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MACMAHON CONTRACTORS
KOMATSU 785-3 & 630E HAUL TRUCK
FUEL EFFICIENCY TRIALS

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CONTENTS

Appendices

EXECUTIVE SUMMARY

Fuel Technology Pty Ltd initiated trials with F K Kanny & Son in Western Australia mid 1987. Initial carbon balance trials were conducted on two low loader prime movers. Following the success of these trials in reducing fuel consumption under a given load condition, trials were conducted at the Golden Valley mine site in Western Australia on a fleet of Caterpillar 773 dump trucks which showed a 7.4% reduction in fuel consumption following FTC treatment of fuel.

A number of further tests were conducted at Kanny, then MacMahon contract sites, namely Eneabba, Orebody 25, Alcoa, Youanmi and Kurara.

The fuel at all MacMahon contract mine sites in Western Australia is FTC treated.

Following discussion with MacMahon's Eastern Region Maintenance Management, agreement was reached to evaluate the performance of FTC in a Caterpillar 777C at Giralambone mine site employing the engineering standard Specific Fuel Consumption test procedure.

The reduction in fuel consumption measured following FTC treatment was 7.6% following correction for variation in inlet air temperature.

The addition of a new contract open cut mining site to MacMahon WA’s workbook namely, Mt Edon Gold Mine’s, Tarmoola operation presented the opportunity to conduct fuel consumption tests to verify the improvement in combustion efficiency provided by FTC. Evaluation methods used to test the effect of FTC were the Carbon Balance test of exhaust emissions on a sample of the Komatsu 785-3 and 630E dump truck fleet and a Volumetric Fuel Consumption test on Dump Truck 2173 (Komatsu 785-3).

Performed on a back to back, untreated-treated basis, the tests **resulted in an efficiency gain of 6.8% by Carbon Balance Test procedure and 6.7% by Volumetric Fuel Consumption Test procedure**. The results were proved to be significant by student t-Test at a 99% confidence level.

INTRODUCTION

Since incorporation in 1982 Fuel Technology Pty Ltd has been supplying a ferrous iron based Organo-metallic combustion catalyst, FTC, to the mining industry to provide improved fuel efficiency and maintenance.

As part of the on going verification of the fuel efficiency benefits of FTC Combustion Catalysts, Fuel Technology, in conjunction with MacMahon Contractors have been engaged in a series of static fuel consumption tests using the exhaust emission Carbon Balance test procedure based on AS2077-1982.

With the acquisition of flow measurement equipment, which could be retro-fitted to the vehicle for the trial, a controlled test was devised (Haul Truck Volumetric Fuel Measurement Procedure) which could be used to evaluate FTC in an actual operational environment. Initiated at the Giralambone operations in NSW, the objective of the test was to measure the absolute amount of fuel consumed against work done over a defined haul.

The tests demonstrated a fuel consumption improvement of 7.6%.

Following further discussions with the WA division, it was agreed to test a fleet of Komatsu 785-3 and 630E dump trucks operating under contract at Mt Edon's Tarmoola Gold Mine. Three 785-3 and two 630E dump trucks were tested by Carbon Balance method. In addition dump truck 2173 (785-3) was test by the Haul Truck Volumetric Fuel Consumption method.

Performed on a back to back, untreated-treated basis, the baseline (untreated) test was commenced on the 18/3/97 followed by the treated tests on 22/4/97.

This report details the test procedures and results measured.

TEST PROCEDURE

1. Haul Truck Volumetric Fuel Measurement

The basis of the Haul Truck Volumetric Fuel Measurement test is to measure the absolute amount of fuel consumed against the work done.

A start point at the base of the pit ramp and a finish point at the top of pit ramp were marked with sighting posts and the distance was measured with a surveyors wheel.

Flow transducers fitted with thermocouple probes were connected to the dump truck's fuel tank outlet and inlet pipework (*Photograph No. 1*).

These transducers, calibrated to ± 0.25% by a NATA Certified Laboratory, were then coupled to a Minitrol totaliser mounted in the cab (*Photograph No. 2*).

Because the temperature of engine return fuel is considerably higher than inlet fuel together with the fact that the fuel temperature continues to rise during the working cycle resulting in density variations, the fuel temperatures at each flow transducer was measured via a Fluke digital dual readout thermometer also mounted in the cab.

Prior to the test commencing a fuel sample was drawn from the test truck and density measured at observed temperature. Density was then corrected to industry standard of 15^{o}C using the Institute of Petroleum Density Correction Table, Volume VIII, Table 53B.

Following loading of the dump truck for each cycle and allowing the load monitor to register, load in kilograms (kg) was recorded. Upon arrival at pit ramp marker the test truck stopped and the Minitrol totaliser and stop watch were zeroed. At signal "*GO*" the driver accelerated and the test engineer activated the stop watch and Minitrol totaliser.

To avoid any driver variables the test truck was driven at full throttle over the test circuit. Fuel temperatures were recorded and upon arrival at the top marker the stop watch and Minitrol unit readings are recorded. Tests were conducted throughout the day on all available runs.

The results achieved by the test trucks are shown in Table I. The results are reported as fuel consumed in kilograms/tonne which relates to a more accurate mass measurement compared to the usual mine operations method of recording litres/hour. However, to fully assess fuel consumed for a given amount of work done the formula:-

$$\frac{\text{Load carried x Distance travelled}}{\text{Fuel consumed}}$$

Should be employed, thus reporting efficiency as *Tonne kilometres/kilogram (Tkm/kg)*. (Koehler & Doglio, 1987)

2. Carbon Balance (CB)

Carbon Balance test (AS2077-1982) works on the principle that carbon entering the engine as a component of fuel must be exhausted from the engine as components of the exhaust gas, namely carbon monoxide (CO), carbon dioxide (CO_2) and unburned hydrocarbon (HC). By measuring the exhaust gas volumetric flow rate by a pitot tube inserted into the exhaust stack and measuring exhaust temperatures and pressure, a mass per unit volume of components containing carbon (CO, CO_2 and HC) can be taken and used to calculate the carbon flow in grams/second (fuel consumption). In back to back, untreated and treated tests, the objective of the test is to measure the percentage change in carbon flow under as close to identical load conditions as possible.

3. Bosch Smoke Tests

Bosch smoke tests were also conducted to analyse soot particulate in exhaust emissions. A Bosch sampling pump was used to take a defined quantity of exhaust smoke and pass it through a filter disc. The resultant darkened filter disc is photoelectronically evaluated with a Bosch smoke meter evaluation unit. The result is expressed as a value between 0.0 (clean) to 9.9 (dirty)

TEST RESULTS

1. HAUL TRUCK VOLUMETRIC FUEL CONSUMPTION KOMATSU 785-3 DUMP TRUCK No 2173

A test run was marked out with marker post from the bottom of the north pit to the pit ramp just prior to the intersection of the waste dump haul road (785m). Gross tonnes hauled by the haul distance per kilogram of fuel (T km/kg) was calculated and the arithmetic mean determined.

TABLE 1
TEST DATA & RESULTS

SPECIFIC FUEL CONSUMPTION TRUCK TRIAL

Customer:	MacMahon Contractors	Engine Hrs	13184
Location	Tarmoola	Amb; Temp; Start deg; C	21.1
Date:	26/03/97	Amb; Temp; Finish deg; C	34
Truck No;	DT 2173	Circuit Distance Metres	785
Make/Model	Komatsu 785-3	Truck Empty Weight	61800

Fuel Sample	Density	Temp Deg C
	0.826	37.2
Corrected	0.842	15

UNTREATED

Run No	Time	Gross	Haul Time		Fuel (Lt)		Fuel (Lt)	Fuel Temp		Density		Fuel (kg)		Fuel (kg)	Fuel (kg)	Tonne km
		Load kg	Mins	Sec	In	Out	Consumed	In	Out	In	Out	In	Out	Consumed	/Tonne	/ Fuel kg
1	7.00	141800	4	06	34.81	21.51	13.30	42.0	50.9	0.823	0.816	28.63	17.56	11.08	0.0781	10.05
2	7.25	141800	4	06	34.86	21.54	13.32	42.2	52.5	0.823	0.815	28.67	17.56	11.11	0.0784	10.02
3	8.15	136800	4	05	34.48	21.21	13.27	43.4	54.2	0.822	0.814	28.33	17.26	11.06	0.0809	9.71
4	8.40	136800	4	08	34.61	21.32	13.29	43.8	54.0	0.821	0.814	28.43	17.36	11.07	0.0809	9.70
5	9.05	138800	4	07	34.50	21.21	13.29	44.6	55.3	0.821	0.813	28.32	17.25	11.07	0.0798	9.84
6	9.25	132800	4	03	34.02	20.92	13.10	45.6	56.6	0.820	0.812	27.90	16.99	10.91	0.0821	9.56
7	10.10	140800	4	16	35.51	21.85	13.66	45.8	55.4	0.820	0.813	29.11	17.77	11.35	0.0806	9.74
8	10.40	144800	4	25	36.48	22.43	14.05	47.3	57.0	0.819	0.812	29.87	18.21	11.66	0.0805	9.75
9	11.10	139800	4	11	34.80	21.39	13.41	49.2	59.6	0.818	0.810	28.45	17.33	11.12	0.0795	9.87
10	11.25	135800	4	13	34.92	21.54	13.38	50.5	60.6	0.817	0.810	28.52	17.44	11.08	0.0816	9.62
11	11.45	136800	4	18	35.17	22.04	13.13	51.8	61.6	0.816	0.809	28.69	17.83	10.86	0.0794	9.89
12	12.00	134800	4	15	34.92	21.51	13.41	53.3	63.3	0.815	0.808	28.45	17.37	11.08	0.0822	9.55
13	12.15	135800	4	07	34.23	21.05	13.18	54.5	64.0	0.814	0.807	27.86	16.99	10.87	0.0800	9.81
14	12.45	137800	4	09	35.03	21.59	13.44	34.2	49.9	0.828	0.817	29.01	17.64	11.37	0.0825	9.51
15	13.00	132800	4	03	34.41	21.22	13.19	36.2	52.2	0.827	0.815	28.45	17.30	11.14	0.0839	9.35
16	13.15	138800	4	15	35.82	22.18	13.64	38.0	53.7	0.826	0.814	29.57	18.06	11.51	0.0829	9.47
Mean		137925					13.38							11.146	0.0808	9.72
Std Dev		3324.154					0.2388							0.2217	0.0016	0.1957
C.V		2.4%					1.8%							2.0%	2.0%	2.0%

Customer:	MacMahon Contractors	Engine Hrs	13646
Location	Tarmoola	Amb; Temp; Start deg; C	8.1
Date:	7/05/97	Amb; Temp; Finish deg; C	22.5
Truck No;	DT 2173	Circuit Distance Metres	785
Make/Model	Komatsu 785-3	Truck Empty Weight	61800

Fuel Sample	Density	Temp Deg C
	0.836	21
Corrected	0.840	15

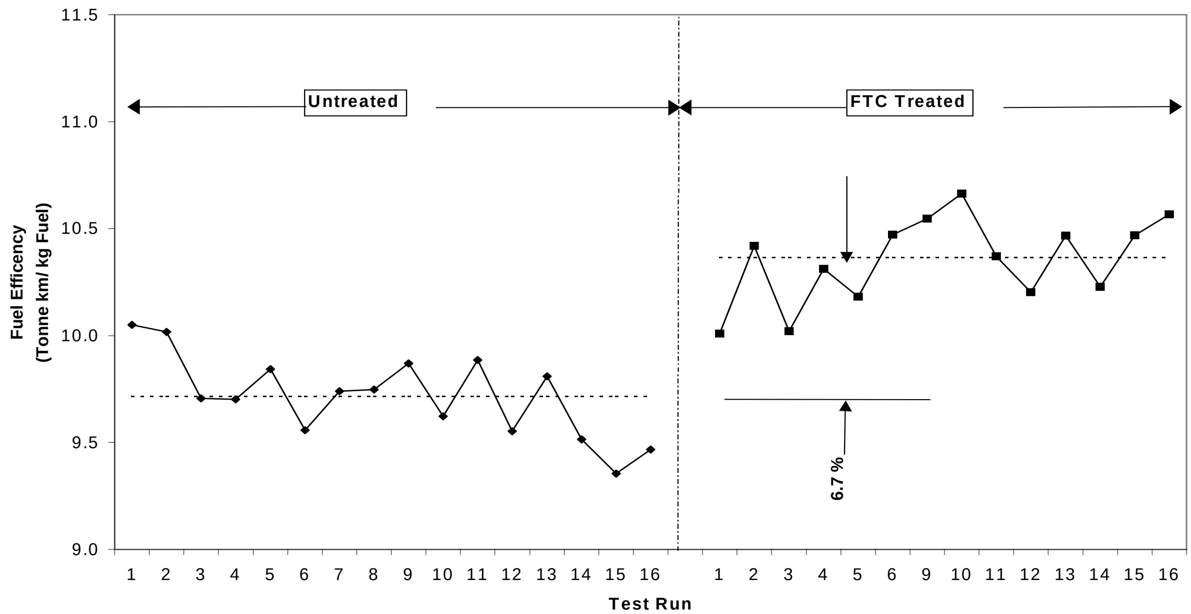
TREATED

Run No	Time	Gross	Haul Time		Fuel (Lt)		Fuel (Lt)	Fuel Temp		Density		Fuel (kg)		Fuel (kg)	Fuel (kg)	Tonne km
		Load kg	Mins	Sec	In	Out	Consumed	In	Out	In	Out	In	Out	Consumed	/ Gross Tonne	/ Fuel kg
1	6.45	138800	3	52	32.95	20.18	12.77	15.4	26.6	0.840	0.832	27.67	16.79	10.88	0.0784	10.01
2	7.10	155800	4	16	35.88	22.15	13.73	16.4	30.1	0.839	0.830	30.11	18.37	11.74	0.0753	10.42
3	7.30	142800	3	52	33.27	20.27	13.00	14.1	31.9	0.841	0.828	27.98	16.79	11.19	0.0783	10.02
4	7.50	147800	3	54	34.00	20.84	13.16	17.8	32.8	0.838	0.828	28.50	17.25	11.25	0.0761	10.31
5	8.05	140800	3	47	32.50	19.77	12.73	19.7	34.1	0.837	0.827	27.20	16.34	10.86	0.0771	10.18
6	8.25	145800	3	49	32.84	20.01	12.83	20.1	33.9	0.837	0.827	27.47	16.54	10.93	0.0750	10.47
7	8.55	152800	4	06	35.11	21.54	13.57	21.0	34.7	0.836	0.826	29.35	17.80	11.55	0.0756	10.38
8	9.35	146800	3	51	33.15	20.30	12.85	23.6	37.8	0.834	0.824	27.65	16.73	10.92	0.0744	10.55
9	9.55	154800	4	07	35.04	21.44	13.60	25.3	38.2	0.833	0.824	29.18	17.66	11.52	0.0744	10.55
10	10.35	158800	4	17	36.02	22.21	13.81	26.8	39.6	0.832	0.823	29.97	18.27	11.69	0.0736	10.66
11	11.00	151800	4	08	35.19	21.61	13.58	27.7	41.1	0.831	0.822	29.25	17.76	11.49	0.0757	10.37
12	11.20	145800	3	59	34.20	20.92	13.28	29.1	42.2	0.830	0.821	28.39	17.18	11.22	0.0769	10.20
13	11.40	152800	4	07	35.08	21.51	13.57	30.0	43.3	0.830	0.820	29.10	17.64	11.46	0.0750	10.47
14	12.05	145800	3	59	34.34	21.06	13.28	31.6	44.2	0.829	0.820	28.45	17.26	11.19	0.0767	10.23
15	12.30	147800	3	58	34.17	21.01	13.16	32.7	45.6	0.828	0.819	28.28	17.20	11.08	0.0750	10.47
16	12.45	143800	3	47	32.83	20.13	12.70	33.4	45.8	0.827	0.818	27.16	16.47	10.68	0.0743	10.57
Mean		148300					13.23							11.229	0.0758	10.37
Std Dev		5656.854					0.3822							0.3215	0.0014	0.1931
C.V		3.8%					2.9%							2.9%	1.9%	1.9%

% CHANGE: **Treated-Baseline**	Load kg	Fuel (Lt) Consumed	Fuel (kg) Consumed	Fuel (kg) /Tonne	Tonne km / Fuel kg
Baseline	7.52%	-1.14%	0.74%	**-6.3%**	**6.7%**

Graph 1 plots the trucks fuel efficiency over each test phase.

GRAPH 1
FUEL EFFICIENCY CHANGE



FUEL EFFICIENCY CHANGE

	Tkm/kg
Untreated	9.71
FTC-1 Treated	10.37
% CHANGE	**- 6.7%**

To prove the statistical significance of the difference in means between baseline and treated test a Students t-test was performed.

Formula: $$t = \frac{x_1 - x_2}{\dfrac{(n_1 - l) S_1{}^2 + (n_2 - l) S_2{}^2}{(n_1 - n_2 - 2)} \quad \dfrac{l + l}{n_1 + n_2}}$$

Hypothesis: $H_o: \quad U_1 - U_2 = 0$

$H_1: \quad U_1 - U_2 \neq 0$

where:-

	Baseline	**Treated**
	$x_1 = 9.72$	$x_2 = 10.37$
	$n_1 = 16$	$n_2 = 16$
	$S_1 = 0.195655419$	$S_2 = 0.193080373$

Confidence Level	=	99%
α	=	0.005
degrees of freedom	=	30
Critical t value	=	2.75
t	=	-9.48

Since –9.48 is outside the range +/- 2.75 we reject H_o and accept H_1 and conclude that the difference between truck efficiency means is significant at a 99% confidence level.

T-test spreadsheet is included in the appendices.

2. CARBON BALANCE TESTS

The dump trucks were tested adjacent the haul road to the south waste dump and atop the north waste dump. Each unit was driven to the test location where unit numbers (630E) 2183, 2184 and (785-3) 2174, 2178 and 2179 had brakes applied, transmission set to park and engine RPM set to (630E) 1900 and (785-3) 2000 RPM.

Once the exhaust temperature had stabilised five readings were taken for each parameter and a Bosch Smoke sample drawn.

A summary of the results of the individual Carbon Balance and smoke tests are shown in Tables II and III.

TABLE II
CARBON BALANCE

Equipment	**Unit No.**	**Carbon Flow g/sec**		
Komatsu Dump truck		Baseline	Treated	% Variation
630E (Top Exhaust)	2183	4.985	4.604	-7.6
630E (Bottom Exhaust)		5.099	4.674	-8.3
Subtotal		10.084	9.278	-8.0
630E (Top Exhaust)	2184	5.137	4.917	-4.3
630E (Bottom Exhaust)		5.158	4.880	-5.4
Subtotal		10.295	9.797	-4.8
785-3	2174	10.047	9.356	-6.9
785-3	2178	12.608	11.359	-9.9
785-3	2179	10.307	9.938	-3.6

FLEET AVERAGE		10.668	9.946	- 6.8

3. BOSCH SMOKE MEASUREMENTS

Bosch Smoke measurements using a Bosch Smoke meter were taken. The Bosch scale ranges from 0.0 (Clean) to 9.9 (Dirty).

Table II
BOSCH SMOKE MEASUREMENTS

Unit No.	Baseline	Treated	% Variation
2183 (Top)	0.3	0.2	-33
2183 (Bottom)	0.3	0.2	-33
2184 (Top)	0.4	0.4	N/C
2184 (Bottom)	0.6	0.3	-50
2174	0.5	0.5	N/C
2178	0.9	0.6	-33
2179	0.8	0.4	-50
FLEET AVERAGE	**0.54**	**0.37**	**- 31**

Smoke patches are included in Appendix A.

CONCLUSION

The controlled fuel efficiency studies conducted at MacMahon Contractor's Tarmoola mine site have provided clear evidence of reduced fuel consumption following the introduction of Fuel Technology's Combustion Catalyst, FTC.

The Measured average reduction in Tonnes kilometre per kilograms of fuel represents an efficiency gain in the order of 6.7%. The Carbon Balance test confirmed the fuel the fuel efficiency improvement with a 6.8% reduction in fuel consumption measured. Improved smoke emissions also demonstrates improved combustion providing the potential for substantial maintenance benefits.

The Student t-Test applied to the Haul Truck Volumetric Fuel Consumption Test confirms that the difference between untreated and treated tests is significant at a 99% confidence level.

BIBLIOGRAPHY

Koehler, D. & Doglio, J. (1987). SAE Technical Paper 872146: Benefits of Multifunctional Diesel Fuel Additives Demonstration in a Fleet Test. The Engineering Society For Advanced Mobility Land Sea Air And Space.

Appendix "*A*"

TEST WORKSHEETS

Appendix "*B*"

CARBON BALANCE SPREADSHEETS

Appendix "D"

BOSCH SMOKE PATCHES

Appendix "C"

STUDENT t-TEST