Surface analysis of electrical arc residues in fire investigation

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key words: fire; oxidized residues; electrical short circuit bead

Abstract: At most fire scenes, electric short circuit (ESC) arc beads that may be provide useful information on the cause and development of the fire are found. Various physical or chemical methods have been proposed for identifying these electric short circuit beads to be either the cause of a fire (primary arc beads) or one caused by the flames of the fire (secondary arc beads). Little was studied, however, on their identification using the different distribution of O and C in the molten marks. In this study, the concentration of O and C in the surface region and subsurface was quantified by X-ray photoelectron spectroscopy (XPS). Corresponding to the sputtering depth, the molten product on a primary ESC arc bead may be distinguished as three portions: surface layer with drastic decrease of carbon content; intermediate layer with gentle change of oxygen content, gradually diminished carbon peak, and consisted of Cu$_2$O; transition layer without Cu$_2$O and with rapid decrease of oxygen content. While the molten product on a secondary ESC arc bead may be distinguished as two portions: surface layer with carbon content decreasing quickly; subsurface layer without Cu$_2$O and with carbon, oxygen content decreasing gradually. Thus, it can be seen that there was an obvious interface between the layered surface product and the substrate for the first type of bead, while as to the second type of bead there was no interface. As a result, the quantitative results can be used to identify these electric short circuit beads to be either the cause of a fire (a primary ESC) or one caused by the flames of the fire (a secondary ESC), as complementary technique for judgments of fire cause.
CFD and Fire Dynamics Informed Modelling Approach to Property Damage Loss Estimates for Semiconductor Fabrication Cleanroom Fires

Steffen Kahrmann, David Lange and Al Brown

(Submission #1002)

Image Caption or Poster Abstract

CFD and Fire Dynamics Informed Modelling Approach to Property Damage Loss Estimates for Semiconductor Fabrication Cleanroom Fires

Steffen Kahrmann 1, David Lange 1,2, Al Brown 2

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Our understanding of the behaviour of fire and smoke under 'common' conditions, e.g. in compartment fires, has grown enormously in the last decades. This has occurred hand in hand with equivalent progress made in computing capacity and Computational Fluid Dynamics (CFD) codes which are frequently applied within the field of Fire Safety Engineering, both for research and within commercial environments. However, the complex air flow found within a cleanroom environment where the unique pattern of recirculation airflow leads to a correspondingly unique spread of smoke presents unique challenges for both numerical and analytical models. Despite these challenges, the susceptibility of cleanroom manufacturing to smoke damage and the total dollar value of these environments makes fire of particular interest from a risk management and loss prevention perspectives.

The poster describes recent work undertaken to model air, and smoke movement within cleanroom environments. The purpose of this work is to qualitatively demonstrate that smoke movement within cleanrooms can be modelled using CFD codes and to apply these modelling techniques to the process of loss estimation. This approach will allow improved accuracy of loss estimation in these environments and could also help to inform the risk management process.

A numerical 3D model was developed to describe the overall movement of air and smoke within the clean environment. Parametric studies were conducted to evaluate the effect of changing air flows on smoke movement - instead of studying the efficiency of bespoke extraction systems, this focuses on the already installed clean air systems which usually facilitate the characteristic airflow. Finally, the results of the parametric studies are used to demonstrate the development of loss estimates given a fire within the cleanroom.

Categories

Submission Category: Poster Abstract
Experimental Investigation of
Bulk Density and its Role in Fire Behavior in Live Shrub Fuels
Jing Li, Shankar Mahalingam, David Weise

ABSTRACT

Fire spread in wildland fuels is influenced by environmental factors and characteristics of the fuel and fuel bed. The fuel bed characteristics of tree and shrub canopies differ from characteristics of litter and grass fuel beds which have been studied and modeled more extensively. This work examines bulk density in chaparral and its combined effects with wind and ignition location on fire dynamics. Empirical functions to predict bulk density as a function of height in four-year old chaparral were developed for two species of shrub fuels in southern California. Fuel beds of chamise (Adenostoma fasciculatum) foliage and small diameter branches were burned in an open-topped wind tunnel. The effects of three levels of bulk density, two ignition locations, and two wind speeds were examined for a total of 24 experiments. Large eddy simulations (LES) of the experiments were compared with observed fire behavior.

Vertical distribution of bulk density appears to differ for sprouting chamise and manzanita (Arctostaphylos glandulosa). Experimental results suggest that bulk density did not affect fire spread rate though total burning time appeared to be slightly reduced. As expected, the presence of an aiding wind increased rate of spread. LES simulations matched experimental results reasonably well. Full details of the experiment will be presented.
Title:
Liquid Fuel Spill Fire Dynamics

Authors:
Christopher Mealy, Matthew Benfer, Daniel Gottuk

Abstract:
Despite the fact that liquid fuel spills present a potential fire hazard in numerous industrial and residential settings there has been minimal research conducted to understand the spill and burning dynamics of these types of scenarios. While testing conducted to date has demonstrated a substantial decrease in the peak fire size achieved in fuel spill fire scenarios when compared to pool fires, the empirical data sets currently available are not large enough to fully understand the phenomena causing this reduction. In general, the interpretation of existing data has led to the hypothesis that the decrease in fire size is due to thermal losses to the substrate. However, both works also conclude that further investigation is required to validate this hypothesis. In order to address this general lack of empirical spill fire data, a research program was conducted to characterize fuel spill fire dynamics with respect to the key variables that potentially impact these types of fires. This poster provides an overview of existing spill fire data as well as the results of a recently completed research program consisting of more than 500 liquid spill and fuel spill fire dynamics tests. Discussion of the results of the testing is presented in two parts: the first being the development of a liquid spill, specifically spill depths and spill progression, and the second being fuel burning dynamics, specifically the impacts of substrate, ignition delay time, and substrate temperature. The development of a spill and the associated liquid depths are described for various fuels and for fuel simulants, whose properties provide bounding spill scenarios for most fuels of interest. The burning dynamics of various fuel spill scenarios are evaluated relative to numerous substrates, ignition delay times ranging from 30 – 300 seconds, and substrate temperatures ranging from 12 – 38°C (54 – 100°F). The impact of these variables was assessed relative to the heat release and mass burning rates measured during these tests.
Title:
Ignitable Liquid Fuel Fires in Buildings

Authors:
Christopher Mealy, Daniel Gottuk

Abstract:
Fire events occurring in both the industrial and residential setting often involve the combustion of ignitable liquids within a confined space with varying amounts of ventilation. The impact of this confinement and ventilation on fire development has been consistently studied over the past three decades. However, this research has generally been limited to the small- to intermediate-scale testing with several researchers identifying the need for full-scale validation. Based upon this need, a research program was developed to characterize the impact of an enclosure on the development of both liquid fuel and Class A fire scenarios and builds upon a previous research program that investigated fuel spill fire dynamics in open-air environments. This study of fire dynamics will also be coupled with an evaluation of the utility of current forensic analysis tools for detecting ignitable liquid residues (ILR). The primary focus of this forensic work is to develop recommended locations for ILR sampling based upon quantitative analysis. In order to accomplish this, a swath of samples will be removed from various locations within the various fire patterns generated during fire testing and quantitatively analyzed using gas chromatograph-mass spectroscopy (GC/MS). Given that this research is ongoing, this poster will provide an overview of the research program and test results collected to date.
IAFSS Poster Abstract

FireFOAM for FireGrid?
François Gallard, Adam Cowlard, and José L Torero

This poster summarises part of an ongoing endeavour to develop understanding of the fire modelling package FireFOAM, for use within the context of the FireGrid project [1] at the University of Edinburgh. FireFOAM is a developing LES software built within the open source OpenFOAM CFD package [2]. The work summarised here aims to assess current and future abilities of the software for application to the FireGrid project, specifically for use as a forward model in an adaptation of data assimilation developed by Jahn [3] using Fire Dynamics Simulator (FDS) [4].

Firstly, an assessment of the models capabilities to reproduce a simple enclosure fire scenario (traditional pool fire within a cubic compartment) is described. Temperatures recorded in designated experiments are compared with an equivalent FireFOAM simulation. Explanations for the observed deviations and comment on their impacts are given.

Secondly, key aspects concerning the integration of FireFOAM within the FireGrid methodology are rationalized. This takes into account the ability to replicate the physics of fire, numerical issues (specifically boundary condition adaptation for fire), software interfacing (informatics), and computational speedup (likelihood of achieving super-real-time simulations).

Finally, a comparison of FireFOAM with FDS in the context of the FireGrid application is made, resulting in a statement of future avenues of research that could help adapt FireFOAM into a viable alternative forward model for FireGrid.

References:

In accordance with the standardization of safety guidelines in the Buildings Standard Act, a verification method for evacuation safety has been introduced. This method uses an engineering approach for predictive calculations in verifying whether heat and smoke produced by a fire would allow people present in a building to evacuate safely. The time length between the emergence of fire and the completion of the evacuation procedure is calculated by summing up time needed to initiate evacuation, to walk to exits and to pass through exits. Methods that take into account the surface area of the room are generally used for calculating the evacuation initiation time. However, it has been argued that these methods lack in foundations. Therefore, it is necessary to develop a method based on engineering premises. Moreover, although previous studies have provided indicators including the time for initiation of evacuation, attempts to establish rigorous foundations have remained fruitless.

One important factor in determining when people initiate evacuation is the timing of accident detection. Previous studies have determined various triggers for accident detection such as visual detection and smell of smoke, sound of automatic fire detection systems, sound emitted by the fire, the commotion of people, heat emitted by the fire, and visual detection of flames. Among these triggers, we focused on the visual detection of smoke and implemented an experiment involving human subjects. In this experiment, by changing parameters such as height of partitions, distance to the target objects which fall on the line of sight at the time of emergence of fire, and orientation of the subject with respect to the fire source, we aimed at obtaining a qualitative understanding of the properties of the field of view of the subject, as well as the state of the surrounding environment, for each condition at the time an accident is detected.

The results indicate following findings.

1) Extinction coefficient when the presence of a smoke layer was detected was 0.12 m⁻¹. 2) Four cues for accident detection were determined namely: smoke above the field of view, ascending smoke, smoke around the PC, and smoke around the subject. 3) Subjects tended to detect the accident by noticing smoke around the PC when the source of smoke was outside their field of view and by noticing either ascending or aggregated smoke when the source of smoke was inside their field of view. 4) In comparison based on distance to the point of regard, no change was observed in the detection cues even when the distance was changed. In the case of detection of smoke around the PC, the detection time became longer as the distance between the subject and the PC was shorter. 5) In comparison based on partition height, when partitions were shorter, percentage of subjects who detected the accident by noticing smoke above their field of view increased. With the partition of 1200 mm height, all subjects detected the accident by noticing smoke above their field of view.
Spray Measurements of an Upright Fire Sprinkler

Xiangyang Zhou

(Submission #1008)

Image Caption or Poster Abstract

Numerical models have long been in development to help solve sprinkler fire protection problems. The transport of water sprays from the sprinklers to the fire is one of the key processes in the sprinkler protection modeling. Because of the complex physical phenomena involved in the spray formation for fire sprinklers, the starting spray conditions currently have to be prescribed based on measurements and empirical correlations. This work describes the spray characterization of an upright sprinkler using a laser-based shadow imaging system for drop size and velocity distributions, and an array of water collection tubes and containers for water volume flux distributions in the near-field and far-field with respect to the sprinkler. A large-scale traverse was constructed to move the laser optics and water collection tubes and containers to the designated measurement locations. A K-162 lpm/bar1/2 (11.2 gpm/psi1/2) upright sprinkler was operated at two different pressures in the measurements. In the near-field at 0.76 m from the sprinkler, measurements were performed in a spherical coordinate at different azimuthal and elevation angles with respect to the sprinkler deflector. In the far-field, the sprays were mapped out in a 110° circular sector at 3.05 m and 4.57 m below the ceiling. The water fluxes based on the shadow imaging system were verified by the measurements obtained from the water collection tubes and containers. Based on measurements, empirical correlations were developed for describing the initial spray distributions. The far-field measurements were used to evaluate the spray transport calculations obtained from FireFOAM.

Categories

Submission Category: Poster Abstract
A New Design for Cone-Calorimeter-Based Gasification Experiments

Xuan Liu and Stanislav I. Stoliarov

University of Maryland, Dept. of Fire Protection Engineering, College Park, MD 20742, USA

Abstract

Gasification experiments, where a flat plaque of a combustible material is subjected to a uniform external heat flux and the sample mass loss is recorded as a function of time, provide excellent means for a quantitative analysis of the degradation thermodynamics and energy transport inside the material. Such experiments require a low oxygen concentration environment to prevent auto-ignition and oxidation of the exposed sample surface. One of the best examples of an implementation of such experiments is the NIST gasification apparatus\(^1\). In this work, we are developing a simplified version of this apparatus based on a standard cone calorimeter\(^2\). Rather than placing the sample and heater into a controlled atmosphere chamber, the low oxygen concentration in the vicinity of the sample is achieved by blowing nitrogen over the sample surface in a configuration which is open to the atmosphere. The nitrogen is delivered through multiple orifices in a stainless steel tube positioned around perimeter of the sample holder as shown in Figures 1 and 2. Preliminary experiments performed on 5 mm thick samples of poly(methyl methacrylate) at 50 kW m\(^{-2}\) of external radiant heat flux indicate that the samples can be gasified without ignition or apparent surface oxidation by flowing nitrogen at a rate of about 100 slpm. Current efforts are focused on identifying optimum nitrogen flow orientation and rate, which is being done in conjunction with mapping of oxygen concentration in the vicinity of the sample.

References

Sodium Pool Heating and Fire – Experiments and Modeling

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ABSTRACT
The Sodium-cooled Fast Reactor (SFR) system is a Gen IV fast-neutrons spectrum nuclear reactor, using liquid sodium as coolant. Sodium is an effective coolant because of its good properties (efficient heat transfer, low melting temperature, high vaporization temperature, low viscosity, no solid crust – layer formation), but it is causing a considerable risk if a leak occurs in the cooling system, as sodium is a very reactive metal with oxygen and water. A sodium fire can have a significant effect, even if the HRR produced by combustion is usually lower than that of conventional hydrocarbon fires, because of the damage risks for electrical - mechanical equipments and concrete. Furthermore, sodium burning is generating very opaque and dense sodium oxides – hydroxide aerosols that are damaging visibility, breathing and materials. Another important phenomenon is the reaction of sodium with water (liquid or steam) that is a fast exothermic reaction generating sodium hydroxide and hydrogen which can burn very quickly.

The poster briefly describes a mathematical model focused on simulation of dynamic development of liquid sodium pool heating and fire. The model is finalized to calculate the pool temperature field for the heating phase and also the vapor mass release rate from the pool to the surrounding air in case of fire. In particular, the lumped parameters grid – network theory is used to model the pool heat transfer and vapor generation phenomena (equivalent circuit model).

The "grid" model was developed to extend the capability of numerical tools CORIUM-2D and ECART and its development was focused on the following implementation inside such codes (CORIUM-2D is a lumped parameters code dedicated to analyze the thermal behavior of a light water or sodium nuclear reactor in case of normal operation or severe accident scenarios; ECART is a lumped parameters numerical tool focused on consequences prediction of an accident in nuclear - conventional installations with airborne transport of dangerous substances and fires).

The model, after a first validation of a stand-alone version, was implemented inside ECART, while the development of CORIUM-2D version that uses this model is currently under development. The model and improved codes validations are carried out by comparison with reference data and results of experimental tests performed at RSE.

At present, the model approach appears as an effective fast-running tool to simulate the sodium pool heating and fire dynamics.

(This work has been financed by the Research Fund for the Italian Electrical System under the Contract Agreement between RSE (formerly known as ERSE) and the Ministry of Economic Development - General Directorate for Nuclear Energy, Renewable Energy and Energy Efficiency, stipulated on July 29, 2009 in compliance with the Decree of March 19, 2009.)
Assessment and Validation of the Fire Brigade Intervention Model

Ed Claridge and Michael Spearpoint

(Submission #1011)

Image Caption or Poster Abstract

New Zealand has operated a performance-based Building Code since 1991 which specifies functional and performance requirements for the safety of fire fighters and their needs. These requirements specifically include performance statements pertaining to rescue operations, and controlling the spread of fire amongst others. Since the New Zealand Fire Service (NZFS) began reviewing building consent applications in 2005 it has become apparent that many practitioners have difficulty in demonstrating fire fighting needs within designs utilising alternative and performance-based design solutions.

The Fire Brigade Intervention Model (FBIM) (1) has been in use for over a decade and is used regularly throughout Australia and to a lesser extent in New Zealand. Since November 2008, the FBIM has been referenced within the New Zealand compliance document, C/AS1 (2) and is accepted by the NZFS as a suitable methodology to quantify fire brigade operations and demonstrate the performance requirements of the New Zealand Building Code (NZBC). However, the FBIM currently has no New Zealand data available to reflect NZFS operations nor has it undergone any validation for New Zealand conditions. Without the appropriate data available to support the FBIM in New Zealand some building designs are using Australian data which is potentially dated and which may not be appropriate for New Zealand.

This project presents data in the form of probabilistic distributions and single values that have been collected to support the use of the FBIM in New Zealand from a number of sources including specifically designed exercises, NZFS incident statistics, incident video footage and from attendance and observation at emergency incidents. Validation of this data has been undertaken against fire ground field experiments and with real emergency incidents attended during the period of the research.

Currently many FBIM analysis are based on single scenario analysis typically using values based on a 95th percentile confidence limit or as agreed with the relevant local fire brigade. However, this approach does not consider all of the likely responses that could be possible across the range of likely fire brigade intervention times and can present overly conservative intervention times that may or may not allow for the requirements of the relevant building codes to be achieved. This research supports a risk-based probabilistic analysis for predicting fire brigade intervention and presents a Monte-Carlo analysis considering a high-rise building scenario. This type of analysis identifies some of the advantages of using a probabilistic methods for performance-based designs utilising the FBIM rather than the traditional percentile approach.

REFERENCES


As part of the current EC AircraftFIRE consortium project, an analysis of fire signatures of typical aircraft materials is being conducted at the BRE Centre for Fire Safety Engineering at University of Edinburgh. The aim of this part of the project is to develop a novel, robust, early fire detection protocol for use aboard aircraft. The initial work presented here aims to establish a methodology for defining these fire signatures, using calorimetry techniques on PMMA that can then be extended and tested on a wider range of materials. Experiments are conducted in the Fire Propagation Apparatus with the addition of a Fourier transform infrared spectroscopy (FTIR) system to track the gases produced pre and post combustion. The production of a number of species is tracked and combinations of the concentrations are shown to give advanced warning of flaming combustion. Furthermore, multiple signatures observed at different stages of the combustion process serve to act as validations of the alarm and thus introduce a level of robustness to the protocol.
Characteristic parameter in fire protection engineering

Florian Berchtold, Paul Georg, Steve Schneider and Michael Rost

(Submission #1013)

Image Caption or Poster Abstract

Nowadays, simulations are regularly used in Fire protection engineering for legitimating discrepancies of legal codes in matter of live safety or expected huge damages. Therefore, the objective is often only one scenario and an assessment of safety capacities is not done. This paper describes the methodology of the characteristic parameter. This parameter has a major influence on the resulting damage of a scenario. It is varied over a wide range of values and the damages are analysed. These damages, compared with an acceptable damage lead to certain safety capacities. Two examples are presented in the following.

Identification of the critical Heat release rate Identification of the critical width of doors

It was shown how to analyse a heat release rate to avoid critical scenarios as well as how to analyse the safety capacities in an evacuation route. This methodology of a characteristic parameter examines the effect of damage independent of a precise scenario. Instead of, there is a variation of an important parameter. Thereby, qualitative evaluations including simulation uncertainties of safety capacities can be made. As a result, decisions are based on a broader basis of information and the constructions of buildings are safer. This could be interesting for buildings with a high number of persons or an huge amount of expected costs after a fire.

Categories

Submission Category: Poster Abstract

File(s)

[Image (PDF)]
Numerical Simulation of Fire Growth in a Rack Storage Configuration

Prateep Chatterjee, Yi Wang, Marcos Chaos, Niveditha Krishnamoorthy, Karl V. Meredith, Mohammed M. Khan, John L. de Ris and Sergey B. Dorofeev

Research Division, FM Global, 1151 Boston-Providence Turnpike, Norwood, MA 02062, USA

Abstract

Fully coupled CFD simulations (pyrolysis, soot & radiation, gas-phase combustion) of fire spread were conducted in a 2x4x3 rack storage configuration [1]. A compressible large eddy simulation (LES) code for buoyant turbulent diffusion flame modeling, FireFOAM [2,3], was used in this study. Radiation heat transfer is modeled with the solution of the radiative transport equation (RTE) with the application of isotropic emission from the turbulent flame-sheet [4]. The emission term is computed from a laminar smoke point based subgrid soot-radiation model [5]. Pyrolysis of charring materials was simulated with the solution of a 1-D, finite-rate (Arrhenius kinetics) model coupled to the gas-phase solver through boundary conditions for mixture fraction, temperature and velocities [6]. The simulations used solid fuel material properties determined from bench scale fire propagation apparatus (FPA) [7] tests and with the application of optimization schemes [8].

Several instrumented fire tests were conducted under a 20 MW fire products collector (FPC) with the purpose of providing validation data. Each of the 24 units in the 2x4x3 configuration consisted of three nested boxes made of double-wall corrugated cardboard enclosing a sheet metal liner. Chemical heat release rates, heat flux on the box surfaces and thermocouple measurements were taken. The sensitivity of predictions to important model inputs, such as material properties, geometrical obstructions, and mesh resolution, are studied. General shape of heat release rate curve and peak heat release rate compare well with experimental data. Initial fire growth rate is found to be sensitive to resolution of geometrical details and model assumptions. Further evaluation of and improvements to computational models are ongoing to capture important physics of fire spread.

References


Glass fallout in windows has the potential to alter the ventilation condition and the characteristics of the fire in a compartment. Therefore, it is of an interest to fire modellers to be able to simulate the behaviour of glass windows in fires. Most research work has dealt with the fracture of glass windows in fires while little work studied the glass fallout behaviour in the general sense. This research investigated the fallout behaviour of 4 mm and 6 mm thick single glazed glass exposed to radiant heat. The results from the experiments carried out in this research enabled the fallout behaviour to be quantified in a probabilistic manner. Standard rubber beadings and non-standard beading made of Kaowool fibres were used to glaze the glass samples in this research.

A total of 117 experiments were carried out in this research. The radiant heat flux which the glass samples were exposed to ranged from 14 kW/m$^2$ to 59 kW/m$^2$. In some experiments, the temperatures at various points on the glass and thermal strains were measured. Radiant heat flux measurements were also taken during the experiments. The time to glass fracture and amount of fallout were recorded in every experiment.

The four-point bending test was carried out on 24 glass specimens to determine the distribution of fracture strength and modulus of elasticity for the glass panes used in this research. The mean fracture strength and modulus of elasticity were 64 MPa ± 15 MPa and 77.1 ± 4.0 MPa respectively.

The simple lumped heat capacity method was used to predict the time to glass fracture in each experiment. Generally, the actual times to glass fracture were within the predicted times to glass fracture at 60% of the experiments.

In experiments where glass temperatures were measured, the distribution of temperature difference at fracture was predicted using the fracture criterion suggested by Keski-Rahkonen (1988). The range of predicted temperature differences at glass fracture were compared with the actual temperature differences in the experiments. The mean temperature difference measured was between 90 °C to 98 °C whereas the predicted ones ranged from 55 °C to 129 °C. Generally, the actual temperature differences were within range of predicted temperature differences at 60% of the experiments.

The measured thermal strains at glass fracture were between 239 $\mu$strain to 697 $\mu$strain.

The type of glazing beading did not affect the glass fallout behaviour. A window with a thinner glass pane is more likely to fallout compared to a window with a thicker glass pane when exposed the same level of heat flux.

The fallout behaviour of glass was quantified with an exponential distribution function and a glass fallout prediction model for 4 mm and 6 mm thick glass was derived from the experimental results.

![Figure 6-1: Post-fracture pattern for experimental sample 4 Test 2](image)
Towards CFD modeling of large scale fire growth and suppression

Yi Wang*, Karl V. Meredith, Prateep Chatterjee, Niveditha Krishnamoorthy, Xiangyang Zhou and Sergey B. Dorofeev

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An open-source CFD solver, called FireFOAM, is being developed for large scale fire growth and suppression based on the object-oriented CFD toolbox OpenFOAM [1]. The gas-phase solver within FireFOAM solves the fully-compressible Navier-Stokes equations using pressure based segregated solution algorithms and implicit Finite Volume discretization schemes. The solver features massive parallelization in arbitrary unstructured polyhedral mesh. Early version of FireFOAM solver [2] and its validations have been published previously [3, 4]. This poster presents new features of the FireFOAM code that are currently under development and being validated: enhanced gas phase solver for buoyancy driven reacting flow, fuel pyrolysis model, soot/radiation model, Lagrangian droplet transport, and surface water film flow, etc. The numerical algorithms of the solver will be presented, along with selected validations of physical models relevant to fire dynamics.

Electricity, as it relates to fire investigations, has long been a hot topic in the fire investigation community. Common misconceptions about electricity have lead to the incorrect determination that it was the ignition source of a fire. This research is focused on improving the understanding of the mechanisms by which fire environments may trigger electrical arcs in common household wiring. An understanding of these mechanisms may help fire investigators determine whether a given arcing event was the cause or result of a fire.

In this study, a cone calorimeter was used to expose one side of an AWG 14/2 with ground non-metallic sheathed cable to a uniform radiant heat flux. The behavior and breakdown of the insulation was monitored by performing two types of measurements: 1) time-to-conduction in an unenergized cable, and 2) time to arc in an energized cable. Preliminary data shown in Figure 1 below indicates the existence of a “critical heat flux” below which the resistance measured between any two of the three conductors comprising the cable stays infinite for the duration of the exposure. By heating and monitoring the temperature and resistance of the cable insulation in multiple experiments, it was found that the resistance lost in the wires/cable can be attributed to the char formed as a result of thermal degradation of the insulation. The conductivity of the char exhibits a considerable and reversible temperature dependence, the physical mechanisms of which are currently being investigated.

![Figure 1](image_url)
Which acoustic and optical signals are best suited for evacuation alarms?

An empirical study on the characteristics of signals.

Authors: Robin Palmgren & Joakim Åberg
Department of Fire Safety Engineering and Systems Safety, Lund University, Sweden

In the present study the authors examine in experiments and surveys how various acoustic and optical signals attract peoples attention. The purpose of the study was to be the basis for a new Swedish standard regarding evacuation signals. The aim of the study was to identify the characteristics that make acoustic and optical signals effective at attracting peoples attention. The aim was also to select a number of signals which possess those qualities.

Initially a literature study was conducted. The literature study included both standards regarding evacuation signals as well as the research in the area. Based on the literature study a sample of ten acoustic and three optical signals were selected. Figure 1 shows the audio signals from the sample.

The basis for the selection was that the signal should either be used in a national standard or have characteristics that corresponded with recommendations from previous research. These signals were tested in two surveys, one for audio signals and one for optical signals. To carry out these surveys both acoustic and optical alarm devices were used to produce the signals. The participants in the surveys assessed how well the signals could attract their attention by listening to recorded audio signals and observing optical signals, see figure 2. The participants then answered the question “How well did the signal attract your attention?” with one of the following responses: very poorly, poorly, neutral, well, very well.

The three acoustic signals that were best at attracting peoples attention in the survey were tested in unannounced evacuation experiments. Seven evacuation experiments were conducted on the faculty of engineering in Lund. There were a total of 103 participants in the experiments, the participants were students from the faculty. The experiments were done to test the validity of the survey and to check if the ranking between the signals was the same as in the survey.

The results of the survey regarding acoustic signals show that three signals got significantly higher mean value than other signals. These signals are hence better at attracting the attention of people than other signals. The signals have one characteristic in common; they are all continuous (without pause between sound pulses). These signals were tested in evacuation experiments in which they continued to get high mean values (i.e. effective at attracting peoples attention).

The results from the survey regarding optical signals show that there is no significant difference between signals with white light, red light and alternating red and white light. However, the red signal received a higher mean value than the other two signals.

By comparing signals with different characteristics the following conclusions could be drawn.

Acoustic signals in evacuation alarms should:
- be continuous
- vary between at least two frequencies
- have a pulse rate not less than 1 Hz
- be within the frequency range 800-1000 Hz

Optical signals in evacuation alarms:
- do not have to alternate between red and white light
- should consist of a red light
Effect of Material Properties on the Flame Propagation Behavior in the Medium-scale Parallel Panel Geometry

Niveditha Krishnamoorthy, Yi Wang, Marcos Chaos, Prateep Chatterjee, Mohammed Khan, and Sergey B. Dorofeev

Research Division, FM Global, 1151 Boston-Providence Turnpike, Norwood, MA 02062, USA

Abstract

The flame propagation behavior of PMMA and corrugated cardboard [1, 2] was numerically studied in the parallel panel geometry [3] using FireFOAM [4]. FireFOAM is a Large Eddy Simulation (LES) solver for buoyancy driven turbulent flows and diffusion flames. Model specific (effective) material properties were obtained by optimizing model results from a 1-D pyrolysis model (with finite rate, single-step Arrhenius kinetics) against bench-scale measurements in the Fire Propagation Apparatus (FPA) using the Shuffled Complex Evolution (SCE) algorithm [5]. The optimization procedure is extended to estimate the Confidence Intervals (CIs) for each property value using asymptotic methods applied locally at the optimization point, found by the optimization scheme. Sensitivity analysis is then performed to study the effect of variations in material properties on the simulation results. Material properties are varied within and outside their CI bounds both in the bench-scale and in the parallel panel simulations and the results are compared against original model results and the experimental data. The analysis is aimed at understanding how the uncertainty in effective material properties affects simulation results across scales.

References


This research project has studied commercial building atrium upper balcony smoke contamination due to a balcony spill plume using computational fluid dynamics (CFD) software, Fire Dynamics Simulator (FDS) version 5.3.0. Simulation prediction on temperature and smoke contamination on small-scale model balcony configuration are compared with earlier researchers’ work, Tan (2009) and Harrison (2009), who conducted a one-tenth small-scale experiment. Twelve experiments are selected for simulation.

Most of the temperature predictions are relatively within the range of the experiment’s records. It is found that 10°C above ambient temperature (20°C ambient) slice files from FDS are also relatively matched to the photographic records of the experiment for smoke contamination. Hence, this shows that these FDS models are able to predict upper balcony smoke contamination fairly accurately.

Subsequently, the FDS small-scale models are extended to small and full-scale five balcony configuration, full-scale five balcony configuration without upstand and a seven balcony configuration for smoke contamination assessment. Full-scale fire size is up to 4.7MW, which is for sprinklered shop fire.

This study shows that full-scale configuration will have higher temperature within the balcony and more severe smoke contamination when compared to the small-scale model. The predictions are also highly sensitive to the boundary conditions.

This study also demonstrated that the upper balcony smoke contamination is also affected by the height of the atrium. Taller atria will have more severe smoke contamination on the lower balcony.

Finally, a new correlation is developed for the three to seven balconies with upstand configuration; this correlation has incorporated the atrium height parameter into the equation. This correlation will allow the designer to make the first order of assessment on upper balcony smoke contamination due to balcony spill plume.
Measured Heat Release Rate in Chinese Kitchen ‘Wok’ Fires

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ABSTRACT
For assessing the thermal environment in a kitchen of Chinese restaurant, heat release rates in burning ‘cooking woks’ at the stoves in accidental fires should be measured. Two identified scenarios of woks with cooking oil were burnt. The first scenario is a stove arrangement with only two woks. The second one is with six woks for serving banquet.

INTRODUCTION
Gas stoves with high thermal power are installed in almost all Chinese restaurants [1]. Many are illegal alterations of gas installations by increasing the gas flow rate without approval from The Authority. Such high thermal power is necessary to heat up the Chinese ‘woks’ quickly to prepare higher quality of food with ‘wok-hay’. Such high power cooking woks might give rise to kitchen fires when the cooking oil inside is heated up above the auto-ignition temperature. Typical kitchens with woks and cooking oil commonly arranged were studied. Full-scale burning tests were carried out to investigate the heat release rate of two fire scenarios identified. The experiments were conducted in an experimental facility at a remote town in Northeast China. Some data were presented in this paper.

ARRANGEMENT OF WOKS
Cooking oil in the woks over the stove was burnt in the full-scale burning facility for measuring heat release rate developed in a remote town Lanxi at Harbin, Heilongjiang, China. A model Chinese kitchen with an exhaust hood and a fan-duct system was constructed with flashover kitchen fires studied. The kitchen model is of length 3.6 m, width 2.4 m and depth 2.4 m as shown in Fig. 1a. Heat release rates were measured by the oxygen consumption method. Two scenarios on typical setups in Chinese restaurants were identified.

• Test 1: Burning cooking oil in two woks in a gas stove as in Fig. 1b. Each wok was filled with 1000 ml soyabean oil.
• Test 2: Burning cooling oil in six woks in a bigger Chinese restaurant as in Fig. 1c. Each of the 6 woks was filled with 1000 ml of soyabean oil.

RESULTS
Results on heat release rate on the two tests are shown in Fig. 2a and b. Smoke was generated when the oil was heated. About 7 min after ignition, the oil was ignited. A sharp increase in heat release rate is shown in Fig. 2a.

CONCLUSION
Two different wok arrangements in a kitchen model of a Chinese restaurant were set up in a remote area of Northeast China. The heat release rate was measured by the oxygen consumption calorimetry. As observed, a wok fire might be developed to onset flashover in the kitchen. The heat release rate would increase to give bigger fires.

REFERENCE
Methodology for a Fire Risk Assessment and an Increase of Passenger Survivability in New Generation of Aircrafts

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The objective of the AircraftFire project is to introduce a comprehensive methodology for increasing passenger survivability in the case of fire aboard next generation aircrafts. The project focuses on the assessment of aircraft fire behaviour by developing fundamental researches on composite material properties, relevant fire scenarios and behaviour response of passengers during evacuation. This AircraftFire project, funded by the FP7 programme of the European Community started January 2011.

The main characteristic of new aircrafts generation is the increased use of composite materials to replace metallic structural parts and of other combustible materials used to reduce aircraft weight or to increase the passenger comfort. But these evolutions raise the fire load in aircrafts significantly. Although each of these materials has passed the certification tests, it is necessary to study and assess fire risks for relevant areas, specific zones of the aircraft and the entire aircraft. Moreover, this work becomes even more important by the use of new avionics equipment and new electronics systems that require more electrical energy thus becoming possible ignition sources... The AircraftFire consortium, composed of aircraft manufacturers, aviation authorities, research establishments and universities, aims at gaining and applying the necessary knowledge to quantify the fire risks in the new generation of aircrafts.

The specific objectives of this work are to a) reduce the consequences of in-flight and post-crash fires and b) enhance the survivability of passengers and personnel. The identification of the fire trends, the characterisation of the present unknown physical and chemical properties of existing and new materials aboard aircrafts, the evaluation and validation of the existing simulation tools for evacuation, constitute the main tracks of the project that can lead to innovation in aircraft design and possibly in evolution of regulations.

Today, the simulation of fire propagation and passenger evacuation in aeronautics suffers from lacking data of material properties and fire behaviour. Relevant and necessary data for the proposed advanced simulation will be gained by experiments as far as not available, yet. The first step of the project consists of a sound analysis of existing data and information maintained by aviation authorities worldwide in order to identify and classify the relevant fire related scenarios for in-flight and post-crash fires. The second step consists of the determination of the intrinsic physical and chemical properties for relevant materials and to develop experimental studies in order to validate physical models on generic fire configurations representative of real fire scenarios. Possible improvements of fire detection and extinction and of operational procedures will be investigated in this specific context. The resulting consolidated information on materials and fire behaviour will be introduced into fire growth and evacuation models. This evolution of simulation capabilities will lead to a better tool for fire risk assessment and for better prediction of passenger survivability in fire related incidents and accidents in aviation. In addition, the AircraftFire project undertakes several activities to transfer the academic research to innovation for the aircraft designers.

The submitted poster will present the methodology used by the AircraftFire project for the identification of the new fire trends in aeronautics, the enhancement of fire prevention and protection, and the development of fire growth and evacuation numerical tools with the objective to assist the aircraft designers and the end-users to increase the survivability of passengers and crew during in-flight and post-crash fires.

Acknowledgment

This project is funded by the “Seventh Framework Programme” of the EU (FP7-AAT-2010.3.3-2)-RTD-1 Transport including Aeronautics), Project number 265612.

\(^{1}\)Inst. Pprime, CNRS, F; \(^{2}\)TUdelft NL, \(^{3}\)TREFLE Lab F, \(^{4}\)CORIA/INSA Rouen F; \(^{5}\)Univ. Ulster UK; \(^{6}\)Univ. Greewich UK.
\(^{7}\)Haskoll Islands; \(^{8}\)Fraunhofer D; \(^{9}\)Univ. Patras Gr; \(^{10}\)Airbus SAS F; \(^{11}\)Univ. Edinburgh UK
The desire to build more sustainable and durable structures has promoted the emergence of innovative precast structural elements which incorporate high performance self-consolidating concrete (HPSCC) with prestressed, sand coated, carbon fibre reinforced polymer (CFRP) bars.

Inherent and beneficial fire insulating conditions for conventional ribbed steel prestressing wires is typically ensured by prescribing a minimum allowable concrete cover to protect the internal reinforcement from the effects of fire.

The fire performance of CFRP prestressed concrete elements, however, is not well known; two issues are critical:

- Considerably less concrete cover is typically required for corrosion protection for structural elements prestressed with CFRP because of the non-corrosive properties of the CFRP bars.
- Bond strength of the CFRP bars is given by a resin rich sand coated surface which is critically degraded at temperatures in the region of 150°C.

This poster presents the results of a study to evaluate the effects of elevated temperature on the bond strength of CFRP bars and steel prestressing wires in HPSCC.

The results of transient elevated temperature bond pullout and tensile strength tests on CFRP bars and steel prestressing wires are presented and discussed, and show that bond failure at elevated temperature is a complex phenomenon which is influenced by a number of interrelated factors, including: the type of prestressing, degradation of the concrete, CFRP, and steel, differential thermal expansion, thermal gradients and stresses, release of moisture from the concrete, and applied loading.

The results of dynamic mechanical analysis (DMA) and thermogravimetric analysis (TGA) performed on the CFRP bars are also shown and correlated with the loss of tensile and bond strength of the CFRP bars.

This study showed that CFRP bars are more sensitive to bond strength reductions than to reductions in tensile strength at elevated temperature. For steel prestressing wires, bond strength is less sensitive to elevated temperatures, but is susceptible to concrete splitting cracking with high sustained loading during the early stages of heating; this is due to a summation of the mechanical and thermal stresses.

**Keywords:** Bond strength, composite materials, DMA, elevated temperatures, carbon FRP, prestressing reinforcement, pullout tests, steel prestressing wire, TGA.
Carbon fiber composite characterization in adverse thermal environments

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Carbon fiber composite materials are increasingly found in transportation vehicles. Greater than 50% of the structural mass is now carbon fiber for some new commercial aircraft designs. Composite materials behave differently from conventional fuel sources and have the potential to smolder and burn for extended time periods. As a result, the response of composite materials in adverse thermal environments is of interest. The purpose of this work was to begin to understand the behavior of carbon fiber composite materials in fire as well as to provide experimental data for model development and validation.

The effects of aircraft composite properties on thermal and combustion behavior were measured in two test configurations. Test materials consisted of Epoxy and Bismaleimide composites composed of uni-directional and woven carbon fibers. In the first test configuration, 75 by 100 millimeter laminate coupons were irradiated by a parallel Inconel shroud heated to 800°C giving an approximate irradiance of 22.5 kW/m². The back face of the coupon was insulated and temperature measurements were made on both faces. In the second configuration, 75 by 225 millimeter test coupons were irradiated by a 1000°C shroud giving an average irradiance of 30.7 kW/m². Here, the coupon was vertical, insulated on the back face, and perpendicular to the shroud. In this set of tests, volatile gases were piloted to characterize flame spread in the upward direction. In general, Bismaleimide coupons produced significantly less smoke and were more resistant to flame spread, as expected for materials with greater thermal stability and increased char formation. All coupons lost approximately 20-25% of their mass which was attributed to resin decomposition. Woven fiber composites displayed localized smoke jetting whereas uni-directional composites developed cracks parallel to the fibers from which smoke and flames emanated. Substantial swelling and delamination were observed.

Average ignition times measured here were 286 seconds and 247 seconds for Bismaleimide and epoxy composites, respectively. The difference in resin types and fiber orientations were not statistically significant given the sample size. Measured data were in reasonable agreement with the work of Gibson and Hume who measured piloted ignition times for epoxy-glass fiber and phenolic-glass fiber of 120 seconds and 500 seconds, respectively, for an incident heat flux of 30 kW/m² (1995). Bismaleimide composites sustained flaming combustion longer than epoxy composites although it was less vigorous. Differences in flame intensity caused by resin composition are not clearly identified in the literature. Video recordings were used to approximate flame spreading rates for epoxy coupons in the piloted tests. Estimated flame spread rates were 380-760 mm/min and were on the same order of magnitude as measurements made by Ohlemiller and Cleary (1999). Reignition also occurred after the initial flame front extinguished in many of the experiments.


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1Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy’s National Nuclear Security Administration under Contract DE-AC04-94AL85000.
Numerical experiments on the influence of the distribution of fire load and ignition location on the fire spread in a family home

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Abstract:
The present paper reports a complex fire scenario in a two-storey family dwelling which occurred in 2003 in Berlin, Germany. The case is especially interesting because fire investigators of the police and those of the defense drew completely different conclusions based on the same traces of the fire. The fire probably started with ignition of a polyurethane mattress with subsequent ignition of other furniture and wooden wall and polystyrene ceiling panels in one room and then after flashover and after the door of this room was opened by one of the inhabitants the fire spread through the entire upper floor and downwards to the ground floor where the living room was set on fire. Fire investigators of the police claimed a scenario including two locations of fire origin – one in the bedroom of the house owner on the upper floor and one in the living room on the ground floor with the use of several litres of ethanol as accelerant.
Based on the same traces of the fire, investigators of the defence excluded the use of ethanol. Instead they purported the bedroom of the house owner being the only location of the fire origin with the fire initially developing as smouldering and subsequently turning into a backdraft.
Due to the unusual high fire load present in the house, the downward fire spread was explainable and – summarizing all the evidence gained – more plausible than arson at two locations in the house.
Hence, the present parameter study performed using the NIST Fire Dynamics Simulator revealed that the rapid evolution of the fire was only possible due to the existence of wooden wall panels and combustible tiles glued to the ceilings in combination with additional combustible appliances and furniture on the floors and the staircase.
Furthermore, the design of the house with the open staircase and the living room separated from it only by a bookshelf allowed the fire to propagate to the living room unhampered.
The computed time until fully developed fire of about eight minutes in the simulations is in reasonable agreement with the observations of fire fighters and other witnesses of the event.
When the walls and the ceilings were considered as inert (no wooden panels or ceiling tiles present), the fire remained contained on the upper floor and the ground floor was unaffected.
In contrast to the downward fire propagation, the amount of combustibles and their distribution along the pathway of the fire was seemingly less important for upward fire spread induced by ignition of the carpet in the living room. In the simulations temperature distributions and times to flashover showed nearly no differences, no matter if wooden wall panels and ceiling tiles were present or not.
Comparison of adiabatic and isoperibolic basket tests on the self-ignition of combustible bulk materials

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Abstract:
The European standard test for assessment of the self-ignition of solid combustible materials is the isoperibolic basket test according to EN 15188 [1]. The results derived from the tests are the self-ignition temperatures of accumulations of the combustible material in dependence on the characteristic length and formal kinetics data (apparent activation energy and apparent frequency factor) for the lumped reaction. There are two main disadvantages with this test:

- to match the intrinsic scale-dependence of the self-ignition phenomenon a large number of single test runs is necessary,
- for small sample volumes the storage temperature has to be comparatively high so that exothermic effects starting below the storage temperature are overlapped.

Alternatively, adiabatic basket tests may be performed which allow to obtain formal kinetics data from one single experiment. In combination with isoperibolic tests for just one characteristic sample length the prediction of self-ignition temperatures for deposits of material in the technical scale becomes possible with much less experimental effort.

The present study gives a comparison between apparent activation energies and frequency factors from isoperibolic and adiabatic tests for five materials prone to self-ignite. A systematic investigation of uncertainties of the adiabatic test method is also presented. This is of special importance for safety measures if designed based on just one single adiabatic test.

Uncertainties in adiabatic tests result mainly from the selection of the starting temperature, from the temperature control of the oven and from the procedure to derive the kinetic data from the plot of dT/dt-vs.-1/T.

For three of the materials tested the differences in the apparent activation energies were in the range of reproducibility of the adiabatic tests, while it was remarkably higher for lignite coal and lower for the coated silicid acid in the isoperibolic test compared to the adiabatic test. Results are given in table 1.

Tab. 1 Apparent activation energies and frequency factors for adiabatic and isoperibolic basket tests

<table>
<thead>
<tr>
<th>Material</th>
<th>Adiabatic basket test</th>
<th>Isoperibolic basket test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$E_A$ [kJ/ mol]</td>
<td>$k_0$ [s$^{-1}$]</td>
</tr>
<tr>
<td>Lignite coal</td>
<td>88,62</td>
<td>2,437E+05</td>
</tr>
<tr>
<td>Black coal</td>
<td>85,85</td>
<td>1,575E+03</td>
</tr>
<tr>
<td>Cork dust</td>
<td>102,04</td>
<td>3,316E+05</td>
</tr>
<tr>
<td>Polymer dust</td>
<td>103,58</td>
<td>2,033E+06</td>
</tr>
<tr>
<td>coated silicid acid</td>
<td>98,73</td>
<td>1,323E+08</td>
</tr>
</tbody>
</table>

Evolution of Flame to Surface Heat Flux during Vertical Flame Spread on Poly(methyl methacrylate)

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Abstract

Flame to surface heat flux has been measured for a number of widely used materials including poly(methyl methacrylate) (PMMA). Most of these measurements were performed for relatively large scale (> 100 kW), steady, vertical wall fires under natural convective conditions. Relatively little has been done to understand the energy feedback from a small, upward-spreading flame on a polymeric surface. Quantifying this feedback is important because it defines the initial fire growth and ignitability of the material of interest.

In this study, we performed thorough measurements of the heat flux from a flame spreading upward on 5cm wide and 0.6cm thick samples of PMMA. The samples were evenly ignited across their base by a 5cm wide propane burner that preheats a 3.5cm tall sample area. The resulting flame attached to the sample’s surface was allowed to propagate freely in the absence of external radiation or forced convection. The heat flux was measured using a 0.95cm in diameter Schmidt-Boelter gauge that was positioned at the top of the sample as shown in Figure 1. The heat flux was recorded as a function of time. The measurements were repeated for a range of sample heights, from 3 to 15 cm, to develop spatially and time resolved map of heat flux from the flame propagating on the full size (15 cm tall) sample.

Figure 2 displays three-point running averages of the measured heat flux from flame to cold (15°C) heat flux gauge for samples of various heights. Readings are plotted as a function of time following removal of the propane burner (the burner is applied for 75s to ignite the surface). Readily apparent in this figure is the increasing delay time needed by larger samples to reach a quasi-steady state reading of between 35 kW m⁻² and 40kW m⁻². This delay represents the time needed for the pyrolysis front to propagate to the position of the gauge (which is always at the top of the sample). Currently, tests are being conducted to examine if the gradual decline in the heat flux obtained for 5 cm samples is a result of increasing deposits on the face of the heat flux gauge or is due to true changes in local heat transfer processes.

Future work will be focused on establishing a quantitative relationship between the measured heat fluxes and sample mass loss rate. The dependence of the heat flux on sample width will be examined. The energy feedback characterization methodology will be applied to other common polymeric materials (such as polypropylene).
Validating the Function of Absorber Plates for Auto-Sprinkler System Activation

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ABSTRACT

Building codes in many countries require an absorber plate with an auto-sprinkler system to enhance sprinkler system efficiency when this system cannot be installed on a ceiling (see Fig.1). This study evaluated experimentally the function of absorber plates. A sprinkler with or without an absorber plate was installed in a room measuring 4.3(L)×3.0(W)×3.3(H) m. Hanging walls 1.1 m long were installed at the edges of the room ceiling to help form a hot smoke layer during a fire. Heptane and methanol into circular pans with diameters of 20-60 cm were the fire sources. The fire sources were positioned at the room center, and 0.5, 1, and 1.5 m from the room center (see Fig. 2) to produce fire plumes that reached both the sprinkler head and absorber plate, directly reached the absorber plate but not the sprinkler head, or reached neither the sprinkler head nor absorber plate, respectively. Temperature and velocity, two parameters important to sprinkler activation, were measured near the sprinkler head, and compared for cases with and without an absorber plate. Experimental data indicate that the absorber plate did not help accelerate sprinkler head activation from temperature and velocity measurements for all cases with and without an absorber plate. An alternative design that separates detection devices and water outlets is recommended in this study.

Fig.1. A practical case of using an AP.

Fig.2. Three scenarios for a fire plume to reach an AP and a sprinkler head.
STATISTICAL ANALYSIS OF TOXICITY MEASUREMENTS OF FIRE EFFLUENTS

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During early spring 2011, an interlaboratory trial will be performed in the Transfeu (Transport Fire Safety Engineering in the European Union) project, aiming at the development of a classification system for the toxicity of fire effluents from products on trains. The objective of the study is to evaluate the accuracy of the combination of the EN ISO 5659-2 smoke chamber test and the FTIR analysis of smoke gases, forming the basis for the classification system.

Three materials in three replicates will be tested in 5–8 laboratories performing FTIR measurements in connection with the smoke chamber test. Statistical analysis will be performed for ca. 10 quantities related to the smoke chamber results, FTIR analysis, and toxicity evaluation parameters. The within-laboratory and between-laboratories precision of the test method will be determined according to the ISO 5725 principles as relative repeatability and reproducibility standard deviations $s_r/m$ and $s_R/m$, respectively.

The evaluation of the quality of the repeatability and reproducibility parameters is not straightforward. The answer to the question “What range of $s_r/m$ and $s_R/m$ values can be considered good/acceptable/poor?” is dependent at least on the nature of the measured quantity and the special features of the test method used. To interpret the results of this study, the accuracy parameters obtained will be compared to the results of earlier interlaboratory trials including cone calorimeter and SBI round robins for heat release and smoke production, and an FTIR analysis round robin (carried out in the European SAFIR project, contract no. SMT4-CT96-2136) for quantities related to toxic gases.

On the basis of the test results of three pilot laboratories, preliminary statistical analysis has been performed. Considering the effect of the scattering of the fire test method included in the FTIR variation, the repeatability and reproducibility of the toxicity measurements of fire effluents can be regarded as promising. The indicative statistical analysis of smoke-related parameters resulted in repeatability and reproducibility standard deviations in the ranges of 5–10 % and 10–15 %, respectively. For parameters describing the production of toxic gases, repeatability and reproducibility standard deviations in the ranges of 5–30 % and 10–40 % were obtained, respectively. The values are of the same order as in the SAFIR project round robin. It is noted, however, that these results are indicative, and more data from other participating laboratories are needed to reliably determine the accuracy parameters.

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007–2013) under grant agreement no. 233786.
TRANSFEU PROJECT – IMPROVING THE FIRE SAFETY OF SURFACE TRANSPORT

Tuula Hakkarainen, Simo Hostikka, Terhi Kling & Esko Mikkola
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TRANSFEU (Transport Fire Safety Engineering in the European Union) is a European FP7 research project studying the fire safety of surface transport. The main goals of the TRANSFEU project are

- to develop efficient methods and tools for performance-based fire safety design able to realistically predict fire development and safety conditions of people on board in case of fire, and
- to support surface transport standardisation related to fire safety, including trains, ships and buses.

In particular, TRANSFEU investigates the toxicity effects of fire effluents generated under dynamic conditions on passengers and crew in railway applications.

The main innovations in TRANSFEU are the following:

- The application of continuous FTIR measurement to fire effluents generated in a bench-scale smoke chamber.
- The application of Fire Safety Engineering simulation tools so that the toxic hazard of fire effluents to passengers and crew on a burning vehicle can be quantified.
- The development of a classification system for products on trains that is validated by real-scale fire tests.

The TRANSFEU consortium includes 21 partners from 10 European countries. The project is coordinated by Laboratoire National de métrologie et d'Essais (LNE). The 3.5-year project started in April 2009, and it will be completed in September 2012. Its total budget is 5.54 M€.

In this poster, the main results achieved during the first two years of the Transfeu project will be described, concentrating especially on the toxicity test method, possible ways of classifying the toxicity of fire effluents, and the evacuation safety assessment by simulation (e.g. development of FED, FEC and FIC calculation).

The research leading to these results has received funding from the European Community's Seventh Framework Programme (FP7/2007–2013) under grant agreement no. 233786.
Local measurement of soot concentration using a white light differential opacimeter.

Bellivier Axel, Delorme Robert, Dupont Sylvie, Benhaiem Philippe, Chen Yuansi, Le Bars Patrick and Bazin Hervé

(Submission #1031)

Image Caption or Poster Abstract

The study of smoke movement is needed in the fields of fire prevention and arson investigation. In the first case, it is directly related to issues of safety. In the second case, its movement and the aerosols it carries contain information about the events that must be decoded. Today, these studies are performed using simulation models, especially Computational Fluid Dynamics (CFD) based ones. However, these models are still under development and checking them against experimental data is necessary in order to validate them.

In this context, we have been developing a white light differential opacimeter. This device measures continuously the local smoke concentration directly in the flow. Spreading several opacimeters allow measuring simultaneously different parts of the area studied. Thus, a comparison of numerical data can be made with experimental one. This measurement technique is local, instantaneous and non intrusive.

Our prototype opacimeter is presented. Experiments are conducted in a smoke chamber. The prototype is compared with the smoke box photometer. The soot concentration is obtained by the Beer-Lambert light-extinction law. While the photometer is measuring across the global height of the chamber (0.914m), the opacimeter measures on a local light path of 0.05m.

Results show that the global measurement does not capture any fluctuations because the optical path of the photometer integrates too thick smoke layer. Thus, the photometer doesn't allow any kind of useful CFD validation measurement. The fluctuation of the local measurement performed by the opacimeter is characterized. We demonstrate the variation of soot concentration in flow structures. It allows to characterize the structures of smoke from a fire as stratification of hot gases, smoke density etc.

For the first time, this prototype allows a validation of soot concentration field calculated by CFD model.

Categories

Submission Category: Poster Abstract
Stochastic Methods for Structural Safety Evaluation in Fire

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ABSTRACT

The stochastic methods, which have been well developed for ambient temperature analysis, offer promising advantages toward addressing the uncertainties when simulating the structural response under fire. However, very few researchers have adopted a stochastic method of analysis for modeling structural response under fire until now. This research focuses on building a reliability-based analysis algorithm by extending stochastic methods to simulate the structural response under fire load. It mainly involves a probabilistic framework in which structural response is evaluated by a perturbation-based finite element simulation and the response gradients are determined using either the finite difference method (FDM) or direct differentiation method (DDM). Once the response sensitivities for all uncertain parameters are known, the system reliability is subsequently computed using the first-order or second-order reliability method. This novel application of the stochastic finite element approach enables accurate and efficient computation of the time-variant probability of failure, allowing the analyst to evaluate a system design based on an acceptable level of risk. This quantification of structural reliability in fire is essential to the realization of a holistic performance-based framework in which structural fire resistance is appropriately accounted for.

This poster will provide details about the proposed reliability-based framework and will illustrate its application through the analysis of a relatively simple structure exposed to fire conditions. The analysis specifically considers the response of a steel beam given uncertainties in fire load and structural resistance. The perturbation-based finite element simulation is evaluated through comparisons to Monte Carlo simulations carried out on the same structure. This preliminary work on stochastic structural simulation in fire demonstrates that the reliability-based framework for structural fire design offers promising results and is the motivation for future research in this topic.
This poster describes application of a new urban post-earthquake fire spread simulation model to the 2007 Grass Valley, California fire. The model takes as input digitized footprints and other attributes of buildings in the study region. Ignition and wind data are either input by the user or simulated. The model explicitly represents the primary modes of urban fire spread: (1) evolution of fire within a room or on a roof; (2) room-to-room spread within a building through doorways to adjacent rooms, by burnthrough to adjacent rooms or a room or roof above, or by leapfrogging through windows to a room above; and (3) building-to-building spread by flame impingement and radiation from window flames, radiation from room gas, radiation from roof flames, branding, and surface vegetation. The model was developed for use in post-earthquake situations, but can be used for any urban fire situation, where building-to-building spread is a key factor. It is intended to estimate how much, how fast, and where fires will spread, and also to provide insight into how fires spread and factors that influence fire spread. It was designed to support emergency managers, insurance companies, and other risk managers in estimating future losses and developing effective risk reduction strategies.

The Grass Valley fire started on October 22, 2007 near Lake Arrowhead in the San Bernardino mountains. It spread through an area of dense residential development, ultimately damaging or destroying 199 homes. Although the wildfire started the residential burning, almost all of the homes ignited from fire spread through surface vegetation or from structure flames and brands. In this analysis, the fire spread model was applied to the Grass Valley residential community, and the model results are compared to the observed fire spread in the 2007 fire. We compare the model results and the observations from reconnaissance reports based on the geographic extent and timing of the spread, and the relative importance of different modes of spread in the fire spread. The implications of the comparison for future model improvements and uses are discussed.
A simple Law governs heat flux to façade
C. Abecassis-Empis & J. L. Torero, The University of Edinburgh, UK

In multi-storey buildings there is often a risk of external fire spread beyond the compartment of fire origin. Post-flashover compartment fires can lead to external flaming, imposing a heat insult to elements of the external building envelope. Such heat flux falling incident on the façade plane may ignite external cladding, may cause breakage of other compartment windows (and potentially ignite combustible items within) and will impose fire loading on the external structure. In order to adequately design these building components to ensure mitigation of external fire spread and minimise adverse effects to the structure, it is essential to quantify the heat flux that falls incident on the façade plane, resulting from a compartment fire.

Developed in the 1970s, the Law Model [1] was the first methodology for determining the external heat exposure resulting from a compartment fire. When it was developed, it was recognised that “as more use is made of the method it is likely that more straightforward rules will be worked out” [2] however the original model is still in standard use today [3,4]. Although it is most commonly employed to assess heat flux to (and the resultant temperature of) structural steel members external to the building façade [2-4], the model can be adapted to additionally provide the heat flux incident on the façade plane – which is of greater use for the mitigation of external fire spread (i.e. applied to design of cladding, windows, the structure, etc.). Such an adapted version is employed in a computational implementation of the Law Model – *FirExHeat* (using MATLAB®) – enabling a thorough sensitivity study of the many root parameters involved in the Law Model. The study uses Dalmarnock Fire Test One [5] – a contemporary compartment fire scenario that uses furniture as fuel with comprehensive data describing the characteristics of both the internal compartment fire and the heat flux to the façade – as a benchmark scenario for ballpark comparison of the Law Model with modern experimental measurements and for evaluation of the effect of individual parameter variation. Both physical and numerical limits of the applicability of the Law Model are also identified by reviewing the tests that gave origin to the Law Model [6-9] as well as the model itself. The study identifies the compartment fire load as the sole parameter of key influence on the resultant heat flux incident on the façade plane, dwarfing the effects of other parameters, such as compartment and opening geometry.

A simplified model for determining the heat flux incident on the façade is proposed, incorporating these findings and providing a more straightforward tool with clearer limits of applicability. Further essential areas of research are recommended in order that the model applications can be further refined and such that external heat exposure can be quantified for scenarios that fall outside the limits of the current models.

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Flame Spread over Inert Porous Bed Wetted with Highly Flammable Liquid under Given Ignition Delays

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ABSTRACT

Flame spread caused by accidental spillage of highly flammable liquid over porous beds (e.g. sand and soil) is considered a major safety concern in industrial zones and residential areas. The majority of these fires spread and grow rapidly into catastrophic size, which claim many lives and destroy properties. The characteristics of this flame spread phenomenon, in such cases, are different from those flame spread which occur over combustible non-porous solids such as polymers or wood. Regardless of the recent progress in the field, the mechanism underlying the rate of flame spread over porous beds under given conditions are not fully understood. In order to address this shortcoming, a research project conducted at the University of Newcastle, Australia, with collaboration of the University of Kashan, Iran, to study the rate of flame spread over porous beds soaked with different amounts of flammable liquid. The experimental results presented within are related to the fuel penetration section of this study only.

Experiments for fuel penetration rate and flame spread rate were conducted in Perspex and insulated stainless steel channels respectively, the beds were soaked with propanol. Measurement of the fuel penetration and temperature distribution were performed using a fuel distribution system designed and developed as part of the apparatus in our laboratory and a thermocouple grid, respectively. The rate of flame spread was determined using high-speed video recording and image processing techniques.

Results corresponding to the zero ignition delay (i.e. immediate ignition) indicate that the rate of flame spread for the bed containing fine particles (i.e. 0.5 mm) increases as the fuel ratio increases. Regardless of the fuel ratio and/or ignition delay the rate of flame spread decreases for deeper beds and coarser particles. The highest flame spread rate of approximately 1.65 m/s corresponds to the bed depth of 13.3 mm and fuel ratio of 0.15. The rate of flame spread for the same bed depth decreases to 1.55 m/s and 1.50 m/s as the fuel ratio decreases to 0.125 and 0.1, respectively. A similar pattern was observed for deeper beds as well. But, as a general observation, the flame spread rates corresponding to the deepest bed (39.9 mm) were 8% lower than those of the shallow bed counterparts.

Unlike zero ignition delay, the cases of ignition with 10 or 15 min delay the rate of flame spread decreases as the fuel ratio increases. However, the flame spread deceleration rate is more distinct for larger fuel ratio and longer ignition time delay. For instance, the rate of flame spread for a 15 minute ignition delay was lower by nearly 15% when compared with a 10 minute ignition delay. Furthermore, for any given ignition delay, the rate of flame spread over coarse particles was lower then fine particles.

Key words: flame spread, fuel soaked porous bed, fuel ratio, ignition delay, liquid fuel.

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Probabilistic Fire-Risk-Assessment Function

JACK WATTS and YAPING HE

POSTER ABSTRACT
The study of probabilistic risk assessment methodology is driven by and in support of the development of risk informed performance based building codes [1, 2]. Fire safety engineering is risk management engineering. The design objective is to minimize risk in terms of failure probability and potential consequences. Probabilistic risk assessment allows designers to make risk informed decision on fire safety system designs. This poster describes a probabilistic fire-risk-assessment function which can be used to analyze success/failure probability of a fire safety system design. The fire safety design evaluation parameter pairs, such as required safe egress time (RSET) and available safe egress time (ASET) or fire severity and fire resistance level, are treated as continuous random variables. An analogy of the ASET-RSET (or severity-resistance) relationship to stress-strength relationship in engineering design is established [3]. A general expression of risk assessment function for evaluating failure probability from the probability density distribution functions of the design evaluation parameter pairs is given. The expression is in the form of convoluted integration of the probability functions. The special cases of normal and lognormal distributions are analyzed in detail to demonstrate the use of the risk assessment function. The safety factor approach which most fire safety engineers are familiar with is an empirical approach to dealing with uncertainties in design parameters. The link between the probabilistic risk assessment function and the traditional safety factor approach [4] is explained in the current poster.

The implementation of the probabilistic risk assessment function is quite straightforward. An EXCEL spreadsheet solution is explained. This solution is also used in a sensitivity study of failure probability to the influential parameters (i.e. means, standard deviations and correlation coefficient) that govern the probability density distribution functions of the design parameter pairs. The analysis was conducted in terms of safety index, ratio of variation coefficients and correlation coefficient. The results revealed that the safety factor-failure probability relationship is very sensitive to variations in safety index and ratio of variation coefficients, but less sensitive to correlation coefficient. This outcome could help identify effective means of reducing risk or increasing safety of fire engineering designs.

The evaluation of failure probability is part of the risk assessment. The poster also outline future studies for obtaining probability density distributions of design parameters and risk analysis in terms of expected fatalities and economic costs.

KEYWORDS: failure probability, risk assessment, safety factor, safety index

REFERENCES
Effect of the architectural design parameters on natural forces driving air and smoke flow patterns

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Building’s natural ventilation and smoke ventilation strategies are designed to achieve different objectives. The two strategies should be incorporated compatibly at some stages of the design. Although fire engineers (FE) and building service engineers (BSE) develop their designs for the same building within the same context, they appear to have different sets of priorities and strategies. To successfully integrate these systems with the building design process rather than an “add-on” design solution, it is important to address the FE and BSE sets and priorities and how those are related or indeed integrated with the architects’ plans. In this research, two sets of priorities in the design of shopping malls are examined. The research examines the relative importance of the design parameters that affect air and smoke movement by FE and BSE (practitioners and experts) with respect to the natural driving forces. The research also investigates the degree of importance placed by architects (practitioners and experts) on smoke and building ventilation considerations. The design parameters that affect air and smoke movement have been identified and refined into seven design parameters. The adopted design parameters include “building geometry”, “building façade and glazing”, “opening orientation”, “opening characteristics”, “space profile”, “landscaping and adjacent buildings”, and “Construction and interior material-in terms of thermal impact”.

Two questionnaires that are based on the Analytic Hierarchy Process approach were conducted. The two questionnaires were related to UK shopping mall buildings with atria spaces (majority in UK are two story buildings- multi-story buildings). The results highlighted the gap between FE and BSE understanding regarding the impact of the design parameters on air and smoke movement one hand, and between engineers and architects on the other.

Results of the first assessment that measures the agreement level between FE and BSE understanding regarding the influence of the design parameters on air and smoke movement shows that there is a 100% agreement between FE and BSE on the ranking of the influence of the design elements on air and smoke movement with respect to the wind-driven flow, 71.4% agreement with respect to stack-driven flow, and 14.28% with respect to buoyancy-driven flow. On the other hand, results from the second assessment that measures the agreement level between the current importance placed by architects and the engineers’ perception on the influence of the design parameters on air and smoke movement, there is 57% agreement between architects’ perception and the engineers’ perception.

The research provides an insight of the differences in design priorities for ventilation and smoke prevention among architects, FE, and BSE towards the development of truly integrated strategies within the design process of shopping malls.
Comparison of CFD Predictions to Experimental Measurements from Medium-scale Pool Fires under Natural and Forced Ventilation

Francesco colella, Adriano Sciacovelli, Nicolas Bal and Vittorio Verda

(Submission #1038)

Image Caption or Poster Abstract

In the last two decades, the application of Computational fluid dynamics (CFD) as a predictive tool for fire induced flows has become more widespread. The results are still limited due to the difficulties in modelling turbulence, combustion, buoyancy and radiation but great achievements have been made since the predictions are sufficiently realistic to allow CFD models to be used for fire safety design in buildings and enclosures. However, validation studies should be always conducted to point out their limitations and strengths. The current work presents several experimental results from medium-scale heptane pool fires localized in the centre of a 2.4×2.4×2.4 m enclosure. In order to achieve a steady burning the fuel pans have been laid down in larger pans containing water. The experimental setup consisted of 29 gas phase temperature and mass loss measurements. Different pool fire scenarios have been considered including natural and forced ventilation, open and closed compartment, different pan sizes and amount of fuel. The attained HRR ranged between 20kW and 100kW depending on the pan size and ventilation conditions. The data obtained from these experiments have been then used in some validation studies developed in two different CFD environments: FLUENT and FDS. Full transient simulations have been conducted in FLUENT adopting the k-ε turbulence model and the eddy break-up combustion model. The FDS runs have been conducted adopting the LES turbulence model complemented with a mixture fraction combustion model. The same input data have been used for both the CFD tools. The simulations have been conducted on a particularly refined grid (average grid size around 1 cm) which is unusual in this kind of studies. Both the CFD tools have shown valuable prediction capabilities with a significant matching also for the local thermocouple readings in the close vicinity of the flames. The poorer matching has been found for side locations in the vicinity of the floor. This is most probably due to air leakages that could not be considered in the numerical models. The FDS and the FLUENT models performed equally well in the natural ventilated scenarios. The latter showed superior prediction capabilities for the mechanically ventilated scenarios where unstable flames have been observed. The computational complexity was largely in favour of FDS which showed a 6 fold reduction in the computing time in comparison to FLUENT. The study confirmed that accurate temperature predictions could be obtained only if the actual HRR curve reconstructed from the mass loss curve and corrected for the amount of evaporated water was input in the models. Poorer predictions have been obtained if literature correlations are used for the HRR evaluation especially when simulating fire scenarios that did not show a clear steady burning.

Categories

Submission Category: Poster Abstract
A Novel Multiscale Methodology for Simulating Tunnel ventilation Flows During Fires

Francesco Colella, Guillermo Rein, Vittorio Verda, Romano Borchiellini and Jose L. Torero

(Submission #1039)

Image Caption or Poster Abstract

The poster will present a novel and fast multiscale approach to model ventilation flows and fires in tunnels. The complexity and high cost of full CFD models and the inaccuracies of simplistic zone or analytical models are avoided by efficiently combining mono-dimensional (1D) and CFD (3D) modelling techniques. The multiscale model couples a 3D-CFD solver with a simple 1D model allowing for a more rational use of the computational resources. The 1D network models tunnel regions where the flow is fully developed (far field), and detailed CFD is used where flow conditions require 3D resolution (near field). The methodology has been applied to a modern tunnel of 7 m diameter section and 1.2 km in length. Different fire and ventilation scenarios are investigated involving different settings of the ventilation system and fire sizes ranging between 10MW and 100MW. The multiscale model has been proved to be as accurate as the traditional time consuming CFD techniques but provides a reduction of two orders of magnitude in the computational time widening the number of tunnel fire scenarios that can be potentially explored. The much lower computational cost is of great engineering value, especially when conducting comprehensive risk analyses, parametric, sensitivity and redundancy studies, or when solving detection, activation and smoke propagation problems required in the design or assessment of ventilation and fire safety systems.

Categories

Submission Category: Poster Abstract
Mechanism of Flame Spread of Electrical Cables

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A flame spread followed by the forced ignition of low-smoke, halogen-free electric cable, so called “eco-material (EM) cable” have been examined experimentally. The main objective of this study is to propose the universal methodology to predict the spread rate of the various scales of the cable, then obtain acceptable mechanism of flame spread over the cables. In this study tested samples are single and multi-core cables (cable O.D.: 3.0~15.5 mm). Flame spread behavior of EM cable is compared with that of previously-studied, laboratory-scale cables (O.D.: ~ 1.0 mm). Sample, whose length is 250 mm, is placed horizontally in the chamber and ignited by the electric heater equipped at the one end. Whole combustion events are recorded by digital video camera to analyze the spread behavior. It is found that all cables could achieve the complete flame spreading (burnout of the sample occurs) when a sufficient amount of energy is delivered by igniter. Averaged spread rate and flame width are found to be constant although the flame fluctuates tremendously by buoyancy-driven flow. Pe-Λ correlation, previously developed by authors based on one-dimensional conduction model including both effect of heat flow from flame and wire, is applied to EM cable and found that our model could be applicable to any size of cable satisfactory. It is convinced that the heat transfer both from flame and through the wire is always equally important to predict the flame spread behavior irrespective of the scale of the cable.
Experimental study of a generation of fire whirls downwind of a flame in a cross-flow

Masahiko Shinohara and Sanae Matsushima

(Submission #1041)

Image Caption or Poster Abstract

Fire whirls have caused destructive damage in large scale fire incidents such as city fires and wild fires. They occur frequently downwind of fires. However, formation mechanisms of this type of fire whirls are not well understood. We studied the formation process using flow visualization. The experiments were performed in a low-speed, blow-down wind tunnel with a 0.5 x 0.5-m cross section. A 30-mm diameter burner was placed flush with the floor of the test section. A diffusion flame was produced by injecting methane gas from the burner at a velocity of 3.0 cm/s or 0.7 cm/s into a cross-flow with a velocity of 20 cm/s. We observed that vortices forming along the flame just downwind of the flame shed occasionally downwind. The formation process of the vortices is clearly different from that of wake vortices which generate at the velocity boundary layer on the floor downwind of the flame and shed periodically. In order to identify the vortices, we investigated the relationship between the vortices and the flow structure around it using the smoke-wire flow visualization technique. We found that the vortices which occasionally shed are the vortex pair called CVP (Counter-rotating vortex pair) formed in the plume from the flame when the plume is inclined because of a cross-flow. This result supports field observations that CVP formed in the plume from fire seemed to move downwind in large-scale fire experiment and wild fire. Therefore, there is high possibility that CVP from fire is one of origins of fire whirls which occur downwind of the fire and shed downwind.

Categories

Submission Category: Poster Abstract
Numerical Feasibility Study of Data-Driven Simulations of Wildfire Propagation.

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A wildfire propagation results from the complex multi-scale interactions between multi-physics processes, namely the pyrolysis taking place at the scale of the vegetation, the combustion and flow dynamics at the flame scale, and the atmospheric dynamics at large regional scales. These processes are highly connected to the local vegetation characteristics, topography and wind. Much progress has been made on the development of wildfire models; in France this work is partly carried out within the project ANR-COSINUS-IDEA that is aimed at building a real-time simulation tool of large-scale wildfires [1]. Despite recent progress made in wildfire modeling [2], the fire models are far from being predictive due to both modeling inaccuracies and uncertainties in input parameters, boundary conditions and initial conditions.

The present study aims at demonstrating that some of the limitations of wildfire modeling can be overcome by combining information from observation and numerical simulation using data assimilation techniques. This approach is similar to that adopted in other scientific fields, for instance for weather forecasting applications; it appears as an efficient framework to provide an optimized description of the fire dynamics by calibrating the parameters and input data of a fire model, and thereby providing more accurate descriptions of the fire spread.

A first prototype for a data-driven fire model was developed using a simplified configuration to evaluate the potential of data assimilation methodologies for simulations of wildfire propagation. The prototype uses the Best Linear Unbiased Estimator (BLUE) algorithm for data assimilation; it also describes the fire front as a one-dimensional line propagating along a two-dimensional surface. At the regional scale, a premixed combustion model appears to be relevant to describe the front propagation [3]; the fire model uses a reaction-diffusion equation for a reaction progress variable in which the local flame speed (i.e., the local rate of spread) is the main physical quantity. In a preliminary step, the local flame speed is assumed to depend linearly on a single variable that represents the effects of a non-uniform vegetation (i.e., fuel) distribution. It is here assumed that the uncertainty on the model is due mostly to the uncertainty on the constant of proportionality between the flame speed and the fuel load, which defines the control parameter in the data assimilation prototype. The observations are generated with the numerical model, and provide measurements of the progress variable at fixed spatial locations; the treatment of real observations as produced by fire sensors is not addressed here. Numerical sensitivity tests indicate that the BLUE prototype performs well even though the fire physics are non-linear and the error statistics on the parameter do not follow a Gaussian distribution. A consistent behavior of the data-driven solution with respect to the error statistics on the model and observations is obtained. The corrected parameters lead indeed to a simulation that is more consistent with true trajectory. Certainly, this work was limited to a stand-alone numerical feasibility study. Ongoing research is aimed at assimilating more realistic observations such as time-evolving positions of the fire front, and a more physical fire model taking into account vegetation, wind and topography characteristics. However, results already illustrate the potential of a data-driven simulation tool to provide more accurate predictions of the fire spread.

KEYWORDS: wildfire, fire modeling, CFD, data assimilation, parameter calibration, flame spread.

Poster Abstract – Bypass Stockholm
Maryland, IAFSS

A new motorway is planned in Stockholm. The motorway is 21 km long of which 18 km is below ground. The bypass Stockholm is a motorway-link between Kungens Kurva in Southern Stockholm to Häggvik in northern Stockholm. The link will provide long-distance traffic with a bypass so that it no longer has to pass through the centre of Stockholm. The tunnel will be used by cars, busses and heavy goods traffic. A quantitative risk analysis has been performed with the aid of using CFD-modelling software.

Introduction
As part of the planning process a detailed quantitative risk analysis has been performed. The analysis intends to describe the risk that persons are exposed to when passing through the tunnel system. No set acceptance criterion for risk level is available within the legislative work. To be able to provide input data for the quantitative risk analysis a vast number of smoke spread analysis and egress simulations has been performed using FDS-modelling and STEPS. The analysis also provides information with regards to what installations are necessary in the tunnel system to provide a safety level that is acceptable to society.

Purpose of the report
The purpose of the report is to provide data for the quantitative risk analysis by investigate the proposed longitudinal ventilation strategy, the effect of an active fire suppression system in terms of fire development and egress aided means. In the report it is also investigated how a transverse ventilation system would work in the proposed tunnel. With respect to the different ventilation strategies a proposal is made on how the control should be set up to minimise the risk for those who occupy the tunnel system.

The tunnel
The proposed tunnel is divided into two main tunnels, one in the northern direction and one in the southern direction. Each tunnel consists of three lanes and has a one way traffic direction. From the main tunnels on and off ramps are provided. The gradient is varied across the length with a maximal gradient of 3.5% in the main tunnel. In some of the off ramps a gradient up to 7% is provided. Every 5th kilometre a ventilation shaft is installed subtracting 600 m$^3$/s. Egress routes are provided each 150 metres.

The analysis
The analysis describes how a fire in vehicles in tunnels can develop due to the radiant heat, longitudinal ventilation and fire spread to adjacent vehicles. The effect of different active suppression systems is analysed in terms of controlling a fire or extinguishing it. The effects from smoke and its contained components are evaluated in terms of people safety.

The analysed representative fire scenarios are a car, 2-3 cars, buss, small lorry and heavy goods vehicle. Each scenario is evaluated and simulated using FDS to provide information about visibility, toxicity and temperature. For each scenario further analysis has been performed to evaluate how the different strategies will affect personnel safety. For these scenarios fire location (gradient, up or downhill), longitudinal ventilation, the effect of a fire suppression system has been varied.

The result is presented with detailed information on how many occupants are exposed to critical conditions.
Inverse Zone Modelling based Numerical Fire Predictions using Real Time Video and Thermocouple Information

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A recently developed methodology [1,2] is applied to an actual experimental test, conducted at Ghent University. The main objective of this methodology is to assist emergency response (in case of a fire) based on real time information. The under-lying idea is similar to Numerical Weather Predictions (NWP), be it on different time and length scales. Jahn et al. [1,2] presented a series of radially spreading compartment fire cases (closed compartment with floor leaks). The fire growth, upper layer temperature and smoke layer height were predicted using FDS and these results acted as data for assimilation in a zone model.

In our work at hand, the methodology is extended to an ISO-room fire with open door. The data used for assimilation is provided by a video camera and a set of thermocouples. The video camera was placed at the door level to estimate the smoke layer height. The thermocouples were located inside the room to measure the average upper layer temperature. Complementary FDS results are also used as supportive data for assimilation. The Zone Model output (i.e. smoke layer height, upper layer temperature and heat release rate) is continuously updated to best fit the data thanks to a dynamic estimation (using the Tangent Linear technique) of the set of model invariants: the fire growth rate, the delay time, the radiative fraction, the plume entrainment rate, and the vent flow coefficient.

References

The Load Fire Test of RCST (Reinforced Concrete Steel Tube) Column

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RCST (Reinforced Concrete Steel Tube) column are used to many low rise buildings in Japan. RCST column is one kind of concrete filled steel tube columns. The one of the characteristics of the columns is that both ends of the column are not connected to the beams. The other characteristic of the columns is that the reinforcement which resists to the bending moment are placed only the portion of both ends of the columns.

This paper reports the fire resistance of this column. The fire resistance of the column is clarified by two kinds of fire load test.

The first fire test is load fire test using two specimens, the diameter of the specimens is 406.4mm, and the length of the columns is 3,364mm. The heating is according to the heating curve of ISO-834. And the heating time is two hours.

The second test is also load fire test using five beam-column specimens, the column diameter is 318.5mm, and the length of the columns is 1,200mm. The specimens are composed of two columns and three connections. In this test, the axial force and the bending moments imposed to the columns simultaneously. The heating is also according to the heating curve of ISO-834. And the heating is continued until the specimen is collapsed.

By these tests, the following characteristics were clarified.

1. RCST column have two hours load baring capacity for the axial load that one-thirds of the strength of the part of the concrete.
2. RCST column have three hours load baring capacity for the axial loads one-fifths of the strength of the part of the concrete, if the diameter length ratio is under eight and the column angle 1/25 at the fire.
The Effects of Sprinkler Sprays on the Transport of Toxic Products, Comparison of Experimental and Numerical Results

Zachary L. Magnone*, Robert F. Accosta Jr., Nicholas A. Dembsey, and Brian J. Meacham

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POSTER ABSTRACT

Large numbers of people become victims of fire each year. Many of them, located outside the room of fire origin, become incapacitated or deceased due to exposure to toxic products of combustion. Although the death rate in sprinklered buildings is lower than in unsprinklered buildings, deaths still occur, and incapacitation due to toxic products remains a concern. In any building design, safety is the utmost goal, and the use of performance-based design frameworks is becoming more and more common in the fire protection community due to the increased flexibility the approach provides to architects and engineers. In the case of toxic product exposure within a structure, these methods rely heavily on the use of robust and well validated engineering tools to effectively understand the balance between Available Safe Egress Time and Required Safe Egress Time. While these predictive tools are well validated for the case of the fire itself, there is limited data available to support their use for the sprinkler-controlled fire scenarios.

To address this shortcoming in knowledge, a collaborative study was undertaken to investigate the effect of sprinkler waterflow on the fire driven transport of toxic products from a room of fire origin to remote locations within a structure. To serve as the foundation of the study, full-scale experiments were conducted in a modified UL 1626 test compartment with an attached L-shaped corridor. The fire consisted of a shielded propane burner located in the corner of the test compartment opposite the opening into the corridor. As the focus was on the buoyant transport of toxic products rather than the production of such species, a known amount of carbon monoxide (CO) was seeded into the convective fire plume. A single sprinkler was centered 2.44 m from the adjacent walls near the fire corner. Vertical temperature profiles, velocity profiles, and CO concentration profiles were collected and analyzed in the compartment, doorways, and the corridor to investigate the tenability conditions remote from the fire source as well as in the room of origin. Experiments were run with several sprinkler types and flow rates, two fire heat release rates, and three CO seeding rates.

As a work in progress, the poster will focus on the specific portion of the project associated with the ability of CFD tools – specifically Fire Dynamics Simulator (FDS) – to predict fire driven toxic product transport in an attached corridor remote from the sprinklered fire compartment. Using data obtained in the aforementioned experiments, factors such as compartment mass flow rates, temperatures and toxic species transport associated with multiple sprinklered fire scenarios are investigated. While the specific focus is on the far field, understanding the conditions within the room of origin is of high importance as the physics associated with heat transfer and turbulent mixing play a critical role in the movement of any gasses through openings in the compartment. As a result, specific issues associated with the careful design and calibration of the virtual fire scenario and sprinkler spray will be discussed, along with a proposed framework utilizing a statistical design of experiments methodology to design a calibrated sprinkler spray in FDS to replicate the real world spray. Overall, the poster will cover the objectives of this research effort, details of the experimental program, development of the numerical simulations, initial experimental and numerical results comparisons, and suggested future work.
Tall Building Design - Fit for Purpose?

Adam Bittern, Jose Torero and Luke Bisby

(Submission #1047)

Image Caption or Poster Abstract

Tall Building Design – Fit for Purpose? Adam Bittern1,2, J. L. Torero1, L. Bisby1 1 BRE Centre for Fire Safety Engineering, School of Engineering and Electronics, University of Edinburgh, EH9 3JL, UK 2 Astute Fire Ltd, 6 Elmgrove, St.Monans, Fife, KY10 2DA, UK With the increase in world population putting enormous pressures on the availability of suitable land within urban centres, current trends in designing and constructing high rise buildings is accelerating. Tall buildings offer unique challenges for fire safety engineering which are often not addressed by the prescriptive codes used to design such complex, unique, and massive buildings. Furthermore, designers may not fully appreciate the specific issues to be addressed in tall buildings, due to the prescriptive-centred approaches used for the majority of the building designs. The prescriptive codes generally do not distinguish between a 10 storey building and a 100 storey building. The underlying assumptions used in fire safety strategies may not befit actual fire behaviour observed in real fires.

There are three core components to be addressed in the fire safety design of tall buildings; 1) structural stability of the superstructure, 2) compartmentation to limit both horizontal and vertical fire spread, and 3) protection of the vertical escape routes from fire and smoke. The failure of any one core component can lead to an unsatisfactory outcome; historically there have been repeated examples of when one or more of these three key components have failed, resulting in severe outcomes.

A detailed review of the available literature reporting on historical tall building fires questions the suitability of the current tall building fire safety design philosophies and provisions. Current international design practices explicitly assume no vertical fire spread, while the historical data show that both internal and external vertical fire spread is a reasonably common and serious concern in high rise buildings. Historically, fires have been reported breaching several compartments and multiple floors, leading in some cases to local or (admittedly rarely) global structural failure. However, structural fire engineering practice routinely ignores multiple floor fires for the purpose of designing for structural stability and global collapse prevention.

What is of great interest in our current work, and most concerning, is the frequency with which vertical escape routes have historically become impassable, often leading to serious injury or death. This also prevents evacuation, often affecting two or more stairs within a building. A common theme reported in the literature is that escape stairs become impassable during the very early stages of a fire, often before the building is evacuated.

Stair failure has been reported for different types of smoke control protection. Reasons for failure have included mechanical or electrical failures, fire doors wedged open, too many doors open, passive failure of stairs, etc. Pressurisation of evacuation stairs, a foundation element of egress strategies in many tall buildings, showed the greatest failure rates.

However, what has the most ramifications for tall building design, considering the frequency of single stair buildings being constructed, is that as soon as fire fighting operations commence, stairs are often lost for evacuation, no matter what smoke control systems are provided. This is a common theme identified though out the historical fires looked at.
Development of an Oxidation Model for Cardboard Char

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This poster presents progress in the development of an oxidation model for cardboard that is commonly used in storage and packaging applications. Cardboard can be the primary fuel for fires that start in storage areas, so it is important to understand the ignition and heat release characteristics of cardboard and its combustion products. Two main apparatuses utilized in this investigation were a cone calorimeter (Govmark CC-1) and a thermal analyzer capable of simultaneous thermogravimetry and scanning differential calorimetry (Netzsch STA 449 F3). The experiments with the cone calorimeter were intended to simulate flaming degradation and post-flaming oxidation of the cardboard in a typical fire scenario. The simultaneous thermal analyzer allowed data to be collected regarding the reaction kinetics of the cardboard on a microgram scale in a well-defined atmosphere at a dynamic, well-defined temperature.

Cone calorimeter tests were conducted with incident heat fluxes ranging 20-60 kW/m². These heat fluxes were chosen to represent a realistic range of the heat fluxes experienced in a real fire, while still allowing a reasonable amount of time for observation of all noteworthy phenomena. Several separate cone calorimeter tests were conducted with type K thermocouples inserted into the sample to provide temperature data that can be analyzed to describe the heat transfer characteristics of the cardboard and char samples, as well as the peak temperatures these samples reach during the cone calorimeter experiments.

A typical mass loss curve obtained in the cone calorimeter experiment conducted with a heat flux of 40 kW/m² is shown in Figure 1. The mass loss history consists of three distinct regions. The pre-heating mass loss process occurs before sustained ignition, and features a mass loss rate on the order of about 1 g/m²s. The flaming mass loss process is the transition between ignition and flame extinction and is characterized by a mass loss rate approximately an order of magnitude larger than the initial pyrolysis of the sample. The smoldering process occurs after the flame has extinguished while the sample is still oxidizing. The mass loss rate during the smoldering process generally ranges on the order of 0.1-2 g/m²s. Based on the thermocouple data, it appears there is a thermal wave propagating through the sample from the top surface, downward. The temperature of the sample increases rapidly at the beginning of the test and reaches a point when it remains steady. The temperature of each thermocouple peaks successively as the sample continues to be heated. The thermocouple positioned under the upper planar layer of cardboard reached a peak temperature of approximately 650°C exposed to 25 kW/m² which coincided with the time of flame extinction. The temperatures of the thermocouples positioned under the middle and bottom planar cardboard layers appeared to be unaffected by flaming combustion and reached peak temperatures of approximately 650°C during the non-flaming combustion period as seen in Figure 2.

Two consecutive STA runs were conducted at a heating rate of 10°C/min on 16-28 mg cardboard samples. The first run performed in nitrogen atmosphere from 40°C to 650°C was used to examine the thermal degradation, which takes place during flaming combustion. The second run performed in air from 40°C to 700°C was used to examine the oxidation of char formed in the first run. Preliminary data indicate that the mass loss kinetics are not affected by the sample preparation method. The onset of the anaerobic thermal degradation occurs at approximately 280°C. The onset of the char oxidation takes place at about 340°C.
Abstract

Accumulation and ignition of dust on hot surfaces is a common precursor to dust explosions [1,2]. The susceptibility to ignition is given by the minimum ignition temperature (MIT). MIT values are based on experiments done on layers with a thickness of 5 mm and with a constant-temperature ignition source [3]. However, ignition sources with constant heat flux represent a more realistic ignition scenario and in addition give lower ignition temperatures compared to constant-temperature ignition sources [1,4]. In this poster effects of different heat-flux scenarios for the onset of smoldering in cotton is studied. Four different heating scenarios have been investigated: High heat flux with exponential cooling, high heat flux followed by constant temperature, low heat flux followed by constant temperature and multiple heating and cooling of the same sample.

Experimental tests have been carried out using an electrically heated hotplate. The cotton-sample was 0.15 m x 0.15 m x 0.15 m, and the density of the cotton was varied in the range 20-100 kg/m$^3$. To monitor the temperature, a type K thermocouple was placed directly on top of the hotplate, giving the temperature of the ignition source. In addition, seven thermocouples were used to measure the temperature within the sample. The thermocouples were 2 cm apart along the vertical centerline of the sample. The thermocouples used had a diameter of 0.5 mm [5].

Experimental results are shown in Table 1. Different heat flux scenarios do affect the minimum ignition temperature significantly. The difference in ignition temperature between high heat flux with exponential cooling and low heat flux followed by constant temperature for cotton at 100 kg/m$^3$ is 19 °C. Ignition of solids is dependent on the generation of a hot layer where material degradation and heat production may occur. The low heat flux scenario generated a deeper hot layer at a lower temperature that the high heat flux, resulting in lower ignition temperatures. The cotton density also influenced the ignition temperature. The difference in ignition temperature for cotton at 40 and 100 kg/m$^3$ with low heat flux followed by constant temperature, is 36 °C.

The experiments indicate that a low heat flux scenario followed by constant temperature should be used where minimum ignition temperature is determined. Standard tests for the minimum ignition temperature should also incorporate density.

<table>
<thead>
<tr>
<th>Density (kg/m$^3$)</th>
<th>$T_{ign}$ (°C) with exponential cooling</th>
<th>$T_{ign}$ (°C) followed by constant temperature</th>
<th>$T_{ign}$ (°C) low heat flux followed by constant temperature</th>
<th>Multiple heating and cooling of the same sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.5</td>
<td>*</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>20</td>
<td>307 ± 2</td>
<td>336 ± 4</td>
<td>306 ± 4</td>
<td>-</td>
</tr>
<tr>
<td>40</td>
<td>318 ± 3</td>
<td>√</td>
<td>320 ± 6</td>
<td>338 ± 2</td>
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<tr>
<td>60</td>
<td>315 ± 2</td>
<td>√</td>
<td>319 ± 7</td>
<td>-</td>
</tr>
<tr>
<td>80</td>
<td>309 ± 2</td>
<td>√</td>
<td>305 ± 5</td>
<td>-</td>
</tr>
<tr>
<td>100</td>
<td>303 ± 2</td>
<td>√</td>
<td>284 ± 5</td>
<td>319 ± 2</td>
</tr>
</tbody>
</table>

* No ignition, - Not investigated, √ To be investigated

Reference

IAFSS 2011 Poster Abstract

Hydrogen Release and Mixing in a Partially Confined Space: Comparison of Model and Full Scale Experimental Data
Kuldeep Prasad, William M. Pitts, Marco G. Fernandez and Jiann C. Yang

National Institute of Standards and Technology (NIST)

Increase in the number of hydrogen fueled applications in the marketplace will require a better understanding of the potential for fires and explosion associated with the unintended release of hydrogen within a structure. Predicting the temporally evolving hydrogen concentration in a compartment, with unknown release rates, leak sizes and locations is a challenging task. The uncertainty in prediction can increase due to external factors such as wind and thermal gradients. A series of experiments were conducted to understand the release and dispersion of a buoyant gas (helium) released under an automobile placed in the center of a full scale garage (6.8 m x 5.4 m x 2.4 m). Helium was used as a surrogate gas, for safety concerns. The rate of helium released under an automobile was scaled to represent 5 kg of hydrogen released over 4 hours. A simple analytical model was developed concurrently to predict the natural and forced mixing and dispersion of a buoyant gas released in a partially enclosed compartment with vents at multiple levels. The model is based on determining the instantaneous compartment over-pressure that drives the flow through the vents and assumes that the helium released under the automobile mixes fully with the surrounding air. CFD simulations are performed to confirm the observed physical phenomena. Analytical model predictions for helium volume fraction during natural and forced ventilation were found to compare favorably with measured experimental data. The poster will describe parametric studies to understand the effect of release rates, vent size and location on the predicted helium volume fraction in the garage. Results demonstrate the applicability of the model to effectively and rapidly reduce the flammable concentration of hydrogen in a compartment through forced ventilation.
The propellant fire safety related to drilling loaded cartridges

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ABSTRACT

In order to obtain the ballistic properties of new gun propellants lots, it is required to test samples in the actual application. As is often the case in laboratory testing, references are used to assess that the testing equipment is in good working order. In the majority of cases, the reference ammunition is purchased already loaded in a cartridge that has a hole machined on the side to allow for the pressure measurement. When a new type of propellant has to be tested, it often occurs that the specification requires that the pressure hole be placed in a different location. Hence, it becomes necessary to have the capability to drill a new hole in the loaded reference cartridges if the testing performed is to fully satisfy the specification. The goal of this research is to determine under what operating conditions, if any, the drilling process could be done with a minimum risk of igniting the propellant contained within the cartridge.

In the present study, the risk associated with drilling a loaded 25 mm cartridge was analyzed. Given the data already available on the materials in question here (drill metal, cartridge metal, propellant) and a number studies that have been made on frictional heating, including some cases related to drilling, it was possible to conduct this study based on established principles. A semi-empirical method devised for this study was used to calculate the temperature of various parts of the system. The methodology applied involves a series of temperature measurements used to calibrate a finite element heat transfer model. The results show that very high temperatures are attained at the drill tip. Figure 1 shows the results obtained for a sample case. The product of this study is a list of specific steps that should be taken to minimize the fire hazard of this operation. It is also shown that using a worn drill is an unsafe practice.

KEYWORDS: Drilling, propellants, numerical modeling, tribology.

Figure 1: Calculated temperature profile (in Kelvin) in the cartridge (top half) and propellant bed (bottom half) after drilling for 10 seconds. Note that the x and y axis are physical dimensions in meters.
Lumped parameter numerical modeling of solid propellant gas flow through a nozzle

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ABSTRACT

Many applications that require very high pressures make use of propellants as gas generators. These applications are as diverse as the deployment of airbags during crashes in automobiles, guns and rocket launchers (such as the space shuttle boosters). The large gas pressures required and the very small times in which they are generated are the main reasons for choosing propellants in these applications. A major drawback with the use of propellants is the potential hazard of accidental fires and explosions in industrial settings. Venting is a concept which can be used in order to better design facilities and equipments for propellants fires. In a way similar to what is seen in the case of dust and gas explosions, it is also conceivable that small scale enclosures could be used to obtain venting correlations which would be useful in vent designs for propellant applications. Such an enclosure would consist of a small constant volume chamber where the combustion of the propellant takes place. This chamber would be connected to the exterior environment through a diaphragm with a given opening pressure. Following the diaphragm opening, the vent would act as nozzle discharging the gases.

The goal of this work is to design and test a lumped parameter model which calculates the transient gas flow properties during the venting of propellant combustion gases generated in a small scale vessel. Results obtained with the model in the case of a nitrocellulose based propellant are shown on Figure 1. The input parameters are the geometry of the system, the rate of gas generation and the thermodynamic properties of the propellant gases. It must be noted that since the opening of the diaphragm occurs before the end of the propellant burning phase, pressure is still being generated when the system begins to vent. The numerical simulation thus takes this into account when applying the conservation relations. To simplify the problem, the flow is assumed as isentropic and adiabatic (except for shockwaves, which are not isentropic). The results of this simulator shall ultimately be used in designing nozzles for different venting applications.

KEYWORDS: Venting, explosions, propellants, numerical modeling.

Figure 1: Pressure and temperature profile in the enclosure for a nitrocellulose based propellant.
An important part of life safety in the fire protection community where most research has been done over the past several decades focuses on the decent of occupants in high-rise stairwells during emergency situations. The current model most commonly used for determining occupant local speeds as a function of density is the hydraulic model presented by Steven Gwynne and Eric Rosenbaum in Section 3, Ch.13 of the 4th Edition of the SFPE Handbook of Fire Protection Engineering.

The authors state that the model “tends to an optimistic estimate of evacuation time” due to the simplicity of the model. In the hydraulic model, occupants are treated as fluid particles that are not distinguishable from one particle to the next. Therefore, differing behaviors of different occupants that are seen in live evacuations is not considered. Currently, a research project funded by NIST involves analyzing data collected in videos within the stairwells of multiple high-rise office buildings within the United States during predetermined fire drills. The intent of the research is to explore the behavior and movement characteristics of occupants as they descend the stairwell to the bottom floor.

Preliminary analyses of the data collected from the video footage and compiled on spreadsheets that give the raw enter and exit time of each occupant on each landing show the phenomenon of platooning. Platooning, or the grouping, of occupants during evacuations has been touched on very briefly by multiple sources within the fire protection community. Many researchers in the fire protection literature acknowledge that platooning does occur, but do not explore why it occurs or how to accurately define a “platoon.” There is also very little quantitative analysis on the subject of platoons in human movement. However, the concept of platoons in traffic flow theory within the civil engineering community gives quantitative models for tracking the movement of cars along a highway, and shows strikingly similar characteristics to human movement in high-rise stairwells.

A definition of “platoon” will be established to try and produce a quantitative model for local speeds and how high density and queues affect the speed and flow of groups of individuals within the high-rise stairwells. Currently platoon leaders are being identified and tracked based on the exit time gaps from one individual to the occupant in front of them. Hopefully, a useful trend can be found across the differing stairwells. The models used in traffic flow theory will be investigated and used as seen fit considering the amount of raw data that NIST has collected for each high-rise stairwell. Qualitative analysis of one of the buildings has shown certain behavioral characteristics that classify the start of a platoon (i.e. the identification of a platoon leader). The characteristics observed that constitute a platoon leader include, but are not limited to, the social interaction between one occupant to another, whether the individual is holding anything, the age of an occupant, and the aggressiveness of the individual.
Spontaneous Combustion of Linseed Oil Soaked Cotton

Justin Worden

(Submission #1054)

Image Caption or Poster Abstract

The topic I will be including on my poster will be the Investigation of Spontaneous Combustion of Linseed Oil Soaked Cotton. This research has been done to help find an easier way for investigators to better assess spontaneous ignition, the methodology in testing spontaneous material and ways to analyze the data. There are many ways to go about testing spontaneous material including calorimetry testing, flask testing, adiabatic storage, hot plate testing, etc. The specific method in which I have tested the linseed oil soaked cotton is called the standard oven test method. I used this method due to its quick and easy sample preparation and its universal application to most spontaneous materials.

There are also many ways to analyze the temperatures recorded from each of the tests with the typical way of analyzing the temperatures being the Frank kamenetskii Method. The method I decided to use is called the Crossing Point Method (CPM). The CPM is another shortcut that I tested to make it easier for investigators to test their specified spontaneous material. Opposed to the already established way of analyzing temperatures from the oven tests (Frank kamenetskii Method) the CPM makes analyzing easier by requiring less time and resources.

During the linseed oil soaked cotton testing there were three different sized stainless steel mesh baskets (5cm, 7.5cm and 10cm) used which would contain the linseed oil soaked cotton. For each test the dry cotton material was cut out into squares of a specific size then soaked to a specific concentration using two different methods. One method used was saturating the cotton then wringing it out through a set of rollers and the other method was spraying the linseed oil onto the cotton squares till the desired concentration was met. After this was done the linseed oil soaked squares were inserted into the steel mesh basket till the basket was filled to the top. While the sample was put together a thermocouple was inserted into the center so the center temperature could be recorded throughout the test. After the sample was prepared it was then hung in an already preheated forced convection oven and the temperature collection was started. After the sample had run its course the temperature collection was stopped, the remains of the sample were safely discarded and the temperature data was analyzed.

I'll show on my poster the procedure in which I prepared the samples, how I instrumented each sample and the oven I used, the safety precautions I implemented, the results of the CPM and other interesting findings including: what “ignition” of the sample looks like, how after ignition the sample goes to a state of smoldering and then possibly flaming, how Ignition times are affected by the size of the sample and how the time it takes to go from “ignition” to smolder is fairly consistent between oven temperatures.

Categories

Submission Category: Poster Abstract
Experimental study on the role of thermal feedback from different wall linings in a room fire

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Department of Civil Engineering, Technical University of Denmark, 2800 Kgs. Lyngby, Denmark.

Poster Abstract
Experiments with round heptane pool fires as the fuel source investigated the changes in burning behavior in a room with different wall linings and compared the results to free burn tests. The experiments were conducted in an ISO 9705 room corner test facility, where pools of different sizes were placed either in the middle of the room or under the hood. Two different non combustible lining materials with different thermal inertia were used in order to change the thermal feedback from the room to the pools without changing ventilation conditions.

The experimental results showed that the thermal feedback for the larger pools resulted in an initial increase of the heat release ending in a thermal runaway. A good correlation was found between lining temperatures and heat release rates before the thermal runaway occurred, irrespectively of the lining material. This correlation was not found after thermal runaway, as the increases of heat release rate per unit time were the same for both linings. The thermal runaway occurred at lower temperatures for the lower thermal inertia lining. The lowest onset room temperature for thermal runaway was found to be 350°C. As thermal runaway is a process associated with flashover, this onset temperature indicates that flashover related phenomena may happen at lower temperatures than what would normally be expected, especially for linings with low thermal inertia. These findings also indicate that it is important to keep the effect of the thermal feedback in mind not only when designing fire experiments, but also when the fire experiments are used as a basis for design fires decisions.

Keywords
Full scale enclosure fires, thermal runaway, thermal feedback, wall linings, heptane pool fire

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Water mist spray modeling - A OpenFOAM experience

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ABSTRACT

Water mist fire protection strategies are arousing considerable interest in recent years because of their high potential in fire control and suppression, but many phenomena, like ventilation, can reduce or enhance the effectiveness of those fire fighting systems.

The impact of a firefighting strategy against fire is often supported by numerical simulations. Expensive experiments can't provide anytime a full comprehensive parametric study to evaluate and compare the results of different solutions and, also with strong limitations, validated models can be effective in calculating temperatures, visibility and concentration of combustion products (requiring just a prescribed heat release rate curve) in order to verify the respect of certain safety criteria. The great number of independent variables describing the objective function needed to optimize the systems design (e.g. tunnel geometry, ventilation strategies, airflows, RSET - Required Safe Egress Time, etc..) is increased by the water sprays parameters (positions of the nozzles, flow rates, droplet sizes, etc..) and time consuming CFD simulations may be ineffective due to high computational costs.

This research work is focused on the development and validation of a numerical tool to simulate water mist transport and evaporation due to the presence of heat sources and natural - forced ventilation, in order to perform an effectiveness assessment of water mist fire strategies. As numerical toolbox we adopted OpenFOAM, because of its increasing popularity and open source philosophy, which allows us to modify standard solvers and easy integrate it with external tools like a network model in order to prescribe dynamic boundary conditions. After working with Lagrangian spray modeling we decided to switch to the Eulerian one, because of its advantages in getting good statistical averaged values among the domain of droplets concentration. The well known equations of the Eulerian-Eulerian two phase model are not yet completely implemented in the version 1.6 of OpenFOAM as the reference for this kind of solver is the twoPhaseEulerFoam application that has not an energy equation and evaporation model. We didn't considered combustion at all, since the tool has design purposes, and smoke is considered in this early stage as hot air.

The results of our simulations of water mist sprays with the Eulerian approach evidenced good agreements with experimental results. In order to compare simulation with evaporation we need to work on measurements of local flux and concentration whose are very challenging for PDA measurements. The introduction of a polydisperse description with a moments model which can be validated by PDA measurements in a controlled evaporating spray is also ongoing.

When the CFD tool will be validated for simple cases, then it will be coupled with the 1D network tool to try simulations of real scale scenarios (e.g. tunnel fire scenarios).
Study of Interaction of Entrained Coal Dust Particles in Lean Methane – Air Premixed Flames

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² Department of Mechanical Engineering, Indian Institute of Technology, Chennai, India

This study investigates the interaction of micron-sized coal particles entrained into a lean methane – air premixed flame. In a typical axisymmetric burner, coal particles are made to naturally entrain into a stream of the premixed reactants using an orifice plate setup. Pittsburgh seam coal dust, with typical particle sizes in the range of 63 to 90 µm, is used. In this setup, the rate of entrainment of the coal dust into the premixed reactant stream depends on the volumetric flow rate of the premixed reactants. The effects of coal dust at equivalence ratio (methane-air) of 0.77 and 0.85 are studied. The results show that the addition of coal dust in methane-air premixed flame enhances the burning velocity. Implications of this lab-scale study to the conditions observed in coal mines are also discussed.
Fire Effluents Analysis of Rigid Poly-Urethane Core Sandwich Panel by Fourier Transform Infrared Spectroscopy

Kaoru Wakatsuki*, Koji Masumura*, Tatsuya Nakaoka** and Yoshifumi Ohmiya**

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Foamed plastics such as poly-urethane and poly-styrene have been utilized for sustainable building design. Recently, the fires caused by foamed plastic core sandwich panels have been happened in cold storages and high-rise buildings in Asian countries. The fires were spread so fast that fire brigades do not have enough time to tackle the fire.

The objective of this study is to investigate the fire effluents produced by burning two types (Non-flame retardant and Flame-retardant) of rigid poly-urethane core steel surface sandwich panels by Fourier Transform Infrared Spectroscopy (FTIR). Two pieces of 0.9 m x 1.8 m (total 1.8 m x 1.8 m) the sandwich panels were jointed together by poly-vinyl-chloride (plasticized) joint assembly and hanged from the light weight steel beams shown in Fig 1. A 50 kW propane burner heated on the center of the joint and fire effluent was collected at 0.4 m from the edge of the panels and 0.01 cm underneath from the panel surface. The tests were conducted at the open space. ISO 19702 real-time fire effluents analysis was utilized to determine the quantitative measurement of CO, CO2, HCN, HCl, HCHO, NO2 and SO2 at every 20 seconds with 2 cm⁻¹ resolution and 15 scans.

At the beginning of the test, real-time infrared spectrum shows the peaks that hydrocarbon C-H stretching broad peak at 3000 cm⁻¹ and hydrogen-chloride sharp peaks had been observed which imply pyrolysis from poly-vinyl-chloride (plasticized) joint. As the time increased, the smoke got more volatilized fuel shown in Figure 2 (100 sec). Then the volatilized gas was ignited since the fuel might reach lower flammable limit. This process was observed by the chronological changes in the infrared spectra. Finally, the steel sheet metal was fallen down to the ground due to the loss of adhesion of the sheet metal to the core panels, then the volatilized gas released from the sandwich panel ignited and large fire spread in Fig 3. During the fire tests for both types rigid poly-urethane core sandwich panels, CO and CO2 were the main chemical species within the fire effluents. HCN from burning the poly-urethane had been assumed to detect, but not clearly, NO2 had been measured, instead. Since the fire test were open space and well-ventilated, this NO2 production was due to the oxidation of urethane structure within open fire.
Radiation Properties of Turbulent Multiphase Spray Flames and Laboratory Scale Investigations of Oil Well Blowout Fires

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Historical oil spill events, including the recent oil well blowout fire in the Gulf of Mexico, have taught us many lessons. One of the most profound but often overlooked insights is that offshore oil platform fire safety and structural integrity under large radiation heat loads differentiate an event from a disaster. Oil well blowout fires that are not effectively detected, controlled, and suppressed can lead to the collapse of an entire platform, uncontrollable oil spills, and human and environmental disasters of global significance. Effervescent atomization of high pressure two-phase hydrocarbons simulates the spray flames observed in oil well blowouts. The present work briefly reviews research relevant to oil well blowout fires and presents a laboratory scale effervescent atomization facility for the investigation of turbulent multiphase flames. Preliminary results of radiation and spray characterization are reported for a turbulent diesel spray flame.

Previous research has shown that reproduction of blowout flames in the laboratory is complicated by the multiphase flow of crude oil and natural gas. Loss of containment and expansion of the gases to atmospheric pressure results in atomization of the liquid fuels and the formation of fuel-rich spray flames. An effervescent atomizer is used to safely reproduce these conditions in the laboratory [1]. Research has demonstrated the effects of finite rate evaporation and differential transport between gas and liquid phases are important for high water loading in gaseous fuel flames [2].

A turbulent multiphase diesel flame atomized with methane and stabilized with hydrogen is studied in the present work. Planar time-dependent radiation intensity measurements of the spray flames are acquired using high speed visible and infrared cameras. Drop sizes, velocities, and spray patterns are measured using laser diffraction, laser Doppler anemometry, and optical pattern factor measurements, respectively. These data provide novel physical insights into the control of laboratory scale multiphase spray flames and oil well blowout fires.

Review of Theoretical Expressions for Laminar Burning Velocity of Particle-Air Flames

Authors: Scott R. Rockwell, Ali S. Rangwala

Abstract:

The objective of this study is to review the development of theories for computing the characteristics of laminar premixed particle-air flames. Unlike gaseous flames, where conduction, species diffusion, and chemical reaction are important processes, particle-laden flames such as coal-air systems involve additional processes such as devolatalization, particulate and gaseous radiation, and conduction between gaseous and particulate phases. Development of four theories by Cassel et al. [1], Seshadri et al. [2], Goroshin et al. [3] and Bidabadi and Rahbari [4] are presented. Each theory is applied to predict laminar burning velocity of coal dust particles with size range between 10 – 60 µm followed by a sensitivity analysis to analyse the controlling parameters. Comparison of predictions with measurements by Smoot and Horton[5] is also presented.

Utilization of Walkthru Fire Simulator
for Examining Evacuation Guiding Effect in Case of Fire.

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ABSTRACT
A walkthrough fire simulator with immersive audio and visual system have been developed for
studying capability of future engineering applications in fire safety research field. Two kinds of
experiment are conducted by using this simulator for examining evacuation guiding effect in case of
fire.

The first study is to study evacuation route finding in a subway station where real fire was occurred. A
virtual subway station of 3 floors under the ground was reconstructed and fire smoke behavior was
represented with CFD prediction. Under various conditions of lighting environment and exit signs, i.e.,
size and brightness, almost 40 subjects participate in experiments escaping from the 3rd basement floor
to the ground level individually as shown in Fig.1. All escape routes were logged as shown in Fig.2
and the guiding effect of exit signs is examined. The result shows larger size of exit sign in the dark
gives more guiding effect, and some escape route patterns determined by floor planning were observed.

The second study is to examine the effect of audio guidance both in real and virtual spaces. Highly
directional and ordinary type speakers are adopted for evaluating guiding effect. Even in a virtual
space, stereophonic environment are reproduced corresponding to experiments in real space.
Comparisons of experiments between real and virtual space are made. The result indicates that the
audio guiding effects can be estimated qualitatively, however further improvement of stereophonic
will be needed.

KEYWORDS: evacuation, simulator, exit sign, virtual reality

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Reality Technique Part 3.Experimental study of evacuation route finding in a subway station yard by using virtual reality
2) Abe Nobuyuki,Yamada Tokiyoshi, Suga Masaaki, "Evacuation Experiment by Using Audio Guidance in Virtual and Real
Space, Part1 and 2", Japan Association for Fire Science and Engineering Annual Symposium, pp.490-497, 2006 (in
Japanese).
Fire safety performance required for buildings are life safety, protection of fire effects to surroundings, prevention of fire outbreak and prevention of urban fires. For fire safety design of buildings, it is necessary to develop the evaluation methods for these performances. If a fire occurred in a building, fire safety measures installed in a building are expected to work effectively and timely. However, in case of failures or malfunctions of these fire safety measures in the buildings, public fire service will be expected to take the fire-fighting operation. So, the performance of supporting fire-fighting activities in buildings is important for fire safety design.

Supporting fire-fighting activities means that fire service personnel can work effectively and safely. It will be assured, if a building has following conditions.

a) Fire compartment which limited fire size
b) Fire-fighting base, such as vestibule of exit stairs, lobby of fire-fighting elevators
c) Access to fire-fighting base and fire-fighting area from the ground

The problem is how long these conditions are needed to perform well. For getting real situation in building fires, fire-fighting data related above conditions are analyzed by using the fire incident report data of 14 years during 1995-2008 in Japan.

The eight occupancy groups (apartment, restaurants, shops, hotels, factories, offices, storages, and mixed use) and over 34,000 fire incidents data were selected for the analysis. The average time from stating spray water to suppression is 16 - 34 minutes for the eight occupancy group. The 95 percent of fire incidents are less than 49 - 101 minutes of the time of suppression, and varied between each occupancy group. The distribution of the suppression time for apartments or offices is concentrated in shorter time. On the other hand, the distribution of the suppression time for factories or storages is wide and scattered. The suppression times are varied along total floor area of a building for some occupancy groups. For large factory buildings, the suppression times are prolonged proportionally.
An experimental study of upward flame spread over inclined fuels

M.J. Gollner, X. Huang, A.S. Rangwala and F.A. Williams

Recently, it was hypothesized that a modification in the heat-flux profile from an upwardly spreading flame to virgin surface ahead of the flame was responsible for a slower spread behavior than traditional theories predict, and that this was caused by protrusion of burnt material in the boundary layer of the flow (Gollner et al., Combustion and Flame, 2011). In order to further investigate the influence of variable heat-flux profiles ahead of the flame front, a variable-buoyancy apparatus (which can rotate around a central axis) has been developed that includes the ability to measure heat fluxes ahead of the flame front under different orientation angles (-90 to +90). Experimentally determined quantities that include heat flux in the combusting plume region, ratio of flame length to pyrolysis length, flame standoff distance, and mass loss rate are used to analyze the upward flame spread over inclined fuels to test and possibly extend this hypothesis.

The experimental apparatus constructed for this study held a sheet of SuperWool insulating board, 1.27 cm thick, 65 cm tall, and 25 cm wide mounted atop an aluminum sheet which could be rotated 360 degrees, measured with 1 degree accuracy by a magnetically mounted accelerometer. A 10 cm wide by 20 cm tall 1.27 cm thick slab of Acrylite GP (PMMA) was mounted flush with the surface of the insulating board 5 cm from the base of the insulating wall, providing a wide surface that limited side-entrainment effects. Above the sample, 11 thin-skin calorimeters made of 1.2 mm thick 304 stainless steel with K-type thermocouples spot-welded to the rear surface measured the total convective/radiative heat flux profile from the flame to the surface ahead of the flame. Seven K-type thermocouples were melted to the face of the PMMA sample to measure the progression of the pyrolysis front, the slope of which revealed average flame-spread rates for each test. These rates are shown and compared with previous literature in the figure. Error bars indicate deviation of the measured flame-spread rates fit for four tests that were run at each angle of inclination.
Advanced Detection System for Toxic Gases in Fire by using Terahertz Electromagnetic Waves

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ABSTRACT
In recent years, fire risk is drastically increasing along with the utilization of new space (high-rise and underground) and the utilization of new materials (mainly, aluminum and plastics) due to modernization, industrialization and energy conservation. The increasing of toxic gases generated by a fire, such as carbon monoxide (CO) and hydro cyanogen (HCN), is one of the serious problems for activities of fire fighters and evacuation.

A system that can detect toxic gases remotely and instantly must be extremely effective method for the fire safety. For this purpose, authors focus on a remote sensing system using terahertz (THz) electromagnetic waves. THz electromagnetic waves have a frequency region between light waves and millimeter waves. This gives them both the spatial resolution of light waves and the ability of millimeter waves to penetrate non-metallic material. In addition, THz waves resonate with the rotation or vibration of gas molecules, and since each toxic gas has its own characteristic absorption lines, the patterns of the lines obtained can be used to identify the types of toxic gases present. In other words, THz waves can be used to detect various gases included toxic gases in fire rooms and building from the outside, even if visibility in a room is very poor due to smoke contamination.

The full-scale fire experiments were carried out in a room with dimensions according to the ISO 9705 Room corner test, which is (D)3.6 x (W)2.4 x (H)2.4 m. The room has one opening of size (W)0.8 x (H)1.8 m for ventilation. The opening dimension was varied in order to make the conditions of ventilation controlled fire in the experiments. Polyurethane blocks which are used in upholstered furniture, nylon fabric and wooden crib were used as fire source. A remote spectroscopic sensing system having the unique characteristics of the THz electromagnetic waves developed by authors, which are longer in wavelength than infrared light so that they pass through soot and smoke, was investigated in this experiment.

As a result, for example, the absorption lines at 265, 355, and 444 gigahertz were observed in the combustion products (smoke) of polyurethane blocks. These absorption lines identical with those of HCN, and also the concentration (absorption intensity) of it agreed with it measured by a chemical analysis of the sampled gas. In addition, absorption lines of the water (vapor) generated by the combustion were also identified at 380 and 448 gigahertz.

The above interesting experimental data and effectiveness of the remote sensing system using THz electromagnetic waves will be shown in this poster.

KEYWORDS: Terahertz Electromagnetic Waves, Remote Sensing System, Toxic Gases, Full-scale Fire Experiment, Absorption Lines

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The prediction of the ceiling-jet spreading and its conditions in the building spaces having large floor area is important for the estimating the detection response and the evacuation route designs. In this study, the ceiling-jet smoke spread model by Alpert is extended to adapt to the unsteady prediction for the ceiling-jet in a large building space. Using of the steady model by Alpert, the velocity, the temperature and the average thickness of the ceiling-jet could be predicted reasonably only in the steady condition after spending several minutes from ignition of a fire with almost constant heat release rate.

In this model these values of the ceiling-jet can be calculated transiently by the unsteady analytic approach. Besides histories of the temperature and the thickness, the smoke spread area (the distance of the front) can be obtained. The governing equations were revised to unsteady. The convective heat transfer to the ceiling and the temperature rise within the ceiling by the conductive heat transfer were considered. The calculation domain is divided into multiple control volumes by the vertical concentric circles boundaries whose center axis is on the fire source (Fig.1.). Then the velocity of each boundary and the gas temperature and the volume of each smoke layer are computed by difference method, considering the influence of the heat loss into the ceiling and the dilution by the air entrainment.

For verification of this approach, the comparison of the predictions was presented against measurements of smoke spread experiment using a large building space (Fig.2.). The predicted the profiles of the gas temperature, the smoke depths and the distances that the smoke reached were almost agreement (Fig.3-5). However the load of this calculation is absolutely light and it needs a few seconds in most cases. Then it is considered as a practical and useful tool for researchers and designers of fire safety.
A FATAL FIRE INCIDENT EVER EXPERIENCED IN BANGLADESH: Scientific Investigation of the Effect of Illegal Storage of Chemicals at the Residential Area in Bangladesh

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Bangladesh experienced the most fatal fire incident at Nimtoli in old Dhaka on 03 June, 2010. There were two stages within the fire. At the first stage, the fire ignited from the illegal chemical storage (50-52 tons) due to the continuous emission of heat from the open stove situated just beside the wall of the chemical storage and spread very rapidly. The fire ball leapt up to around 60 meter high and then rained downed on the surrounding houses. And at the second stage, the roaring fire soon raced through the neighborhoods setting the 08 buildings, 01 biscuit factory and 16 stores ablaze turning the crammed congested area on a narrow street. The fire caused totally the death of 125 and injury of 40 victims.

The main purpose of this study was to (1) determine the chemicals at the first stage which had a major adverse effect on the fatality (2) investigate the major critical characteristics of the chemicals against temperature and (3) understand how the fire ignited and spread.

Four kinds of stored chemicals expected to be the explosive substances at the fire site i.e. Dicumyl peroxide, Dinitrosopentamethylenetetramine, Rubber (Black) and Carbon Black. All these chemicals along with the burnt ashes were experimented using the Thermogravimetry-Differential Thermal Analysis (TG-DTA) and Differential Scanning Calorimetry (DSC).

The result shows that in Dicumyl peroxide at 88° C, the weight loss is very high and sharp and at 172° C, the heat flow is at sharp peak. In Dinitrosopentamethylenetetramine at 105° C, the weight loss is very high and sharp and at 156° C, the heat flow is at sharp peak. In Rubber (Black) at 188° C, the weight loss is very high and sharp and at 433° C, the heat flow is at sharp peak. In Carbon Black at 405° C, the weight loss is very high and sharp and at 433° C, the heat flow is at sharp peak. From the physical survey, interviewing and gathered data (National Investigation Report & Fire Service & Civil Defence Report), the thermal exposure by continuous emission of heat transfer through the wall, generated by the open stove, was the key factor. From the thermal analysis, Dicumyl peroxide and Dinitrosopentamethylenetetramine which react at the temperature at around 100° C and have possible blowing substances.

Investigation was also done by Attenuated Total Reflection (ATR) method of Infrared Spectroscopy comparing the materials found from the fire site and pure material supplied by a chemical company and the spectral data disclosed at the National Institute of Advanced Industrial Science and Technology (AIST), Japan. Characteristics band peaks of the all materials by ATR method were the same, although the one at the fire site shows an additional peak which implies impurity of the materials.

Authors acknowledge to National Research Institute of Fire and Disaster (NRIFD), Japan, especially to Mr. Y. Ogawa for infrared spectroscopy measurements.
Assessment of vulnerability to fire in the wildland-urban interface  
Application to the Mediterranean region of southern France

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Poster abstract

In the Mediterranean region of southern France, fires may burn large areas and have major ecological, social and economic consequences. Many large fires are linked to the land use changes that have taken place in the Mediterranean Region in recent decades, which have generally increased the likelihood of fire spread and the severity of fire impacts. On the one hand, the area under flammable vegetation is increasing due to abandonment of agricultural land and subsequent colonisation by vegetation, and on the other hand, existing forests and woodlands are not sufficiently used, both of which result in increased accumulation of fuels. In addition, urbanization combined with forest extension results in new spatial configurations of the wildland-urban interface. The WUI is of key significance in fire management: in Mediterranean Europe 90% of fire ignitions are related to human activities in the WUI. Our research focuses on fire vulnerability and the input key is the Wildland-Urban Interface. The WUI intrinsically carries synthetic information on risk/assets/vulnerability, and allows a direct and global evaluation of the risk, with a holistic method. Our objectives are to develop a global fire risk assessment approach for WUIs and to contribute to reduce forest fire risk in these areas. Our project has three main stages. We firstly develop a spatially explicit database of the damages due to fire on dwellings and their surrounding vegetation; here, we take both physical impacts and social response to fire into account. In the second phase we develop methods for the characterization and mapping of the damage caused by fire as a function of their intensity and the type of interface. The third phase consists of the modeling of fire risks using the field observation of damage to dwellings and vegetation, in order to feed the model of global risk. With this research we aim to contribute to better risk assessment for houses in the wildland-urban interface and more generally to better management of fire-prone environments in southern Europe.

Keywords

vulnerability; wildland-urban interface; spatial analysis; wildland fire; fire risk; fire impacts; social response
Investigation on Life Style of Elderly People Living Alone in Japan and its Influence to Residential Fire

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Elderly people in Japan, particularly who live alone, have the high risk to be involved in the fire. In fact, fire death of elderly people (65-year-old or more) in Japan occupies about 61% (628 people) of total fire death in 2009. This number was increased by 5.4% relative to the one in 1999. Fire death due to the electrical appliances is one key in elderly people in winter. The objective of this study is to research on the characteristic of fire death on Japanese elderly peoples living alone and investigation of fire behavior based on their living circumstances in winter.

Living circumstances of Japanese elderly people who live alone was investigated. They spend their daily life at a restricted space in a small room (about 15m²/room) with many materials including clothing, electric appliances and others. In addition, they tend to keep the old materials in the small room. Since the storage space is very limited in Japanese housing, this characteristic implies that the fire load in a room becomes higher. Especially in electrical appliances, elderly people tend to use familiar ones until it becomes dead. Therefore, elderly people in Japan have high risk both in terms of initiating the fire and making flashover fire within their small room once the fire started.

Characteristic of elderly people’s death is described by the response and function of the body. Due to the disadvantage in terms of decision making at initial stage of fire, delay of starting egress make injury or fatality. Smoke alarm is the one of the factor to help the notice of the fire, but decision making and egress are not good enough relative to young people. Focusing in winter season, they wash clothes and dry them hanging above the heating appliances or dry within a Kotatsu, which is one of Japanese traditional low tables with an electric heater underneath and covered by a quilt, and dry them inside. Touching the clothes and linens to the heater often makes serious fire.

Fire test on the Kotatsu and a typical elderly people living room were conducted to understand how fire starts from the Kotatsu and propagates within the room. Temperature measurement and thermal imaging in Kotatsu were conducted to see how fire propagates within the Kotatsu. It took 31 min to transition from smoldering to the flaming. Also heat release rate of Kotatsu with clothes and linens were also measured using the furniture calorimeter and max. 250 kW. For room fire test (about 12 m² floor area), all lining materials were gypsum board except flooring, but flame spread was so fast once fire came out from Kotatsu and ignited hanging clothes on the wall. In this experiment, we found that fire propagated so fast in case of typical Japanese elderly people room in winter once fire starts since fire load in the small room is so high. Kotatsu is the first item to start the fire, but other materials also control the fire.
The possibility for wood-based products to reach the new European K classes for Fire protection ability has been studied. The main aim with the K classes is to demonstrate that inner layers, e.g., combustible insulation products in a wall or ceiling construction are protected from being ignited during a specified time period (10-60 minutes).

The K classes have not earlier been possible to reach for ordinary wood-based products. The K classes originate from the Nordic countries, where they have been used mainly for gypsum plasterboards, since the Nordic criteria also included reaction-to-fire requirements. However, in the European system, only fire resistance criteria prevail, so this is a great opportunity for wood products to demonstrate their fire protection abilities.

The goal is to demonstrate that wood-based products fulfill the criteria for all three levels, K 10, K 30 and 60. Products included are different wood-based panels as particleboard, plywood, OSB, hardboard and solid wood panels (cross laminated wood panels) and ordinary solid wood panelling and cladding.

The K classes are based on fire resistance testing at horizontal orientation according to EN 14135. The main parameter is the temperature behind the panel after different time intervals (10, 30 and 60 minutes). Charring on the substrate, fall down, collapse or failure of the covering is also observed. Two types of K classes are defined depending on the substrate behind. Class $K_1$ 10 includes substrates with density less than 300 kg/m$^3$, while classes $K_2$ 10 - $K_2$ 60 includes all substrates, so in practice $K_2$ classes should be sufficient for wood-based panels.

The results demonstrate that $K_2$ 10 has been obtained for the wood-based panels included (particleboard, plywood, OSB, solid wood panels and hardboard) at thicknesses 9-13 mm and for 15 mm solid wood panelling and cladding with tongue and groove joints. Class $K_2$ 30 has been verified for plywood and SWP at thicknesses 24-26 mm and for solid wood panelling and cladding at 27 mm thickness with tongue and groove joints. Data for Class $K_2$ 60 will be included in the full poster.
Experimental Study on the Effectiveness of RIP Cigarettes to Fire Ignition

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There has been an increasing concern on the effectiveness of reduced ignition propensity (RIP) cigarettes in mitigating fire ignition potential worldwide. And, some countries like the USA, Canada, Finland, and Australia have recently started the restriction of distribution of conventional cigarettes other than RIP cigarettes. It is obvious that RIP cigarettes may have lower possibility of the chance of fire ignition due to the mechanism by its speed bump to stop the propagation of combustion in certain conditions like the RIP cigarette test. On the other hand, the question is how the characteristics of RIP cigarettes have the practical performance in reducing fire ignition potential in real condition of the living context in Japan.

In order to examine the effectiveness of RIP cigarettes in the context of fire situation in Japan, we started the experimental study to compare the ignition potential of the two types of RIP cigarette (RIP1 and RIP2) with conventional cigarettes using ‘futon’ (the traditional style of Japanese bedding), assuming smoking in bed.

The experimental model of futon smoldering with a cigarette as an ignition source (see Fig.1) was used reflecting the following three aspects, which Japanese Fire statistics shows; (1) futon is the major first material ignited; (2) a dropping or discarding cigarette is the main process in smoking-material related fires; and (3) CO poisoning is the largest cause of fire death. In such kind of futon smoldering model, it is known that continuous smoldering rarely occurs, when a lit cigarette is simply put on the futon without covering it. By contrast, stable smoldering can be seen when a cigarette is held between two futons.

Accordingly, a lit cigarette was put on the futon and then covered by another futon. After a certain period of time elapsed, whether or not the cigarette smoldering propagated to the futon was confirmed by visual judgment. In order to help the judgment, temperature together with mass loss was monitored in real time using thermocouples placed between the cigarette and the lower futon, and an electronic balance.

While the futon consisting of 100% cotton cover and 100% cotton batting was smoldered by the conventional, RIP1 and RIP2 cigarettes in 5, 5, and 4 out of each 5 trials respectively, that of 100% cotton cover and 50/50 polyester cotton blend batting was smoldered by the conventional, RIP1 and RIP2 cigarettes in 0, 0, 0 out of each 5 trials respectively. As far as the results from the experiments that we have done to date show, the difference in smoldering propagation from the cigarette to Japanese futon was detected depending more on the bedding material in futon rather than on the cigarette propensity. We found the bedding material and its condition of placement around a lit cigarette would be more contributing factors of smoldering occurrence on futon at least under this experimental model. Since there is a wide variety of other condition on actual residential fires in Japan, it is required to have further study under other conditions or experimental models in order to find out the effectiveness of RIP cigarette. The experimental results and the discussion will be presented in more detail at the poster presentation.

KEYWORDS: reduced ignition propensity cigarette, RIP cigarette, fire ignition, residential fire, smoldering, fire death, fire statistics
Calculation of the Heat Release Rate from Oxygen Consumption in the Cone Calorimeter using the Controlled-atmosphere box

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ABSTRACT
A way to calculate the rate of heat release for tests with a commercially available vitiated air attachment for the Cone Calorimeter operating under ISO 5660 is presented in this work. Especially effects of dilution by excess air, which are strongly given from the equipment configuration, and the influence of reduced oxygen volume fraction in the gas supply are considered.

KEYWORDS: heat release rate, oxygen consumption, controlled-atmosphere cone calorimeter, vitiated-air burning, dilution by excess air

INTRODUCTION
While retaining all the accepted and advantageous precision and reproducibility of the Cone Calorimeter operating under ISO 5660-1 a vitiated air enclosure can modify the standard apparatus in a way that allows performing tests under non-ambient conditions to control the variables ventilation, vitiation and radiation [1]. These variables mostly affect relevant fire properties used to assess thermal and non-thermal fire hazard [2].

METHOD / CALCULATION
A commercially available vitiated air attachment which is combined with the Cone Calorimeter is used to modify the standard apparatus in the aforementioned way [3]. The attachment is placed below the standard Cone Calorimeter exhaust hood so that the exhaust gases leaving the enclosure and entrained air from surroundings are collected. The entrained air is an excess air, which is not involved in the combustion.

Due to the additional air inflow from the laboratory the exhaust gases leaving the enclosure are diluted during their transport to the measurement unit. Assuming the exhaust gases as primary volume-flow, laboratory flow is a secondary one. Hence and as a consequence of thermal expansion of the exhaust gases the additional flow is not constant but varies with test-time. This causes a deviation in the determination of the oxygen intake during the test compared to the initial conditions: The oxygen intake-concentration $X_{O_2}^0$ which is normally determined prior to the test as oxygen baseline $X_{O_2}^0$ is not constant, too. Rather, the effective intake-flow should be considered as a time-dependent variable. The equation concerning this is given by:

$$X_{O_2} = X_{O_2}^0 \frac{\dot{m}_{e}}{\dot{m}_{e}} - 0.2095 \left( \frac{\dot{m}_{e}}{\dot{m}_{e}} - 1 \right)$$

(Eq. 1)

CONCLUSION
The conventional Cone Calorimeter procedure assumes a constant oxygen intake-mass-flow which is determined prior to the test in order to calculate the heat release rate by oxygen consumed. However, the application to this conventional approach and the use of the known equations to the reported Cone Calorimeter Vitiated Air Attachment as an open flow-system results in a significant overestimation-failure in case of reduced oxygen volume fraction in the gas supply to the attachment. Correcting the pre-experimental oxygen-intake for each time step by Eq. 1 provides an estimation of heat release rate taking varying dilution effects into account.

So it is recommended to calculate rate of heat release in consideration of Eq. 1 when using the reported vitiated air enclosure.

REFERENCES
Investigations on the Detectability of Fire Accelerants after different Fire Scenarios in the Cone Calorimeter

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ABSTRACT
Investigations on the detectability of three fire accelerants are presented in this work. The fire accelerants were applied on particle board, spruce wood and carpet and exposed to different scenarios in the Cone Calorimeter afterwards. Three different sample digestion methods were used prior to the chemical analysis of the samples with GC-MS (gas chromatography coupled with mass spectrometer). The detectability of the fire accelerator depending on the fire scenario is shown.

KEYWORDS: forensics, fire investigation, fire accelerator, chemical analysis

INTRODUCTION
Chemical analysis of fire debris is a common method in fire investigations. The aim of these analyses is the detection of fire accelerants to provide evidence in case of suspected arson. But the influence of the fire scenario on the detectability of fire accelerants is not well examined. Examinations that deal with this subject are mostly focused on the analytical method and work with less hard fire scenarios.

The examined specimens were particle board, spruce wood and carpet. The fire accelerants used were spirit, gasoline and diesel fuel.

METHOD
The fire scenarios were realized with the Cone Calorimeter (ISO 5660-1). The Cone Calorimeter was supplemented with a vitiated air enclosure (commercially available from FTT) that was fed with synthetic air. The fire accelerants (max. five milliliters) were applied with an injection on the specimen surface through a closable opening in the enclosure's side panel straight before the opening of the shutter. In some cases the specimens were saturated for 30 seconds in the fire accelerant instead of applying it with the injection. The specimens with the fire accelerant were exposed to heat fluxes of 25 and 50 kW/m² for five, ten and 15 minutes.

Samples of the exposed specimens were put into vials after the test. The gas phase in the vials was extracted with the passive headspace technique and with solid phase microextraction (SPME). Afterwards the gas phase was analyzed in order to verify the fire accelerant with gas chromatography coupled with a mass spectrometer.

RESULTS
The detection of any fire accelerant after a test duration of ten minutes only succeeded with particle board and SPME. No fire accelerant on any specimen was assuredly detectable after 15 minutes of exposure. It was not possible to detect all marker compounds for a positive confirmation within sufficient intensity.

Only diesel fuel and gasoline in combination with particle board were detectable after tests at 50 kW/m². The headspace method only succeeded at five-minute-tests with gasoline and diesel fuel on particle board. The detectability of fire accelerants seems to depend more on the burnt material than on the fire scenario in this examination.
To prevent extensive damage in car parks in case of fire, a horizontal ventilation system is usually installed. This system extracts hot smoke from one of the sides of the car park, to (partly) clear the car park from smoke and to limit smoke temperatures in the car park.

For tunnels, formulae have been developed for critical velocity. The critical velocity is the minimal velocity required to maintain all the smoke in the downstream direction of the fire (Figure 1). In tunnels, the critical velocity is usually defined as an inlet velocity, of cold air into the tunnel.

Car parks, however, have quite a different width to height aspect ratio, compared to tunnels. While in tunnels the width and height are usually in the same order of magnitude, and much smaller than the length ($w \approx h < l$), in car parks the height is much smaller than width and length ($h < w \approx l$) (Figure 2). Thus, it can be questioned if formulae that were developed for tunnels can also be used for car parks.

Furthermore, in car parks, usually some backlayering is allowed. That means that smoke is allowed to travel in the upward direction of the ventilation flow, for a specified distance. For example, Belgian and European standards allow 15 m of backlayering, as this is the distance required for firemen to be able to extinguish the fire.

Other than in tunnels, where cold air is pushed into the tunnel as means of ventilation, in car parks hot smoke is usually extracted with the ventilation system. As the density of this hot extracted smoke is lower than that of cold entering air, the extraction ventilation velocity will be higher than the incoming cold air velocity, according to conservation of mass. It is important to account for this difference in the design of the ventilation system.

Because of the three above explained differences between car park and tunnel ventilation (aspect ratio – backlayering – extraction ventilation system), a complete study is performed with Computational Fluid Dynamics. These CFD-simulations will be regarded as “numerical experiments”. In the study, a large number of simulations are performed, in which four parameters of the car park are varied: the convective fire heat release rate per unit area ($\dot{q}_{\text{conv}}''$), the fire source area ($A_f$), the car park height ($h$) and the car park width ($w$).

Postprocessing of all these simulations results in
- a correlation between the critical inlet velocity in the car park ($v_{cr,in}$) and the four parameters,
- a correlation to account for the difference between inlet ($v_{in}$) and outlet ($v_{out}$) velocity in the car park, derived from simple fire dynamics theory and confirmed with simulation results and
- a correlation for the required ventilation velocity in the car park when a certain backlayering distance ($d$) is allowed.
Mathematical Model for Popularization of Residential Smoke Alarms

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How we spread residential smoke alarms is one of important measures in prevention of residential house fire. Recently, existing house in Japan has obligation to installing residential smoke alarms in a bedroom and stairs mainly, we think this spread is effective to decrease residential house fire. According to some researches, this installing rate are increasing gradually (Fire and Disaster Management Agency in Japan said that the average of installing rate is 63.6% at Dec. 2010 in Japan), but some areas are late to installing residential smoke alarms. From such a background, this study examines following two purposes to find effective strategies in these late areas.

1. We use the method of marketing researches (or operations research).
2. We examine a personal attribute and choice factor about installing residential smoke alarms and calculate mathematical model about this.

At first, \( n(t) \) is the ratio of the house which has already installed residential smoke alarms at time \( t \). In addition, We assume that a price of residential smoke alarms is \( x \) [yen] per one house and owners feel \( v_i(x) \) as certain utility of setting residential smoke alarms. And we suppose that the choice motivation of installing residential smoke alarms has some kind of unpredictable random factors and we consider this choice as "The Random Utility Theory". Concretely, We use a logit model that have Gumbel distribution as utility of probability \( u_i = v_i(x) + \varepsilon \). So probability of residential choice of installing residential smoke alarms \( p(x) \) shown following equations.

\[
p(x) = 1/(1 + \exp[-v_i(x)]) \quad (1)
\]

But a resident doesn't install Smoke Alarms immediately even if he has intention to install the Smoke Alarms. In many cases, it is natural to need a period of some months or some years during this process. Therefore, we call a resident having intention to install the Smoke Alarms "a potential purchaser of Smoke Alarms". And I refer to Author's past research and consider an arrival of opportunity to purchase this as Poisson arrival (arrival rate is \( \lambda \)). So the ratio of the house which has installed Smoke Alarms at time \( t \) is shown following differential equations. This is the Diffusion Model for residential smoke alarms.

\[
dn(t)/dt = \lambda(p(x) - n(t)) = \lambda(1/(1 + \exp[-v_i(x)]) - n(t)) \quad (2)
\]

We calculated setting rates using by Japanese real data about the diffusion models briefly, So this setting rate will change shown in Figure 1. The calculated results and the discussion will be presented in more detail at the poster presentation.

REFERENCES:
CFD parameter variation study for smoke extraction in small-scale atria

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Atria have become an increasingly popular type of architectural structure, e.g. in shopping malls, hotels or office buildings. A smoke and heat exhaust ventilation system (SHEVS) can be very effective in case of fire, to ensure safety for occupants, firemen and building structures. One of the most important criteria in the design of these SHEV systems is the smoke free height in the atrium. This smoke free height is the result of a number of other parameters that can be varied in the atrium. The onset of a large CFD parameter variation study is discussed here.

As a starting point, we use the data of the experiments carried out by Poreh et al. [1]. In this configuration, the fire is in a room adjacent to the atrium (Figure 1). Four different heat release rates of the fire ($Q$) were studied. For every heat release rate, the extraction mass flow rate at the top of the atrium ($M(z)$) was varied, resulting in different smoke free heights above the spill edge ($z_s$) in the atrium. From extrapolation of the experiments, a formula was proposed.

The first step in the research is to confirm that the CFD-results provide good agreement with the experiments. Simulations were carried out with FDS (Fire Dynamics Simulator, version 5.2.5). The CFD-results show little deviation from each other and from the experiments. After ensuring qualitatively good CFD-results are obtained, a parameter study is performed.

The first varied parameter is the imposed extraction mass flow rate at the top of the atrium. The outlet velocity is varied to exceed the experimentally studied extraction mass flow rates, which were up till about 0.2 kg/s.

From a certain value of mass flow rate on, the smoke layer starts to become multi-dimensional in the atrium, e.g. the interface height changes with x-position in the atrium. As long as the smoke layer is one-dimensional, the simulation results agree well with the experimentally derived formula. (Figure 2) However, from $M(z) = 0.32$ kg/s onwards, the results start to deviate from the equation. From this point on, the smoke layer interface height does no longer increase with increasing extraction mass flow rate.

Another varied parameter is the position of smoke extraction opening in the atrium ceiling. The smoke layer interface results for the centre and right-hand-side opening are in very good agreement with each other. When the left-hand-side opening is present, however, the smoke layer interface height keeps on increasing with increasing extraction mass flow rate, in good agreement with the equation from the experiments (Figure 3). From 0.4 kg/s on, the smoke layer interface remains at a constant height of about 3 m, equal to the height of the atrium.

Submission for Poster Section of the 10\textsuperscript{th} IAFSS Symposium

Title: Fire Engineering Design for Shanghai Expo UK Pavilion

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UK Pavilion for Shanghai World Expo 2010 ‘Seed Cathedral’ is designed a box-like structure, pierced by thousands of slender acrylic rods placed in a contoured landscape and sway in the breeze from the river. The architectural design of the Seed Cathedral comprising several decades of thousands of acrylic spikes imposes a great challenge for both structural and fire engineers. As a result, Ramboll Safe developed a bespoke fire engineered solution based on fire data and theories which are supported by a series of small scale fire testing and a full scale water mist system fire testing in order to provide the required fire protection to life safety and property protection for the Seed Cathedral.

In terms of fire safety the two main concerns for the Seed Cathedral are, life safety of occupants inside the Seed Cathedral and property protection. This combination of the time box and the acrylic spikes construction is the first public building in the world where highly combustible construction materials are used. First principle of fire analysis applied published data and theories to demonstrate that the fire development of acrylic would not affect escape from the Seed Cathedral. Ramboll Safe proposed and designed four types of fire tests specific for the project which are: ignitability of the acrylic spikes; surface spread of flame along the acrylic spikes at different orientations and smouldering dripping; fire spread between the acrylic spikes – effects of flame height and dripping and fire suppression performance of water mist system on full-scale partial mock-up fire tests.

The last series of the fire test are also the most important tests which required knowledge of hands on fire testing experience and understanding the advantages of using water mist method to demonstrate effectiveness of water mist fire suppression system to extinguish a fire in an outdoor environment. A bespoke high pressure water mist fire suppression system, incorporating a fire detection system, is installed in both the external and internal faces of the Seed Cathedral.
Chemical analysis of scorch marks during smouldering of spruce wood - Fire debris, particles and smoke gas composition

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Wood is a typical component of homes equipment. If a fire is sparked in homes, the emanating smoke spreads rapidly and large quantities of toxic smoke gases are produced. The assessment of smoke emission and composition is essential for safety in flats and other facilities. The most common cause of fire is in the field of electricity, but also arson is very common with a share of 15%. The assessment of scorch marks or fire accelerants and the reconstruction of the fire development are based on the precise chemical analysis of combustion products. In this work an innovative methodology was developed to combine available analysis techniques in order to draw conclusions from the fire process with the help of solid, liquid and gaseous fire residues.

The specimens with additional accelerants (benzine, spirit, etc) were exposed to an ignition source in a closed test chamber (SDC, according to DIN EN ISO 5659-2) to perform different fire debris of spruce wood specimens. A mobile FTIR-spectrometer was directly coupled with the chamber, which offers the advantage to measure components of gases continuously. In addition to the gas components the resulting particles were investigated according to their particle size distribution during the smouldering in the Smoke Density Chamber using Engine Exhaust Particle Sizer (EEPS) and Laser Counter (LC). The burned spruce wood samples were extracted in different solvents (toluol, etc.) using the Accelerated Solvent Extraction (ASE) method. The extracts were evaporated and analysed by gas chromatography coupled with mass spectrometry (GC-MS) in order to detect substances, like polycyclic aromatic hydrocarbons, PAHs. Furthermore, the fire residues were investigated by Headspace- and SPME (Solid-phase microextraction)-GC-MS analysis in order to detect low concentrations of volatile components of the fire accelerants.

The smoke evolution (transmission, specific optical density), mass loss and the qualitative and quantitative smoke gas compositions showed differences regarding the varied conditions during smouldering (irradiance, irradiation time, additional flame, kind of wood and the use of a fire accelerator). But the influence of the kind and the amount of additional fire accelerants to the smoke evolution and the smoke gas composition are barely detectable and only cause a small time shift in emission.

The particle number size distribution and the particle number concentration vary with the conditions during the smouldering experiments with or without additional flaming. While two particle modes at 190 nm and 80 nm were produced during smouldering without flame, only smaller particles at 34 nm were formed during smouldering with an additional flame. In contrast to the experiments without additional flaming, there are fewer and smaller particles during the smouldering with additional flame. Furthermore, there was no formation of agglomerates.

Fire debris analyses during the fire scenario smouldering was realised with different extraction techniques and GC-MS analysis. The detection of fire accelerants and typical fire markers in the fire debris can be achieved. The volatile substances could be detected with a developed SPME method and Headspace-GC-MS analysis. The evidence of fire accelerants is critically dependent on the sampling technique, the storage conditions and especially the storage time. In this study the impact of these parameters and also the fire parameters like irradiance, irradiation time, smouldering with and without additional flame, oxygen availability, kind and amount of additional fire accelerants on wood samples during smouldering will be presented.

KEYWORDS: fire investigation, fire chemistry, smouldering, fire debris, smoke gas, particle
Opacimetry and visibility through water mists in laboratory conditions and real scale fire tests

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Abstract. Water mists are well known to be good solutions for firefighting. Aside the benefit taken from an improved droplet evaporation ability, they present interesting shielding properties against thermal radiation. This has been long explained through absorption and scattering phenomena. However, this desired ability to attenuate infrared radiation when fighting against fires, might become a problem for visibility concerns in the visible range when safe escape of people is sought or when firefighters want to go closer to the fire area. The question is: how much a water mist can penalize the visibility because of the direct interaction of water droplets with visible light on the one hand, and because droplet injection also modifies the smoke dynamics, possibly resulting in a destratification of smokes on the other hand.

In order to investigate this problem, a numerical study simulating a water curtain in interaction with radiation, from the infrared up to the visible range, has been carried out. In the visible range, water properties result in a very weak absorption, whereas scattering effects are very strong. It has been computed thanks to the Mie theory for the evaluation of the mist radiative properties, combined with a Monte Carlo method for the radiative flux evaluation. In parallel, opacimeters have been built combining a laser diode (emitting radiation at 635 nm) for the source and a photodiode for the detection of the transmitted signal. At laboratory scale, without fire and using low flow rate nozzles, these opacimeters have been tested, calibrated and comparisons have been done with numerical simulations. A quantification of light attenuation has been done and a classical analysis has been conducted in order to evaluate the mist properties without smoke entrainment effects. Then, the same opacimeters have been used in real scale fire tests. Located on given horizontal and vertical lines, they have produced experimental data on the loss of visibility during the step of fire development and after the activation of the nozzles. In the same time, visualisation of dedicated test patterns through visible camera have been registered, giving a complementary information on visibility and contrast decrease.

The poster will include a short description of the involved devices, a physical explanation of the involved phenomena and an analysis in terms of opacimetry, visibility and contrast characteristics.
Case study of a BLEVE in a single containment LNG-tank.

BLEVE (Boiling Liquid Expanding Vapor Explosion) is a rare occurrence for LNG (liquefied Natural Gas) tanks. When BLEVE occurs it is usually related to transportation. The API (American Petroleum Industry) standard indicates that, a BLEVE is not likely to happen in LNG tanks with single containment. Since 1993 there have been 4 cases were BLEVE has been reported, all in transportation with vehicles.

This poster will present results of calculations related to the effect of placing a vehicle fire next to a LNG fueling stations in an area with high population density. The case is simulated using FDS to get the fire temperatures and heat load on the LNG tank. The result from the FDS simulations was then imported into Argos to analyze the heat transfer to the tank.

According to the simulations it will take approximately 21 hours before the LNG will start to heat. This showed that a BLEVE could not occur if the fire strain that gave a surface temperature of 600°C, see Figure 1 average value multiply by a safety factor of 1.3, did not last for 21 hours. After 21 hours the temperature within the tank will start to increase. When LNG tanks are placed in areas with high population density, it is very important to avoid a BLEVE. Within the 21 hours period it should be possible to extinguish the fire, cool the tank or evacuate the population.

This scenario maybe confirmed whit analyzes in COMSOL 4.1 and furthered simulations in FDS and Argos.

This work will prepare the builders of LNG fueling stations to avoid big scale accident. The LNG industry is growing world vide, since it does not require pipeline to all facility. In Norway the pipeline network are small and the population are spread. Fueling stations must be placed were people live, like the gas stations are placed today.

Reference:
FDS
Argos®
"Risikovurdering av gassfyllestasjon i tettbygd strøk.” (2010), Kolstad, Haugan

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Simulation of Smoke Entrainment to Compartments through Small Openings

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Smoke entrainment through small openings is important when studying smoke spread. For example smoke spread between compartments can be important in fire safety design of buildings. Another issue is the investigation of detection times of smoke detectors in voids or attic spaces. Smoke detectors in cold attics on one-story buildings are sometimes used in Swedish buildings to detect exterior fires. The smoke from an exterior fire spreads into the attic space thorough ventilation openings on the buildings eaves. A couple of full-scale experiments have been conducted in Sweden, which demonstrates that smoke detectors in attic spaces can give a shorter detection time than heat detection cables placed on the façade. No tools are however available to design these types of smoke detection systems. Computational fluid dynamics (CFD) might be used for this purpose.

A set of small-scale experiments has been conducted at Lund University. Smoke entrainment to a small space has been studied in these experiments. A 1,5 meter high wall was constructed and a box was placed on of the top of the wall. Openings were made on the bottom of the box, which meant that smoke could spread into the box. Simulations were conducted with the Fire Dynamics Simulator (FDS) before the experiments were conducted to get a priori estimates.

Heptane and propane were used as fuel in the experiments. Several experiments were conducted where fire source, fire size and ventilation openings were varied. Each experiment was done twice. The obscuration was measured in the box with a laser system and the flow out of the box was measured with bi-directional probes.

The a priori estimates made with FDS could predict the conditions in the box to some extent. After modification of the input files to FDS better results could be obtained form the simulations. The experiments yield in recommendations on how to simulates entrainment of smoke though small openings. These recommendations could be used to look at the previous described problem with smoke detection on attics.
A correlation for predicting smoke layer temperature in a room adjacent to a room involved in a pre-flashover fire

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Advanced computer modelling software, that can predict smoke spread and compartment temperatures, have been developed during the last decades. With two-zone and computational fluid dynamics (CFD) software it is possible to e.g. calculate smoke layer heights, species and temperatures in a multi-room geometry. The programs are generally good tools for fire engineering purposes, but they have however not removed the need for simple engineering correlations. Simple correlations can be used for hand-calculations to get a first estimate of for example a smoke layer temperatures in an analytic fire safety design of a building. The result of a hand-calculation can e.g. help an engineer to determine if it is necessary to perform a detailed CFD calculation.

Correlations that predict compartment temperatures for single room enclosures dates back to the early eighties and are still used for different purposes by fire engineers. However there are few correlations when it comes to predicting temperatures outside the room of fire origin. This is something that for example can be useful when evaluating conditions for evacuees in a room (escape way) next to the room of fire origin.

Problems with elevated temperatures in adjacent rooms have been raised in an ongoing research project at Lund University. A simple two-zone steady state model, using equations for conservation of heat and mass, was created in Matlab to study a two-room configuration. The created Matlab script randomly selected geometries (width, depth, height and opening sizes) of the two rooms as well as fire size in the fire room. Hundreds of simulations of different two-room configuration could be simulated. The results from the simulations yielded that there is a reasonable correlation between geometrical parameters, heat release rate and the smoke layer temperature in an adjacent room.

To test the correlation a CFD model (FDS) was also used. Input files to FDS, with randomly sized two-room configurations, were again created with a Matlab script. Approximately 140 FDS files were simulations with different heat release rates on the Lund cluster. The correlation from the two-zone simulations represented the results from the FDS simulations reasonable. A better fit to the FDS results was however found when some constants in the correlation formulae were changed.

The correlation was later tested against results from full-scale tests both found in literature and conducted within the project. There was a good fit between experimental data and the correlation. The formulae can therefore be used when rough engineering calculations need to be done in fire performance based designs.
Comparative Evaluation of Prescriptive, Performance-Based and Risk-Based Fire Safety in an Office Building

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One of the major motivations for introducing performance-based design in Denmark was that it would reduce the building costs compared to that of prescriptive designs, while retaining the same safety level. The safety level of a building is determined by the ratio ASET/RSET. The Danish fire safety regulations predominately address occupant safety and define an adequate safety level for a performance-based design as one in which the ASET exceeds the RSET (also for single system failures).

It has been observed that when applying a performance-based analysis on a prescriptive design, it does not meet the acceptance criteria. This is mainly due to the fact that a performance-based analysis must include scenarios with single system failures. These failure scenarios must provide the same safety level as the non-failure scenarios. As a result of this more fire installations are needed which will then in turn increase the building costs. If this hypothesis holds the performance-based legislation will have failed one of its key success criteria.

In order to perform a cost-benefit analysis of the fire safety design, performance-based and risk-based methods were applied to a generic three-storey office building with an open plan layout and a centrally placed atrium. The basic fire safety design was made according to the prescriptive part of the Danish fire legislation.

As ASET must exceed RSET in a performance-based design, there is no acceptance for untenable conditions, as determined by criteria for heat flux, temperature, visibility and smoke layer height. The criteria for a risk-based approach are not well-defined, and therefore, the same criteria as in the performance-based were used. In the risk-based design safety levels below one can be accepted as long as the probability is deemed low enough to compensate for it.

In the performance-based study, plausible severe scenarios including system failures were analyzed using FDS and the level of safety was evaluated.

In the risk-based approach the effects of simultaneous failures of fire installations were considered along with distributions of fire growth rates, fire sizes, occupants and location of the fire. Thousands of scenarios were analyzed by simple two-zone calculations, and the input for each scenario was sampled from probability distributions by the use of Monte Carlo simulations. A curve containing the cumulative probability vs. the number of people exposed to critical conditions was compared to a risk profile in order to evaluate the fire safety design.

The preliminary results of the investigation show, that the prescriptive design will not meet the requirements of the performance-based design as a direct result of including the scenarios with single system failures on equal terms with the non-failure scenarios. However, in the risk-based analysis the prescriptive design meets the acceptance curve. As a result the prescriptive approach, which has been used for decades, is validated. The validation is only true as long as the probability of failure is taken into account, and that a given risk-level for scenarios resulting in occupants exposed to critical, or even deadly, conditions is accepted.

Another conclusion of the study is that in order for risk-based design to gain acceptance in Denmark there is a need for a risk-profile, which is accepted and approved by both society and legislative parties. The development of such a risk-profile merits further study.
EXPERIMENTAL DETERMINATION OF MIEs OF PROPANE/(AIR + N₂) AND ETYLENE/(AIR + N₂) MIXTURES

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The primary goal of the present investigation is to produce experimental data for the minimum ignition energies (MIE) of premixed propane resp. ethylene and mixtures of air and various proportions of additional nitrogen. It has not been possible to trace any published experimental MIE data for propane resp. ethylene in such mixtures. If it can be shown that adding comparatively modest fractions of nitrogen to the air raises MIEs to values larger than the equivalent spark energy of typical brush discharges, dilution of explosive IIA and IIB atmospheres by nitrogen may present a means of eliminating the brush discharge ignition hazard. It is then important, however, that the required fractions of added nitrogen will not be so large as to produce any suffocation risk.

Lewis and von Elbe [2] presented some MIE data for a variety of premixed fuels and oxygen/nitrogen mixtures of ratios larger than that of air. By cautious extrapolation these may indicate trends for MIEs in the range of smaller oxygen/nitrogen ratios than that of air.

The present MIE determinations are performed by means of a standard ASTM MIE test apparatus (Fig. 1), combined with the Moorhouse method for data analysis, as described by Eckhoff, Ngo and Olsen [1]. It is expected that by the time of a possible poster presentation a series of experimental data for propane and ethylene in oxygen/nitrogen mixtures down to an oxygen/nitrogen volume ratio of about 0.17 will be available.

As illustrated in Fig. 2, taken from Freytag [3], any explosive gas mixture exhibits a specific minimum distance between the electric-spark electrodes in MIE experiments, below which the measured minimum spark energy for ignition raises significantly above the true MIE. With glass flanges on the electrode tips, as also illustrated in Fig. 2, the increase of the required spark energy for ignition becomes very abrupt. As discussed by Kuchta [4], when considering MIEs for various gas mixtures, there is a strong correlation between this minimum electrode separation distance for optimal ignition, named the quenching distance, and the actual MIE. Therefore, in the case of large MIEs, the distance between the spark electrodes has to be correspondingly large to avoid quenching and erratic MIE measurements. Then very high voltages may be needed for inducing breakdown of the electrode gap, which is required for obtaining a spark discharge. When using thin needle-point electrodes, the quenching effect can be reduced. In the present investigation these challenges are addressed.

Fig. 1. Photo from top of the explosion vessel used in the present investigation, showing the spark electrode gap with glass flanges

Fig. 2. Minimum capacitive electrical spark energies for ignition of a stoichiometric mixture of a natural gas and air, as a function of the length of the gap between the spark electrodes, with and without glass flanges on the electrode tips

Effects of Individual Behavior on Egress Speeds on Stairs
By: Bryan Hoskins and James Milke University of Maryland

Previous studies of high-rise building evacuations have focused on total evacuation times and average movement speeds based primarily on density. With some computer models now allowing individual characteristics during the simulations, data is needed that will enable a better understanding of how individuals interact with each other and the physical environment.

A current research project is using data from high-rise building evacuation drills to accomplish this. The goal of the research is to identify the characteristics that determine the localized movement speed of individuals as they descend stairs and to provide a better understanding of how individuals use stairs during evacuations.

In this project, the speeds of individuals are calculated over a few floors (rather than the entire building) in order to account for changes in the velocity (and other variables) as an individual descends. Many variables, including density, have been found to vary from one observation of a given individual to the next observation. Variables of interest include those that arise from interactions with the building, interactions with other occupants, characteristics of the individuals, and choices made by the individual.

Preliminary analysis of these variables indicates that certain behaviors follow definitive patterns. Individuals are not behaving as lone particles randomly distributed within the population. Instead, there are dynamic interactions taking place in a regular manner. Using these patterns, occupants can be placed into groups within the larger collection of individuals that are evacuating. Furthermore, there are certain behavioral norms that seem to be adopted by many individuals.

Multiple regression modeling is then used to determine which variables are significant in determining individual movement speeds and whether there are any significant interactions based on different levels of the variables.

This poster will highlight preliminary findings from one building in the study. Variables from all of the different classifications are found to be significant in predicting individual movement speeds. The inclusion of the other variables, aside from only density as has been done in previous studies, increases the accuracy of the predicted speeds.
Flame Behaviors in Small-scale Explosion with Localized Instability Development after Vent Activation

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ABSTRACT

Pressure relief devices such as rupture disk are intended to mitigate hazards caused by overpressure at gas explosion in enclosure. However, after the first pressure peak observed at the activation of a pressure relief device, the second or multiple pressure peaks which often yield excess pressures follow the first pressure peak. Then, pressure histories for venting explosion with and without the vent cover have been studied extensively and several mechanisms that control flame behaviors have been proposed. Nevertheless, the details of the flame front behavior are very complicated depending on many factors. In our recent studies1,2, to study basic physical features of venting explosion process accompanied by a second pressure peak achieved under simplified conditions, flame behaviors and pressure variations have been examined for a small cubic explosion vessel filled with uniform propane-air mixture with using high-speed schlieren video, and it has been shown that the evolution of the second pressure peak is readily produced for a certain range of rich mixture with appropriate ignition locations and that the second pressure peak with apparent excess pressure follows the flame-front instability development starting after the vent activation by rupture. The observed flame instabilities are featured by the combination of developments of fine-scale stripe-shaped or cellular-type wrinkled flame structure and large-scale cellular flame structure that is convex toward the unburned mixture located opposite to the vent. The fine structure was considered to be yielded by the Rayleigh-Tayor instability mechanisms driven by acoustic oscillation normal to the local averaged flame front. The dominant oscillation mode may gradually changes from early Helmholtz type oscillation to resonance type oscillation around the second peak. However, in those studies, the relation between the developments of the fine structures and the large structure has not been apparent. In the present study, for the sake of understanding of the relation between these structure developments, behaviors of propagating flame with weakly developing flame instability toward the weak second peak, which are observed at the conditions close to the lean limit concentration for the occurrence of second pressure peak with larger vent diameters, were examined in detail from high speed schlieren video records. After the establishment of fine wrinkling structures over the flame front which appeared following the first pressure peak continued for a little, the structures once disappeared widely and localized fine wrinkling structure regions were left. It was shown that the large scale convex cellular structure tends to appear from relatively dense stripe/cell region, and the diameter of the large cell increases with producing more protruding shape. The fine stripes on the large cell surface have often concentric ring structure, and the distance between adjacent rings increases with the growth of the large cell size. The fine stripes/cells located at the central region of the large cell are apt to become spiky structure. The region of fine cellular structure on the large cell structure repeats disappearance and appearance locally with relatively short interval. It is interesting that the newly appeared fine stripes/cells have the similar sizes corresponding to those just after the first pressure peak. After a while, the fine scale region area finally spreads widely and it leads to the increase of whole flame area within a short time producing resumption of pressure increase toward the second pressure peak. From the present study, it can be inferred that the developments of the fine flame front structure and the large scale front structure have close interactions. Further studies of the mechanisms of these interactions will be useful to elucidate the flame instability development toward strong second pressure peak observed widely.

References


An experimental study on blast wave from a gas explosion by using soap-bubble method

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Abstract

To understand the consequence of accidental gas explosions in an open space, the flame propagation behavior and the intensity of blast wave during a gas explosion of homogeneous premixed combustible gas (methane/air) in an open space have been measured simultaneously by using soap bubble method. The results show that the overpressure in lean mixtures increases accelerantly by the flame wrinkling which is considered to be generated by diffusive-thermal instability ((a) in Fig.1, \( L_{\text{eff}} < 1 \)). On the other hand, the overpressure in rich mixture grew linearly with time in the early stage and accelerated in the later stage. The accelerating increase of the overpressure in the later stage of rich mixtures might be induced by the generation of the flame front turbulence ((b) in Fig.1), which is considered to be generated by the non-uniform mixing with the surrounding air at the sudden rupture of the soap bubble. The overpressure can be predicted by the acoustic theory if the real burning velocity could be known. The theory indicates that the intensity of blast wave is affected by burning velocity, volumetric expansion ratio and the flame acceleration. The intensity of the blast wave tends to increase accelerantly by the flame acceleration by the flame wrinkling. The flame wrinkling observed in this study is generated spontaneously by flame front instabilities. It is elucidated that the flame front instabilities have significant effects on the intensity of the blast wave.

![Figure 1. Comparison between measured overpressure of methane/air mixtures and predicted one calculated by the acoustic theory, and variation of effective Lewis number \( L_{\text{eff}} \).](image)

- \( \phi = 0.9 \)
- \( t = 46\text{ms} \)
- \( \phi = 1.3 \)
- \( t = 118\text{ms} \)
- \( \phi = \frac{\text{burning velocity of existing literature}}{\text{measured burning velocity}} \)
- \( t = \text{time from ignition} \)
Experimental results for validation of CFD codes
– Evaluation of alternative measurement techniques for room fire experiments

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Joakim Bood, Billy Kaldvée, Malin Jonsson, Christian Brackmann, Lund University, Dept of combustion physics, Sweden

Use of CFD (computational fluid dynamics) software packages within fire safety engineering is increasing substantially. As a result of this more stringent requirements are put on the validation and verification of these models. CFD models give the possibility to calculate in detail the temperature distribution in e.g. a room as you obtain the variables for each cell. In turn, this puts requirements on the validation by means of experiments. Today’s techniques are limited to single point measurement e.g. by thermocouples or bi-directional probes. In order to obtain 1D, 2D or even 3D profiles of temperature and flow distribution (e.g. turbulence), introduction and development of new measuring techniques are necessary. Some data is available from Brown et al (2008) but more effort in this area is strongly needed. The objective of the experiments is twofold. One objective is to investigate the feasibility of advanced laser measuring techniques for use in room fire experiments. Another objective is to provide detailed measurement data for a room fire experiment, which can be used for validation of CFD codes.

An experimental series, which often is used for validation of CFD codes, is described by Steckler, Quintiere and Rinkinen (1982). During the experiments the temperature in the corner of the room and in the opening was measured with thermocouples. Also, the gas velocity was measured with bi-directional probes. Both these measurement techniques are associated with limitations. For example, the radiation effect on the temperature measurement with thermocouples can be significant and the bi-directional probes are sensitive to the direction of the flow. Moreover the fixing of the thermocouples and probes can disturb the flow pattern.

For the present project a similar room was built based on the dimensions of ISO9705 but at ½ scale. In the experiments, traditional measurements of flow speed and temperature in the opening were taken as in the Steckler experiments. In addition, measurements with new techniques such as LIDAR, CARS are made. The measurements should produce at least 1D profiles of the velocity and/or temperature at steady state, i.e., when the temperature profile inside the walls is linear. The achievement of steady state was controlled with thermocouples at the exterior surfaces of the walls and ceiling. A fuel that does not generate large amounts of smoke and soot was used in the experiment, i.e., methane and methanol. The results of the first series of experiments with LIDAR is presented and discussed.

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An Experimental Study of the Influence of Particle Size Distribution in Flame Inhibitors on Flame Propagation

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Abstract
Explosions and fires involving flammable gases and vapors pose a great danger in the process industries [1]. It is therefore devoted a great effort to minimize the risk of such scenarios. This is done either by reducing the likelihood or reducing the consequences. In this project the effect of a new consequence reducing measure for vapour explosions, flame inhibitors [2], is studied experimentally.

The influence of particle size distribution in inhibitor powder on the flame propagation is studied in a 20-liter explosion vessel. A burning velocity can be calculated from the experimental data obtained in the vessel [3]. An explosive premixed propane/air mixture is first ignited without inhibitor, and a reference value for the burning velocity is calculated. Then an inhibitor powder is added to the propane/air mixture from a pressurized reservoir and ignited.

The powder particle size distribution and concentration are varied and the effect on the burning velocity is studied. At least two different flame inhibitor powders will be tested.


Quantifying differences between computational results and measurements in the case of a large-scale well-confined ventilated fire scenario using ANSYS CFX

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Use of CFD (computational fluid dynamics) software packages within fire performance based engineering and risk assessment is increasing substantially. An important part in the process is the quality assurance. This work is a part of a larger effort [1] to quantify comparisons between several computational results and measurements performed during a pool fire scenario in a well-confined compartment with forced ventilation. Fires in enclosures equipped with forced (or mechanical) ventilation remain one of the key issues for fire safety assessment in the nuclear industry. The ventilation system ensures confinement by setting an appropriate pressure cascade. The scenario of a fire in a confined and ventilated enclosure is a typical hazard during which the pressure may vary to an extent where it modifies the confinement levels and hence the safety of the installation. An understanding of the mechanisms leading to pressure variations during a fire scenario is of prime interest. Few validation efforts have been done up to now.

The experimental scenario was conducted at the French “Institut de Radioprotection et de Sûreté Nucléaire” (IRSN). The quantitative comparisons between measurements and numerical results obtained from “open” calculations concerns six important quantities from a safety viewpoint: gas temperature, oxygen concentration, wall temperature, total heat flux, compartment pressure and ventilation flow rate during the whole fire duration.

The collaborative work was initiated under the framework of the OECD fire research program and involves the most frequently used fire models in the fire community, including field and zone models. Most of the software packages used in the published paper [1] are non-commercial and mostly used for scientific or specific in-house purposes. But there are also commercial software packages capable of performing fire and smoke spread modelling. One of these is ANSYS CFX, which has been the focus of this particular work. ANSYS CFX software is a high-performance, general purpose fluid dynamics program that has been applied to solve wide-ranging fluid flow problems for over 20 years [2].

The purpose of this work is to compare the experimental data and the numerical results from the fire test using ANSYS CFX. The results will also be compared against the non-commercial codes used in the project to evaluate the pros and cons with using commercial software, especially for this type of scenarios where ventilation and the confinement play an important role.

References

1. L. Audouin et al., Quantifying differences between computational results and measurements in the case of a large-scale well-confined fire scenario, Nuclear Engineering and Design, Volume 241, Issue 1, January 2011, Pages 18-31.

The fracture energy based material model for the uniaxial behaviour of reinforced concrete was extended to elevated temperatures in order to tackle the problem of localization of deformations associated with the post-peak stress-strain relation of reinforced concrete. Four current compressive models formed the basis for the new model, of which two solely considers the instantaneous stress-related strain and two includes the effects of the LITS (Load Induced Thermal Strain). It was established that the current compressive elevated temperature models does not agree on the post-peak behaviour and that the LITS does not seem to have an effect on the post-peak response.

The new mesh independent material model enables a higher fidelity in the structural fire safety assessment of structures. It accounts for the tension stiffening effect, which gradually shifts the load-bearing capacity from the concrete to the reinforcement as the cracking progresses, by defining an element size dependent interaction stress contribution that is combined with the concrete contribution for the definition of the post-peak behaviour.

Prior to extending the existing ambient condition models, an evaluation of the models was performed and it was found necessary to express limits for the application range of the new model. It was already well established that a limit on the maximum element size existed; however, we have also found restrictions on the minimum element size and, if modelling the tension stiffening through the definition of an interaction stress contribution, on the minimum admissible level of the reinforcement. Though these limitations enabled the extension to elevated temperatures, it is still only possible to obtain meaningful result within a very limited range of mesh-sizes for an analysis of concrete temperatures above 500ºC. Further, as experimental data is currently not available on the evolution of the compressive and the tensile fracture energy with temperature, the fracture energies inherent in the existing elevated temperature models were utilized.

This novel model for the uniaxial behaviours of reinforced concrete at elevated temperatures can readily be applied for FE-analysis, for example in ABAQUS, and, if the modelling is performed within the limits of application, it is possible to get mesh independent results of the analysis with different mesh configurations. As the new model circumvents the convergence problems arising in FE (Finite Element) analysis due to deformation localization problems, it enables more accurate and realistic modelling of concrete behaviour at elevated temperatures. As such, the new model can be a useful design tool in preventing disasters in concrete structures that are exposed to a thermal load, such as nuclear facilities or structures exposed to a fire.
PREDICTING FULL-SCALE FIRE TEST RESULTS
OF POLYURETHANE FOAM USING CONE
CALORIMETER DATA

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Understanding the fire behaviour of polyurethane foam and products that contain this material, such as mattresses and upholstered furniture, is very important to industry, fire protection engineers, regulators and the fire service. A number of full-scale fire tests are used to evaluate the fire behaviour of products that contain polyurethane foam, including open flame tests of mattresses in Canada (CAN/ULC-S137) and the United States (16 CFR Part 1633). Small-scale tests, such as the cone calorimeter, are also used to evaluate these products. As full-scale fire tests are expensive, and there are limited test facilities, there is a need to develop methods to reliably scale cone calorimeter test data to predict full-scale fire test results.

There are a number of methods that have been proposed to scale cone calorimeter results. The CBUF (Combustion Behaviour of Upholstered Furniture) project, a research initiative involving over 50 European Scientists from nine countries, developed a number of such models including both correlations and physics based models. Some predict peak heat release rates whereas others attempt to predict the time dependant HRR curve. In this research project, the convolution integral model developed during the CBUF project is used. This model assumes that the heat release rate curve can be predicted as the convolution of the area burning rate in the full scale specimen and time-dependant heat release rate data from a cone calorimeter test of a representative specimen.

The full scale fire tests modeled in this research were conducted on specimens ranging in thickness from approximately 2.5 cm to 10 cm and ranging in size from 60 cm by 62 cm to 125 cm by 122 cm. Specimens were ignited either in the center or on one edge, and combustion data was collected using a furniture calorimeter. The cone calorimeter tests used as input to the convolution integral model were conducted on smaller specimens of the same foam. To examine the influence of cone calorimeter incident heat flux setting on measured heat release rates, cone calorimeter testing of polyurethane foams was conducted at heat flux levels of 25 kW/m², 35 kW/m², 50 kW/m² and 75 kW/m². One of the issues addressed in this research is the ability of this model to predict HRR for foams of different thickness. Another issue addressed is whether the model adequately simulates all of the fire behaviour found in full scale tests of polyurethane foam, including three-dimensional heat transfer and flame spread, and pool fire behaviour.

In this poster, full-scale heat release rates predicted using the convolution integral model will be compared to the furniture calorimeter test results. Predictions made using cone calorimeter HRR density data from tests with different incident heat fluxes will also be compared. Possible modifications to the convolution integral model, which would help to better simulate fire behaviour of polyurethane foam in full-scale tests, will also be described.
Analysis of the error between prediction and reality generated by model complexity: Application to solid ignition

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The ignition of solid samples exposed to an external radiative source has been an area of active research for several decades. A better understanding of the physical and chemical mechanisms responsible for ignition helps to develop models able to predict the pyrolysis behaviour of a solid up to ignition. Torero [1] provides a review of the current state-of-the-art concerning solid ignition.

Every model includes approximations and/or simplifications which are the consequence of the extent of current knowledge, of the available resources (human or computational), of the mathematical techniques to solve the problems and of the level of accuracy required. As the complexity $C$ of a model increases by adding mechanisms, the error $\varepsilon$, defined as the difference between the prediction and the reality, should decrease as shown in Fig. 1a.

Every model requires input parameters and the accuracy of the prediction is a direct function of the knowledge of the values of these parameters. As the complexity of a model increases, the number of input parameters is multiplied, thus the error due to the inaccurate assessment of parameter values is further compounded and increases correspondingly (see Fig. 1b).

The global error is a combination of both lacks of knowledge: description of the mechanisms and prescribed value of input parameters. Inclusion of new mechanisms will not systematically be synonymous with improvements in prediction. However, for a fixed complexity, experiments are essential to obtain the actual value of the input parameters and reduce the error (Fig. 1c). The design and the analysis of these experiments should be assigned to a particular model since the different assumptions or simplifications between models can generate strong disparities between input parameters with identical names.

Finally, current experimental techniques and associated uncertainties define a limit of accuracy which implies that the global error cannot be lower than a certain level as shown by the opaque area in Fig. 1d.

This concept is presented and applied with a synthetic set of experimental data extracted from tests carried out by Kashiwagi and Ohlemiller [2]. For different level of complexity, the semi-virtual material, corresponding to PolyMethylMethAcrylate (PMMA), is used to assess the influence of both lacks of knowledge: description of the mechanisms and prescribed value of input parameters.

References:

Abstract

Fire safety measures in High Speed Passenger Trains have been focused on preventing the beginning of the fire or delaying its growth and its spread, through small-scale tests of its materials. However, new Fire Safety approaches to deal with fire problems in trains consider a systemic approach. This approach globally takes into account the numerous factors that influence on the fire dynamic, such as the influence of the vehicle design, the selection of the materials and installed active and passive systems.

In the present paper, Full Scale Tests were carried out in a specially adapted passenger train. The Tests represented interior design conditions in a 112 series railcar. This newly built train series is similar to the 102 series train currently in operation that has been manufactured by Talgo/Bombardier consortium. The various construction parts and furniture were arranged over the train body, similar to those in the vehicle operation, in order to have materials that are present in the vehicle.

The results of both types of tests (Small and Full Scale) will be presented for the new generation of high speed trains working in Spain. The materials results of the small scale tests and full scale tests confirmed the good fire behavior of both kinds of approaches. Additionally, an analysis of the quality of different kinds of materials was performed and the influence of the position of the ignition source in the fire development will be presented.

KEYWORDS: CFD, modeling, fluid dynamics, neural network.
Observation of extinction of oil pan fire by foam agent using a high-speed video camera

Heptane was burned in oil pans. Cross section of a pan was 0.9 m in width by 0.9 m in depth. Number of oil pans changed up to eight. Foam agent was applied to extinguish heptane fire. Activity of extinction was done by firefighters. Extinction phenomena by foam agent application were observed using a high-speed video camera with a telephoto lens and analysed. Small bubbles penetrated flames, dropped on the surface of burning heptane, and covered the surface. Foam agent applied to the water surface was also observed using a high-speed video camera with a telephoto lens and compared. Size of bubbles dropping on the burning heptane surface was much smaller than that on the water surface.
Possibilities of Fire Computer Dynamics using Neural Networks

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Abstract

During past years, a major development of the Fire Computer Modeling has taken place, and its employment in the study of the Fire Safety, fire investigation, etc. has increased. The two most important types of Fire Computer Models are the Field Model and the Zone Model. The first one reaches a better approximation to fire dynamics, but the second one needs less computational time. Additionally, it should be noted that in past years a great step forward has been taken in data processing, using artificial neural networks and it has become a useful tool with application in very diverse fields.

The present study examines the possibilities of using artificial neural networks in fire computer models. In the first approach to this objective we try to achieve similar results that in field models, reducing the computer time required performing the simulation. In this case a General Regression Neural Network was employed, and its training simulations in the FDS field model were conducted with 4640 simulations.

In this study two output parameters, upper layer temperature and layer height, has been taken into account. These two parameters are crucial for quantifying the level of sustainability of human life in a fire. And it has also been considered like input parameter, the dimensions of the enclosure containing the ignition source defined by its position in the room and its heat release rate per unit area (HRRPUA) and the ambient temperature in the enclosure.

Finally, the model has been tested against FDS, CFAST, and it has been validated against a full scale test. The results were successful in all cases and the accuracy was very close to the field model. In later stages other phenomena will be assessed and different types of networks will be analyzed.

KEYWORDS: CFD, modeling, fluid dynamics, neural network.
Effectiveness of Coatings and Wrapping Systems for Structural Fire Protection in the Wildland Urban Interface

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Abstract:

Wildland fires that occur in the Wildland Urban Interface (WUI) cause significant property loss and threat to firefighters and citizens lives. It is in the interest of federal, state, agencies and affected communities to explore alternative methods to protect these communities. Intumescent coatings and composite wraps are two promising Passive Fire Protection (PFP) systems for WUI structure fire protection. Existing fire testing methods for evaluating the fire performance of coatings and wraps are developed for building interior finishing applications and are based on evaluating the flame spread and smoke generation properties. The main objective of PFP in WUI fire areas is to provide a reasonable level of exterior wildfire exposure protection. There is a lack of systematic study to evaluate the effectiveness of fire protection from PFP systems such as coatings and wraps.

The goal of this research is to provide technical basis for developing testing methods to evaluate the effectiveness of coatings/wraps types of PFP systems to be used for WUI structure fire protection. The goal is achieved through measuring basic fire reaction properties which includes Temperature, Time to Ignition (TTI), Heat Release Rate (HRR), Mass Loss (ML) and Mass Loss Rate (MLR). The study consists of three major phases: Bench-scale testing by a Cone Calorimeter, Intermediate-scale Calorimeter (ICAL) testing and Full-scale validation testing (outdoor tests). Phase I is material selection, where 10 types of coatings and 7 types of wraps were tested at 25, 65 and 85KW/m² heat flux levels. Using Phase I fire performance data, 5 coatings and 4 wraps were selected for Phase II ICAL testing. 44 ICAL tests were conducted with 25, 35 and 45KW/m² heat flux. Four materials (two coatings and two wraps) with best fire protection capabilities will be evaluated through outdoor full-scale fire testing. Results for this study are from Cone and ICAL tests.

Our Cone and ICAL tests show that TTI is the most important factor for evaluation coating materials as a PFP system for WUI structure fire protection. Mass Loss and Mass Loss Rate and the insulation/shielding effect measured by Temperature can be used as secondary performance criteria. Wraps can greatly improve the structure’s resistance to ignition. A structure protected by aluminumized wraps did not ignite after 30 minutes at 85KW/m² on a Cone. However, to properly evaluate wraps’ fire performance, the most important factor should be the insulation and shielding effects measured by the front surface temperature history and the wrap/structure interface temperature history. Mass Loss and Mass Loss Rate can be used as secondary performance criteria to evaluate the effectiveness of warps as PFP systems for WUI structure fire protection.
SPILL AND BURNING BEHAVIOR OF FLAMMABLE LIQUIDS

Matthew Benfer and James Quintiere

(Submission #1097)

Image Caption or Poster Abstract

At present there is no model developed for an unconfined liquid spill fire and which addresses heat losses to the spill substrate. The objective of this work was to determine the spill and burning behavior of unconfined flammable liquid spill fires. This was accomplished experimentally with spills of both flammable and nonflammable liquids in addition to flammable liquid spill fires. Unconfined liquid spill thicknesses were found to be less than 0.1 cm in all fuels and liquids with similar physical properties as the fuels used. Average burning rates for spill fires increased linearly with increasing volume spilled. A liquid spill thickness model was developed and compared to experimental data. Comparisons showed good predictions for half of the liquids used. A liquid spill fire burning rate model was also developed and compared to experimental data. Accuracy of this model could not be determined with precision due to the methods of collecting the experimental data.

Categories

Submission Category: Poster Abstract
INFLUENCE OF IGNITION ENERGY AND FUEL CONCENTRATION ON TURBULENT FLAME PROPAGATION IN PROPANE-AIR MIXTURES AND DUST-AIR SUSPENSIONS

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Abstract

Detailed modelling of industrial dust and gas explosions from first principles is a formidable task, and current methods for mitigating the effects of industrial explosions therefore rely on simplified empirical correlations [1-2]. The aim of the present work is to generate data for model validation through an experimental study of turbulent flame propagation in a 3.6 metre long flame acceleration tube. The tube consists of three equal sections, 1.2 m each, and internal cross-section 0.27 m × 0.27 m. There are six windows along the length of the tube, 0.6 meters apart, and the first/last window 0.3 meters from the end of the tube. Two types of combustible mixtures are investigated: propane-air mixtures and mechanical suspensions of maize starch and air. The tests described here are performed with initial turbulence generated by injecting air from three two-litre pressurized reservoirs. For solid fuels, air from the high-pressure reservoirs disperses the dust in three 0.9-litre pre-dispersion chambers, before the dust is injected into the vessel through specially designed pepper-pot nozzles. For gaseous fuels, the explosive mixture is prepared by evacuating the tube, adding gas while monitoring the pressure, and injecting pressurized air in the same way as for dust explosions. The ignition source is an electric spark from a high voltage coil, or a 1 kJ chemical igniter, positioned 0.3 m from one end of the tube. The ignition delay is 1 second from onset of dispersion. The pressure development in the reservoirs and inside the tube is recorded with Kistler 701A piezoelectric pressure transducers and Kistler 5011 Charge Amplifiers. A Phantom v210 digital high-speed video camera and ten temperature probes measure flame propagation along the tube. The temperature probes are made from 0.3 mm type K thermocouple wire, mounted on rods to reach the centre of the tube. There are two probes for each of the five windows downstream of the ignition location. Figure 1 illustrates the strong influence of the ignition source on turbulent flame in 4.5 percent propane-air mixtures. The results show that it is not straightforward to define unambiguous criteria for flame arrival based on thermocouple measurements. Temperature measurements are nevertheless one of the more promising techniques for measuring flame propagation in dust clouds, but other methods will also be investigated in the future.

![Selected images of turbulent flame propagation through a 4.5 per cent propane-air mixture ignited by either an electric spark (above) and by a 1 kJ chemical igniter (below).](image)

Figure 1.


VALIDATION OF A RADIATIVE TRANSFER MODEL IN FLACS-FIRE

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Abstract

The CFD software FLACS has primarily been developed to model dispersion and explosion phenomena. However, models for simulating industrial fire scenarios are under development, and the current aim is to be able to predict fire loads from jet and pool fires in complex geometries with sufficiently good precision to support quantitative risk assessments. This paper describes the implementation of a Discrete Transfer Model (DTM) for radiation in FLACS-FIRE. The models are evaluated against relevant experiments to examine and quantify its predictive capabilities.

Correct representation of the radiative source term is a key part of fire modelling. A literature review indicated that few radiative transfer models employ the distributed porosity concept to represent geometries. Hence, there is a need to implement such a model in FLACS-FIRE, and DTM is a good candidate since this method can be used to calculate radiative intensity distribution in arbitrary shaped, three dimensional complex geometries.

The calculations are performed based on the data exchange process with the coupled approach of radiation with turbulence and chemistry. Combustion is modelled by the eddy breakup concept and the $k-\varepsilon$ turbulence model, with temperature evaluated from the solved enthalpy field. Radiation calculations are coupled with the transient simulations of flow, and the DTM incorporates the weighted sum of gray gas model for radiation property calculations. The enthalpy equation is supplied with the source term calculated from DTM, and the flow solver provides the temperature and mole fractions of CO$_2$ and H$_2$O used by the radiation code.

A test case is presented in which the results of a simulation are compared with experimental data of jet fires. Simulations are performed using FLACS-FIRE for calculations with and without radiation effects. The results clearly demonstrate the importance of radiation on jet fire flames. A significant change in the temperature distribution along the entire flame structure is observed due to inclusion of radiation effects.

Finally, a detailed study on the reduction in computational time for the coupled fire simulations is performed with radiation calculations. This has proved to be beneficial with a drastic downfall in the time involved for each simulation. Effect of radiation on highly fluctuating flames is also tested with success and found to be significant. Hence, the coupled model system involving FLACS-FIRE and DTM can be applied for obtaining intrinsic details and improved predictions for turbulent flames in complex geometries.
Piloted Ignition Regimes of Wildland Fuel Beds

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Abstract

Pine needle litters, as a representative of a highly porous fuel bed, have been studied in numerous works. The needle litter is an important component in wildland fires as it provides a source of fuel that can be easily ignited as well as provide a continuous fuel medium that will allow flame spread in forest fires. This study is a continuation of previous piloted ignition \cite{1} experimentation with pine needles of different species (\textit{Pinus strobus}). The needles are subjected to an external radiant heat flux using the FM Global Fire Propagation Apparatus. The tests include finding the critical heat flux that will ignite the fuel bed, and time to ignition of the fuel bed under a range of different test conditions (basket open area, flow conditions, and external heat flux) \cite{2}. The results show that the ignition regimes change with the flow conditions and exhibit a solid-like behavior when the flow is blocked, a thermal regime of cooling for low flows and a chemical regime of mixing of the pyrolysis gases with air for high flows. Furthermore this study will evaluate physical and chemical characteristics of the fuel under the range test conditions and compare it to existing fuels. Such characteristics will include surface-to-volume ratio, permeability, volatile content, mass loss and heat release rates.

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Advanced Firefighter Gear Design Tools
B. Hendrickson, J. Perry, J. White, A. Baz, M. diMarzo

The development of firefighter protective clothing is frequently based on trial and error rather than scientific reasoning. To address this issue, a MATLAB code has been developed to evaluate the performance of firefighter protective clothing. The user prescribes the layers of materials as well as each layer’s thermo-physical properties such as thermal conductivity, density, and specific heat. Those materials layers are then discretized in a finite difference grid and solved with an implicit numerical method. Each individual node is assigned the properties of its respective layer. The time-depend boundary conditions are specified by the user or are directly obtained from the testing data.

The code includes the thermal property degradation due to moisture. When moisture is introduced into a material, it fills the gaps that were originally occupied by air. Water, having a higher thermal conductivity than air, is more efficient at conducting heat through a material. Consequently, firefighter protective clothing exposed to moisture results in more harsh heat exposure than would occur if the clothing remained dry. This problem is addressed in the code as a function of regain, which is defined as the ratio of water mass to material mass within a layer of material. Prior research in this area evaluates how the thermal conductivity of a material changes as a function of regain. The ratio of water to material is used to determine the composite density and specific heat. While moisture content is a problem in the sense that it increases the thermal conductivity of the material, there is also a positive contribution of the presence of moisture resulting from the evaporation of water once its temperature reaches 100 °C. The evaporation of water requires a latent heat of vaporization which acts to reduce the temperature of the material. Evaporative processes at lower temperatures are not considered because the relative humidity in the air gaps within the gear quickly reaches 100 percent.

Our research indicates that the presence of air gaps between layers of material greatly increases the effectiveness of the firefighter protective clothing. During firefighter response activities, some areas of clothing are compressed, removing these air gaps. For example, there is a reduction in air gaps on top of the forearm due to gravity and wear of the garment. A shape memory material that expands at a predetermined temperature is being incorporated into the design. These memory materials are placed within the garment creating air gaps in areas where firefighters commonly experience burns. These air gaps act to reduce the thermal insult to sensitive areas and decrease the frequency of occurrence of firefighter burns.

In order to validate the MATLAB program being developed, numerous experimental tests are conducted to ensure that the results observed in the laboratory are closely approximated by the predictions made by the MATLAB program. Sample firefighter protective clothing materials of known thermo-physical properties are subjected to a regulated external heat flux. As the materials are heated, thermocouples positioned within each layer of the protective clothing record the temperatures at each layer.

To address the issue of sweating, an integral sweating plate with a gravity fed fluid supply system is incorporated in the test setup. The sweating capability is achieved through a porous wicking assembly on the surface of the test plate. During tests, this sweating surface seeps moisture into the materials such that the difference in performance between wet and dry conditions can be measured experimentally. In addition, pockets containing the shape memory material are added between layers of material to simulate the effect of air gaps in the clothing. Once completed, this program is providing a useful tool to the gear manufacturer to design and optimize gear assemblies and layering within the assembly that can enhance thermal performance.
Combustion modeling of a premixed jet with and without roughness for definition of MESG

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Maximum experimental safe gap (MESG) is the maximum gap of the joint between the two parts of an interior chamber which prevents the ignited gas inside this chamber from igniting the external gas mixture. MESG is used in safety estimation for different kinds of equipment in the oil and gas industry. A still unresolved problem is definition of MESG for the case when the gap surface roughness is higher than required by international standards, as indicated in experimental studies [1-2].

In this research we performed Computational Fluid Dynamics (CFD) simulations to study hot gas propagation through a narrow opening in order to investigate the influence of surface roughness. The CFD software Star CCM+ was used to model the combustion process. At first different kinds of geometries were tested combined with three turbulent premixed combustion models: the Coherent flame Model (CFM), the Bray Moss Libby (BML)-model and the Eddy Break-Up model [3-4], while the gas turbulence was modelled using the \( k-\varepsilon \) model.

The computational domain was three-dimensional and consisted of a pre-chamber where the explosion was initiated. The chamber was connected with a narrow opening/pipe where the surface roughness was varied in the simulations. Some selected results are shown in Fig. 1.

References


This research investigates the flammability of pultruded fiber reinforced polymer (FRP) composites under different heat flux exposures for various thicknesses. Experiments were conducted on pultruded E-glass fiber reinforced poly ester and vinyl ester composites that are widely used in the construction industry, to study the nature of their fire properties with respect to the thickness of the composite materials. This would give a clear idea of what kind of geometry has to be considered while using these materials in building applications associated with fire scenarios.

The objective is to establish a comparison of the fire characteristics of FRP composites for various thicknesses. The experiments were carried out in the cone calorimeter apparatus with pilot ignition according to ASTM E1354 standard. The Heat release rate and mass loss were measured. The time to ignition and back surface temperature of the specimens were recorded to examine the fire resistance exhibited by the FRP materials for different thicknesses under a specific heat flux exposed. The materials were tested at three different heat flux exposure levels (25kW/m\(^2\), 45kW/m\(^2\) and 65kW/m\(^2\)). Thicknesses chosen for experiments are 1.27mm, 0.635mm and 0.3175mm.

The time to ignition clearly illustrates that the thinner material is more susceptible to catch fire compared to the thicker material under similar conditions. The mass loss is high and faster for the thin material when compared to the thicker one. The peak heat release rate and heat release rate curves show high values for the thinner material. Heat release rate values collected from the time of ignition infers that thinner material happen to burn out more than thicker material under same heat flux exposure and time period.

The observed results from the experiments show that the thinner materials release more heat in to the surroundings that can induce fire in the nearby flammable materials. Though the ignition temperature for the material for different thickness is observed to be the same, the time to ignition and heat release rate varies. This indicates that fire reaction properties is not dependant on the fire exposed surface, But depends on thermal inertia of the composites.
A New Use of an Old Method: Egress Flow for Corridors and Stairs

Paul Reneke

(Submission #1104)

Image Caption or Poster Abstract

Historically, building egress systems have evolved in response to specific large loss incidents. Currently, systems are designed around a concept of providing stair capacity for the largest occupant load floor in the building with little or no consideration of occupant behavior, needs of emergency responders, or evolving technologies. As part of an ongoing research project on the fire-safe design of egress systems, The National Institute of Standards and Technology (NIST) is collecting data on people movement in tall buildings in the United States. The objective of this data collection is to provide scientific building evacuation data to improve the overall level of occupant safety in buildings and to contribute to a sound technical basis for improving the current egress requirements within national building codes and standards.

Additionally, using these data from evacuation drills, work is ongoing at NIST to develop a computational tool that can simulate both evacuation via stairs and elevators. Evacuation calculations usually employ one of two analogues: fluid flow or agent-based methods. Fluid flow analogues consider occupant movement in corridors, stairs, and through doors similar to that of water flowing through pipes. Agent-based models, on the other hand, simulate discrete individuals, often with attributes that influence their movements from one point in the building to another. In general, the fluid flow analogue is has difficulty accounting for the various human behaviors that are observed in an evacuation. However, in a confined space, such as a stairwell, where the physical limits play a major factor in behavior, the fluid analogy may be fruitful.

This poster will feature the technical basis for a fluid flow analogue for stairwells and corridors. The method consists of a system of two partial differential equations, one for density and one for speed. The density equation is thought of as accounting for the physical constraints of the system. Unlike fluids, however, people are self-motivated. The speed equation accounts for this by adjusting speed of occupants according to individual responses to local conditions and not the physical impact of the conditions on occupants. While this system would be limited in its ability to represent a specific evacuation; its power may be in the ability to represent the expected or average evacuation.

Categories

Submission Category: Poster Abstract
Temperature Measurements within a Methanol Pool Fire

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The ignition of the vapors above a horizontal stationary layer of liquid fuel, either contained within an open storage vessel or the result of an accidental spill, creates a pool fire. These diffusion flames can be potentially dangerous to both life and structures due to the rate of conversion of chemical to sensible enthalpy (i.e., their burning rate). Though limited in extent, there is evidence in the literature that key characteristics of pool fire phenomenon can depend strongly on the happenings within the liquid phase of the fuel. This observation raises the possibility that these types of fires can be controlled from the liquid phase and thereby may reduce the challenges of dealing with these kinds of fires.

In a previous experimental study [1], it was shown that flame size and burning rate of a methanol pool fire were strongly dependent on the thermal boundary condition at the bottom of the liquid phase. In that study, the increasing of that boundary temperature from 5°C to 55°C resulted in the flame height and burning rate to increase by 100% and 65%, respectively. The reasons for why these outcomes were so sensitive to this lower boundary temperature have not been addressed, and required a more thorough study of key thermal and flow conditions within the liquid phase of the pool fire. It is also known from the literature that the fuel temperature affects the flame spreading rate over a liquid fuel [2]. A better understanding of this phenomenon is necessary to address issues of fire safety, control and suppression.

Following on from the previous work, this study was an experimental investigation of a square pool (75 mm × 75 mm) with a depth of 10 mm, and the fuel used was methanol. To achieve quasi-steady state conditions, fuel was introduced through a porous plate at the base of the pool and its level was held fixed by controlling the fuel supply pump. The thermal boundary condition at the bottom of the pool was controlled over the temperature range of 5°C to 60°C by circulating either chilled or heated water through a serpentine channel immediately below the porous plate. A thermocouple mounted on a three-axis traverse system was used to measure temperature profiles at various locations within the methanol pool, while the pool fire was held under steady state conditions. These temperature profiles, along with the fuel burning rate, at different thermal boundary conditions were used to determine the energy balance within the liquid phase to examine the heat transfer mechanisms within and at the surface of the liquid methanol. The results could be useful in order to make the pool fire suppression easier.

References:

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Optimal gas firefighting training objects

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In the recent years there has been a growing interest for a safer and more environmentally friendly firefighting training object. More and more of the fire training objects that previous run on kerosene, diesel oil or other petrol liquids are being replaced with modern gas burners. This has several advantages. For instance it drastically reduces the smoke production, eliminates spills of petrol to the ground, and most of all, it is much safer because it quickly can be shut down in case of an emergency. But it is of great importance that the gas burner is constructed in such a way that the flame doesn’t burns out, unless the gas supply is turned off. This mainly because unburned gas leaking out around the firefighter are extremely dangerous, but also to give the firefighters an authentic fire fighting experience as possible.

The purpose of this study is to look at the factors that make a gas flame look and behave as a real fire even under fire fighting. Further how to get the maximum firefighting experience for least amount of gas, and still ensure that the gas flame don’t burn out. The research is done in both the fire lab at Stord Haugesund University College, and at a large scale training facility named RESQ. In the fire lab small pool fires (0.5m x 0.5m) of different liquids, typically used in fire fighting training are being compared to different gases burnt in a sandburner (0.5m x 0.5m). The gases used in the sandburner are those who most likely are replacing the liquids in firefighting training. Many different combustion parameters were measured and compared together with high speed video.

At the large scale training facility, the influence different parameters and arrangement have on the difficulty of extinguishing a gas flame is studied on a half aircraft engine. A great influence of the exit velocity [1] and gas concentration has already been seen. It is expected that by the time of a possible poster presentation a series of data for different nozzles, intermixture of oxygen in the fuel, number of exit points and other parameter will be available.

Extinguish test on a propane burner, at the left side of an aircraft engine.

Reference
A METHODOLOGY FOR THE PREDICTION OF FLAME EXTINCTION AND SUPPRESSION IN THREE-DIMENSIONAL NORMAL AND MICROGRAVITY ENVIRONMENTS

Jason Sutula

(Submission #1107)

Image Caption or Poster Abstract

The probability of a fire occurring in space vehicles and facilities is amplified by the amounts of electrical equipment used. Additionally, the lack of egress for space personnel and irreplaceable resources used aboard space vehicles and facilities require a rapid response of a suppression system and quick extinguishment. Current experimental means that exist to gather data in space vehicles and facilities are limited by both size of the experiment and cost. Thus, more economical solutions must be considered. The aim of this research was to develop a reliable and inexpensive methodology for the prediction of flame extinction and suppression in any three-dimensional environment. This project was split into two parts. Part one included the identification and validation of a computational model for the prediction of gas dispersion. Part two involved the development of an analytical parameter for predicting flame extinction. For model validation, an experimental apparatus was constructed. The experimental apparatus was one-eighth of the volume of electronics racks found aboard typical space facilities. The experimental apparatus allowed for the addition of parallel plates to increase the complexity of the geometry. Data acquisition consisted of gas concentration measurements through planar laser-induced fluorescence (PLIF) of nitrogen dioxide and velocity field measurements through particle image velocimetry (PIV). A theoretical framework for a generalized Damköhler number for the prediction of local flame extinction was also developed. Based on complexities in this parameter, the computational code FLUENT was determined to be the ideal means for predicting this quantity. The concentration and velocity field measurements provided validation data for the modelling analysis. Comparison of the modelling analysis with experimental data demonstrated that the FLUENT code adequately predicted the transport of gas to a remote location. The FLUENT code was also used to predict gas transport at microgravity conditions. The model demonstrated that buoyancy decreases the time to achieve higher gas concentrations between the parallel plates. As an example of the use of this methodology for a combustion scenario, the model was used to predict flame extinction in a blow-off case (i.e., rapid increase in strain rate) and localized flame extinction (i.e., flame shrinking) in a low-strain dilution case with carbon dioxide over time. The model predictions demonstrated the potential of this methodology with a Damköhler number for the prediction of extinction in three-dimensional environments.

Categories

Submission Category: Poster Abstract
Title: Wayfinding architectural criteria for the design of complex environments in emergency scenarios

Author: Elisabetta Carattin, PhD arch. Università IUAV di Venezia, Italy

Keywords: human behavior, performance-based design, human factors, egress, wayfinding, architecture, design, complex environments, supermarkets, shopping malls, evacuation, landmark

Abstract:

This study analyzes human wayfinding strategies in emergencies in relation to the perception of the building’s environment. Wayfinding strategies in complex buildings (by floor plan complexity, type of users, etc. ...) are put in relation to the user’s behavior and the quality of the environment around her/him, especially in emergency situations. The results of case studies concerning wayfinding in two supermarkets and a shopping mall in northern Italy are presented and compared in order to understand efficient wayfinding design criteria, especially in emergency situations. The studies concerned a cognitive mapping test in which customers and workers had to recall emergency exits landmarks inside the building, otherwise indicate how she/he would have exited the supermarket in case of emergency. In all three cases, almost 80% of elderly and adults (who are routine clients of these places) were unable to recall exits or identified themselves as behaving ineffectively in an emergency. This is an important consideration when properly designing wayfinding systems and highlights the importance of understanding human behavior in order to design safer buildings.

Understanding human behavior in emergency is a key issue to highlight the critical elements of architectural design of the building. The designer, in order to improve users’s wayfinding inside the building could give solutions through the proper use of architectural landmarks and devices (tab.1), such as color, signs, paths, lights, etc...

Table. 1. Some architectural devices.
SCALE MODELING OF STATIC FIRES IN A COMPLEX GEOMETRY FOR APPLICATIONS

By: Allison C. Carey and James G. Quintiere

Scale modeling can allow fire investigators to replicate specific fire dynamics at a dramatically reduced cost. This research is a part of a larger effort to provide investigators with the tools to reconstruct fires using scale modeling. Full scale fires were conducted at the Bureau of Alcohol, Tobacco, Firearms, and Explosives in Beltsville, MD. A gas burner, heptane liquid pool, wood crib, and polyurethane foam block were used to represent the wide range of fuels that investigators may encounter. These fuels are classified into two groups: the burner and liquid pool that reach a semi-immediate steady state (static fires) and the crib and foam that have a fire spread and growth period (dynamic fires). The fire sizes ranged from 50 kW to 400 kW, depending on the fuel type. This research examined a proposed scaling method for static fires, namely the gas burner and heptane pools. The fires were burned in an enclosure which consisted of a large corridor with two smaller perpendicular corridors. The enclosure provided an interesting challenge due to the presence of joist-like partitions at the ceiling. These partitions were angled on one side in order to allow hot gases to travel throughout the corridor. The scaled experiments were conducted in a 1/8th scale replica of this enclosure. Temperature and flame height were compared between the full scale and 1/8th scale experiments.

The design fires and the model enclosure were designed based on Froude scaling derived from conservation equations. The fires were scaled based on the heat release rate or mass loss rate of the fire. The eight various sized fires demonstrated acceptable scaling results in the prediction of flame height and temperature at various elevations in the enclosure. The temperature results were impacted by the slight differences in thermal properties of the enclosure materials. Understanding how to accurately model convection driven fires provides fire investigators with the tools to recreate many fire scenarios. It is especially helpful in fires leading up to flashover or where detection plays a major role in the investigation. The dimensionless groups presented in this thesis are an accurate method to model a full scale static fire.
Each German municipality is required to operate a tailored fire department to suit local conditions effectively. Because the effectiveness of a fire department is not clearly defined by law, the needs assessment and resource deployment of fire services are often drawn on guidelines that determine certain quality criteria on the basis of a representative standardized incident. The critical damaging event that routinely causes most personal damage in fire statistics, in view of its frequency of occurrence and the expected extent of damage, both abroad and at-home, is the domestic fire. The guideline of the German Association of Fire Chiefs (AGBF), for example, constitutes that one of the quality criteria is response time of the fire department. According to the guideline, the maximum permissible response time of the first-arriving unit is derived from a timeline assuming certain steps in fire department response time sequence and results in a parameter for further planning of number and location of fire stations, staffing levels and needed equipment.

The purpose of this thesis is to evaluate the timeline used for needs assessment methods of fire services on the basis of the set-up and operating time of fire services at the critical structure fire. Therefore, a series of practical tests, in particular, fire exercises for the critical apartment fire in the upper floor of a multi-story house with stairways impassable by smoke, were carried out with participation of volunteer as well as career fire departments and the rescue time of threatened people in the apartment was measured. Overall, 35 scientific accompanied exercises involving eight fire departments were conducted, quantifying the time from dismounting of the first-arriving officer through removing the occupant from the building.

The study provided rescue times which exceeded the stated value of the AGBF multiple times. The mean set-up and operating time until one can begin CPR on a rescued occupant was 13:04 minutes which is more than three times greater than the current planning value of 4 minutes. None of the participating fire crews in the study were able to meet this set rescue time. The fastest unit required almost 8 minutes to rescue the unconscious person.

This raises the question of how to optimize the tactical rescue approach and what is reasonably possible for fire services to provide. Furthermore, the current method for sizing fire departments by using an absolute time limit, specifically its derivation, must be questioned. As a result, these extensive measures of rescue times once again illustrate the significance of self-rescue actions in case of a fire. Additionally, these measures stress the importance of fire prevention measures and early fire detection by using smoke detectors in the home environment.

Besides the significant influence of fire service deployment methods in Germany, this study shows an effective approach for quantifying the effectiveness of fire departments in general. This could also lead to further considerations of accounting for fire department operations in engineered fire protection design.
A Numerical Study of Solid Fuel Pyrolysis under Time Dependent Radiant Heat Flux Conditions

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\textbf{ABSTRACT}

This study examines the effect of time dependent irradiation on pyrolysis processes. In fire applications, solid pyrolysis corresponds to the transformation of carbon matter from solid to gas phase and thereby controls the rate of formation of flammable vapors that fuels the combustion process. Pyrolysis is driven by the gas-to-solid heat transfer (also called the thermal feedback); this heat transfer includes convection and radiation components. The thermal feedback generally takes place in a strongly unsteady environment and consequently the gas-to-solid rate of heat transfer features strong unsteady variations. We examine in this study the effect of fluctuations in incident radiant heat exposure on the pyrolysis processes taking place inside solid flammable materials. We consider a simple one-dimensional configuration that is similar to the experimental set-up studied in cone calorimeter tests. We follow a popular approach in pyrolysis modeling that consists in treating thermal degradation across a solid as a local one-dimensional problem in the direction normal to the exposed surface. The model formulation is based on classical conservation statements for heat and mass; we assume Arrhenius-like degradation chemistry based on a global one-step pyrolysis reaction with the virgin solid being transformed into volatiles and char. The material properties and reaction parameters used in the pyrolysis model have been calibrated to represent thermal degradation of polyvinyl chloride (PVC). The numerical model allows for constant or fluctuating radiant exposures.

In the present study, we consider harmonic variations in irradiation of the form $q = q_{\text{mean}} + q_A \sin(\omega t)$, where $q_A$ is the amplitude and $\omega$ the pulsation of the periodic forcing. The harmonic variations in gas-to-solid heat loading induce in turn a response of the pyrolysis processes; this response is characterized by oscillations in solid temperature and under certain conditions, significant variations in the fuel mass loss rate. It is found that the oscillations in solid temperature are confined to a small region located close to the exposed surface of the PVC material; the thickness of that region has a characteristic length scale $l = (2\alpha / \omega)^{1/2}$, where $\alpha$ is the thermal diffusivity. The effects of time-varying irradiation are pronounced when the pyrolysis front is within a distance $l$ of the exposed surface and when temperature levels are close to the ignition temperature. Figure 1 presents representative simulation results in the form of a comparison between the time variations of the fuel mass loss rate under steady and unsteady radiant heat flux conditions.

\begin{figure}[h]
\centering
\includegraphics[width=0.5\textwidth]{figure1.png}
\caption{Time variation of the fuel mass loss rate. Case of a PVC sample subjected to a constant (blue line) or time-varying (red dots) radiant heat flux.}
\end{figure}
Fire investigators, often, rely on the appearance of electrical wires and the presence of electrical activity (e.g. arc-beads) on wires to assess the potential involvement of the wires or attached appliances in the initiation of the fire. Many times, a fire investigator will conclude that a device was electrically energized at the time of a fire, and therefore, could have potentially caused the fire, based on the presence of an arc bead on a wire. Hence, a clear understanding of the causes of various effects, such as arc beads, on electrical wires is invaluable to the community. Unfortunately, there are many limitations in the current state-of-the-art for electrical wire analysis. Although many researchers have attempted to define the conditions under which particular characteristics occur on electrical wires, many, if not all, of these studies did not test a control. For example, if it is believed that arc beads are only formed in energized wires, then a control study must be performed to ensure that the same characteristic “bead” cannot be formed on non-energized wires.

The main objective of this research is to determine, experimentally, if distinguishing characteristics exist between energized and non-energized wires exposed to various types of thermal exposures; direct flame impingement, radiative heating only, and radiative/convective heating. Additionally, energized wires will be tested under “load” and “no load” conditions. Under load conditions, the energized wire will have current flow and under “no load” conditions, the energized wire will be plugged into a power source but no current will be flowing through the wire (e.g. electrical potential only). After thermal testing, the wires will be analyzed with a high resolution stereomicroscope, as well as, a Scanning Electron Microscope (SEM) and Electron Dispersive Spectrometry (EDS) to define visual and elemental characteristics and patterns in and on the wires. Tests will be performed in a small-scale compartment and then validated with full-scale testing.

The Scientific Method, the basic tenet of fire investigation, requires that the investigator identify the problem, define the problem, collect and analyze the data, develop and test hypotheses, and select a final hypothesis. A fire investigator’s ability to rule out one or more cause and origin hypotheses, as set forth in the Scientific Method, is dependent on the evidence available to support one particular hypothesis and the factual nature of that evidence. Because the collected data may lead to the development of multiple hypotheses, these hypotheses must be tested against all available data to ensure an objective analysis and to determine, through deductive reasoning, which hypothesis is most probable. This research will have a significant impact on the fire investigation community because it will provide investigators with a validated methodology for analyzing electrical conductors and associate devices.

This project is supported by Award No. 2010-DN-BX-K246, awarded by the National Institute of Justice, Office of Justice Program, U.S. Department of Justice. The opinions, findings, and conclusions or recommendations expressed in the exhibition are those of the authors and do not necessarily reflect those of the Department of Justice.
High percent of each country population are children, elderly and disabled people (e.g. 40% for Russia) i.e. so called vulnerable population. They have a number of physical and social problems and they are obviously under higher danger in case of fire.

**Pre-school and school age children.** Special experiments, including technique called computer video-presentation (video-questionnaire) and pedestrian flow observations, were recently undertaken, fig. 1.

In was found, that pupils are strictly depend on staff behaviour, who are not always well prepared to react on fire: only about one-third of staff followed simple fire instructions. Pedestrian flow study revealed that in general kid’s speed reflects the same density impact, as for adults, but movement on stairs is completely different. Stairs are designed for adult’s steps and kids are very much inconvenient and hard to use stairs. This results in their slow travel speed both upwards and downwards.

**Disabled people.** According to early experiments, there are 4 groups of such people mobility in Russian building codes: M1 – evacuees without mobility limitation, but including deaf people; M2 – elderly people, people with artificial limb and eye-vision limitations, mentally disabled; M3 – people using special walking aids i.e. clutches, sticks, etc; M4 – wheel chair users.

These people are characterized with high pre-movement time, low travel speed, maneuvering, stability in a flow, endurance, higher kinematical dimensions etc. Another problem is that M4 (wheel-chairs) users can’t use stairs, so lift evacuation issues appearing. Moreover, special experiments revealed very effective evacuation chair usage.

However, the most complicated situation is with immobile people who can’t move by themselves. Special hospital study showed that medical staff in fact incapable of timely patients evacuation. In general (considering various weight of patients, distance to move, evacuators physical abilities) one pair of staff can evacuate only three patients.

**Elderly people.** Questionnaire and flow observation study revealed that their psycho-physical conditions strictly impact behaviour in fire. Mostly their limitations are due to sense organs limitations, poor micromotor activity, brain capabilities decrease and distinguishing pedestrian movement.

These inevitable progressive dysfunctions of aged people results in high pre-movement time and their travel speed is in average almost 3 times lower than middle age people speed: 0.33 m/s compare to 1.67 m/s…
AIR CURTAINS USED FOR SEPARATING SMOKE FREE ZONES IN CASE OF FIRE

Gregory Krajewski

(Submission #1115)

Image Caption or Poster Abstract

The aim of this paper is to take the advantage of CFD application in calculating and designing air curtains used to separate smoke free zones in case of fire. Research and experience gave us knowledge that the direct exposure to fire is not the most immediate threat to people’s life in case of fire. The majority of fatalities connected with fire are the result of smoke-inhalation. To prevent this, air curtain devices can be used as a virtual screens to stop smoke spreading in building object, which enables to decrease number of fatalities. Safe evacuation of people and safe intervention of fire fighters are major considerations. Properly designed air curtain produces a pressure drop which forbids transversal flow through the opening. It can be used to stop or reduce the movement of toxic smoke while enabling full access to emergency exits. Main criteria for such air curtain is efficiency which is rate of heat and mass transferred across air curtain. Air curtain efficiency depends on many variables: width and velocity of a stream, angle and a stream character. Factors which have an influence on these parameters are: pressure difference, Temperature difference and geometrical dimensions of protected area. In many cases air curtains used to prevent smoke spreading were tested in scaled down models which are difficult to extrapolate to the real dimensions using Euler number similitude. It often gives an over-efficient device, which can cause lower efficiency, and sometimes increase transfer of heat and mass between two separate fluids. Additionally it is very hard model a temperature difference while we use scaled down models. However we can use CFD applications to analyse air curtains in a real scale and for many different values of pressure and temperature difference. Numerical analysis are based on a laboratory tests of smoke control shutters and gas tracer method used in aerodynamic tunnels to test efficiency of air curtain. The intention of this paper is to present the requirements and the way of carrying out numerical calculations using CFD applications to analyse efficiency of air curtain used as a device in fire protection engineering. Results for different turbulence models and grid resolutions in comparison with experimental data will be presented.

Categories

Submission Category: Poster Abstract
Radiative properties of smoke of under-ventilated fire
A.. Loo, A. Coppalle, J. Yon, F. Ren, CORIA France

The extinction of visible light by smoke is important and it has an effect on the radiative exchanges and on the visibility of people. Under some circumstances, the fire source may be under-ventilated and that could change radiative properties of smokes. The aim of this work is to determine the extinction coefficient ($K_{ext}$) of smokes emitted by under-ventilated flames and to compare the results to well ventilated cases. The smoke is produced by the combustion of different liquid and solid fuel in a small chamber (1m$^3$) with controlled ventilation as it is shown in fig1.

![Image 1: smoke chamber](image1)

![Image 2: optical extinction cell](image2)

Figure 1: smoke chamber
Figure 2: optical extinction cell

The smoke has been sampled with a two-stage dilution system (DEKATI FPS 4000) (Ouf, 2010) in order to be introduced in an optical bench at ambient temperature and pressure (Ren et al, 2010). The path length is $L = 1.5$ m, and the extinction spectra through the tube are measured by a turbidity system, as reported on fig.2 (Ren, 2006). At the exhaust of the extinction cell, the mass concentration of particles present in the smoke have been measured with a microbalance (TEOM-Thermo Scientific).

The mass specific extinction coefficient $\sigma_e$ is defined by

$$\sigma_e = \frac{\ln(\tau)}{Cs}$$

where $\tau$ is optical transmission of the smoke thought the cell, and $Cs$ is the mass concentration of the particle in the smoke (Kg/m$^3$).

Figure 3 shows an example of the spectral variation of $\sigma_e$ for heptane fuel.

![Image 3: mass specific extinction coefficient $\sigma_e$ for heptane.](image3)

Experimental spectra of $\sigma_e$ will be presented and discussed as a function of the fuel (heptane, gasoline, PMMA) and of the ventilation of the flame inside the smoke chamber. As it will be shown, for $\lambda > 0.7$μm, the refractive index of soot do not vary, while it is not possible to conclude for $\lambda < 0.7$μm because scattering can also contribute to the extinction process.

Ouf F.X., Coppalle A., Yon J. And Vendel J. 9th IAFSS symposium, Karlsruhe, Germany, 2008

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Modelling is now often used to improved fire safety, mainly in public or tall buildings. One key is the availability of verified and validated fire models that can correctly predict the consequences of fires. So a modelling exercise has been organised on behalf of the French CNRS research group “GdR Incendie”. The main aim of this work has been to look at the accuracy of several models in the case of an under-ventilated fire and by means of comparison to experimental results. Seventeen research laboratories or institutes have participated.

The full scale test will be described and it corresponds to fire growth in a room and smoke spread in other connected rooms. The experimental set-up will be also presented. It has allowed observations of the weight loss of the fire source, temperature field (230 thermocouples) inside rooms, and gas concentration (O2-Nox) in the exit smoke flow.

The round robin exercise has been planned in two blind steps. First, calculations had to be performed knowing only the dimensions and wall properties of rooms and also the dimensions and the initial weight of the two sources (wooden pallets). Then in the second step, the heat release rate was known and it had to be used as an input data for the calculations. The first step is to highlight the influence of the model user choices. The assumptions which are made, in particular for the heat release rate calculations, and the collection of data for the input are crucial parts of fire safety engineering applications. The second step is to reflect more the mathematical model’s inherent capabilities. It is to highlight differences between models as for example those existing in calculations of radiation, wall heat flux, smoke production or with different mesh sizes. These differences could have been hidden in the previous blind test, due to the predominant influence of the HHR calculations on the results.

Results for the two steps will be presented and discussed.

Acknowledgments: The fire test has been performed and financed by the PROMESIS* consortium in September 2008 using the SERAFIN research station (located at Roanne, France). P.R.O.M.E.S.I.S is an initiative of GIMAEX and ‘Commissariat à l’Energie Atomique’ and it get closer 18 partners on a research program dedicated to the comparative study of the means and the methods for the fire extinguishing systems.

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Radiation heat flux from compartment fires in wind conditions

D.K. Glennie

(Submission #1118)

Image Caption or Poster Abstract

Fire spread between buildings can be limited by using spatial separation distances to reduce the amount of radiative heat flux received by adjacent buildings. Building codes, such as the National Building Code of Canada, provide prescriptive distances to help reduce this risk of fire spread. Full scale tests into spatial separation, including "The St. Lawrence Burns" conducted in 1958, early on identified wind speed and direction as a primary factor in determining the heat flux received at a target building. However, insufficient information has been available to adequately develop building code measures which address the increased risk of building-to-building fire spread due to the effects of wind.

To facilitate a better understanding of radiation exposures in wind situations, large scale tests are currently being performed to measure heat fluxes and temperatures opposite a one room compartment fire in wind and no-wind conditions. Several different window sizes, fire sizes, and ventilation scenarios are being tested to study the effects of wind on flame projection and the resulting received radiation. These measurements can then be incorporated into a new stochastic based model to provide new light on the increased level of risk associated with wind conditions.

Categories

Submission Category: Poster Abstract
Burning properties of plastics at reduced-pressures

Mariusz Zarzecki, F. Javier Diez, Richard E. Lyon, James G. Quintiere and Tobias Rossmann

(Submission #1119)

Image Caption or Poster Abstract

Fire suppression in Class E compartments in cargo airplanes is limited to the depressurization of the compartment to the conditions at altitude. The effectiveness of the decompression has not been well researched, and therefore an in-depth study is needed. The burning behavior of diffusion flames, as encountered in fires, changes with total pressure but the mechanism by which it happens is not yet well understood. Federal Aviation Administration pressure modeling facility will be used to simulate burning behavior of ¼ inch thick PMMA samples. The tests will be performed at different pressures to try to simulate different altitudes. A standard mass loss calorimeter with a cone heater will be used to measure transient mass loss for multiple incident heat fluxes. The cone heater will reproduce the effective heat flux that might be encountered in full scale fires. The oxygen consumption and times to ignition are also going to be measured as a function of total pressure. The results will help determine the viability of decompression as means of controlling onboard fires.

Categories

Submission Category: Poster Abstract
Development of simplified failure mechanisms of composite slabs in fire

Anthony Abu

(Submission #1121)

Image Caption or Poster Abstract

Accidental fires and full-scale fire tests of real buildings have shown that partially-protected steel-framed buildings with composite floors have a higher inherent fire resistance than what is perceived with design to traditional methods. The high capacity is largely as a result of the development of a mechanism known as tensile membrane action. This is a self-sustaining load-bearing mechanism of thin floors under moderately large deflections, in which induced tension in central areas of the slab is balanced by a peripheral ring of compression. The load-bearing resistance of the slab increases with increasing vertical deflection. The necessary conditions for this behaviour are two-way bending and adequate vertical support along the slab’s boundaries. In addition to the high capacity it generates, the use of tensile membrane action in structural fire design introduces economy in composite steel-framed structures, as a large number of floor beams can be left unprotected. In practice, all exposed steel columns are protected; beams that lie on the main column gridlines are also protected, leaving interior beams unprotected. This protection scheme allows the room-temperature one-way spanning floor system to evolve into a two-way system (called a slab panel) when the interior beams have lost significant strength in fire conditions. The protected beams thus simulate the requisite vertical support at elevated temperatures. Due to load redistribution and other complex processes that take place finite element simulations are best suited to tracking the behaviour of the entire structure. However, the immense benefits of tensile membrane action and the demerits of finite element analyses, such as long runtimes, have led to the development of simplified methods for routine design. Prominent amongst these is the Bailey-BRE method, which predicts capacities of isolated composite slabs by calculating the enhancement of their traditional yield-line load capacities due to tensile membrane action. The method assumes that perimeter vertical support is available indefinitely throughout fire exposure. The protected composite beams, however, deflect under a combination of heat and load; this loss of vertical support induces single-curvature bending, which leads to an eventual structural failure by folding of the slab panel. Failure of one slab panel can induce progressive collapse of the entire structure. A simple folding mechanism, which considers the contributions of internal unprotected beams and protected edge beams, has been developed for isolated slab panels. The current study expands on the mechanism to include the contribution of reinforcement in the slab. The study further investigates other potential failure mechanisms by exploring structural continuity, slab aspect ratio, relative beam sizes, their relative strengths, their arrangement in the slab panel considered, the location of the slab panel itself and the severity of fire exposure. These factors are critical to the development of a number of failure mechanisms to serve as an additional check in the Bailey-BRE design method and all other simplified methods. Comparisons are made with the finite element software Vulcan and other design acceptance criteria.

Major Topics Tensile membrane action, composite slabs, slab panels, collapse mechanisms, edge beam failure

Categories

Submission Category: Poster Abstract