Abstract

The deaths of firefighters in the Wingello fires in New South Wales awakened a need for fire truck design in Australia to be reviewed. Protection of fire crews in a bushfire burnover is paramount. With this in mind, CSIRO was employed by the Country Fire Authority of Victoria and the Rural Fire Service of New South Wales to identify those parameters which could be used as truck performance criteria. A test method was developed and 24 full-scale tests allowing the measurement of radiation, temperature and toxic gases were performed. The results of these tests will reflect future fire truck designs. This paper aims to discuss the test method and modifications carried out to the trucks to improve their performance in a bushfire burnover.

Introduction

Bushfires in recent years and their potential to harm a community’s infrastructure, as well as the potential for loss of life, has led all to rethink existing practices relating to bushfire safety. As frontline firefighters are most at risk in the event of a bushfire burnover, the question was posed as to whether the protection afforded by a firefighting vehicle was sufficient.

As a result, two Australian firefighting authorities – the Country Fire Authority of Victoria (CFA) and the Rural Fire Service of New South Wales (RFS) – commissioned CSIRO to help them identify the parameters of importance in protecting firefighters and their vehicles. In addition, the modifications made to the trucks, which included shielding and water sprays, and their effectiveness were assessed. CSIRO Forestry & Forest (FFP) products supplied the theory and measurement relating to the bushfire flame front, whilst CSIRO Manufacturing & Infrastructure Technology (CMIT) supplied the onboard measurement of fire truck performance during testing.

A series of 24 tests were carried out on an artificial flame front simulator built at the RFS’s Hot Test Fire Facility at Mogo, New South Wales, Australia (Figure 1). This simulator was commissioned by gas experts Gameco Pty Ltd. Background information for the design was supplied by FFP, and from work done by CSIRO and Gameco on the Australian Defence Industries (ADI) testing done at Fiskville in Victoria on their Fireking truck. ADI made the background information available for the development of the Mogo tests. Trucks from both authorities were tested by applying various fire intensities and comparing the results from both sprayed and unsprayed vehicle tests. Further information on the experimental setup and discussion of results can be found in (Nichols et al. 2003) and (Sullivan et al. 2003).
Measurements were taken of critical parameters for life safety within the cabin, such as temperatures and radiant heat, as well as toxic gas emissions (Brown et al. 2003). Thermal factors for human survival were calculated (Knight et al. 2004). The measurement of the effects of a flame front on fire trucks had never been done before. The development of systems of measurement that could provide useful data whilst being able to withstand the adverse effects of fire was a challenge.

This aim of this paper is to give an overview of the test methodology employed by CMIT in relation to equipment for temperature and radiation measurement.

Temperature Measurements

All temperatures, whether internal or external, were measured using 1.5 mm ‘K-type’ MIMS (mineral insulated metal sheath) thermocouples with unearthed tips and an inconel sheath. K-type thermocouples have been commonly used in our fire research as they have a temperature range up to 1250°C. Figure 2 shows a typical radiometer and thermocouple.

Thermocouples contain two dissimilar metal wires which are joined at the tip and create an electrical circuit that creates an electromotive force that can be measured and equated to a temperature. Thermocouples have a MIMS length as well as PVC- or teflon-coated lead and can be made to any length. In addition, they can be supplied with a fibreglass-coated lead which we chose for its higher temperature rating. The MIMS length of the lead has a higher temperature rating than the rest of the lead and, as a result, it was decided to use longer MIMS in regions where flame immersion of the thermocouples was an issue.

Thermocouples could be easily tested after installation by heating their tips and observing data on the computer or by testing them with multimeters. Many multimeters now have a mini plug connection for K-type thermocouple inputs. These thermocouples also have a resistance between the wires of approximately 8 ohms, which is also a useful technique to check for bad connections or to determine whether there is a break in their length.
Figure 2. A typical radiometer and thermocouple

Temperatures were measured predominately in-cab as this was the information most pertinent to occupant comfort. Figure 3 shows typical locations of internal thermocouple during testing. External truck temperatures were measured on the driver mirrors, wheel wells and at several external locations. Temperatures were also measured in the ROPS or rear cab on vehicles where this was an addition.

Internal temperatures were measured on all window, roof, door, floor and wall surfaces. Passenger-side air temperatures were measured at head, chest and seat heights as in all tests, this was the side of the truck from which the simulated fire front approached.

Figure 3. Truck side thermocouple locations
Radiation Measurement

Thermopile total heat flux guages (radiometers) with a range of 0–100 kW/m$^2$ were used for all radiation measurements. These produce a millivolts output on the application of radiation. Each radiometer is supplied with a radiation versus millivolts calibration from the manufacturer and this can be verified with in-house calibrations. The heat flux guages used have a main body that is 25 mm in diameter and 45 mm long. The sensor location on the face is coated with a black low-emissivity paint to better absorb the radiation and reduce the reflective component of radiation from its face.

Radiometers need to be water-cooled and failure to do so results in damage to the sensor. In initial experiments, this water was supplied from an underground supply line from an external tap. Silicon tubing of 2.5 mm internal diameter and 5 mm external diameter were used to supply a constant flow rate of 1 L/min. Radiometers were daisy-chained together to reduce the amount of water supply lines needed.

Two radiometers were placed in the passenger side of each vehicle at approximately head height – one facing the windscreen and the other facing the centre of the passenger window (see Figure 4). These were to record radiation levels that would normally be received by a crew member in this position. External radiometers were built into the truck tray (see Figure 5).

As the air temperature in these locations was also monitored, it was easy to later determine the convective and radiative components of the heat flux in these locations.

![Diagram of radiometer locations](image)

NOTE: Thermocouple tree is located in the centre of the passenger seat

Figure 4. Passenger-side radiometer locations
Datalogging

All temperature and radiation data was collected by a datalogger, which allowed multi-channel data collection of analogue or digital inputs, and also allowed for digital switching of items such as relays. The units used were Datataker 505s with the addition of expansion modules to increase the base unit’s logging capabilities, allowing the collection of data from 76 channels. Figure 6 shows the complexity of such multichannel wiring. Datatakers have on-board memory cards and can simultaneously stream data to any computer.
On sending logging routines to the Datataker, they can run indefinitely as long as battery life allows. In the Mogo tests, we wanted all the data logged at 5-second intervals and to be recorded on the memory card for back-up, as well as being streamed live during the experiments to an external computer. The addition of an external computer allowed us to constantly monitor the status of the vehicle and the integrity of the logging system. Data was retrieved as text delimited, so it is easy to transfer it to programs such as Microsoft Excel for data manipulation and graph plotting.

In initial tests, the external feed of data was via an underground cable from the datataker to the logging computer in the control room; this was modified in later tests. The umbilical cable from truck to test bed, as well as all other external cabling, was heavily wrapped in Kaowool™ and aluminium tape. Kaowool is a mineral fibre wool with a high temperature rating that acts as an insulator.

All tests were extensively photographed and videotaped. The use of digital cameras allowed for the easy inclusion of photos in reports, as well as allowing easy back-up to CD or DVD. Digital videos allowed for easy transfer to all mediums, and also enabled post-editing of footage for presentations.

A Better Datalogging System

Expensive scientific equipment often intended to be used ‘on bench’, does not take kindly to the abuse that a bushfire burnover may deliver it. Some equipment failures during the tests led to us finding better means of maintaining equipment integrity. It was decided to make all data collection equipment autonomous from the test bed, and to sever all hard line external connections and replace them with a much improved system.

Extremes of temperature damaged some of the sensors in initial tests. Water penetration into the joints of in-ground cabling was also a problem. There was also failure of the umbilical from ground to truck cabin due to flame damage. Although these problems did not result in significant data loss, the use of standard electrical flex, high-temperature silicon joints and the cable insulation employed was clearly inadequate. The downtime of cable failures reduced the turnaround time of tests, which was of particular annoyance when weather conditions were favourable. All cabling was replaced by silicone-coated leads, which have a higher temperature rating. All external cables were placed in a sheathing of Firemaster™ that had similar temperature and flame immersion ratings as the previous methods but was far quicker to install. In extreme areas, stainless steel flexible sheathing (see Figure 7) was used to provide additional flame impingement protection.

It was decided to protect the datataker system in a ¼” steel fireproof box which was lined with a mineral fibreboard. We considered water cooling or placing icepacks in the box, but dismissed this idea because of the potential for shorting or earthing problems with electronic components due to water condensation.

In early tests, the datataker was supplied by small 12 V sealed batteries, but these were replaced with larger battery banks, which reduced the potential of low battery voltage during or between tests. Batteries were ‘trickle’ charged from an external source between tests to maintain their supply. These were also placed in the fireproof box due to the potentially explosive nature of the batteries with overheating or flame contact.
A radio modem system (Figure 8) was incorporated to provide the external data streaming rather than rely on a hard-wired communication cable between the datataker and the logging computer in the control room. The radio modem has a range of 3 km in a straight line, and operates at a frequency of 2.5 Ghz. The system is such that the receiver and transceiver continuously monitor each other so that if communication is broken, they will automatically reconnect after finding each other. Any data that was to be transferred during this period of lost communication is buffered in the logger and sent as soon as communication is re-established.
**Better Sensor Configuration**

Radiometers now have on-vehicle water reserves which are pumped by small submersible pumps powered by 12 V batteries. The submersion of these pumps keeps them cool, allowing them to operate within manufacturer’s specifications.

**Measurement of Fire Front From Vehicle’s Perspective**

In addition to all equipment previously described, we have now employed a 5 m swing-out boom, which allows us to deploy measuring equipment into the flame front before it reaches the vehicle. This also allows equipment to be sufficiently away from the vehicle to be little effected by spray systems, and thus the flame front without any suppression effects can be measured. The water from spray systems has a clouding and cooling effect on some instruments, flame or smoke.

From the boom we have deployed specialised radiation, soot and smoke meters, designed in-house, which provide further information on the characteristics of flame fronts, whether they be natural such as leaf litter and native grasses, or whether man-made such as the artificial gas fires produced by flame-front simulators. These specialised sensors measure flame properties such as emissivity and radiant heat as a function of flame depth. The understanding of these specific aspects of a flame front are essential in determining the way in which a firefighting vehicle is impacted by different types of fire fronts.

We are in the process of installing a sacrificial camera on the boom which we anticipate will record most of the fire event before being heat effected. The video from this camera will be live fed via a radio link to a computer some 200 m away from the vehicle, allowing observation of the fire event and providing a safe back-up of video footage.

We now use engine analyser units to observe the effects of smoke and temperature on the performance of both truck engines and water pumps during a fire event.

The addition of McCaffrey probes allows us to measure the wind speeds of a fire front at varying heights around the vehicle. These probes measure differential pressure which is then converted to a wind speed via Bernoulli’s equation.

Radiometers have been placed on 2 m high towers above the vehicle’s rear tray to measure the potential radiation effects from gas plumes above the vehicle.

A 15 m high tower has been placed on the rear of the truck which has thermocouples attached at 3 m intervals, giving us the opportunity to measure the temperature gradient of the gas plume above the vehicle.

**Conclusion**

Finetuning of on-board systems and the addition of other measurement devices is an ongoing process, but now we have a solid grounding in quantifying the effects a flame front has on a vehicle during a burnover.
References


