

# Diesel fuel additives for mining and industrial equipment

Rick Gillinder

School of Mechanical Engineering

Pilbara Iron

## Abstract

*For large scale machinery small improvements in fuel efficiency can translate to significant cost savings. Fuel additives may be one way to reduce the fuel consumption of existing machinery economically. Investigations of possible fuel savings from two diesel fuel additives were conducted. It was determined that controlled tests were required as small changes in operating conditions could conceal the effect of the additives. The additives were tested at different loading conditions with the use of generators coupled to resistive load banks. Different loads were chosen in an attempt to relate additive effectiveness to real engine conditions. Results showed improved fuel efficiency with a combustion catalyst. However the effects of the additive were seen to reduce with increasing load. Testing of the second additive is still being conducted to determine the effects of increasing cetane and introducing detergents into the fuel.*

## 1.0 Introduction

Mining corporations consume large volumes of diesel fuel in the order of hundreds of millions of litres per year. Thus reductions of even a few percent in fuel usage translate to considerable economic and environmental savings. Diesel fuel additives are one possible avenue of improving fuel efficiency. There are two main categories of fuel additives, those incorporated during the refining process and aftermarket additives. Aftermarket additives are products purchased by the consumer to further alter the fuels performance and are the focus of this report. Aftermarket diesel fuel additives can usually be divided into four groups: Engine performance, Fuel handling, Fuel stability and Contaminant control (Chevron, 1998). Additives relating to engine performance are considered in this report and they relate more directly to fuel consumption. The report will assess two main types of fuel additives: combustion catalysts and cetane improvers combined with detergents (multifunctional additives).

## 2.0 Background

Several studies have been carried out for Pilbara Iron in regards to the two additives tested in this report. Additive A was tested within the field environment by the additive producer, while laboratory tests were conducted with additive B. Positive test results were found with additive A in field conditions, however the many factors contributing to fuel consumption in the field required further controlled testing against a baseline to validate the results.

Additive B was tested by an independent company however, the tests results were obtained were not comparable with the initial test, and as such requires similar testing. Therefore further investigation into these fuel additives for use on Pilbara Iron site is warranted.<sup>1</sup>



<sup>1</sup> References have been left out to protect proprietary information.

Methods for testing the additives were investigated on Pilbara Iron's Paraburdoo site over a period of weeks. A fuel consumption test on Haul trucks was the initial focus of the project. However this was found to be unworkable as a first approach due to the nature of the mining operation and the variation in fuel consumption from factors generated in field operations. As a first approach for determining the effect of the fuel additives, tests on diesel generators were chosen. The results of these tests, while not being able to be translated exactly to field performance, provide a benchmark test for the additives to determine whether they warrant any further investigation in the field. The additives are to be tested on both near new and worn (greater than 5000hrs) generators as the additives producers claim additional performance benefits on older engines. The results pertaining to the new generators are discussed in this report.

The two additives were chosen on the grounds of past research at Pilbara Iron and the existence of supporting literature. İçingür & Altıparmak (2003) along with Ladommatos, Parsi & Knowles (1996) reported emissions reductions with the use of cetane improving chemicals. Furthermore a study by Garling et. al.(1995) claimed fuel savings of around 3% from improved injector cleanliness on older engines and 2.2% from a standard cetane number increase. Tests conducted by the South West Research Institute (Markworth 1992) along with others such as Guld (1985) found fuel savings from the use of a ferrous picrate combustion catalyst. Thus evidence exists to support the theoretical claims for the additive producers.

### 3.0 Theory

The general claim of most diesel fuel additives is that they provide reduced fuel consumption through improved combustion. The main difference for the two additives tested is the mechanism by which they improve combustion efficiency. For simplicity the relevant theory for each additive is discussed separately. However the consequence of the suggested mechanisms for both additives essentially related to the early stages of combustion. The additives aim to optimise the rate of heat release and the corresponding cylinder pressure rises shown in Figure 1.

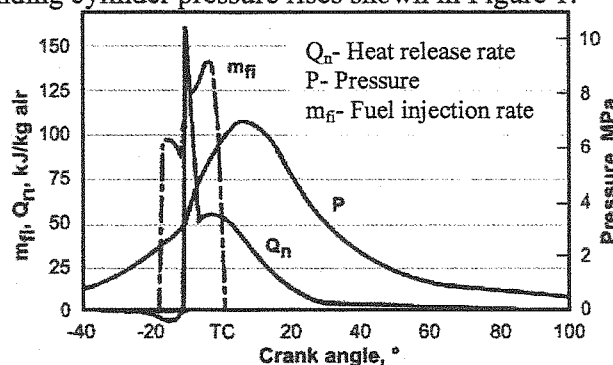


Figure 1 Heat release rate, Cylinder pressure and Injection rate with in a typical diesel cylinder. Adapted from Combustion in Diesel Engines (DieselNet, 2001)

### 3.1 Combustion Catalyst

Combustion catalysts generally contain some type of organo-metallic suspension in an organic solvent. The catalyst used in the testing contains ferrous picrate as the organo-metallic compound. Parsons and Germane (1989) suggest the primary mode of action for ferrous picrate additives is related to a reduction in combustion time. It is claimed that the additive forms flat crystalline particles within the air fuel mixture which act as propagating centres to provide multiple flame fronts and thus promote higher rates of flame propagation. In addition to this increase in combustion sites the decomposition of the additive provides excess kinetic energy to the local fuel molecules. (Guld 1985). Therefore more fuel combusts when the piston is near the beginning of the power

stroke (TDC), thus approaching the idea cycle. (Parsons and Germane, 1989) Therefore providing more a complete and optimally timed combustion is claimed as the overall mode of action of the additive.

### 3.2 Multifunctional Diesel Additive

The Multifunctional additive contains two main components relating to improved fuel consumption; a cetane improver, Ethylhexyl Nitrate (EHN), and a detergent package. The cetane number of diesel fuel is a measure of ignition quality. (Chevron 1998) A fuel with a high cetane number is characterized by a short ignition delay period. (Dieselnet, 2003) (See Figure 2 ). Higher cetane numbers are associated with reduced engine noise and reduced particle matter and NO<sub>x</sub> emissions (DieselNet, 2005). Figure 2 shows reducing the ignition delay (ID) reduces the height of the pre-combustion-pressure-peak and thus reduce engine noise. This pre-combustion peak shown in Figure 1 and 2 produces the effect known as the diesel knock.

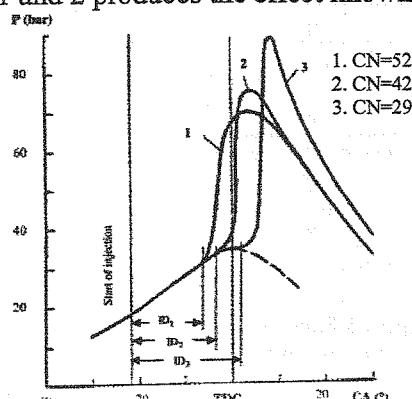


Figure 2 Effect of Cetane Number (CN) on early combustion. Adapted from İçingür and Altıparmak (2003)

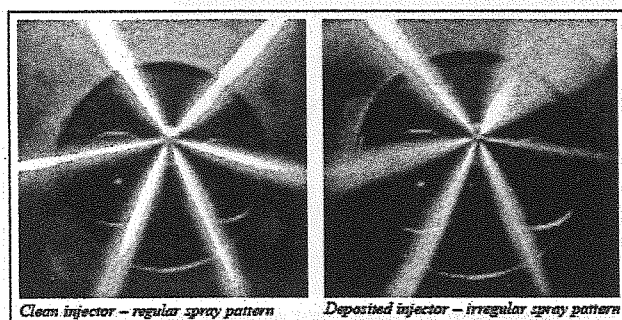


Figure 3 Injector spray patterns. Adapted from (Chevron 1998)

Detergents play two major roles: keeping fuel injectors clean to maintain optimum fuel atomisation and decreasing the surface tension of droplets during the injection process to enable fine atomisation (White 2005). Figure 3 shows the effect of a dirty injector on fuel spray formation. It is quite conceivable that uneven injection may sufficiently affect the air/fuel ratio throughout the cylinder causing the air/fuel ratio to be too lean in some areas and too rich in others. This will lead to incomplete combustion in those affected areas and thus producing undesirable emissions and an increase in fuel consumption. Cleaning effects of additives have been reported to provide fuel savings of around 3% (Garling et. al. 1995).

### 4.0 Methods

Two turbocharged 75kVA generators of the same make and model were run along side one another and coupled to resistive load banks. The ambient conditions were found to affect the fuel usage in a number of ways. Thus a simple calibration was not sufficient for the measurement accuracy required. Therefore one generator was used as a control variable while the other was used for testing. Diesel was stored in 205L drums within a bonded storage area. Two drums were also reserved for the required mixing of the additives. Unfortunately the quantity of diesel permitted for storage was not sufficient for the complete testing of each additive. However the control variable could be used to remove the effect of changing fuel quality. Fuel samples were also taken for further analysis.

Each additive was tested at three different loads (50%, 75% and 100%) at a constant speed of 1500 RPM for a period of approximately 8 hours per load. Baselines were also produced for each

additive at these loads. A conditioning period of 48hrs for additive B and 120hrs for A (due to the special requirements of the additive A) was undertaken. Figure 5 shows the testing procedure of each additive. The generators were serviced (Oil, Oil filter and fuel filters) and a cleaning period of around 48hrs was undertaken before a different additive was introduced.

Fuel usage was measured via positive displacement flow meters on the inlet and outlet fuel lines. Furthermore thermocouples were placed in the fuel lines to enable the density of diesel to be corrected for changes in temperature. The brake specific fuel consumption (BSFC) was calculated via the mass of the fuel consumed by the engine during a 15 minute period divided by the energy produced during that time (kWh). Note the density of the diesel was taken to be a nominal 0.85kg/L at 15°C, any deviation from this is adjusted through the control.

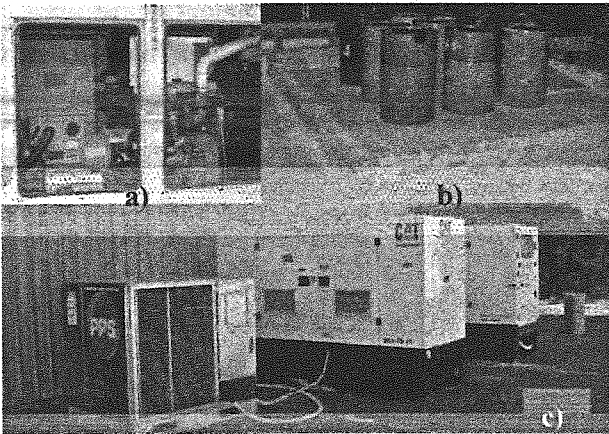


Figure 4 Pictures of equipment a) Inside view of generator, b) banded fuel storage, c) generators and load banks

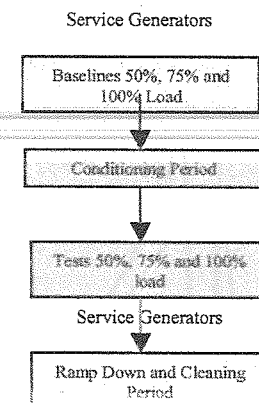


Figure 5 Flow chart for testing per additive

A number of other variables were also measured for the purpose of evaluating engine performance and establishing the reliability of results. These include: exhaust emissions, oil temperature, exhaust temperature, load (kW), frequency, voltages and currents. Fuel and oil samples were also taken for further analyses at a later date. Figure 6 indicates the schematic layout of each generator being used and the various points of measurement.

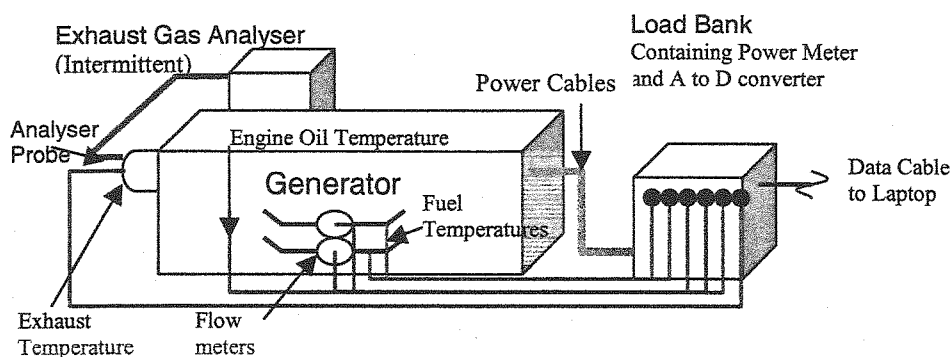


Figure 6 Schematic of the experimental setup

## 5.0 Results

### 5.1 Fuel Consumption

The data presented below has been adjusted with respect to the control to remove the effect of ambient conditions and variation in fuel quality. The following results are presented for additive A. The frequency histograms in Figure 7 depict the statistical significance of the data and Table 1

provides the average values of fuel usage with and without additive treatment. Additive B is still undergoing testing and thus the results are to be presented at a later date.

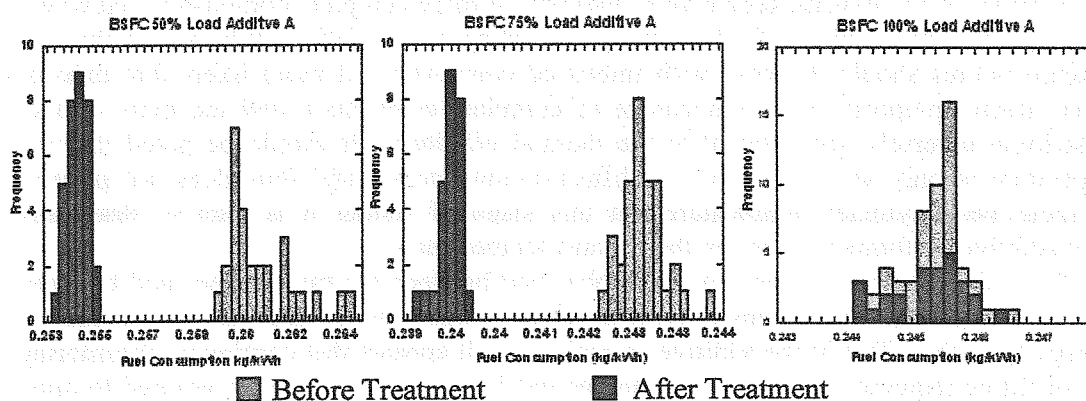


Figure 7 Brake Specific Fuel Consumption (BSFC) before and after treatment with additive A

Table 1 Average Test Results of Additive A

Additive A					
% Load	Before Treatment (kg/kWh)		After Treatment (kg/kWh)		% Change
	Mean	Std dev	Mean	Std dev	
50	0.2609	0.0009	0.2543	0.0003	-2.6
75	0.2429	0.0003	0.2397	0.0001	-1.3
100	0.2454	0.0003	0.2453	0.0005	Insignificant

## 5.2 Exhaust Temperature (Additive A)

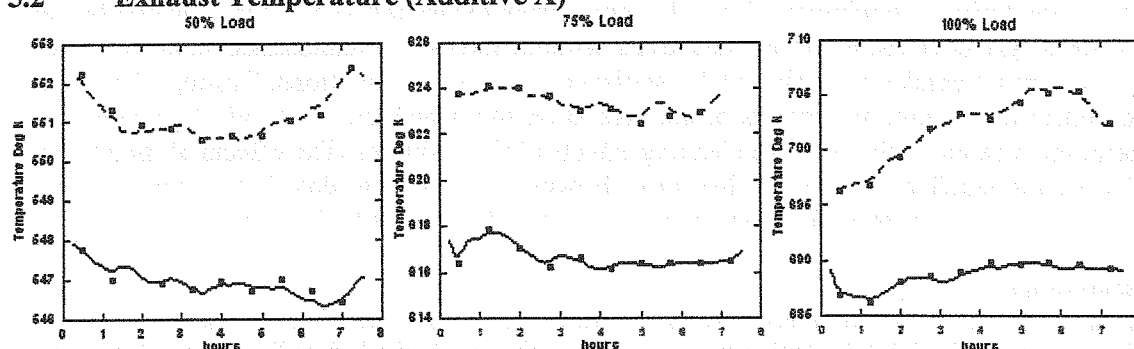


Figure 8 Effect of Additive A on the exhaust temperature ● Before Treatment □ After Treatment

After treating with additive A an increase in the exhaust temperature of around 2.2%, 0.8% and 2.0% was measured for one half, three quarter and full loading respectively.

## 6.0 Discussion

There appears to be a measurable effect on fuel the consumption by treating the system with additive A at half and three quarter load. The fuel savings measured at three quarter load are similar to that found at the Southwest Research Institute (Markworth 1992). The results seem to indicate that the fuel savings provided by the additive reduce with increasing load. This result may not be surprising as the effect of the catalyst is likely to be reduced by the existence of a greater natural percentage of propagating centres at high load.

Figure 8 shows that an increase in the exhaust temperature was found by treating the generator with additive A. These results agree with those found by Guld (1985) with ferrous picrate. Guld (1985) stated that an increase in the exhaust temperature indicated a more complete combustion. However these findings disagree with claims of others such as Garling et. al. (1995). Who stated that the combustion temperatures should decrease with improved combustion. It more likely that exhaust temperature is directly proportional to percentage of complete combustion and the mass of fuel induced. In addition inversely proportional to the thermal efficiency. It should be noted that the exhaust temperature is only an average over a fifteen-minute period and thus does not provide information about peak cylinder temperature. At this stage of testing it is hard to draw any conclusions of additive performance base on the exhaust temperatures.<sup>2</sup>

Significant differences in emissions were observed between the two engines and between the applied loads, however the measurement error in emission data was too great for conclusions to be drawn in regards to the effect of the additive on emissions. It appears that continuous monitoring of emissions would be required to achieve the number and frequency of sampling required to draw any conclusions from emission data.

## 7.0 Conclusions

The results of the fuel consumption tests indicate that savings at half and three quarter loads can be achieved with the treatment using additive A. However the additive appears to have no measurable effect at full load. It should be noted that even though significant savings have been measured with a treatment using additive A, other unrelated changes can also have a significant effect on the measured performance. Cooling system efficiency and air leaks in the fuel system have been the two major factors impeding the study to date, however many others are possible. From the data collected it appears that early detection of equipment failure is conceivable and thus supports the argument for the condition monitoring of equipment. It would appear from the testing to date that it would be very difficult to draw any conclusions from field trials without intensive maintenance schedules and a large number of test vehicles operating under statistically identical conditions. Testing is currently being undertaken to examine the effects of additive B on the generators. Test will be repeated on older generators to examine the putative cleaning effects of the additives. The effects of the additive measured are quite small in relation to the noise. However, the tests to date have demonstrated a method of isolating the effects on fuel consumption of the additives to a high degree.

## 8.0 References

- Chevron Products Company. 1998, "Diesel Fuels Technical Review", Chevron Products Company, San Francisco
- DieselNet Technology Guild, 2001, "Combustion in Diesel Engines"[Online], Available from: DieselNet, [14 Aug 2005]
- Guld, J. 1985 "Performance evaluation of a ferrous picrate combustion catalyst applied to diesel fuel", Western Australia
- Institute of Technology, Bently Western Australia
- Garling, M. et. al. 1995, "The effect of Modern Additive Technology on Diesel Fuel Performance", SAE technical paper series, ref no. 950252
- İçingür, Y. & Altıparmak, D. 2003, "Effect of fuel cetane number and injection pressure on a DI Diesel engine performance and emissions", Energy Conversion & Management, vol.44, pp. 389-397
- Ladommatos, N., Parsi, M. & Knowles, A. 1996, "The effect of fuel cetane improver on diesel pollutant emissions", Fuel, vol. 75, no.1, pp. 8-14
- Markworth, V. 1992, "Evaluation of a fuel additive Final report volume 1", Southwest Research Institute, San Antonio
- White, D. A S Harrison & Co Pty. Ltd., Personal Communication

<sup>2</sup> Some doubt exists in regards to the results at full load as overheating became a problem at full load shortly after the completion of testing. The radiator was cleaned after the problem was detected.