4/35 Limestone Street
Darra 4076
Australia

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Hot Smoke Testing and Australian Standard AS4391

Thoughts of Stacey Agnew as at February 2015

INTRODUCTION

As fire and ventilation engineers, we have been involved in hot smoke tests for several years. Since 2010, we have built our own capability in hot smoke testing, starting with methylated spirit pans and moving on to what we see as improved techniques. We are focussed primarily on tunnels and underground transportation stations. For those applications particularly, it is apparent to us that the Australian Standard for Hot Smoke Testing (AS4391:1999) is not particularly relevant in its current form and that there are more convenient and safer alternatives for meeting typical commissioning objectives. We record our thoughts on that here and invite anyone with strong opinions on the matter to contact us (admin@staceyagnew.com) with a view to making a coherent representation to Standards Australia on amending or replacing the standard, specifically for tunnels and stations.

Our prime criticism of AS4391 is that it is more in the nature of a prescriptive recipe than a statement of the minimum or desirable requirements for a satisfactory test. While there is some good information on one type of test, it is the narrow specification of just one test type that is the problem. Rather than just providing a basis for test design and outcomes, it is more in the nature of an organisation's internal documentation on test procedure development.

APPLICATION AND OBJECTIVES

The AS4391 commentary on its application is relatively clear:

> ***C1.2*** *This test is intended to verify the correct performance of a smoke management system including operation, sequence of control and, where practical, specified smoke layer depths. It is not intended as a means of establishing smoke obscuration levels or system integrity under real fire conditions. It is not intended that this test be mandatory for all systems, rather, it provides a tool to resolve uncertainties in some smoke management systems.*

The key in that extract is the statement that the intention of an AS4391 test is to verify the performance of a smoke management system, among other design aspects. For most structures it is just not possible to do that at anywhere near the designed peak heat release rate. This is particularly true for major underground infrastructure, especially vehicle tunnels, which have large design fires.

For real fires in buildings or tunnels, the smoke generation rate will be much greater than can realistically be produced as test smoke. This is simply because the real fire plume is driven by much more heat. That is OK, as the purpose of the test smoke is to show where the plume goes, not to reproduce the same obscuration. The test smoke is hot rather than cold so that it has buoyancy and will follow the same paths that smoke from an unplanned fire would follow.

AS4391 prescribes one type of test fire which, in the absence of wind, could give calibrated plume entrainment and heat release rates. It could be used as a repeatable methodology for generating a flow of smoke at a known rate and temperature under ideal no-wind conditions. In that respect, it could be argued that AS4391 provides an appropriate methodology for assessing standard building compartments where there is no significant wind and the balance between smoke generation and extraction is important. Before we would use it for that purpose, we would want to do some verification. The plume mass flow equation in Appendix A of AS4391 seems to have the temperature ratio upside down. It doesn't seem plausible that for the same fire perimeter, a hotter flame (higher fire power) produces less plume mass flow.

In a relatively straight tunnel with no underground intersections, the behaviour of lukewarm smoke with a given tunnel airflow is pretty well known beforehand. The smoke is then only a visual demonstration that the airflow is achieved. That demonstration can be done, less visually, with an anemometer on a pole, aided perhaps by a stick with a ribbon tied to it.

We have found that smoke testing can be very informative in unusual geometries, such as tight radius tunnel curves, changes in cross section, or merge and diverge caverns. It allows flow recirculation and vorticity to be seen. The control of overshoot when local extraction is used can also be demonstrated beneficially, although flow measurement on both sides of the extraction point is also pretty conclusive. Since the test fire is very much smaller than the design fire, the dependence of smoke control on tunnel grade in straight tunnels cannot be tested realistically. This means that repeating tests at several locations where the only difference is grade is not informative.

It is clear that 'low' heat release rate smoke tests are only warranted in tunnels when there is a need to visualise some unusual aerodynamic aspect of the tunnel where the outcome can't readily be checked more simply.

HEAT GENERATION FOR TUNNEL TESTING

The two essential ingredients of a hot smoke test are, not surprisingly, heat and smoke. We look first at the heat. For flow visualisation it matters not whether the heat is generated by burning methylated spirits, LPG, diesel or gum leaves, or by focussing a giant solar collector.
AS 4391 is focussed solely on methylated spirits pans as the heat source. We prefer LPG for the following reasons.

We have never seen a metho test aborted or cut short, but using a hose reel to spray enough to dilute 96 L of metho (2.5 MW test) would not be fast, without blasting the metho out of the pans. Then there is the issue of disposing of up to 300 L of water-metho solution before the next test.

We have aborted an LPG-fuelled test just after ignition. When the witnesses wanted more time to discuss matters, it was just a matter of signalling to the burner operator and the test was stopped in a couple of seconds with no waste. Of course it was also ready to restart immediately when everyone was ready for the test to run. Why would you not allow that convenience in a standard?

While we do not suggest that the metho tests cannot be conducted safely, it seems to us that, with a large flame, the ability to extinguish the flame in seconds has safety benefits, for people and tunnel fittings, over a method that requires a manual fire suppression effort.

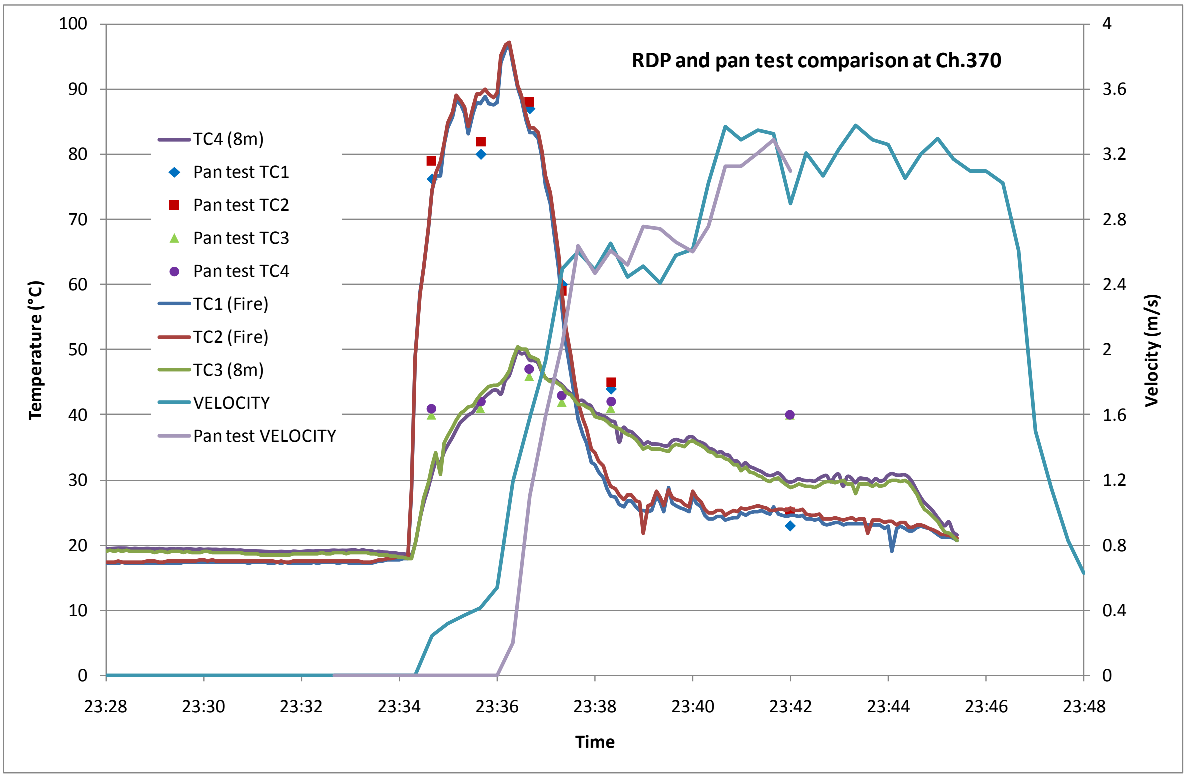
Manually pouring 16 L of metho into each pan requires the exclusion zone to be set up well before the test starts, and carries a risk of spillage. Open trays of flammable liquid are not normal except in fire training sites. By contrast, the storage and carriage of LPG in tanks is very well practiced and the burner controls are standard industrial components, subject to their own Australian Standards. We see the use of LPG as offering useful safety benefits over metho. If that is the case, why would a standard mandate an approach that may not be the safest?

The levelling of water pans and re-location, draining and re-filling between tests all takes time, on top of the time to handle the metho. While we have made inroads in that time with our purpose-built trailer, it still takes time. With the other associated equipment relocation between tests, they often run so late into the night (they usually start after dark for smoke release reasons) that the time of the witnesses creates a pressure that competes with the other test objectives. With the LPG burners, most of the setup time can be done off-site during normal hours.

We heard objections that LPG burners produce a jetting flame (which they can) that is a source of significant horizontal momentum and so is unrepresentative of anticipated real fires. We deal with tunnel ceiling heights at 5 m or more. With that height, any jetting is dissipated well before the plume hits the smoke layer and the only effect is to make the seat of the fire seem to be in a slightly different position. The photo below shows that. Of course the fire seat position can be adjusted to allow for that horizontal shift, if it is important.

The other characteristic of LPG burners is that the heat release may be much more concentrated than for a general fire, giving a faster initial plume rise. The perception by some that LPG flames were not 'realistic' led us to develop the RDP (photo below). The vehicle shell is simply a diffuser for the plume at source.

To us, it seems that the difference between a diffuse and a more concentrated fire seat is generally irrelevant as it is all about getting a truly buoyant plume infused with a decent (visible) amount of tracer smoke. With the test fire only a source of buoyancy to check smoke handling, and being just one point in a continuous spectrum of possible fire intensities, fussing about 'realism' compared to a particular imagined event is pointless. The only feature which may matter is the safety of the ceiling, which could see a higher temperature for a concentrated plume and a low(ish) ceiling. In that regard, results below from a pair of comparative tests demonstrated nicely that our RDP at 1.5 MW produced similar temperatures to 1.5 MW of metho pans.

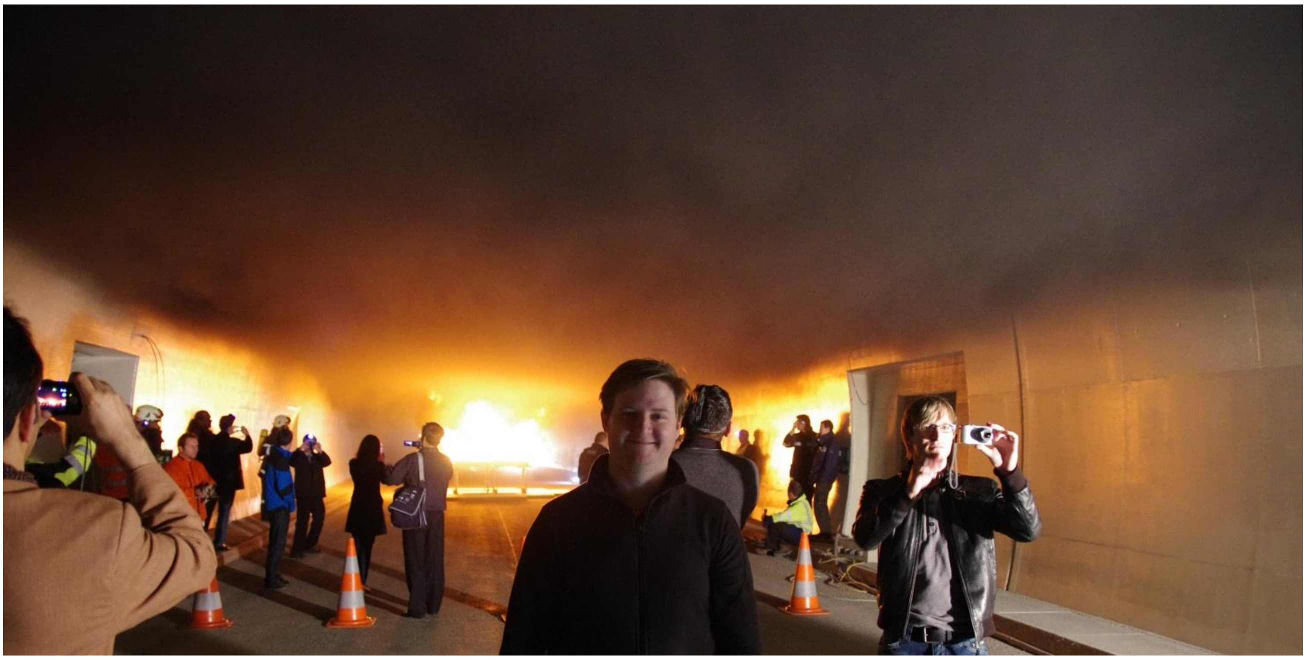


To the extent that an LPG flame produces a more concentrated heat source, it can be seen as beneficial for testing. While tunnel designs may be for a heat release rate of say 50 MW, it is generally not the done thing to test at the full design heat release rate. The closer you can get to the same plume behaviour with less heat the better. The only small change you can make in that regard is to keep the initial plume temperature up and generate a fast thermal rise just above the fire. Of course that means a concentrated heat source. So, if the ceiling can take the heat, a single LPG flame is probably a better proxy for the design fire than are a set of metho pans at the same heat release rate.

From all of the arguments above, it seems to us that everything points to LPG being preferable as a heat source. We do not believe that the standard should change to LPG burners, but rather that it be totally recast to require only that heat be generated, with guidance perhaps on how much in each type of situation. Appendices about metho or LPG could be included if desired. It would be prudent to include some data to assist in selecting test heat release rates.

SMOKE GENERATION FOR TUNNEL TESTING

On smoke, there are also options. The source of smoke is immaterial, except that options such as diesel soot or gum leaf smoke are less desirable for reasons not related to the primary objectives. We don't believe that the standard should be mandating the particular methods of achieving either heat or smoke, other than that they be sufficiently safe. Fortunately AS4391 leaves the smoke source as open as could reasonably be expected, except that we see no reason for mandating smoke colour. Our European friends are happy with the nice black smoke from diesel pans, which also saves making separate efforts for heat and smoke and then mixing the two. If your structure is OK with a little diesel soot in it (and a road tunnel will see plenty over its life) then why not do it that way. In our risk-averse society, the possible effects of diesel soot on witnesses, tunnel neighbours, or on the environment may be a step too far for many tunnel locations and jurisdictions. Conrad's photos below show two separate tests in Austria using diesel pans.



Nick recently attended a hot smoke test in Marseille, France where potassium nitrate and starch were used to generate both heat and smoke. The flow visualisation objectives were met quickly and simply. Photos of that test are below.

Combining 200 kW of LPG heaters and electric smoke generators, we recently conducted a flow visualisation test in a bus station. That methodology, the results of which are shown below, allowed for six detailed response mode tests to be conducted over a period of two and a half hours. This test methodology, perhaps using a higher heat release rate, would be well-suited to road tunnels.

DETAIL

While we believe strongly that the source of heat should not be mandated for tunnel tests, even if it were to be mandated, there is much unnecessary detail in AS4391. Take for example the specification of the fire pans. The sides must be vertical. That is hopeless for stacking them in your shed, but could be useful for checking deluge rate on another occasion. The handles must be welded on the inside of the water trays, lest they keep the trays a further 10 or 20 mm further apart! The handles on the 0.5 m^2 metho trays must be welded on the outside of the trays, get this; “so that they do not affect the geometry of the hot plume”!

These few examples show that there are some ‘low-hanging fruit’ to be had in cleaning up AS4391. Until such time as it is cleaned up, details like that make it clear that, while the standard was put together by volunteers with good intent and no reward other than satisfaction, it does not embody all wisdom but must be interpreted rationally.

WRAP UP

In recording the thoughts above, we hope that our clients and colleagues might help build some interest in changing AS4391 beneficially.

Regardless of any future changes to AS4391, those commissioning or executing hot smoke tests in tunnels with the current edition cannot ignore the possibility that there may be safer, faster, more convenient, and perhaps cheaper, approaches which fulfil the same test objectives. Whether it gets amended or not, if you can see a better way than in the standard, including a safer way, should anyone really be insisting on compliance with the standard for tunnel or station applications?

Please let us know what you think.

Conrad Stacey and Nick Agnew
Stacey Agnew Pty Ltd