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A Numerical Study on the Effects of the Smoke Exhaustion on Safe Evacuation in Emergency Situations during Fires on Ships

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Abstract : *Sometimes, an evacuation should be executed from a ship for many reasons. This study considers on emergency evacuation on fire in a ship, one of the many reasons for evacuation. Due to the characteristic of fire, the most loss of life is known to be caused by suffocation resulted by smoke. To reduce the suffocation by smoke, the time available for evacuation should be improved for the higher survival rate of crews. In this study, crews' survival times and Evacuation time are analyzed quantitatively in during fire in the same sealed space in two different cases of the natural ventilation and the forced ventilation.*

Key words : *Emergency Evacuation, Fire in a Ship, Suffocation by smoke, Evacuation time, Crews' survival times*

1. Preface

1.1 Overview

A marine accident caused by a ship would be a collision, a contact, a strand or a fire. In this study, the interrelationship between fire and evacuation time when an emergency evacuation is executed by crews in various marine accidents. Especially, the cases for the same space are classified as ① if the space is sealed, ② if natural ventilation is possible ③ if forced ventilation is possible, and the crews' survival time is analyzed. To verify the actual evacuation time, the analysis includes walking speed reduction caused by soot density and disturbances according to a ship's characteristics such as rolling and pitching is conducted.

1.2 Study method

For this study, FDS(Fire Dynamics Simulator), the most frequently used program for analysis regarding fire, developed by NIST(National Institute of Standards and Technology) is used. The fire space and flammable materials are produced in DXF file, converted to data format required by FDS and executed using FDS. The application is as shown in Fig.1 (NIST, 2004a and 2004b).

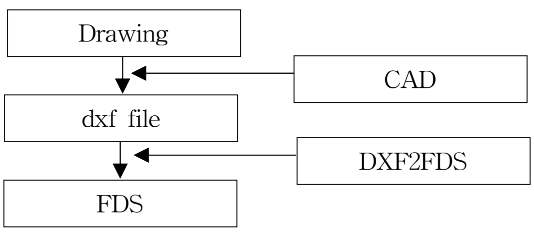

Fig. 1 Method of format conversion

2. Fire Simulation

2.1 Review on Regulatory regarding Fire

The regulatory regarding fire is specified in National Emergency Management Agency Administrator's Notification No.2006-11, NFSC(National Fire Safety Codes) in Korea. In the U.S., for an example, NFPA(National Fire Protection Association) performs the role for fire prevention and safety.

2.2 Review on Regulatory regarding Fire in Ships

Ships, except in Korean coastal areas, are subjected to the international maritime regulations. IMO(International Maritime Organization) is the international organization for the entire maritime issues including ship's safe sailing, safe transportation and maritime pollution prevention. MSC(Maritime Safety Committee) and FP(Fire Protection) of the organization specifically manage the entire matters regarding ship's fire control (Kim et al., 2004). In SOLAS 74(International Convention for the Safety of Life At Sea) Chapter Ⅱ-2 "Construction - fire Protection, fire detection and fire extinction", the matters regarding fire prevention, fire detection and fire extinction in ship are specified in

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detail. The almost all regulations and laws in the entire world are based on the specification (MOMAF, 2006).

Korea applies the Ministry of Maritime Affairs and Fisheries Notification No.61, Year 2004, “Ship’s Fire Extinction Facility Standard”, Korean Ship’s Classification and Steel Ship’s Rule No. 8 “Fire Protection Structure and Fire Extinction” also based on SOLAS Regulation.

2.3 Overview of FDS

FDS is the program calculates equations emphasizing heat and heat flow with the field model numerically analyzing a form of Navier-Stokes equation for heat flow in low speed as CFD model to calculate fluid flow caused by fire. The calculation method is forecasted by the conservation equation regardless to LES(Large Eddy Simulation) or DNS(Direct Numerical Simulation).

2.4 Condition for Model Production and Simulation

The firing sector is produced using AutoCAD. Since the fire sector should be produced in dxf file format for the simulation using FDS, the fire sector is produced in 3D file after the conversion to dxf file using AutoCAD. The converted file is converted for FDS using DXF2FDS program. To perform the simulation using FDS, the firing space’s material, various conditions and variables including the scale of fire, the speed of inflowing air and the firing location are required.

2.5 Simulation Performance

The calculation condition for the simulation is as stated below. Below picture’s showing the area of Fire simulation. Below picture showing 3D rendering model of fire simulation space. Data collection point locates on 0.5m in width, length away from datum point and height is 1.5m. Data collection point is set on “check point”to concern breathing height of person and exit according to the safety of evacuation. Vent is randomly assigned on same fire situation.

○ Fire Space	5m × 5m × 2m
○ Simulation Duration	100 Seconds
○ Fire Scale	100kW
○ The Size of Fire Source	50cm x 50cm
○ Flammable Material	Wood
○ Interior Temperature	25°C
○ The Size of Ventilation Door	0.5m × 0.5m
○ Air Vent Capacity	2m/s

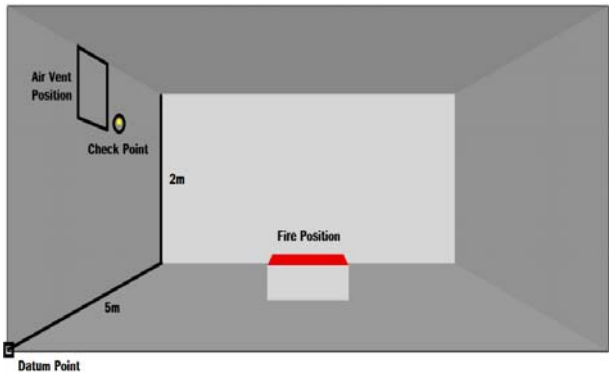

Fig. 2 Fire position & check point

And, in this simulation, the evacuation limit temperature and the visibility are calculated. It is regulated that the temperature of the evacuation space shouldn't exceed 60°C

Table 1 Time(sec) to reach a temperature of 60°C

Condition	Time
Close	18
Open	19
Open-fan	30

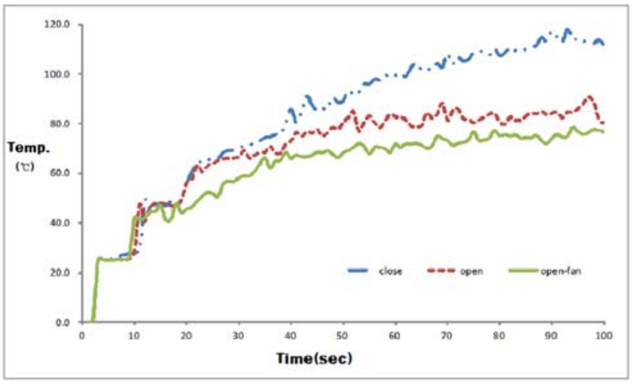

Fig. 3 Temperature

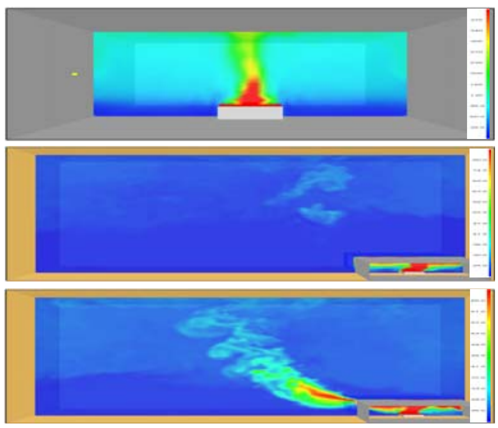

Fig. 4 Temperature (3D graphic)

and reflecting objects without self-lighting such as exit doors, walls and stairs should be identifiable in 6 m range (Rie and Lew, 2003). The time taken to reach 60°C in temperature is as sfown in Table 1. The entire temperature analysis graph is as shown in Fig. 3 And, Fig. 4 is the 3D representation of the temperature. And We set the condition 60°C and 6m because it is the limit value of habitable area.

Also, in NFPA130(1997), the regulation states the visibility should satisfy the condition that reflecting objects without self-lighting such as exit doors, walls and stairs should be identifiable in 6 m range. The analysis results of

Table 2 Time(sec) to reach the visibility range to reach 6m

Condition	Time
Close	31
Open	33
Open-fan	54

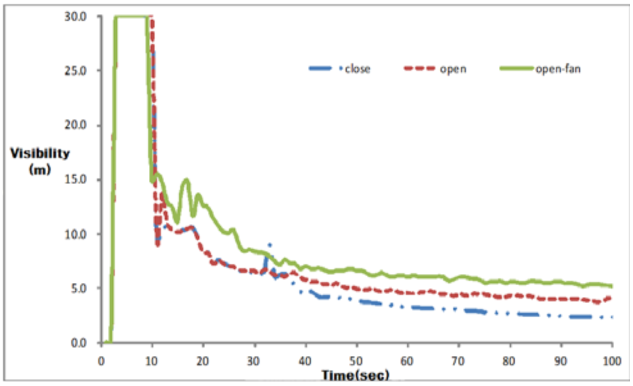

Fig. 5 Visibility

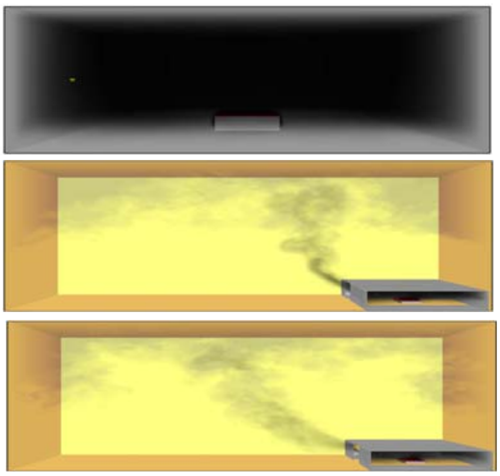
Fig. 6 Visibility (3D graphic)

time taken in the visibility shorter than 6m are as Table 2. And, the entire temperature analysis graph is as shown in Fig. 5 And, Fig. 6 is the 3 D representation of the temperature.

3. Evacuation Time Review

3.1 Evacuation Time Forecast

In this study, the time required for the evacuation in the condition that total 25 people are in the firing space with width of 5m, length of 5m and height of 2 m while the width of the evacuation path is 1 m is forecasted. The forecast is made using Harold E. "Bud" Nelson's evacuation estimation method of study for mobilities in emergency (SFPE, 2005). And, the simulation is performed using Pathfinder developed by THUNDERHEAD, an exclusive application for evacuation with sufficient consideration of human behavior characteristics.

1) Harold E. "Bud" Nelson's Research

Evacuation time means the time taken by people to escape from the firing space. The calculation is defined as Eqn. (1) and the time taken before evacuation is calculated as shown on Eqn. (2).

$$T_{ae} = T_{me}e + T_d \quad (1)$$

where

T_{ae} = Actual Evacuation Time

$T_{me}e$ = Calculated Evacuation Time

e = Evacuation Efficiency

T_d = Initial Evacuation Delay

$$T_d = \frac{\sqrt{\sum A_{area}}}{30}$$ [Japanese Ministry of Construction Notification No. 1441(2000)] (2)

The evacuation start time of the firing space of this study shows to be approx. 10 seconds. And, according to the simulation, the evacuation time is approx. 20.2 seconds. Therefore, it is determined that total 30.2 seconds would be spent. Fig. 7 is analysed by pathfinder what using SEPE system. And it explains evacuation time and type according to characteristic of human behavior(Thunderhead Engineering, 2009).

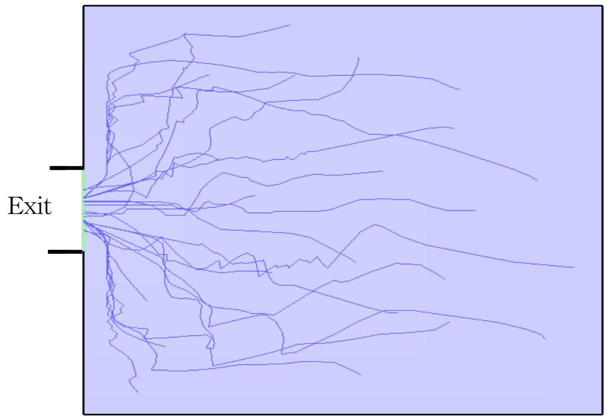

Fig. 7 Types of crews evacuation

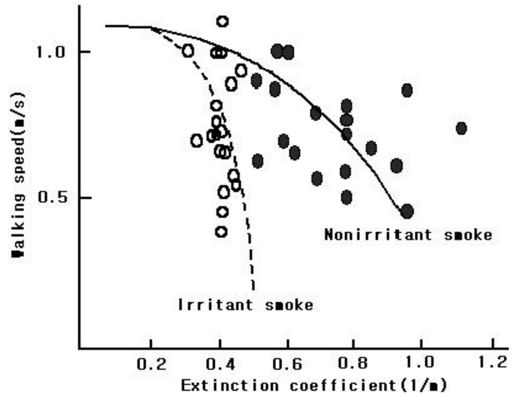

Fig. 8 Walking speed according to Extinction coefficient

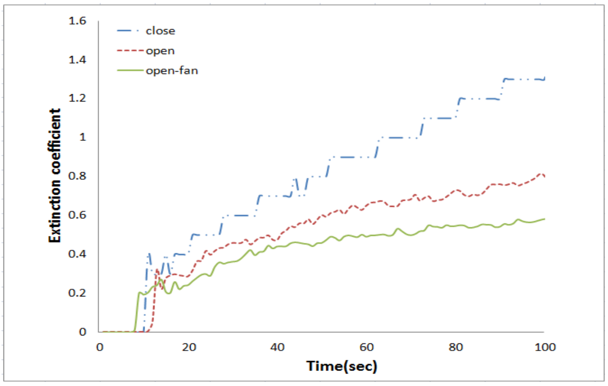

Fig. 9 Extinction coefficient

3.2 Evacuation Time Increase According to Ship's Distinctiveness

Although walking speeds are different depending on ages and genders, in general, the walking speed for the passage and the entrance is analyzed to be 1.19m/s in average (SEPE 2005). However, for a ship, the walking speed is expected to be reduced due to rolling and pitching.

As a part of MEP Design (Mustering and Evacuation : Scientific Basis for Design) Program, the Netherlands's TNO Human Factors BriteEuram Project, the walking speeds of 150 adults with age from 18 to 83 year-old in a passage and on a slope of stairs interrupted by rolling were reviewed. And, the result shows that both in vertical and horizontal rolling, the walking speed is found to be reduced with approx. 15% depending on the rolling frequency (Kim et el., 2004). In other words, when a ship is rolling, the actual evacuation time is estimated to be 19.2 seconds, 15% increase from 16.7 seconds according to this function and approx. 23.2 seconds, the 15% increased from the simulation result, 20.2 seconds. The average of the two results for more trustful result shows the evacuation to be 21.2 seconds.

3.3 Evacuation Time Increase Due to Extinction Coefficient

As Fig. 8 displays, if the extinction coefficient of smoke including toxic gas is higher than 0.4, the walking speed is reduced to 1/2. The extinction coefficient analyzed in this study is as Fig. 9 (KFPA, 2005). Extinction coefficient is used as a method of visibility measurements. The Extinction coefficient 0.4 is equal to 6m of visibility.

According to the pathfinder result obtained by SEPE formula the time for the extinction coefficient to reach 0.4 is about 8 seconds so that total 9 persons will escape during a normal execution of evacuation. Since walk speeds of the 16 persons left is reduced to 1/2 to be approx. 20.7 seconds, when the evacuation starting time 10 seconds is added, the total evacuation time becomes 38.7 seconds. If the room is naturally ventilated, after 19 seconds, the time for the extinction coefficient reaching 0.4, total 23 persons will escape while the remaining 2 persons are taking additional 3.7 seconds due to their reduced walk speed. Therefore, the total evacuation time is 22.7 seconds and will be 32.7 seconds if the evacuation start time is added. As the last, if a forced ventilation is performed for the room, the total 25 crews will escape completely in 20.2 seconds before the extinction coefficient reaches 0.4 so that the evacuation time will be 30.2 seconds in total.

However, for the actual evacuation time estimation, the characteristics caused by the ship's roll should be considered. In other words, since walking speed is reduced by approx. 15% by the ship's rolling, the actual evacuation time is considered to be for the sealed room, 44.5 seconds, for the naturally ventilated room, 36.1 seconds and for the forced ventilation 23.2 seconds.

Table 3 Actual evacuation time(sec)

Condition	Evacuation time
Close	44.5
Open	36.1
Open-fan	23.2

4. Conclusion

According to various researches, more lives are lost by suffocations with various toxic materials produced during fire compared to the temperature increase. This happens because speedy evacuation is unavailable due to lack of visibility. In general, when the visibility is limited by smoke, people becomes in panic condition to be hard to escape. Therefore, only when the visibility, the state with more than 6 m visible range is secured, an evacuation trial can keep the safety of lives. In this study, the temperatures and the visibilities in the sealed room, the naturally ventilated room and the forced ventilated room are examined separately.

As a results, as shown on Table 1 & 2, the times for temperature to be 60°C, the evacuation limit temperature are reached before the completion of evacuation in all cases except the room with forced ventilation so that the crews' survival rates are expected to be reduced. In other words, a ventilation of smoke is analyzed to improve the survival rate by increasing safe evacuation time for crews.

However, ventilations should be made to air out of a ship. If a forced ventilation is made toward the inside of the ship, smoke will be rapidly spread to reduce the survival rate.

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