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Simulación de conatos de incendio en almacenes de calzado de poliuretano utilizando ignífugos inorgánicos

Simulation of fire outbreaks in polyurethane footwear warehouses using inorganic fire retardants

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Palabras claves: CFAST, Smokeview, Ignífugos, humo, incendio.

Resumen

Introducción: en la actualidad, se ha observado un incremento significativo en la cantidad de incendios que afectan especialmente a tiendas comerciales de calzado, sin que se adopten medidas preventivas eficaces para reducir las posibles pérdidas. Se llevó a cabo una simulación de un almacén de calzado de poliuretano utilizando el software *Consolidated Model of Fire and Smoke Transport (CFAST)* y el visualizador de humo SmokView. Para tener un punto de comparación primero se modeló el escenario de incendio sin implementar ninguna medida de prevención o control. Luego, se simuló un segundo escenario de incendio diseñando un sistema de *Sprinklers* de agua en la sala del recinto con más carga térmica siguiendo la norma UNE 12845 y la norma NFPA 13. Después, para comprobar la eficacia del desalojo del humo y la temperatura del incendio en el recinto se utilizó un ignífugo inorgánico a base de Mg (OH)2 en el agua de alimentación del sistema de *Sprinklers* modificando la Curva de Crecimiento de Calor (CCC) en un 18%. **Objetivos:** Los objetivos del estudio fueron evaluar la eficacia de diferentes estrategias de mitigación de incendios en un almacén de calzado mediante simulaciones con el software CFAST, identificando tecnologías innovadoras para reducir la liberación de potencia del fuego (HRR) y optimizar los tiempos de activación de los sistemas de supresión. **Metodología:** La simulación del incendio se realizó utilizando el software CFAST, considerando las condiciones ambientales de la ciudad de Ambato y las propiedades termodinámicas de los materiales del almacén de calzado. Se diseñó un sistema de Sprinklers de agua según las normativas NFPA 13 y UNE 12845. Además, se evaluó el efecto del ignífugo inorgánico a base de Mg (OH)2 en el sistema de Sprinklers. **Resultados:** los resultados indican un tiempo de saturación de humo de 1510seg y una temperatura del recinto de 34°C a los 34seg sin sistema contra incendio. En la simulación son sistema contra incendios a base agua se determinó: a) el tiempo de saturación de humo en todas las salas a los 67seg, b) el tiempo necesario para enfriar el recinto fue en 1500 seg. para llegar a 34°C. Finalmente, la simulación de incendio utilizando el ignífugo redujo un 22.56 % el tiempo de enfriamiento del recinto hasta llegar a una temperatura fría de 35 °C. La simulación se realizó para la ciudad de Ambato, a una altitud de 2560 m, con una temperatura de 16 °C, una presión de 97172.02 Para una humedad relativa del 65 % y una cantidad límite de oxígeno del 15 %. **Conclusiones:** La implementación de estrategias de mitigación de incendios, como el uso de sistemas de Sprinklers de agua y el empleo de ignífugos inorgánicos, puede reducir significativamente los tiempos de respuesta ante un incendio y minimizar el riesgo de pérdidas materiales y humanas en establecimientos comerciales de calzado. Es crucial considerar la eficacia técnica y la viabilidad económica de estas medidas para promover su adopción en la normativa local y mejorar la seguridad contra incendios en todo el sector comercial. **Área de estudio general:** Ingeniería. **Área de estudio específica:** Prevención y Control de Incendios.

Keywords:
CFAST, Smokeview, Flame retardants, smoke, fire.

Abstract

Introduction: Currently, a significant increase has been observed in the number of fires that especially affect commercial footwear stores, without effective preventive measures being adopted to reduce possible losses. A simulation of a polyurethane footwear warehouse was carried out using the Consolidated Model of Fire and Smoke Transport (CFAST) software and the SmokView smoke viewer. To have a point of comparison, the fire scenario was first modeled without implementing any prevention or control measures. Then, a second fire scenario was simulated by designing a water sprinkler system in the enclosure room with the highest thermal load following the UNE 12845 standard and the NFPA 13 standard. Afterwards, to check the effectiveness of the smoke removal and the temperature of the fire in the premises, an inorganic fire retardant based on Mg (OH)2 was used in the feed water of the Sprinklers system, modifying the Heat Growth Curve (CCC) by 18%. Objectives: The objectives of the study were to evaluate the effectiveness of different fire mitigation strategies in a footwear warehouse through simulations with CFAST software, identifying innovative technologies to reduce firepower release (HRR) and optimize fire activation times. suppression systems. Methodology: The fire simulation was carried out using the CFAST software, considering the environmental conditions of the city of Ambato and the thermodynamic properties of the materials in the footwear warehouse. A water Sprinkler system was designed according to NFPA 13 and UNE 12845 regulations. In addition, the effect of the inorganic fire retardant based on Mg (OH)2 on the Sprinkler system was evaluated. Results: the results indicate a smoke saturation time of 1510sec and an enclosure temperature of 34°C at 34sec without a fire protection system. In the simulation of a water-based firefighting system, the following were determined: a) the smoke saturation time in all rooms at 67 seconds, b) the time necessary to cool the room was 1500 seconds. to reach 34°C. Finally, the fire simulation using the fire retardant reduced the cooling time of the room by 22.56% until it reached a cold temperature of 35 °C. The simulation was carried out for the city of Ambato, at an altitude of 2560 m, with a temperature of 16 °C, a pressure of 97172.02 for a relative humidity of 65% and a limit amount of oxygen of 15%. Conclusions: The implementation of fire mitigation strategies, such as the use of water sprinkler systems and the use of inorganic fire retardants, can significantly reduce response times in the event of a fire and minimize the risk of material and human losses in commercial establishments. footwear. It is crucial to consider the technical effectiveness and economic viability of these measures to promote their adoption into local regulations and improve fire safety throughout the commercial sector.

Introduction

Most of the fires in shoe stores are very significant and persist due to the chemical composition of the materials involved in the combustion that generates the fire, especially the combustible materials of the polymer-based shoe soles. The condition of these traditional commercial places does not comply with most of the regulations determined for fire control, which generates unsafe working conditions due to the lack of a fire protection system.(Suárez et al., 2021). These materials that occupy shoe stores at the time of a fire produce a high thermal load and many toxic chemical species. In addition, it is known that the mass of gases in a fire with shoe materials produces high temperatures and a quantity of smoke that causes incapacity in the occupants and severe burns inside and outside the body.(Sandoval et al., 2019)These unwanted incidents are responsible for the majority of losses, not only in industrial environments, but also in homes and family buildings.(de Silva et al., 2024).

The combustion of sports and school shoes in fires in traditional retail stores has the capacity to generate Dioxins, Furans, Carbon Dioxide, Carbon Monoxide and Particulate Matter that can accelerate the poisoning processes and cause inability to move and loss of consciousness in people who breathe them.(Flowers, 2018)Local regulations require preventive measures that employers try to comply with, but due to lack of knowledge they only establish administrative action plans or preventive signage, which is inefficient.(Rodriguez, 2008). One of the alternatives to control fires is to develop automatic detection and activation systems based on water. But nowadays these fire fighting systems can be improved with the use of water and a mixture of substances that help to slow down the fire and extinguish the action of the fire. These compounds known as fire retardants are of organic origin, although more environmentally friendly materials have been developed and have the same or even a better response capacity in fire and are of inorganic origin.(Sierra, 2010).

Inorganic flame retardant treatments reduce the time it takes for materials to ignite and burn when in contact with fire, improving their reactions and providing more time for people to escape or be rescued if trapped in a confined space. Aluminum Hydroxide Al(OH) and Magnesium Hydroxide Mg(OH)2 are common retardants used to mitigate fires, and can be applied to a variety of combustible surfaces.(Córdova-Suárez et al., 2021). Although these efforts have focused on cost reduction, fireproof materials have been used for several decades. Today, there is greater awareness of their use and benefits, and modern builders incorporate these materials into walls, floors, ceilings, finishes, and furniture. Therefore, testing these alternative solutions can be very expensive and dangerous as it involves live fire scenarios and material consumption to see their effectiveness. More feasible solutions can then be opted for, such as the use of fire simulation.(Alvear, 2007)These tools provide a quick and visual results table to find the best alternative solution and avoid a fire and its consequences. There are many computer tools to model and simulate fires, but they are expensive. Although commercial software such as PiroSym give good results, there are alternatives such as Consolidated Fire and Smoke Transport (CFAST) which, although they do not use field models, manage equations by fire zones and give acceptable results. In addition, its use is becoming more common because it is freely accessible.(Romanovsky et al., 2004).

This study performs a fire simulation using wooden furniture treated with inorganic Mg(OH)-based fire retardants to evaluate their effectiveness using the CFAST computer simulation tool and the SmokView viewer.(Sunta, 2021)The research will serve as a reference for designing autonomous fire-fighting systems in commercial premises selling footwear.

Goals

- Improve the efficiency of firepower reduction (HRR) strategies by 25% by identifying and implementing innovative technologies and fine-tuning the CFAST program to more accurately reflect planned reduction scenarios.
- Reduce the activation times of sprinklers and temperature sensors by 15%, integrating advanced technologies and optimizing the time response of the devices. Priority will be given to improving the accuracy of the CFAST program in simulating the activation of these systems, using real data to validate and adjust the models.

Methodology

Fire Simulation with CFAST

The CFAST software considers the following elements for its simulation: a) environmental conditions, b) thermal properties of the walls, ceiling and floor, c) dimensions of each of the compartments, d) compartment vents, e) mechanical vents if they exist, f) the fires that will originate and all their elements, g) the elements that will help detect and reduce the fire, h) the thermal connections between walls of the enclosure on the same level horizontally and vertically.(Zurita, 2020). For the heat balance, it considers: a) energy accumulation, b) expansion or compression work of the gas layer, c) input flow rate by enthalpy, d) degree of heat release and e) heat transferred. Once the external and internal conditions of the compartment and materials used are entered; the equations used by the CFAST calculate: a) the quantities of species formed stoichiometrically, b) activation times of the suppression systems installed, c) temperatures of the upper and lower smoke layers formed, d) speeds of the masses of combustion products formed.(Boulandier et al., 2001).

CFAST visualizes the results of simulations using the SmokeView program and according to the calculation interval conditions determined in the data entry stage. This software allows to observe in three dimensions what occurs during the entire simulation time and also if the user needs an individual analysis, the results can be made available in Excel sheets that are generated when the CFAST program is executed.

This research simulated three cases of fire under environmental conditions in the city of Ambato. See table 1.

Table 1

Environmental conditions in Ambato

Item	Worth
Height	2560 m
Temperature	16 °C
Pressure	97172.0221 Pa
Humidity	65%
Limit amount of oxygen	15%

In addition, the thermodynamic properties of the materials that will make up the commercial establishment were defined.See table 2.

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Table 2

Thermodynamic properties of materials

	Ceiling	Walls	Floor
Conductivity (kW/m°C)	0.0029	0.0008	0.0014
Specific heat (Kj/kg°C)	1	0.84	0.837
Density (kg/m^3)	600	1800	2220
Material thickness (m)	0.0127	0.15	0.05
Emissivity	0.9	0.93	0.93

In addition, the characteristics of the calorific value of combustion of priority gases were provided, being 27000 kJ/kg, with average molar indices of carbon (C=6), hydrogen (H=10), oxygen (O=5), nitrogen (N=0) and chlorine (Cl=0). The radiation fraction was set at 0.35. The fire power release curve, HRR, is described by the values of 0 kW, 80.5 kW, 322.0 kW, 322.0 kW for the time instants 0 s, 90 s, 180 s, 360 s, respectively. In addition, it was indicated that the fire generates a mass fraction of 0.02 for CO and 0.03 for soot particles.

Sprinkler System Design

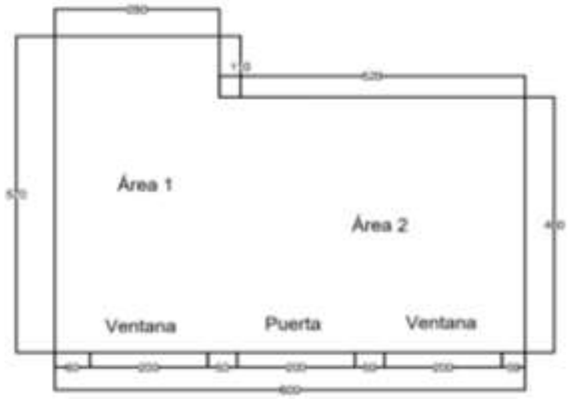
For the design of the Sprinkler system, the NFPA 13 standard was used, which begins with the selection of the type of Sprinkler based on the level of fire risk at the site.(Cedeño, 2019). Hydraulic design calculates: a) system components and accessories, b) system requirements, c) installation requirements, d) design methods, e) plans and calculations, f) water supplies, g) system acceptance and h) system maintenance.(Wass et al., 2020)In addition, they must be located in risk sectors, following a technical analysis of the heat load and the activity carried out.

For this simulation, the suppression system calculations considered: a) water flow rates, b) water density per unit area covered by sprinkler and c) bulb break temperature according to fire risk in the room. The distribution of the network was not detailed in the house plan because it takes advantage of the CFAST's ability to recommend the location of the suppression system in the center of the room. A clearance of 10 cm from the ceiling was considered to avoid contact with the temperature sensor and smoke detectors.

The commercial establishment has a floor plan with a ceiling height of 2.1 m and 3.7 m above the floor. In addition, it is established that the lower frame of the windows is 1 m from the floor, and the doors have a height of 2 m. The initial dimensions of the fire are described as 1 m wide, 1.25 m long and 0.1 m high. See figure 1.

Figure 1

Conditions



In the second evaluation in the CFAST software for the same shoe sales establishment, the simulation focused on the implementation of water sprinklers. No modifications were made to the fire area, thermal conductivity, radiation fraction or combustion heat. The same thickness of the materials was maintained. To further the study,A third simulation was carried out using sprinklers and inorganic fire retardant, reducing the CCC by 22.56%. No adjustments were made to the fire area, thermal conductivity, radiation fraction, combustion heat or material thickness, keeping these variables constant with respect to the previous cases.

Results

Figure 2 shows the temperature profiles under initial conditions of the site without any type of fire control or prevention means.

Figure 2

Temperature profile under normal fire conditions

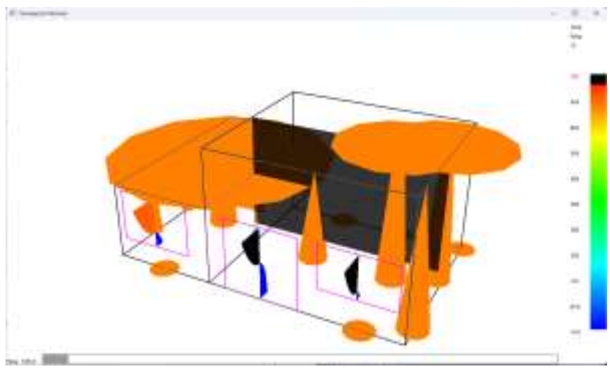


Figure 3 shows the temperature profiles in the simulation of the fire with a sprinkler system and water without inorganic fireproof materials. See Figure 3.

Figure 3

Temperature profile with use of sprinklers

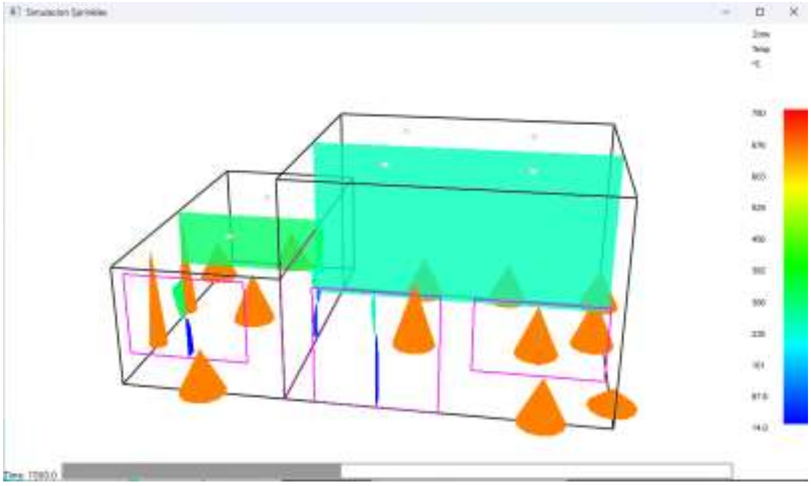


Figure 4 shows that by reducing the CCC by 22.56% through the use of fire retardants, the fire does not spread uncontrollably and can be controlled in less time.

Figure 4

Temperature profile with use of sprinklers and fire retardant

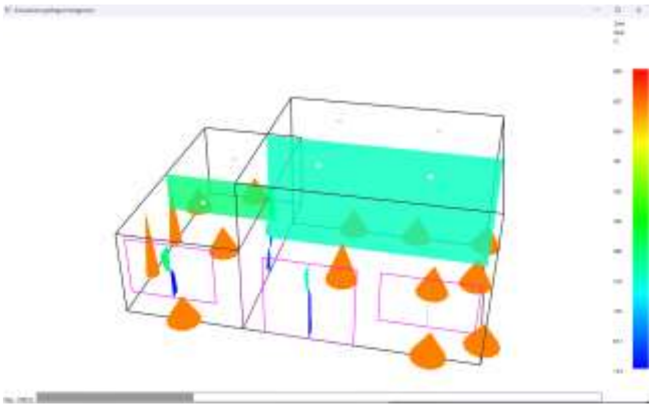


Table 3 shows the cooling and heating times of the fire layers under all conditions simulated with CFAST.

Table 3

Comparison of the three cases

Items	Case 1	Case 2	Case 3
Activating the sprinkler	-	0 s	100 s
Sensor activation	-	80s	100 s
Initial fire time	0 s	40 s	40 s
Warm layer	180 s	180 s	180 s
Cold layer	2000s	1200 s	600 s
Total cooling time	2000s	1500s	1000 s

Discussion

Indeed, although the results obtained with Sprinklers and inorganic fireproof materials may be comparable, it is crucial to include in the design of new commercial premises selling footwear fire prevention measures that comply with the provisions of the REGULATIONS FOR PREVENTION, MITIGATION AND PROTECTION AGAINST FIRE of Ministerial Agreement 1257. These regulations are designed to guarantee the safety and protection of people, as well as the preservation of property in the event of an incident.

In the simulation phase, the introduction of real parameters is crucial for a more accurate and meaningful analysis. However, when considering the implementation of the resulting recommendations, the economic factor emerges as a fundamental consideration. In the Ecuadorian context, the scarce regulations related to the use of advanced fire control systems, such as sprinklers, have contributed to the reluctance in the application of numerous studies (Carrillo, 2022). The lack of specific regulations in Ecuador could raise doubts about the viability and acceptance of solutions that involve additional costs, especially those related to more advanced technologies. This situation highlights the need to not only propose improvements based on simulations, but also advocate for the implementation of regulations that support and promote the adoption of safer practices and technologies. In this sense, it is suggested not only to evaluate the technical effectiveness of the solutions proposed in the simulation, but also to actively address the awareness and promotion of fire safety standards, seeking their integration into local policies and regulations. In this way, the cost barrier can be overcome by demonstrating not only the technical efficiency, but also the importance of these measures for overall safety and the protection of life and property.

Conclusions

- By reducing the fire power output (HRR) curve by 22.56%, as described in the final case with values of 0 kW, 22.5 kW, 122.2 kW and 249.4 kW, it was concluded that the amount of fire is significantly lower compared to the initial case. In the latter, the fire spread was higher. This decrease in fire power output suggests that the implementation of the planned reduction effectively contributed to controlling and mitigating the fire spread in the final scenario.

- The information provided indicates that the activation times of the different fire prevention elements have been determined using the CFAST program. In the first case, which lacks a fire control system, sprinklers were not activated, and the fire was extinguished over time by consuming the merchandise inside the premises, generating glass explosions and excessive smoke in a space of 16 m2. In the second case, the sprinkler was activated after 80 seconds, and in the third case, it was activated after 100 seconds. Then, the temperature sensor was activated after 80 seconds in case one and after 100 seconds in case two. In both cases, the fire started after 40 seconds, and the hot layer started after 180 seconds. The cold layer started after 1200 seconds in the second case and after 600 seconds in the third case. The total cooling time in the room was 1500 seconds in the second case and 1000 seconds in the third case. These data suggest that the use of inorganic fire retardants is beneficial in fire management. In addition, the CFAST program greatly helps to prevent and detect fires through simulations with real data, also offering solutions to problems within a home.

Conflict of interest

The authors declare that they have no conflict of interest.

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