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Simulation Analysis of Fire safety System Onboard Indonesia Ro-Ro PaxCrossing Ferries

Sunaryo[a*], Yulianto Nugroho[b], AlfiIndra Azhary[c]

[a]Naval Architecture Study Program, Universitas Indonesia, Kampus UI Depok 16424, Indonesia
[b]Mechanical Engineering Department, Universitas Indonesia, Kampus UI Depok 16424, Indonesia
[c]Naval Architecture Study Program, Universitas Indonesia, Kampus UI Depok 16424, Indonesia

*Corresponding author: naryo@eng.ui.ac.id

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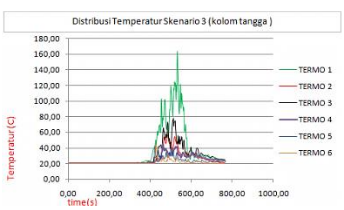
Graphical abstract



Abstract

Fire onboard ro-ro ferry usually claims a great number of casualties. In Indonesia 41% of major marine accidents were fire accidents. Victims of ferry fire accident are usually due to smoke, heat, and low visibility. The research is aimed to simulatethe flow of heat and smoke during a fire from car decks of the ferry to passenger decks and how the fire safety systemsprovide sufficient time for the passengers to escape from the affected areas. Fire Dynamic Simulator V5 (FDS V05) software was used in three different fire scenarios namely without sprinklers; with sprinklers but without smoke exhaust and fresh air supply fans; and with sprinklers, smoke exhaust and fresh air supply fans. It is proven that water sprinklers could suppress the distribution of heat, and smoke exhaust and fresh air supply fans have contribution in maintaining the visibility.

Keywords: Simulation; fireonboard; ro-ro ferries; fire safety devices; escape time

1.0 INTRODUCTION

Ro-ropax ferries play important role in connecting the islands of Indonesia.There are more than 165 official ferry-crossing routes, and served by more than 240 ferries in various sizes, Gunawan[1] stated that most of these ferries are considerably old and many are poorly maintained therefore accidents rate is high. According to the National Committee for the Safety of Transport [2] 41% of the accidents were fire accidents.

Fire accidents according to DnV investigation [3] usually started fromthe engine room or from the vehicle decks. Many of onboard fire accidents claimed a great number of casualties and material lost [4]. The highest causes of casualties were toxic gas and panic due to low visibility caused by thick smoke and heat from the fire.Ventilation and fire extinguishing systems play very important roles in combating the fire and preventing the spreading of fire and smoke. The study was carried out to simulate and analyze the effectiveness of water sprinklers, smoke detectors, smoke exhaust and fresh air supply fans to suppress the spreading of fire and smoke from vehicle decks to passenger lounge, so that passengers would have sufficient time to escape from the fire and smoke affected areas.

2.0 METHODOLOGY

The simulation was carried out using Fire Dynamic SimulatorV5 (FDS V05) released by National Institute of Standards and Technology (NIST) [5] to investigate the heat release rate (HRR) of fire, visibility and temperature distribution in the specified space in this case the vehicle decks and passenger lounge so that the effectiveness of fire safety system applied in the ferry analyzed.

2.1 Fire Hazards

Preliminary fire hazard in a ro-ro passenger ferry could be explained as shown in Table 1.

2.2 Heat Release Rate

Fire is measured in accordance to its heat release rate (HRR) [6]. Equation 1 shows that HRR $\dot{Q}$ is depended on the mass combustion rate ṁ and combustion enthalpies Δh_c. With m as expressed in Equation 2 where ṁ”, k, and β are fire mass combustion rate per sectional area, combustion regression rate of fuel, and fuel density respectively.

$$\dot{Q} = \dot{m}\Delta h_c \quad (1)$$

$$m = \dot{m}''_{max}[1 - exp(-k\beta D)] \quad (2)$$

Table 1 Preliminaryfire hazards

Source	Causes	Consequances
Engine	Over heat	Fire starts in engine room creeps to car deck and passenger lounge
Electrical	Short circuit	Over heat and trigger fire
Vehicle	Engine Electrical	Fire starts in car deck and spread to other places
Cargo	Explosion or trigger fire	Fire starts in car deck and spread to other places
Human	Intentional	Explosion & Fire spread to other places
	Unintentional	Fire spread to other places

2.3 Fire Dynamic Simulator

Fire Dynamic Simulator (FDS) [7] is simulation software that operates based on computational fluid dynamic model to calculate the equations related to flow of mass, energy, and momentum in a specified discrete space particularly for the flow of fire. Numerically FDS calculate the Navier–Stokes equation for slow heat gradient flow that focused on the smoke and movement of heat from fire. The software simulates the phenomena of fire based on determined conditions. Preparation for the simulation include:arrangement of computational area which consists of determination of computational dimensions and discrete volume; geometrical arrangement; materials and geometrical surface arrangement; fire condition arrangement; and simulation parameters arrangement.

2.4 Computational Area and Discretion

The size of computational area was determined as: 0 to 50 m on x axis, -1 to 14 m on y axis, and 0 to 15.45 m on z axis, with the number of discretion 250, 77, and 60 on x, y, and z direction respectively. The number of discretion is relevant to the size of discrete area i.e. 0.19 m X 0.2 m X 0.3 m. And the geometry of selected ro-ro passenger ferry to be investigated was 49.3 m on x axis, 13 m on y axis, and 15.45 m on z axis.

2.5 The Simulation

The simulation was conducted as if the vessel is on fire with three different scenarios: scenario 1, no fire safety device was activated; scenario 2, only smoke detectors and water sprinklers were activated; and scenario 3,all the fire safety devices including smoke exhaust and fresh air supply fans were activated.

The value of HRR was determined at 28 MW with HRR per unit area was 380 kW/m^2,and the area of fire source was 0.17 m^2. The fire source was assumed as burning polyurehtane foam from the upholstery with the burning time 1,000 seconds.

Based on the investigation of the most vulnerable position of the source of fire where, the smoke developed fastest in reaching the passenger deck was the aft of the lower vehicle deck, which only needed 64 seconds, while the fore lower vehicle deck needed 70.2 seconds, and middle lower vehicle deck needed 153.6 secondsas shown in Figure 1.

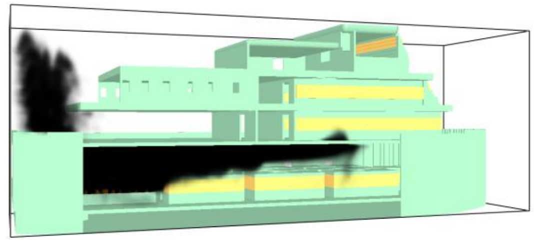


Figure 1 Source of fire

In order to investigate the effectiveness of the fire safety system devices in providing sufficient time for passengers to escape from the heat and smoke affected space, some monitoring devices were installed at certain locations. The monitoring points for investigating the visibility and radiation of heat gas flux were located 1.8 m at the stair cases, and for detecting the heat located 1 m high at every window in the passenger deck.

The effectiveness of fire safety system devices being analyzed were: smoke detectors, water sprinklers, smoke exhaust fans, and fresh air supply fans. Smoke detectors will automatically activate when the accumulation of smoke has reached a certain level of thickness. The water sprinklers will start to function when the heat from fire has reached the set limit and water will be sprayed to the covering area to extinguish the fire and to cool down the heat. The smoke exhaust fans will suck the smoke out from the affected space, and fresh air supply fans will blow and direct the smoke to the smoke exhaust fans, this will make smoke in the room will be thinner, the visibility will be better, so that the passengers will not panic and have more time to escape.

The number of sprinklers to be installed $X_{sp}$is derived from formula 3.

$$X_{sp} = A_t/A_{sp} \quad (3)$$

Where A_t is total area to be covered and A_{sp} is coverage area of each sprinkler. With total area of vehicle deck to be covered 640 m^2, and A_{sp} = 4.6X4.6 m^2 with assumption of 25% overlapping the number of sprinklers to be installed are 56.

The number of smoke detectors to be installed is 12 which were obtained based on the height and area of the vehicle deck i.e. 49.3m X 13 m, and as determined by the distance between each smoke detectors S in formula 4.

$$S = 12 \text{ X } f \,\% \quad (4)$$

Where f is multiplying factor based on the height of the space, for the height of the vehicle deck 5 m the value of f is 71, hence S is 8 m.

According to Grandison [8] the capacity of smoke exhaust and fresh air supply fans should be 2.7 m/s each, or 100,000 m^3/hr for the whole vehicle deck.

3.0 RESULTS

Results of the simulation are as follows:

3.1 Heat Release rate

For scenario 1fire started to develop after the 70th second and got bigger until the 186th second, then ceased after the 312th second, and the value of HRR was 28 MW as shown on Figure 2.

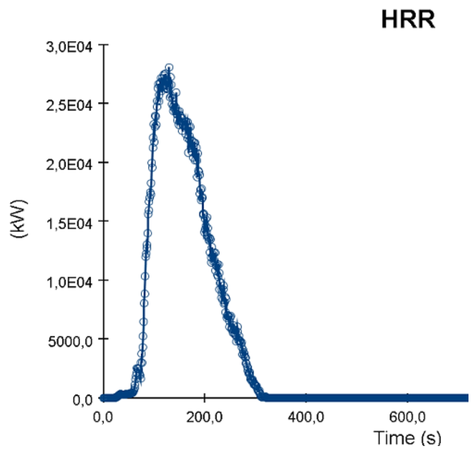


Figure 2 HRR for scenario 1

For scenario 2 the value of HRR was also 28 MW, but the fire ceased after the 210th second as shown on Figure 3. This shows that the water sprinklers had been functioning well in extinguishing the fire.

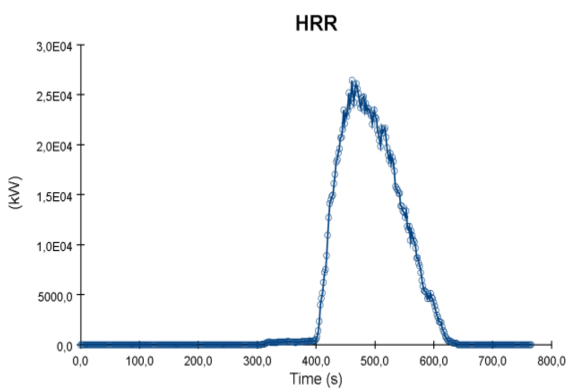


Figure 3 HRR for scenario 2

For scenario 3 the value of HRR was 25 MW, which is 3 MW lower than scenario 1 and 2, fire started to develop at 324th second and kept on growing until the 630th second then beginning slowly to cease as shown on Figure 4.

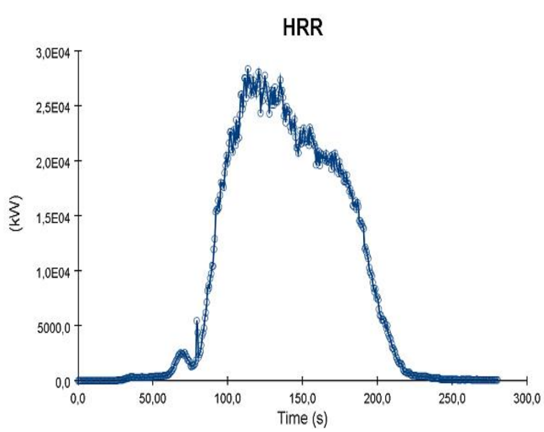


Figure 4 HRR for scenario 3

3.2 Visibility

Visibility results of the simulation are as follows:

For scenario 1the visibility dropped due to thick smoke just after the 100th second as shown on Figure 5.

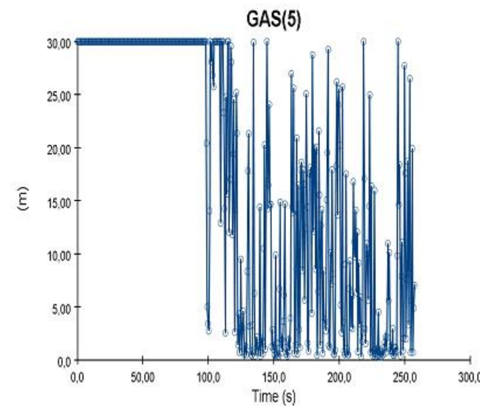


Figure 5 Visibility for scenario 1

For scenario 2 the visibility were fluctuated and started to drop at the 100th second as shown on Figure 6.

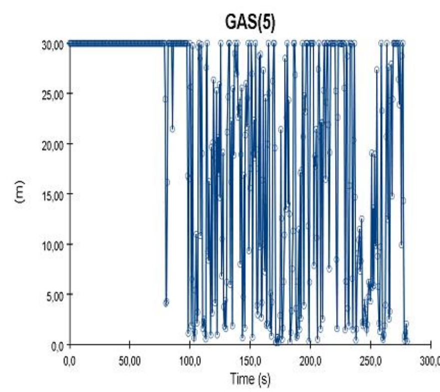


Figure 6 Visibility for scenario 2

For scenario 3 the visibility was maintained until the 400th second, then gradually dropped to the lowest condition as shown on Figure 7.

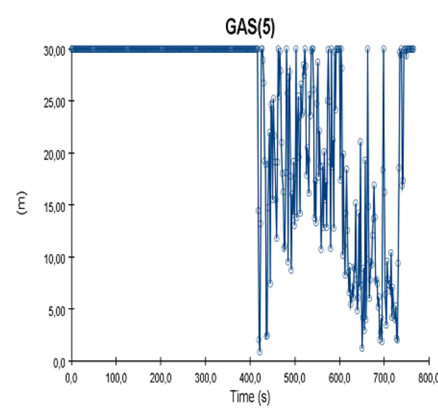


Figure 7 Visibility for scenario 3

3.3 Temperature Distribution

Results of the simulation for the distribution of temperature are as follows:

For scenario 1the heat from the fire reached 380kW after 120 seconds from its start, and the temperature at the stair cases were 270^0C as shown on Figure 8.

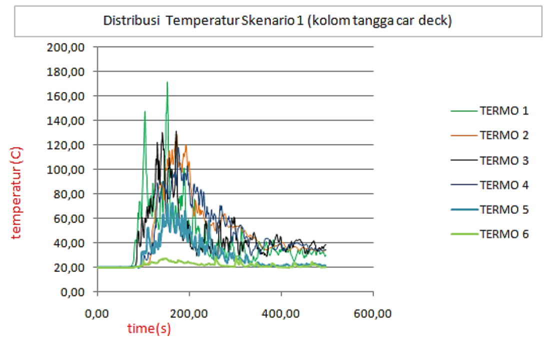


Figure 8 Temperature distribution for scenario 1

For the second scenario the temperature started to increase at the 100^{th} second and gradually ascended to reach its peak at 240^0C at the 140^{th} second as shown on Figure 9.

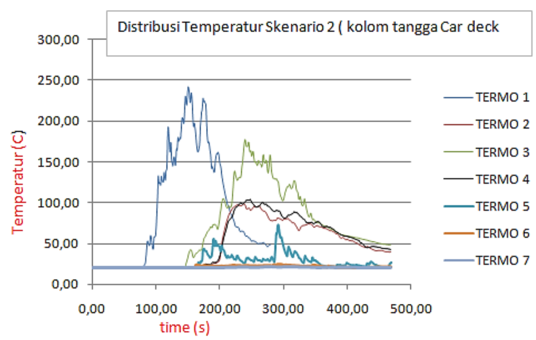


Figure 9 Temperature distribution for scenario 2

For the third scenario the heat started to increase just after the 400^{th} second, and only the stair case that near to the source of fire that reached 160^0C, and the rest only reached less than 80^0C as shown on Figure 10.

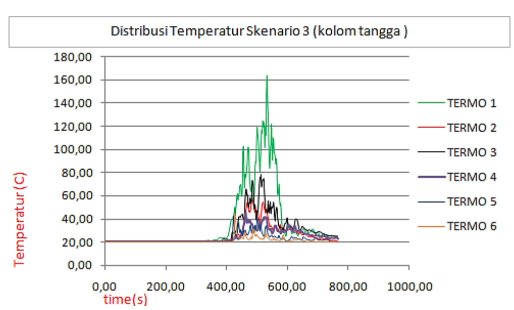


Figure 10 Temperature distribution for scenario 3

4.0 ANALYZES OF THE SIMULATION RESULTS

For the heat release rate second scenario had shown that water sprinklers contributed to the extinguishing of the fire, and the third scenario when all the fire safety system devices were activated the smoke exhaust fans and fresh air supply fans reduced the heat release rate for 3 MW and delaying the development of fire for 254 seconds, which according the Saputra [9] provide enough time for passenger to escape from the affected area.

For the visibility the water sprinklers did not give much contribution, but when all the fire safety system devices were activated the visibility could be maintained for about 400 seconds which, means that the passengers had sufficient time to evacuate to the safer place.

For the distribution of temperature scenario 1 and scenario 2 did not give much contribution for the evacuation of passengers, but when all the fire safety system devices were activated the temperature could be maintained at the safety level for about 400 seconds and the highest temperature was only 100^0C at the stair case nearest to the source of fire.

5.0 CONCLUSIONS

Water sprinklers had contributed to extinguish the fire if the water could reach the source of fire effectively, hence the rest of the fire risks could be prevented, but if the spread of fire could not be avoided, and the smoke started to develop the presence of smoke exhaust fans together with fresh air supply fans had proved significantly in providing sufficient time to maintain the bearable temperature and visibility so that the passengers could evacuate from the affected space safely.

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