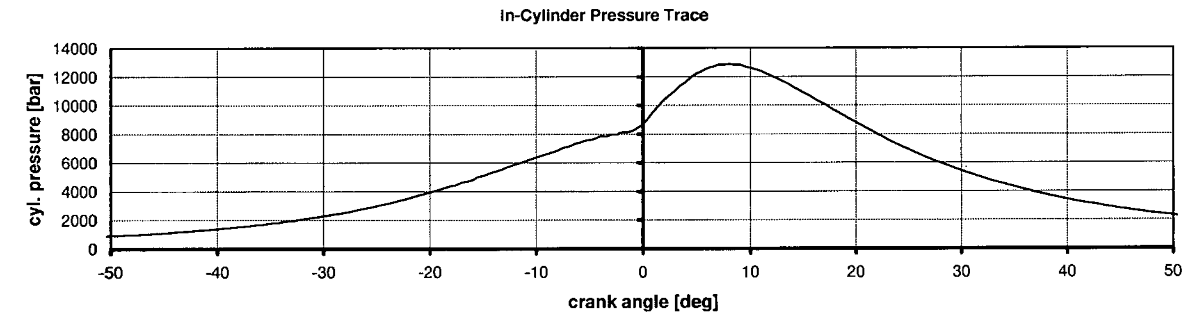



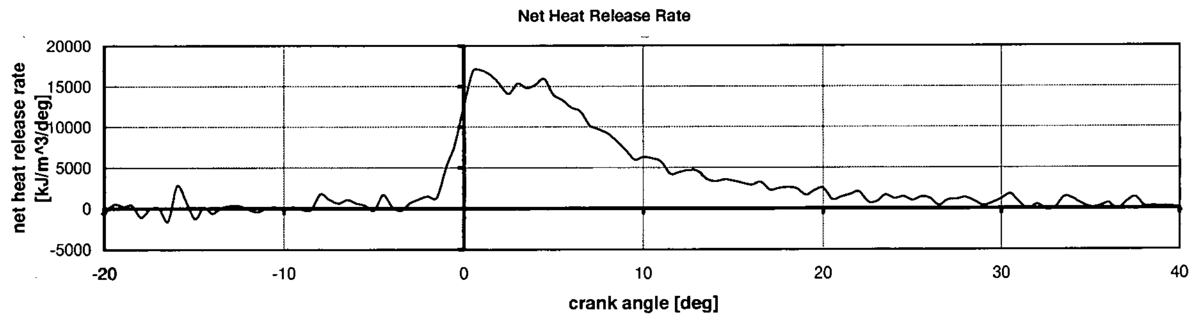
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 12886.52 |
| CA @ P_max [deg] | 8.0 |
| dP/dCA_max [bar/deg] | 890.912 |
| CA @ dP/dCA_max [deg] | 0.5 |
| IMEP [bar] | 1125.30 |
| HHR_max [kJ/m^3/deg] | 16982.2 |
| IHR_max [kJ/m^3] | 197075.7 |
| 5% MFB [deg w.r.t TDC] | -1.0 |
| 10% MFB [deg w.r.t TDC] | 0.0 |
| 50% MFB [deg w.r.t TDC] | 5.0 |
| 90% MFB [deg w.r.t TDC] | 19.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.33 |
| poly-n compression corrected | 1.33 |
| poly-n expansion uncorrected | 1.32 |
| poly-n expansion corrected | 1.32 |

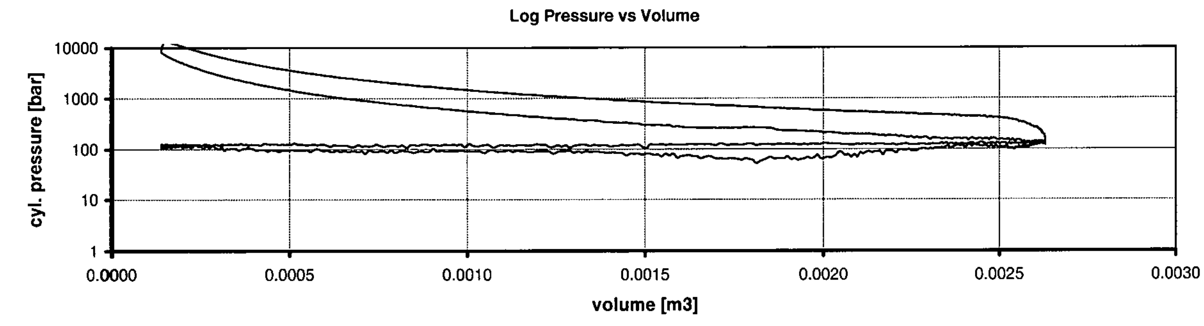
Comments

| | |
|---|---|
| Data Summary for filter: | C3 |
| Date: | 4/9/02 |
| Time: | 10:42:28 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 804.5 |
| Load - approx(%) | 75.0 |
| Power (kW) | 18.9 |
| IMEP (bar) | 11.27 |
| Pmax(bar) | 129.04 |
| Pmax location (degrees) | 368.5 |
| Diesel Flow(kg/hr) | 0.15 |
| CNG Flow(kg/hr) | 2.93 |
| Air Flow(kg/hr) | 89.4 |
| Exhaust Flow(kg/hr) | 92.5 |
| Exhaust Back Pressure (kPa) | 10.7 |
| EGR Fraction(%) | 0.0 |



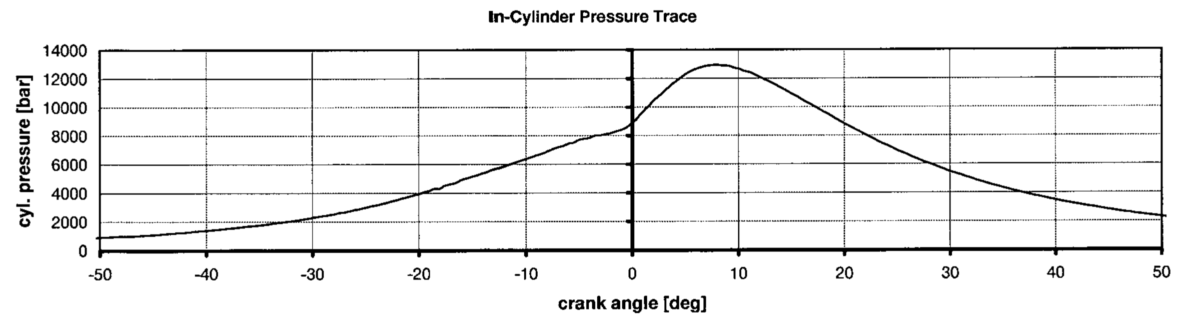



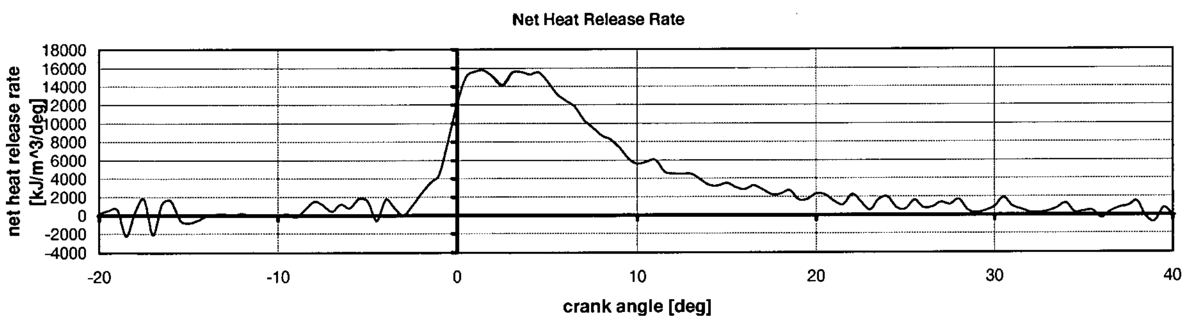
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 12939.99 |
| CA @ P_max [deg] | 8.0 |
| dP/dCA max [bar/deg] | 796.135 |
| CA @ dP/dCA max [deg] | 1.0 |
| IMEP [bar] | 1141.04 |
| HHR max [kJ/m^3/deg] | 15735.3 |
| IHR max [kJ/m^3] | 199633.0 |
| 5% MFB [deg w.r.t TDC] | -1.5 |
| 10% MFB [deg w.r.t TDC] | -0.5 |
| 50% MFB [deg w.r.t TDC] | 5.0 |
| 90% MFB [deg w.r.t TDC] | 20.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.34 |
| poly-n compression corrected | 1.34 |
| poly-n expansion uncorrected | 1.35 |
| poly-n expansion corrected | 1.35 |

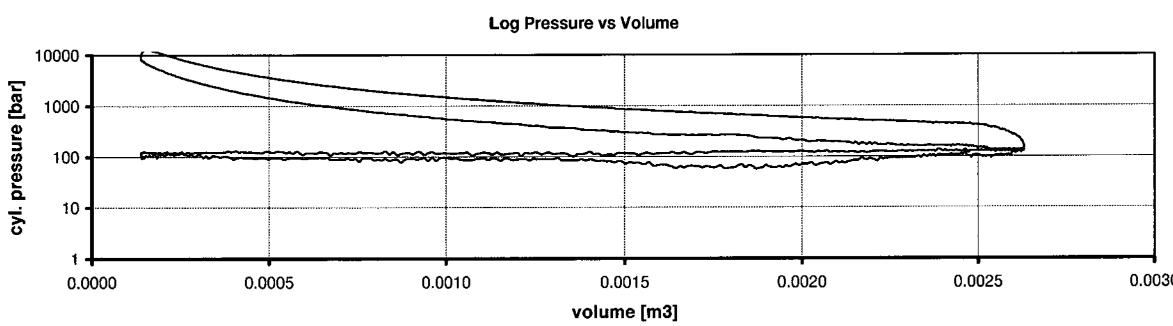
**Comments**

| | |
|---|---|
| Data Summary for filter: | C4 |
| Date: | 4/9/02 |
| Time: | 10:49:30 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 804.9 |
| Load - approx(%) | 75.0 |
| Power (kW) | 19.2 |
| IMEP (bar) | 11.43 |
| Pmax(bar) | 129.66 |
| Pmax location (degrees) | 368.3 |
| Diesel Flow(kg/hr) | 0.16 |
| CNG Flow(kg/hr) | 2.91 |
| Air Flow(kg/hr) | 89.5 |
| Exhaust Flow(kg/hr) | 92.6 |
| Exhaust Back Pressure (kPa) | 10.8 |
| EGR Fraction(%) | 0.0 |



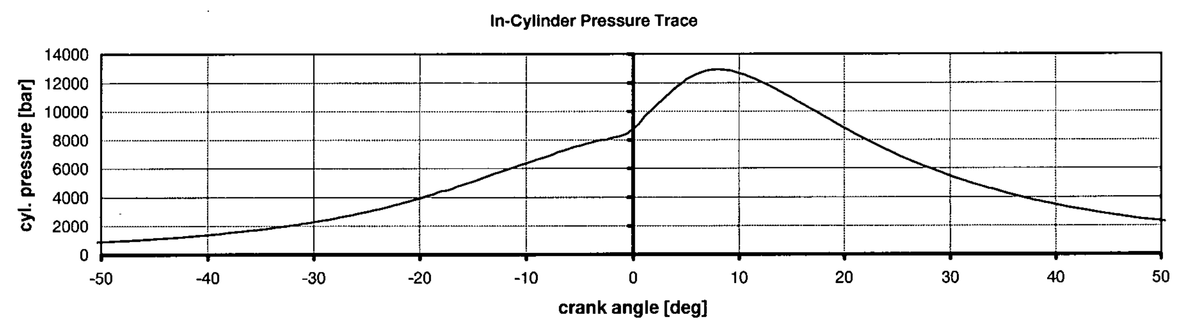



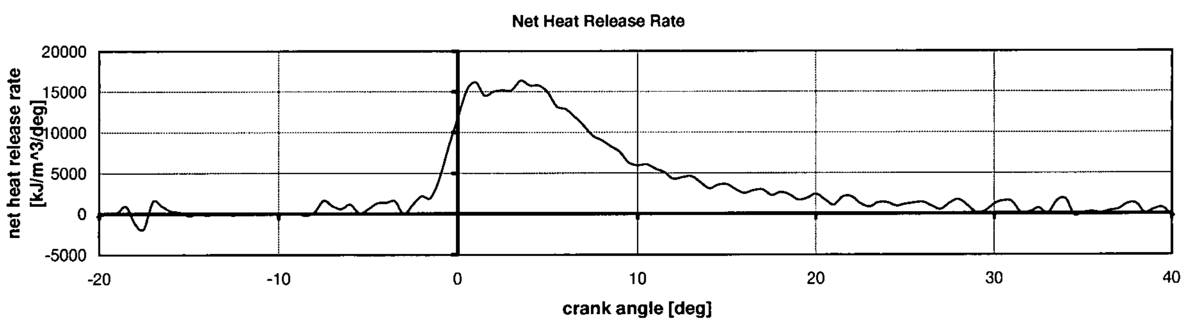
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 12910.55 |
| CA @ P_max [deg] | 8.0 |
| dP/dCA_max [bar/deg] | 827.153 |
| CA @ dP/dCA_max [deg] | 1.0 |
| IMEP [bar] | 1139.71 |
| HHR_max [kJ/m^3/deg] | 16407.6 |
| IHR_max [kJ/m^3] | 200893.2 |
| 5% MFB [deg w.r.t TDC] | -1.5 |
| 10% MFB [deg w.r.t TDC] | -0.5 |
| 50% MFB [deg w.r.t TDC] | 5.0 |
| 90% MFB [deg w.r.t TDC] | 21.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.32 |
| poly-n compression corrected | 1.32 |
| poly-n expansion uncorrected | 1.31 |
| poly-n expansion corrected | 1.31 |

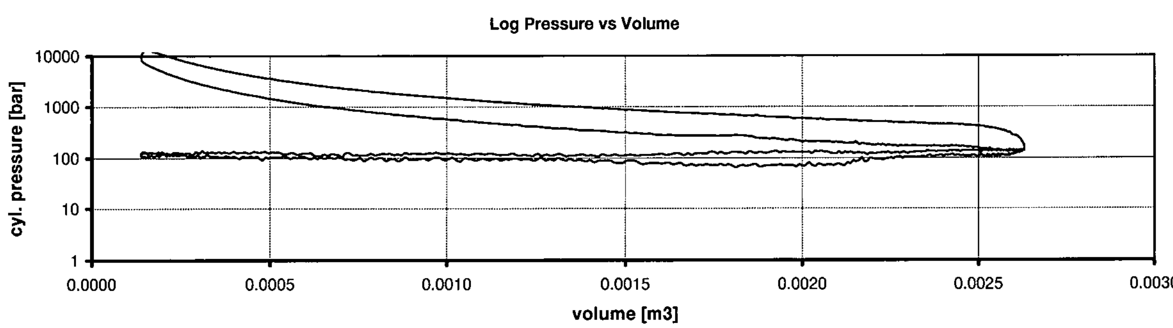
**Comments**

| | |
|---|---|
| Data Summary for filter: | C5 |
| Date: | 4/9/02 |
| Time: | 10:55:53 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 804.7 |
| Load - approx(%) | 75.0 |
| Power (kW) | 19.1 |
| IMEP (bar) | 11.41 |
| Pmax(bar) | 129.43 |
| Pmax location (degrees) | 368.5 |
| Diesel Flow(kg/hr) | 0.16 |
| CNG Flow(kg/hr) | 2.93 |
| Air Flow(kg/hr) | 89.4 |
| Exhaust Flow(kg/hr) | 92.5 |
| Exhaust Back Pressure (kPa) | 10.8 |
| EGR Fraction(%) | 0.0 |



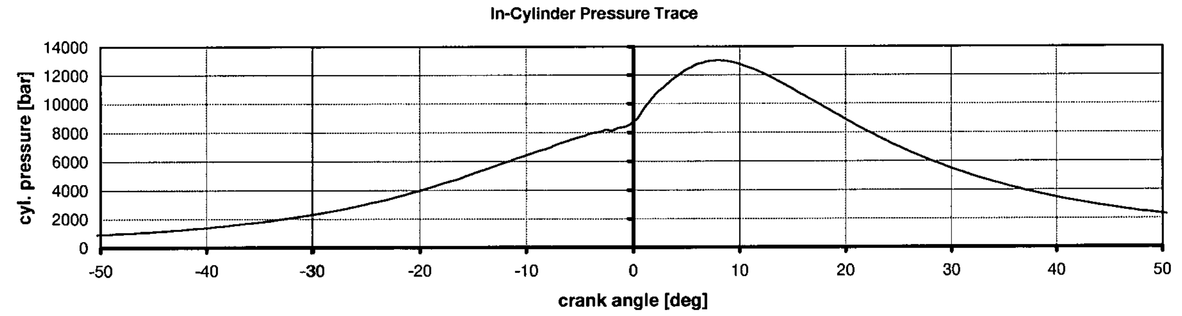



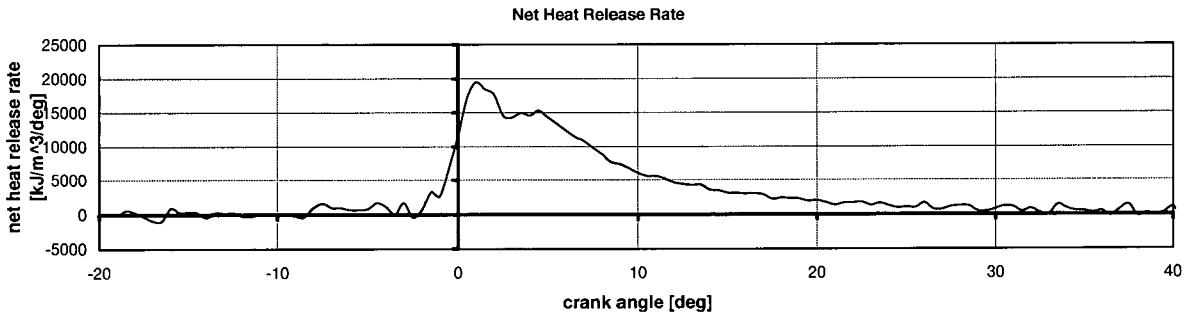
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 13031.34 |
| CA @ P max [deg] | 8.0 |
| dP/dCA max [bar/deg] | 1002.923 |
| CA @ dP/dCA max [deg] | 1.0 |
| IMEP [bar] | 1143.00 |
| HHR max [kJ/m^3/deg] | 19449.6 |
| IHR max [kJ/m^3] | 199415.4 |
| 5% MFB [deg w.r.t TDC] | -1.0 |
| 10% MFB [deg w.r.t TDC] | 0.0 |
| 50% MFB [deg w.r.t TDC] | 5.0 |
| 90% MFB [deg w.r.t TDC] | 19.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.35 |
| poly-n compression corrected | 1.35 |
| poly-n expansion uncorrected | 1.31 |
| poly-n expansion corrected | 1.31 |

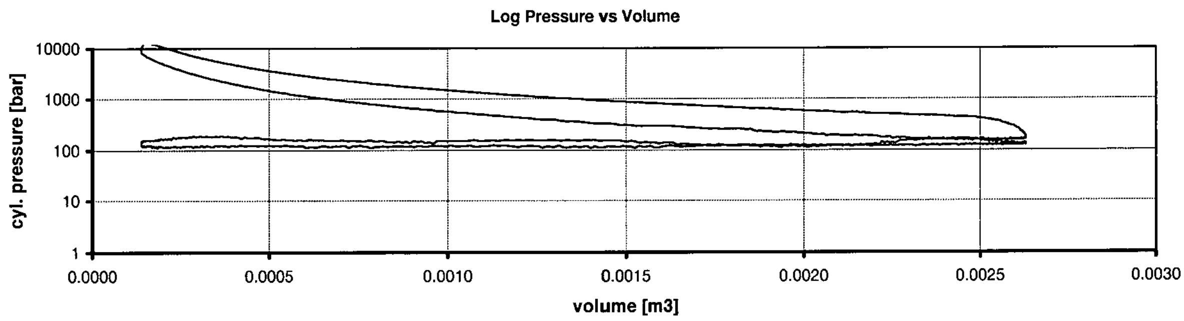
**Comments**

| Data Summary for filter: | C6 |
|---|---|
| Date: | 4/9/02 |
| Time: | 11:03:18 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 800.8 |
| Load - approx(%) | 75.0 |
| Power (kW) | 19.1 |
| IMEP (bar) | 11.44 |
| Pmax(bar) | 130.64 |
| Pmax location (degrees) | 368.5 |
| Diesel Flow(kg/hr) | 0.16 |
| CNG Flow(kg/hr) | 2.91 |
| Air Flow(kg/hr) | 87.9 |
| Exhaust Flow(kg/hr) | 91.0 |
| Exhaust Back Pressure (kPa) | 69.9 |
| EGR Fraction(%) | 0.0 |



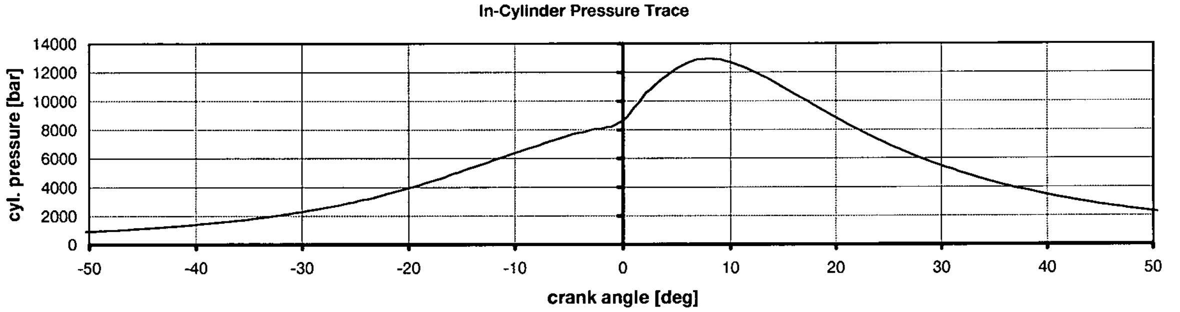



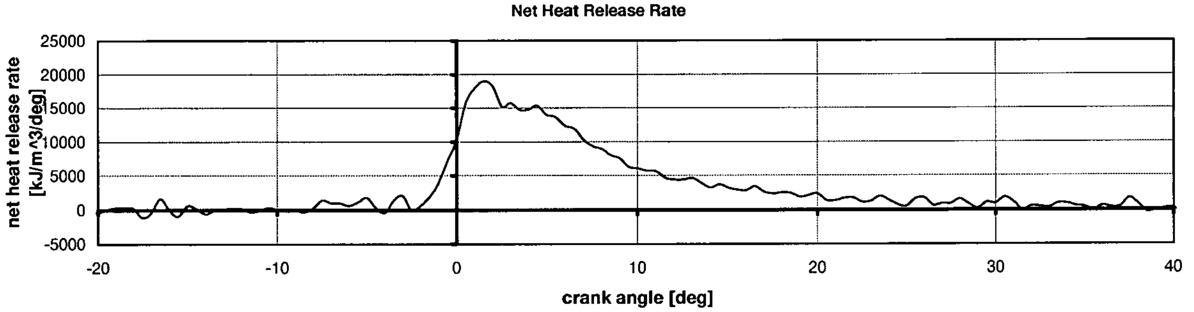
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 12941.43 |
| CA @ P_max [deg] | 8.0 |
| dP/dCA_max [bar/deg] | 951.226 |
| CA @ dP/dCA_max [deg] | 1.5 |
| IMEP [bar] | 1137.06 |
| HHR_max [kJ/m^3/deg] | 18987.3 |
| IHR_max [kJ/m^3] | 199581.9 |
| 5% MFB [deg w.r.t TDC] | -1.0 |
| 10% MFB [deg w.r.t TDC] | 0.0 |
| 50% MFB [deg w.r.t TDC] | 5.0 |
| 90% MFB [deg w.r.t TDC] | 20.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.32 |
| poly-n compression corrected | 1.32 |
| poly-n expansion uncorrected | 1.29 |
| poly-n expansion corrected | 1.29 |

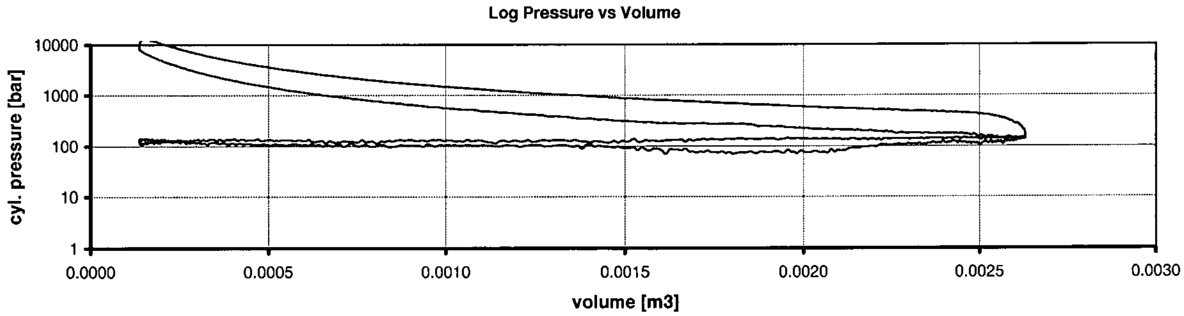
**Comments**

| | |
|---|---|
| Data Summary for filter: | C7 |
| Date: | 4/9/02 |
| Time: | 11:10:07 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 806.5 |
| Load - approx(%) | 75.0 |
| Power (kW) | 19.1 |
| IMEP (bar) | 11.39 |
| Pmax(bar) | 129.59 |
| Pmax location (degrees) | 368.5 |
| Diesel Flow(kg/hr) | 0.18 |
| CNG Flow(kg/hr) | 2.93 |
| Air Flow(kg/hr) | 89.4 |
| Exhaust Flow(kg/hr) | 92.5 |
| Exhaust Back Pressure (kPa) | 10.1 |
| EGR Fraction(%) | 0.0 |



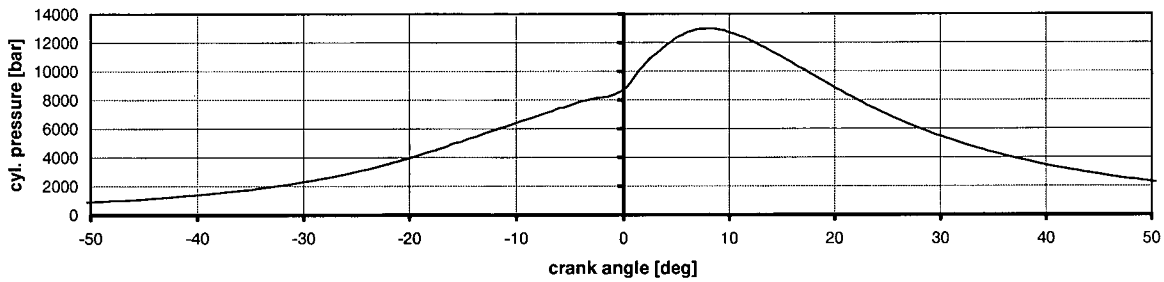
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 12967.01 |
| CA @ P_max [deg] | 8.0 |
| dP/dCA_max [bar/deg] | 1009.816 |
| CA @ dP/dCA_max [deg] | 1.0 |
| IMEP [bar] | 1139.51 |
| HHR_max [kJ/m^3/deg] | 19572.1 |
| IHR_max [kJ/m^3] | 198843.6 |
| 5% MFB [deg w.r.t TDC] | -1.0 |
| 10% MFB [deg w.r.t TDC] | 0.0 |
| 50% MFB [deg w.r.t TDC] | 5.0 |
| 90% MFB [deg w.r.t TDC] | 19.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.35 |
| poly-n compression corrected | 1.35 |
| poly-n expansion uncorrected | 1.31 |
| poly-n expansion corrected | 1.31 |

**Comments**

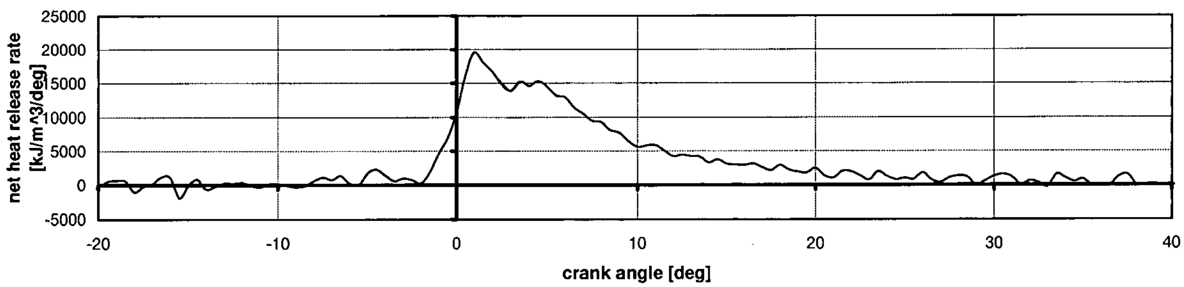
| | |
|---|---|
| Data Summary for filter: | C8 |
| Date: | 4/9/02 |
| Time: | 11:18:58 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 804.2 |
| Load - approx(%) | 75.0 |
| Power (kW) | 19.1 |
| IMEP (bar) | 11.41 |
| Pmax(bar) | 130.05 |
| Pmax location (degrees) | 368.6 |
| Diesel Flow(kg/hr) | 0.17 |
| CNG Flow(kg/hr) | 2.92 |
| Air Flow(kg/hr) | 88.3 |
| Exhaust Flow(kg/hr) | 91.4 |
| Exhaust Back Pressure (kPa) | 58.5 |
| EGR Fraction(%) | 0.0 |

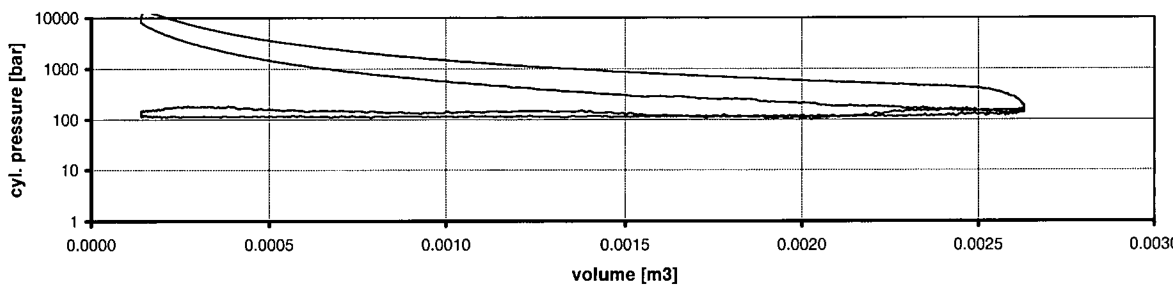
**In-Cylinder Pressure Trace**




**Net Heat Release Rate**




**Log Pressure vs Volume**



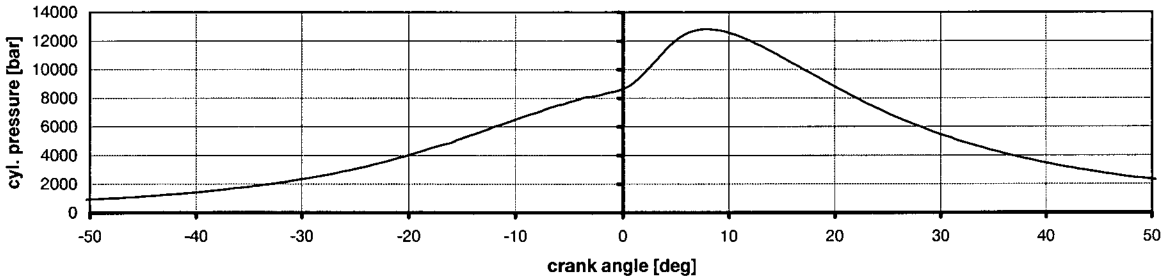
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 12820.58 |
| CA @ P_max [deg] | 8.0 |
| dP/dCA_max [bar/deg] | 792.688 |
| CA @ dP/dCA_max [deg] | 3.5 |
| IMEP [bar] | 1125.69 |
| HHR_max [kJ/m^3/deg] | 18728.4 |
| IHR_max [kJ/m^3] | 199511.1 |
| 5% MFB [deg w.r.t TDC] | -1.0 |
| 10% MFB [deg w.r.t TDC] | 0.5 |
| 50% MFB [deg w.r.t TDC] | 5.5 |
| 90% MFB [deg w.r.t TDC] | 22.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.33 |
| poly-n compression corrected | 1.33 |
| poly-n expansion uncorrected | 1.32 |
| poly-n expansion corrected | 1.32 |

**Comments**

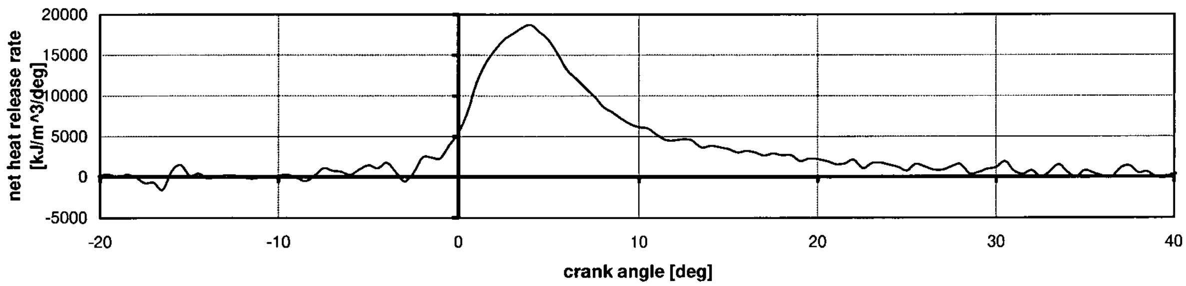
| | |
|---|---|
| Data Summary for filter: | C9 |
| Date: | 4/9/02 |
| Time: | 11:33:09 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 802.1 |
| Load - approx(%) | 75.0 |
| Power (kW) | 18.8 |
| IMEP (bar) | 11.27 |
| Pmax(bar) | 128.45 |
| Pmax location (degrees) | 368.5 |
| Diesel Flow(kg/hr) | 0.18 |
| CNG Flow(kg/hr) | 2.91 |
| Air Flow(kg/hr) | 73.6 |
| Exhaust Flow(kg/hr) | 76.6 |
| Exhaust Back Pressure (kPa) | 72.0 |
| EGR Fraction(%) | 16.9 |

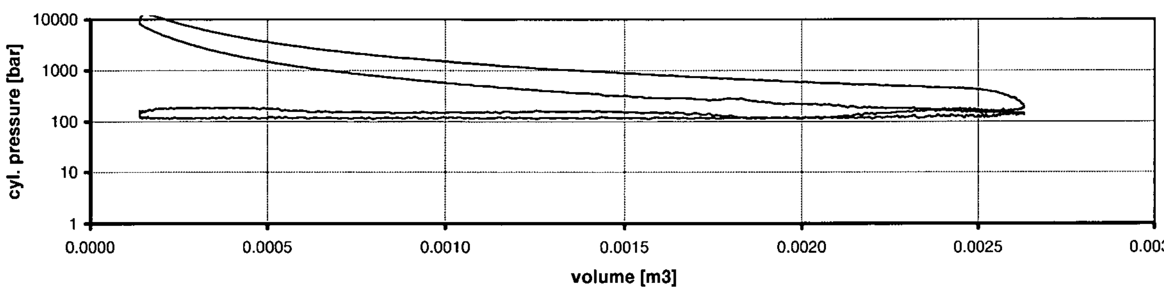
**In-Cylinder Pressure Trace**




**Net Heat Release Rate**




**Log Pressure vs Volume**

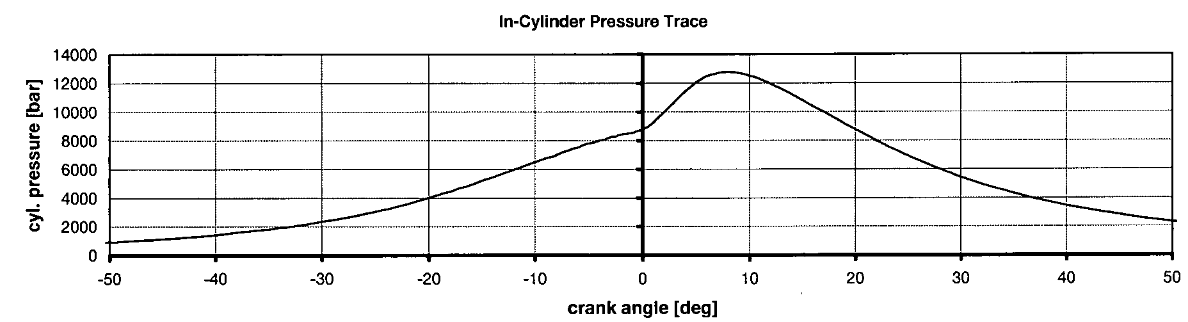


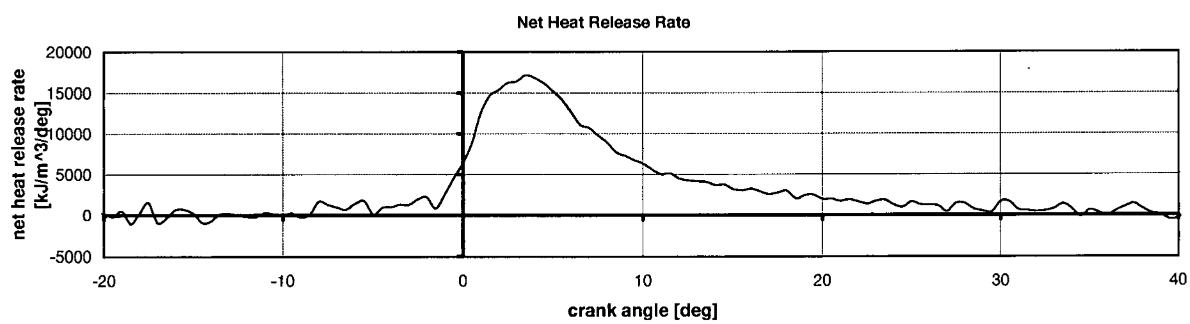
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 12758.70 |
| CA @ P max [deg] | 8.0 |
| dP/dCA max [bar/deg] | 744.438 |
| CA @ dP/dCA max [deg] | 2.5 |
| IMEP [bar] | 1117.28 |
| HHR max [kJ/m^3/deg] | 17150.5 |
| IHR max [kJ/m^3] | 197220.6 |
| 5% MFB [deg w.r.t TDC] | -1.5 |
| 10% MFB [deg w.r.t TDC] | 0.0 |
| 50% MFB [deg w.r.t TDC] | 5.5 |
| 90% MFB [deg w.r.t TDC] | 22.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.30 |
| poly-n compression corrected | 1.30 |
| poly-n expansion uncorrected | 1.29 |
| poly-n expansion corrected | 1.29 |

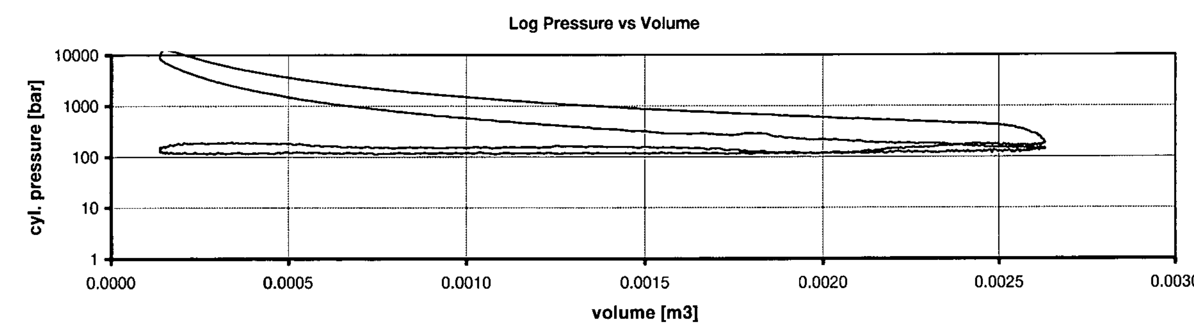
Comments

| | |
|---|---|
| Data Summary for filter: | C10 |
| Date: | 4/9/02 |
| Time: | 11:39:35 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 802.2 |
| Load - approx(%) | 75.0 |
| Power (kW) | 18.7 |
| IMEP (bar) | 11.19 |
| Pmax(bar) | 127.76 |
| Pmax location (degrees) | 368.5 |
| Diesel Flow(kg/hr) | 0.21 |
| CNG Flow(kg/hr) | 2.89 |
| Air Flow(kg/hr) | 73.4 |
| Exhaust Flow(kg/hr) | 76.5 |
| Exhaust Back Pressure (kPa) | 72.7 |
| EGR Fraction(%) | 16.7 |



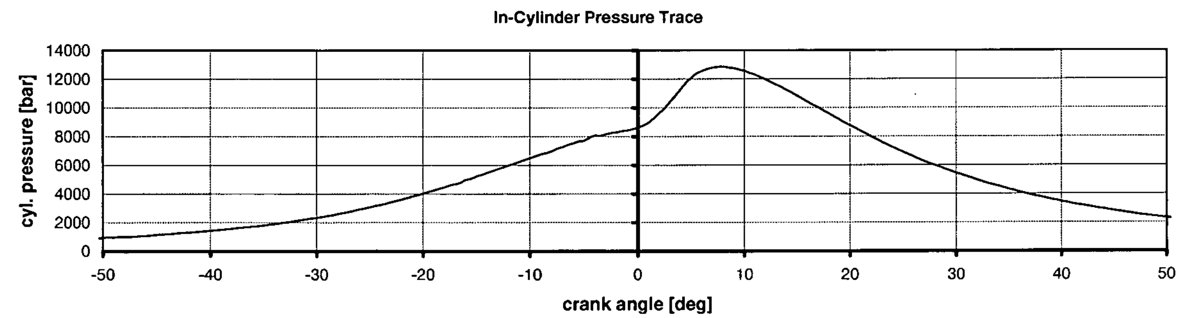



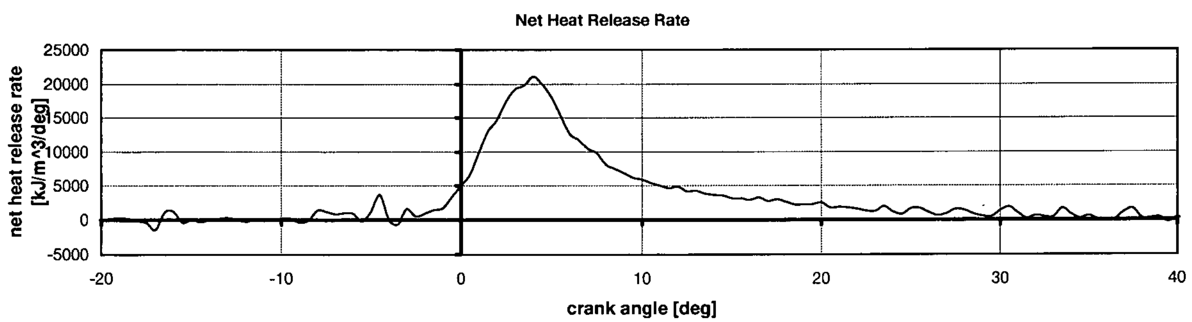
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 12846.54 |
| CA @ P_max [deg] | 8.0 |
| dP/dCA_max [bar/deg] | 901.252 |
| CA @ dP/dCA_max [deg] | 4.0 |
| IMEP [bar] | 1113.07 |
| HHR_max [kJ/m^3/deg] | 21104.5 |
| IHR_max [kJ/m^3] | 196465.8 |
| 5% MFB [deg w.r.t TDC] | -1.0 |
| 10% MFB [deg w.r.t TDC] | 0.5 |
| 50% MFB [deg w.r.t TDC] | 5.0 |
| 90% MFB [deg w.r.t TDC] | 21.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.31 |
| poly-n compression corrected | 1.31 |
| poly-n expansion uncorrected | 1.31 |
| poly-n expansion corrected | 1.31 |

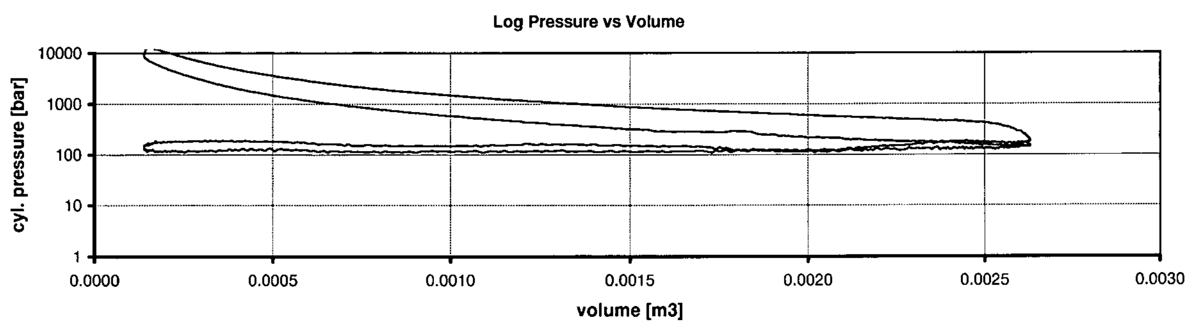
**Comments**

| | |
|---|---|
| Data Summary for filter: | C11 |
| Date: | 4/9/02 |
| Time: | 11:46:33 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 800.8 |
| Load - approx(%) | 75.0 |
| Power (kW) | 18.6 |
| IMEP (bar) | 11.15 |
| Pmax(bar) | 128.67 |
| Pmax location (degrees) | 368.4 |
| Diesel Flow(kg/hr) | 0.17 |
| CNG Flow(kg/hr) | 2.92 |
| Air Flow(kg/hr) | 73.5 |
| Exhaust Flow(kg/hr) | 76.6 |
| Exhaust Back Pressure (kPa) | 72.5 |
| EGR Fraction(%) | 16.9 |



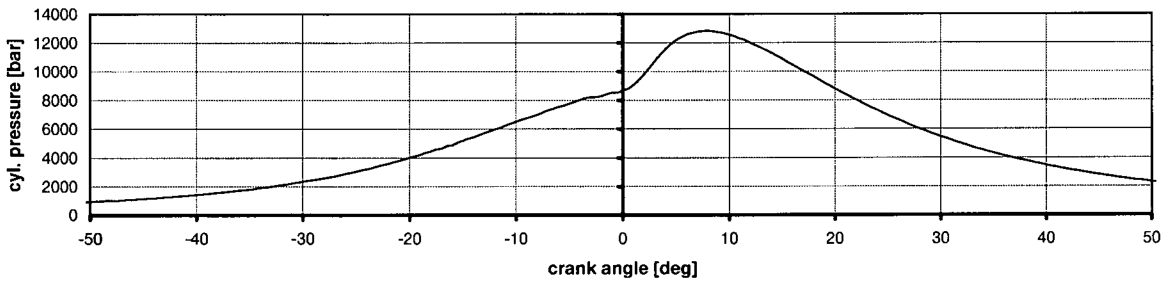
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 12825.77 |
| CA @ P_max [deg] | 8.0 |
| dP/dCA_max [bar/deg] | 901.252 |
| CA @ dP/dCA_max [deg] | 2.5 |
| IMEP [bar] | 1122.46 |
| HHR_max [kJ/m^3/deg] | 19436.4 |
| IHR_max [kJ/m^3] | 198361.7 |
| 5% MFB [deg w.r.t TDC] | -1.0 |
| 10% MFB [deg w.r.t TDC] | 0.5 |
| 50% MFB [deg w.r.t TDC] | 5.0 |
| 90% MFB [deg w.r.t TDC] | 22.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.31 |
| poly-n compression corrected | 1.31 |
| poly-n expansion uncorrected | 1.29 |
| poly-n expansion corrected | 1.29 |

Comments

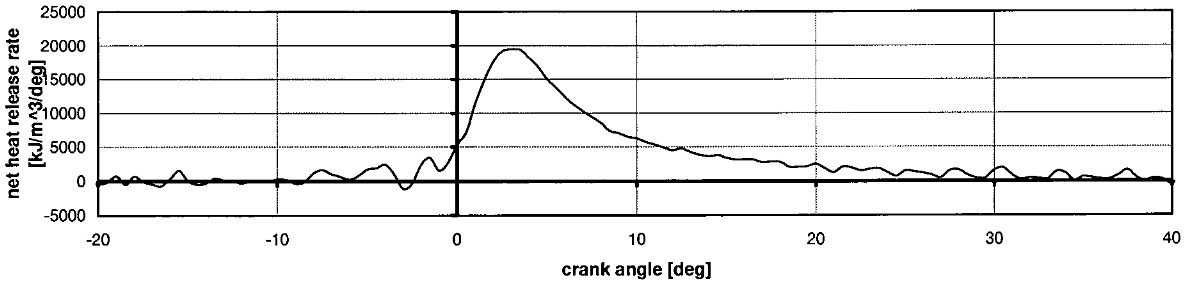
| Data Summary for filter: | C12 |
|---|---|
| Date: | 4/9/02 |
| Time: | 11:53:43 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 800.8 |
| Load - approx(%) | 75.0 |
| Power (kW) | 18.8 |
| IMEP (bar) | 11.24 |
| Pmax(bar) | 128.43 |
| Pmax location (degrees) | 368.4 |
| Diesel Flow(kg/hr) | 0.19 |
| CNG Flow(kg/hr) | 2.91 |
| Air Flow(kg/hr) | 73.6 |
| Exhaust Flow(kg/hr) | 76.7 |
| Exhaust Back Pressure (kPa) | 72.6 |
| EGR Fraction(%) | 16.8 |

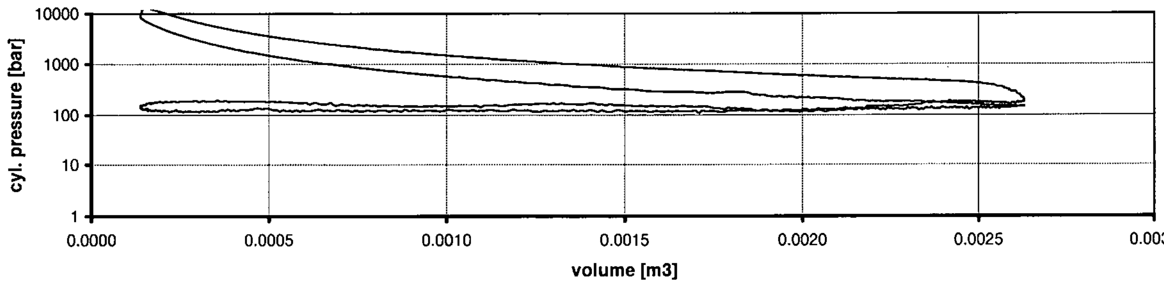
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume



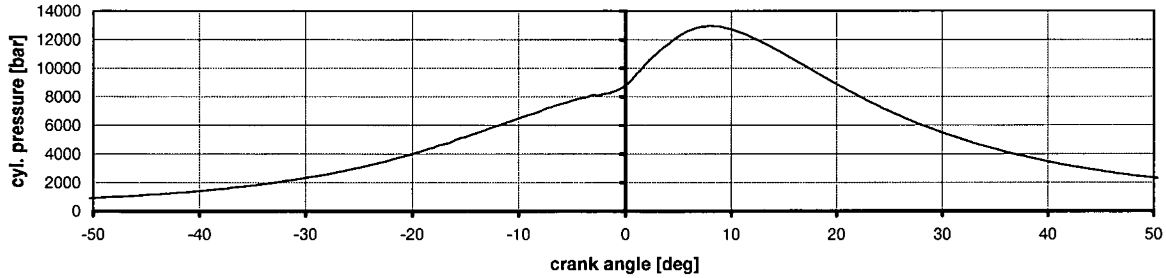
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 12961.26 |
| CA @ P_max [deg] | 8.0 |
| dP/dCA_max [bar/deg] | 813.367 |
| CA @ dP/dCA_max [deg] | 1.5 |
| IMEP [bar] | 1127.58 |
| HHR_max [kJ/m^3/deg] | 16728.2 |
| IHR_max [kJ/m^3] | 198785.8 |
| 5% MFB [deg w.r.t TDC] | -1.0 |
| 10% MFB [deg w.r.t TDC] | 0.0 |
| 50% MFB [deg w.r.t TDC] | 5.0 |
| 90% MFB [deg w.r.t TDC] | 20.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.32 |
| poly-n compression corrected | 1.32 |
| poly-n expansion uncorrected | 1.31 |
| poly-n expansion corrected | 1.31 |

**Comments**

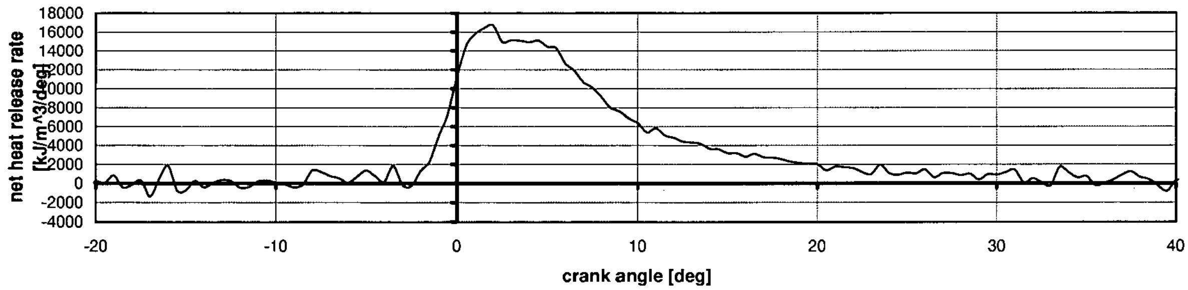
| | |
|---|---|
| Data Summary for filter: | C13 |
| Date: | 4/9/02 |
| Time: | 12:02:18 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 805.4 |
| Load - approx(%) | 75.0 |
| Power (kW) | 18.9 |
| IMEP (bar) | 11.29 |
| Pmax(bar) | 129.73 |
| Pmax location (degrees) | 368.5 |
| Diesel Flow(kg/hr) | 0.16 |
| CNG Flow(kg/hr) | 2.93 |
| Air Flow(kg/hr) | 92.3 |
| Exhaust Flow(kg/hr) | 95.3 |
| Exhaust Back Pressure (kPa) | 13.1 |
| EGR Fraction(%) | 0.0 |

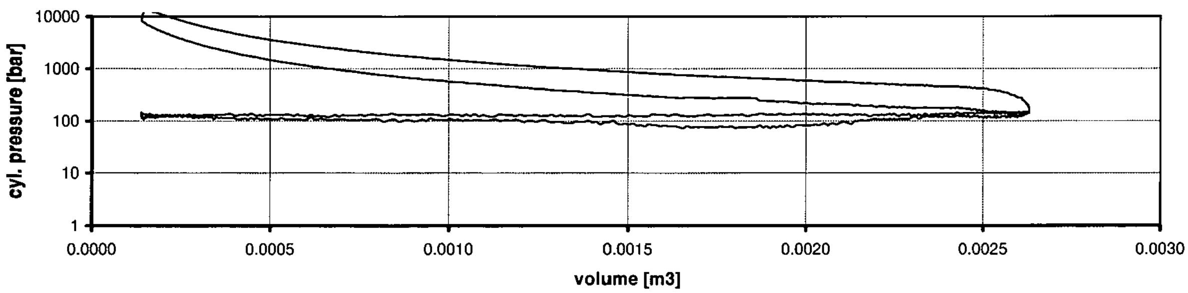
In-Cylinder Pressure Trace



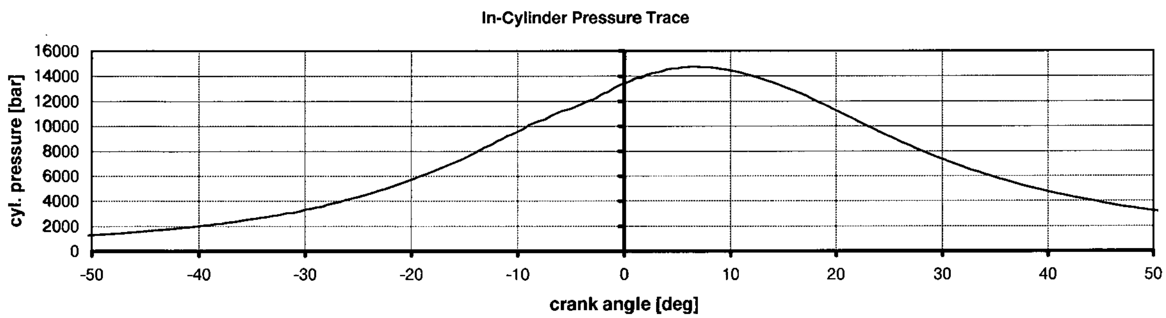

Net Heat Release Rate

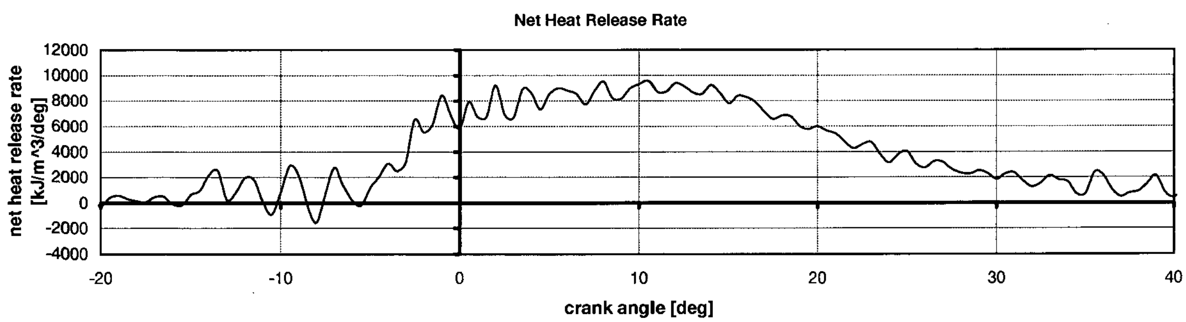


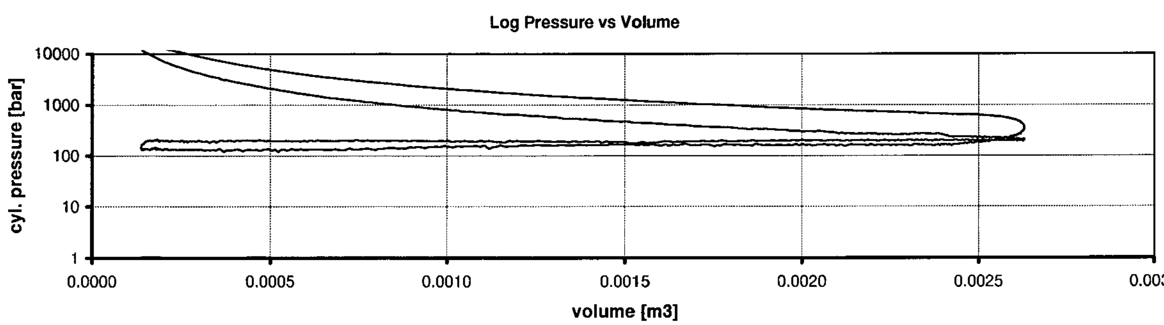

Log Pressure vs Volume



| | | Comments | |
|---|---|---|---|
| Speed [RPM] | | | |
| Torque [N-m] | | | |
| Load [%] | | Data Summary for filter: | D1 |
| P_max [deg] | 14746.47 | Date: | 4/10/02 |
| CA @ P_max [deg] | 6.5 | Time: | 10:06:30 |
| dP/dCA_max [bar/deg] | 516.970 | | |
| CA @ dP/dCA_max [deg] | -1.0 | **Engine Parameters** | **Average** |
| IMEP [bar] | 1437.21 | Speed(RPM) | 1408.5 |
| HHR_max [kJ/m^3/deg] | 9560.6 | Load - approx(%) | 85.0 |
| IHR_max [kJ/m^3] | 261827.4 | Power (kW) | 42.2 |
| 5% MFB [deg w.r.t TDC] | -5.0 | IMEP (bar) | 14.39 |
| 10% MFB [deg w.r.t TDC] | -2.0 | Pmax(bar) | 147.62 |
| 50% MFB [deg w.r.t TDC] | 11.0 | Pmax location (degrees) | 367.0 |
| 90% MFB [deg w.r.t TDC] | 30.0 | Diesel Flow(kg/hr) | 0.28 |
| Assumed poly-n during comprn. | 1.37 | CNG Flow(kg/hr) | 6.18 |
| zero-level. pr. offset [bar] | 0.000 | Air Flow(kg/hr) | 276.2 |
| poly-n compression uncorrected | 1.37 | Exhaust Flow(kg/hr) | 282.6 |
| poly-n compression corrected | 1.37 | Exhaust Back Pressure (kPa) | 11.1 |
| poly-n expansion uncorrected | 1.28 | EGR Fraction(%) | 0.0 |
| poly-n expansion corrected | 1.28 | | |



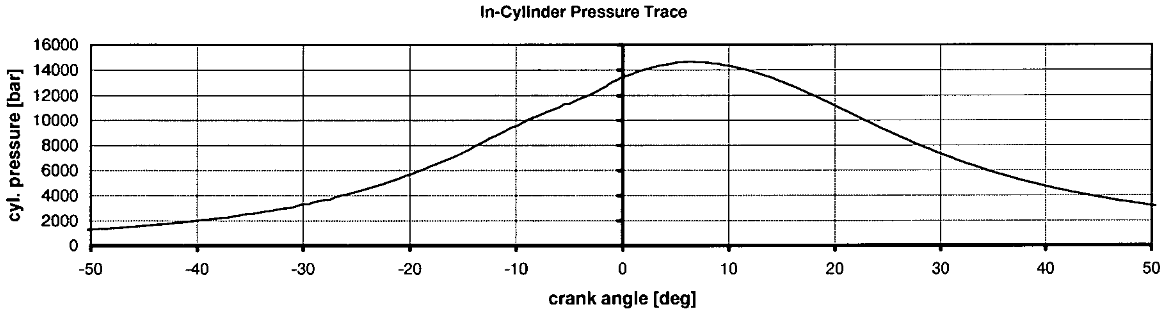



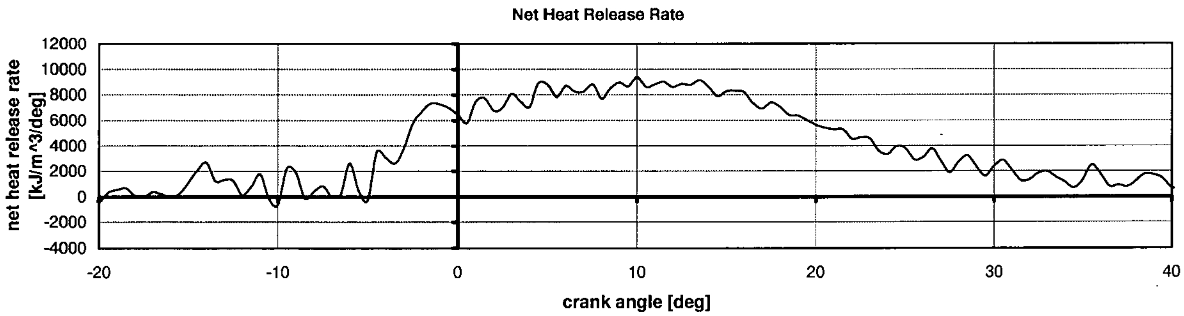
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 14657.64 |
| CA @ P_max [deg] | 6.5 |
| dP/dCA_max [bar/deg] | 484.229 |
| CA @ dP/dCA_max [deg] | -1.5 |
| IMEP [bar] | 1429.24 |
| HHR_max [kJ/m^3/deg] | 9402.5 |
| IHR_max [kJ/m^3] | 262041.9 |
| 5% MFB [deg w.r.t TDC] | -6.5 |
| 10% MFB [deg w.r.t TDC] | -2.0 |
| 50% MFB [deg w.r.t TDC] | 11.0 |
| 90% MFB [deg w.r.t TDC] | 30.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.36 |
| poly-n compression corrected | 1.36 |
| poly-n expansion uncorrected | 1.28 |
| poly-n expansion corrected | 1.28 |

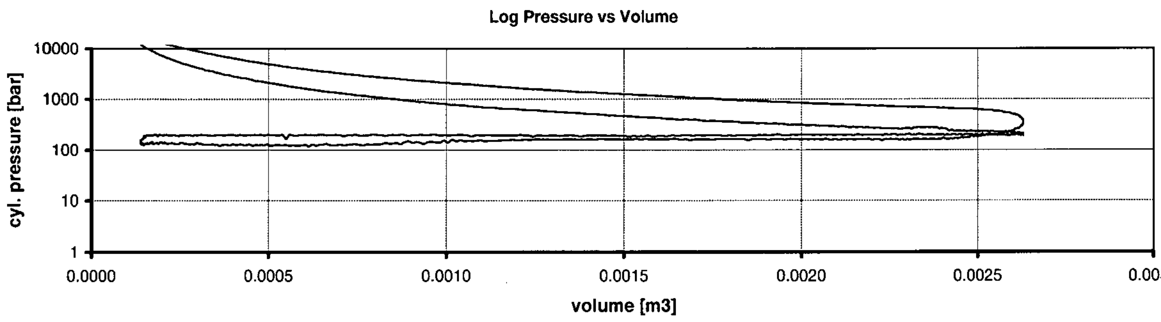
**Comments**

| Data Summary for filter: | D2 |
|---|---|
| Date: | 4/10/02 |
| Time: | 10:19:52 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1406.1 |
| Load - approx(%) | 85.0 |
| Power (kW) | 41.9 |
| IMEP (bar) | 14.31 |
| Pmax(bar) | 146.80 |
| Pmax location (degrees) | 367.0 |
| Diesel Flow(kg/hr) | 0.34 |
| CNG Flow(kg/hr) | 6.18 |
| Air Flow(kg/hr) | 275.9 |
| Exhaust Flow(kg/hr) | 282.5 |
| Exhaust Back Pressure (kPa) | 11.4 |
| EGR Fraction(%) | 0.0 |



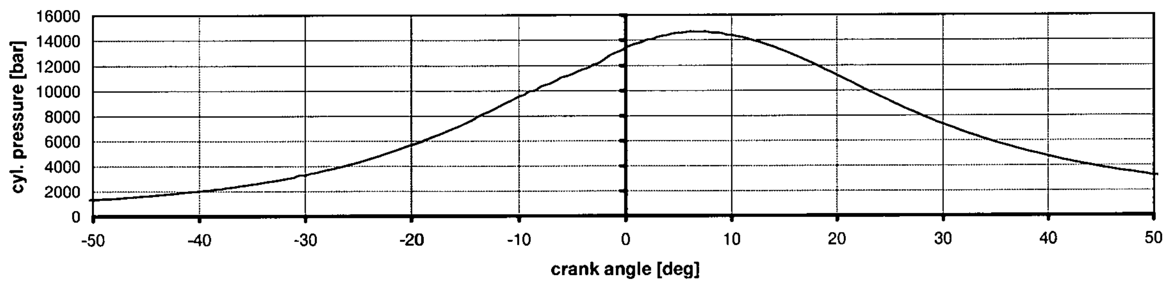
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 14691.74 |
| CA @ P_max [deg] | 6.5 |
| dP/dCA_max [bar/deg] | 584.177 |
| CA @ dP/dCA_max [deg] | -2.0 |
| IMEP [bar] | 1431.31 |
| HHR_max [kJ/m^3/deg] | 9689.4 |
| IHR_max [kJ/m^3] | 262169.7 |
| 5% MFB [deg w.r.t TDC] | -5.0 |
| 10% MFB [deg w.r.t TDC] | -2.0 |
| 50% MFB [deg w.r.t TDC] | 11.0 |
| 90% MFB [deg w.r.t TDC] | 31.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.35 |
| poly-n compression corrected | 1.35 |
| poly-n expansion uncorrected | 1.28 |
| poly-n expansion corrected | 1.28 |

Comments

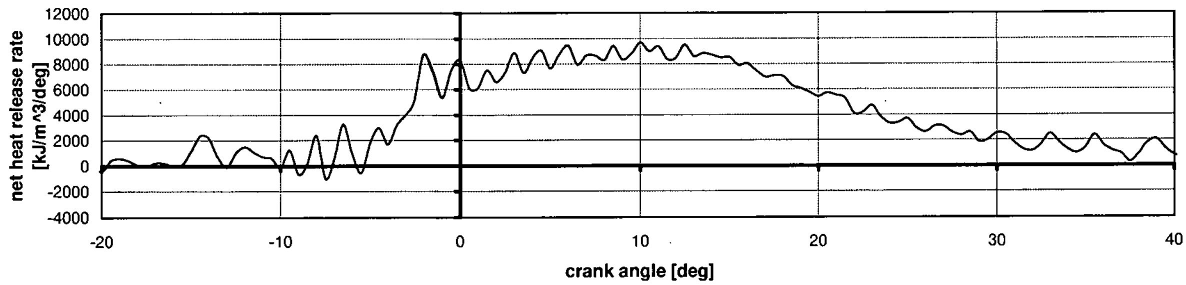
| | |
|---|---|
| Data Summary for filter: | D3 |
| Date: | 4/10/02 |
| Time: | 10:25:15 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1405.7 |
| Load - approx(%) | |
| Power (kW) | 42.0 |
| IMEP (bar) | 14.33 |
| Pmax(bar) | 147.19 |
| Pmax location (degrees) | 367.2 |
| Diesel Flow(kg/hr) | 0.29 |
| CNG Flow(kg/hr) | 6.21 |
| Air Flow(kg/hr) | 275.8 |
| Exhaust Flow(kg/hr) | 282.3 |
| Exhaust Back Pressure (kPa) | 11.4 |
| EGR Fraction(%) | 0.0 |

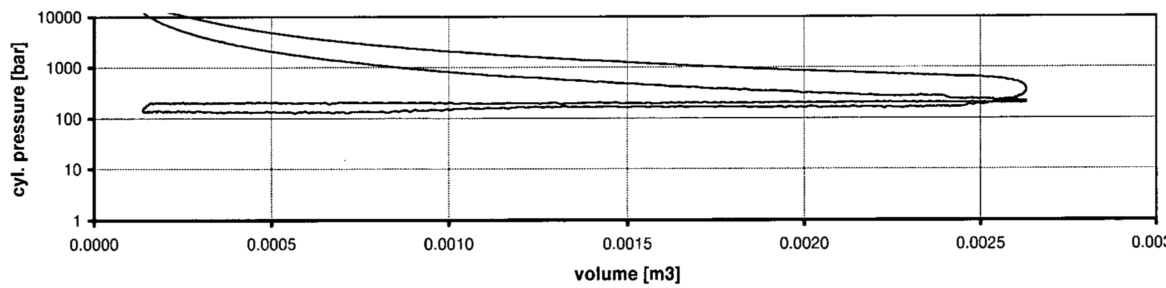
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume

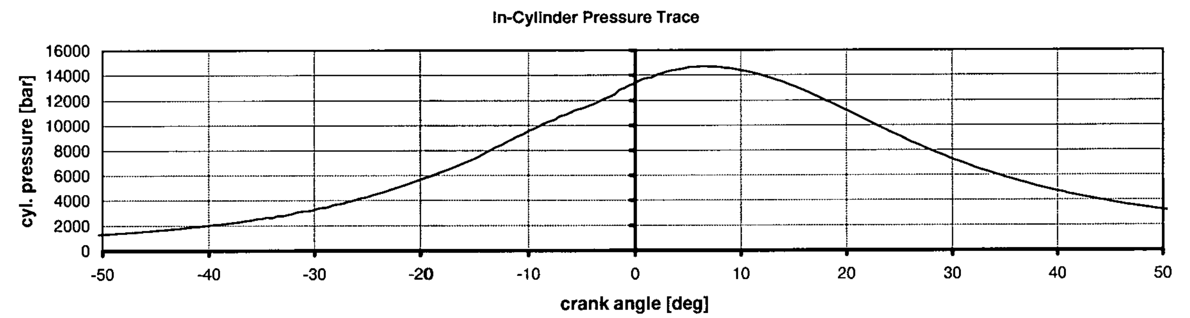


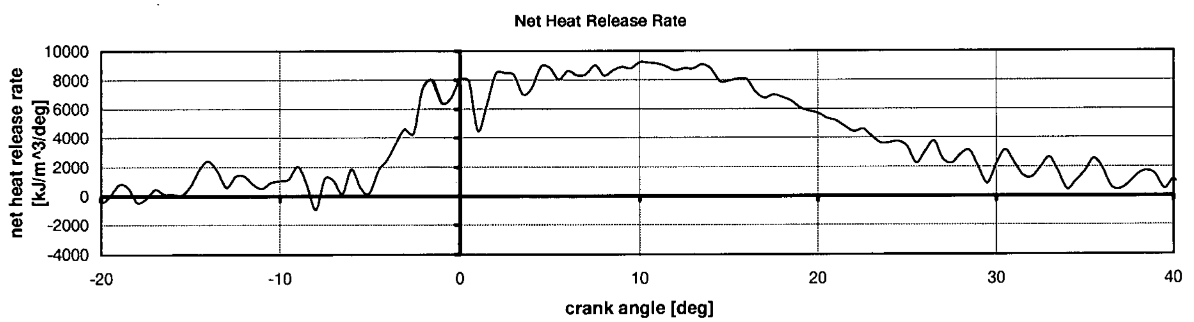
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 14682.71 |
| CA @ P max [deg] | 6.5 |
| dP/dCA max [bar/deg] | 522.140 |
| CA @ dP/dCA max [deg] | -1.5 |
| IMEP [bar] | 1429.61 |
| HHR max [kJ/m^3/deg] | 9214.5 |
| IHR max [kJ/m^3] | 261545.7 |
| 5% MFB [deg w.r.t TDC] | -6.5 |
| 10% MFB [deg w.r.t TDC] | -2.0 |
| 50% MFB [deg w.r.t TDC] | 10.5 |
| 90% MFB [deg w.r.t TDC] | 30.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.37 |
| poly-n compression corrected | 1.37 |
| poly-n expansion uncorrected | 1.29 |
| poly-n expansion corrected | 1.29 |

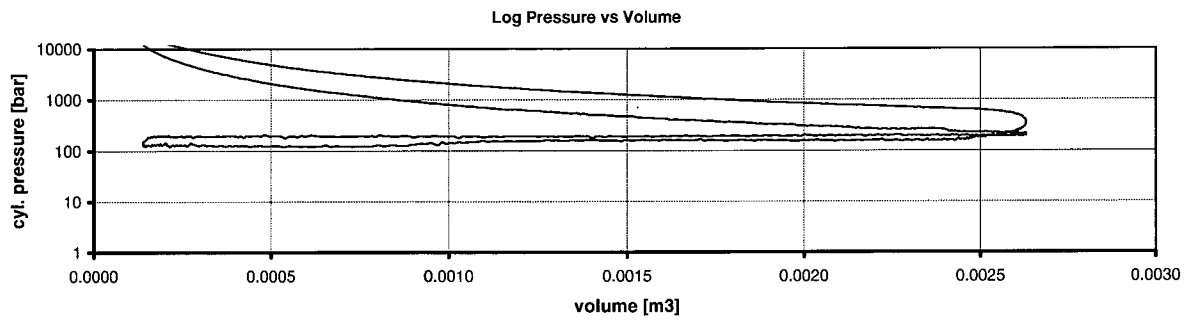
**Comments**

| | |
|---|---|
| Data Summary for filter: | D4 |
| Date: | 4/10/02 |
| Time: | 10:32:11 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1404.5 |
| Load - approx(%) | |
| Power (kW) | 41.9 |
| IMEP (bar) | 14.31 |
| Pmax(bar) | 147.03 |
| Pmax location (degrees) | 366.9 |
| Diesel Flow(kg/hr) | 0.33 |
| CNG Flow(kg/hr) | 6.13 |
| Air Flow(kg/hr) | 277.8 |
| Exhaust Flow(kg/hr) | 284.3 |
| Exhaust Back Pressure (kPa) | 11.4 |
| EGR Fraction(%) | 0.0 |



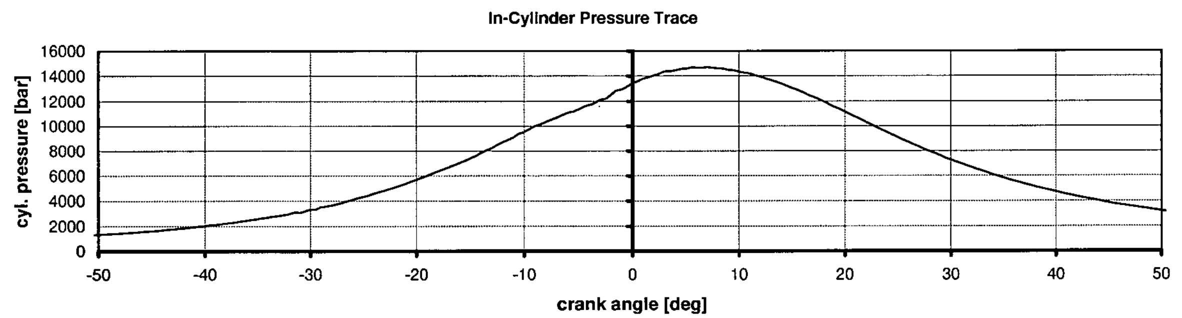



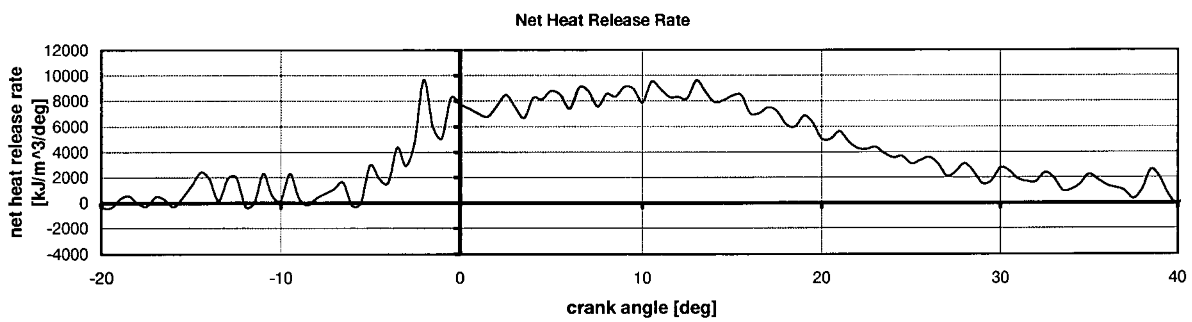
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 14712.44 |
| CA @ P_max [deg] | 7.0 |
| dP/dCA_max [bar/deg] | 635.874 |
| CA @ dP/dCA_max [deg] | -2.0 |
| IMEP [bar] | 1418.21 |
| HHR_max [kJ/m^3/deg] | 9671.0 |
| IHR_max [kJ/m^3] | 262138.5 |
| 5% MFB [deg w.r.t TDC] | -5.5 |
| 10% MFB [deg w.r.t TDC] | -2.0 |
| 50% MFB [deg w.r.t TDC] | 11.0 |
| 90% MFB [deg w.r.t TDC] | 32.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.35 |
| poly-n compression corrected | 1.35 |
| poly-n expansion uncorrected | 1.27 |
| poly-n expansion corrected | 1.27 |

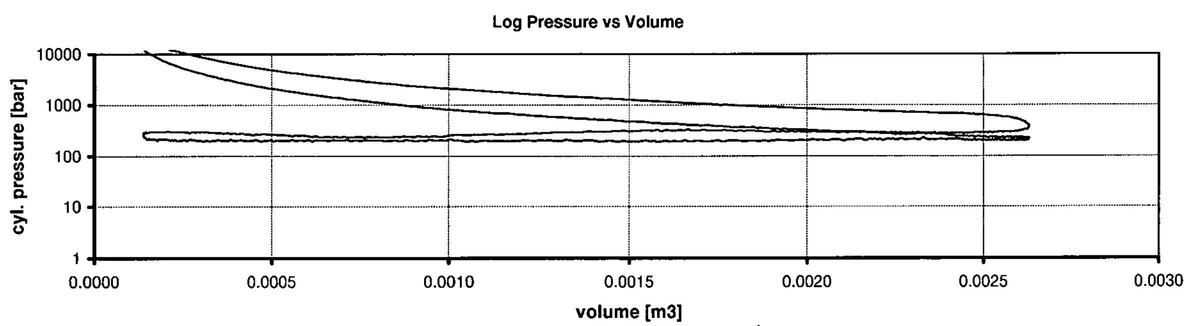
Comments

| | |
|---|---|
| Data Summary for filter: | D5 |
| Date: | 4/10/02 |
| Time: | 10:41:12 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1386.9 |
| Load - approx(%) | |
| Power (kW) | 41.0 |
| IMEP (bar) | 14.20 |
| Pmax(bar) | 147.33 |
| Pmax location (degrees) | 366.9 |
| Diesel Flow(kg/hr) | 0.30 |
| CNG Flow(kg/hr) | 6.07 |
| Air Flow(kg/hr) | 277.8 |
| Exhaust Flow(kg/hr) | 284.2 |
| Exhaust Back Pressure (kPa) | 151.6 |
| EGR Fraction(%) | 0.0 |



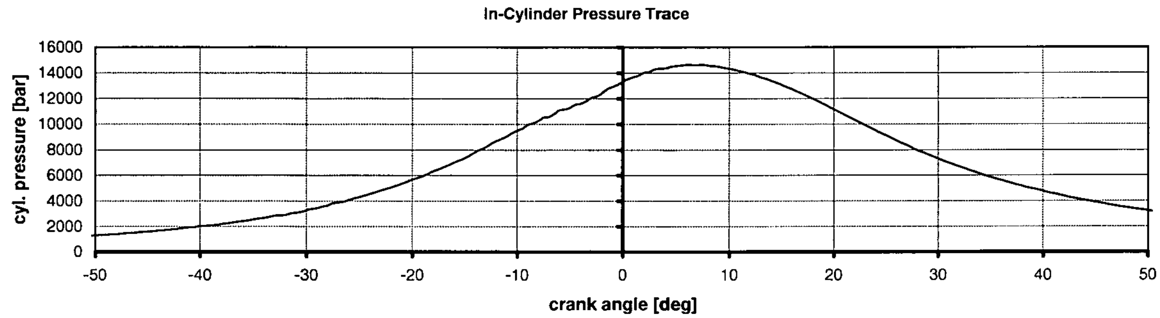



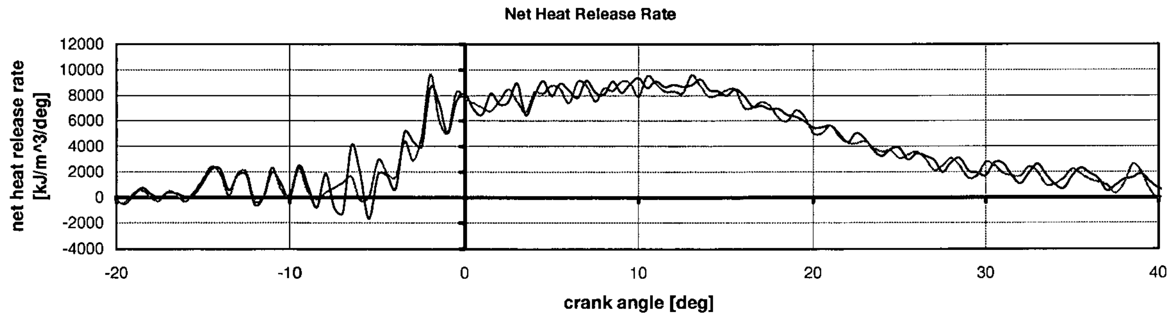
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 14652.51 |
| CA @ P_max [deg] | 6.0 |
| dP/dCA_max [bar/deg] | 577.284 |
| CA @ dP/dCA_max [deg] | -2.0 |
| IMEP [bar] | 1441.77 |
| HHR_max [kJ/m^3/deg] | 9375.3 |
| IHR_max [kJ/m^3] | 264839.9 |
| 5% MFB [deg w.r.t TDC] | -5.0 |
| 10% MFB [deg w.r.t TDC] | -2.0 |
| 50% MFB [deg w.r.t TDC] | 11.0 |
| 90% MFB [deg w.r.t TDC] | 32.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.35 |
| poly-n compression corrected | 1.35 |
| poly-n expansion uncorrected | 1.28 |
| poly-n expansion corrected | 1.28 |

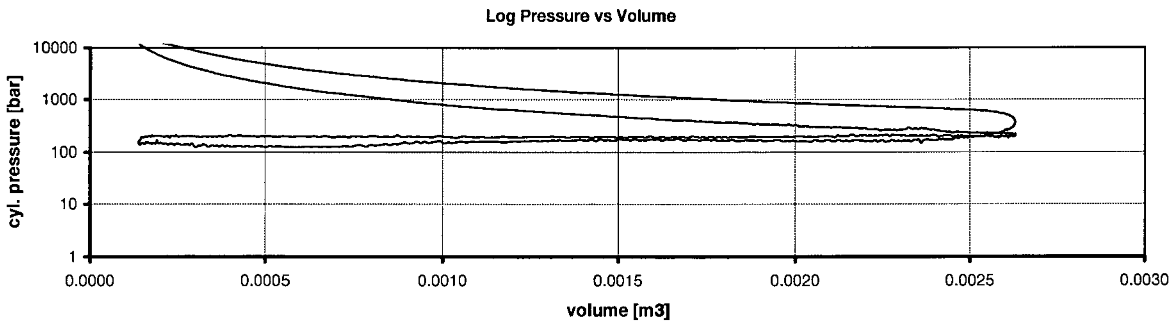
Comments

| Data Summary for filter: | D6 |
|---|---|
| Date: | 4/10/02 |
| Time: | 10:47:38 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1405.1 |
| Load - approx(%) | 85.0 |
| Power (kW) | 42.3 |
| IMEP (bar) | 14.44 |
| Pmax(bar) | 146.80 |
| Pmax location (degrees) | 367.1 |
| Diesel Flow(kg/hr) | 0.30 |
| CNG Flow(kg/hr) | 6.25 |
| Air Flow(kg/hr) | 278.1 |
| Exhaust Flow(kg/hr) | 284.7 |
| Exhaust Back Pressure (kPa) | 13.7 |
| EGR Fraction(%) | 0.0 |



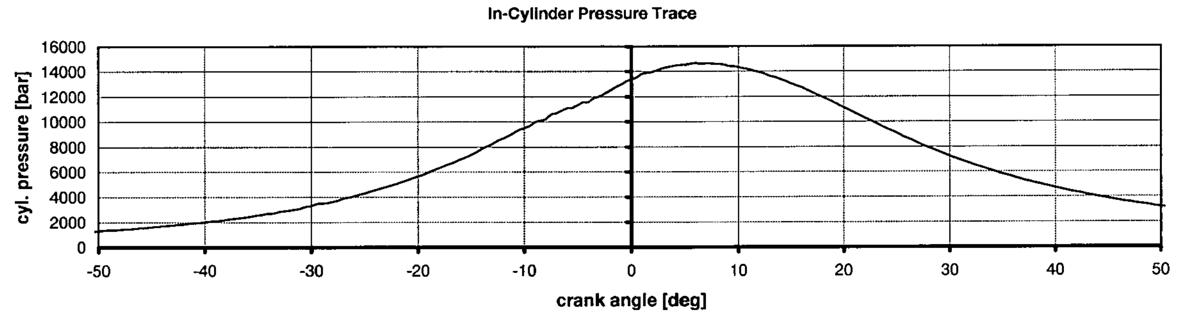



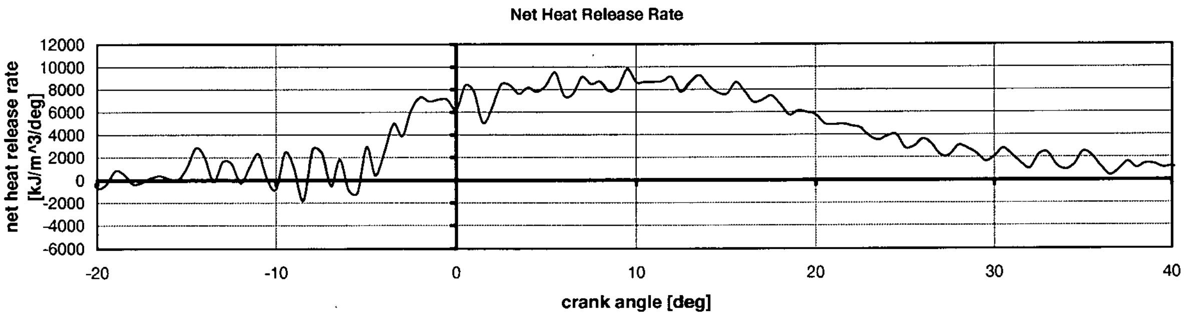
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 14665.01 |
| CA @ P_max [deg] | 6.0 |
| dP/dCA_max [bar/deg] | 508.354 |
| CA @ dP/dCA_max [deg] | -2.0 |
| IMEP [bar] | 1418.88 |
| HHR_max [kJ/m^3/deg] | 9822.6 |
| IHR_max [kJ/m^3] | 258117.8 |
| 5% MFB [deg w.r.t TDC] | -4.0 |
| 10% MFB [deg w.r.t TDC] | -2.0 |
| 50% MFB [deg w.r.t TDC] | 11.0 |
| 90% MFB [deg w.r.t TDC] | 32.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.35 |
| poly-n compression corrected | 1.35 |
| poly-n expansion uncorrected | 1.26 |
| poly-n expansion corrected | 1.26 |

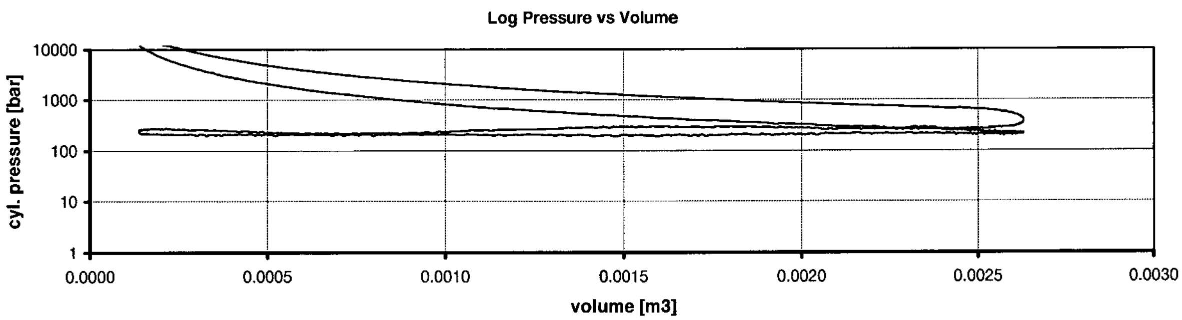
Comments

| Data Summary for filter: | D7 |
|---|---|
| Date: | 4/10/02 |
| Time: | 10:54:57 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1393.3 |
| Load - approx(%) | 85.0 |
| Power (kW) | 41.2 |
| IMEP (bar) | 14.21 |
| Pmax(bar) | 146.77 |
| Pmax location (degrees) | 366.6 |
| Diesel Flow(kg/hr) | 0.28 |
| CNG Flow(kg/hr) | 6.11 |
| Air Flow(kg/hr) | 278.0 |
| Exhaust Flow(kg/hr) | 284.3 |
| Exhaust Back Pressure (kPa) | 127.8 |
| EGR Fraction(%) | 0.0 |



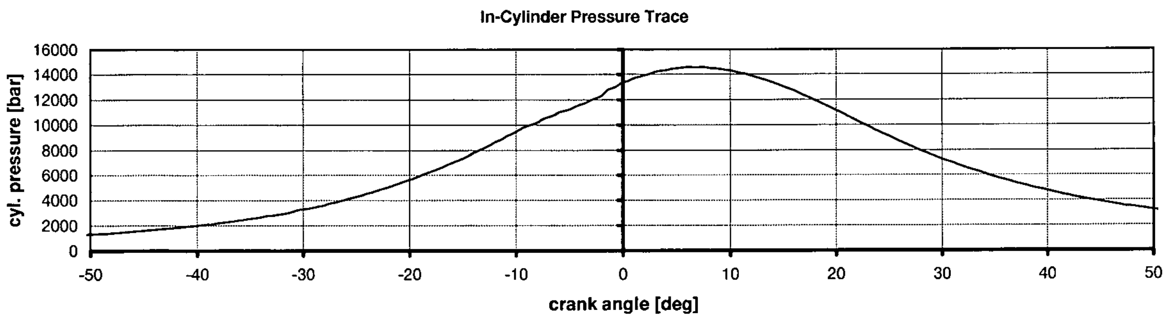



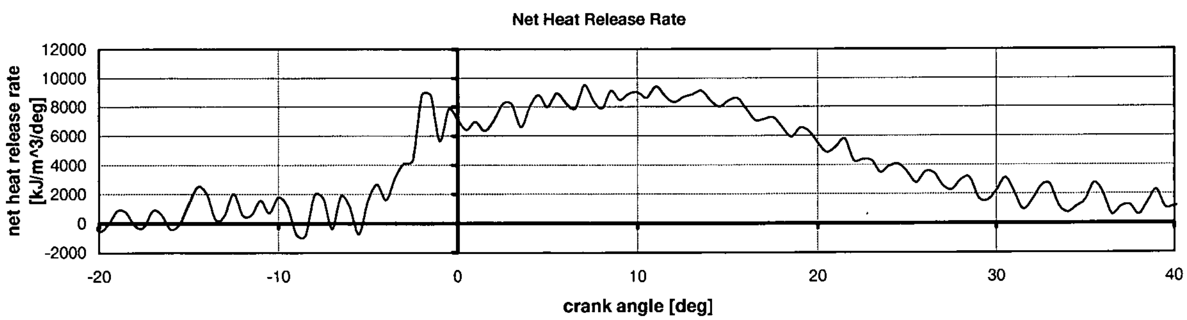



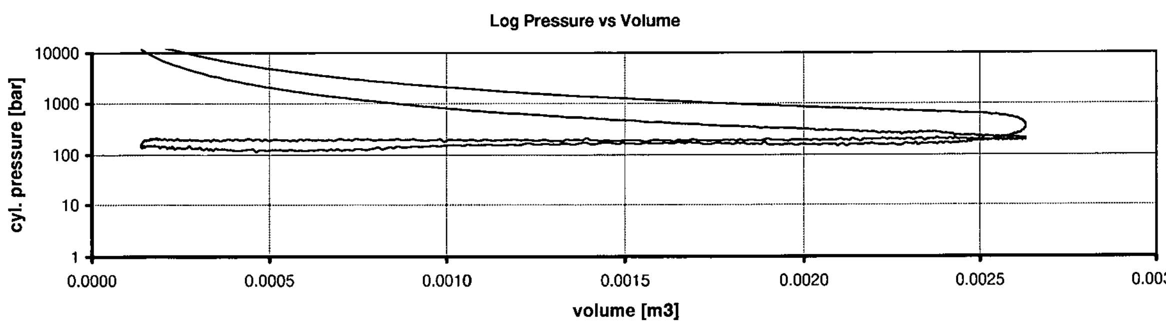
| | | Comments | |
|---|---|---|---|
| Speed [RPM] | | | |
| Torque [N-m] | | | |
| Load [%] | | | |
| P_max [deg] | 14596.87 | | |
| CA @ P_max [deg] | 7.5 | | |
| dP/dCA_max [bar/deg] | 587.623 | | |
| CA @ dP/dCA_max [deg] | -2.0 | | |
| IMEP [bar] | 1435.68 | | |
| HHR_max [kJ/m^3/deg] | 9533.6 | | |
| IHR_max [kJ/m^3] | 263881.6 | | |
| 5% MFB [deg w.r.t TDC] | -5.5 | | |
| 10% MFB [deg w.r.t TDC] | -2.0 | | |
| 50% MFB [deg w.r.t TDC] | 11.0 | | |
| 90% MFB [deg w.r.t TDC] | 31.5 | | |
| Assumed poly-n during comprn. | 1.37 | | |
| zero-level. pr. offset [bar] | 0.000 | | |
| poly-n compression uncorrected | 1.36 | | |
| poly-n compression corrected | 1.36 | | |
| poly-n expansion uncorrected | 1.26 | | |
| poly-n expansion corrected | 1.26 | | |

| Data Summary for filter: | D8 |
|---|---|
| Date: | 4/10/02 |
| Time: | 11:03:00 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1404.2 |
| Load - approx(%) | 85.0 |
| Power (kW) | 42.1 |
| IMEP (bar) | 14.37 |
| Pmax(bar) | 146.21 |
| Pmax location (degrees) | 367.2 |
| Diesel Flow(kg/hr) | 0.31 |
| CNG Flow(kg/hr) | 6.21 |
| Air Flow(kg/hr) | 278.0 |
| Exhaust Flow(kg/hr) | 284.5 |
| Exhaust Back Pressure (kPa) | 12.4 |
| EGR Fraction(%) | 0.0 |



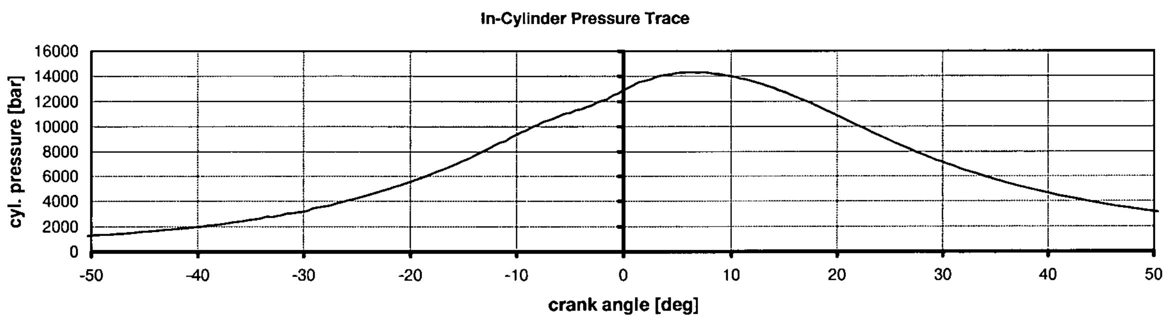



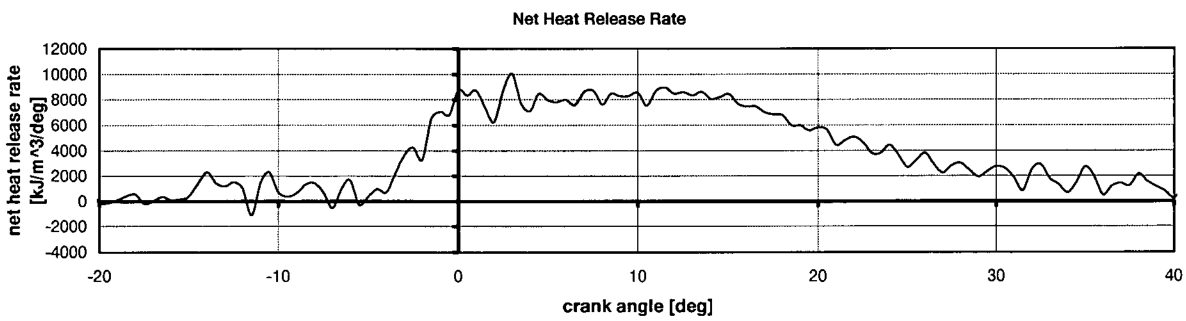
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 14308.29 |
| CA @ P_max [deg] | 6.0 |
| dP/dCA_max [bar/deg] | 479.059 |
| CA @ dP/dCA_max [deg] | -10.5 |
| IMEP [bar] | 1401.80 |
| HHR_max [kJ/m^3/deg] | 10035.1 |
| IHR_max [kJ/m^3] | 257640.4 |
| 5% MFB [deg w.r.t TDC] | -4.0 |
| 10% MFB [deg w.r.t TDC] | -1.5 |
| 50% MFB [deg w.r.t TDC] | 11.5 |
| 90% MFB [deg w.r.t TDC] | 33.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.35 |
| poly-n compression corrected | 1.35 |
| poly-n expansion uncorrected | 1.27 |
| poly-n expansion corrected | 1.27 |

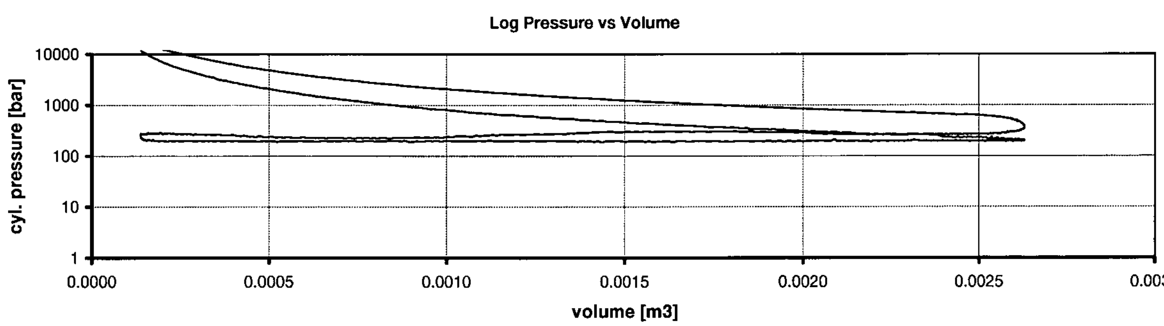
Comments

| Data Summary for filter: | D9 |
|---|---|
| Date: | 4/10/02 |
| Time: | 11:23:31 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1386.2 |
| Load - approx(%) | 85.0 |
| Power (kW) | 40.5 |
| IMEP (bar) | 14.04 |
| Pmax(bar) | 143.26 |
| Pmax location (degrees) | 367.2 |
| Diesel Flow(kg/hr) | 0.28 |
| CNG Flow(kg/hr) | 6.09 |
| Air Flow(kg/hr) | 231.9 |
| Exhaust Flow(kg/hr) | 238.3 |
| Exhaust Back Pressure (kPa) | 143.0 |
| EGR Fraction(%) | 13.5 |



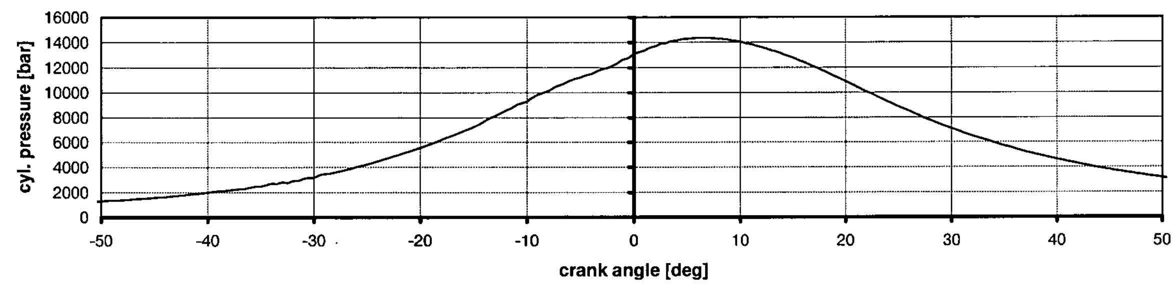
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 14366.46 |
| CA @ P_max [deg] | 6.0 |
| dP/dCA_max [bar/deg] | 530.756 |
| CA @ dP/dCA_max [deg] | -9.5 |
| IMEP [bar] | 1398.29 |
| HHR_max [kJ/m^3/deg] | 8839.6 |
| IHR_max [kJ/m^3] | 256158.5 |
| 5% MFB [deg w.r.t TDC] | -5.0 |
| 10% MFB [deg w.r.t TDC] | -1.5 |
| 50% MFB [deg w.r.t TDC] | 11.5 |
| 90% MFB [deg w.r.t TDC] | 33.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.34 |
| poly-n compression corrected | 1.34 |
| poly-n expansion uncorrected | 1.26 |
| poly-n expansion corrected | 1.26 |

**Comments**

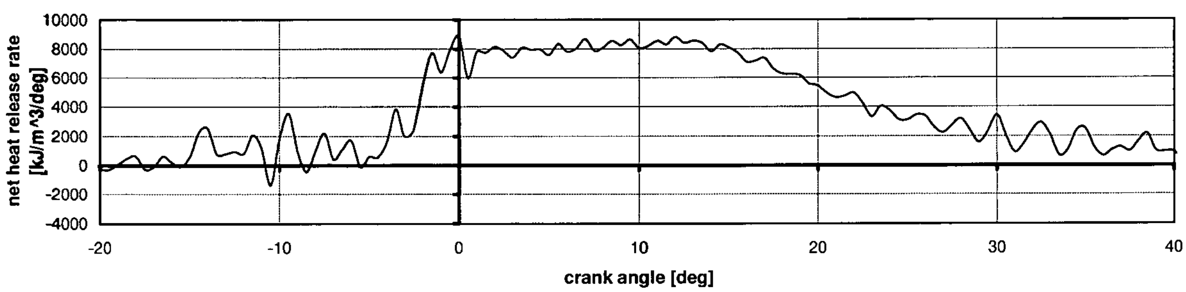
| | |
|---|---|
| Data Summary for filter: | D10 |
| Date: | 4/10/02 |
| Time: | 11:28:43 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1387.3 |
| Load - approx(%) | 85.0 |
| Power (kW) | 40.5 |
| IMEP (bar) | 14.00 |
| Pmax(bar) | 143.89 |
| Pmax location (degrees) | 366.9 |
| Diesel Flow(kg/hr) | 0.34 |
| CNG Flow(kg/hr) | 6.06 |
| Air Flow(kg/hr) | 232.0 |
| Exhaust Flow(kg/hr) | 238.4 |
| Exhaust Back Pressure (kPa) | 142.5 |
| EGR Fraction(%) | 13.4 |

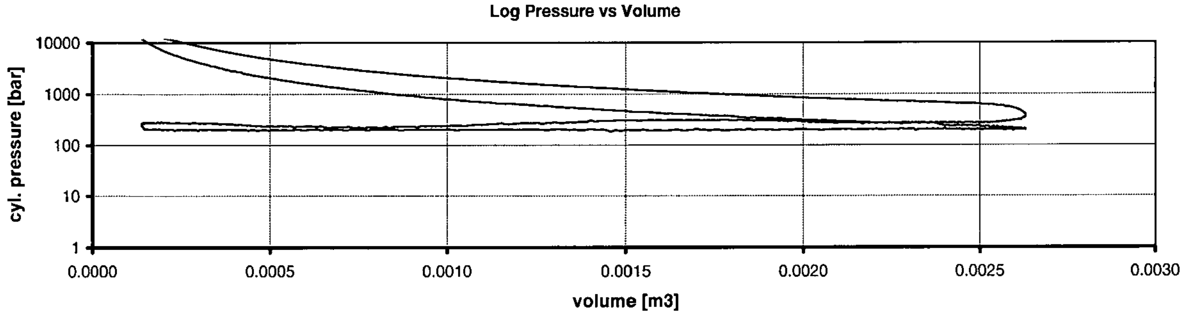
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume



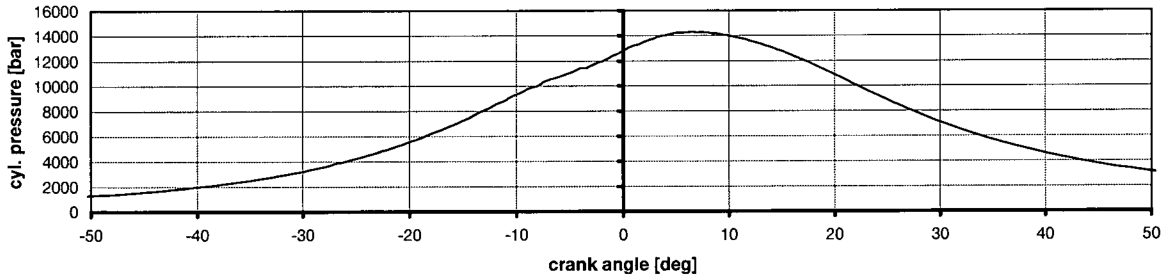
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 14304.18 |
| CA @ P_max [deg] | 6.5 |
| dP/dCA_max [bar/deg] | 516.970 |
| CA @ dP/dCA_max [deg] | 0.0 |
| IMEP [bar] | 1396.67 |
| HHR_max [kJ/m^3/deg] | 9573.5 |
| IHR_max [kJ/m^3] | 256997.2 |
| 5% MFB [deg w.r.t TDC] | -4.0 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 11.0 |
| 90% MFB [deg w.r.t TDC] | 33.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.34 |
| poly-n compression corrected | 1.34 |
| poly-n expansion uncorrected | 1.26 |
| poly-n expansion corrected | 1.26 |

Comments

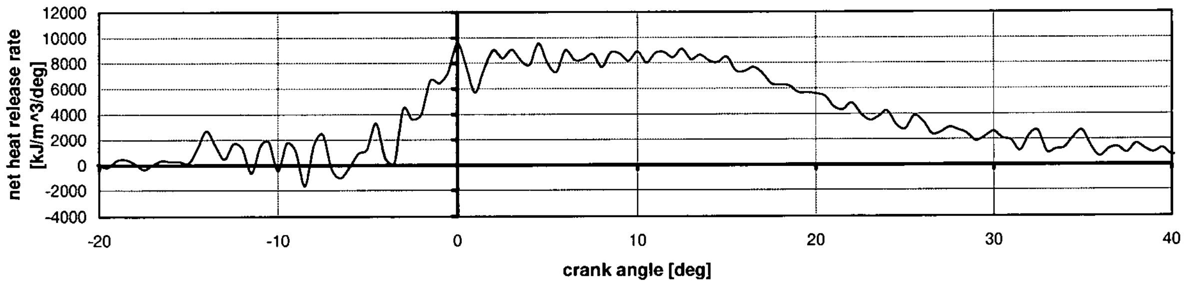
| | |
|---|---|
| Data Summary for filter: | D11 |
| Date: | 4/10/02 |
| Time: | 11:34:34 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1387.0 |
| Load - approx(%) | 85.0 |
| Power (kW) | 40.4 |
| IMEP (bar) | 13.98 |
| Pmax(bar) | 143.13 |
| Pmax location (degrees) | 367.2 |
| Diesel Flow(kg/hr) | 0.27 |
| CNG Flow(kg/hr) | 6.11 |
| Air Flow(kg/hr) | 232.2 |
| Exhaust Flow(kg/hr) | 238.6 |
| Exhaust Back Pressure (kPa) | 142.2 |
| EGR Fraction(%) | 13.4 |

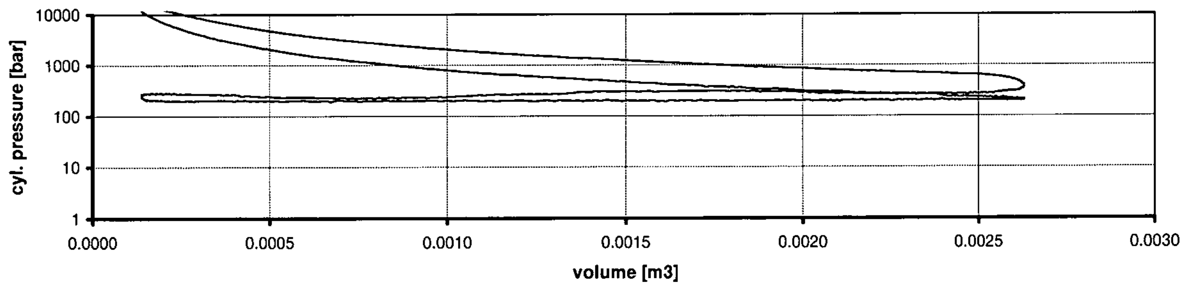
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume



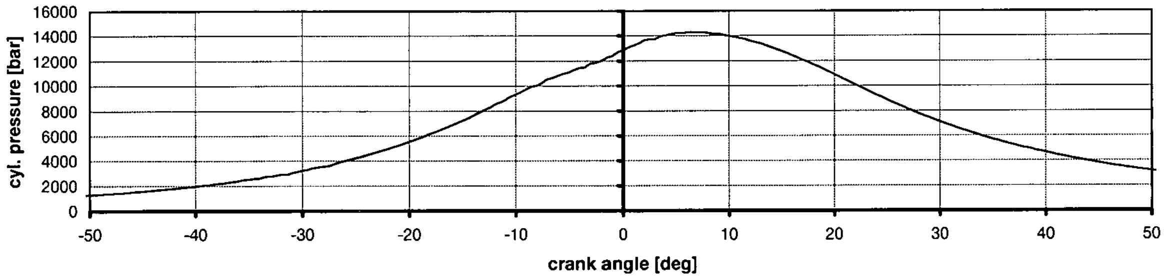
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 14281.23 |
| CA @ P max [deg] | 6.5 |
| dP/dCA max [bar/deg] | 508.354 |
| CA @ dP/dCA max [deg] | -7.5 |
| IMEP [bar] | 1408.28 |
| HHR max [kJ/m^3/deg] | 10004.3 |
| IHR max [kJ/m^3] | 259179.3 |
| 5% MFB [deg w.r.t TDC] | -5.0 |
| 10% MFB [deg w.r.t TDC] | -1.5 |
| 50% MFB [deg w.r.t TDC] | 11.5 |
| 90% MFB [deg w.r.t TDC] | 34.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.34 |
| poly-n compression corrected | 1.34 |
| poly-n expansion uncorrected | 1.25 |
| poly-n expansion corrected | 1.25 |

Comments

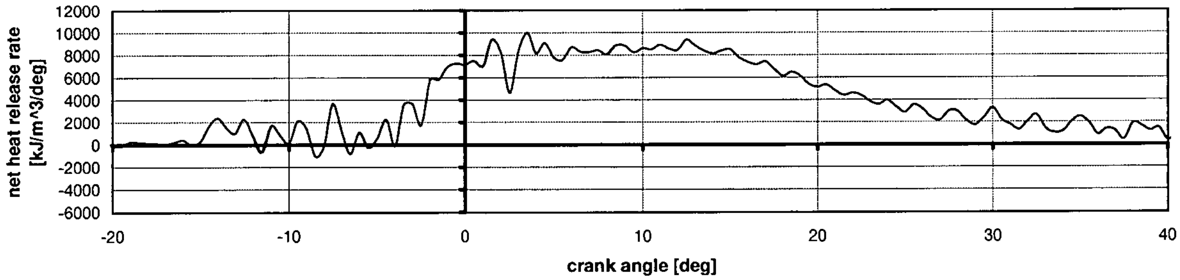
| Data Summary for filter: | D12 |
|---|---|
| Date: | 4/10/02 |
| Time: | 11:41:08 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1388.2 |
| Load - approx(%) | 85.0 |
| Power (kW) | 40.8 |
| IMEP (bar) | 14.10 |
| Pmax(bar) | 143.02 |
| Pmax location (degrees) | 367.2 |
| Diesel Flow(kg/hr) | 0.32 |
| CNG Flow(kg/hr) | 6.10 |
| Air Flow(kg/hr) | 232.6 |
| Exhaust Flow(kg/hr) | 239.0 |
| Exhaust Back Pressure (kPa) | 141.6 |
| EGR Fraction(%) | 13.3 |

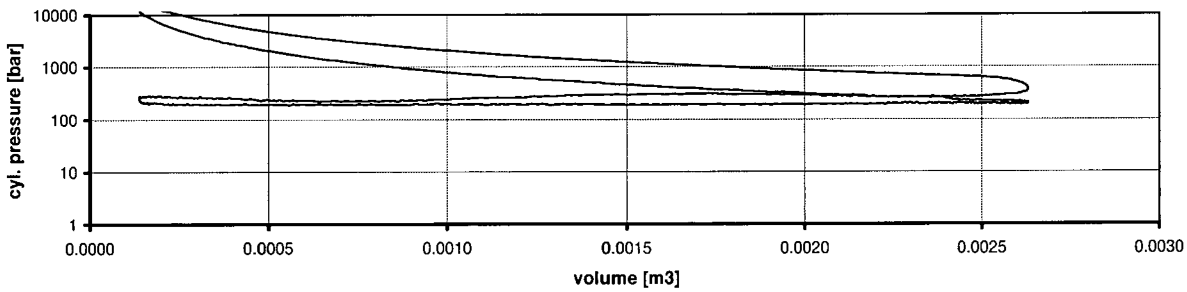
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume



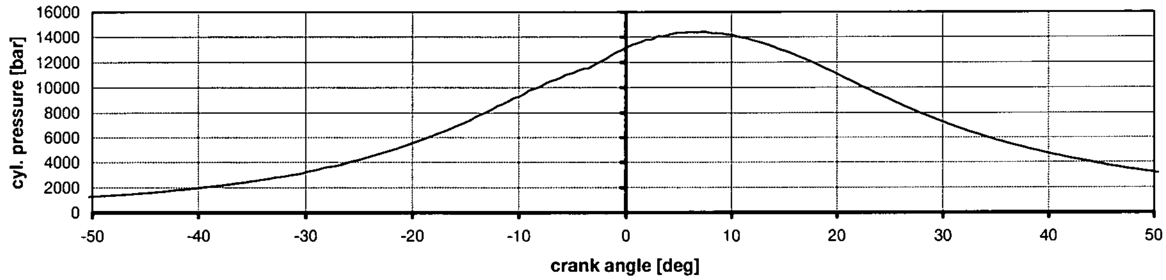
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 14431.90 |
| CA @ P max [deg] | 7.5 |
| dP/dCA max [bar/deg] | 527.310 |
| CA @ dP/dCA max [deg] | -1.5 |
| IMEP [bar] | 1444.58 |
| HHR max [kJ/m^3/deg] | 9468.2 |
| IHR max [kJ/m^3] | 265858.9 |
| 5% MFB [deg w.r.t TDC] | -5.5 |
| 10% MFB [deg w.r.t TDC] | -2.0 |
| 50% MFB [deg w.r.t TDC] | 11.0 |
| 90% MFB [deg w.r.t TDC] | 32.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.35 |
| poly-n compression corrected | 1.35 |
| poly-n expansion uncorrected | 1.25 |
| poly-n expansion corrected | 1.25 |

Comments

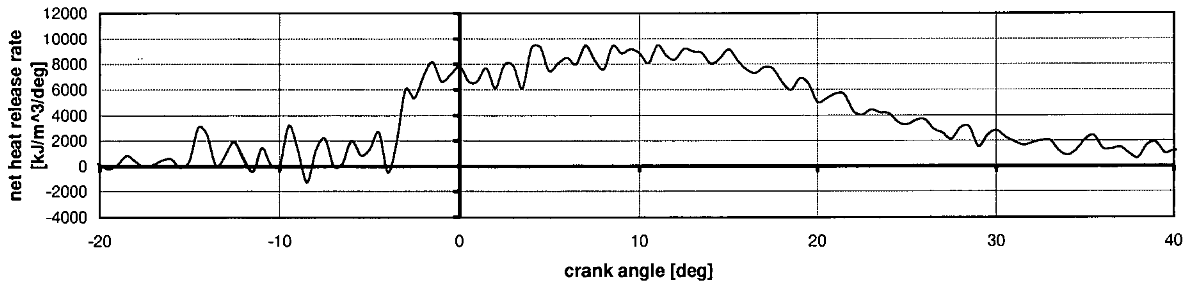
| Data Summary for filter: | D13 |
|---|---|
| Date: | 4/10/02 |
| Time: | 11:53:41 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1407.6 |
| Load - approx(%) | 85.0 |
| Power (kW) | 42.4 |
| IMEP (bar) | 14.46 |
| Pmax(bar) | 144.44 |
| Pmax location (degrees) | 367.2 |
| Diesel Flow(kg/hr) | 0.30 |
| CNG Flow(kg/hr) | 6.30 |
| Air Flow(kg/hr) | 277.1 |
| Exhaust Flow(kg/hr) | 283.7 |
| Exhaust Back Pressure (kPa) | 5.2 |
| EGR Fraction(%) | 0.0 |

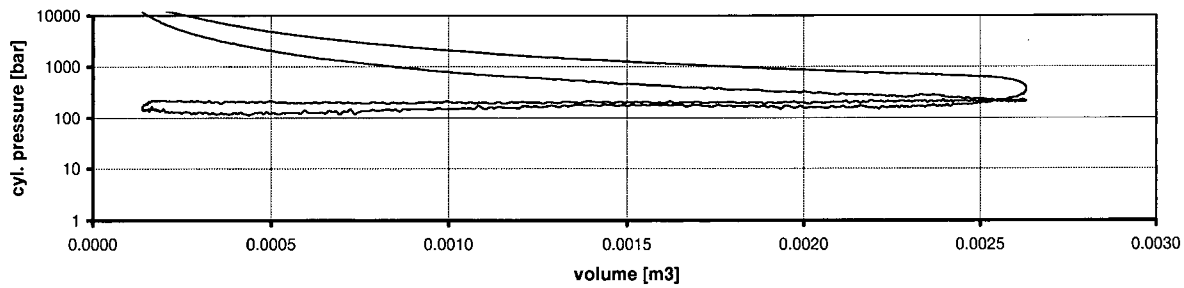
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume

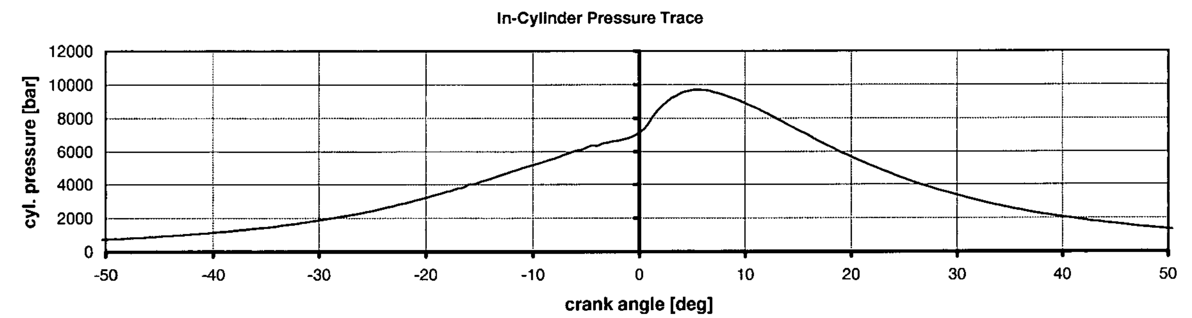


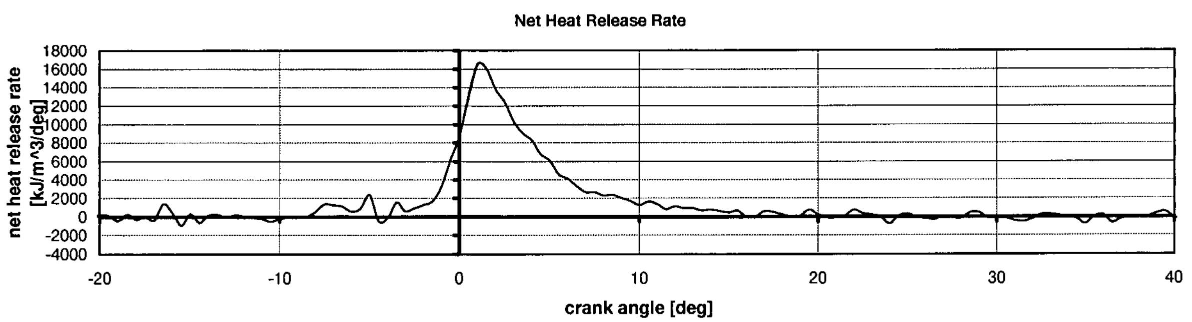
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 9695.77 |
| CA @ P max [deg] | 5.5 |
| dP/dCA max [bar/deg] | 854.725 |
| CA @ dP/dCA max [deg] | 1.0 |
| IMEP [bar] | 523.92 |
| HHR max [kJ/m^3/deg] | 16540.4 |
| IHR max [kJ/m^3] | 91875.2 |
| 5% MFB [deg w.r.t TDC] | -3.5 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 2.0 |
| 90% MFB [deg w.r.t TDC] | 8.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.35 |
| poly-n compression corrected | 1.35 |
| poly-n expansion uncorrected | 1.35 |
| poly-n expansion corrected | 1.35 |

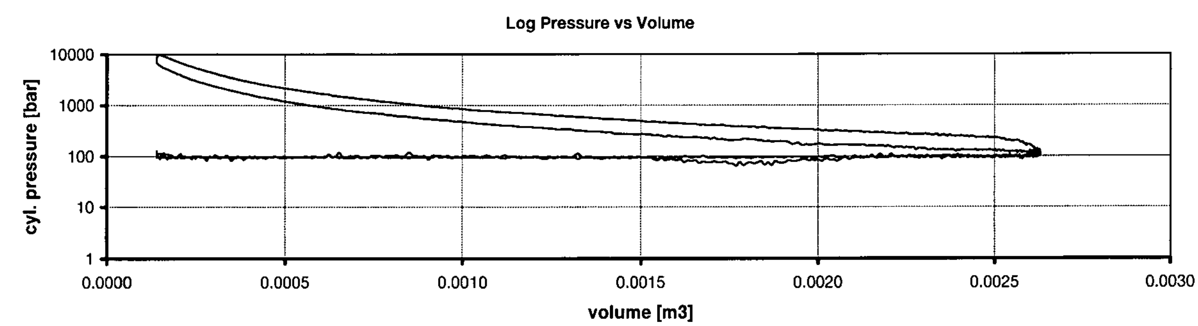
**Comments**

| | |
|---|---|
| Data Summary for filter: | E1 |
| Date: | 4/10/02 |
| Time: | 12:29:19 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 809.0 |
| Load - approx(%) | 25.0 |
| Power (kW) | 8.8 |
| IMEP (bar) | 5.25 |
| Pmax(bar) | 97.11 |
| Pmax location (degrees) | 366.0 |
| Diesel Flow(kg/hr) | 0.15 |
| CNG Flow(kg/hr) | 1.23 |
| Air Flow(kg/hr) | 73.4 |
| Exhaust Flow(kg/hr) | 74.7 |
| Exhaust Back Pressure (kPa) | 11.9 |
| EGR Fraction(%) | 0.0 |



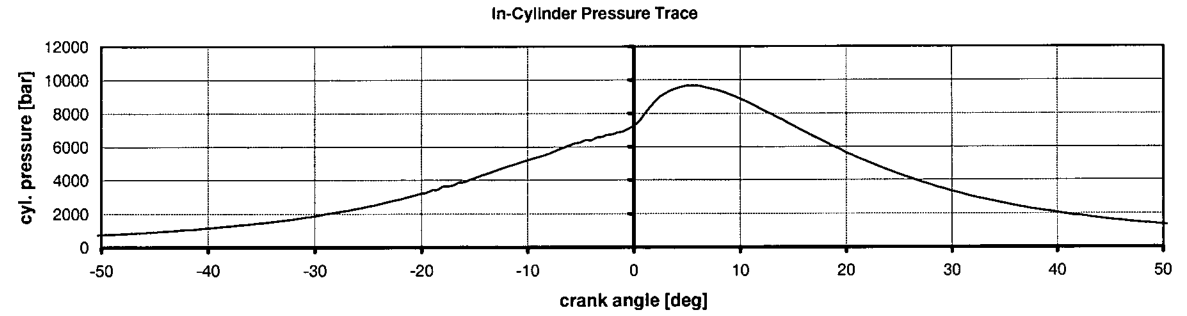



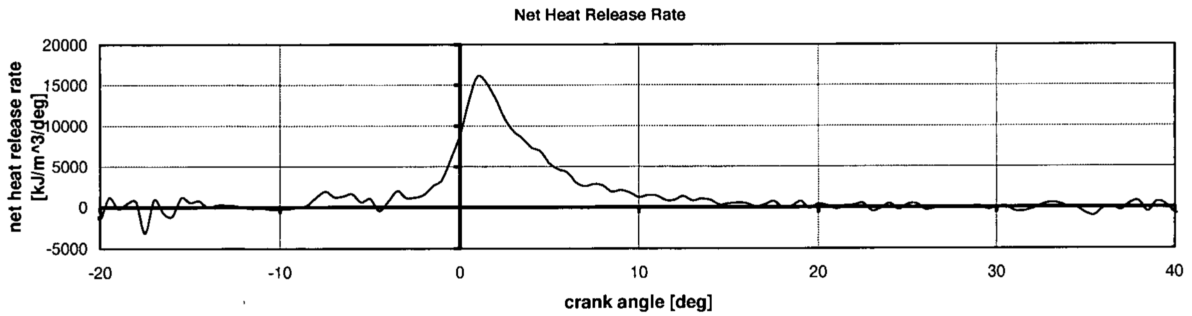
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 9656.02 |
| CA @ P max [deg] | 6.0 |
| dP/dCA max [bar/deg] | 830.599 |
| CA @ dP/dCA max [deg] | 1.0 |
| IMEP [bar] | 518.82 |
| HHR max [kJ/m^3/deg] | 16104.3 |
| IHR max [kJ/m^3] | 90390.0 |
| 5% MFB [deg w.r.t TDC] | -4.0 |
| 10% MFB [deg w.r.t TDC] | -1.5 |
| 50% MFB [deg w.r.t TDC] | 1.5 |
| 90% MFB [deg w.r.t TDC] | 8.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.33 |
| poly-n compression corrected | 1.33 |
| poly-n expansion uncorrected | 1.32 |
| poly-n expansion corrected | 1.32 |

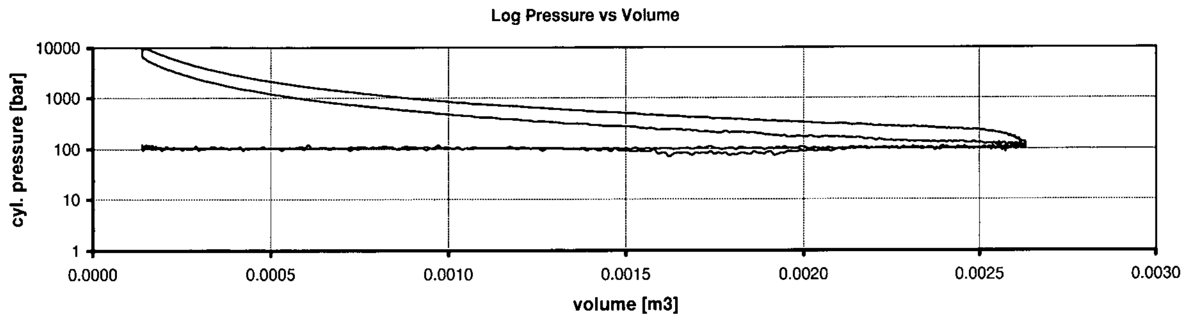
**Comments**

| | |
|---|---|
| Data Summary for filter: | E2 |
| Date: | 4/10/02 |
| Time: | 12:35:02 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 808.3 |
| Load - approx(%) | 25.0 |
| Power (kW) | 8.7 |
| IMEP (bar) | 5.20 |
| Pmax(bar) | 96.90 |
| Pmax location (degrees) | 365.9 |
| Diesel Flow(kg/hr) | 0.24 |
| CNG Flow(kg/hr) | 1.21 |
| Air Flow(kg/hr) | 73.5 |
| Exhaust Flow(kg/hr) | 74.9 |
| Exhaust Back Pressure (kPa) | 11.3 |
| EGR Fraction(%) | 0.0 |



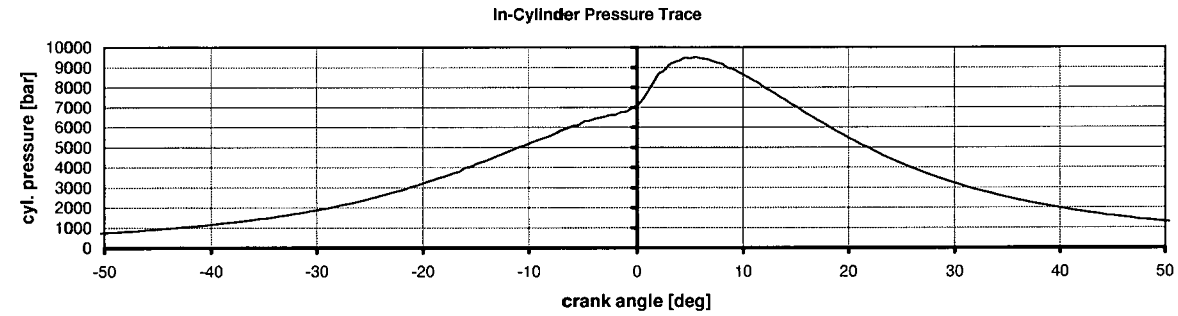



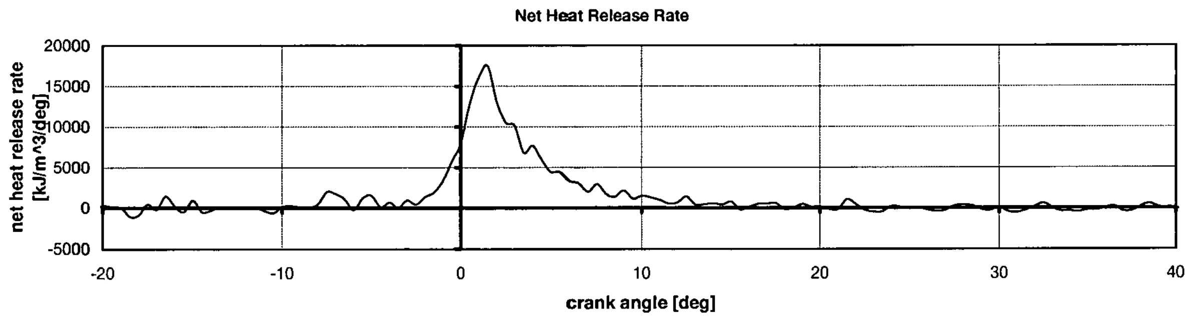
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 9504.36 |
| CA @ P max [deg] | 5.5 |
| dP/dCA max [bar/deg] | 884.020 |
| CA @ dP/dCA max [deg] | 1.5 |
| IMEP [bar] | 479.78 |
| HHR max [kJ/m^3/deg] | 17513.9 |
| IHR max [kJ/m^3] | 84655.4 |
| 5% MFB [deg w.r.t TDC] | -4.5 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 1.5 |
| 90% MFB [deg w.r.t TDC] | 7.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.33 |
| poly-n compression corrected | 1.33 |
| poly-n expansion uncorrected | 1.35 |
| poly-n expansion corrected | 1.35 |

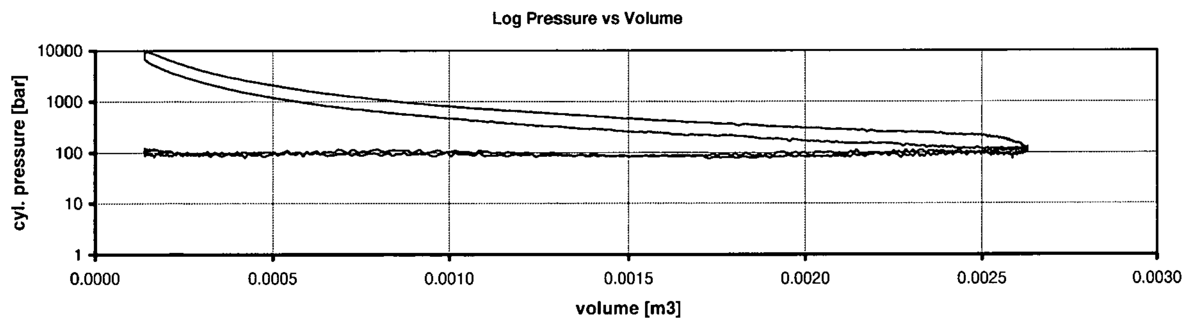
Comments

| | |
|---|---|
| Data Summary for filter: | E3 |
| Date: | 4/10/02 |
| Time: | 12:42:23 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 805.2 |
| Load - approx(%) | 25.0 |
| Power (kW) | 8.1 |
| IMEP (bar) | 4.80 |
| Pmax(bar) | 95.30 |
| Pmax location (degrees) | 365.7 |
| Diesel Flow(kg/hr) | 0.14 |
| CNG Flow(kg/hr) | 1.20 |
| Air Flow(kg/hr) | 73.5 |
| Exhaust Flow(kg/hr) | 74.9 |
| Exhaust Back Pressure (kPa) | 11.5 |
| EGR Fraction(%) | 0.0 |



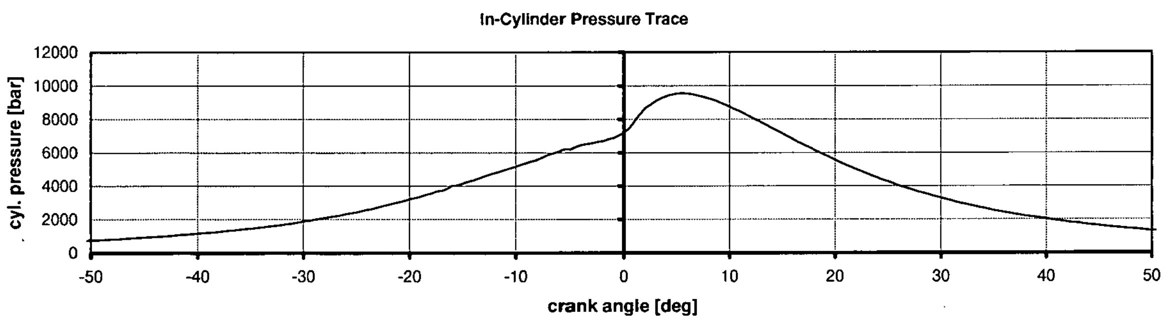



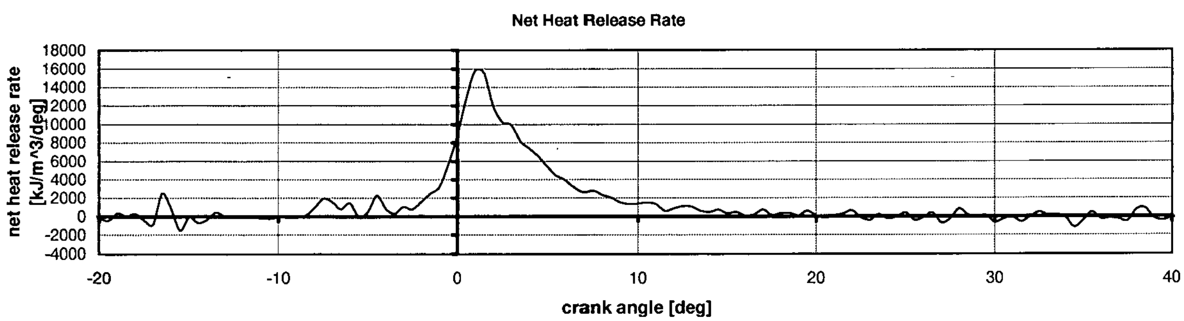



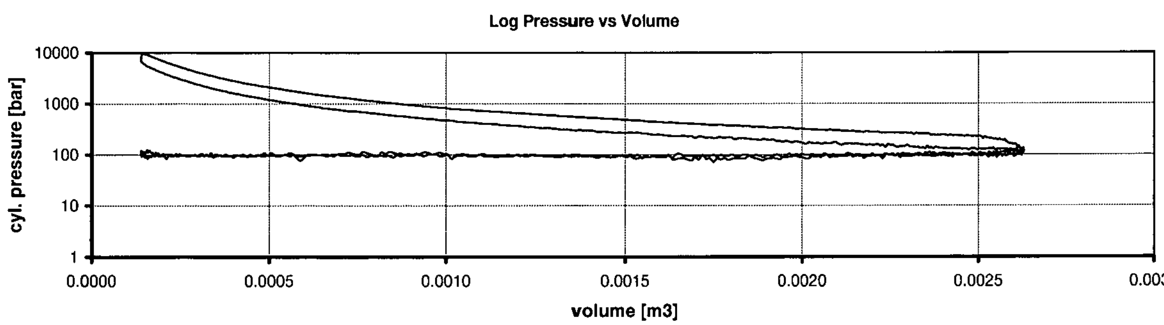
| | | Comments |
|---|---|---|
| Speed [RPM] | | |
| Torque [N-m] | | |
| Load [%] | | |
| P_max [deg] | 9545.69 | |
| CA @ P_max [deg] | 5.5 | |
| dP/dCA_max [bar/deg] | 813.367 | |
| CA @ dP/dCA_max [deg] | 1.0 | |
| IMEP [bar] | 497.31 | |
| HHR_max [kJ/m^3/deg] | 15777.1 | |
| IHR_max [kJ/m^3] | 87537.0 | |
| 5% MFB [deg w.r.t TDC] | -5.0 | |
| 10% MFB [deg w.r.t TDC] | -1.5 | |
| 50% MFB [deg w.r.t TDC] | 1.5 | |
| 90% MFB [deg w.r.t TDC] | 8.0 | |
| Assumed poly-n during comprn. | 1.37 | |
| zero-level. pr. offset [bar] | 0.000 | |
| poly-n compression uncorrected | 1.35 | |
| poly-n compression corrected | 1.35 | |
| poly-n expansion uncorrected | 1.33 | |
| poly-n expansion corrected | 1.33 | |

| | |
|---|---|
| Data Summary for filter: | E4 |
| Date: | 4/10/02 |
| Time: | 12:49:00 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 805.3 |
| Load - approx(%) | 25.0 |
| Power (kW) | 8.4 |
| IMEP (bar) | 4.98 |
| Pmax(bar) | 95.72 |
| Pmax location (degrees) | 365.9 |
| Diesel Flow(kg/hr) | 0.17 |
| CNG Flow(kg/hr) | 1.19 |
| Air Flow(kg/hr) | 73.7 |
| Exhaust Flow(kg/hr) | 75.1 |
| Exhaust Back Pressure (kPa) | 11.2 |
| EGR Fraction(%) | 0.0 |



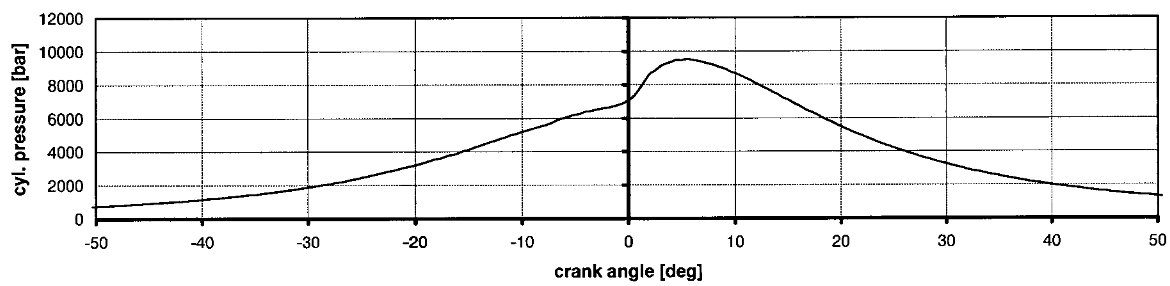
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 9525.04 |
| CA @ P_max [deg] | 5.5 |
| dP/dCA_max [bar/deg] | 882.296 |
| CA @ dP/dCA_max [deg] | 1.5 |
| IMEP [bar] | 487.07 |
| HHR_max [kJ/m^3/deg] | 17478.5 |
| IHR_max [kJ/m^3] | 85457.3 |
| 5% MFB [deg w.r.t TDC] | -3.5 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 1.5 |
| 90% MFB [deg w.r.t TDC] | 7.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.34 |
| poly-n compression corrected | 1.34 |
| poly-n expansion uncorrected | 1.31 |
| poly-n expansion corrected | 1.31 |

**Comments**

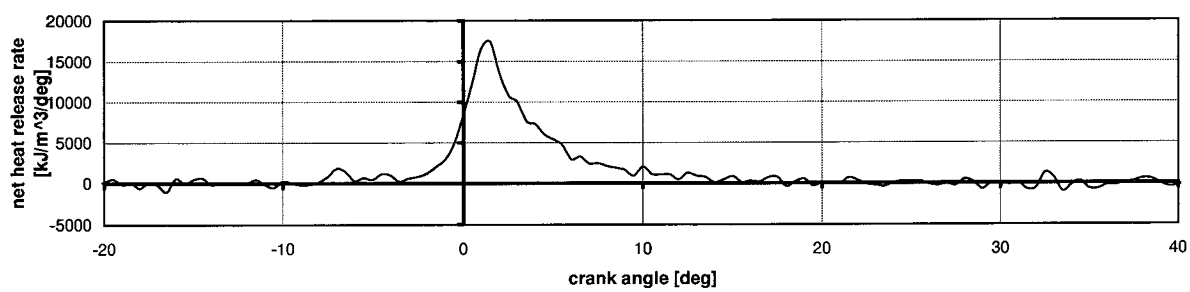
| | |
|---|---|
| Data Summary for filter: | E5 |
| Date: | 4/10/02 |
| Time: | 12:56:29 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 802.9 |
| Load - approx(%) | 25.0 |
| Power (kW) | 8.2 |
| IMEP (bar) | 4.88 |
| Pmax(bar) | 95.34 |
| Pmax location (degrees) | 366.0 |
| Diesel Flow(kg/hr) | 0.15 |
| CNG Flow(kg/hr) | 1.17 |
| Air Flow(kg/hr) | 73.8 |
| Exhaust Flow(kg/hr) | 75.1 |
| Exhaust Back Pressure (kPa) | 11.1 |
| EGR Fraction(%) | 0.0 |

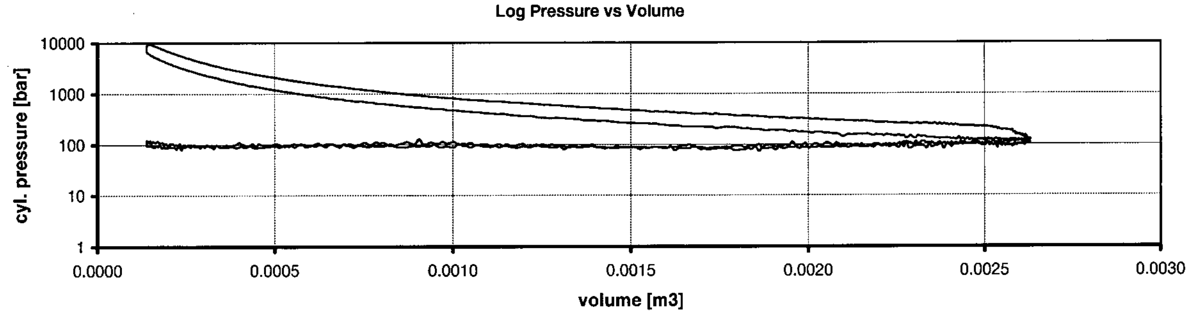
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume



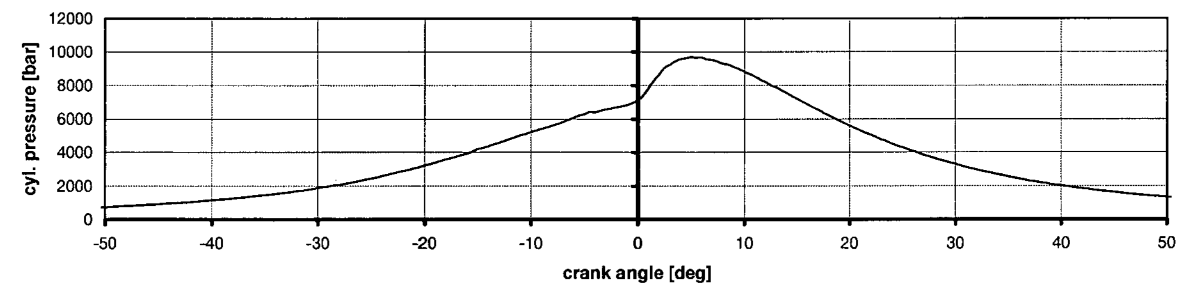
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 9687.47 |
| CA @ P_max [deg] | 5.0 |
| dP/dCA_max [bar/deg] | 890.912 |
| CA @ dP/dCA_max [deg] | 1.0 |
| IMEP [bar] | 503.20 |
| HHR_max [kJ/m^3/deg] | 17213.8 |
| IHR_max [kJ/m^3] | 88546.6 |
| 5% MFB [deg w.r.t TDC] | -3.5 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 1.5 |
| 90% MFB [deg w.r.t TDC] | 8.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.34 |
| poly-n compression corrected | 1.34 |
| poly-n expansion uncorrected | 1.36 |
| poly-n expansion corrected | 1.36 |

Comments

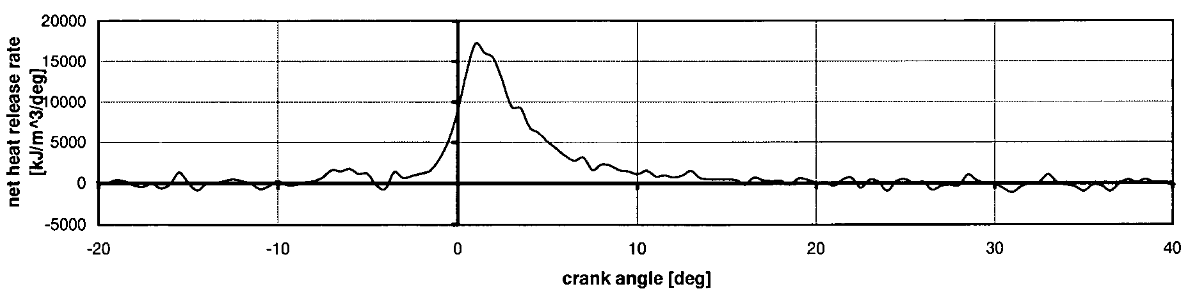
| | |
|---|---|
| Data Summary for filter: | E6 |
| Date: | 4/10/02 |
| Time: | 13:04:01 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 797.5 |
| Load - approx(%) | 25.0 |
| Power (kW) | 8.4 |
| IMEP (bar) | 5.04 |
| Pmax(bar) | 97.12 |
| Pmax location (degrees) | 365.8 |
| Diesel Flow(kg/hr) | 0.15 |
| CNG Flow(kg/hr) | 1.16 |
| Air Flow(kg/hr) | 73.2 |
| Exhaust Flow(kg/hr) | 74.5 |
| Exhaust Back Pressure (kPa) | 31.1 |
| EGR Fraction(%) | 0.0 |

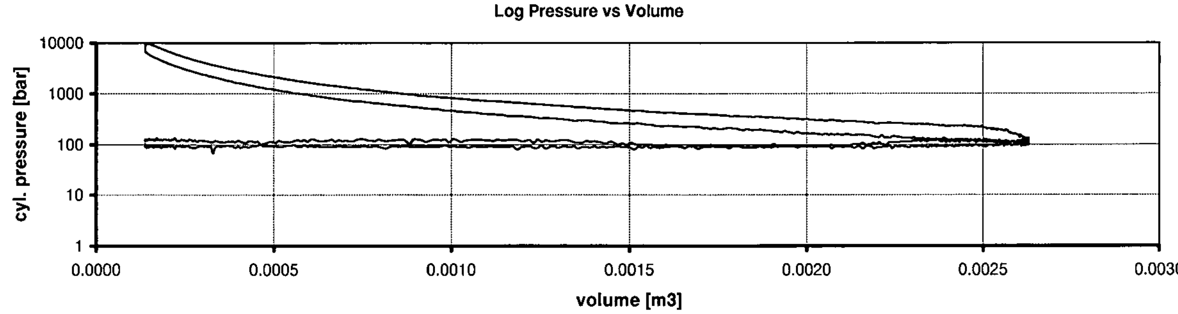
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume

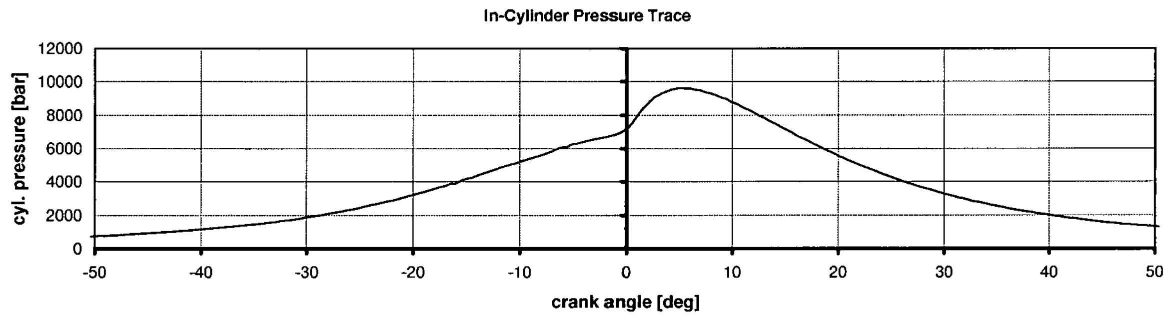


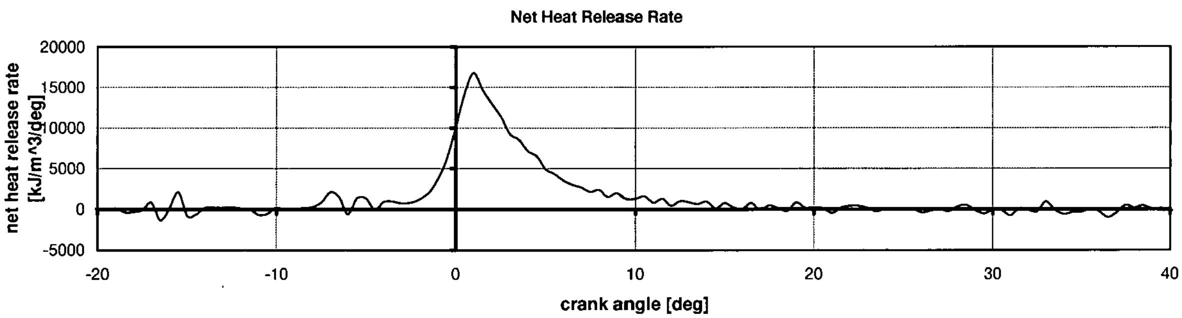
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 9621.54 |
| CA @ P_max [deg] | 5.0 |
| dP/dCA_max [bar/deg] | 866.787 |
| CA @ dP/dCA_max [deg] | 1.0 |
| IMEP [bar] | 498.56 |
| HHR_max [kJ/m^3/deg] | 16774.5 |
| IHR_max [kJ/m^3] | 87565.4 |
| 5% MFB [deg w.r.t TDC] | -3.5 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 1.5 |
| 90% MFB [deg w.r.t TDC] | 7.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.35 |
| poly-n compression corrected | 1.35 |
| poly-n expansion uncorrected | 1.34 |
| poly-n expansion corrected | 1.34 |

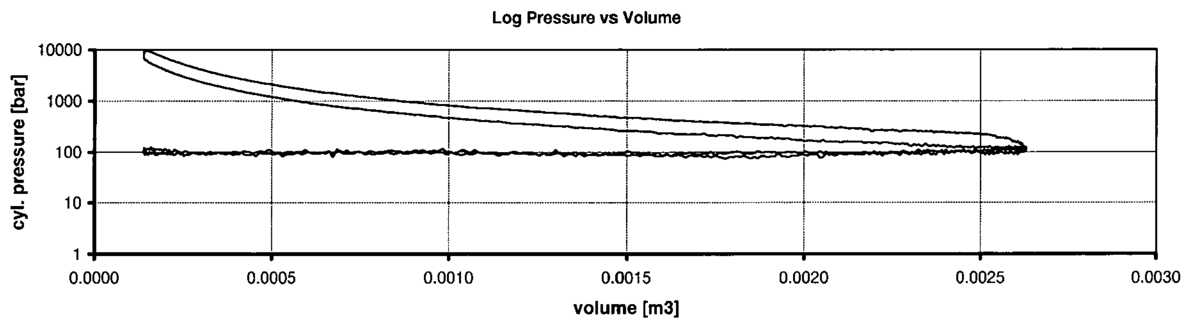
Comments

| | |
|---|---|
| Data Summary for filter: | E7 |
| Date: | 4/10/02 |
| Time: | 13:11:28 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 797.0 |
| Load - approx(%) | 25.0 |
| Power (kW) | 8.3 |
| IMEP (bar) | 4.99 |
| Pmax(bar) | 96.47 |
| Pmax location (degrees) | 365.8 |
| Diesel Flow(kg/hr) | 0.16 |
| CNG Flow(kg/hr) | 1.15 |
| Air Flow(kg/hr) | 73.7 |
| Exhaust Flow(kg/hr) | 75.0 |
| Exhaust Back Pressure (kPa) | 10.1 |
| EGR Fraction(%) | 0.0 |



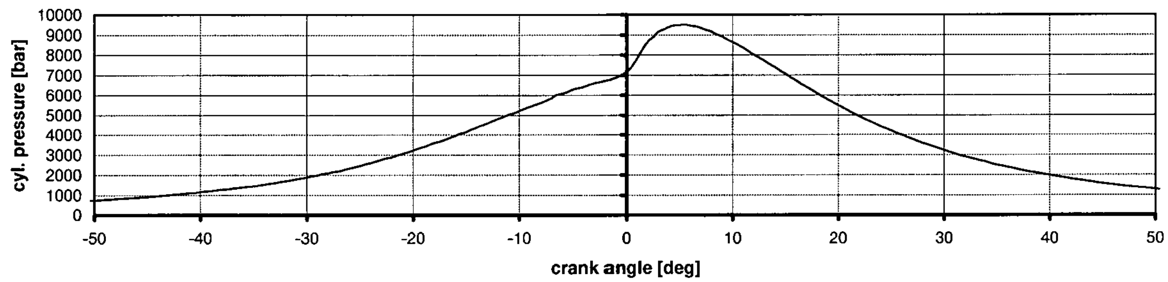
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 9517.12 |
| CA @ P_max [deg] | 5.5 |
| dP/dCA_max [bar/deg] | 866.787 |
| CA @ dP/dCA_max [deg] | 1.0 |
| IMEP [bar] | 474.25 |
| HHR_max [kJ/m^3/deg] | 16765.6 |
| IHR_max [kJ/m^3] | 83937.2 |
| 5% MFB [deg w.r.t TDC] | -3.5 |
| 10% MFB [deg w.r.t TDC] | -1.5 |
| 50% MFB [deg w.r.t TDC] | 1.5 |
| 90% MFB [deg w.r.t TDC] | 8.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.33 |
| poly-n compression corrected | 1.33 |
| poly-n expansion uncorrected | 1.39 |
| poly-n expansion corrected | 1.39 |

**Comments**

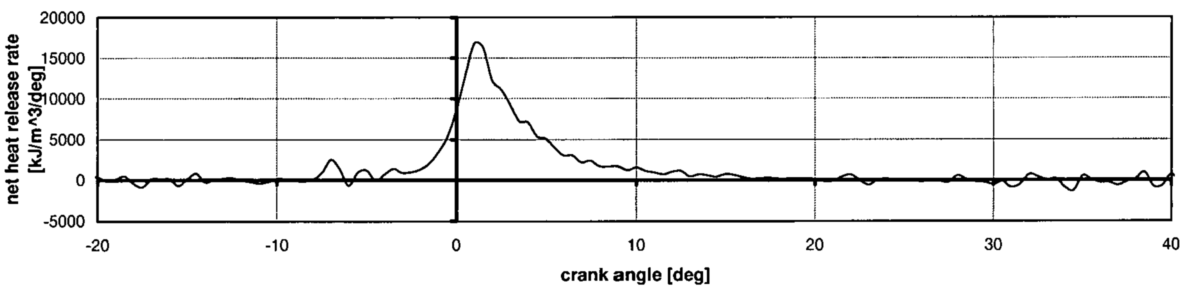
| | |
|---|---|
| Data Summary for filter: | E8 |
| Date: | 4/10/02 |
| Time: | 13:18:54 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 793.4 |
| Load - approx(%) | 25.0 |
| Power (kW) | 7.8 |
| IMEP (bar) | 4.75 |
| Pmax(bar) | 95.29 |
| Pmax location (degrees) | 365.9 |
| Diesel Flow(kg/hr) | 0.14 |
| CNG Flow(kg/hr) | 1.13 |
| Air Flow(kg/hr) | 73.1 |
| Exhaust Flow(kg/hr) | 74.4 |
| Exhaust Back Pressure (kPa) | 38.8 |
| EGR Fraction(%) | 0.0 |

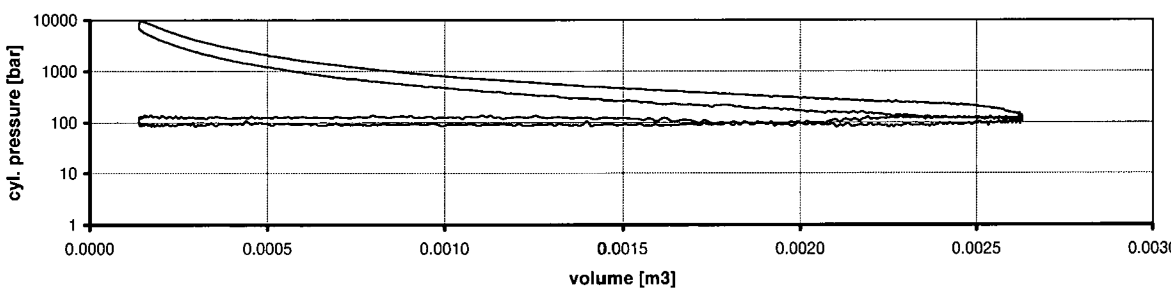
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume

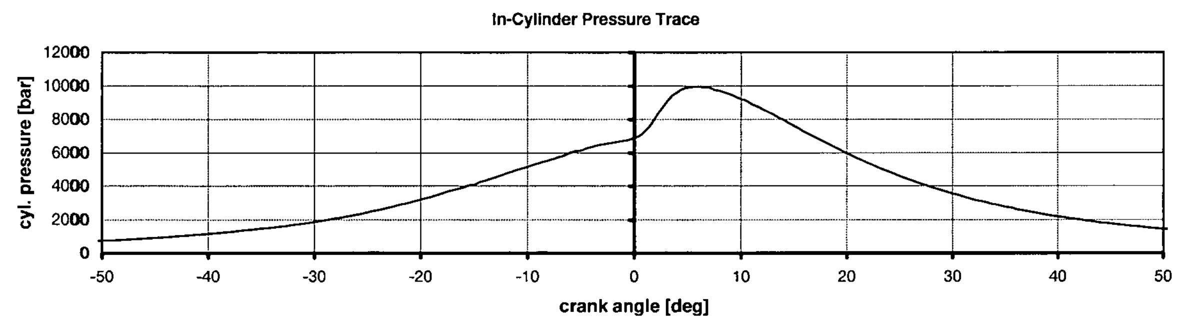


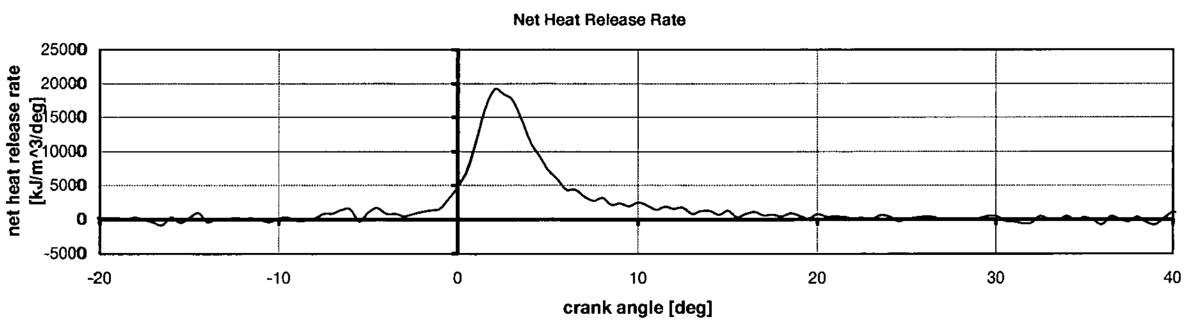
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 9958.69 |
| CA @ P_max [deg] | 6.0 |
| dP/dCA_max [bar/deg] | 949.502 |
| CA @ dP/dCA max [deg] | 2.0 |
| IMEP [bar] | 597.87 |
| HHR_max [kJ/m^3/deg] | 19125.3 |
| IHR_max [kJ/m^3] | 104273.9 |
| 5% MFB [deg w.r.t TDC] | -2.0 |
| 10% MFB [deg w.r.t TDC] | 0.0 |
| 50% MFB [deg w.r.t TDC] | 2.5 |
| 90% MFB [deg w.r.t TDC] | 10.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.32 |
| poly-n compression corrected | 1.32 |
| poly-n expansion uncorrected | 1.31 |
| poly-n expansion corrected | 1.31 |

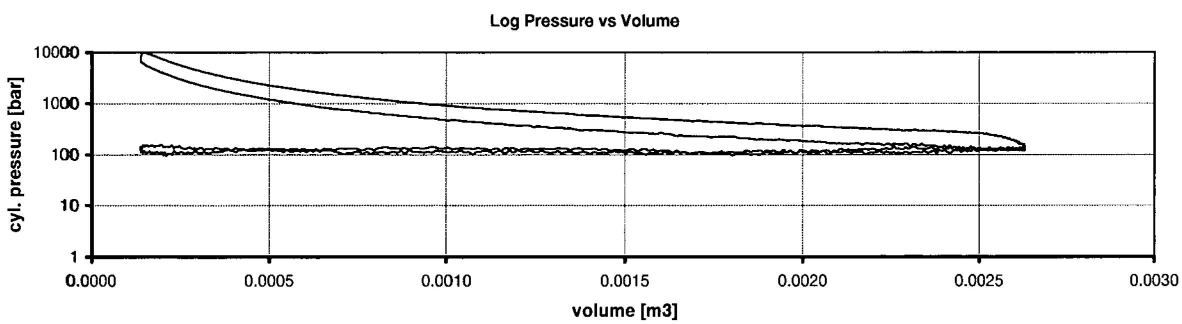
Comments

| | |
|---|---|
| Data Summary for filter: | E9 |
| Date: | 4/10/02 |
| Time: | 13:33:57 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 800.1 |
| Load - approx(%) | 25.0 |
| Power (kW) | 10.0 |
| IMEP (bar) | 5.99 |
| Pmax(bar) | 99.98 |
| Pmax location (degrees) | 366.2 |
| Diesel Flow(kg/hr) | 0.13 |
| CNG Flow(kg/hr) | 1.40 |
| Air Flow(kg/hr) | 60.4 |
| Exhaust Flow(kg/hr) | 61.9 |
| Exhaust Back Pressure (kPa) | 26.9 |
| EGR Fraction(%) | 14.9 |



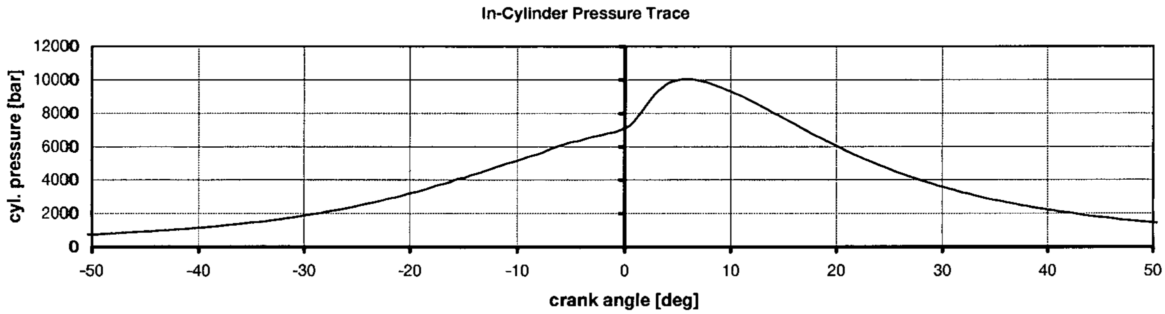



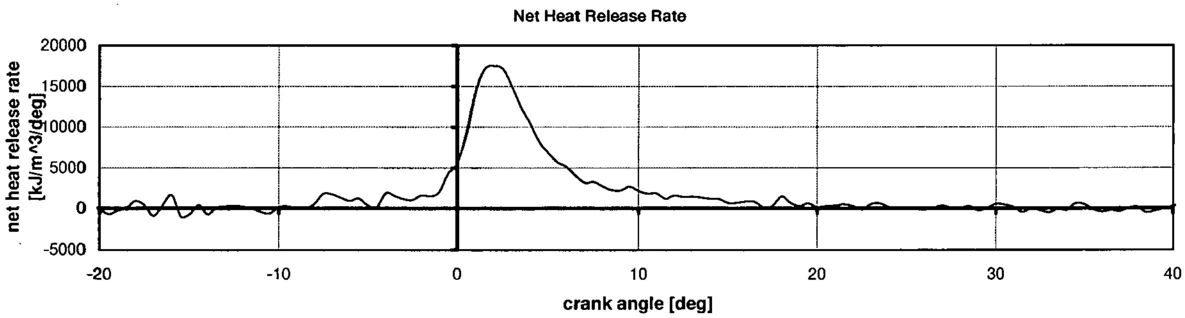
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 10029.73 |
| CA @ P max [deg] | 6.0 |
| dP/dCA_max [bar/deg] | 866.787 |
| CA @ dP/dCA_max [deg] | 1.5 |
| IMEP [bar] | 610.42 |
| HHR max [kJ/m^3/deg] | 17483.8 |
| IHR max [kJ/m^3] | 106150.1 |
| 5% MFB [deg w.r.t TDC] | -4.0 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 2.5 |
| 90% MFB [deg w.r.t TDC] | 10.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.35 |
| poly-n compression corrected | 1.35 |
| poly-n expansion uncorrected | 1.34 |
| poly-n expansion corrected | 1.34 |

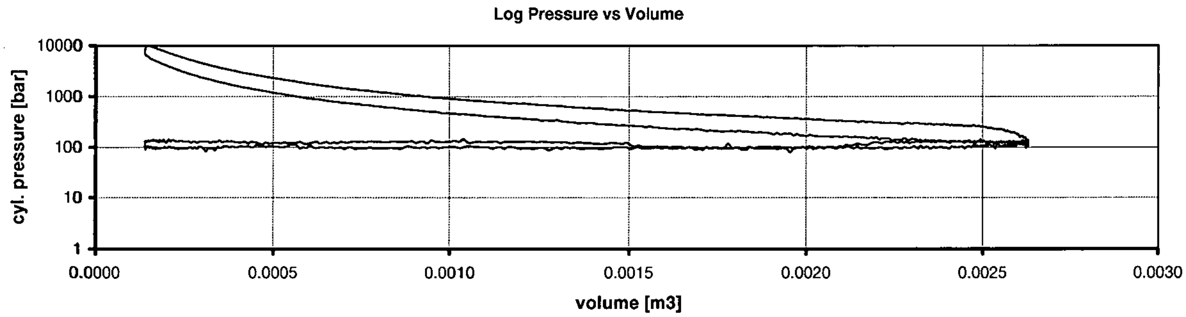
**Comments**

| | |
|---|---|
| Data Summary for filter: | E10 |
| Date: | 4/10/02 |
| Time: | 13:41:19 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 798.9 |
| Load - approx(%) | 25.0 |
| Power (kW) | 10.2 |
| IMEP (bar) | 6.11 |
| Pmax(bar) | 100.52 |
| Pmax location (degrees) | 366.4 |
| Diesel Flow(kg/hr) | 0.20 |
| CNG Flow(kg/hr) | 1.41 |
| Air Flow(kg/hr) | 60.0 |
| Exhaust Flow(kg/hr) | 61.6 |
| Exhaust Back Pressure (kPa) | 27.2 |
| EGR Fraction(%) | 14.2 |



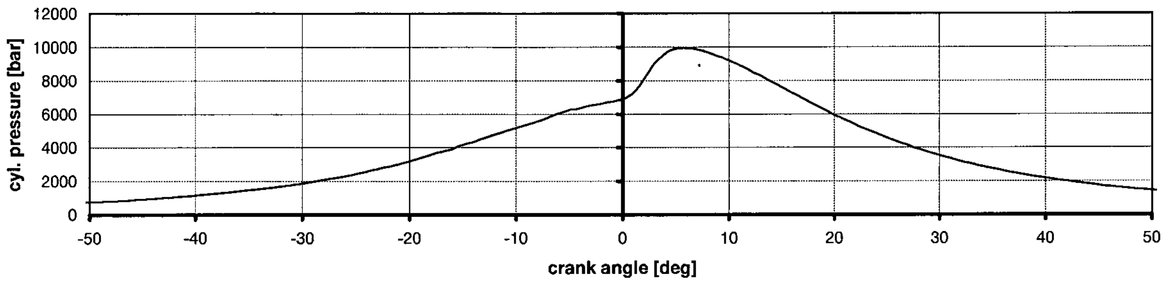
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 9948.80 |
| CA @ P_max [deg] | 6.0 |
| dP/dCA_max [bar/deg] | 940.886 |
| CA @ dP/dCA_max [deg] | 2.5 |
| IMEP [bar] | 589.99 |
| HHR_max [kJ/m^3/deg] | 19493.5 |
| IHR_max [kJ/m^3] | 102549.7 |
| 5% MFB [deg w.r.t TDC] | -2.0 |
| 10% MFB [deg w.r.t TDC] | 0.0 |
| 50% MFB [deg w.r.t TDC] | 2.5 |
| 90% MFB [deg w.r.t TDC] | 9.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.33 |
| poly-n compression corrected | 1.33 |
| poly-n expansion uncorrected | 1.33 |
| poly-n expansion corrected | 1.33 |

**Comments**

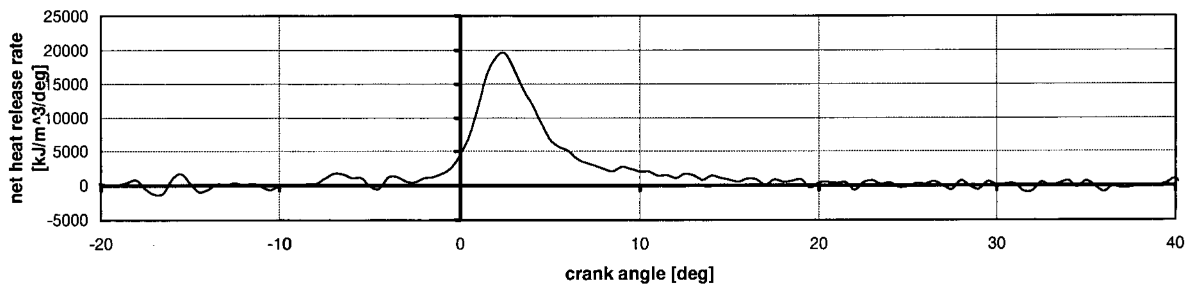
| | |
|---|---|
| Data Summary for filter: | E11 |
| Date: | 4/10/02 |
| Time: | 13:48:22 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 798.6 |
| Load - approx(%) | 25.0 |
| Power (kW) | 9.8 |
| IMEP (bar) | 5.91 |
| Pmax(bar) | 99.83 |
| Pmax location (degrees) | 366.3 |
| Diesel Flow(kg/hr) | 0.15 |
| CNG Flow(kg/hr) | 1.42 |
| Air Flow(kg/hr) | 59.9 |
| Exhaust Flow(kg/hr) | 61.4 |
| Exhaust Back Pressure (kPa) | 27.3 |
| EGR Fraction(%) | 14.9 |

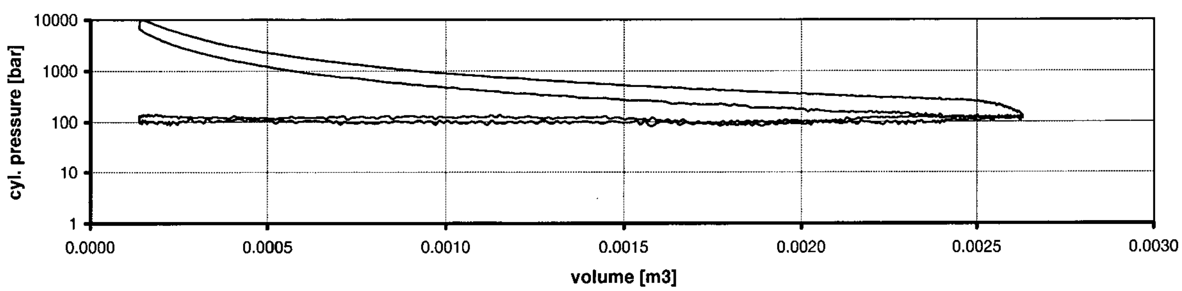
In-Cylinder Pressure Trace



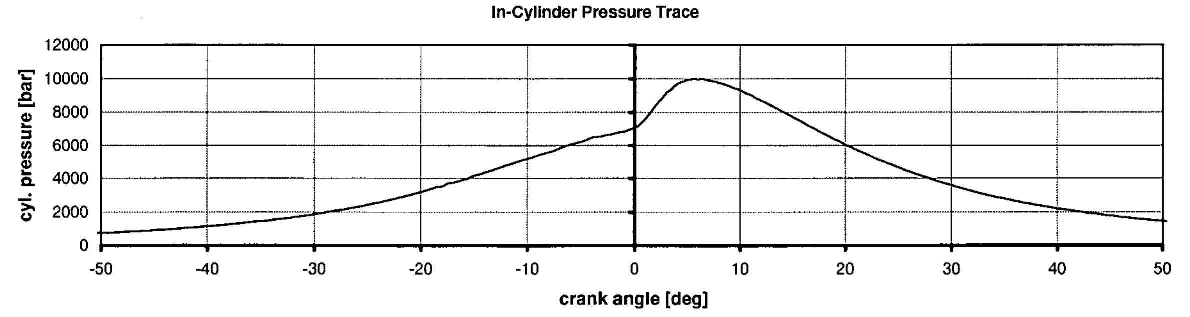

Net Heat Release Rate

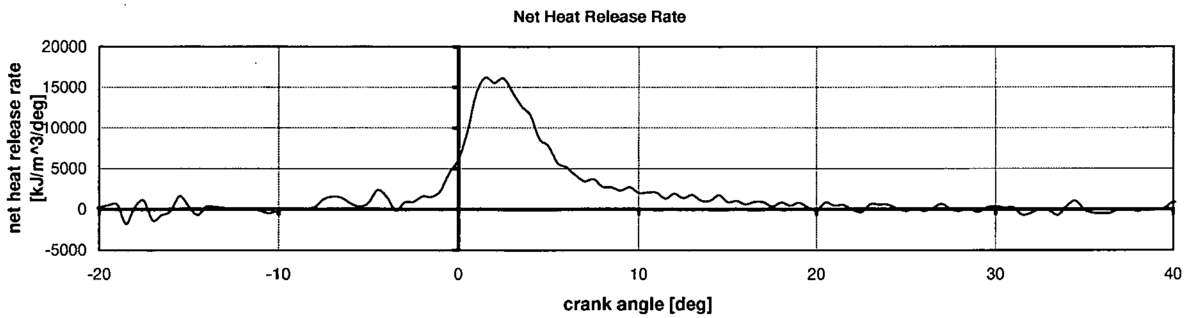


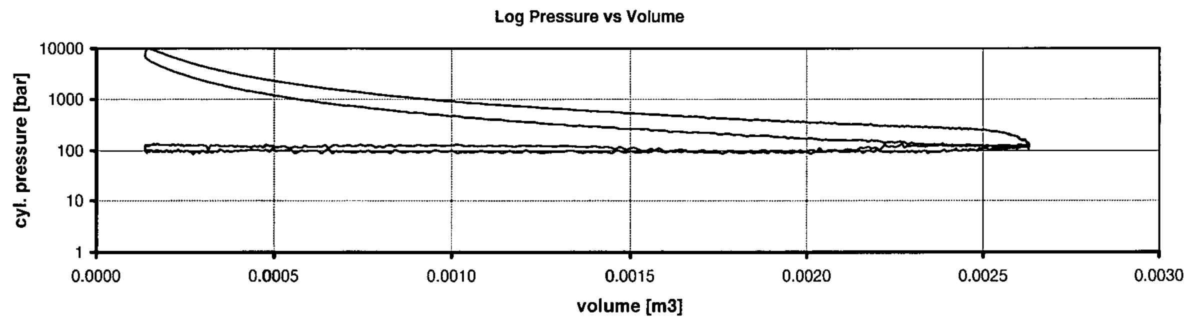

Log Pressure vs Volume



| | | | |
|---|---|---|---|
| Speed [RPM] | | Comments | |
| Torque [N-m] | | | |
| Load [%] | | Data Summary for filter: | E12 |
| P_max [deg] | 9983.36 | Date: | 4/10/02 |
| CA @ P_max [deg] | 5.5 | Time: | 13:55:41 |
| dP/dCA_max [bar/deg] | 815.090 | | |
| CA @ dP/dCA_max [deg] | 1.5 | Engine Parameters | Average |
| IMEP [bar] | 612.55 | Speed(RPM) | 799.7 |
| HHR_max [kJ/m^3/deg] | 16202.0 | Load - approx(%) | 25.0 |
| IHR_max [kJ/m^3] | 106578.3 | Power (kW) | 10.2 |
| 5% MFB [deg w.r.t TDC] | -3.5 | IMEP (bar) | 6.13 |
| 10% MFB [deg w.r.t TDC] | -1.0 | Pmax(bar) | 100.07 |
| 50% MFB [deg w.r.t TDC] | 2.5 | Pmax location (degrees) | 366.4 |
| 90% MFB [deg w.r.t TDC] | 10.5 | Diesel Flow(kg/hr) | 0.18 |
| Assumed poly-n during comprn. | 1.37 | CNG Flow(kg/hr) | 1.42 |
| zero-level. pr. offset [bar] | 0.000 | Air Flow(kg/hr) | 59.8 |
| poly-n compression uncorrected | 1.35 | Exhaust Flow(kg/hr) | 61.4 |
| poly-n compression corrected | 1.35 | Exhaust Back Pressure (kPa) | 27.4 |
| poly-n expansion uncorrected | 1.35 | EGR Fraction(%) | 14.3 |
| poly-n expansion corrected | 1.35 | | |



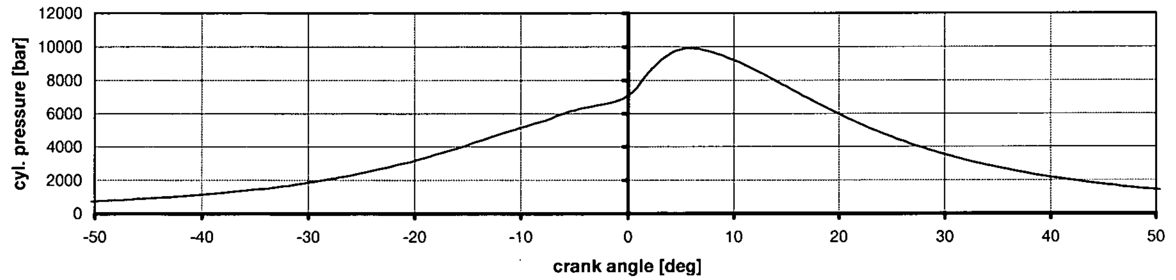
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 9911.32 |
| CA @ P_max [deg] | 5.5 |
| dP/dCA_max [bar/deg] | 816.813 |
| CA @ dP/dCA_max [deg] | 1.0 |
| IMEP [bar] | 598.92 |
| HHR_max [kJ/m^3/deg] | 16094.6 |
| IHR_max [kJ/m^3] | 103844.1 |
| 5% MFB [deg w.r.t TDC] | -2.5 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 2.5 |
| 90% MFB [deg w.r.t TDC] | 10.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.34 |
| poly-n compression corrected | 1.34 |
| poly-n expansion uncorrected | 1.34 |
| poly-n expansion corrected | 1.34 |

Comments

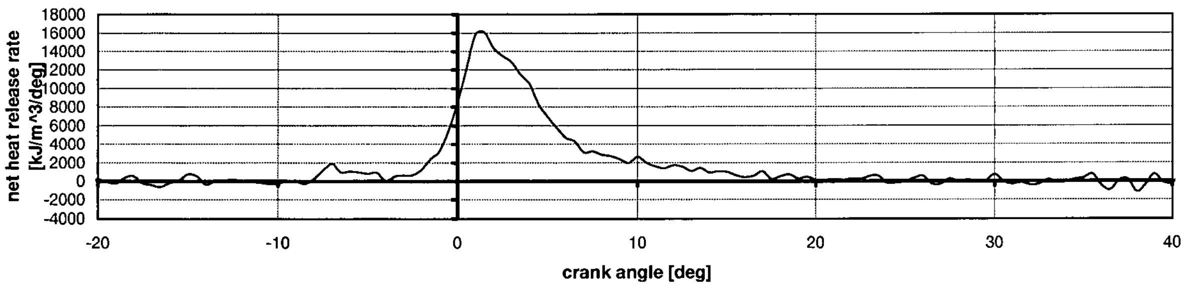
| Data Summary for filter: | E13 |
|---|---|
| Date: | 4/10/02 |
| Time: | 14:08:14 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 801.4 |
| Load - approx(%) | 25.0 |
| Power (kW) | 10.0 |
| IMEP (bar) | 6.00 |
| Pmax(bar) | 99.41 |
| Pmax location (degrees) | 366.2 |
| Diesel Flow(kg/hr) | 0.14 |
| CNG Flow(kg/hr) | 1.43 |
| Air Flow(kg/hr) | 72.8 |
| Exhaust Flow(kg/hr) | 74.4 |
| Exhaust Back Pressure (kPa) | 12.3 |
| EGR Fraction(%) | 0.0 |

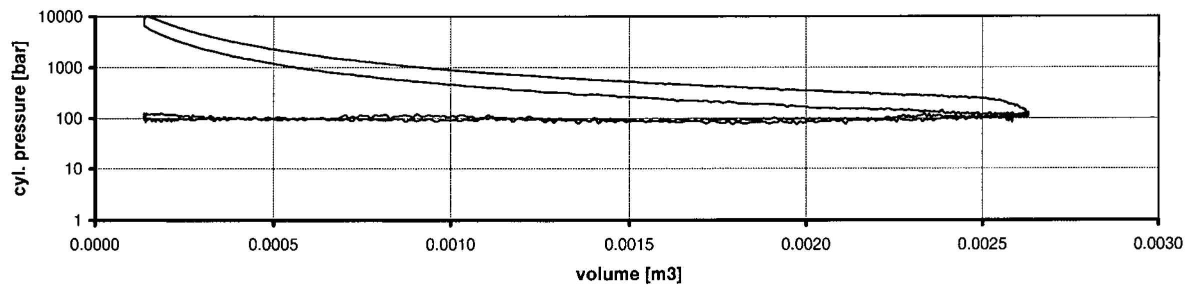
**In-Cylinder Pressure Trace**




**Net Heat Release Rate**




**Log Pressure vs Volume**

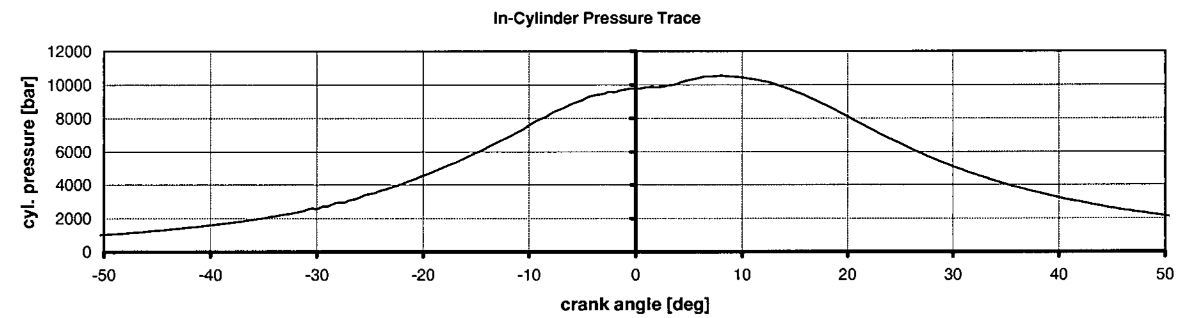


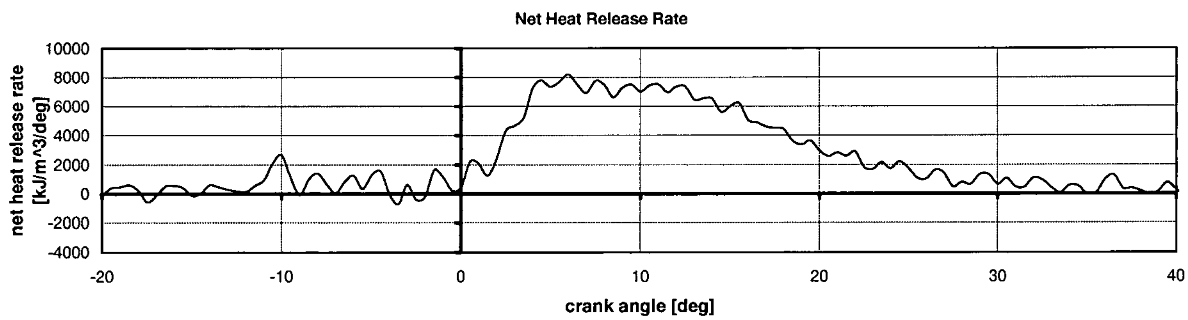
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 10536.77 |
| CA @ P max [deg] | 8.0 |
| dP/dCA max [bar/deg] | 422.193 |
| CA @ dP/dCA max [deg] | -10.0 |
| IMEP [bar] | 845.22 |
| HHR max [kJ/m^3/deg] | 8192.6 |
| IHR max [kJ/m^3] | 151758.2 |
| 5% MFB [deg w.r.t TDC] | -10.5 |
| 10% MFB [deg w.r.t TDC] | 0.5 |
| 50% MFB [deg w.r.t TDC] | 10.0 |
| 90% MFB [deg w.r.t TDC] | 23.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.38 |
| poly-n compression corrected | 1.38 |
| poly-n expansion uncorrected | 1.33 |
| poly-n expansion corrected | 1.33 |

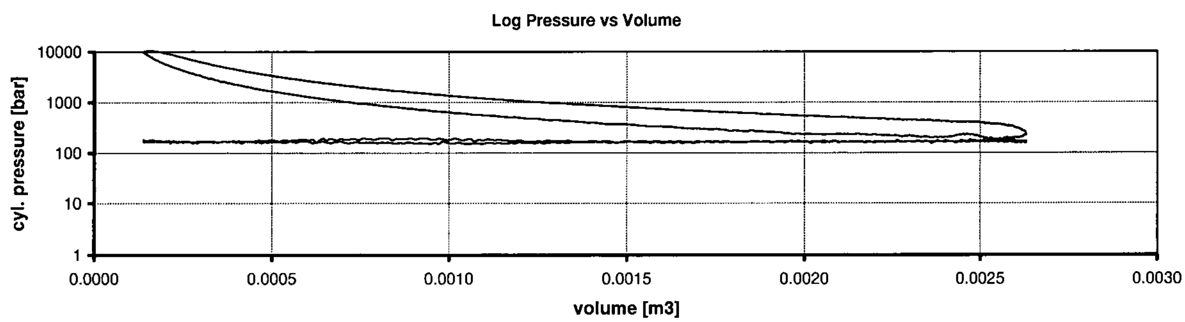
**Comments**

| | |
|---|---|
| Data Summary for filter: | A14 |
| Date: | 3/7/02 |
| Time: | 11:03:01 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1610.3 |
| Load - approx(%) | 40.0 |
| Power (kW) | 28.4 |
| IMEP (bar) | 8.46 |
| Pmax(bar) | 105.73 |
| Pmax location (degrees) | 368.1 |
| Diesel Flow(kg/hr) | 0.32 |
| CNG Flow(kg/hr) | 3.84 |
| Air Flow(kg/hr) | 210.0 |
| Exhaust Flow(kg/hr) | 214.2 |
| Exhaust Back Pressure (kPa) | 11.3 |
| EGR Fraction(%) | 0.0 |



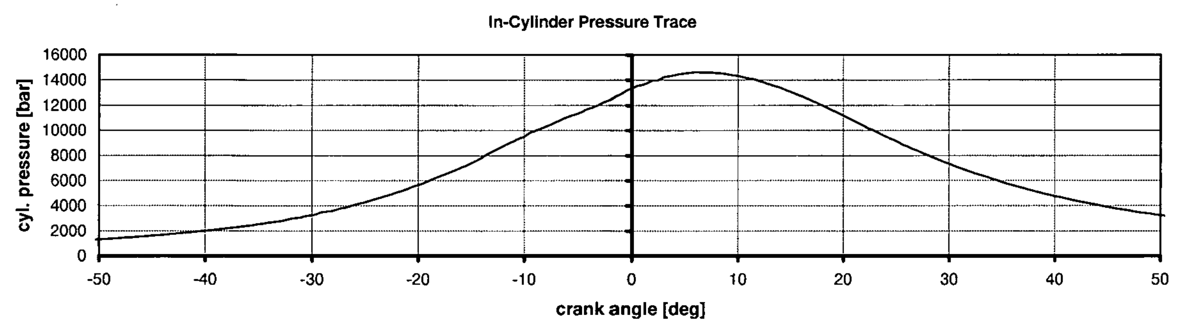



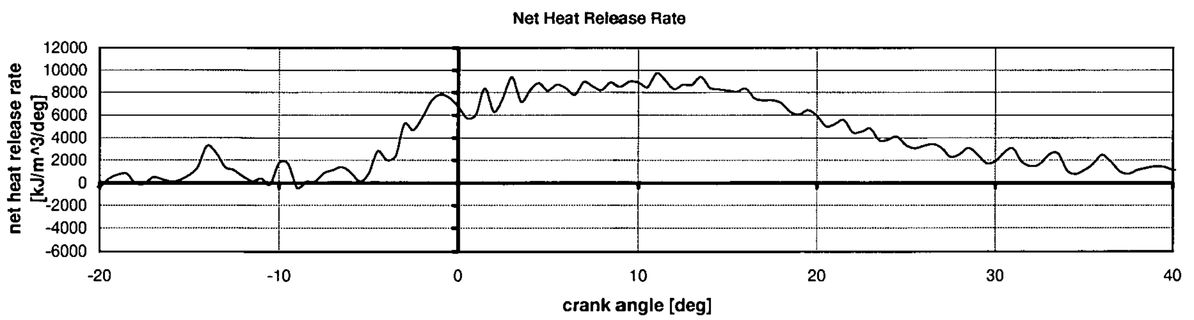
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 14630.38 |
| CA @ P_max [deg] | 6.0 |
| dP/dCA_max [bar/deg] | 504.908 |
| CA @ dP/dCA_max [deg] | -14.0 |
| IMEP [bar] | 1441.93 |
| HHR_max [kJ/m^3/deg] | 9750.7 |
| IHR_max [kJ/m^3] | 264933.1 |
| 5% MFB [deg w.r.t TDC] | -5.0 |
| 10% MFB [deg w.r.t TDC] | -2.0 |
| 50% MFB [deg w.r.t TDC] | 11.0 |
| 90% MFB [deg w.r.t TDC] | 31.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.34 |
| poly-n compression corrected | 1.34 |
| poly-n expansion uncorrected | 1.28 |
| poly-n expansion corrected | 1.28 |

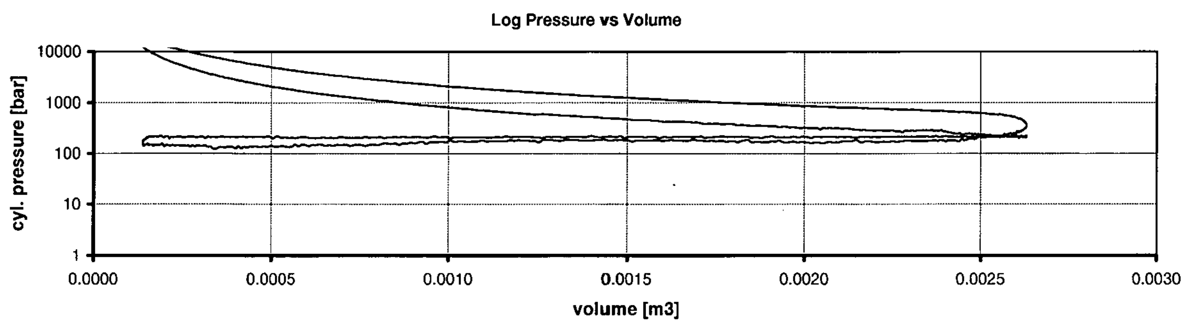
**Comments**

| | |
|---|---|
| Data Summary for filter: | A15 |
| Date: | 3/7/02 |
| Time: | 11:41:03 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1406.3 |
| Load - approx(%) | 85.0 |
| Power (kW) | 42.3 |
| IMEP (bar) | 14.44 |
| Pmax(bar) | 146.55 |
| Pmax location (degrees) | 366.9 |
| Diesel Flow(kg/hr) | 0.28 |
| CNG Flow(kg/hr) | 6.26 |
| Air Flow(kg/hr) | 273.4 |
| Exhaust Flow(kg/hr) | 279.9 |
| Exhaust Back Pressure (kPa) | 10.6 |
| EGR Fraction(%) | 0.0 |



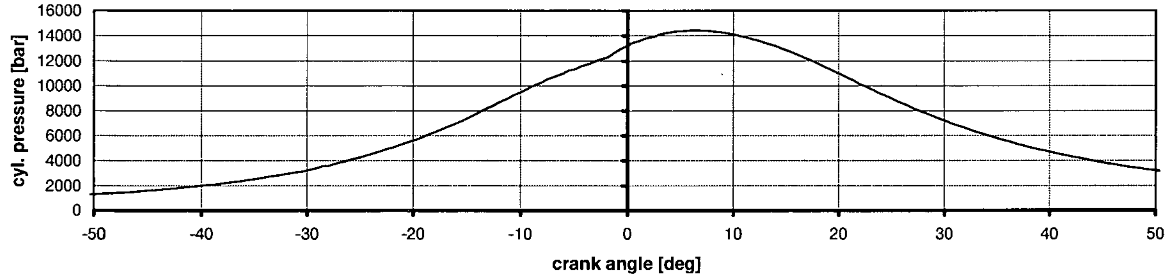
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 14445.84 |
| CA @ P max [deg] | 6.0 |
| dP/dCA_max [bar/deg] | 541.096 |
| CA @ dP/dCA max [deg] | -1.5 |
| IMEP [bar] | 1418.34 |
| HHR max [kJ/m^3/deg] | 9014.6 |
| IHR_max [kJ/m^3] | 263196.7 |
| 5% MFB [deg w.r.t TDC] | -8.5 |
| 10% MFB [deg w.r.t TDC] | -2.0 |
| 50% MFB [deg w.r.t TDC] | 11.5 |
| 90% MFB [deg w.r.t TDC] | 33.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.34 |
| poly-n compression corrected | 1.34 |
| poly-n expansion uncorrected | 1.26 |
| poly-n expansion corrected | 1.26 |

Comments

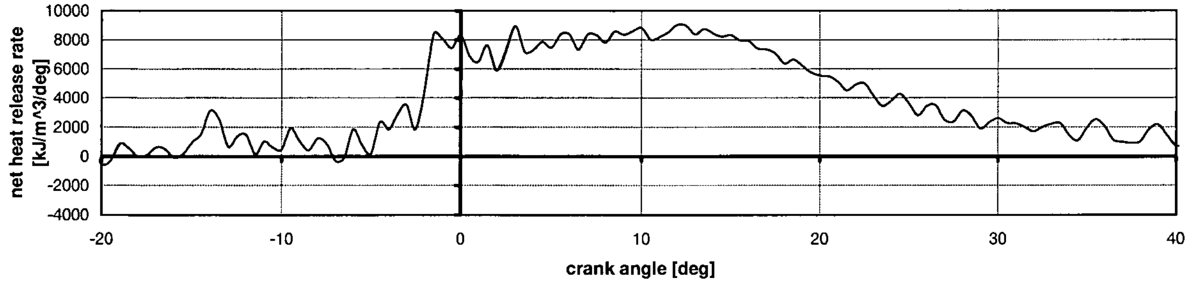
| | |
|---|---|
| Data Summary for filter: | A16 |
| Date: | 3/7/02 |
| Time: | 11:57:57 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1409.0 |
| Load - approx(%) | 85.0 |
| Power (kW) | 41.7 |
| IMEP (bar) | 14.20 |
| Pmax(bar) | 144.63 |
| Pmax location (degrees) | 366.9 |
| Diesel Flow(kg/hr) | 0.28 |
| CNG Flow(kg/hr) | 6.19 |
| Air Flow(kg/hr) | 258.0 |
| Exhaust Flow(kg/hr) | 264.5 |
| Exhaust Back Pressure (kPa) | 144.2 |
| EGR Fraction(%) | 8.5 |

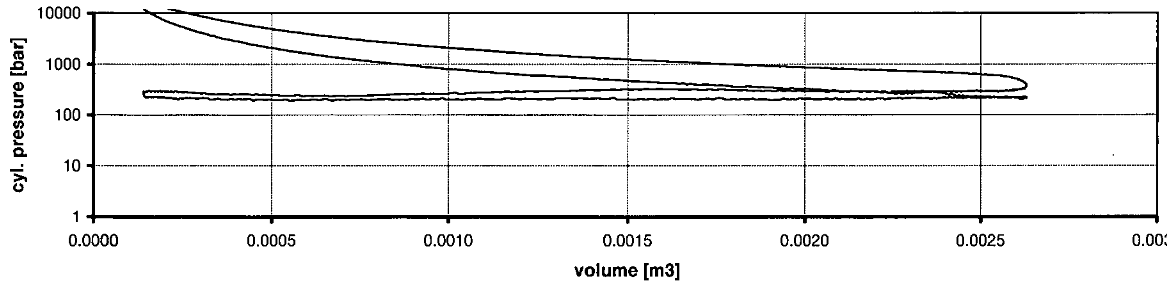
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume

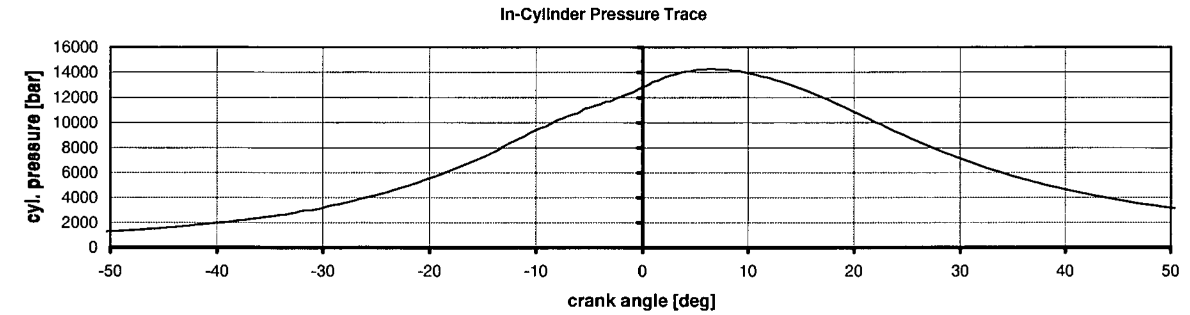


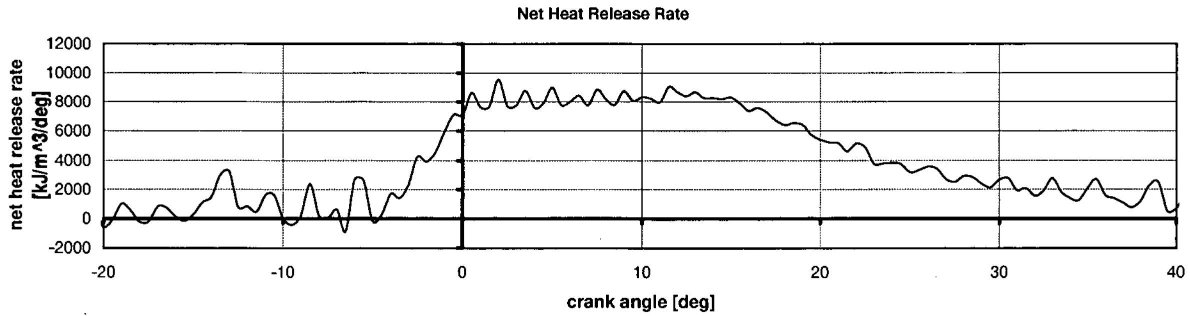
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 14269.67 |
| CA @ P max [deg] | 6.5 |
| dP/dCA_max [bar/deg] | 510.078 |
| CA @ dP/dCA max [deg] | -13.0 |
| IMEP [bar] | 1410.32 |
| HHR max [kJ/m^3/deg] | 9536.9 |
| IHR max [kJ/m^3] | 261141.3 |
| 5% MFB [deg w.r.t TDC] | -6.0 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 11.5 |
| 90% MFB [deg w.r.t TDC] | 34.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.34 |
| poly-n compression corrected | 1.34 |
| poly-n expansion uncorrected | 1.25 |
| poly-n expansion corrected | 1.25 |

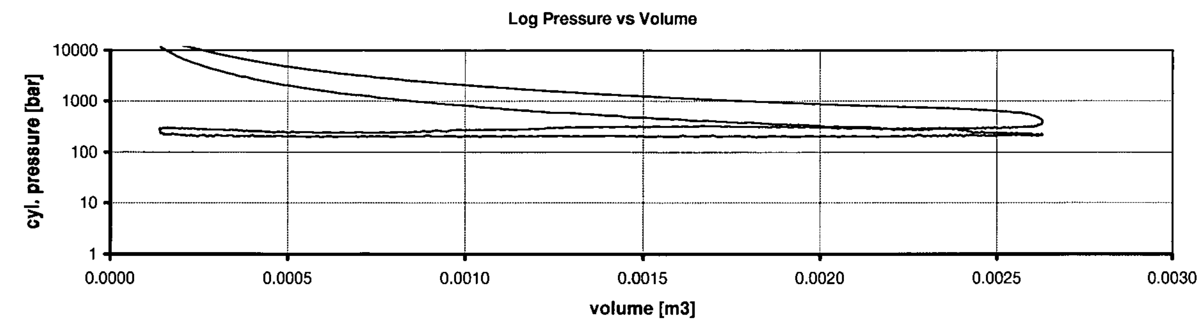
**Comments**

| Data Summary for filter: | A17 |
|---|---|
| Date: | 3/7/02 |
| Time: | 12:14:00 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1407.9 |
| Load - approx(%) | 85.0 |
| Power (kW) | 41.4 |
| IMEP (bar) | 14.12 |
| Pmax(bar) | 142.90 |
| Pmax location (degrees) | 367.0 |
| Diesel Flow(kg/hr) | 0.28 |
| CNG Flow(kg/hr) | 6.23 |
| Air Flow(kg/hr) | 229.3 |
| Exhaust Flow(kg/hr) | 235.8 |
| Exhaust Back Pressure (kPa) | 142.5 |
| EGR Fraction(%) | 16.5 |



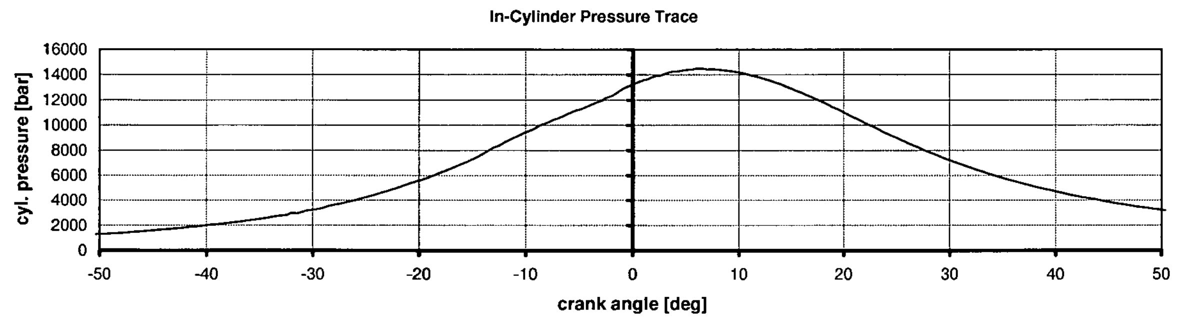



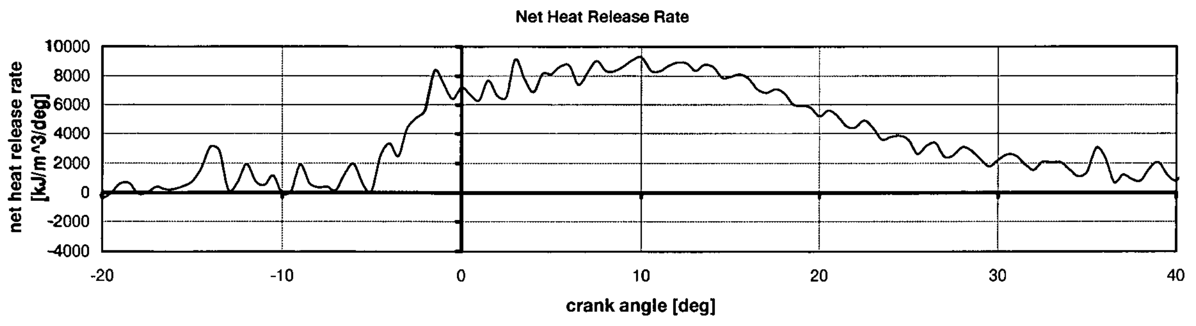
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P max [deg] | 14482.80 |
| CA @ P max [deg] | 6.0 |
| dP/dCA max [bar/deg] | 537.649 |
| CA @ dP/dCA max [deg] | -1.5 |
| IMEP [bar] | 1425.50 |
| HHR max [kJ/m^3/deg] | 9276.4 |
| IHR max [kJ/m^3] | 266563.1 |
| 5% MFB [deg w.r.t TDC] | -9.5 |
| 10% MFB [deg w.r.t TDC] | -2.5 |
| 50% MFB [deg w.r.t TDC] | 11.0 |
| 90% MFB [deg w.r.t TDC] | 33.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.34 |
| poly-n compression corrected | 1.34 |
| poly-n expansion uncorrected | 1.28 |
| poly-n expansion corrected | 1.28 |

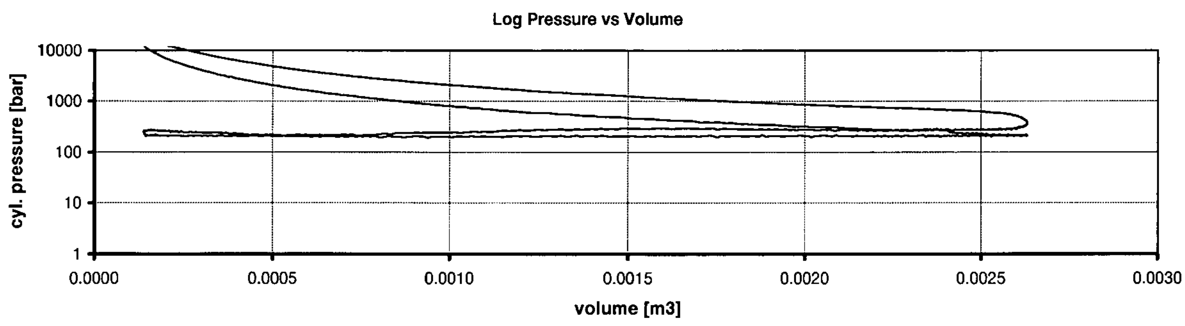
Comments

| Data Summary for filter: | A18 |
|---|---|
| Date: | 3/7/02 |
| Time: | 12:24:01 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1415.6 |
| Load - approx(%) | 85.0 |
| Power (kW) | 42.1 |
| IMEP (bar) | 14.27 |
| Pmax(bar) | 145.02 |
| Pmax location (degrees) | 366.9 |
| Diesel Flow(kg/hr) | 0.28 |
| CNG Flow(kg/hr) | 6.08 |
| Air Flow(kg/hr) | 278.7 |
| Exhaust Flow(kg/hr) | 285.0 |
| Exhaust Back Pressure (kPa) | 123.2 |
| EGR Fraction(%) | 0.0 |



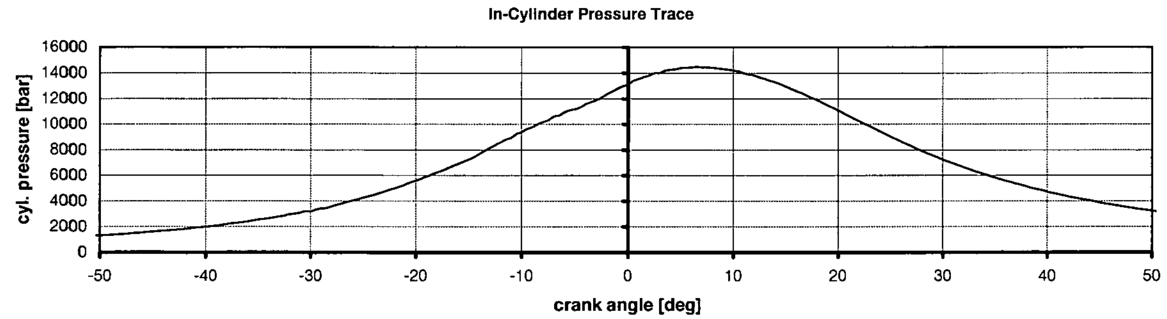



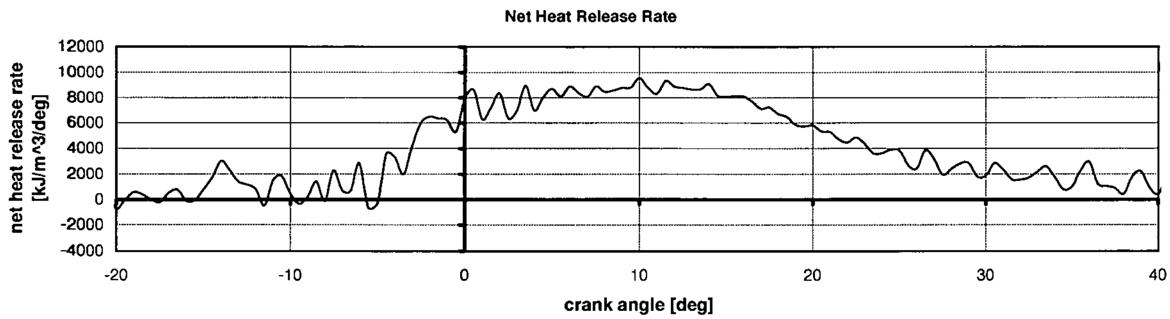



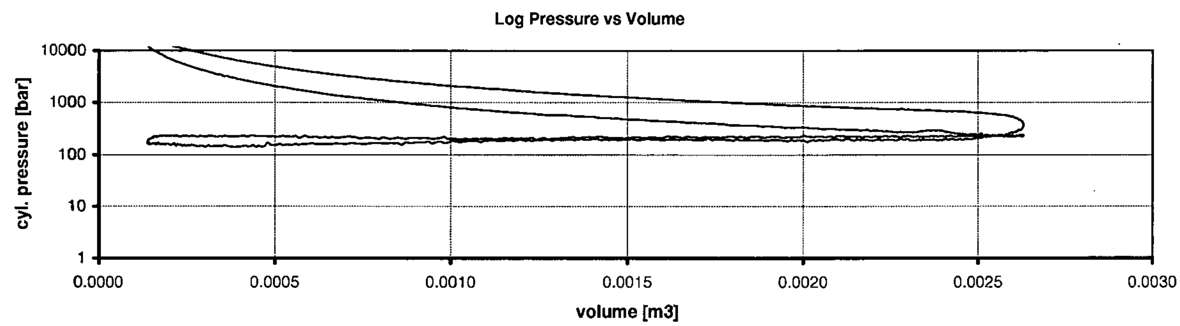
| | | Comments |
|---|---|---|
| Speed [RPM] | | |
| Torque [N-m] | | |
| Load [%] | | |
| P_max [deg] | 14490.41 | |
| CA @ P_max [deg] | 6.5 | |
| dP/dCA_max [bar/deg] | 489.399 | |
| CA @ dP/dCA_max [deg] | -14.0 | |
| IMEP [bar] | 1437.03 | |
| HHR_max [kJ/m^3/deg] | 9543.8 | |
| IHR_max [kJ/m^3] | 268859.7 | |
| 5% MFB [deg w.r.t TDC] | -6.5 | |
| 10% MFB [deg w.r.t TDC] | -2.0 | |
| 50% MFB [deg w.r.t TDC] | 11.5 | |
| 90% MFB [deg w.r.t TDC] | 34.5 | |
| Assumed poly-n during comprn. | 1.37 | |
| zero-level pr. offset [bar] | 0.000 | |
| poly-n compression uncorrected | 1.33 | |
| poly-n compression corrected | 1.33 | |
| poly-n expansion uncorrected | 1.26 | |
| poly-n expansion corrected | 1.26 | |

| Data Summary for filter: | A19 |
|---|---|
| Date: | 3/7/02 |
| Time: | 12:30:31 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 1433.3 |
| Load - approx(%) | 85.0 |
| Power (kW) | 43.0 |
| IMEP (bar) | 14.39 |
| Pmax(bar) | 145.01 |
| Pmax location (degrees) | 367.1 |
| Diesel Flow(kg/hr) | 0.28 |
| CNG Flow(kg/hr) | 6.39 |
| Air Flow(kg/hr) | 278.8 |
| Exhaust Flow(kg/hr) | 285.4 |
| Exhaust Back Pressure (kPa) | 11.7 |
| EGR Fraction(%) | 0.0 |



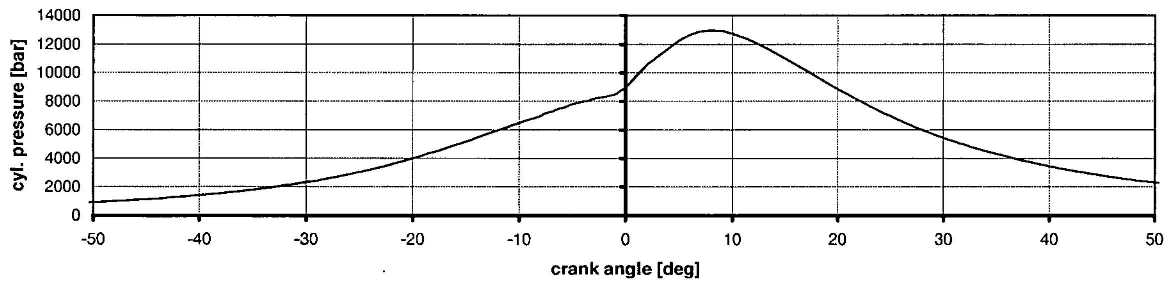



| | | Comments |
|---|---|---|
| Speed [RPM] | | |
| Torque [N-m] | | |
| Load [%] | | |
| P_max [deg] | 12973.86 | |
| CA @ P_max [deg] | 8.0 | |
| dP/dCA_max [bar/deg] | 859.894 | |
| CA @ dP/dCA_max [deg] | 0.5 | |
| IMEP [bar] | 1125.81 | |
| HHR_max [kJ/m^3/deg] | 16619.4 | |
| IHR_max [kJ/m^3] | 196610.4 | |
| 5% MFB [deg w.r.t TDC] | -2.0 | |
| 10% MFB [deg w.r.t TDC] | -0.5 | |
| 50% MFB [deg w.r.t TDC] | 5.0 | |
| 90% MFB [deg w.r.t TDC] | 18.5 | |
| Assumed poly-n during comprn. | 1.37 | |
| zero-level. pr. offset [bar] | 0.000 | |
| poly-n compression uncorrected | 1.38 | |
| poly-n compression corrected | 1.38 | |
| poly-n expansion uncorrected | 1.33 | |
| poly-n expansion corrected | 1.33 | |

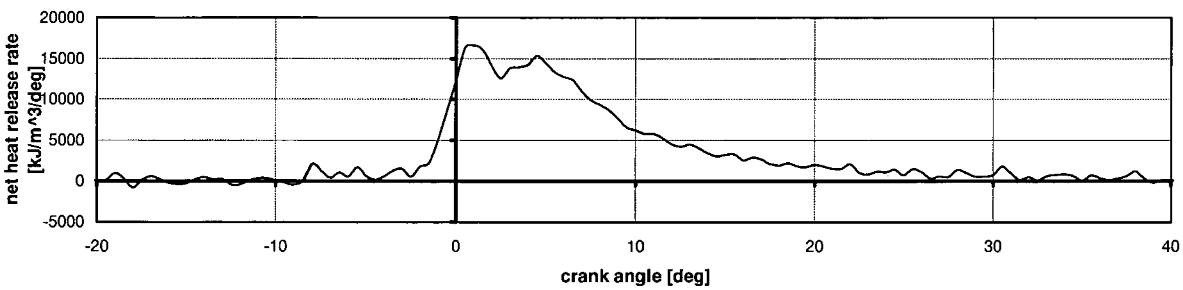
| Data Summary for filter: | A20 |
|---|---|
| Date: | 3/7/02 |
| Time: | 12:53:49 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 810.5 |
| Load - approx(%) | 75.0 |
| Power (kW) | 19.0 |
| IMEP (bar) | 11.27 |
| Pmax(bar) | 129.91 |
| Pmax location (degrees) | 368.7 |
| Diesel Flow(kg/hr) | 0.21 |
| CNG Flow(kg/hr) | 2.89 |
| Air Flow(kg/hr) | 92.1 |
| Exhaust Flow(kg/hr) | 95.2 |
| Exhaust Back Pressure (kPa) | 11.3 |
| EGR Fraction(%) | 0.0 |

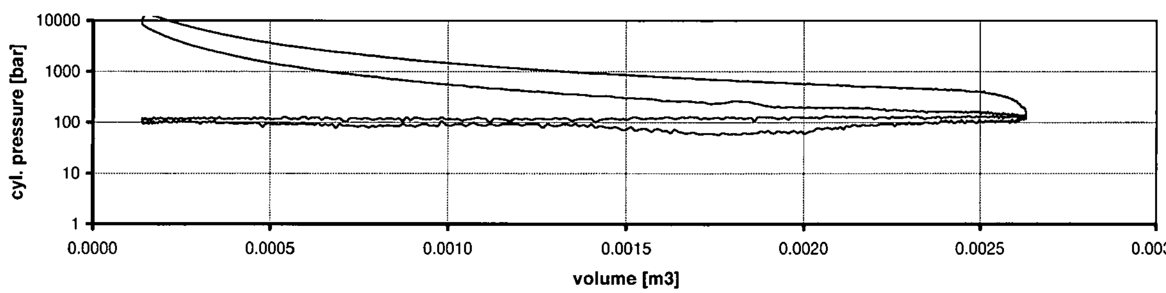
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume



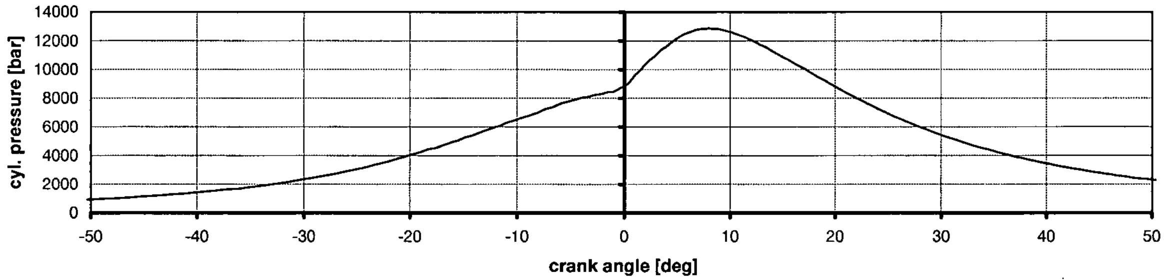
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 12879.13 |
| CA @ P_max [deg] | 8.0 |
| dP/dCA_max [bar/deg] | 801.304 |
| CA @ dP/dCA_max [deg] | 1.0 |
| IMEP [bar] | 1113.13 |
| HHR max [kJ/m^3/deg] | 16308.3 |
| IHR max [kJ/m^3] | 195292.2 |
| 5% MFB [deg w.r.t TDC] | -1.5 |
| 10% MFB [deg w.r.t TDC] | 0.0 |
| 50% MFB [deg w.r.t TDC] | 5.0 |
| 90% MFB [deg w.r.t TDC] | 20.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.34 |
| poly-n compression corrected | 1.34 |
| poly-n expansion uncorrected | 1.31 |
| poly-n expansion corrected | 1.31 |

**Comments**

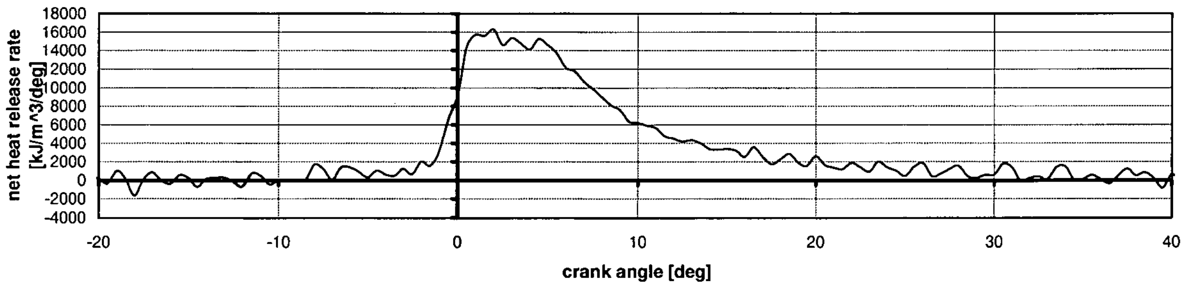
| | |
|---|---|
| Data Summary for filter: | A21 |
| Date: | 3/7/02 |
| Time: | 13:16:59 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 806.6 |
| Load - approx(%) | 85.0 |
| Power (kW) | 18.7 |
| IMEP (bar) | 11.15 |
| Pmax(bar) | 128.84 |
| Pmax location (degrees) | 368.5 |
| Diesel Flow(kg/hr) | 0.21 |
| CNG Flow(kg/hr) | 2.88 |
| Air Flow(kg/hr) | 82.0 |
| Exhaust Flow(kg/hr) | 85.1 |
| Exhaust Back Pressure (kPa) | 77.6 |
| EGR Fraction(%) | 8.7 |

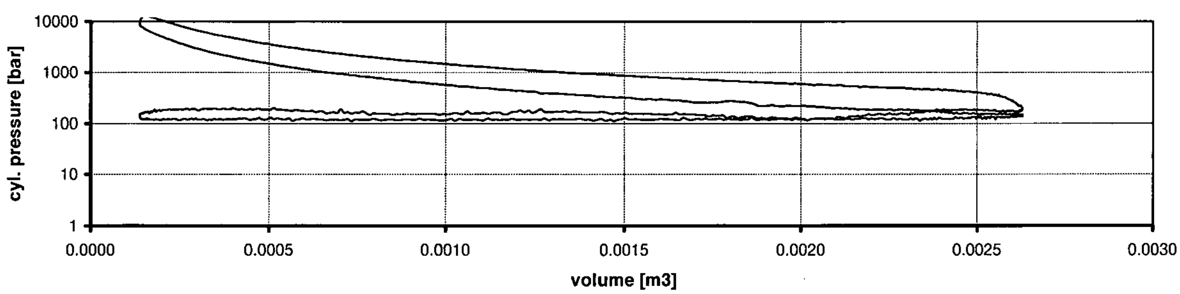
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume

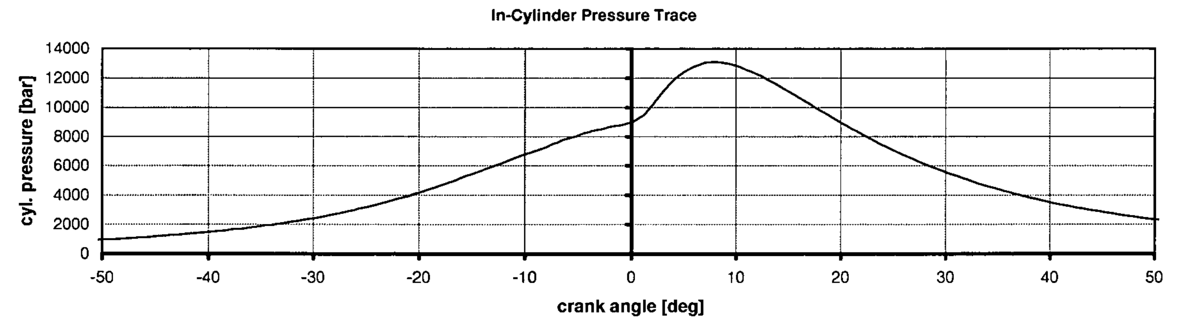


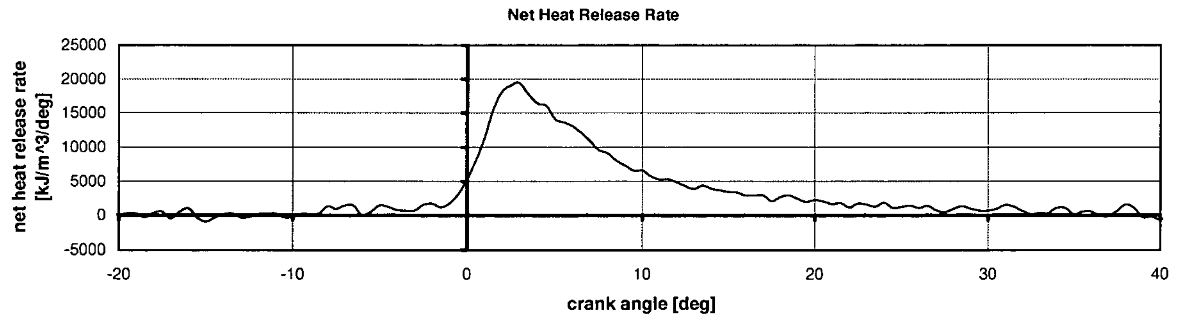
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 13092.36 |
| CA @ P_max [deg] | 8.0 |
| dP/dCA_max [bar/deg] | 892.636 |
| CA @ dP/dCA_max [deg] | 2.5 |
| IMEP [bar] | 1125.01 |
| HHR_max [kJ/m^3/deg] | 19440.1 |
| IHR_max [kJ/m^3] | 198010.1 |
| 5% MFB [deg w.r.t TDC] | -1.5 |
| 10% MFB [deg w.r.t TDC] | 0.5 |
| 50% MFB [deg w.r.t TDC] | 5.0 |
| 90% MFB [deg w.r.t TDC] | 20.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.35 |
| poly-n compression corrected | 1.35 |
| poly-n expansion uncorrected | 1.31 |
| poly-n expansion corrected | 1.31 |

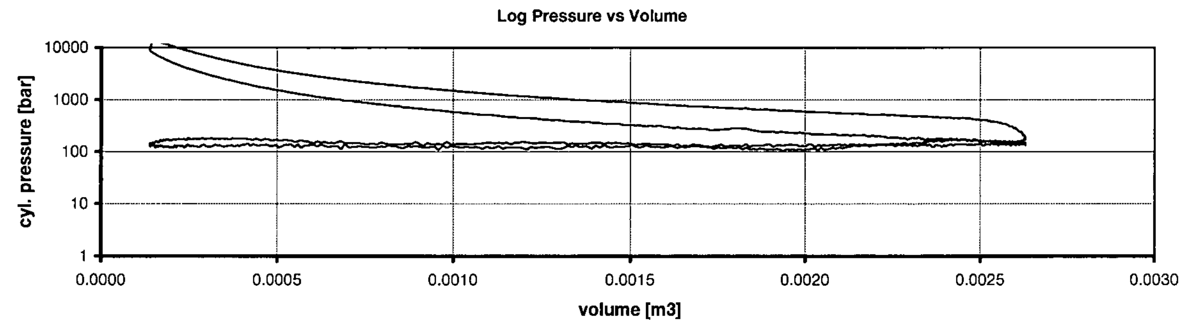
**Comments**

| Data Summary for filter: | A22 |
|---|---|
| Date: | 3/7/02 |
| Time: | 13:30:30 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 806.4 |
| Load - approx(%) | 75.0 |
| Power (kW) | 18.9 |
| IMEP (bar) | 11.26 |
| Pmax(bar) | 131.10 |
| Pmax location (degrees) | 368.4 |
| Diesel Flow(kg/hr) | 0.21 |
| CNG Flow(kg/hr) | 2.90 |
| Air Flow(kg/hr) | 76.7 |
| Exhaust Flow(kg/hr) | 79.8 |
| Exhaust Back Pressure (kPa) | 66.9 |
| EGR Fraction(%) | 17.5 |



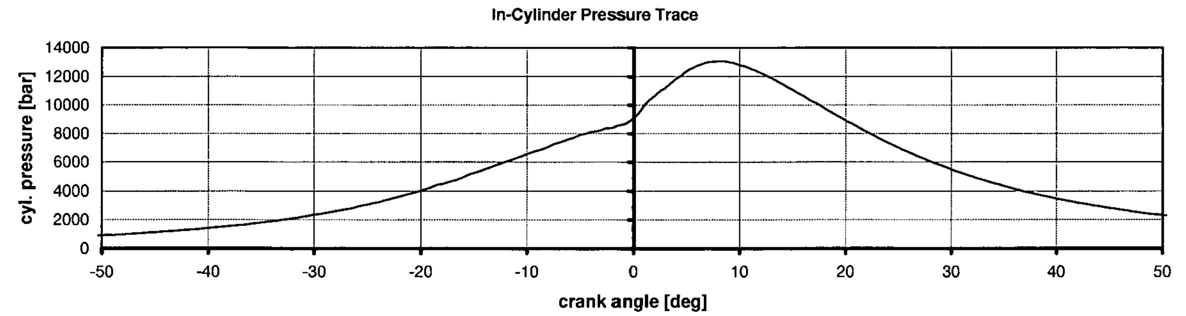



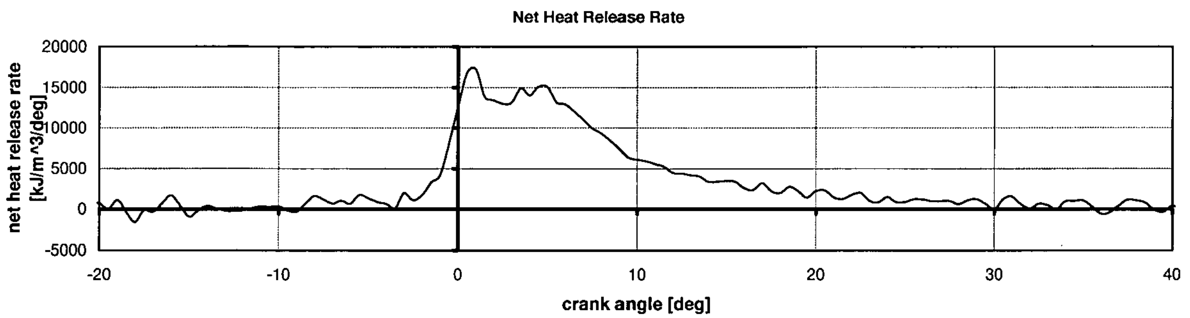



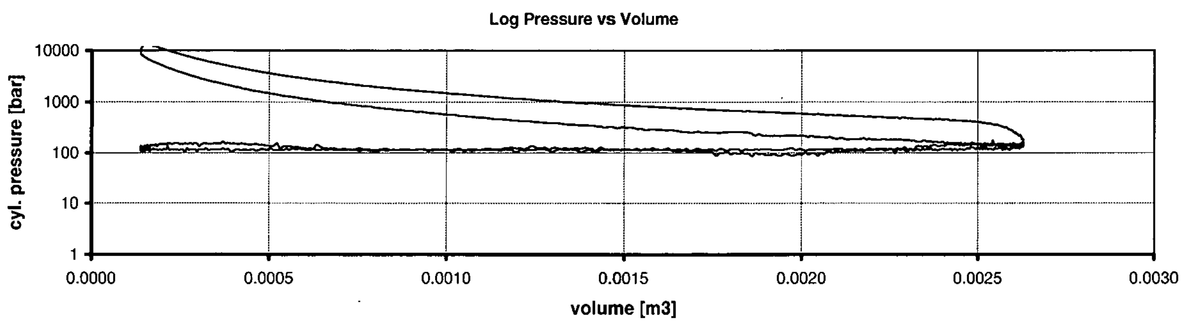
| | | Comments |
|---|---|---|
| Speed [RPM] | | |
| Torque [N-m] | | |
| Load [%] | | |
| P_max [deg] | 13051.33 | |
| CA @ P_max [deg] | 8.0 | |
| dP/dCA_max [bar/deg] | 887.466 | |
| CA @ dP/dCA_max [deg] | 0.5 | |
| IMEP [bar] | 1134.27 | |
| HHR_max [kJ/m^3/deg] | 17304.9 | |
| IHR_max [kJ/m^3] | 198429.3 | |
| 5% MFB [deg w.r.t TDC] | -2.0 | |
| 10% MFB [deg w.r.t TDC] | -0.5 | |
| 50% MFB [deg w.r.t TDC] | 5.0 | |
| 90% MFB [deg w.r.t TDC] | 19.0 | |
| Assumed poly-n during comprn. | 1.37 | |
| zero-level. pr. offset [bar] | 0.000 | |
| poly-n compression uncorrected | 1.37 | |
| poly-n compression corrected | 1.37 | |
| poly-n expansion uncorrected | 1.33 | |
| poly-n expansion corrected | 1.33 | |

| Data Summary for filter: | A23 |
|---|---|
| Date: | 3/7/02 |
| Time: | 13:42:00 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 808.1 |
| Load - approx(%) | 75.0 |
| Power (kW) | 19.1 |
| IMEP (bar) | 11.36 |
| Pmax(bar) | 130.75 |
| Pmax location (degrees) | 368.5 |
| Diesel Flow(kg/hr) | 0.21 |
| CNG Flow(kg/hr) | 2.90 |
| Air Flow(kg/hr) | 92.8 |
| Exhaust Flow(kg/hr) | 95.9 |
| Exhaust Back Pressure (kPa) | 48.2 |
| EGR Fraction(%) | 0.0 |



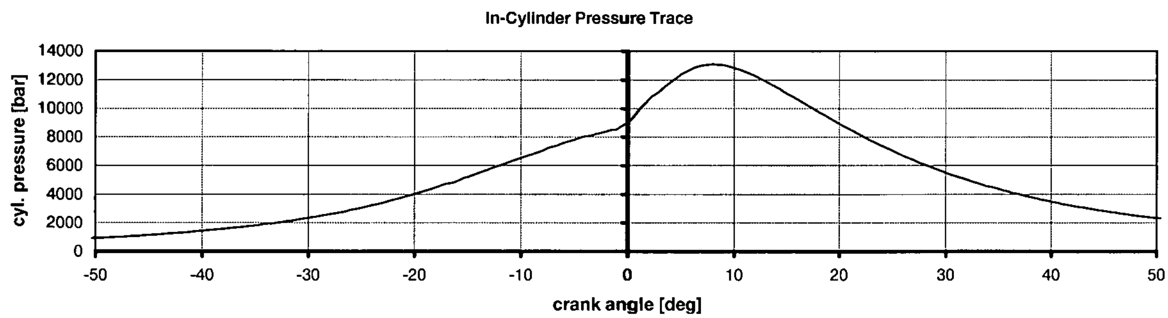



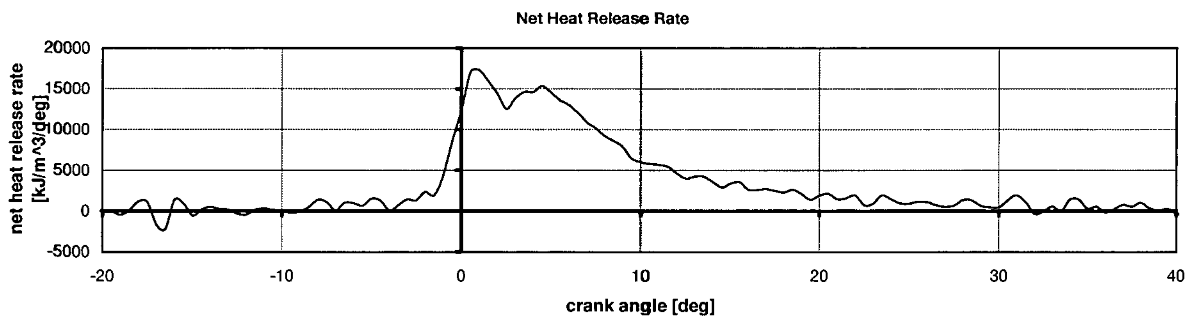
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 13086.51 |
| CA @ P_max [deg] | 8.0 |
| dP/dCA_max [bar/deg] | 901.252 |
| CA @ dP/dCA_max [deg] | 0.5 |
| IMEP [bar] | 1138.34 |
| HHR_max [kJ/m^3/deg] | 17330.9 |
| IHR_max [kJ/m^3] | 200837.7 |
| 5% MFB [deg w.r.t TDC] | -1.5 |
| 10% MFB [deg w.r.t TDC] | -0.5 |
| 50% MFB [deg w.r.t TDC] | 5.0 |
| 90% MFB [deg w.r.t TDC] | 20.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.36 |
| poly-n compression corrected | 1.36 |
| poly-n expansion uncorrected | 1.30 |
| poly-n expansion corrected | 1.30 |

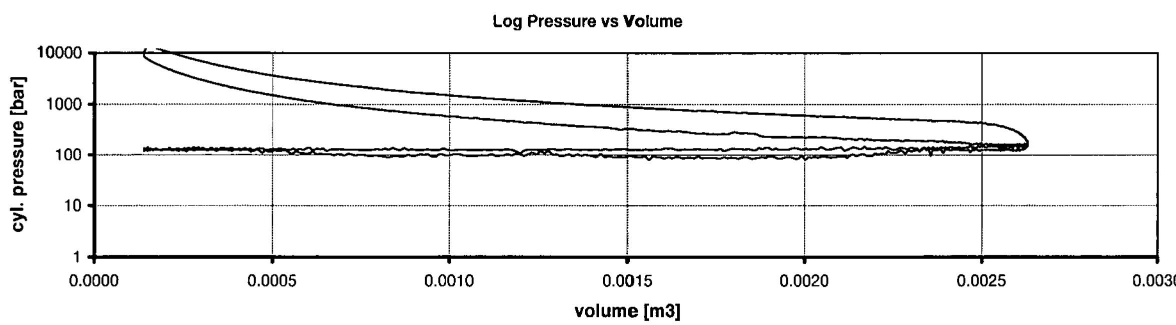
**Comments**

| Data Summary for filter: | A24 |
|---|---|
| Date: | 3/7/02 |
| Time: | 13:51:00 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 810.1 |
| Load - approx(%) | 75.0 |
| Power (kW) | 19.2 |
| IMEP (bar) | 11.40 |
| Pmax(bar) | 131.09 |
| Pmax location (degrees) | 368.5 |
| Diesel Flow(kg/hr) | 0.21 |
| CNG Flow(kg/hr) | 2.92 |
| Air Flow(kg/hr) | 93.4 |
| Exhaust Flow(kg/hr) | 96.6 |
| Exhaust Back Pressure (kPa) | 12.7 |
| EGR Fraction(%) | 0.0 |



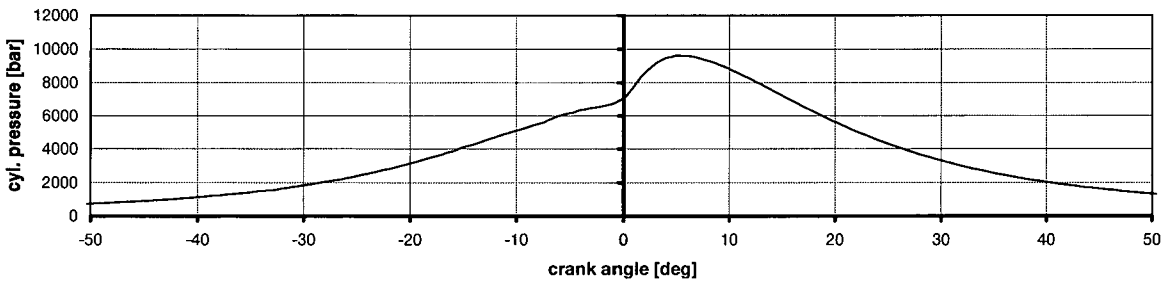
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 9624.92 |
| CA @ P_max [deg] | 5.0 |
| dP/dCA_max [bar/deg] | 839.215 |
| CA @ dP/dCA_max [deg] | 1.0 |
| IMEP [bar] | 521.33 |
| HHR_max [kJ/m^3/deg] | 16249.7 |
| IHR_max [kJ/m^3] | 91757.0 |
| 5% MFB [deg w.r.t TDC] | -4.5 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 1.5 |
| 90% MFB [deg w.r.t TDC] | 8.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.30 |
| poly-n compression corrected | 1.30 |
| poly-n expansion uncorrected | 1.37 |
| poly-n expansion corrected | 1.37 |

**Comments**

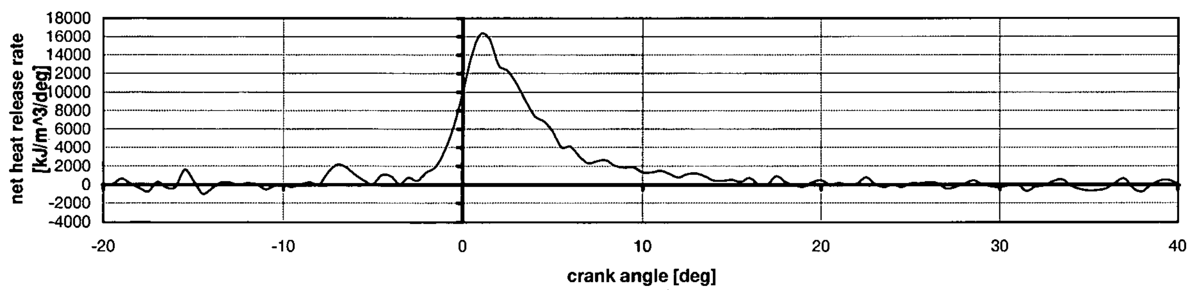
| | |
|---|---|
| Data Summary for filter: | A25 |
| Date: | 3/7/02 |
| Time: | 14:06:02 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 805.0 |
| Load - approx(%) | 25.0 |
| Power (kW) | 8.8 |
| IMEP (bar) | 5.22 |
| Pmax(bar) | 96.42 |
| Pmax location (degrees) | 365.8 |
| Diesel Flow(kg/hr) | 0.15 |
| CNG Flow(kg/hr) | 1.23 |
| Air Flow(kg/hr) | 73.4 |
| Exhaust Flow(kg/hr) | 74.8 |
| Exhaust Back Pressure (kPa) | 9.6 |
| EGR Fraction(%) | 0.0 |

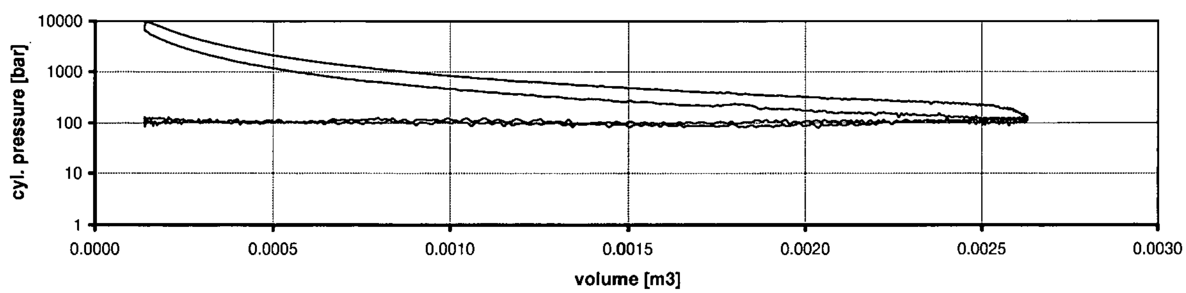
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume



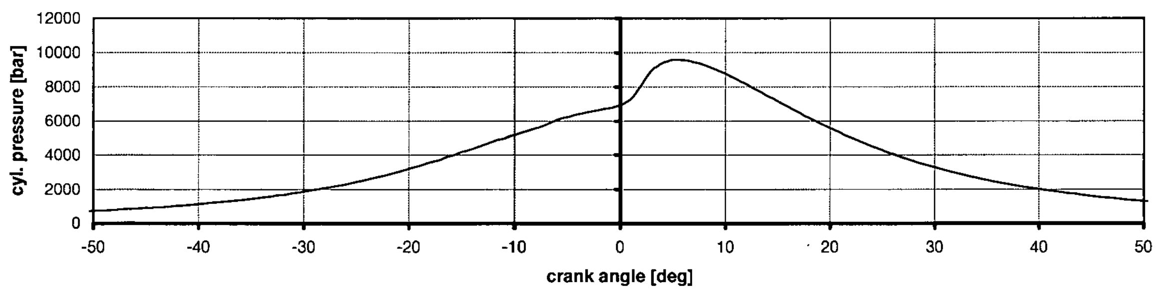
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 9598.05 |
| CA @ P_max [deg] | 5.5 |
| dP/dCA_max [bar/deg] | 940.886 |
| CA @ dP/dCA_max [deg] | 2.0 |
| IMEP [bar] | 498.55 |
| HHR_max [kJ/m^3/deg] | 18964.2 |
| IHR_max [kJ/m^3] | 88420.2 |
| 5% MFB [deg w.r.t TDC] | -4.5 |
| 10% MFB [deg w.r.t TDC] | -0.5 |
| 50% MFB [deg w.r.t TDC] | 2.0 |
| 90% MFB [deg w.r.t TDC] | 7.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.30 |
| poly-n compression corrected | 1.30 |
| poly-n expansion uncorrected | 1.36 |
| poly-n expansion corrected | 1.36 |

**Comments**

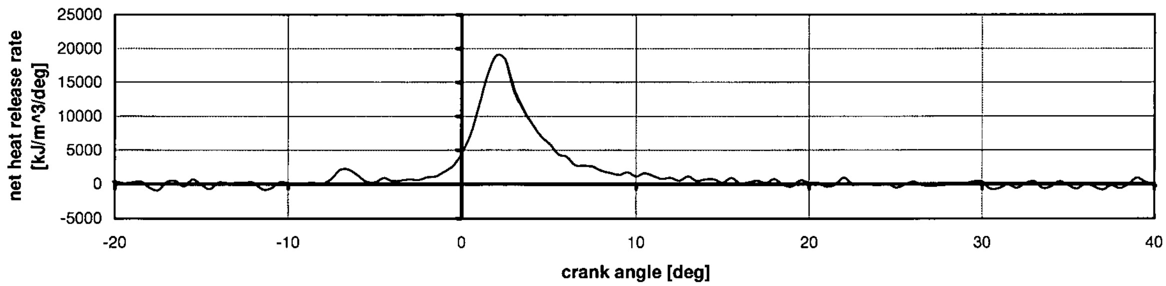
| | |
|---|---|
| Data Summary for filter: | A26 |
| Date: | 3/7/02 |
| Time: | 14:23:31 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 797.1 |
| Load - approx(%) | 25.0 |
| Power (kW) | 8.3 |
| IMEP (bar) | 4.99 |
| Pmax(bar) | 96.33 |
| Pmax location (degrees) | 366.0 |
| Diesel Flow(kg/hr) | 0.17 |
| CNG Flow(kg/hr) | 1.15 |
| Air Flow(kg/hr) | 57.1 |
| Exhaust Flow(kg/hr) | 58.4 |
| Exhaust Back Pressure (kPa) | 27.0 |
| EGR Fraction(%) | 22.1 |

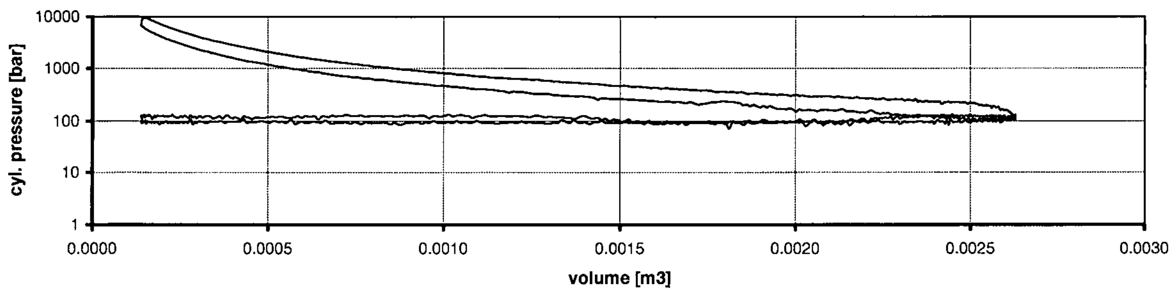
In-Cylinder Pressure Trace




Net Heat Release Rate



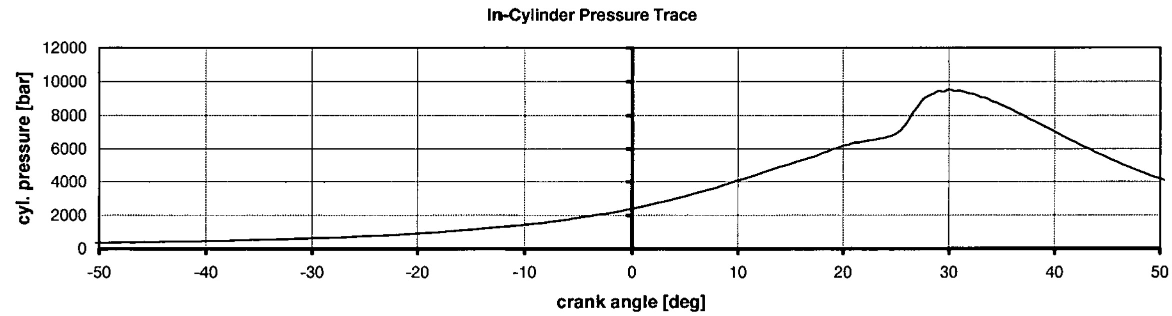

Log Pressure vs Volume

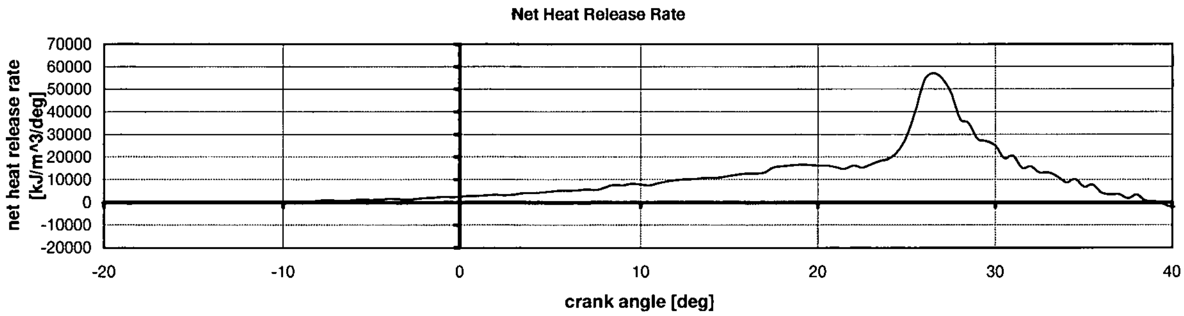


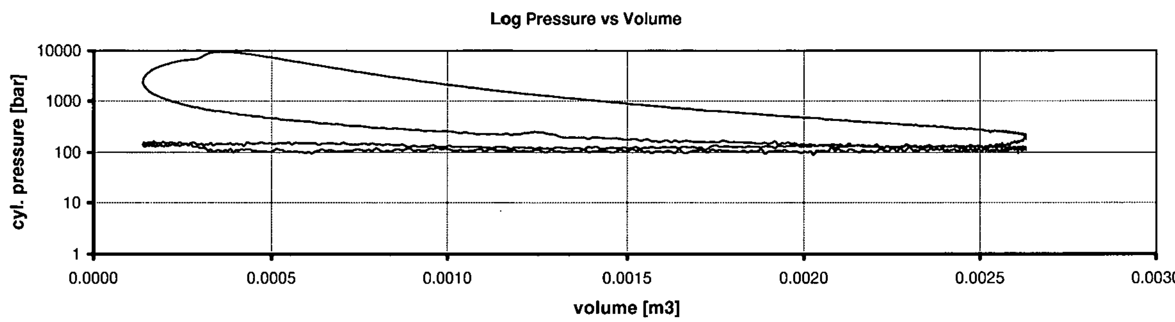
| | | Comments |
|---|---|---|
| Speed [RPM] | | |
| Torque [N-m] | | |
| Load [%] | | |
| P_max [deg] | 9545.47 | |
| CA @ P_max [deg] | 30.0 | |
| dP/dCA_max [bar/deg] | 952.949 | |
| CA @ dP/dCA_max [deg] | 26.5 | |
| IMEP [bar] | 2057.71 | |
| HHR_max [kJ/m^3/deg] | 57066.3 | |
| IHR_max [kJ/m^3] | 555233.2 | |
| 5% MFB [deg w.r.t TDC] | 5.5 | |
| 10% MFB [deg w.r.t TDC] | 9.5 | |
| 50% MFB [deg w.r.t TDC] | 25.0 | |
| 90% MFB [deg w.r.t TDC] | 31.0 | |
| Assumed poly-n during comprn. | 1.37 | |
| zero-level. pr. offset [bar] | 0.000 | |
| poly-n compression uncorrected | 0.85 | |
| poly-n compression corrected | 0.85 | |
| poly-n expansion uncorrected | 2.09 | |
| poly-n expansion corrected | 2.09 | |

| | |
|---|---|
| Data Summary for filter: | A27 |
| Date: | 3/7/02 |
| Time: | 14:35:00 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 795.2 |
| Load - approx(%) | 25.0 |
| Power (kW) | 34.1 |
| IMEP (bar) | 20.61 |
| Pmax(bar) | 95.49 |
| Pmax location (degrees) | 390.5 |
| Diesel Flow(kg/hr) | 0.15 |
| CNG Flow(kg/hr) | 1.14 |
| Air Flow(kg/hr) | 65.5 |
| Exhaust Flow(kg/hr) | 66.8 |
| Exhaust Back Pressure (kPa) | 36.1 |
| EGR Fraction(%) | 9.8 |



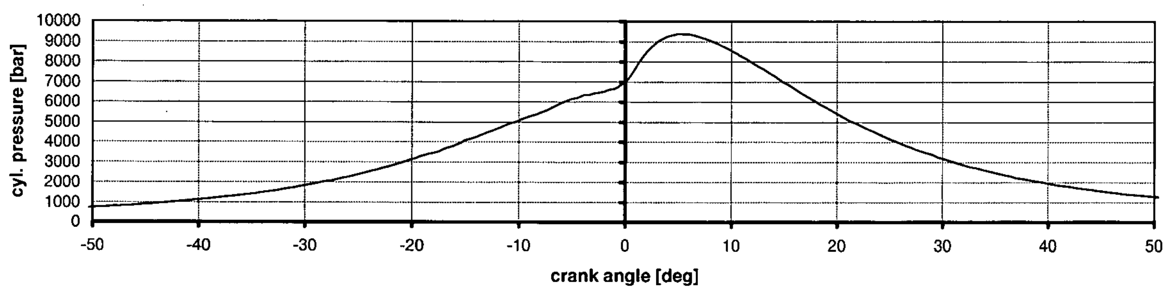
| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 9388.38 |
| CA @ P_max [deg] | 5.0 |
| dP/dCA_max [bar/deg] | 818.537 |
| CA @ dP/dCA_max [deg] | 1.0 |
| IMEP [bar] | 477.30 |
| HHR_max [kJ/m^3/deg] | 15860.5 |
| IHR_max [kJ/m^3] | 84792.1 |
| 5% MFB [deg w.r.t TDC] | -5.0 |
| 10% MFB [deg w.r.t TDC] | -1.0 |
| 50% MFB [deg w.r.t TDC] | 1.5 |
| 90% MFB [deg w.r.t TDC] | 7.5 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.28 |
| poly-n compression corrected | 1.28 |
| poly-n expansion uncorrected | 1.36 |
| poly-n expansion corrected | 1.36 |

Comments

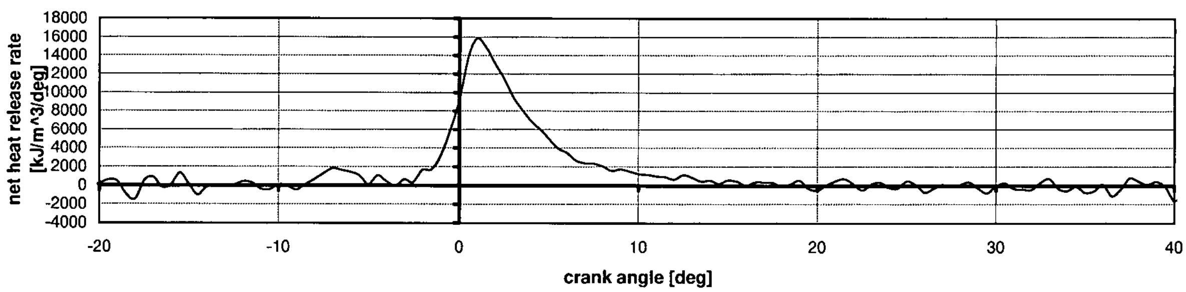
| Data Summary for filter: | A28 |
|---|---|
| Date: | 3/7/02 |
| Time: | 14:47:30 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 799.7 |
| Load - approx(%) | 25.0 |
| Power (kW) | 8.0 |
| IMEP (bar) | 4.78 |
| Pmax(bar) | 94.23 |
| Pmax location (degrees) | 365.9 |
| Diesel Flow(kg/hr) | 0.15 |
| CNG Flow(kg/hr) | 1.13 |
| Air Flow(kg/hr) | 73.3 |
| Exhaust Flow(kg/hr) | 74.6 |
| Exhaust Back Pressure (kPa) | 10.7 |
| EGR Fraction(%) | 0.0 |

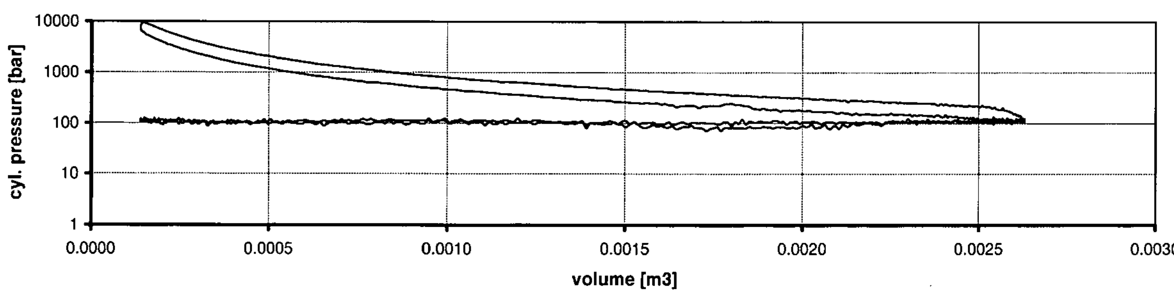
In-Cylinder Pressure Trace




Net Heat Release Rate




Log Pressure vs Volume



| | |
|---|---|
| Speed [RPM] | |
| Torque [N-m] | |
| Load [%] | |
| P_max [deg] | 9605.48 |
| CA @ P_max [deg] | 5.5 |
| dP/dCA_max [bar/deg] | 985.690 |
| CA @ dP/dCA_max [deg] | 1.0 |
| IMEP [bar] | 514.85 |
| HHR_max [kJ/m^3/deg] | 18985.6 |
| IHR_max [kJ/m^3] | 91376.2 |
| 5% MFB [deg w.r.t TDC] | -5.5 |
| 10% MFB [deg w.r.t TDC] | -2.0 |
| 50% MFB [deg w.r.t TDC] | 1.5 |
| 90% MFB [deg w.r.t TDC] | 8.0 |
| Assumed poly-n during comprn. | 1.37 |
| zero-level. pr. offset [bar] | 0.000 |
| poly-n compression uncorrected | 1.29 |
| poly-n compression corrected | 1.29 |
| poly-n expansion uncorrected | 1.39 |
| poly-n expansion corrected | 1.39 |

Comments

| Data Summary for filter: | A29 |
|---|---|
| Date: | 3/7/02 |
| Time: | 14:55:26 |

| Engine Parameters | Average |
|---|---|
| Speed(RPM) | 800.2 |
| Load - approx(%) | 25.0 |
| Power (kW) | 8.6 |
| IMEP (bar) | 5.16 |
| Pmax(bar) | 96.24 |
| Pmax location (degrees) | 365.9 |
| Diesel Flow(kg/hr) | 0.21 |
| CNG Flow(kg/hr) | 1.11 |
| Air Flow(kg/hr) | 73.4 |
| Exhaust Flow(kg/hr) | 74.7 |
| Exhaust Back Pressure (kPa) | 10.8 |
| EGR Fraction(%) | 0.0 |