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RESEARCH ARTICLE

Prediction of Smoke Temperature in a Warehouse Using Fire Dynamic Simulator

M. Naim, N. Suria Suhaimi* and M. I. Mohd Fadzhil

Faculty of Industrial Sciences and Technology, Universiti Malaysia Pahang Al-Sultan Abdullah, Lebuh Persiaran Tun Khalil Yaakub, 26300 Kuantan, Pahang Darul Makmur, Malaysia

ABSTRACT - The purpose of this study is to use computational fluid dynamics software, specifically the Fire Dynamics Simulator, to analyze the spread of smoke in high-rack warehouses. The significance of this research is risk that posed to human lives by smoke during fire incidents. High-rack warehouses were chosen as the focus due to their widespread construction globally, particularly in Malaysia where over 200 such warehouses exist. The developed model was modified multiple times to account for different parameter combinations, allowing for the simulation of numerous scenarios. The aim is to propose improvement that can assist designers and engineers in creating safer designs. The research objectives are to examine the relationship between smoke temperature and type of fire source in warehouse fires where the developed model was undergoing a few modifications on parameters and fire scenarios. The findings demonstrate that smoke temperature decreases with increasing building height and the presence of natural ventilation. Type of fire source also influence the smoke temperature. As a result, three recommendations have been derived from the results, intended for utilization by engineers and architects in the design of safer atriums in the future.

ARTICLE HISTORY

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1. INTRODUCTION

A warehouse fire can be a very dangerous and serious event. Large amounts of products and materials, many of which may be flammable or combustible, are frequently kept in warehouses. A warehouse fire can swiftly spread and consume the entire structure, causing huge property damage, the loss of merchandise, and potentially injuries or fatalities. It is essential to plan carefully for, execute, and maintain fire prevention and protection measures in a warehouse to ensure fire safety. Installation of sprinkler and fire alarm systems, regular maintenance of heating and electrical systems, secure storage of dangerous goods, and staff training on fire safety procedures are a few examples of these precautions [1]. In general, ventilation systems should be used to protect industrial buildings or warehouses with huge amounts of stored items. Yet, many of these structures still exist today without these safety precautions. The building's fire protection is often provided by a detection system, fire ventilators, and the local fire department [2]. There is a dearth of information on the spread of fire in structures of this size. With these types of buildings containing stored items, it is practically impossible to get precise information on how the fire spread. The fire's damage is too great, or if it was contained, the knowledge regarding how the fire developed is difficult to understand. According to statistics, suffocation deaths from smoke, fumes, and poisonous gases make up a large portion of all fire-related fatalities [3]. Academic institutions, shopping centres, hotels, businesses, warehouses, and so forth are a few locations where smoke control and path prediction are critical [4].

The exploration of fire dynamics in confined spaces has been a focal point of extensive research. A previous author has conducted experiments and simulations in their studies to scrutinize the behavior of fire in enclosed environments [5], [6]. Their findings highlighted the critical role of ventilation and spatial configurations in influencing fire growth and smoke dispersion. Recent strides in Fire Dynamic Simulator (FDS) applications for warehouse fire safety were made by Arunraj et al., 2015 [7]. Their study concentrated on leveraging FDS to evaluate the impact of fire scenarios on diverse storage configurations. The insights gleaned from this research significantly contribute to optimizing fire safety measures in warehouse design. Addressing challenges in warehouse fire safety, Jahan et al., 2016 [8] presented a comprehensive study identifying gaps in existing safety measures and proposing innovative solutions. Their emphasis on the need for advanced simulation techniques resonates with the current study, which aims to enhance the understanding of fire dynamics in complex storage environments using FDS.

2. METHODS AND MATERIAL

Figure 1 shows a flow chart of this study with the main goal to analyse the risk from smoke and fire produce in warehouse by simulating the fire scenario using FDS. For this research, a quantitative study was conducted using FDS with data collected from warehouse building located in Jitra, Kedah. The study aimed to determine the risk from smoke temperature and fire sources. Beside identification of the fire hazard and risk, fire risk assessment (FRA) also used to verify building compliance with fire safety requirement as stated in building code. Numerical simulations with FDS

***CORRESPONDING AUTHOR | N. Suria Suhaimi** | ✉ nurud@umpsa.edu.my

predicted temperature distribution within a virtual warehouse model, an approach proven effective by Suhaimi et al., 2021 [9] and Johansson, 2014 [10] due to its cost-effectiveness.

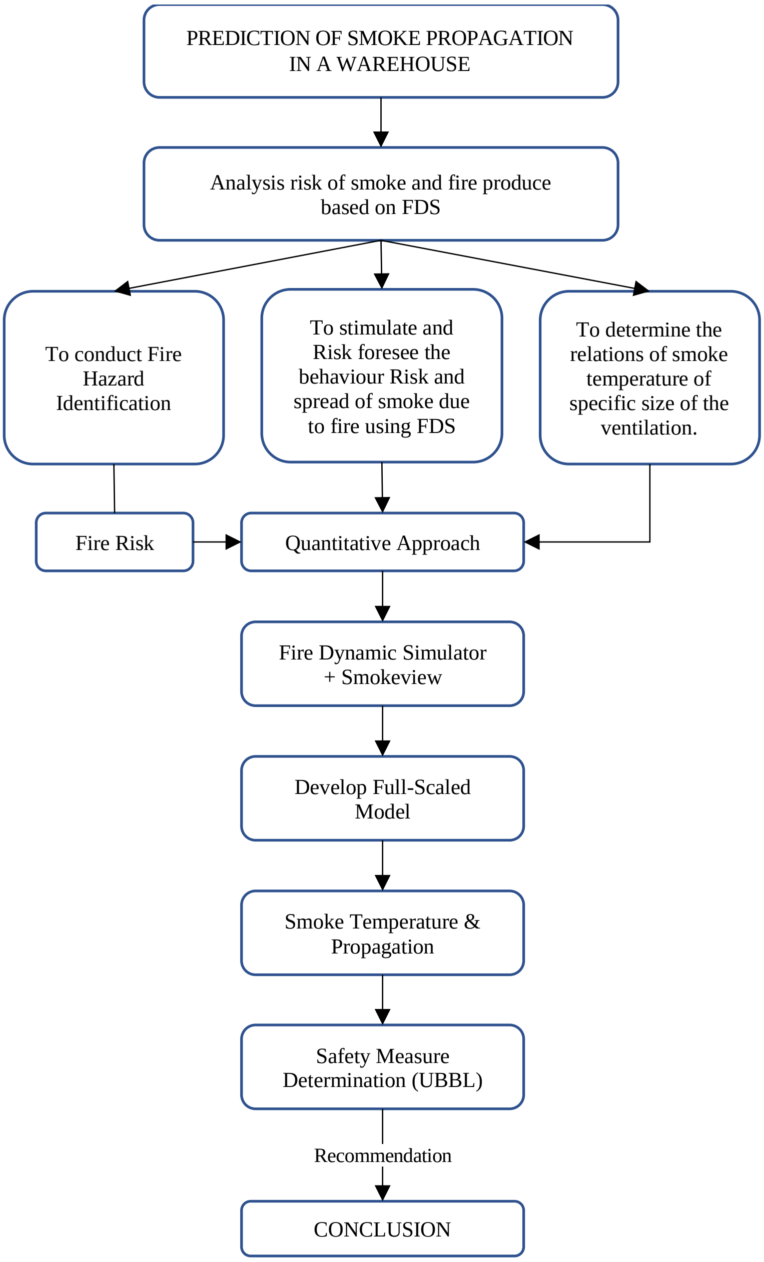

Figure 1. Flow chart of study

2.1 Research Sampling

The target warehouse, that located at Jitra, Kedah is one of the warehouses operated to distribute good and customer needs, such as dry food for daily needs. The warehouse distributor is fully operated since 2015. With a retail space of 3,500 square metres, these warehouses utilize high-density racking systems which are selective pallet racks, drive-in racks, and push-back racks. The layout has fixed low dense and easy to access and feature tall rack structures to maximize vertical storage space. The warehouse is lack of equipment of firefighting systems for maintaining air quality, controlling temperature and humidity levels, and ensuring a safe and comfortable environment for employees and customers.

2.2 Data Collection Method

Fire Risk Assessment was conducted to foresee the fire hazard and predict the temperature of smoke due to fire in high storage rack at a warehouse. This activity was used to identify the fire ignition sources, fuel sources, potential fire spread, and compliance with warehouse fire safety regulations. A quantitative approach has been used for the purpose of the study. In the context of fire dynamic simulators, quantitative investigations involved the interpretation and analysis of simulation findings. The data collection method of the smoke propagation in the warehouse are obtained from the FDS's result based on the smoke temperature. The smoke temperature can be obtained from the simulation in term of graph or table. In this study, there are independent variables and dependent variables. Independent variable is the variable that is manipulated or controlled by the research is type of fire source while dependent variable is the variable that measured or observed to assess the outcome or effect of the independent variable which is the smoke propagation and temperature.

The source of fire in the warehouse will be in the warehouse, consists of various type of source that produce different trend of smoke. The smoke propagation will be measured by one main parameters, which are the size of the opening ventilation and the source of fire. The opening ventilation will contain different measurements that correlation to the size of warehouse differ to Fire Safety Legislations which is Uniform Building by Law (UBBL) 1984. The source of fire in the warehouse will be in the centre and side of the warehouse, consists of two type of source that produce different temperature of smoke. Based on the statistics, the type of fire source contains two items that may happen in the warehouse which are electrical source and gas equipment. The result obtained from the simulation will determine the optimum ventilation opening for the warehouse.

2.3 Data Analysis

After completing the Fire Dynamic Simulation, the obtained data, specifically smoke temperature, is analyzed using visualization techniques such as contour plots, colour maps, or animations. These visual representations offer insights into smoke flow patterns, concentration levels, and the presence of stagnation zones within the warehouse. In this quantitative approach, a comparative analysis of smoke behavior under different fire scenarios is conducted, focusing on smoke temperature and its correlation with natural ventilator sizes for various electrical fire sources. The analysis adheres to safety criteria outlined in regulatory frameworks, including the Uniform Building By-Laws 1984 (UBBL), National Fire Protection Association (NFPA) Section 92, Fire Service Act 1988, and the International Building Code (IBC). Compliance with these standards ensures the effective functioning of fire services and the protection of life, health, and property. The safety implications of simulated smoke propagation are discussed, addressing potential risks to occupants, evaluating the effectiveness of ventilation strategies, and identifying the need for additional safety measures. Recommendations for enhancing smoke control strategies are derived from the data analysis results, contributing to the overall improvement of warehouse safety protocols.

3. RESULTS AND DISCUSSION

Findings from fire risk assessment in warehouse has identified two potential fire sources; DB electric box and electric forklift. The risk level was based on risk matrix has been referred from Guideline established by Department of Occupational Safety and Health (DOSH) [11]. Risk assessments were conducted for each source, considering likelihood and severity. For the DB electric box, the likelihood was assessed as "possible (3)" due to potential events like overheating, arcing, and tripped circuit breakers. Severity was classified as "insignificant (1)" because of minimal impact on warehouse goods. The overall risk level was deemed low, suggesting acceptable conditions with implemented control measures. In the case of the electrical forklift, the likelihood of failure was assessed as "possible (3)," with severity categorized as "fatal (4)" due to potential harm to property and goods. The risk level was evaluated as medium, indicating the necessity for a structured approach and interim measures if required.

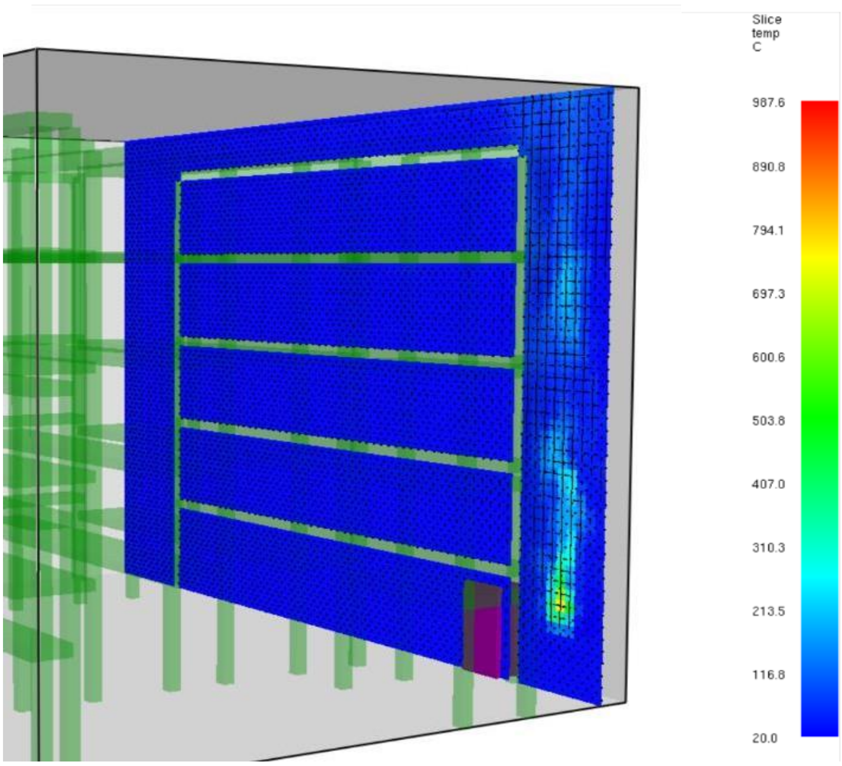

Figure 2. Smoke temperature slice reading of experiment 1

The study conducted Fire Dynamic Simulations (FDS) for two different fire scenarios: Experiment 1 involving the electric Distribution Board (DB) and Experiment 2 involving an electrical forklift. Temperature readings from each rack and compartment were selected, and the results indicated distinct outcomes for both experiments. Figure 2 and Figure 4 show in Experiment 1, the FDS results revealed a smoke layer with a highest temperature of 116.0°C and 120 kW of Heat Release Rate (HRR). This was attributed to effective dispersion facilitated by the natural ventilation system in the warehouse, preventing smoke accumulation near the burning source. On the other hand, Figure 3 and Figure 5 show a smoke temperature profile from a Smokeview in Experiment 2, involving the fire source from electrical forklift, exhibited a smoke layer in the lower warehouse area with a highest temperature of 318°C and nearly 720 kW of HRR. However, in the upper warehouse region, there was a notable accumulation of a smoke which indicating less efficient smoke dispersal likely due to challenges with the natural ventilation system. The study emphasized the need for proactive measures to prevent potential accidents.

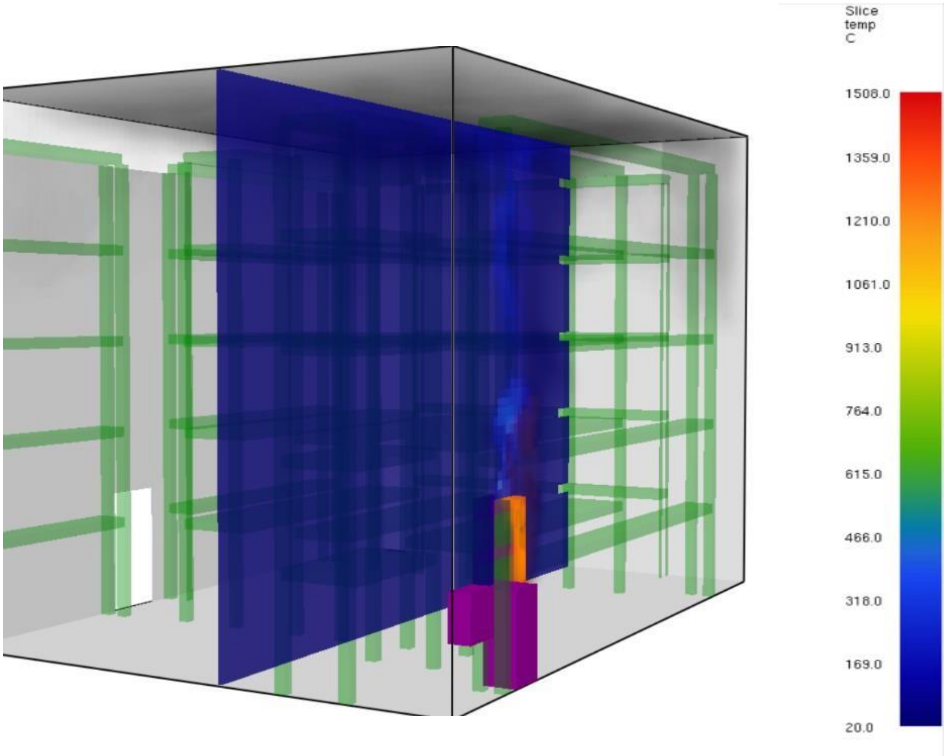

Figure 3. Smoke temperature slice reading of experiment 2

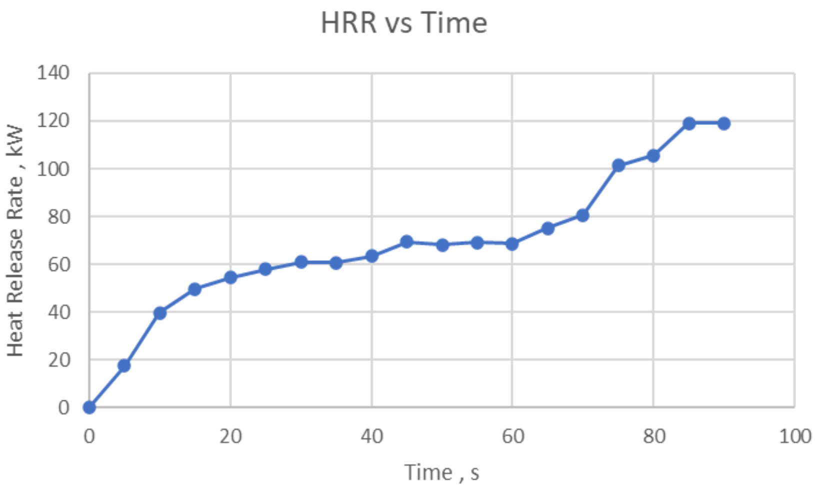

Figure 4. Stability of heat release rate for experiment 1

In summary, the FDS results highlighted the importance of tailored preventive measures for distinct fire scenarios in the warehouse. The risk assessments provided valuable insights for effective risk management, ensuring the safety of the warehouse environment and its occupants [12]. The findings from the experiments involving the DB electric box and electrical forklift highlight significant variations in smoke dynamics, emphasizing the need for comprehensive improvements in warehouse design and firefighting systems.

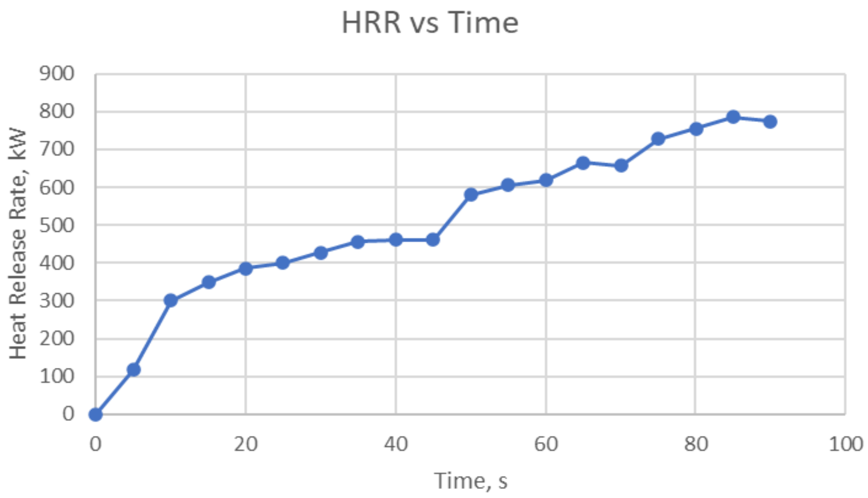

Figure 5. Stability of heat release rate for experiment 2

Experiment 1, focusing on the DB electric box, demonstrated a more controlled and systematic smoke propagation, primarily concentrated at the warehouse ceiling. This suggests that the current warehouse design effectively manages smoke contamination in such scenarios. On the other hand, Experiment 2, involving the electrical forklift, revealed challenges with rapid smoke propagation towards the upper warehouse, resulting in a dense smoke layer. This situation exposes potential shortcomings in the existing warehouse design, particularly in addressing the unique challenges posed by forklift-related incidents. The identified delays in smoke reaching the upper rack during the forklift burning experiment raise concerns about the potential impact on goods stored in the affected area. Goods, even if not directly exposed to fire, could become defective due to delayed smoke dispersal. This underscores the importance of addressing smoke dynamics comprehensively to safeguard stored items. The proposed enhancements involve strategic installations of firefighting systems, considering the nature of stored goods and potential water exposure. Good housekeeping practices and organized storage based on fire load density are recommended to minimize the adverse effects of smoke contamination on stored items. Designated parking areas for electrical forklifts, equipped with firefighting equipment, aim to prevent the rapid spread of fire and reduce the associated risks.

The simulation of the warehouse, spanning 3,500 square meters, indicates that it follows an open corridor design. The need for specific firefighting systems, as outlined by the Uniform Building By-Laws (UBBL) of 1984, emphasizes the importance of compliance with regulations to ensure adequate fire safety measures and also to avoid potential penalties for non-compliance with fire safety regulations, further emphasizing the urgency for warehouse owners and managers to implement preventive measures. Risk control measures, such as regular maintenance and inspections of electrical systems, are crucial in mitigating the probability and impact of potential hazards, particularly those arising from electrical faults [13]. In summary, the discussion underscores the importance of a holistic approach to warehouse safety, considering both design aspects and firefighting systems. Implementing the proposed enhancements and adhering to regulatory requirements are essential steps in reducing the risk of fire-related incidents and protecting the integrity of stored goods in warehouses.

4. CONCLUSION

In conclusion, the Fire Dynamic Simulator (FDS) simulations for experiments involving the DB electric box and electrical forklift offer critical insights into smoke propagation dynamics within the warehouse. Experiment 1 shows controlled smoke concentration at the ceiling, while Experiment 2 reveals rapid smoke propagation to the upper warehouse, forming a thick dense layer. The study underscores the need for enhanced warehouse design and fire control systems, especially addressing challenges from Experiment 2. Recommendations include a designated parking area for forklifts with firefighting equipment, regular electrical system maintenance, and the introduction of exhaust fans for effective smoke control. The study emphasizes proactive risk control measures, regular inspections, and sound warehouse management to minimize fire risks and protect stored goods.

The incorporation of wall-mounted exhaust fans is recommended to enhance smoke ventilation in warehouses. These fans, strategically placed on exterior walls, effectively expel air from the warehouse, preventing smoke accumulation during a fire incident. Their direct removal capability and strategic positioning enable prompt response to smoke, limiting its spread and ensuring specific placement to address high concentration areas. Particularly valuable in confined spaces and buildings with complex layouts, these fans offer a swift activation mechanism upon smoke detection. They not only function independently but also complement other ventilation systems, forming part of a comprehensive smoke control strategy. Integration with fire detection systems allows for automated responses during fire events. A notable benefit is the significant role these fans play in minimizing smoke damage to stored goods, especially in warehouses housing sensitive or valuable items prone to adverse effects from smoke exposure.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHORS CONTRIBUTION

M. Naim (Data curation; Writing - original draft, Conceptualization; Formal analysis; Visualisation)

N. Suria Suhaimi (Methodology; Resources Conceptualization; Formal analysis; Supervision)

M. I. Mohd Fadzil (Methodology; Formal analysis; Supervision)

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