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FUEL EFFICIENCY STUDY
AT
CAROSUE DAM OPERATIONS FOR
SARACEN GOLD PTY LTD

December, 2011

Prepared by:

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C O N T E N T S

EXECUTIVE SUMMARY

The FTC Combustion Catalysts manufactured and marketed by Fuel Technology Pty Ltd has proven in laboratory and field trials to reduce fuel consumption in the range of 2% to 8% under comparable load conditions and also substantially reduce greenhouse gas emissions. Recent studies conducted by "Centre For Energy" department at UWA by world renowned expert in the field of combustion Professor Zhang, has scientifically proven beyond doubt the ability of this unique catalyst to improve combustion and significantly reduce fuel consumption.

Following discussions with Carosue Dam Operations General Manager Mr Grant Haywood, who has had previous experience in the efficiencies FTC-3 Combustion Catalyst provides, it was agreed that a fuel efficiency study should be conducted in the Kalgoorlie Power Supply's (KPS) generation plant at Carosue Dam operations.

This study was primarily designed to eliminate KPS management concerns as to any detrimental effect FTC may have on engine components and secondly to reconfirm the fuel efficiency provided by FTC-3. The trial encompassed two engines, one to remain untreated for control comparison and one to have fuel supply treated with the FTC-3 Combustion Catalyst.

The engineering standard test procedure employed in this test program was Specific Fuel Consumption tests (SFC).

The ***net*** efficiency gain (reduction in fuel consumption) measured in this very well run power generation operation by this international engineering standard test method was **2.7%**.

INTRODUCTION

Baseline (untreated) fuel efficiency tests were conducted on two Cummins KTA 50 Generator sets, No's 2 and 3 during the week commencing 6th September, 2011 employing the SFC test procedure.

Fuel Technology Pty Ltd supplied, on loan, an air operated FTC catalyst metering system which was calibrated and commissioned following completion of the baseline tests. This unit injected catalyst into the fuel supply of the selected treated fuel test engine No. 3. Engine No. 2 continued to operate on untreated fuel.

Treated tests on engine 3 and control tests on engine 2 employing the SFC test procedure were conducted during the week commencing 21st November, 2011.

For all tests the engine loads were set at 0.8 MW.

TEST METHODS

The Specific Fuel Consumption (SFC) test procedure employed in this efficiency study measures the absolute amount of fuel consumed against work performed by the engine over time at a constant load. From this raw data the engine's efficiency can be calculated.

This evaluation of FTC involves a series of back to back untreated (baseline) and treated fuel tests conducted approximately two months apart.

Calibrated Hoffer turbine flow transducers were used to measure fuel supplied to the engine and also fuel returning from the engine from which the net volume of fuel consumed can be calculated.

The flow transducers are fitted with thermocouple probes which enable measurement of fuel temperature at each transducer. All these measurements are automatically downloaded to a data taker every 10 seconds.

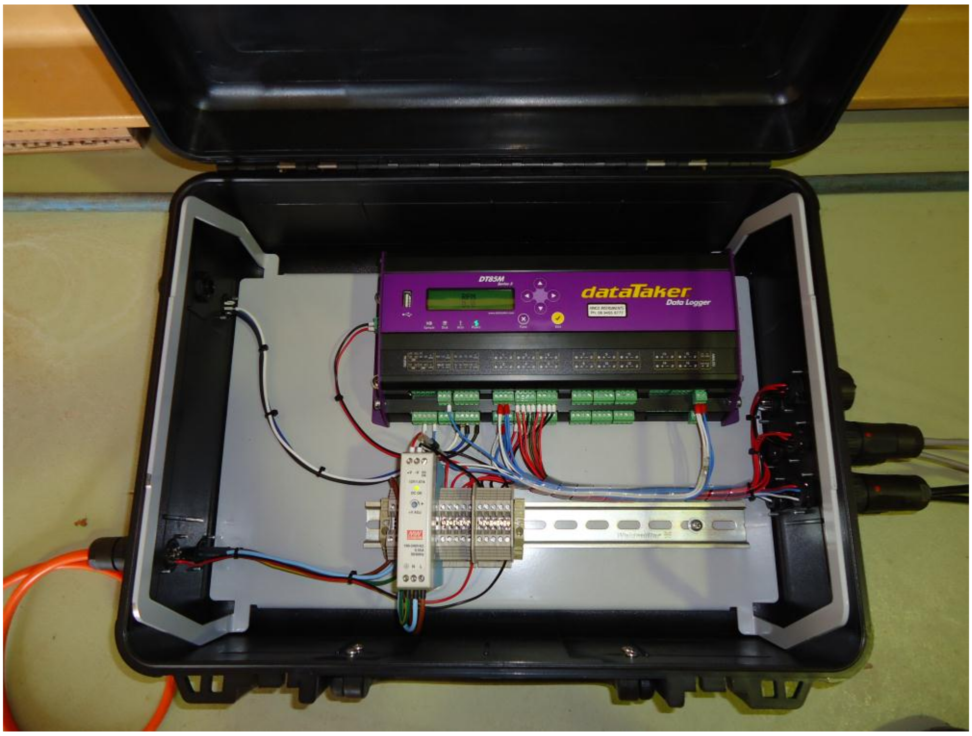
From the fuel temperature the density at that temperature is calculated. A sample of fuel was taken for laboratory analysis and the density determined at industry standard of 15°C. Copies of the laboratory reports are included in the *Appendix*.

Volumetric fuel flows are corrected for density and temperature and reported in mass (kg) of fuel.

Work done, or KWh's produced, are normally also recorded every 10 seconds by data taker but due to KPS management concerns with usage of this equipment in their operations, KWh's produced were recorded manually every 10 minutes from stations instrument panel.

TEST EQUIPMENT

Data Taker



Hoffer Turbine Flow Transducers

TEST RESULTS

Fuel Efficiency

A summary of the fuel efficiency results achieved in this test program are detailed in the following table.

The results are represented graphically in Graphs 1 and 2.

TABLE 1

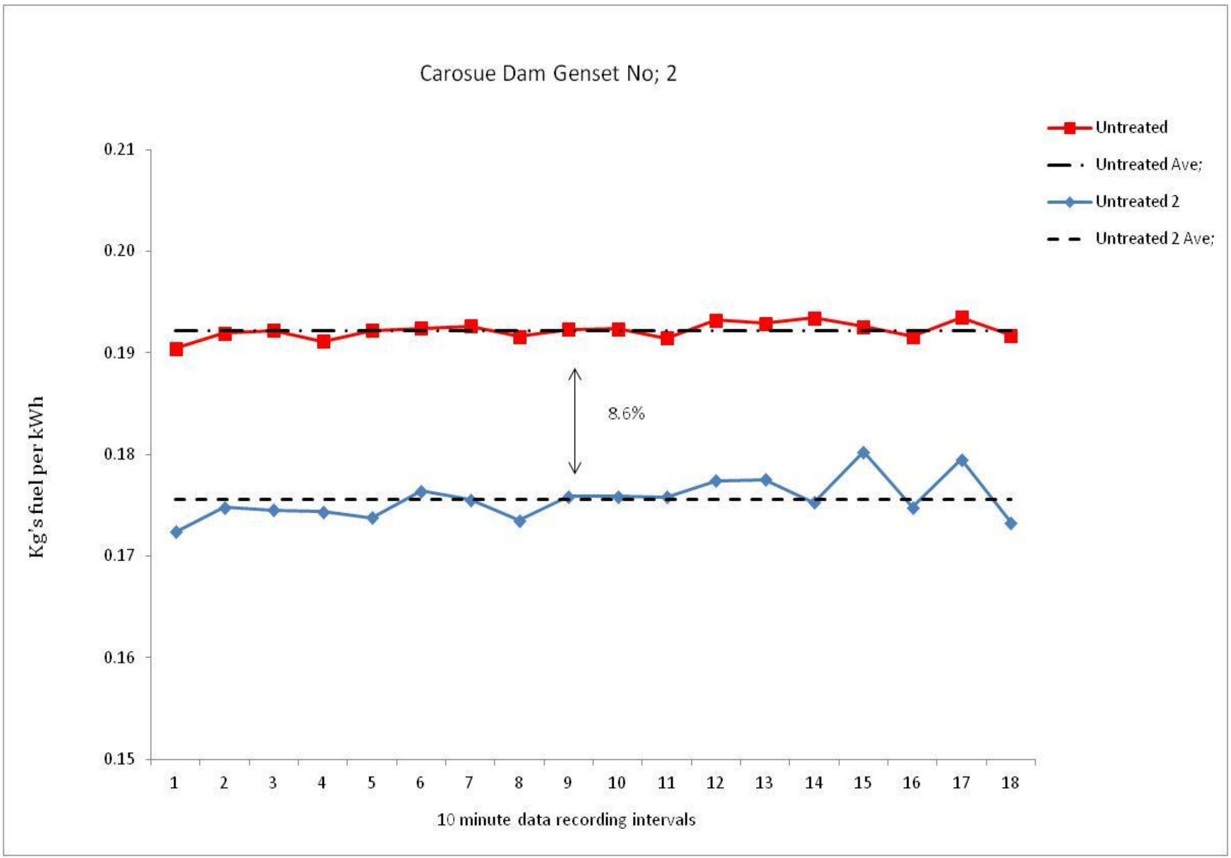
Specific Fuel Consumption Test Results
(Average over 3 Hour period)

Engine No.	Baseline 6/9/11 Kg/kWh	Retest 21/11/11 Kg/kWh	Variation
2	0.1922	0.1756	- 8.6%
3	0.2033	0.1978	- 2.7%

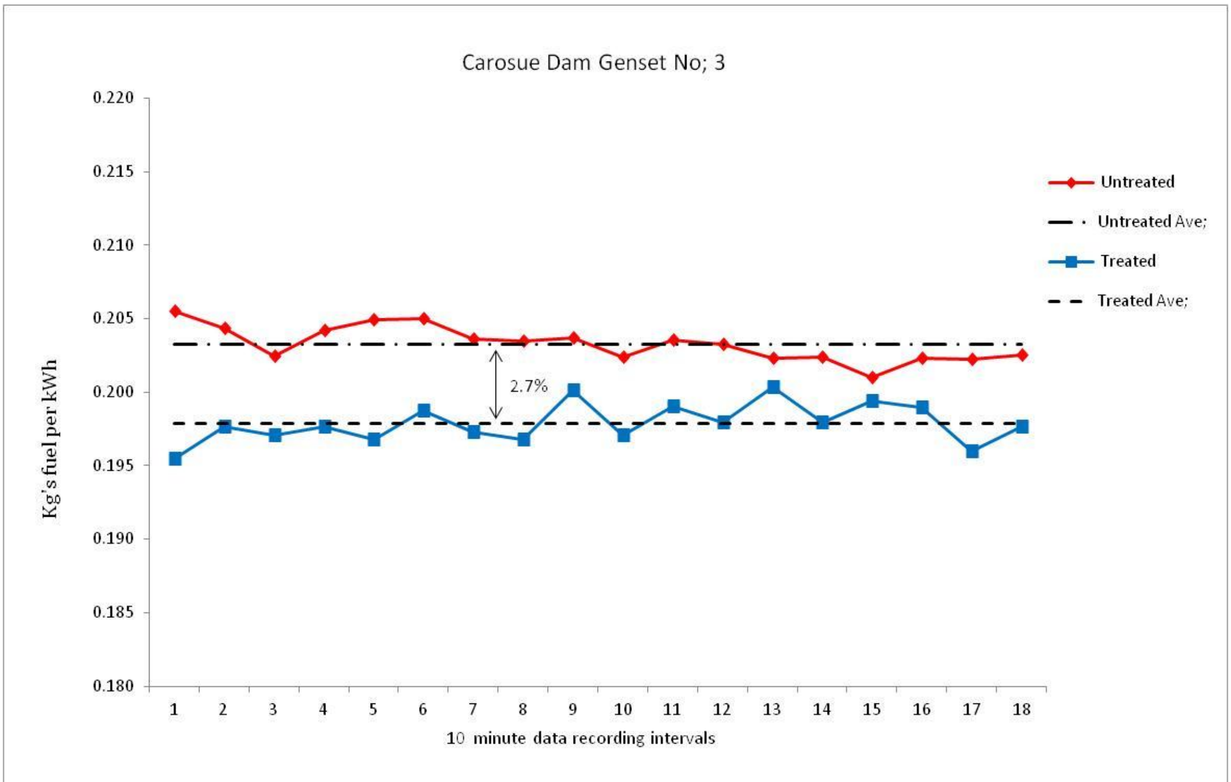
As baseline tests conducted 6th September indicate, engine No.2 is slightly more efficient than engine No.3.

Treated tests indicate engine No.3 following FTC-3 treatment has an improved fuel efficiency of 2.7%. Engine No.2 although still untreated has shown an unachievable efficiency of 0.1756 Kg's of fuel per KWh. This anomaly indicates an error in recordings which is believed to be caused by one meter. The suspect meter is being returned to manufacturer in the USA to confirm and have repaired. (It should be noted that two different sets of fuel meters were used on the two engines although the same meters were used for each test on each engine)

GRAPH NO. 1



GRAPH NO. 2



The efficiency gain of 8.6% recorded by the untreated test engine can only be a result of instrumentation malfunction. The net efficiency gain resulting from fuel treatment with the FTC-3 Catalyst is **2.7%**. Although this is at the lower end of efficiency normally achieved, it must be pointed out that this operation is a very well run station and engines were base loaded (locked in) during tests at their most efficient load of 0.8MW.

CONCLUSION

This carefully controlled engineering standard test conducted on Cummins KTA 50 Gensets, confirm that FTC-3 Combustion Catalyst will have no detrimental effect on engine components and will provide reduced fuel consumption of a minimum 2.7%. At normal operating parameters where load swings are experienced and in mobile equipment that does not operate as efficiently, it is expected this fuel efficiency benefit would be 2-3% higher. (Varying efficiencies at varying loads is demonstrated in paper published in journal "Applied Science" enclosed in appendix).

A fuel efficiency gain of 2.7% as measured by the Specific Fuel Consumption test method if applied to the total fuel currently consumed by Carosue Dam operations will result in a **Net** saving of approximately $444,000 and 1,600 tonnes per annum reduction in CO_2 emissions.

Appendix "A"

Laboratory Reports

Intertek GEOTECH

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Locked Bag 27, Welshpool DC, Western Australia 6986
Email: geotech @ geotechnical-services.com.au

GEOTECHNICAL SERVICES PTY LTD

Telephone: (08) 9458 8877 (24 hours)
Facsimile: (08) 9458 8857
ACN 050 543 194

LUBRICANT ANALYSIS REPORT

FUEL TECHNOLOGY PTY LTD
2 TIPPING ROAD KEWDALE WA 6105

Fleet Number: **P/O 1279**
Compartment:

Phone: **(08) 9353 1016** **Fax:** **(08) 9353 1013**
Lubricant: DIESEL FUEL
Site:
Machine: .
Area:
Atten: **NOEL MILLIN**
Submission No: **43101** **Date:** **1/12/2011**

Lab. Number	:	**263155**
Date Sampled	:	**06/09/2011**
Date Received	:	**29/11/2011**
Unit Hours	:	**0**
Oil Hours	:	**0**

DENSITY @ 15 C (ASTM D4052)	kg/L	**0.8403**

A = Abnormal D = Danger I/S = Insuficient Sample N/D = Not Determined

Comments:
Density is within the diesel fuel specifications (0.82 - 0.87kg/L)

Report enquiries to: Ken Traynor

Results apply to the samples as received

Test Methods :

Flash Point - D93-10a, Viscocity - D445-11a/D7042-11, Elements - D5185-09, Acid Number - D974-11, Base Number - D2896-07a, Soot SAM001, Water (Screening Test) SAM002, Density - D7042-11, Water SAM003, Colour - D1500-07, Flash Point (Setaflash) SAM004 NOTE : ppm = ug/g

End of Report

Intertek GEOTECH

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ACN 050 543 194

LUBRICANT ANALYSIS REPORT

FUEL TECHNOLOGY PTY LTD
2 TIPPING ROAD KEWDALE WA 6105

Fleet Number: **P/O 1279**
Compartment:

Phone: **(08) 9353 1016** **Fax:** **(08) 9353 1013**
Lubricant: DIESEL FUEL
Site:
Machine: .
Area:
Atten: **NOEL MILLIN**
Submission No: **43101** **Date: 1/12/2011**

Lab. Number	:	**263156**
Date Sampled	:	**21/11/2011**
Date Received	:	**29/11/2011**
Unit Hours	:	**0**
Oil Hours	:	**0**
DENSITY @ 15 C (ASTM D4052)	kg/L	**0.8349**

A = Abnormal D = Danger I/S = Insuficient Sample N/D = Not Determined

Comments:

Density is within the diesel fuel specifications (0.82 - 0.87kg/L)

Report enquiries to: Ken Traynor

Results apply to the samples as received

Test Methods :

Flash Point - D93-10a, Viscocity - D445-11a/D7042-11, Elements - D5185-09, Acid Number - D974-11, Base Number - D2896-07a, Soot SAM001, Water (Screening Test) SAM002, Density - D7042-11, Water SAM003, Colour - D1500-07, Flash Point (Setaflash) SAM004 NOTE : ppm = ug/g

End of Report

Appendix "B"

Applied Science Journal Paper

Contents lists available at SciVerse ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Effect of a homogeneous combustion catalyst on the combustion characteristics and fuel efficiency in a diesel engine

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ARTICLE INFO

Article history:
Received 8 June 2011
Received in revised form 4 September 2011
Accepted 7 September 2011

Keywords:
Combustion characteristics
Diesel engine
Fuel efficiency
Homogeneous combustion catalyst

ABSTRACT

The influence of a ferrous picrate based homogeneous combustion catalyst on the combustion characteristics and fuel efficiency was studied using a fully instrumented diesel engine. A naturally aspirated four stroke, single cylinder, air cooled, direct injection diesel engine was tested at engine speeds of 2800 rpm, 3200 rpm and 3600 rpm under variable load conditions, with different dosing ratio of the catalyst in a commercial diesel fuel. The results indicated that the brake specific fuel consumption decreased and the brake thermal efficiency increased with the addition of the catalyst. At the catalyst dosing ratio of 1:10,000, the brake specific fuel consumption was reduced by 3.3–4.2% at light engine load of 0.12 MPa and 2.0–2.4% at heavy engine load of 0.4 MPa due to the application of the catalyst. From the in-cylinder pressure and heat release rate analysis, it was found that the catalyst reduced ignition delay and combustion duration of fuel in the engine, resulting in slightly higher peak cylinder pressure and faster heat release rate.

1. Introduction

Diesel engines are widely used in road transportation, remote and small scale diesel-fuelled power generation system, heavy machineries and mining equipments powered by diesel fuel [1–3]. Due to ever increasing fuel costs and the public concerns of the urban air quality due to increased use of petroleum fuels-, many studies have been conducted over the past few decades in an effort to develop cleaner and more efficient diesel engines and their use [4–9]. One possible alternative is homogeneous combustion catalysts added into diesel fuel to improve auto-ignition and combustion quality of diesel within the diesel engines, leading to higher fuel efficiencies. Fuel efficiency is often characterised by the brake specific fuel consumption, which is defined as the rate of the fuel consumption divided by the power produced, allowing the energy conversion efficiency of different engines to be compared directly [2].

Effective homogeneous combustion catalysts should have the following several characteristics: (1) they must be soluble in the diesel fuel homogeneously without settling out or agglomeration during application, storage and on-board consumption; (2) they must have excellent catalytic activity promoting hydrocarbon combustion so that only a very tiny amount of the catalyst is required; and (3) the catalyst would not change the fuel specification significantly and generate the secondary pollutions. Two groups of combustion catalysts are commonly used: metal-containing catalysts and ash-free catalysts [10,11]. Compared to the ash-free catalysts, metal containing compounds are claimed to be more effective [10]. A number of metal ions are found to promote hydrocarbon combustion such as Iron [11–15], Cerium [16–18], Platinum [19,20], Copper [21], Barium [22], Sodium [23] and Manganese [24,25]. These metal-based catalysts are either manufactured in the form of the organometallic compounds or nano-particles using proprietary technologies. With the application of the homogeneous combustion catalysts in diesel engines, up to 12% fuel saving was claimed based on field trial tests and laboratory tests [11].

Manufactured by Fuel Technology Pty Ltd., the homogeneous combustion catalyst used in the present study was a ferrous picrate-water-butanol solution with additives. These additives are mainly short-chain alkyl benzene and its derivatives, which help improve the stability of the ferrous picrate-water-butanol-diesel mixture [11,26]. When applied in proper proportion in diesel engines, this dark green catalyst was claimed to improve fuel efficiency [26]. However, the reported fuel savings due to the use of the catalyst in diesel engines were varied and at times, controversial [11]. In addition, the mechanisms of the working of the homogeneous combustion catalyst in the diesel combustion process in engines remain unclear, which hinders its widespread applications. It is postulated that the catalyst promotes the ignition and heat release rate in diesel engines [12] but some researchers believe that the catalyst only participates in the carbon deposit reaction within engine cylinder [13]. Thus, a science-based, systematic study of the effect of the catalyst on fuel efficiency and combustion characteristics in diesel engines is necessary. Against this backdrop, the

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doi:10.1016/j.apenergy.2011.09.007

influence of the combustion catalyst on fuel efficiency and combustion characteristics as a function of catalyst dosing ratio, engine load and speed were investigated on a single cylinder compression ignition engine in the present study.

2. Experimental setup

The experiments were conducted with an air-cooled, single cylinder, four-stroke diesel engine system which was manufactured by Advanced Engine Technology Pty Ltd. (AET). Major specifications of the engine are listed in Table 1.

The engine was mounted on an automated bed and coupled with an eddy-current dynamometer which was equipped with a load cell for engine load measurement. There were two sensors placed in the load cell, one for the engine load and the other for the engine speed. These signals were fed into a controller through which the operator can set speed and load of the dynamometer. Coolant and lube-oil systems were assured by electronically driven pumps to control the operation temperature of the dynamometer and engine. Instantaneous engine oil temperature, engine cylinder head temperature and intake air temperature were recorded and acquired by a computer to monitor the combustion quality within the engine. A schematic diagram of the engine test bench is illustrated in Fig. 1.

A 1 l tank and a digital weighing scale (Acculab LT-3200) on the top deck of the fuel system frame measured the fuel consumed at a fixed time interval (5 min in the present experimentation). The fuel tank was refilled automatically from a 4 l fuel reservoir. The digital scale is connected to the data acquisition system so that the brake specific fuel consumption during each test could be calculated and displayed on the computer.

Fuel injection in the engine was achieved with a YANMAR PFE-M type pump, capable of supplying injection pressures of up to 19.6 MPa. Injection timing was mechanically controlled and was fixed. To measure the instantaneous pressure within the cylinder, a high accuracy piezoelectric pressure sensor (Kistler 6052B1) was used, mounted to the cylinder head. The fuel injection pressure was measured using a piezoresistive transducer (Kistler 4067BB2000) connected on the injector side of the pipe linking the injection pump and injector. The needle lift was measured using a Hall-effect proximity sensor mounted within the injector nozzle body. In the present experimentation, cylinder pressure, fuel injection pressure and needle lift were measured every 5 min and 10 cycles were acquired in each measurement with a sampling rate corresponding to 0.2° CA. The cylinder head temperature, dynamometer coolant temperature and exhaust gas temperature were measured by thermocouples. All these signals were connected to the input of an A/D board installed on an IBM compatible Pentium PC. This board can acquire input data at a high

Table 1
SCIEEF Test Engine specifications.

Engine type	Four stoke, direct injection, compression ignition (Yanmar L48AE-DG)
Cylinder number	Single
Bore (mm) × stroke (mm)	70 × 55
Total displacement (L)	0.211
Compression ratio	19.9
Fuel injector body and nozzle	Fuel injection pump: YANMAR PFE-M type Injection timing: 14 ± 1 BTDC (before top dead center) Fuel injection pressure: 19.6 Mpa Fuel injection nozzle: Hole nozzle YANMAR YDLLA-P type Nozzle: 4 nozzle holes with hole diameter 0.22 mm

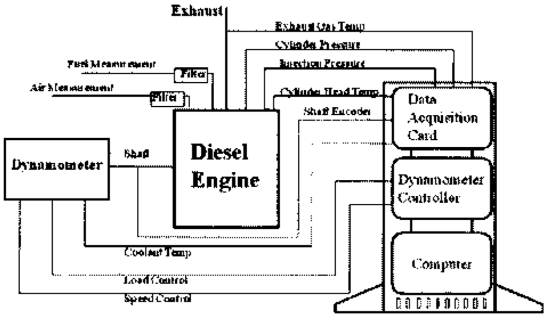

Fig. 1. A schematic diagram of the diesel engine test bench.

rate, capable of recording these high frequency engine signals with an acceptable resolution.

3. Parameters tested

The performance of a compression engine is generally characterised by several key parameters including [2,27]:

- The brake specific fuel consumption (bsfc), for measuring the fuel efficiency within a diesel engine. A higher brake specific fuel consumption means a lower fuel efficiency.
- The brake thermal efficiency (bte), for measuring the efficiency and completeness of combustion of the fuel within a diesel engine.
- The heat release rate, for characterising the rate of heat released due to the combustion within a diesel engine.

In each test, by knowing the engine load and speed which were set for a given experiment and kept constant by the engine dynamometer controller, the key engine performance parameters were computed using the following formula:

The brake mean effective pressure, *b.m.e.p.* (in bar).

$$b.m.e.p = (4\pi M/V_c) \times 10^{-5} \quad (1)$$

The brake power, *P* (in W)

$$P = (M \times 2\pi N)/60 \quad (2)$$

The brake specific fuel consumption, *b.s.f.c.* (in g/kW h).

$$b.s.f.c. = (\dot{m}/P) \times 3.6 \times 10^9 \quad (3)$$

The brake thermal efficiency, *b.t.e.*

$$b.t.e = P/(\dot{m} \times \phi) \quad (4)$$

where M is the engine brake torque, Nm; N is the engine speed, rpm; P is the engine power, W; $\dot{m}$ is the fuel consumption rate, kg/s; Vc is the engine displacement volume, m^3; and ϕ is the lower calorific value of the diesel, MJ/kg.

The heat release rate is calculated based on a single-zone model where the mixture in the cylinder is assumed to be uniform in both composition and temperature and the internal energy of mixture is calculated using the first law of thermodynamics [2]. The detailed description of the heat release calculation can be found in Ref. [2,27]. By knowing the cylinder pressure which was experimentally obtained and the instantaneous cylinder volume, the heat release rate was given using the following formula [2]:

$$dQ_n/dt = (1 + c_v/R)p(dV/dt) + (c_v/R) \cdot V \cdot (dp/dt) + hA(T - T_w) \quad (5)$$

where A is the heat transfer surface area of the combustion chamber walls; Qn is the gross heat release; Cv is the specific heat capacity of

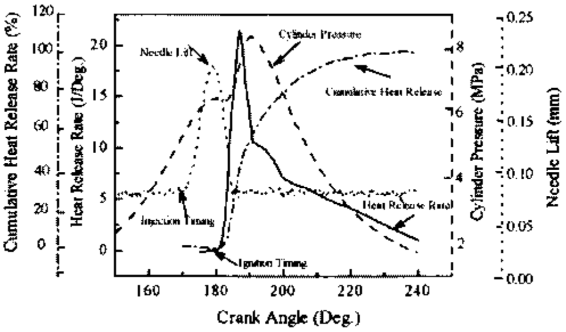

Fig. 2. Definitions of combustion characteristics in diesel engines.

the mixture at constant volume; p is the pressure and V is the cylinder volume; h is the heat transfer coefficient which was calculated based on the Annand equation [27]; and Tw is the wall temperature.

With the measured cylinder pressure and the calculated heat release rate, the typical combustion characteristics can be determined including the cylinder pressure rise rate, ignition delay and total combustion duration. These characteristics are shown in Fig. 2. These combustion characteristics reveal some interesting features, which assist in the understanding of the combustion mechanisms associated with the use of the homogeneous combustion catalyst in the diesel engine.

As shown in Fig. 2, the injection timing, which is the start of fuel injection, was determined at the crank angle where the injector needle lift rises suddenly. The ignition timing, which is the start of combustion, was determined at the point where the heat release starts [2]. The difference between the ignition timing and the injection timing is the ignition delay. The end of a combustion process in a cycle was taken as the point where 90% of the cumulative heat release had occurred [2]. The difference between the end of the combustion and the ignition timing was taken as the total combustion duration.

4. Experimental procedure and statistical analysis

Caltax no. 2 diesel was used as the baseline fuel in the present study and its specifications are listed in Table 2. The homogeneous combustion catalyst was added into the baseline diesel fuel at dosing ratios of 1:20,000, 1:15,000, 1:10,000, 1:5000 (by volume), respectively. It was found that the addition of the catalyst in diesel fuel does not change the fuel specifications.

In the present study, a series of tests were conducted at four loads corresponding to about 100%, 75%, 50% and 25% of the maximum load for three engine speeds at 2800 rpm, 3200 rpm and 3600 rpm.

All experimental runs began with running the engine the pure diesel fuel in order to determine the baseline of the fuel consumption under each of set of the test conditions against which the brake specific fuel consumption data when the homogeneous combustion catalyst was applied to the diesel were compared under the same conditions. The same procedure was repeated for each fuel with a different catalyst dosing ratio by keeping the same operating conditions. At each fuel change, the engine was run for at least 30 min to purge the remaining previously tested fuel in the engine fuel system. Tests on each fuel with a different catalyst dosing ratio were repeated five times to ensure the repeatability and statistical validity of the results. All results presented in this study were the average of five measurements under the same conditions, with error bars showing the standard derivations of these measurements.

In order to determine the statistical validity of the measured results, a statistical analysis was performed using SPSS software (SPSS Inc, Chicago). The procedure was consisted of an analysis of the variance (ANOVA) and Fisher's least significant difference (LSD) [28]. A statistical level of significance was defined by a (p) value less than or equal to 0.05 which would indicate that the mean value of the brake specific fuel consumption of at least one of the fuels was not equal to the others. Statistical non-significance was defined by (p) value greater than 0.05.

Table 2
Properties of diesel fuel.

Fuel parameters	Caltax no. 2 diesel fuel	Analytical method
Viscosity, cSt (@40 °C)	2.03	ASTM D445
Flash point (°C)	80	ASTM D93
Pour point (°C)	10	ASTM D97
Distillation range (°C)	180–360	ASTM D86
Density, g/mL (15 °C)	0.8435	ASTM D1298
Sulphur content (ppm)	<10	ASTM D1266

5. Results and discussion

5.1. Effect of the catalyst on fuel efficiency

The effect of the catalyst dosing ratio on the brake specific fuel consumption with the full loaded engine working at speeds of 2800 rpm, 3200 rpm and 3600 rpm, respectively, is shown in Fig. 3. It can be seen that the brake specific fuel consumption decreased with increasing the catalyst dosing ratio under the tested engine conditions. However, the brake specific fuel consumption did not decrease linearly with the catalyst dosing ratio. At the tested engine speeds, the reduction of the brake specific fuel consumption with the catalyst dosing ratio from 0 to 1:15,000 is about three or four times than that with the catalyst dosing ratio from 1:15,000 to 1:5000.

The results of statistical analysis of ANOVA and LSD are presented in Table 3 including the differences in average means of the brake specific fuel consumption for each fuel and the associated p value. The statistical analysis indicates that the brake specific fuel consumption does not change significantly until the catalyst dosing ratio reached 1:15,000 under the three tested speeds. It can also be seen that there is a significant difference in the brake specific fuel consumption between the fuel with catalyst dosing ratio of 1:15,000 and the fuel with the catalyst dosing ratio of 1:10,000, while the brake specific fuel consumption between the fuel with catalyst dosing ratio of 1:10,000 and the fuel with cata-

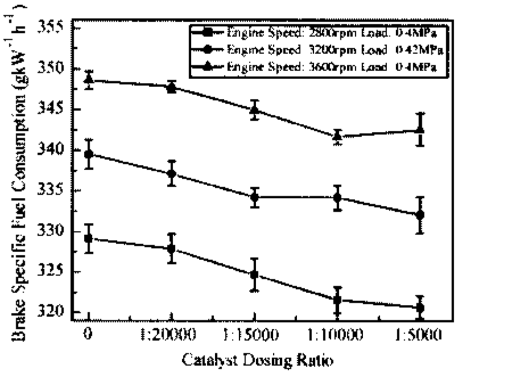

Fig. 3. The brake specific fuel consumption as a function of the catalyst dosing ratio.

Table 3
Results of ANOVA analysis.

		3600 rpm, 0.4 MPa		3200 rpm, 0.42 MPa		2800 rpm, 0.4 MPa	
		Mean difference	p-Value	Mean difference	p-Value	Mean difference	p-Value
Pure diesel	1:20,000	0.78	0.336	2.38	0.037	1.12	0.315
	1:15,000	3.64	<0.0001	5.32	<0.0001	4.42	0.01
	1:10,000	6.92	<0.0001	5.32	<0.0001	7.44	<0.0001
	1:5000	6.02	<0.0001	7.4	<0.0001	8.4	<0.0001
1:20,000	1:15,000	2.86	0.002	2.94	0.012	3.3	0.007
	1:10,000	6.14	<0.0001	2.94	0.012	6.32	<0.0001
	1:5000	5.24	<0.0001	5.02	<0.0001	7.28	<0.0001
1:15,000	1:10,000	3.28	0.001	0	1.0	3.02	0.012
	1:5000	2.38	0.007	2.08	0.065	3.98	0.002
1:10,000	1:5000	−0.9	0.269	2.08	0.065	0.96	0.388

Note: Mean difference in the table refers to the difference between the mean values of BSFC the two fuels compared. p-Value indicates the significance of the difference at the 95% confidence level.

lyst dosing ratio of 1:5000 is almost the same. This implies that the optimum catalyst dosing ratio seems to be around 1:10,000.

The dependency of the brake specific fuel consumption on the engine load (BMEP) when the engine was run at engine speeds of 2800 rpm, 3200 rpm and 3600 rpm, respectively, with pure diesel and diesel dosed with different catalyst dosing ratios are is presented in Fig. 4. It is obvious that the application of the homogeneous combustion catalyst reduced the brake specific fuel consumption under all tested load conditions. It is also evident that the homogeneous combustion catalyst has a greater effect when the diesel engine was run under light loads. For example, under the engine speed of 2800 rpm, the use of the homogeneous combustion catalyst reduced the brake specific fuel consumption from 573.1 to 548.9 $gkW^{-1}\,h^{-1}$ (4.2% fuel saving), at the engine load of 0.12 MPa and the catalyst dosing ratio of 1:10,000. As the engine load increased, the influence of the homogeneous combustion catalyst on the brake specific fuel consumption become less significant. Under the tested engine speeds and engine load of 0.4 MPa, the brake specific fuel consumption is reduced by 2–2.4% when the fuel was dosed with the catalyst at a dosing ratio of 1:10,000. The reason may be interpreted as follows. The gas temperature in the cylinder is higher when the engine load is higher, leading to a better burning condition of the fuel mixture, with or without the catalyst. Consequently, the ability of the homogeneous combustion catalyst to promote diesel combustion process at higher engine loads is not as significant as that at light engine loads.

The variation of the brake thermal efficiency on the engine load when the engine was run at engine speeds of 2800 rpm, 3200 rpm and 3600 rpm, respectively, with pure diesel and diesel dosed with catalyst at dosing ratio of 1:10,000 is illustrated in Fig. 5. It can be seen that the brake thermal efficiency increases with increasing engine load, reaching the maximum values of 24–26%. This implies that the energy conversion efficiency is higher at the higher engine load condition due to the higher gas temperature and better burning conditions. It is also evident that the brake thermal efficiency increases due to the use of the homogeneous combustion catalyst under the tested engine conditions. At the engine speeds of 2800 rpm, 3200rom and 3600 rpm and with the catalyst dosing ratio of 1:10,000, the improvement of the brake thermal efficiency reached approximately 0.3–0.8%. It is also seen that the improvement of the brake thermal efficiency is slightly greater in the light load range. For example, under engine speed of 2800 rpm and the catalyst dosing ratio of 1:10,000, the brake thermal efficiency was improved by 0.52% at the engine load of 0.12 MPa but by 0.3% at the engine load of 0.4 MPa.

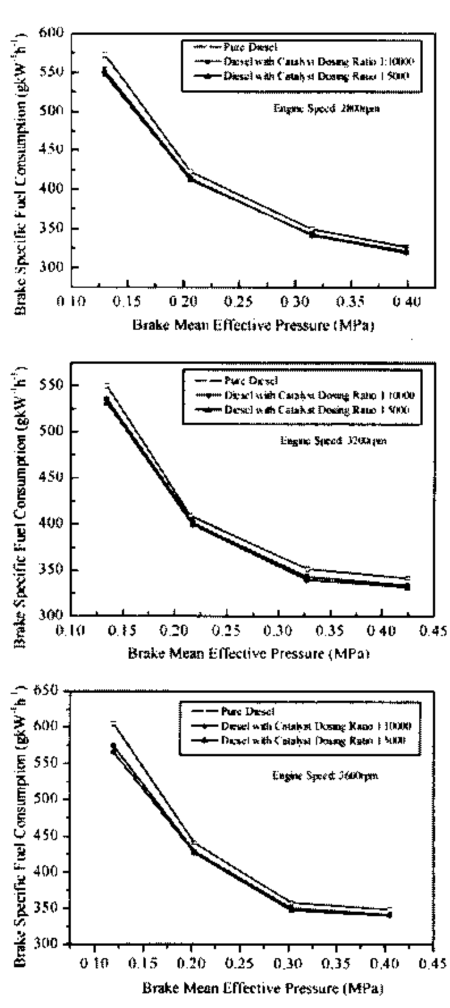

Fig. 4. The brake specific fuel consumption as a function of the engine load (BMEP).

5.2. *Effect of the catalyst on combustion characteristics*

Fig. 6 illustrates the engine cylinder pressure and pressure rise rate under the conditions of engine speeds 2800 rpm and 3200 rpm at the engine load 0.4 MPa and 0.42 MPa, respectively, when the fuel was dosed with catalyst at different ratios. In comparison with those with the pure diesel, the ignition timing is shortened with the diesel dosed with the homogeneous combustion catalyst and

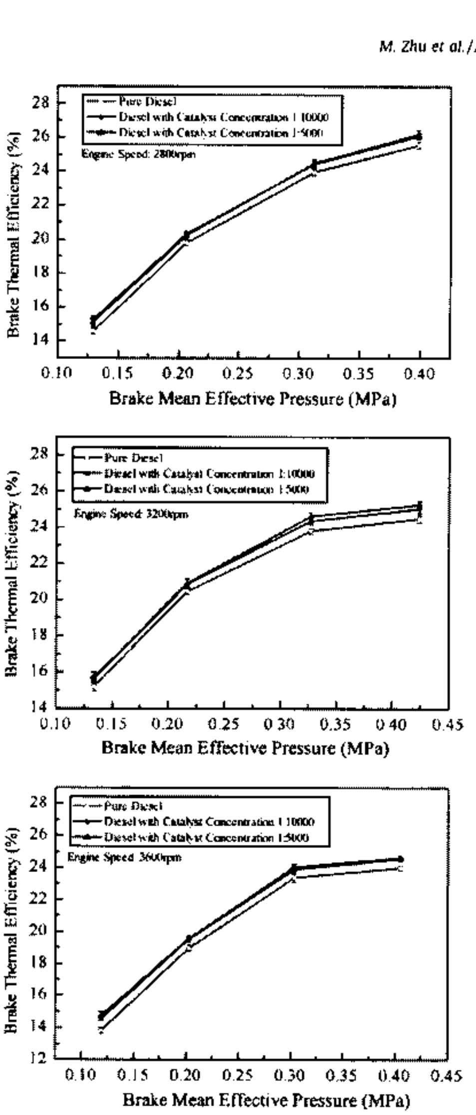

Fig. 5. The brake thermal efficiency as a function of the engine load (BMEP).

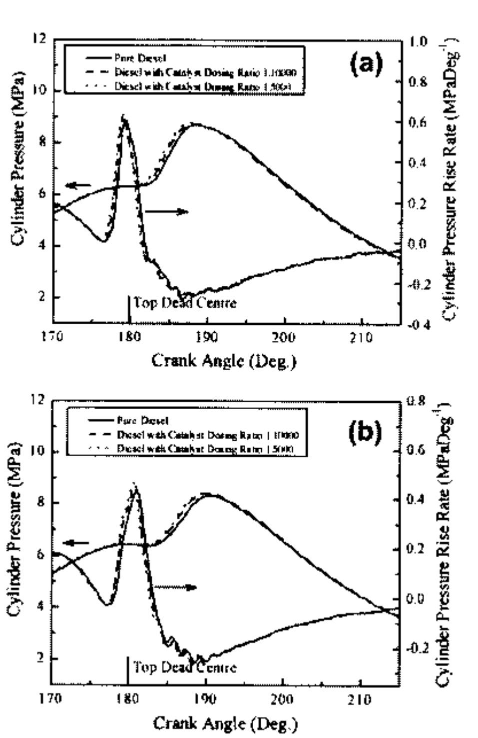

Fig. 6. In-cylinder pressure and pressure rise rate of the engine with the pure diesel and diesel dosed with the catalyst. (a): engine speed: 2800 rpm and engine load: 0.4 MPa; and (b): engine speed: 3200 rpm and engine load: 0.42 MPa.

the maximum pressure increases slightly. Due to the fact that the ignition timing occurred after the top dead center under both conditions seen in Fig. 6, the reduction of ignition timing with the addition of the catalyst implies that the combustion occurred closer to the top dead center, resulting in a higher maximum pressure and a higher rate pressure rise. It is also obvious that the ignition timing and the maximum pressure and pressure rise rate does not change significantly when the catalyst dosing ratio increases from 1:10,000 to 1:5000. This observation is consistent with the finding that the brake specific fuel consumption does not change significantly when the catalyst dosing ratio increased from 1:10,000 to 1:5000 as shown in Fig. 4.

Based on the above measured pressure data, the heat release rates of the pure diesel and the fuel dosed with the catalyst at dosing ratios of 1:10,000 and 1:5000 were calculated and shown in Fig. 7. It is very clear that the rate of burning is very high after the ignition, which corresponds to the period of rapid cylinder pressure rise. This is followed by a period of gradually decreasing heat release rate. The commencement of heat release is advanced when the catalyst was dosed into the diesel fuel, resulting in a shorter ignition delay. The reduction of the ignition delay is less than 1 degree when the homogeneous combustion catalyst was added into the diesel fuel up to the dosing ratio of 1:5000. The end of the combustion was also advanced with the addition of the catalyst, shortening the total combustion duration. The reduction of the combustion duration is about two degrees when the homogeneous combustion catalyst was added into the diesel fuel up to the dosing ratio of 1:5000.

Fig. 8 shows the effect of the catalyst on the ignition delay and the combustion duration under different engine loads (BMEP) at the engine speed of 3200 rpm. It is seen from Fig. 8a that the ignition delay slightly decreased with increasing engine load for both pure diesel and diesel being dosed with the catalyst. Adding the catalyst into the diesel fuel resulted in a shorter ignition delay under all tested engine load conditions. However, it is evident that the effect of the catalyst on the ignition delay is more significant under lower engine loads. For instance, with the diesel fuel dosed with catalyst at a dosing ratio of 1:10,000, the ignition delay was shortened 0.7 °CA (decreasing from 14.2 °CA to 13.5 °CA) under engine load BMEP of 0.13 MPa while only 0.4 °CA (from 12.7 °CA to 12.3 °CA) under engine load BMEP of 0.42 MPa. It is also manifested that increasing the catalyst dosing ratio from 1:10,000 to 1:5000, the ignition delay did not change significantly. From Fig. 8b, it is seen that the combustion duration for all the tested fuels increased with increasing the engine load. With the increase of the engine load, more fuel is injected and consumed, which takes a longer time to complete the combustion. A significant reduction in the combustion duration was observed with the catalyst dosed in the diesel fuel and this was more remarkable under lower engine load. Under the BMEP of 0.13 MPa, the combustion

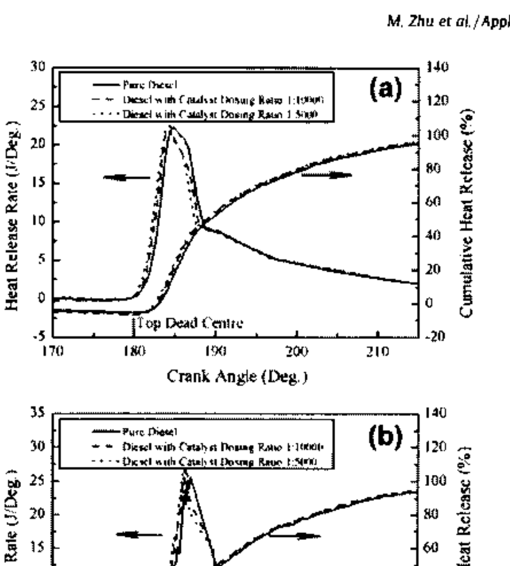

Fig. 7. Heat release rate and cumulative heat release of pure diesel and the diesel dosed with the catalyst. (a): engine speed: 2800 rpm and engine load: 0.4 MPa; and (b): engine speed: 3200 rpm and engine load: 0.42 MPa.

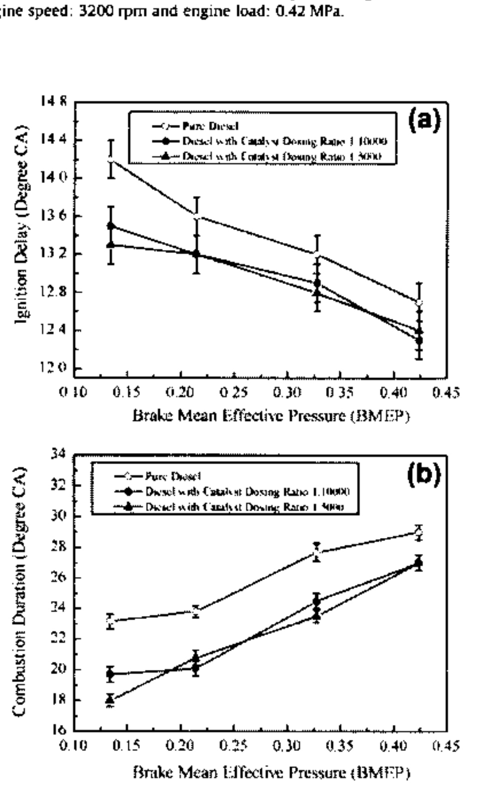

Fig. 8. Effect of the catalyst on the ignition delay and combustion duration under different engine loads (BMEP) at the engine speed of 3200 rpm.

duration was reduced by 3.5 °CA from 23.2 °CA to 19.7 °CA while only 2.2 °CA from 29.3 °CA to 27.1 °CA under the BMEP of 0.42 MPa with the use of the catalyst at a dosing ratio of 1:10,000. However, the combustion duration was not further shortened when the catalyst dosing ratio was doubled, especially at higher engine loads.

From Figs. 6–8, it is inferred that the homogeneous combustion catalyst plays a catalytic role during the diesel combustion process in the diesel engine. It promotes the ignition and accelerates the heat release of the diesel combustion in the engine, which allowing time for more complete fuel combustion [29].

6. Conclusions

The effect of the homogeneous combustion catalyst on fuel consumption and combustion characteristics in a diesel engine has been investigated under different engine speeds, loads and catalyst dosing ratios. The main conclusions can be drawn as follows:

1. The brake specific fuel consumption can be reduced up to 4.2% with the addition of the homogeneous combustion catalyst. However, the brake specific fuel consumption reduction does not correlate linearly with the catalyst dosing ratio and, when the catalyst dosing ratio is greater than 10,000, the brake specific fuel consumption becomes less variant.
2. The reduction of the brake specific fuel consumption is greater at light loads. With the catalyst dosing ratio of 1:10,000, the brake specific fuel consumption is reduced by 3.3–4.2% at light engine load of 0.12 MPa and only 2.0–2.4% at higher engine load of 0.4 MPa.
3. The brake thermal efficiency is increased with the addition of the catalyst. The brake thermal efficiency is increased by 0.3–0.8% at engine speeds of 2800 rpm, 320 rpm and 3600 rpm with the catalyst dosing ratio of 1:10,000.
4. The addition of the homogeneous combustion catalyst shortens the ignition delay and combustion duration of diesel in the engine, resulting in slightly higher peak cylinder pressure and faster heat release rate.

Acknowledgments

This project is supported by the Australia Research Council under the ARC Linkage Projects Scheme (Project Number: LP0989368) in partnership with Fuel Technology Pty Ltd. and BHPBilliton Iron Ore Pty Ltd.

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Appendix "C"

KWh Data Sheets

CONTROL ENGINE AMBIENT TEMP START 11.·
FINISH 15.·

SPECIFIC FUEL CONSUMPTION GENSET TRIAL

Customer: CALOSUG DAM
Genset No: 2
Date: 7 - 9 - 11

Make & Model: CUMMINS KTA 50
Engine Hrs: 59798.83
Date: Untreated/Treated: UNTREATED

Fuel Sample	Density	Temp Dec C
Corrected		15

Run No	Time Start	Period Mins	kWh Meter	kWh	Avg Load kW	Volts	Amps	L Exhaust Temp	R Exhaust Temp	Engine Temp	Fuel (L) Per kWh	Fuel Temp (C) In	Fuel Temp (C) Out	COMMENTS
START	7.15		31021813											
1	7.25	10	31021947	134		3400	1800	434	457	80				
2	7.35	10	31022080	133		3400	1800	433	457	79.7				
3	7.45	10	31022213	133		3400	1800	435	458	80				
4	7.55	10	31022347	134		3400	1775	431	457	79.5				
5	8.05	10	31022480	133		3400	1775	431	457	79.6				
6	8.15	10	31022613	133		3400	1775	434	460	79.9				
7	8.25	10	31022746	133		3400	1800	434	460	79.7				
8	8.35	10	31022880	134		3400	1800	440	462	80.3				
9	8.45	10	31023013	133		3400	1800	436	460	80.1				
10	8.55	10	31023146	133		3400	1775	437	460	80.2				
11	9.05	10	31023280	134		3400	1775	437	460	80.0				
12	9.15	10	31023413	133		3400	1775	438	461	80.4				
13	9.25	10	31023546	133		3400	1775	439	462	80.5				
14	9.35	10	31023679	133		3400	1775	438	461	80.0				
15	9.45	10	31023812	133		3400	1775	434	457	79.9				
16	9.55	10	31023946	134		3400	1775	437	461	80.1				
17	10.05	10	31024079	133		3400	1775	436	459	79.9				
18	10.15	10	31024213	134		3400	1775	434	461	79.5				

TEST ENGINE

START AMB. TEMP 27.9
FINISH AMB TEMP 25.6

SPECIFIC FUEL CONSUMPTION GENSET TRIAL

Customer: CAROSUE DAM
Genset No: 3
Date: 21 - 11 - 11

Make & Model: CUMMINS KTA 50
Engine Hrs: 62145.77
Date: Untreated/Treated: TREATED

Fuel Sample	Density	Temp Dec C
Corrected		15

L/EXHAUST R/EXHAUST ENG TEMP

Run No	Time Start	Period Mins	kWh Meter	kWh	Avg Load kW	Volts	Amps	~~Fuel (L) In~~ Trial	~~Out~~ Temp	~~L~~ Consumed	Fuel (L) Per kWh	Fuel Temp (C) In	Fuel Temp (C) Out	COMMENTS
START	5.15		36128579					46.5	44.1	86.5				
1	5.25	10	36128714	135		3400	165.0	46.5	44.0	86.8				
2	5.35	10	36128849	135		3400	165.0	46.2	43.7	85.3				
3	5.45	10	36128985	136		3400	165.0	46.1	43.6	84.6				
4	5.55	10	36129120	135		3400	165.0	46.0	43.7	84.7				
5	6.05	10	36129255	135		3400	165.0	45.8	43.4	84.1				
6	6.15	10	36129389	134		3400	165.0	45.9	43.6	84.6				
7	6.25	10	36129524	135		3400	165.0	45.5	43.1	83.1				
8	6.35	10	36129659	135		3400	165.0	45.4	43	82.8				
9	6.45	10	36129793	134		3400	165.0	45.3	42.9	82.1				
10	6.55	10	36129928	135		3400	165.0	452	42.9	81.8				
11	7.05	10	36130062	134		3400	165.0	454	43.1	82.2				
12	7.15	10	36130197	135		3400	165.0	455	432	82.8				
13	7.25	10	36130331	134		3400	165.0	453	430	82.2				
14	7.35	10	36130466	135		3400	165.0	451	429	81.6				
15	7.45	10	36130601	135		3400	165.0	453	430	82				
16	7.55	10	36130735	134		3400	165.0	45.2	42.9	81.6				
17	8.05	10	36130871	136		3400	165.0	45.1	43	81.6				
18	8.15	10	36131007	136		3400	160.0	45.3	43	81.4				

CAIN SET BASELOAD @ 800 KW — TEST ENGINE

AMB TEMP START 17.
FINISH 17.

SPECIFIC FUEL CONSUMPTION GENSET TRIAL

Customer: CARCASUK DAM

Genset No: 3

Date: 6-9-11

Make & Model: CUMMINS KTA 50

Engine Hrs: 60357.95

Date: Untreated/Treated: UNTREATED

Fuel Sample	Density	Temp Dec C
Corrected		15

Run No	Time Start	Period Mins	kWh Meter	kWh	Avg Load kW	Volts	Amps	Fuel (L) ~~In~~ FUEL TEMP	~~Out~~ L EXHAUST TEMP	~~Consumed~~ R EXHAUST TEMP	Fuel (L) Per kWh	Fuel Temp (C) In	Fuel Temp (C) Out	COMMENTS
START	2:05		34806690											
1	2:15	10	34806823	133										
2	2:25	10	34806956	133		3400	180.0	80.3	442	418				
3	2:35	10	34807090	134		3400	180.0	80.2	442	418				
4	2:45	10	34807223	133		3400	185.0	80.1	440	416				
5	2:55	10	34807356	133		3400	185.0	79.7	439	415				
6	3:05	10	34807489	133		3400	185.0	79.8	440	416				
7	3:15	10	34807623	134		3400	180.0	79.8	441	416				
8	3:25	10	34807757	134		3400	180.0	79.8	442	418				
9	3:35	10	34807890	133		3400	180.0	80.2	444	420				
10	3:45	10	34808024	134		3400	180.0	80.0	444	419				
11	3:55	10	34808157	133		3400	180.0	80.1	444	420				
12	4:05	10	34808290	133		3400	180.0	80.2	445	420				
13	4:15	10	34808423	133		3400	180.0	79.9	444	418				
14	4:25	10	34808556	133		3400	180.0	79.7	443	417				
15	4:35	10	34808690	134		3400	185.0	79.6	442	418				
16	4:45	10	34808823	133		3400	185.0	79.7	442	417				
17	4:55	10	34808956	133		3400	185.0	79.6	441	417				
18	5:05	10	34809089	133		3400	180.0	79.5	441	416				

CONTROL ENGINE

START AMBIENT TEMP 29.1
FINISH AMB. TEMP 27.9

SPECIFIC FUEL CONSUMPTION GENSET TRIAL

Customer: CAROLINE DAM
Genset No: 2
Date: 21-11-11

Make & Model: CUMMINS KTA 50
Engine Hrs: 81522.11
Date: Untreated/Treated: UNTREATED

Fuel Sample	Density	Temp Dec C
Corrected		15

Run No	Time Start	Period Mins	kWh Meter	kWh	Avg Load kW	Volts	Amps	L/EXHAUST Temp (Fuel (L) In)	R/EXHAUST Temp (Out)	ENG TEMP (Consumed)	Fuel (L) Per kWh	Fuel Temp (C) In	Fuel Temp (C) Out	COMMENTS
START	2.00p		32287281											
1	2.10	10	32287415	134		3400	1600	455	482	82.6				
2	2.20	10	32287549	134		3400	1600	458	484	83.2				
3	2-30	10	32287682	133		3400	16 00	456	484	83				
4	2.40	10	32287816	134		3400	1600	451	479	81.7				
5	2.50	10	32287951	135		3400	160.0	457	484	83.4				
6	3.00	10	32288085	134		3400	160.0	458	485	83.8				
7	3.10	10	32288220	135		3400	165.0	456	482	83.1				
8	3.20	10	32288355	135		3400	160.0	457	483	83.6				
9	3.30	10	32288490	135		3400	165.0	457	484	83.4				
10	3.40	10	32288626	136		3400	165.0	458	484	83.9				
11	3.50	10	32288761	135		3400	165.0	461	488	85				
12	4.00	10	32288897	136		3400	165.0	461	489	85.1				
13	4.10	10	32289033	136		3400	165.0	462	489	85.3				
14	4.20	10	32289169	136		3400	160.0	456	484	83.6				
15	4.30	10	32289305	136		3400	165.0	455	482	82.9				
16	4.40	10	32289441	136		3400	165.0	456	483	83.6				
17	4.50	10	32289578	137		3400	165.0	459	485	84.1				
18	5.00	10	32289715	137		3400	165.0	456	492	83.6				

SFCdatasheet