Fire Safety Journal 45 (2010) 206–210

Contents lists available at ScienceDirect

Fire Safety Journal

journal homepage: www.elsevier.com/locate/firesaf

Short Communication

# A simple method to assess the quenching effectiveness of fire suppressants

C.T. Avedisian [a], C. Presser [b,*], J. Stiehl [a], R.E. Cavicchi [b]

[a] Sibley School of Mechanical and Aerospace Engineering, Cornell University, Ithaca, NY 14853-7501, USA
[b] Chemical Science and Technology Laboratory, National Institute of Standards and Technology, 100 Bureau Dr., Stop 8360, Gaithersburg, MD 20899-8360, USA

ARTICLE INFO

*Article history:*
Received 19 January 2010
Accepted 28 February 2010

*Keywords:*
Fire suppressant
Pulse heating
Extinction
Transient heating
Thermal conductivity
Quenching effectiveness
Suppression effectiveness

ABSTRACT

A screening concept is suggested for evaluating the effectiveness of fluids to thermally suppress fires. It is based on measuring a fluid's ability to inhibit (or quench) the temperature rise of a material that is rapidly heated. The experimental design is similar to the transient hot wire technique, in which the evolution of the average material temperature is recorded for a given input power, and internal temperature gradients in the material are minimized. A gold wire (100 μm long and 5 μm diameter) is used as the surface which heats the fluid. The wire temperature response due to a power pulse provides a measure of the effectiveness of the fluid to suppress thermally the temperature increase. The results indicate that the "quenching effectiveness", $QE=(T_{\max}-T_{\infty})/(T_{\max,ref}-T_{\infty})$, correlates with the ratio of the fluid thermal conductivity to that of the wire, $k_{fluid}/k_{solid}$, using different Nusselt numbers (representing both conduction and natural convection) for the liquids or gases. The concept developed here could be included in a more comprehensive screening protocol, which would assess the thermal potential of candidate fire suppressants.

Published by Elsevier Ltd.

## 1. Introduction

A fire suppressant derives its effectiveness by extinguishing a burning surface through chemical, thermal, and physical mechanisms. Previous work [1] is notable for the articulation of thermal, physical, and chemical effects on flame extinction especially for gaseous agents (e.g., trifluoromethane, $CF_3H$ and bromo-trifluoromethane, $CF_3Br$) [2]. The ability to separate suppressant mechanisms when using an actual fire configuration in testing is difficult. Experimental screening methods generally rank agents according to the integrated physical, thermal, and chemical effects that lead to flame extinction [3]. The efficacy of new fire suppressants is facilitated by screening methods that segregate the mechanisms involved in the processes leading to flame extinction. A testing protocol that decouples these effects could provide a clearer understanding of the mechanisms associated with suppressant of a particular fire. Linteris et al. [4] noted that the flame configuration itself could influence the relative suppression effectiveness. At the same time, useful information can be obtained even if the results are unique to that configuration, and indeed, this is the case for standardized screening protocols (e.g., counterflow burner (e.g., [5]), cup burner screens (e.g., [6]), and turbulent spray flames (e.g., [7]).

Several studies have attempted to isolate individual mechanisms of suppression. For example, Pitts et al. [8] ranked suppressants according to their thermophysical properties (i.e., the latent heat of vaporization, heat capacity, and boiling point were used to estimate the total absorbed heat). Agents were selected according to this ranking to test in various screens for their suppression effectiveness. Lentati and Chelliah [9] used a numerical model to unmask physical, thermal, and chemical effects in a counterflow configuration, in which monodispersed water droplets were introduced into the flow field. A follow-up experimental study [10] indicated that water mists were effective suppressants due to their thermal behavior (as effective as $CF_3Br$), and that a strategy of mixing thermal components with chemical components may lead to the development of superior fire suppressants.

Presented is a concept to evaluate the heat transfer properties of fire suppressant fluids, through the interaction of a cold fluid with a hot surface. The experimental approach is based on the pulse heating of a solid material – a metal in the proposed configuration – that is submerged in a test fluid, and monitoring the temperature change of the solid during the power pulse. This configuration is relevant to a re-ignitable hot surface in fire scenarios, as had been investigated by Hamins et al. [3]. We did not consider the condition where vaporization would occur, but the approach is amenable to the characterization of vaporization effects. Vaporization of the fluid would be manifested as an inflection point at the start of nucleation and an increased rate of temperature rise thereafter [11].

## 2. Experimental arrangement

Fig. 1 presents a schematic of the experimental arrangement. In general, a programmed power pulse is imposed on a small

* Corresponding author. Tel.: +1 301 975 2612.
*E-mail address:* cpresser@nist.gov (C. Presser).

0379-7112/$ - see front matter Published by Elsevier Ltd.
doi:10.1016/j.firesaf.2010.02.002

**Nomenclature**

| | |
|---|---|
| $Bi$ | Biot number ($=hDk_{solid}^{-1}$) |
| $D$ | wire diameter (m) |
| $h$ | convection heat transfer coefficient ($W\,K^{-1}$) |
| $k$ | thermal conductivity ($W\,m^{-1}\,K^{-1}$) |
| $L$ | wire length (m) |
| $Nu$ | Nusselt number (Eq. (9.34) of Ref. [14]) |
| $p$ | power (W) |
| $\overline{p}$ | nondimensional power |
| $QE$ | quenching effectiveness based on the temperature derivative |
| $R_h$ | wire resistance ($\Omega$) |
| $R_{ho}$ | wire resistance at room temperature ($\Omega$) |
| $R_p$ | adjustable resister ($\Omega$) |
| $R_1$ | bridge resistances ($\Omega$) |
| $t$ | time (s) |
| $T$ | wire temperature (K) |
| $T_{TC}$ | oven temperature (K) |
| $T_\infty$ | ambient fluid temperature (K) |
| $V_{in}$ | bridge input voltage |
| $V_{out}$ | bridge output voltage (V) |

*Greek letters*

| | |
|---|---|
| $\alpha$ | thermal diffusivity ($m^2\,s^{-1}$) |
| $\Delta t$ | time duration (s) |
| $\theta$ | nondimensional temperature difference |
| $\theta_R$ | thermal coefficient of resistivity ($K^{-1}$) |
| $\xi$ | suppression effectiveness parameter base on $T_{max}$ |
| $\tau$ | nondimensional time |

*Subscript*

| | |
|---|---|
| *fluid* | referenced to the suppression agent |
| *gas* | gaseous agent |
| *liquid* | liquid agent |
| *max* | referenced to the value near end of pulse (near $t=50\,\mu s$) |
| *ref* | referenced to the value of water |
| *solid* | referenced to the gold wire |

diameter metal wire that forms one leg of a bridge circuit. The wire is immersed in the fluid and supported only by its electrical wire-bond connection at either end. During the pulse, the wire electrical resistance is monitored with a fast-transient data acquisition system. The hot wire serves as both an energy source to impart a precise and controllable amount of thermal energy to the surrounding fluid and a temperature sensor through the relationship of electrical resistance with temperature of the wire material from a separate calibration. The fluid that best restrains the temperature change of the wire during the heating process is considered to be the most thermally effective agent.

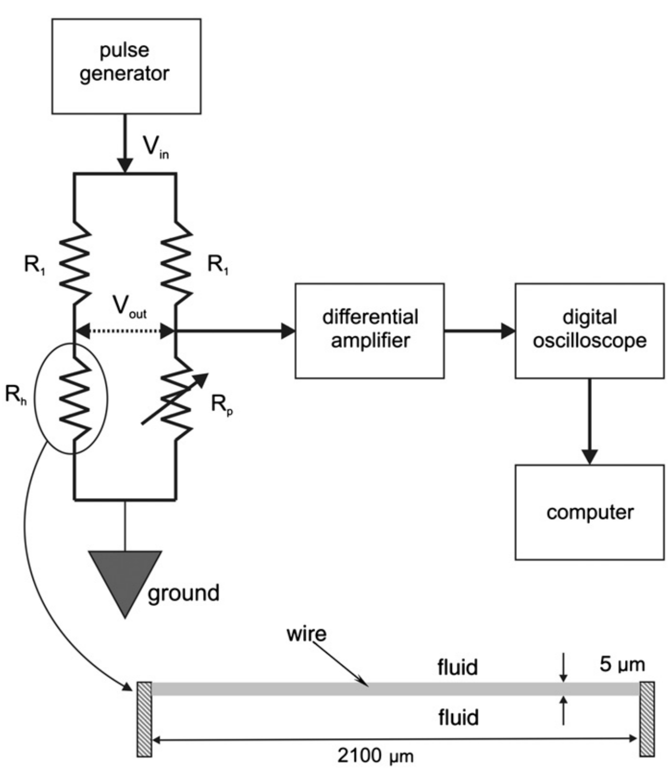


**Fig. 1.** Schematic of the experimental arrangement.

The gold wire is 5 μm in diameter ($D$) and 2.1 mm in length ($L$).[1] This choice of physical dimensions and material for the wire simplifies the analysis of the results by satisfying the so-called 'lumped-capacitance approximation', which is characterized by a small Biot number ($Bi=hD/k_{solid}<0.1$, where $h$ is the convection heat transfer coefficient and $k_{solid}$ is the wire thermal conductivity). The measured room temperature resistance of this wire is $R_{ho}=2.58\,\Omega$ (at 295 K). An adjustable resister ($R_p$) is used to balance the wire resister $R_h$ on the opposite leg of the bridge prior to heating the gold wire, as shown in Fig. 1, and we take $R_1=2.29\,\Omega$. The bridge is mounted on a 3M[2] Model 309 breadboard which facilitates changing bridge resistances, as needed. The wire is mounted across corner pads of a 40 pin dual-in-line package (DIP, Aries Model 40-6553-18 high-temperature test socket, max: 523 K). The DIP is incorporated directly into the bridge circuit (see Fig. 1).

A voltage pulse ($V_{in}$) is imposed across the bridge of time duration $\Delta t$ by an Agilent Model 8114A pulse generator. The output voltage ($V_{out}$) is monitored by a LeCroy WaveRunner Model 44xi 5Gs/s digital oscilloscope through a LeCroy Model AP033 differential amplifier, and the voltage is converted to wire resistance with the equations of bridge circuitry [12]. Data files are stored directly on the oscilloscope and later transferred to a personal computer for analysis. A calibration of wire resistance is used to obtain the average wire temperature during the power pulse.

A 50 μs pulse duration was selected and fixed throughout the study to provide a valid basis for comparing different fluids. The input voltage to the bridge was adjusted so that the average wire temperature in air was about 560 K at the end of the 50 μs pulse. The choice of a 50 μs pulse mitigated thermal shock effects and potential damage associated with repeated thermal stressing of the wire. The pulse time was short enough to reduce the onset of

[1] Relevant properties of gold (at 300 K) are the following: solid density (19,300 $kg\,m^{-3}$); specific heat (129 $J\,kg^{-1}\,K^{-1}$); thermal conductivity (318 $W\,m^{-1}\,K^{-1}$).

[2] Certain commercial equipment or materials are identified in this publication to specify adequately the experimental procedure. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment are necessarily the best available for this purpose.

Download English Version:

https://daneshyari.com/en/article/270262

Download Persian Version:

https://daneshyari.com/article/270262

Daneshyari.com