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Analysis of Fire Suit with Flame Test Manikin System

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Abstract

Firefighters are involved in managing different types of firefighting activities for the safety of society from fire accidents. Their life is very important. So, it is required to test firefighting/heat resistant clothing depending on the end usage. There are different international standard to test the heat resistant clothing. Nowadays instrumented flame test manikin system, is being used for testing of complete body fire ensembles. Heat resistant clothing performance can be evaluated using an assessment based on an instrumented manikin under controlled fire condition similar to real-life fire.

Keywords: *Fire, Heat resistant Fabric, CFD, Flame Test etc.*

1. Introduction

In the field of firefighter protective clothing research, it is important to obtain a reliable assessment of the thermal performance of heat resistant clothing exposed to fires. Bench scale laboratory testing does not take into account the effects of garment design and construction, nor the effects of garment seams, zippers, pockets and breathability. Therefore, these studies cannot accurately predict the protective performance of clothing without considering the spatial effects of the clothing. A better assessment of the protective properties of clothing can be achieved by using a mannequin fire test system with realistic simulations of real fire effects. The purpose of this test is to predict the reduction in the severity of skin burns from thermal radiation when covered with fire resistant clothing. Flame spread is governed by heat transfer to a surface and the subsequent thermal response or behaviour of the material. The heat exposure that occurs results in the release of combustible pyrolysis gases. As heat accumulates within the material, the rate at which combustible gases are released eventually becomes sufficiently high to produce a flammable mixture in the boundary layer, which can either ignite spontaneously, if the temperature is high enough or be ignited by a pilot flame. This rather complex phenomenon, including the boundary layer interaction between a fluid and a solid phase and the thermal degradation of the material, has been studied in varying detail ever since the late 1960s, both experimental and theoretical work in this area having been presented frequently ever since.

Prediction of Skin Burns from Thermal Radiation

Skin accounts for about 15% of the average adult body weight and is the largest organ in the human body (SFPE Guide). The skin serves many purposes and is a very complex organ. A basic understanding of the skin is necessary to understand the physiology of skin burns. The components of the skin can be divided into three main layers: epidermis, dermis and subcutaneous tissue (SFPE guide). The epidermis measures approximately 75–150 µm (0.4–0.6 mm, excluding palms and soles) and is the outermost layer of the skin. The dermis lies just below the epidermis and is 1 to 4 mm thick. The subcutaneous tissue consists of fat, followed by muscle. Fat thickness varies from almost none in certain areas to areas of 1.5-2.0 cm. The thickness of this fat layer is subject to individual and anatomical differences. These differences can be very large and, in the case of severe burns, may play a role in determining the severity of injury. Three skin regions are shown in Figure 1

(Majchrzak and Janinski, 2001).

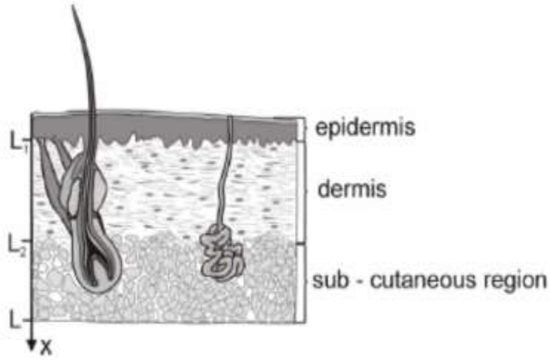

Fig. 1: Human skin layers

Revolutionary progress in Computational Fluid Dynamics (CFD) modeling over the last two decades manifests itself in fire research through transition from zone to field models. This coincides with the concurrent trend towards the introduction of performance-based flexible fire protection regulations. The aim of the present review is to provide the reader with a broad discussion on the mathematical modeling techniques, currently available for compartment fires. A brief comparison between zone and field approaches to fire simulation is presented first. Then the most widely used class of field models, based on conventional two-equation closure for turbulence, is considered in detail, including various submodels for specific physical processes. The relevance of underlying physical assumptions is discussed and the conventional model performance is analyzed in a broad range of applications. The extension of the model involving Eulerian–Lagrangian formulation for two-phase flow is discussed in relation to fire extinguishment problems.

Flame/ Heat resistant clothing analysis system

The actual manikin experiment is conducted in Flame Manikin protective clothing analysis system, which is composed of three parts: flame manikin body, nozzles and combustion chamber, as shown in Figure 2.

Skin simulant sensors (134 Nos) were placed at appropriate positions. The manikin is suspended from the ceiling of a 16” x 10” x 10” fire resistant combustion chamber and surrounded by 12 industrial burners capable of producing a flash fire that can fully engulf the manikin.

The overall performance of the thermal protective clothing can only be evaluated using an assessment based on an instrumented manikin under defined, close to real-life conditions in a laboratory. However, the manikin tests can only give a few of pointwise information. This paper presents a three-dimensional transient CFD simulation of heat and mass transfer in the flame manikin test of thermal protective clothing.

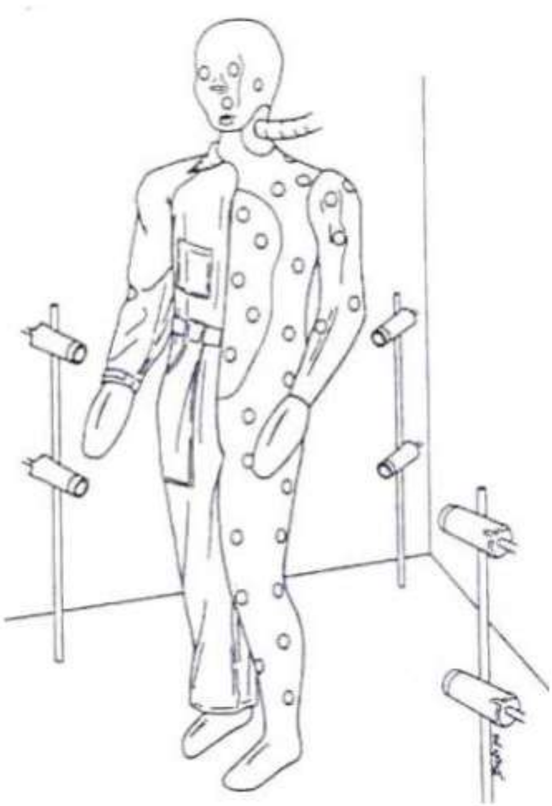

Fig. 2: Flame test manikin system along with 134 sensors positions.

Experiment protocol

Single-layer garments based on cotton and Nomex were used. In a typical experiment, a mannequin was clothed, engulfed in flames for 4 seconds, and then left in the room for 120 seconds. The exposure of the naked mannequin test was the decisive factor in the calibration. Suits were first preconditioned at 65% relative humidity and 28°C temperature according to ASTM F1930. The average heat flux is controlled at 84 ± 2.5 and the default heat flux variance is 21. The nominal fuel flow rate is 0.006 per burner nozzle, but there is variation in the experimental process. The flux is produced using propane as fuel and is believed to react with a stoichiometric amount of air. Propane has an adiabatic flame temperature of about 2000°C and a minimum ignition point of 480°C.

3. Results and Discussion

The clothed manikin was subjected to a heat flux of 84 kW/m^2 and the results in terms of increase in temperature was measured. Figure 3 shows the layout of 12 groups of burners. The fuel of 12 burners is industrial propane (mass fractions are Propane 90%, Butane 5%, and 5% propylene). The manikin is instrumented with 134 heat flux sensors distributed over the surface of its body, as shown in Fig.2. A computer system controls data acquisition, calculates surface heat flux and skin temperature distribution histories, and predicts skin burn damage for each sensor location.

On the basis of systematic CFD simulations, it was shown that the heat flux from the flame and from hot fire gases is clearly dependent upon several computational assumptions, such as grid resolution and numerical scheme. On the other hand, predictions of gas temperature showed less sensitivity to variations in the computational conditions than heat-flux predictions did. It was also noted that different CFD codes based upon the same general principles and model equations showed appreciable variation in the results they provided.

Six different pyrolysis models of varying sophistication and complexity were discussed and evaluated. The models were first evaluated on stand-alone basis in terms of a level of heat flux specified by the user, the results being compared with corresponding Cone Calorimeter measurements. This procedure provides a measure of the consistency of the computational results as compared with experiments using cone fluxes of differing magnitude. It can also provide assistance in obtaining input data or determining how reasonable such data is before its being used in large scale modelling, in which the pyrolysis model is implemented in its original CFD environment. Simulations of two large-scale tests of differing geometry representing a challenge to the overall models, were likewise performed. It was concluded that none of the models were able to provide adequate and consistent predictions of the resulting flame spread and fire growth for the two scenarios. In comparing the measured and the computed incident heat flux it appeared that the of best-fit correlations with results obtained in the Cone Calorimeter involved certain inadequacies.

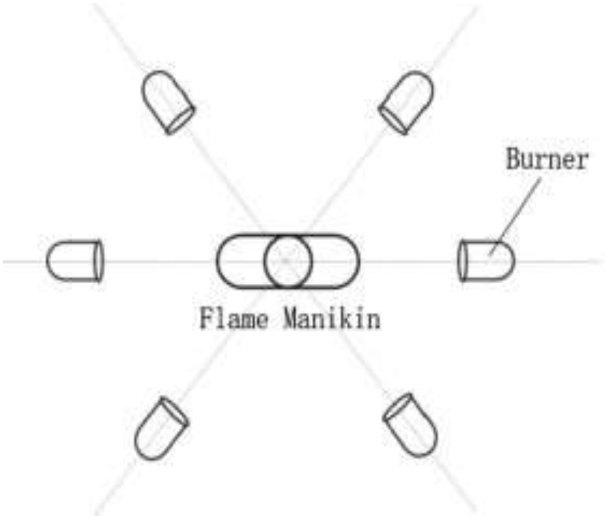

Fig. 3: Layout of 12 burners in 2 groups

Appropriate clothing design are beneficial for preventing the wearers from skin burn injuries and heat strains simultaneously. The intention of this work was to investigate the effects of clothing ventilation designs on its thermal protective performance by bench-scale tests. Four boundary conditions were designed to simulate the garment aperture structures on fabric level. Tests of thermal shrinkage, mass loss and time-to-second-degree-burns were performed with and without air gap under three heat-flux levels for two kinds of inherently fire-retardant fabrics. The impacts of fabric type, heat-flux level, air gap and boundary condition were analyzed. The presence of a 6.4-mm air gap could improve thermal protective performance of the fabrics, however, the garment openings would decrease this positive effects. More severe thermal aging found for spaced test configuration indicated the importance of balancing the service life and thermal protective performance of the clothing. The findings of this study implied that the characteristics of fabric type, air gap, boundary condition, and their effects on fabric thermal aging should be considered during clothing ventilation designs, to balance the thermal protection and comfort of the protective gear.

Using the most advanced software and technology we create a replica model of your project to graphically and numerically map the spread of flames, heat and smoke which we then use to create the most efficient fire strategy for your building, in accordance with the relevant statutory requirements and other fire safety objectives.

CFD fire modelling can be a powerful tool but only when used correctly. Warringtonfire Australia employs experts in CFD fire modelling who use their many years of wide experience to competently utilize the CFD fire modelling to predict potential fire behavior and development.

Fire modelling is a key tool when trying to predict the spread of smoke and heat from fires in built environments and when used correctly can be a powerful design and safety tool.

When a building burns often the smoke inhalation or heat transfer can be more hazardous than the movement of the flames, so it is important to assess how this may occur in the event of a fire. This can then influence means of escape planning and the design of passive and active fire systems.

CFD fire modelling looks to solve equations describing the fluid flow and heat transfer from the growth and spread of fire. They predict smoke and heat movement in buildings of any design and is a key tool in fire engineering.

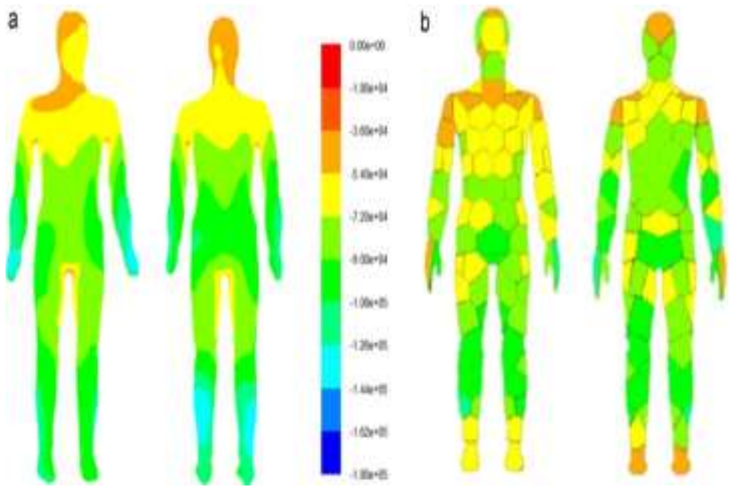

Fig. 4: Comparison of heat flux (kW/m^2) profiles on the surface of the numerical manikin. and actual manikin at the 4th second after flaming.

Fire, which is conventionally defined as uncontrolled flame spread, is arguably one of the most complex phenomena considered in combustion science. It embraces nearly all the effects found in subsonic chemically reacting flows. Fluid dynamics, combustion, kinetics, radiation, and in many cases multi-phase flow effects are linked together to provide an extremely complex physical and chemical phenomenon. Fire Safety Science has grown significantly especially over the last twenty years. Mathematical modelling of fire, however, is still young and a rapidly developing area of Computational Fluid Dynamics. A complexity of the phenomenon makes it extremely challenging from the mathematical point of view. The underlying fluid dynamics, turbulence and combustion problems have not yet been fully resolved and represent significant challenges themselves. Incorporation of all these processes into a unified computational model is an even more formidable task. The development of CFD modeling made it possible to model fire phenomena from first principles via solution of the basic conservation equations. This approach is known in fire research as field or CFD modeling. It has shown success in application to various fire safety problems and its role in fire research is steadily increasing as the models become progressively robust and sophisticated and validation studies make them more reliable. The CFD approach is considered to be fundamental to the future development of fire models which can provide the basis for the development of performance-based fire safety regulations. CFD modeling of fires has become an established and important area in fire research and it is, therefore, worthwhile to review developments and achievements in this field of expertise.

Thermetrics' advanced Flame Test Manikin system is a complete turn-key package, with male or female manikin form, control electronics, modular burn chamber, PC computer and burn prediction software, allowing the operator to characterize the performance of garments or protective clothing ensembles in a simulated flash fire environment having controlled heat flux, flame distribution, and duration.

Manikin shell is constructed from a non-degrading ceramic composite material that is completely fireproof and will not combust or char. Standard mounting support and cable pass-thru located at the back of the neck for minimum influence on garment fit and flame exposure. 134 Copper guarded disc calorimeters are robust and proven technology for years of continuous service.

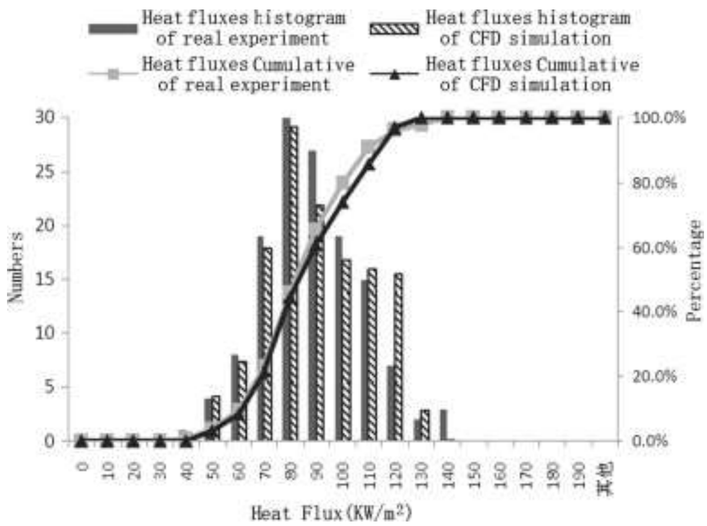

Fig. 5: Comparisons of heat fluxes histogram of CFD simulation and those of actual manikin tests.

This section is devoted to the CFD modelling of fire extinguishment. Suppression by water sprinklers, which are the most widespread fire control systems for buildings, is the only type of extinguishment for which sufficient attempts have been made to model it mathematically. Such modelling basically requires consideration of a gas/water spray medium as a two-phase system. Generally, two methods are applicable: liquid phase may be considered via Lagrangian or Eulerian approaches. Fire protective clothing made of inherent flame-resistant materials shrinks easily when exposed to flash fire. This thermally induced shrinkage affects the thermal protective performance. Methods to evaluate the thermal shrinkage of fire protective garments are under development and there are currently no documentary standards available.

This method involved a portable three-dimensional (3D) body scanner that could be mounted into the flame chamber to capture the 3D images of the nude and clothed manikin immediately before and after exposure. Based on the advanced post-processing techniques, the 3D images of the clothed manikin pre- and post-exposure were compared, and thermal shrinkage of the garment was characterized by three parameters, namely garment surface area change and volume and thickness change of the air layers entrapped between the manikin and garment. This method was supposed to provide basic knowledge for the quantitative research into the effect of thermal shrinkage on thermal protective performance.

4. Conclusion

In this study, 3D CFD simulations were used to study heat and mass transfer in a fire test system for thermal protective clothing against the human body. The grid model used, simulated by the Donghua manikin, has real dimensions and an accurate shape of a typical Chinese man. The temperature and velocity fields across the chamber determined by the CFD simulations in the naked mannequin test with a 4 second flash exposure show reasonable distributions. A real manikin test is also performed for further verification. By comparison, the simulated results of the heat flux distribution on the manikin surface are basically consistent with the actual experimental results. The heat flow in the main part of the body, the torso, is very close to the measured value. However, the heat flow in the limbs in the CFD simulation is higher than in the actual measurements. One of the main reasons for localized errors is the smaller size of the chamber in the simulation than in the real chamber. The heat flow accumulation curves in the CFD simulations are very close to the curves measured with 134 sensors in experiments with real manikin. However, the temperature and soot volume fraction profiles on the turbulent flames do not exhibit similar accuracy as the laminar flames and there is still room for improvement. The evolution of the PSD is computed for both flames in the entire flame region exhibiting weak bimodal distribution in some points. The performance of complex coupled phenomena in PBE modelling via soot kinetics, detailed chemistry, radiation and turbulence interactions is explored.

Based on these results, we conclude that the CFD model can predict the temperature and velocity fields throughout the chamber in the manikin test.

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