Performance of Personnel Transport Vehicles in high methane concentrations

Ray Davis
Principal Engineer
Department of Mines and Energy - Simtars

ABSTRACT

Simtars has been investigating the operation of underground coal mine personnel transport vehicles in non standard mine atmospheres.

This paper describes the performance testing of a number of flameproof diesel engines currently in use in personnel transport vehicles in Queensland and New South Wales underground coal mines in high levels of methane.

The results of this testing showed that flameproof diesel engines did not display characteristics suggestive of acting as a possible ignition source for the external methane atmosphere. While flame proof diesel engines have been found to have the potential to develop significantly more power under these circumstances, they can be operated so as to perform similarly to a vehicle driven in normal air.

To be able to show this in a more practical fashion, Simtars undertook a test demonstration of a complete vehicle under conditions simulating those which could be encountered in exiting an underground coal mine.

The demonstration, viewed by a number of mining industry representatives, proved quite successful. It showed that a vehicle suddenly encountering high methane concentrations would have more power available to it, but that this extra power could be easily controlled by reduced throttle position. While the engine may exhibit very high idling revs due to the presence of methane, it was still possible to drive the vehicle as slowly as 3 to 4 km/hr in first gear without having to ride the brakes.

The observation is that when the vehicle is only required to perform as it would normally, regardless of the methane concentration present (i.e. the extra power was not exploited), engine temperatures should remain similar to that for the vehicle driven in normal air and not impose any increased risk of ignition.

INTRODUCTION

Simtars, under the auspices of the Queensland Mines Rescue Service (QMRS) and Australian Coal Association Research Program ACARP, has been investigating the operation of underground coal mine personnel transport vehicles in non standard mine atmospheres.

The first stage of the project resulted in a design specification for a vehicle to assist in the aftermath of an underground coal mine emergency.

The second stage of the project involved testing three commonly used diesel engines in low oxygen, relatively high methane (outside the explosive range) and increased levels of carbon dioxide atmospheres. A matrix of gas concentrations was investigated and a safe operational atmospheric envelope was established for the engines tested.

The third stage of the project involved modification of an existing mine personnel transport vehicle and the actual demonstration of this vehicle at venues in Queensland and New South Wales. This involved some engine modifications to enable the vehicle to operate in a variety of atmospheres that may be present in an underground coal mine after an emergency event. Other modifications included a high speed methane analyser, a sonic navigation device and onboard emergency air supply.

The successful conclusion of the third stage was the demonstration of a vehicle, which would be able, in certain circumstances, to facilitate the safe removal of personnel from underground coal mines in emergency situations.

While stage 2 explored the response of the diesel engines when exposed to various atmospheres including the presence of methane up to 4% in air (just below the lower explosible limit), the ability of an engine to function safely outside this range (well into the explosive range) was unknown. To gain more confidence in the ability of personnel transport vehicles to be operated safely in emergency situations, Simtars researchers undertook controlled testing of a typical personnel transport vehicle in explosive methane/air atmospheres. Testing was undertaken using a PJB flameproof man rider.

All testing at Simtars indicated that the engines tested were quite usable under a variety of atmospheric conditions. The PJB fitted with a Kia Perkins engine was the only vehicle subjected to the high methane environment. It continued to run safely under complete control in methane atmospheres up to 17% in air.

An incident that occurred at a New South Wales colliery shortly after the testing carried out at Simtars suggested that a diesel engine could possibly run on, uncontrollably, given sufficient methane in the air intake. While the vehicle involved in the incident did not cause an external ignition of methane, it did severely overheat before it could be removed from the high methane concentration (around 8%). The reason for this overheating however was not conclusively determined.

Given this particular circumstance there remained some doubt as to the ability to safely operate such vehicles in atmospheres following an emergency where methane concentrations above the lower explosible limit could be suddenly encountered.

Following the New South Wales incident, the New South Wales and Queensland Mines Inspectorate as well as a number of industry representatives met in Newcastle in July 2005. At this meeting, they, recommended these engines be tested in more detail to provide more confidence in their use in such emergencies.

The testing work undertaken in this fourth stage was designed to provide as much information as possible to allow the mining industry in Queensland and New South Wales to decide on the safe use or otherwise of personnel transport vehicles in emergency situations.

PROJECT OBJECTIVES

The aim of the fourth stage of the project was to test the performance of 4 diesel engines covering the range of engines currently used in underground coal mines in personnel transport vehicles in high levels of methane by:

1. Determining torque and power characteristics at various methane/air concentrations covering the explosible range to a practical limit
2. Determining controllability in terms of throttle response and ability to shut down the engine
3. Investigating the controllability in respect of well worn and reconditioned engines
4. Determining impacts of this testing on relevant engine temperatures.

TESTING UNDERTAKEN

Four separate tests were undertaken covering the following:

Test 1 – 6 cylinder Perkins flameproof diesel engine in “as traded” condition with the exception of an overhauled fuel pump and injectors (supplied by Specialised Mining Vehicles)

Test 2 – 6 cylinder Perkins flameproof diesel engine in “as traded” condition with a reconditioned cylinder head (supplied by Specialised Mining Vehicles)

Test 3 – 4 cylinder Tier 2 Perkins flameproof diesel engine, in new condition (supplied by P. J. Berrimen)

Test 4 – Personnel Transport Vehicle, fitted with a 6 cylinder Perkins flameproof diesel engine, in “as traded” condition (supplied by Specialised Mining Vehicles).

ENGINE TEST PROCEDURE

The three engines (Tests 1, 2 and 3 as above) were load tested on an engine dynamometer at TestSafe's premises at Londonderry, New South Wales, in normal air and then at various concentrations of methane in air at roughly 2% increments starting from 4%. Other in-between concentrations were tested as the behaviour of the engines became evident.

Natural gas was used in all testing in lieu of methane as it was much cheaper. Natural gas is essentially 90% methane and 7% ethane, with the balance basically nitrogen. The 3% error in concentrations reported was considered negligible (maximum of 0.36% at 12%) due to the fluctuation in concentrations recorded. All references to methane in the testing phase should be inferred as natural gas.

Each engine was supplied with a premixed methane/air mixture to the air intake. While the amount of this premixed air was set to meet maximum demand from the engine, it also meant that the actual gas concentration did vary somewhat as the engine revs changed.

The standard test procedure for developing a torque curve is to take an engine to flight revs (2500rpm) unloaded (close to 100% fuel setting) and then gradually apply load, recording the torque at 100rpm increments until the peak torque has been established.

In order to gain further insight into the performance of the engine under normal operating conditions, a torque curve was developed at 100%, 50% and 0% fuel setting in air. A vehicle is not normally driven at full throttle and therefore the combination of full fuel setting and high gas concentrations could give over fuelling problems not encountered in normal driving.

The torque curves were then repeated at the various methane concentrations.

At each concentration the engine fuel solenoid was shut and the state of the engine noted. In cases where the engine ran on, an attempt was made to load the engine and explore its performance under those conditions.

VEHICLE TEST PROCEDURE

Following the engine testing on a number of engines Simtars decided to test a complete vehicle to show controllability in a more practical fashion (Test 4 as above). The demonstration involved the testing of a complete vehicle under conditions simulating those which could be encountered in exiting an underground coal mine.

The personnel transport vehicle was an “as traded” unit chosen to highlight certain unusual operating characteristics of worn engines. It was mounted on a chassis dynamometer at Diesel Test Australia's facility at TestSafe and operated with the engine exposed to high concentrations of methane gas. Refer Figures 1 and 2. The gas inlet system to the engine was modified from that used in the previous tests. It consisted of a three stage regulator with a venturi mixing system. Refer Figure 3. The result gave more flexibility to the testing phase as the percentage of gas entering the engine remained fairly constant with change in engine revs.

Figure 1: Vehicle on Dynamometer

Figure 2: Vehicle on Dynamometer rear view

Figure 3: Gas Inlet system

The following is a summary of the test sequence performed:

Test sequence	Test Description
a	Produce a power curve for the vehicle in normal air.
b	Show how the vehicle behaved with 4% methane and no throttle (under no load, in first gear).
c	Produce a power curve for the vehicle in 4% methane.
d	Show how the vehicle behaved with 7% methane and no throttle (under no load, in first gear).
e	Produce a power curve for the vehicle in 7% methane.
f	Show how the vehicle behaved with 9% methane and no throttle (under no load, in first gear).
g	Produce a power curve for the vehicle in 9% methane.
h	Drive the vehicle at full throttle (in third gear) in normal air on a simulated 10% grade. Note the speed attained.
i	Suddenly inject 7% methane to above conditions. Note the speed attained.
j	Following this, adjust the throttle to match the original speed attained.
k	Drive the vehicle at full throttle (in third gear) in normal air on a simulated 20% grade. Note the speed attained.
l	Suddenly inject 7% methane into above conditions. Note the speed attained.
m	Following this, adjust the throttle to match the original speed attained.
n	While still injecting 7% methane, place the vehicle in neutral. Turn off the diesel fuel and observe the result.
o	If the vehicle continues to run on, engage first gear with minimal load. Observe result.

FINDINGS

In relation to the objectives of the project, the findings are as follows:

1. All engines were able to cope with the addition of methane with peak performance gained between 4% and 8% methane depending on the condition of the engine. For all engines tested, real increases in torque of up to 25% were obtained over that for the engines operating in normal air. Refer Figure 4 for typical performance curves.

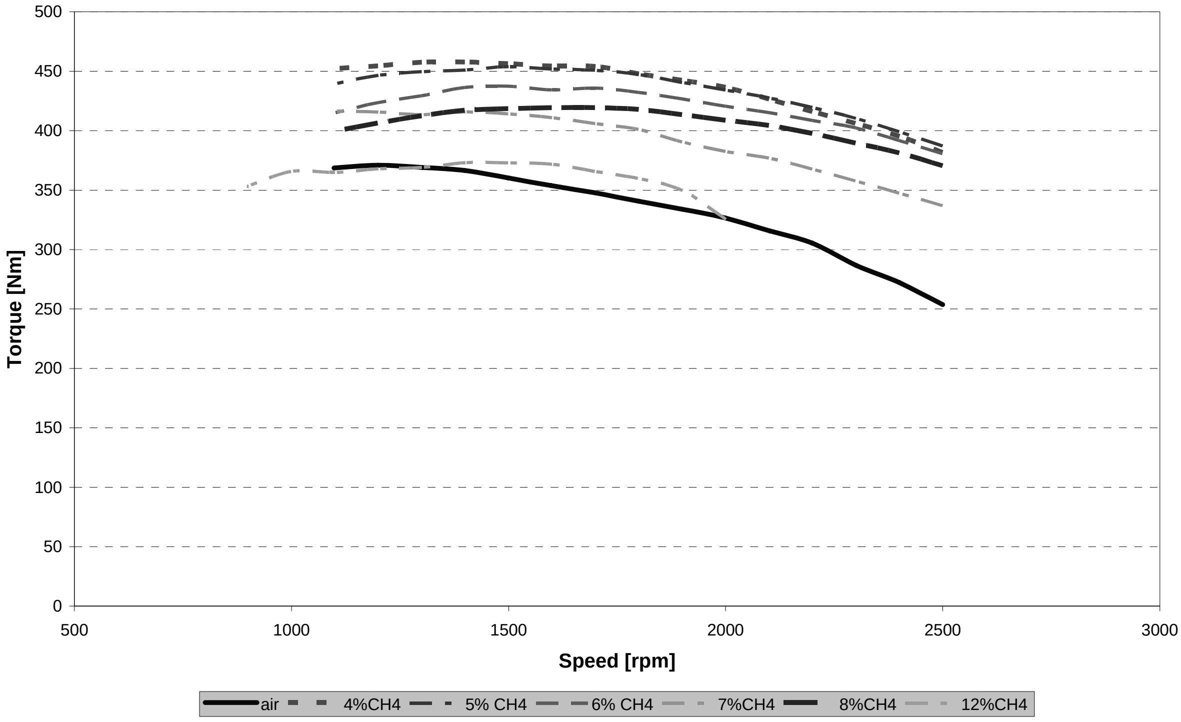

Figure 4: Engine Dynamometer Torque Curve at 100% Fuel Setting (Engine 1)

2. The vehicle tested on the chassis dynamometer gave increases in power at the wheels of up to 100%. Refer Figure 5.

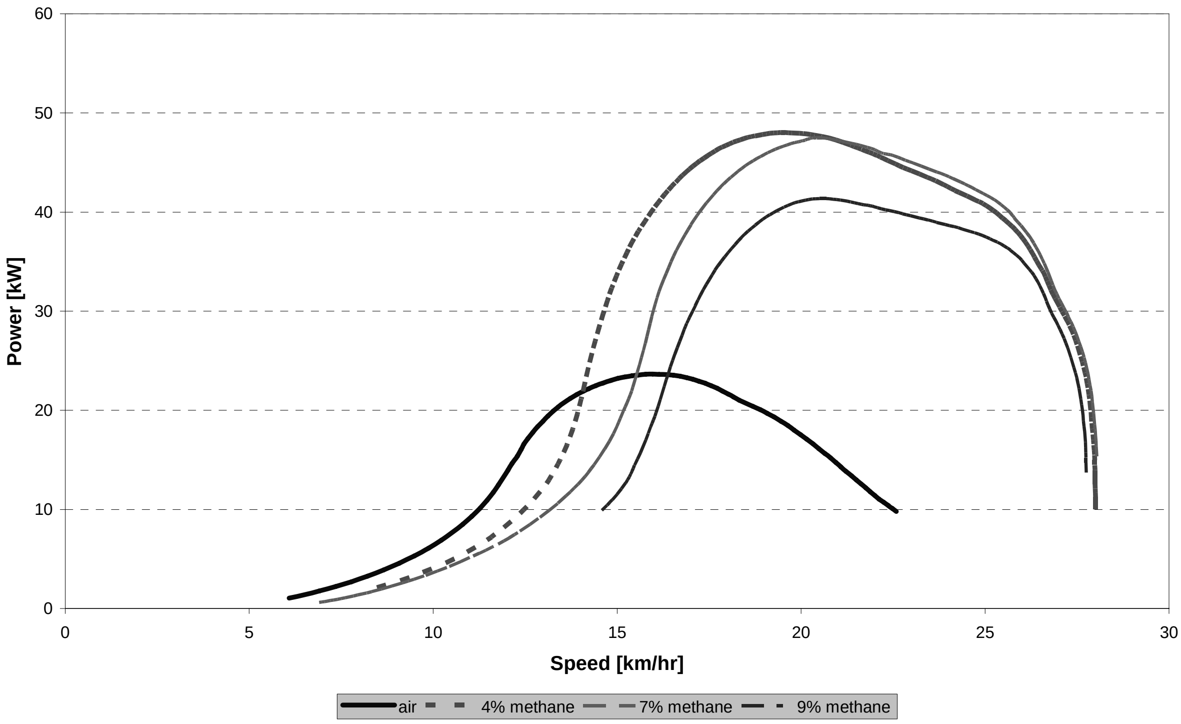

Figure 5: Chassis Dynamometer Power Curves for Transport Vehicle

3. Worn engines showed a tendency to rev quite high (up to 2500rpm) at idle when methane concentrations reached 6 to 8%, whereas the new engine did not.

   In the vehicle as tested on the chassis dynamometer this tendency meant that the vehicle could be driven at speeds up to 10 km/hr in top gear on level ground without using the accelerator pedal. Selecting first gear kept this speed to 3 to 4 km/hr. Essentially, any speed required less than this would need the application of the brakes. Slightly slower speeds may be required when negotiating a mine roadway with zero visibility.

   Worn engines did have a tendency to "run on" once the diesel fuel was turned off but any application of load tended to stall the engines. All engines did experience some form of instability (hunting) when methane levels increased. This did not however affect the engines ability to perform.

4. The results suggest that new or reconditioned engines may not show this tendency to rev high at idle, enabling the vehicle to reach appreciable speeds with no pedal effort. They should therefore be more controllable than worn engines.

5. Four different engine temperatures were monitored. They were:

   - Raw exhaust temperature
   - Engine coolant temperature
   - Conditioned exhaust temperature
   - Surface temperature.

   - Raw exhaust temperatures tended to vary proportionate to the power being developed. This tendency seems obvious as these temperatures give us the best indication of what is happening in the combustion chamber. Interestingly, though, at methane concentrations above roughly 8% the increased power was delivered at reduced temperatures. At all methane concentrations investigated, sufficient power was delivered at 50% diesel fuel setting to equal that normally delivered in air but at lower temperatures.

   - Engine coolant temperatures did not vary appreciably during testing, with the highest temperature recorded on engine No 2 at 95.2°C.

   - Conditioned exhaust temperatures did not generally show any significant increase. The highest temperature reached was 106°C on engine 3.

   - Surface temperatures were measured at three locations. The maximum surface temperature recorded was on engine No 1 at 128.3°C. This is well below the maximum allowable surface temperature of 150°C.

CONCLUSIONS

- A transport vehicle fitted with a flameproof diesel engine suddenly encountering a high methane concentration would have more power available to it.

- The operator could easily allow for this increased power by reducing pedal effort.

- Given the demonstrated maximum power output available, even after methane injection (48kW) and its ability to affect the performance of a vehicle weighing at least 6.2 tonnes, it is hard to envisage the operator temporarily losing control.

- In the worst case, and particularly with worn engines, the engine may idle at high revs (up to 2500rpm).

- When the vehicle is only asked to perform as it would normally, regardless of the methane concentration present (i.e. the extra power was not exploited), engine temperatures should remain similar to that for the vehicle driven in normal air.

- These temperatures should only increase if demand for more power was required.

- If methane gas is suddenly encountered, the vehicle could still be driven as slow as 3 – 4 km/hr in first gear without the operator having to ride the brakes.

- The testing undertaken was limited to addressing the effect high levels of methane have on the operation of a personnel transport vehicle and on the operator of a vehicle suddenly encountering such high methane atmospheres.

- The results of this testing continue to support the position from the previous project that if the vehicle is capable of starting and operating it can be used to effect self-assisted rescue.

RECOMMENDATIONS

- The testing undertaken was limited to only a few different engines. The condition of the engines, especially the "as traded" units, was not explored. This was done for a purpose as typically a vehicle used in an emergency could be in a condition somewhere between an "as traded" vehicle and a new or newly reconditioned one. With limited testing all possibilities could not be covered. Therefore, while the testing demonstrates that these vehicles could be safely operated in high levels of methane without loss of control, it is recommended that emergency shutdown systems be maintained in all such vehicles.

- A risk assessment be undertaken into the use of Personnel Transport Vehicles in the aftermath of an emergency, possibly by the Queensland Mines Fight/Flight Committee, to ensure this research is not wasted.