Clean Techn Environ Policy (2005) 7: 127–132
DOI 10.1007/s10098-004-0264-9

ORIGINAL PAPER

**Daniel Ecker · Klaus Dieter Pohl · Andreas Wieneke
Friedrich Wilhelm Wittbecker**

Assessment of extinguishing waters from intermediate-scale fire tests

Received: 15 December 2003 / Accepted: 11 May 2004 / Published online: 19 January 2005

Abstract Water is, for several reasons, by far the most widely used agent for extinguishing fires. Large quantities will turn to steam, but much will drain away with more or less ecotoxic effects on the ground and aquatic environments. Although this fire water run-off does not usually present a serious risk to the environment, it is reasonable to take precautions and to have quick in situ measures for predicting the likely consequences for, for example, a nearby mechanobiological, wastewater treatment plant. The enormous environmental damage caused by extinguishing waters in the past has focused attention on this environmental problem. From the detailed assessments of relevant parameters, it is demonstrated that product-related potency values may be capable of distinguishing between products. Some products tend to have toxic potencies that can be as much as almost four times higher than others. Risk assessments will not only reveal the routes by which major environmental damage might occur but also areas where fire precautions are inadequate. Special tasks must be allocated to the fire brigade: the earlier a fire can be tackled, the greater the chance of successfully extinguishing it and minimising the quantity of contaminated water. In this context, other active precautions such as fire detectors and sprinklers also help to minimise the ecotoxic effect of extinguishing waters. The primary fire-safety objective is to prevent any fires, rather than to deal with their consequences.

Introduction

The extent of measures to protect the environment from the effects of extinguishing waters will depend on the likelihood of an accident occurring and the likely consequences. These depend on the nature and quantities of hazardous substances on site, the activities carried out and existing accident-prevention measures. A guidance for extinguishing water was published in the UK [1].

For estimating consequences, a method has been developed to evaluate extinguishing waters, using different parameters [2–4]. The development of assessment criteria was based on 35 realistic in situ investigations and the relevance of the selected parameters has been proven. Material-oriented assessments using laboratory-scale decomposition methods are, however, rare [5] and there is only a little knowledge concerning interrelated fire parameters affecting the extinguishing water's toxicity.

The aim of this investigation was to develop a procedure for repeatable tests with the objective of assessing extinguishing waters from products, taking into account realistic decomposition conditions as far as possible.

The assessment of water should be based on the findings by Wieneke [3]. The procedure is an intermediate-scale test simulating a realistic large fire. Several materials have been selected covering a range of end-use products involved in a fire.

Tests were conducted at the Bayer fire-testing laboratory and the extinguishing waters were analysed at Wuppertal University with some additional investigations in Bayer's environmental analytical department.

The results of this study have to be regarded as relative potency values. For a direct quantitative hazard assessment of an aquatic system, the application rate and the amount of water must be considered in addition to other parameters of natural fires.

Fire scenario

For the scenario, it was assumed that a fire in a compartment is fully developed. Smaller fires in the developing stage are extinguished by a small amount of water

D. Ecker · K. D. Pohl · A. Wieneke · F. W. Wittbecker (✉)
Safety Engineering, Fire and Explosion Safety,
Wuppertal University, Gaußstr 20, 42097 Wuppertal, Germany
E-mail: wittbeck@uni-wuppertal.de

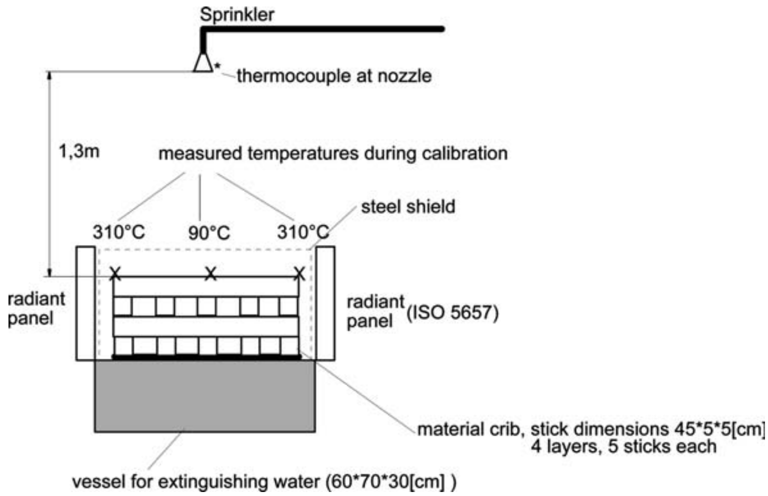

Fig. 1 Pattern and dimensions of the test rig

or other means and will cause minor environmental damage. Flame retarded (FR) treated products are particularly resistant to primary ignition sources [6] and self extinguishing can be expected, hence scenarios simulating the early stages of a fire do not require further consideration for these types of products.

Fully developed fires are characterised by comparatively high temperatures and a large burning area, leading to depleted oxygen in the fire compartment. In the flashover phase, combustible-product surfaces are set on fire almost instantaneously, with flame spread velocities of up to several meters per second. Detailed descriptions of realistic fire conditions are explained in ISO TR 9122 [7].

In addition to the chemical nature of the products and the dilution factor of the extinguishing water, decomposition parameters, such as temperature and O_2-depletion in the atmosphere, are dominant for fire-effluent yields.

A flashover scenario is assumed to be the worst-case situation in which the fire brigade discharges large amounts of extinguishing water.

Decomposition procedure

As full-scale tests with a variation of parameters, including the size of compartment, ventilation, amount of water etc., are not affordable, the experimental approach, which has been developed to resolve problems in connection with the toxicological effect on the aquatic system, needs simplification and implies scale effects.

Figure 1 shows the test arrangement and two photographs of it are shown in Fig. 2. The decomposition apparatus mainly consists of two radiant panels that simulate the impact of a surrounding fire on the product to be tested. The radiant intensity was adjusted to create a surface temperature just below the flash ignition of a variety of products, i.e. approximately 300°C. This allows preheating of the material and an instantaneous spread of fire across the whole product surface after ignition, representing flashover. Hence, no additional ignition sources such as fuel, which could pollute the extinguishing water, are necessary. Perpendicular to the radiant panels, steel shields obstruct air entrainment. It

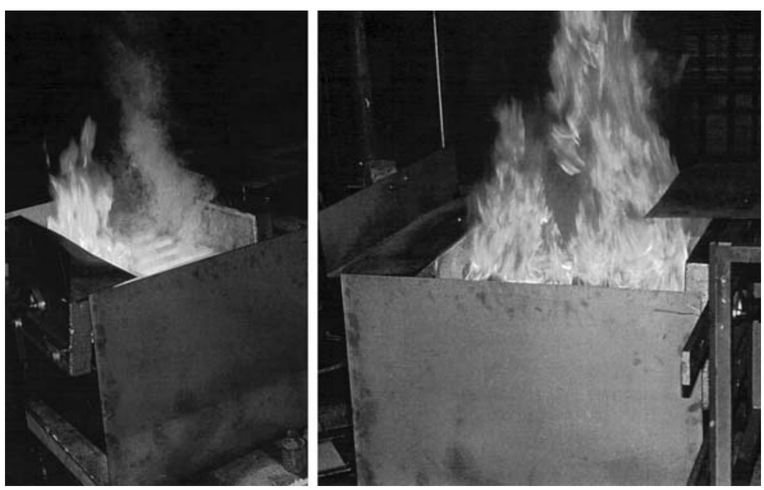

Fig. 2 Photographs taken during the test: ignition and fully developed fire

Table 1 Materials

Test no.	Type
1	Polyurethane (PUR) rigid foam
2	Polyurethane (PUR) flexible foam 1 (A polyether foam of density 30 kg/m^3, containing 12 parts per 100 polyol of flame retardant comprising 90% tris (1,3-dichloroisopropyl) phosphate and 10% triaryl phosphate.)
3	Polyurethane (PUR) flexible foam 2 (A polyether foam of density 30 kg/m^3, containing no flame retardant additives)
4	Polyurethane (PUR) flexible foam 3 (A high resilience foam of density 28 kg/m^3, meeting UK Domestic Furniture requirements using only melamine as flame retardant)
5	Coconut fibres
6	Pine wood
7	Wool

must be recognised that the means used for obtaining reduced ventilation conditions cannot be as effective as those found in almost all real-life flashover fire conditions.

In preliminary tests, homogeneous blocks of materials did not burn sufficiently for the special purpose of the test, i.e. instantaneous spread of flame across the whole surface to generate a reasonable amount of extinguishing water. Tests were, therefore, conducted with materials forming cribs (see Fig. 1).

The sprinkler was activated by hand at estimated maximum temperatures measured directly at the nozzle. It is presumed that maximum temperatures indicate a whole burning surface and maximum fire intensity. For constant test parameters concerning ventilation and heat flux, different maximum temperatures were therefore measured depending on material type.

The active sprinkler times in all tests were kept constant at 10 s. In preliminary tests, the original sprinkler nozzles were thermally activated automatically. This procedure has been found to be inappropriate for the tests due to the delay time of the sprinklers.

Concerning the extinguishing procedure, there are some parameters which have not been investigated in this study and which would influence the concentration of effluents, i.e. the application rate of water and time. Details are reported by Stolp [8] and Fuchs [9].

The extinguishing water was collected in a container underneath the product cribs (see Fig. 1) and then stored in closed vessels. In this intermediate-scale test procedure, it is not possible to determine how much water is evaporated or spilled during extinguishing.

Materials and fire parameters

The natural and plastic test materials, each tested three times, are summarised in Table 1. Samples include FR and non-FR materials. To have base values of the analytical results, one test was carried out with fresh water using identical extinguishing procedure but without any material in the test rig. The test numbers in Table 1 represent the sequence of measurements.

All materials were conditioned in a climate at 23°C and with 50% relative humidity for at least 48 h.

An example of the measured temperature profile is given in Fig. 3. The fire parameters, such as activation time, temperatures, weight of the extinguishing water etc., are listed in Table 2.

Toxic parameters and assessment

The ecotoxicity relevance is characterised by a sum of parameters developed by Wieneke [3, 4]. They include the pH value of physical parameters, and conductivity

Fig. 3 Temperature profile

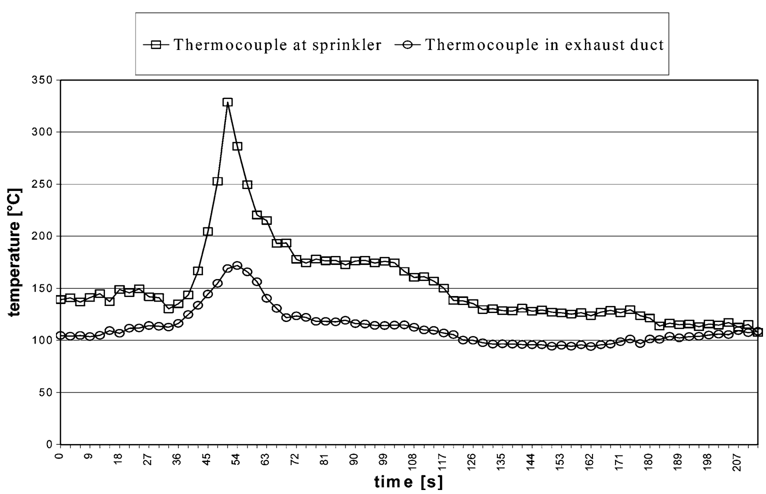

Table 2 Measured parameters of the decomposition procedure

Material	No.	Material weight before test (g)	Temperature (°C) in sprinkler at activation	Temperature (°C) in duct system at activation	Extinguishing water (g)	Extinguishing time (s)	Test duration (s)
PUR rigid foam	1.1	629	332	171	1,130	46	56
	1.2	630	281	168	1,319	55	65
	1.3	624	298	168	865	55	65
PUR flexible foam 1	2.4	423	183	135	1,100	43	53
	2.5	417	165	136	1,079	40	50
	2.6	424	165	140	1,104	39	49
PUR flexible foam 2	3.7	395	240	155	2,181	36	46
	3.8	402	192	145	1,184	33	43
	3.9	395	250	140	2,254	39	49
PUR flexible foam 3	4.10	420	145	122	836	48	58
	4.11	416	149	124	862	51	61
	4.12	419	137	123	873	42	52
Coconut fibres	5.13	757	182	143	3,678	28	38
	5.14	761	231	168	3,640	34	44
	5.15	753	192	150	3,452	42	52
Pine wood	6.16	3,226	165	139	3,680	240	250
	6.17	3,245	181	143	2,348	245	255
	6.18	3,242	187	148	4,159	253	263
Wool	7.19	581	217	172	3,191	32	42
	7.20	623	227	160	3,243	31	41
	7.21	552	203	167	3,458	42	52

Table 3 Corresponding points to the physical hazard parameters (pH, conductivity and SAK)

pH values	Points	Conductivity	Points	SAK [254]	Points
6–8	0	≤ 1,000	0	≥50	0
< 6–5/ > 8–9	1	> 1,000–2,000	1	< 50–200	1
< 5–4/ > 9–10	2	> 2,000–6,000	2	> 200–500	2
< 4–3/ > 10–11	3	> 6,000–10,000	3	> 500–1,000	3
< 3–2/ > 11–12	4	> 10,000–20,000	4	> 1,000–2,000	4
< 2–1/ > 12–13	5	> 20,000–40,000	5	> 2,000–10,000	5
< 1/ > 13	8	> 40,000	8	> 10,000	8

given as (µs/cm) and $SAC_{254\ nm}$ (spectral absorbent coefficient), the chemical oxygen consumption (COC) as well as the biological effect on luminescent bacteria expressed as G_L values. The G_L value is derived from the inhibition of the bioluminescence of luminescent bacteria and represents the smallest dilution rate G for a sample at which the bacterial light emission decreases by less than 20%. G_L values are determined following DIN 38412.

As far as COC and G_L values are concerned, thresholds introduced by the German "Rahmen -Abwasser-Verwaltungsvorschrift RabwVwV" (Framework Administrative Provision on Waste Water) are taken into account. pH values refer to the general requirements for waste waters, and conductivities refer to the freshwater decree. Each sample obtains values in the range from 0 to 8 (Tables 3, 4) for every parameter, which are then summarised.

This allows the incorporation of different sum parameters into a final assessment of the extinguishing water and presents an approach for an integral evaluation. For relative comparisons using a hazard factor, the sum is finally divided by the sum of parameters taken into account, i.e. $n = 5$.

$$\text{Factor} = \frac{\text{Sum}}{\text{Number of parameters}}$$

The following classification (Table 5) is proposed.

The individual analytical results are summarised in Table 6. Table 7 gives the hazard factors for a final assessment.

Table 4 Corresponding points to the chemical (COC) and biological (G_L) hazard parameters

COC value (mg/l)	Points	G_L value	Points
≤ 50	0	≤ 2	0
> 50–250	1	> 2–16	1
> 250–1,400	2	> 10–48	2
> 1,400–3,000	3	> 48–256	3
> 3,000–6,000	4	> 256–2,048	4
> 6,000–10,000	5	> 2,048–4,096	5
> 10,000	8	> 4,096	8

Conclusions

The comparison of repetitive tests in this study indicates a sufficient repeatability of the decomposition procedure, although a statistical evaluation is not possible. Repeatability was also checked in preliminary tests. Results are developmental in terms of the test method and no effort has been made to relate them to real-scale behaviour.

However, from the detailed assessments of relevant parameters in this study, it is demonstrated that the method gives product-related potency values capable of distinguishing products. Some products tend to have toxic potencies that can be as much as almost four times higher than others. Assuming comparable fire parameters with regard to the fire load, amount of extinguishing water, etc., the investigated products did not exhibit significant differences in the toxic potencies of their extinguishing water. With regard to the enormous environmental damage caused by extinguishing waters

Table 5 Hazard classes according to factors

Factor	Hazard class
< 1	0
< 2	1
< 4	2
> 4	3

Table 6 Analytical results of extinguishing waters

Material	No.	pH value	Conductivity (µs/cm)	SAC (254 nm)	COC (mg/l)	G_L value
PUR rigid foam	1.1	7.3	839	262	67	128
	1.2	7.2	840	216	29	64
	1.3	7.7	887	281	51	128
PUR flexible foam 1	2.4	6.7	881	868	402	256
	2.5	5.7	864	1,140	492	256
	2.6	5.1	928	1,885	692	512
PUR flexible foam 2	3.7	7.6	794	652	577	128
	3.8	7.8	837	804	929	128
	3.9	7.6	780	513	418	32
PUR flexible foam 3	4.10	8.0	782	1,226	311	256
	4.11	8.1	808	1,145	272	64
	4.12	8.1	812	1,155	264	64
Coconut fibre	5.13	6.9	1,033	243	27	8
	5.14	6.9	981	258	23	16
	5.15	7.0	965	206	17	16
Pine wood	6.16	7.2	716	160	0	8
	6.17	7.2	756	207	24	32
	6.18	7.2	700	134	0	16
Wool	7.19	7.8	986	309	34	32
	7.20	7.6	1,057	364	35	32
	7.21	7.8	1,037	365	37	32
Fresh water	22	7.1	710	0	0	2

Table 7 Hazard parameters

Material	Test no.	pH value	Conductivity	SAK	COC	G_L value	Sum	Sum/5
PUR rigid foam	1.1	0	0	2	1	3	6	1.2
	1.2	0	0	2	0	3	5	1
	1.3	0	0	2	1	3	6	1.2
PUR flexible foam 1	2.4	0	0	3	2	3	8	1.6
	2.5	1	0	4	2	3	10	2
	2.6	1	0	4	2	4	11	2.2
PUR flexible foam 2	3.7	0	0	3	2	3	8	1.6
	3.8	0	0	3	2	3	8	1.6
	3.9	0	0	3	2	2	7	1.4
PUR flexible foam 3	4.10	0	0	4	2	3	9	1.8
	4.11	1	0	4	2	2	9	1.8
	4.12	1	0	4	2	2	9	1.8
Coconut fibre	5.13	0	1	2	0	1	4	0.8
	5.14	0	0	2	0	1	3	0.6
	5.15	0	0	2	0	1	3	0.6
Pine wood	6.16	0	0	2	0	1	3	0.6
	6.17	0	0	2	0	2	4	0.8
	6.18	0	0	2	0	1	3	0.6
Wool	7.19	0	0	2	0	2	4	0.8
	7.20	0	1	2	0	2	5	1.0
	7.21	0	1	2	0	2	5	1.0

in the past, the products investigated in this study may not explain these disasters.

References

1. The control of fire-water run off from CIMAH sites to prevent environmental damage, guidance note EH70, HSE health and safety executive, UK
2. Pohl KD, Wieneke A, Berger T, Voss S (1994) Analysis of contaminated extinguishing water (original German title: Analytik kontaminierter Löschwässer), WLB Wasser, Luft und Boden, 9/94
3. Wieneke A (1996) Development of concepts for the assessment and cleaning of contaminated extinguishing water (original German title: Erarbeitung von Konzepten zur Beurteilung und Reinigung kontaminierter Löschwässer), PhD Thesis, Wuppertal University
4. Wieneke A (1996) New findings concerning the analysis of contaminated extinguishing water (original German title: Neue Erkenntnisse zur Analytik kontaminierter Löschwässer), TÜ Bd. 37, No. 10
5. Sklorz M (1998) Decomposition experiments with plastics, generation and chemical-toxicological characterisation of extinguishing water and fire effluents (original German title: Verbrennungsexperimente mit Kunststoffen, Erzeugung und chemisch- toxikologische Charakterisierung von Löschwasser und Rauchgas), VDI Reihe 15: Umwelttechnik, Nr. 117
6. ISO 10093 (1994) Plastics—fire tests—standard ignition sources
7. ISO TR 9122: Toxicity testing of fire effluents
8. Stolp M (1976) The extinction of small wood crib fires by water. TNO, The Netherlands
9. Fuchs P, Seeger PG: A mathematical model for determining the amount of extinguishing water and comparison with experiments (original German title: Ein mathematisches Modell zur Bestimmung der Löschwassermenge und Vergleich mit Experimenten), vfdb-Zeitschrift, 1/81