An attack team advances into the fully involved burn room in the Tremonia trials.

Daniel Guischard

# Foam follows function:

## The Tremonia and Wattenscheid trials

The results of comprehensive tests in Germany cut through the hype about the effectiveness of Class A foam and other firefighting additives versus plain water.

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This is the third article in a series featured by Fire Chief, which started with a description of the problems encountered when fire and extinguishment trials with new agents are conducted, when the results are to stand up against scientific as well as real-life firefighting challenges. (See "When did you fight your last crib fire?" March 1997, available at <www.firechief.com>.)

A year later, we were able to publish the first part of results that we obtained from trials extinguished using CAFS. (See "CAFS goes to Germany," August 1998, available at <www.firechief.com>.) In 1997 and 1998, we ran 21 more fully instrumented room-and-contents fire trials, as well as eight fire trials with paper-recycling containers.

### The Tremonia trials

The first scenario, in which 21 fire trials were performed, was a room-and-contents fire. Inside a tunnel of the former research mining field Tremonia of Deutsche Montantechnik, in Dortmund, we set up a burn room. The tunnel was approximately 3 meters wide and 3 meters high.

Inside this tunnel we created a room 5 meters deep by erecting two walls from magnesia-silicate board on 2-inch steel C-frames. This drywall construction had a rated fire resistance of 90 minutes. One wall had a window, the other a door opening. On the "door side" of the room, two little hatches near the floor were opened to allow for video surveillance of the room and for improved ventilation, since firefighting was to be started after flashover.

Twenty-four thermocouples were installed at various heights and positions evenly inside the room, as shown in Figure 1. There were also nine gas-sampling probes, three each for oxygen, CO and $CO_2$. Data was obtained and stored

Figure 1

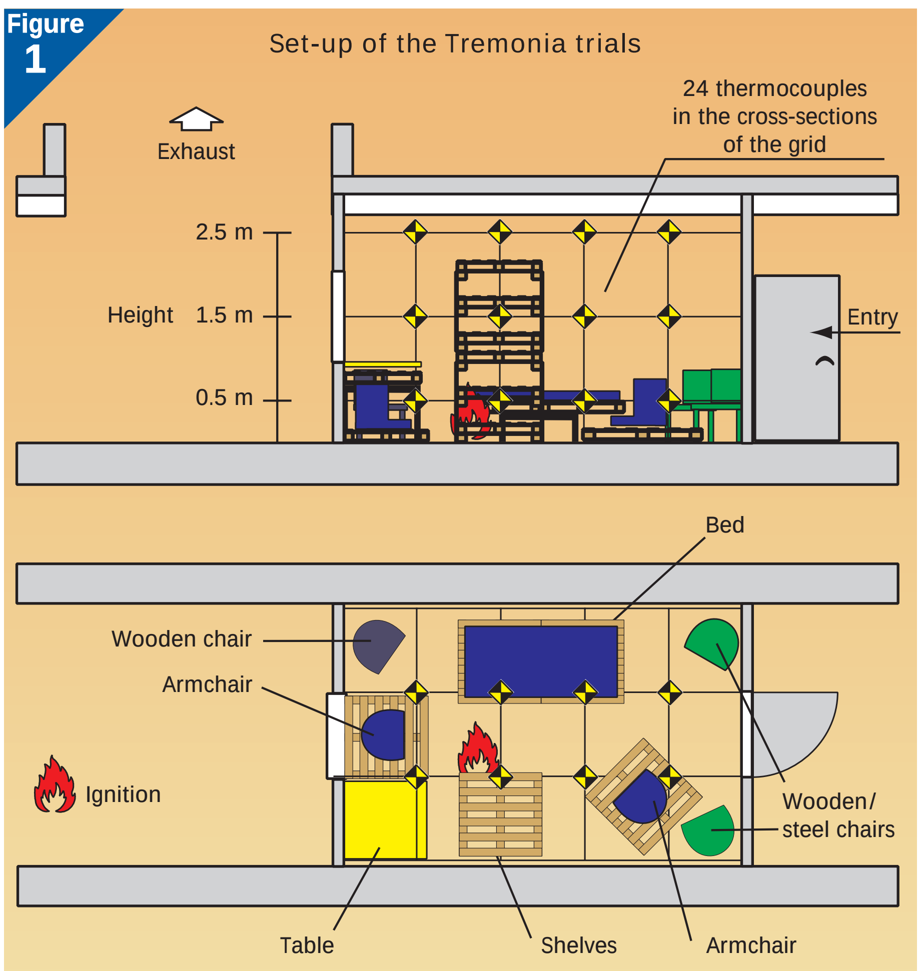


Table 1: Fire load inside the Tremonia burn room

| Fire load | Mass of single item (kg) | Total mass (kg) |
|---|---|---|
| Bed consisting of steel frame with: | | |
| One mattress | 17.5 | 17.5 |
| Two wood pallets | 16 | 32 |
| Shelf consisting of: | | |
| 10 wood pallets | 16 | 160 |
| Wooden table on steel frame | 8.5 | 8.5 |
| Two armchairs consisting of: | | |
| Two automotive seats | 15 | 30 |
| Two pallets | 16 | 32 |
| Wooden chair | 6 | 6 |
| Two wooden chairs with steel frames | 5.5 | 11 |
| Shredded newspapers | 4.5 | 9 |
| Cotton-polyester fabric (to simulate tablecloth, bedspread, etc.) | 2 | 2 |
| Heptane (in steel tray under shelf) | 2 | 2 |
| Total mass of combustible materials | | 310kg |

every second. The facility's water pipe was supervised electronically so that the water flow used for fire attack was also recorded every second.

Three hundred eight kilograms (680 lbs.) of solid fuel were set up as "furniture" inside the burn room. (See Table 1.) The energy released inside the burn room was predominantly from solid Class A fuels; that released by the 2 liters of heptane used to ignite were negligible. Given a pre-burn time of 15 minutes, the overall energy released by that fireload was between 738 and 1,029kwh (or 2.5 million BTUs to 3.5 million BTUs), with an energy release rate of between 2.9 and 4.1mw (megawatts), or 2,750 BTUs/second to 3,890 BTUs/second.

In Germany, there are no regulations governing the performance of live fire trials. Given the testing tunnel's structural integrity, we followed NFPA 1403, Live Fire Training Evolutions (1997), and the German "Standing Orders for Firefighter Occupational Safety and Health" for the given scenarios (safety officer, backup team, backup water supply, communications, EMS and so forth).

We needed to choose an appropriate nozzle and flow for the attack line, so as to neither "flood" the burn room nor have no impact. According to the Iowa rate-of-flow formula, a room this size required a minimum flow rate of 59lpm (16gpm), while according to German formulas between 67.5 and 150lpm (18-40gpm) were required. We thus chose to use a Task Force Tips Quadra-Fog 40gpm (adjustable-flow) nozzle on a 1-inch attack line. (Pressure loss inside the 50-foot line was negligible.) The backup team was provided with a 2-inch line and an Elkhart Brass SM 10 F nozzle, providing a 380lpm (100gpm) flow in case of an emergency intervention.

Table 2 gives an overview of the trials. During the first three trials, the position of the fire load was altered to achieve a fast fire spread to a fully involved room. Furthermore, there were slight variations of the beginning of the intervention during these trials. For trial W-20, the participating Berlin firefighters wanted a triple fire load and 60 minutes of pre-burn to evaluate their new turnout gear, so this trial won't be regarded any further.

We used three extinguishing agents (water, Class A foam at 0.5% and a sodium polyacrylic additive at 3%) and two different attack methods (direct and indirect).

For the induction of 0.5% Silv-ex G (the German version of Ansul's Silv-ex), we used Robwen's Flow-Mix 500 bladder tank proportioner and a FireDos 1000 water motor proportioner. The FireDos proportioner, made by MSR Dosiertechnik (Am Heiligenstock 2, D-61200 Woelfersheim, Germany), is basically a fine piece of equipment, but it had problems responding to the low flows in this scenario, so it was replaced by the Flow-Mix in the following trials.

The idea of the sodium polyacrylic additive is to thicken the water, thus preventing it from running off the fuel before it can properly cool it down. For the induction of the SPA, representatives of the manufacturer were on site and provided an in-line eductor. However, the SPA repeatedly clogged that eductor, our own bypass eductor, the hoselines and the TFT nozzle, so that setup and flushing required a major effort. Furthermore, the SPA created a very slippery layer on the burn room floor, so that the safety of the participating firefighters was at risk.

Table 2: Overview of the Tremonia trials

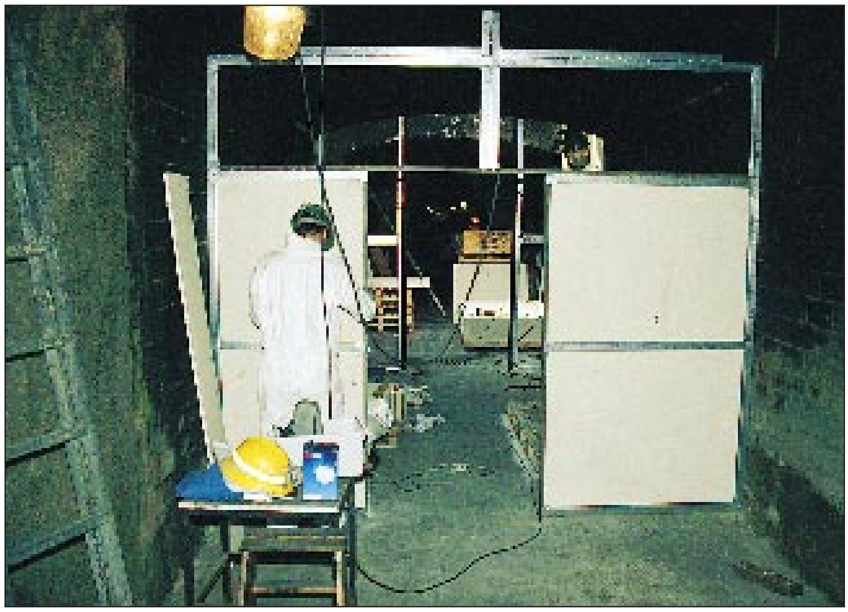
| Trial name and abbreviation | Extinguishing method | Start of intervention after ignition [min:100ths] | End of intervention after ignition [min:100ths] |
|---|---|---|---|
| Water 1 (W-1) | Indirect | 24:23 | 30:90 |
| Water 2 (W-2) | Indirect | 16:04 | 24:20 |
| Water 3 (W-3) | Indirect | 14:75 | 28:77 |
| Water 4 (W-4) | Indirect | 15:02 | 24:50 |
| Water 5 (W-5) | Indirect | 16:25 | 24:28 |
| Water 6 (W-6) | Indirect | 18:84 | 29:85 |
| Water 7 (W-7) | Indirect | 15:60 | 26:81 |
| Water 8 (W-8) | Indirect | 17:13 | 34:03 |
| Water 9 (W-9) | Indirect | 14:73 | 23:96 |
| Silv-ex 10 FireDos (S-10) | Indirect | 15:10 | 20:29 |
| Silv-ex 11 FireDos (S-11) | Indirect | 15:31 | 25:48 |
| Gel 12 Z1 in-line eductor (G-12) | Indirect | 20:20 | 33:88 |
| Gel 13 Z2R by-pass eductor (G-13) | Indirect | 15:44 | 24:89 |
| Silv-ex 14 Flow-Mix (S-14)[1] | Indirect | 15:23 | 23:21 |
| Water 15 (W-15)[B] | Direct | 15:32 | 21:30 |
| Water 16 (W-16)[B] | Direct | 15:52 | 27:75 |
| Silv-ex 17 Flow-Mix (S-17)[2] | Indirect | 15:50 | 27:84 |
| Water 18 (W-18)[B, 2] | Direct | 15:52 | 23:73 |
| Water 19 (W-19)[B] | Direct | 15:85 | 21:13 |
| Water 20 (W-20)[B, 3] | Direct | 61:15 | 84:40 |
| Silv-ex 21 Flow-Mix (S-21)[4] | Indirect | 15:40 | 26:34 |

B: Attack team provided by Berlin Fire Department.
1: Hoseline burst, attack somewhat impaired but successful.
2: Trials 17 and 18 run on one day with different attack teams.
3: Triple fire load, 60 minutes of pre-burn (not used for comparison).
4: Attack team changed from Flameco 10gpm foam nozzle back to TFT nozzle during attack.
"Silv-ex" was Silv-ex G Class A foam at 0.5% induction rate
"Gel" was sodium polyacrylic additive at 3% induction rate.
Direct attack involved predominant use of a full stream directed at the fuel.
Indirect attack involved use of fog stream to cool hot gas layers under the burn room ceiling, then further advance using fog and full stream on the fuel
Times are given in minutes and decimal seconds.

As shown in Table 2 (below left), in five trials, the Berlin Fire Department provided the attack team. These firefighters preferred direct attack, while the Wuppertal entry team advanced using indirect and combination attack.

The fires were ignited by 2 liters of heptane poured into a steel tray under the "shelf." The standard pre-burn time was 15 minutes, then the attack team opened the burn room door, entered and began firefighting. The attack team was always covered by a backup team only a few feet away.

The reports of the backup teams gave valuable information on the situation inside the burn room in comparison to the attack method: Indirect attack, as used by the Wuppertal teams, usually led to a collapse of the flames under the room's ceiling after applying only a few bursts of fog spray upright into the hot gas layers. Since water using indirect/combination attack was applied patiently and the nozzlemen observed the effects of their actions before applying more water, the burn room floor after extinguishment was basically dry; the water applied had time to evaporate and do its job. The attack team then was able to safely advance without the hot flame radiation and without impaired vision.



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The Tremonia live burn room under construction.

On the contrary, when teams used direct attack, the hot water steam arose instantly from the fuel, pushing flames upward, across the ceiling and in at least two trials hitting the attack team literally in the back before the flames collapsed. Vision inside the burn room was much more impaired during the trials with direct attack than in those using indirect attack. Nonetheless, neither direct nor indirect attack showed an advantage over the other method in terms of the times or the water quantity used. The advance using indirect attack, however, was definitely safer and caused less water damage.

## Data processing

To determine which of the trials are comparable in terms of the pre-burn time, we summed up all temperatures recorded by all thermocouples at all times per trial. By comparing these values with a Gaussian standard distribution, we found out that trials W-4 and W-6 have to be considered "too cold" and that trial G-12 has to be considered "too hot" and must not be used for further comparison.

Furthermore, attack didn't always start at the very beginning of minute 15. But by looking at that data and their maximum impact of the statistical methods applied, we found that these inaccuracies are negligible.

The bandwidths of the recorded temperatures were:

- 200°–500°C (400°–900°F) at 0.5 meters (approx. 2 feet) above floor level
- 300°–800°C (600°–1,500°F) at 1.5 meters (approx. 5 feet) above floor level
- 400°–800°C (750°–1,500°F), at times over 1,000°C (1,800°F), at 2.5 meters (approx. 8 feet) above floor level

and thus represent fully involved room-and-contents fires. To put this in a perhaps more familiar context, under the Project FIRES research sponsored by the IAFF in the 1980s and early 1990s, these fires would be rated as Class IV. In other words, they were characterized by temperatures in the 500–1,500°F range, with thermal radiation up to and equal to flashover conditions (from 0.175 to almost 4 watts/cm²).

## Temperature gradients, versus a better way

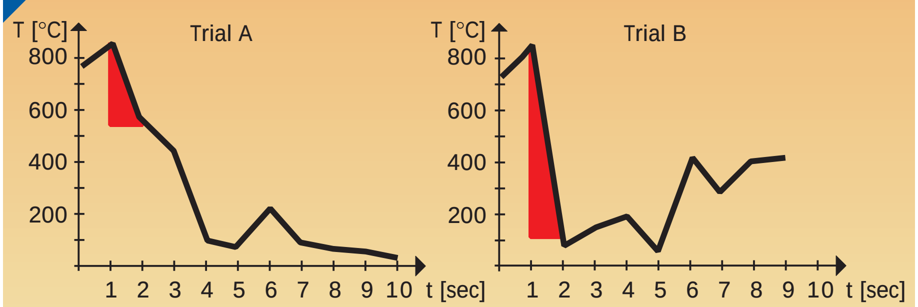
Since temperature recordings at a certain point in time can't be definitely assigned to certain firefighting activities, but rather represent the temperature situation inside the burn room in general, using temperature gradients (the change of temperature versus time or location) to describe extinguishment progress doesn't make sense. We can't be sure that the fall in temperature at a certain place or certain time can be attributed to, for example, only the cool draw of air into the burn room upon opening the door, or the cooling properties of the water spray, or just a single drop of that spray literally hitting the thermocouple, while the major portion of the burn room is still fully involved.

Figure 2 below shows how little temperature gradients represent extinguishment progress. The graphs shown here weren't derived during actual fire trials, but made up for the explanation. In this example, during Trial A, the temperature gradient is $\Delta T/\Delta t = -320K/sec$ between the second and third seconds, while during Trial B the same gradient is $-750K/sec$. This may mean that in Trial B a water drop has hit the thermocouple, or that firefighting progress really is faster. However, after that, there is obviously rekindling during Trial B.

Temperature gradients are poor indicators for extinguishment progress, especially if only one reading of one thermo-

**Figure 2**

Sample temperature gradients



couple is used to "prove" the efficacy of extinguishing agents, as is done by the industry when discussing the "Salem" fire trials. ("Quantifying the effect of class A foam in structure firefighting: The Salem tests," Fire Engineering, February 1993.) From a scientific as well as from a firefighting standpoint, it must be said clearly that the fire industry is abusing the "Salem" fire trial results and misleading its customers.

The better alternative to using temperature gradients is calculating temperature sums. The gradient looks at the change every second, for example, which is a very small event to measure. This in turn means that the inherent inaccuracies of measurement can distort the temperature reading itself. Fires are such fast-changing chemical processes that it's very hard to tell what one temperature reading (or gradient) really means. On the other hand, a temperature sum, which takes into account all temperature readings from a group of thermocouples over a longer stretch of time, represents the energy situation in a room much better.

We looked at the data of the first 10 minutes after the start of intervention. Again, we derived the temperature sums, but this time the temperature sums per thermocouple per minute per fire trial. We calculated the mean values and standard deviations for all 10 minutes, 24 thermocouples and 17 comparable trials. The results was that water and Class A foam performed similarly regarding the cooling of the burn room. Gel provided a slight advantage here, but since there was only one valid trial with it, the statistical background for this is too weak.

Table 3: Results of the Tremonia trials

| Trial | Extinguishing agent quantity (liters) | Time to extinguishment (minutes) | Extinguishment effort (liters x min) |
|---|---|---|---|
| W-1 | 305 | 7 | 2,036 |
| W-2 | 255 | 8 | 2,077 |
| W-3 | 401 | 14 | 5,616 |
| W-5 | 282 | 8 | 2,268 |
| W-7 | 358 | 11 | 4,010 |
| W-8 | 224 | 17 | 3,792 |
| W-9 | 131 | 9 | 1,213 |
| W-15 (Berlin 1) | 244 | 6 | 1,458 |
| W-16 (Berlin 2) | 165 | 12 | 2,018 |
| W-18 (Berlin 3) | 211 | 8 | 1,730 |
| W-19 (Berlin 4) | 184 | 5 | 971 |
| G-13 | 206 | 9 | 1,945 |
| S-10 (FireDos) | 129 | 5 | 671 |
| S-11 (FireDos) | 157 | 10 | 1,592 |
| S-14 (Flow-Mix)[1] | 176 | 8 | 1,405 |
| S-17 (Flow-Mix) | 112 | 12 | 1,382 |
| S-21 (Flow-Mix)[2] | 177 | 11 | 1,936 |

NB: Quantities and times are rounded, but extinguishment effort was calculated from the exact measurements.

1: Hoseline burst

2: Nozzle change

## Comparison of extinguishment

Table 3 (at right) shows the quantity of extinguishing agent, time required for extinguishment and extinguishment effort for the remaining 17 comparable trials.

Trial s-17 required the least extinguishing agent quantity with 112 liters (30 gallons), followed by s-10 using 129 liters (34 gallons). The maximum was observed in trials w-3 and w-7 requiring 401 and 358 liters (106 and 94 gallons) of water. The mean value of extinguishing agent required using Class A foam is 69 liters (18 gallons), or 31%, less in comparison to all 17 trials. The mean value of Class A foam required is 101 liters (27 gallons), or 40%, less in comparison to plain water. Gel achieved an average value.

Trials w-19 and s-10 required the shortest times for extinguishment, each about five minutes. w-8 and w-3 required the longest time for extinguishment, at 17 and 14 minutes. The mean time values of all extinguishing agents are of the same order.

The "extinguishment effort" is the product of "extinguishing agent quantity" and "time to extinguishment." The term "extinguishing effort" replaces the term "extinguishment work" used in my earlier articles, whereas the definition remains the same. The reason for the change in nomenclature is that "work" is too strictly defined by natural sciences to be used in this context.

Extinguishment effort is a derived ("artificial") value representing the effort of a firefighter to put out a fire. By concluding that the time to extinguishment is also the time that a firefighter exposes himself to a hostile environment and heat stress, it helps to better differentiate between the various possible efficacies of firefighting agents. Given comparable scenarios, the smaller the value of extinguishment effort, the better the agent.

The maximum extinguishment effort was required by trial w-3 and its 5,616 liters × minutes, followed by w-7 and w-8 with 4,010 ltr × min and 3,792 ltr × min. The minimum extinguishing effort was measured during s-10 at 671 ltr × min, followed by trials w-19 and w-9 needing 971 ltr × min and 1,213 ltr × min. Gel achieved an average value. The mean extinguishment effort using Class A foam observed in these trials is 1,075 ltr × min, or 43% lower than the mean value of pure water, and 728 ltr × min, or 34% lower than the mean value of all 17 trials. Table 4 lists the means and bandwidths of the values measured. (See next page.)

Table 4: Mean values and standard deviations of the Tremonia trials results

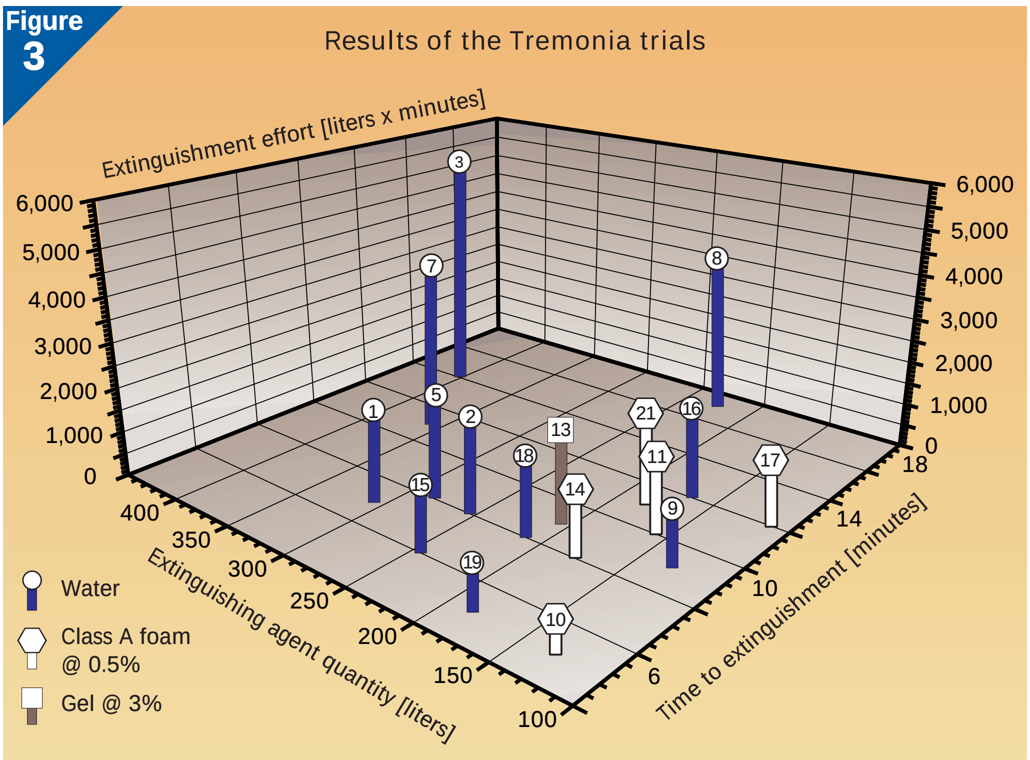
| | Extinguishing agent quantity (liters) | Time to extinguishment (minutes) | Extinguishment effort (ltr x min) |
|---|---|---|---|
| **All 17 trials** | 219 ± 78 = 140 … 297 | 10 ± 3 = 6 … 13 | 2,125 ± 1,209 = 915 … 3,334 |
| **Water** | 251 ± 78 = 173 … 329 | 10 ± 3 = 6 … 13 | 2,472 ± 1,349 = 1,123 … 3,820 |
| **Class A foam** | 150 ± 26 = 124 … 176 | 9 ± 3 = 7 … 12 | 1,397 ± 414 = 984 … 1,811 |
| **Gel** | 206 | 9 | 1.945 |

## Findings of the Tremonia trials

The three-dimensional Figure 3 (below) shows the results of the Tremonia trials. A "corridor of pins" can be recognized, representing the Class A foam trials, in which clearly less than 200 liters (53 gallons) of extinguishing agent were required, whereas a significant number of trials with pure water required more time and extinguishing agent. Even the Class A foam trials s-14 (when the hose burst) and s-21 (when the attack team changed the nozzle) required less agent and effort to be blackened out than most water trials. Thus it can be concluded that Class A foam is a superior extinguishing agent to plain water.

Gel achieved only average values. I've already commented on the induction problems with our use of gel. Besides the slippery layer on the burn room floor, the SPA gel formed a Vaseline-like coating on the SCBA masks that the firefighters couldn't remove by using their gloves or turnout sleeves. On top of that, by requiring an induction rate of 3%, versus the 0.5% rate of Class A foam, gel has a logistical disadvantage. Thus the use of sodium polyacrylic gel can't be recommended.

Figure 3




## The Wattenscheid trials

Protecting a population of 400,000 in an area of 145 square kilometers (56 square miles) with four full-time stations and 15 volunteer stations, Bochum Fire Department responds to about 2,000 fire calls per year. Of these fire calls, about 18.9% are to paper-recycling containers on fire, requiring 850 man-hours per year and tying up a first-due pumper with a crew of four for between 30 minutes and an hour, sometimes even requiring a ladder company to respond in order to lift the container, open it, and dump the smoldering and burning paper onto the pavement.

Until summer 1996, the Bochum Fire Department had responded out of five full-time stations and is now about to reduce to three. Thus the availability of first-due companies for time-critical calls (working fire, persons reported) has to be increased. It was found that using a full-stream nozzle off a booster reel wasn't efficient, so the University of Wuppertal was asked to investigate this problem.

The containers used in Bochum to collect paper for recycling are permanently located on roadsides and parking lots. They are made from zinc-coated steel, having a volume of 3.2 cubic meters (113 cubic feet). They consist of two symmetrical, almost semi-cubically-shaped "shells," which are kept in place by a hinge at a top and their own weight. On two opposite sides of the containers, there is one lid (100cm by 9cm, or 4 feet by 4 inches) for the disposal of paper trash into the container. The paper-collection trucks lift these containers with a crane, then manipulate the shells to fold open and drop their paper contents into the truck.

We ran eight fire trials at the Bochum Fire Department's training facility at Wattenscheid fire station, with containers provided by the paper-recycling company. They were set on fire and allowed to pre-burn for 30 minutes. The results are summarized in Table 5. (See next page.)

**Trial: Water 1**

Equipment used was a 2-inch line with a Cordova Fire Equipment Feather Lite 20-95 nozzle, maximum flow 360lpm (95gpm) at 7 bars pressure (100psi), pump pressure 5 bars (72psi). Fire attack was through the lids, requiring 15 minutes and 1,854 liters (490 gallons) of water.

**Trial: Water 2**

For this trial, a "lance nozzle" was homemade by the author because the ones available through the fire industry are unnecessarily expensive. The lance nozzle consists of a standard 1-inch ball valve with a ½-inch, 3-foot-long pipe and a stainless-steel ball-shaped sprayhead at the end, delivering 140lpm (37gpm) at 5 bars (72psi). The ball-shaped sprayhead has 40 machined holes, placed evenly and covering 240° of the spherical surface.

Using a pry bar, the attack team can easily force the gap between the two shells of the containers just wide enough to push the lance nozzle into the paper inside. When opening the

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The homemade lance nozzle being used on a paper-recycling container at Wattenscheid.

lance nozzle's ball-valve, the nozzle basically thrusts itself deeper into the paper, minimizing the physical effort required of the attack team. In the first trial with this lance nozzle and pure water, 11 minutes and 345 liters (91 gallons) of water were required.

**Trial: Water 3**

For this trial, we used a homemade L-shaped 3-inch pipe devised by Bochum firefighters, which can be hooked into the lid in order to literally flood the inside of the container. However, handling this basically open-ended 3-inch nozzle was not only difficult, but dangerous. The water ran out of the gaps in the container too fast, so that pump pressure had to be increased, thus increasing the nozzle's reaction force. Bochum's first-due engines carry 2,400 liters (630 gallons) of water, which wasn't enough to extinguish the fire.

**Trial: Carbon dioxide**

Another alternative suppression method that was looked into was to flood the container with carbon dioxide, thus trying to deplete the oxygen necessary for combustion inside the container. From two carbon dioxide extinguishers used simultaneously, a total of 6,444 liters of carbon dioxide (twice the volume of the container) was discharged through both lids. Extinguishment was not achieved.

**Trial: Foam 1**

This trial was performed using standard equipment: A 2-inch line with eductor, 3% polysynthetic foam agent and a smoothbore nozzle. It required 6 minutes and 251 liters (66 gallons) of foam solution to extinguish the fire.

**Trial: Foam 2**

Almost like Foam 1, this trial used standard equipment, only the smoothbore nozzle was replaced with a medium-expansion foam nozzle. The problem here was that the diameter of the discharge side of the foam nozzle was too big for the containers' lids. Furthermore, the foam degraded almost instantly when it came into contact with the hot steel surfaces of the container. Fire attack took four minutes and required 150 liters (40 gallons) of foam solution.

**Trial: Foam 3**

This time a Robwen Flow-Mix 500 bladder tank proportioner was used to induce 0.3% Class A foam solution and to feed the 1-inch hoseline to the lance nozzle at 5 bars (72psi) of pump pressure. Fire attack through the lids and gaps of the container, as described before, took 13 minutes and required 353 liters (93 gallons) of foam solution.

**Trial: Foam 4**

Set-up was identical to trial Foam 3, only this time pump pressure was increased to 8 bars (116psi). Fire attack through the lids and gaps of the container, as described before, took seven minutes and required 339 liters (90 gallons) of foam solution.

## Findings of the Wattenscheid trials

After each trial, the containers that were considered to be extinguished were opened and their paper contents inspected. It was found that in the trials where only pure water and/or polysynthetic foam agent at 3% were used, only the surface of the paper was wet, and that paper was still smoldering in lower regions of the containers. Thus, "late fires" would have been most likely, requiring another response by the fire department.

Contrary to that, the paper contents of the containers were thoroughly soaked in the trials in which foam agent was used as an additive, thus also suppressing smoldering fires. Setting up a "conservative" foam attack with a feed line, an in-line eductor, foam agent pail, attack line and nozzle seems a work effort out of proportion to the problem.

Table 5: Results of the Wattenscheid trials

| Trial | Extinguishing agent quantity (liters) | Time to extinguishment (minutes) | Extinguishment effort (liters x min) |
|---|---|---|---|
| Water 1 | 1,854 | 15 | 27,810 |
| Water 2 | 345 | 11 | 3,795 |
| Water 3 | 2,400 | n/a | ∞ |
| Carbon dioxide | (12kg) | n/a | ∞ |
| Foam 1 | 251 | 6 | 1,506 |
| Foam 2 | 150 | 4 | 600 |
| Foam 3 | 353 | 13 | 4,589 |
| Foam 4 | 339 | 7 | 2,373 |

Furthermore, it was found that the lance nozzle on a 1-inch line was the easiest device to handle. A built-in bladder proportioner relieves the crew of having to set up foam equipment. Finally, a 1-inch hoseline can most easily be withdrawn in case the first-due engine has to leave the scene fast and attend to a more critical fire.

These trials showed that Class A foam increases the penetration of paper fuels and helps to extinguish deep-seated smoldering fires. The recommendation following this research was to take advantage of Class A foam and to purchase built-in proportioners and lance nozzles. FC

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