NUMERICAL SIMULATION OF FLAME PROPAGATION CHARACTERISTICS FROM RUPTURED FURNACE WALL OF A NAPHTHA REFORMER

Ahn J.* and Jang S.I.
*E-mail: jahn@kookmin.ac.kr
School of Mechanical Systems Engineering,
Kookmin University,
Seoul, 02707,
Korea,
E-mail: jahn@kookmin.ac.kr

ABSTRACT

Petrochemical plant is dealing with high temperature and high pressure conditions that must be handled properly. In particular, the reformer as the main equipment of the plant to decomposing naphtha is a high-risk facility. If any failure, such as cracks in the pipes inside reformer is happening, it can cause leakage and explosion may occur. In this study, the event of an accident by a leakage of the inner tube in reformer is evaluated using a numerical analysis with respect to the occurrence and spread of the flame. The result is visualization of flame and hazard area.

INTRODUCTION

Chemical Plant in Korea has increased rapidly since the late 1960s. As a result, the number of refineries and petrochemical plants in South Korea is the world's top 10 [1]. Meanwhile the chemical plant that processes a lot of hazardous substances at a high pressure and temperature are potentially dangerous. In addition, these facilities are grouped in petrochemical complex and it is not close to a residential area. Therefore, sometime it has a geographic vulnerability. Thus, due to accidents such as fire, explosion and large toxic leak could lead to national disaster [2]. As many plants operating in Korea for over than 10 years, it becoming increasingly deterioration in the long-term use. Thus, interest in plant maintenance and reliability evaluation has recently been increasing accordingly.

Most Korean petrochemical plant accident occurred in the pipeline and it frequently happen during the distribution of naphtha process[2]. Thermal cracking method of hydrocarbons such as naphtha, ethane, propane and their mixtures is the most common method used to olefin production [3]. The reformer is operated at 500 ℃ to 1200 ℃ and 90kPa, this extreme condition may lead to a serious accident if any leakage happened during the process. The hazardous naphtha arise from wide range of flammability and the substantial amount of energy released if it burns or explodes [4]. Many complicated transfer and reaction processes, including mass transfer, momentum transfer and heat transfer, as well as thermal cracking reactions and fuel combustion, which are intimately coupled and interact each other, take place in furnaces.

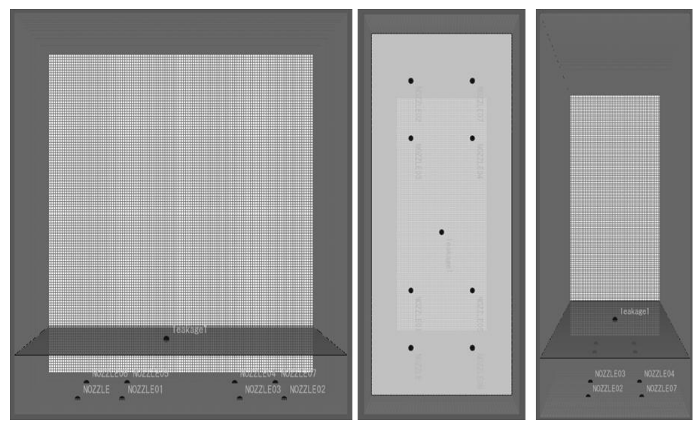

Figure 1 Computational domain and grid system: In-furnace fire

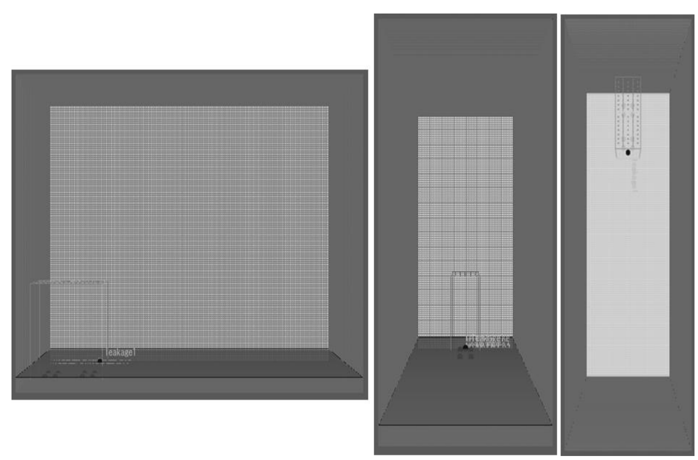

Figure 2 Computational domain: Fire leakage out of the furnace

It is difficult to obtain the detail operating parameters in the furnace from direct measurements due to the limitation of current techniques [5]. In this study, the numerical analysis on flame propagation of the gas leakage in the pipe wall is assessed. The numerical results is utilized to develop methods for minimizing the damage caused by the leakage accident .

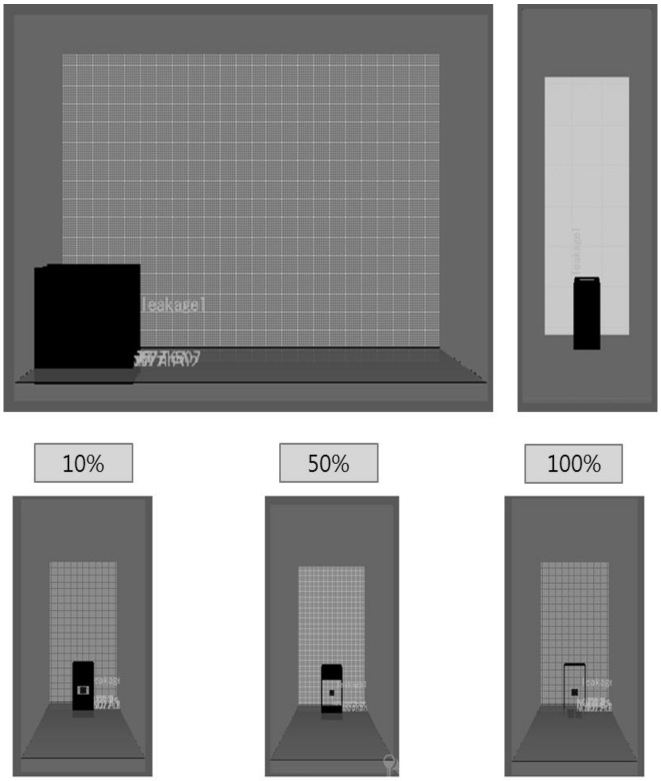

Figure 3 Grid system: Damage on the Wall

The steps of this numerical study, firstly the reformer tube is assumed has a gas leak and analyzed the characteristics of flame propagation inside the reformer in the certain case. Second step is the wall of the furnace is destroyed by the fire, which is assumed that the flame is ejected to the outside furnace. Numerical analysis was performed with respect to the flame propagation characteristics according to the rupture geometry. Numerical analysis is performed using LES (large eddy simulation) of FDS code.

PROBLEM DESIGN AND NUMERICAL SIMULATION

Flame Propagation inside a Naphtha Reformer

In this study, the geometry of the furnace is shown in Figure 1. The computational domain was inside the naphtha reformer located in South Korea. The furnace size is 11.8 m$\times$5.4 m$\times$12.3 m which has 8 burners. Fuel flow rate to be set at 0.125 ℓ/sec and rupture section of the tube is one point. The gas leakage flow rate is assumed as 4.2 ℓ/sec and flue gas outlet is located in the upper right corner of the furnace. Grid system based on the Hexagonal mesh is configured with 770,000 hexahedron of grids are used. The scenario of leakage gas is set to be 60 seconds.

Design of Flame Propagation Scenario from Ruptured Furnace Wall of a Naphtha Reformer

The computational domain in the simulation is all inside the reformer. Domain size is 51.8 m×19.3 m×37.3 m and shown in Figure 2. Reformer is placed in the lower left corner of the domain and set a hole in the right wall of the reformer, and analyzed the characteristics of flame propagation from the hole.

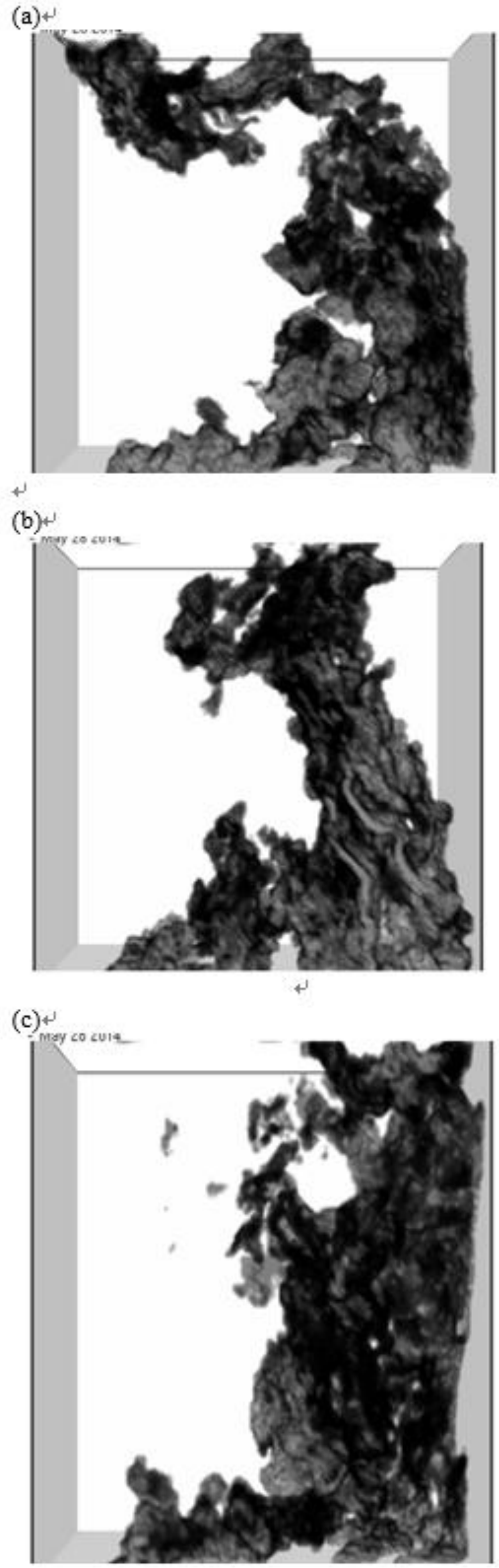

Figure 4 Flame images: In-furnace fire
(a) 22.5 sec (b) 30 sec (c) 60 sec

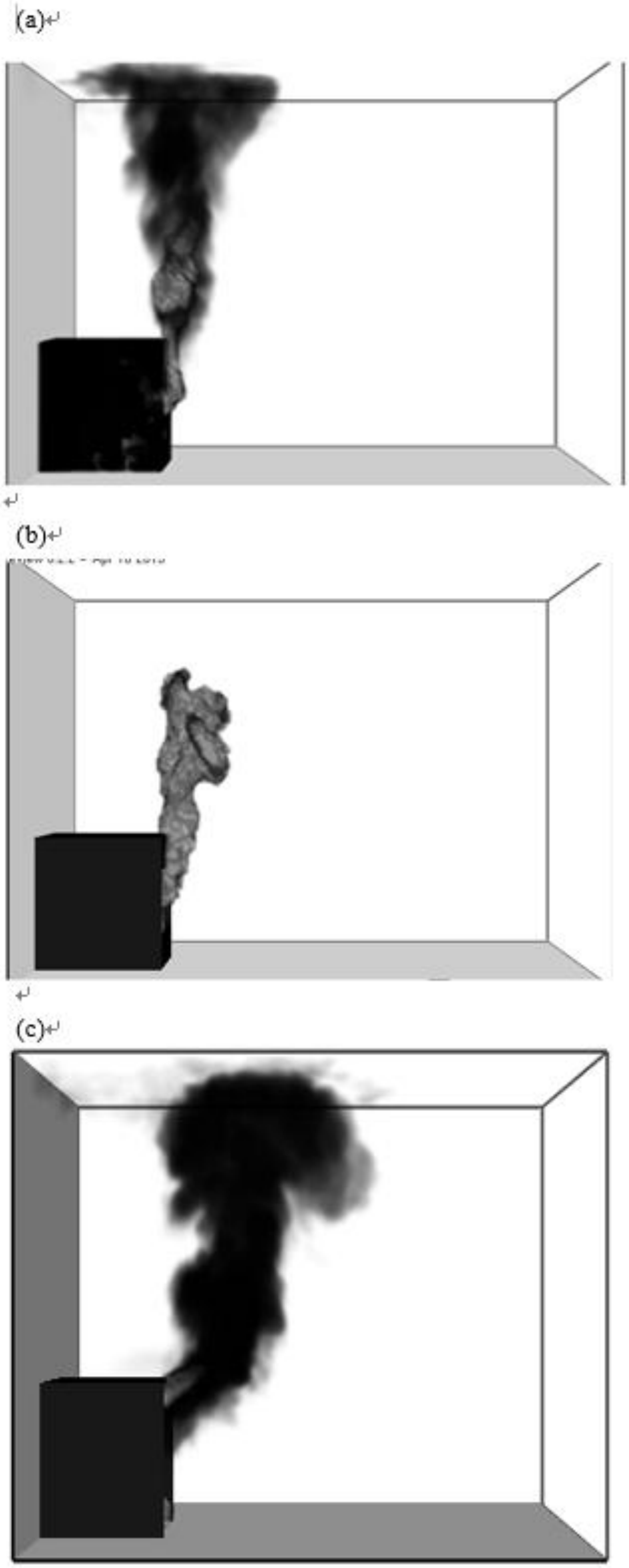

Figure 5 Flame images: Maximum flame size
(a) 10% (b) 50% (c) 100%

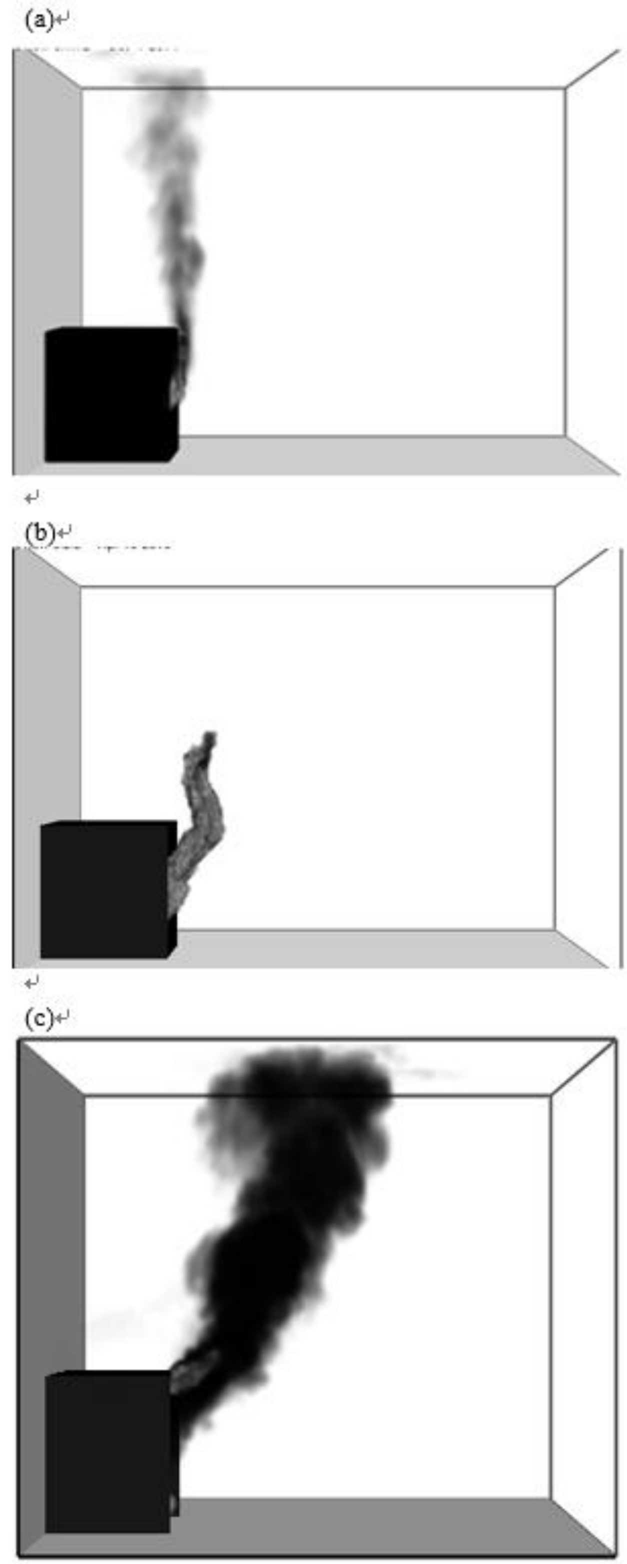

Figure 6 Flame images: After 30 seconds
(a) 10% (b) 50% (c) 100%

The size of the holes occurred in reformer is 10%, 50% and 100% of the right side wall area.

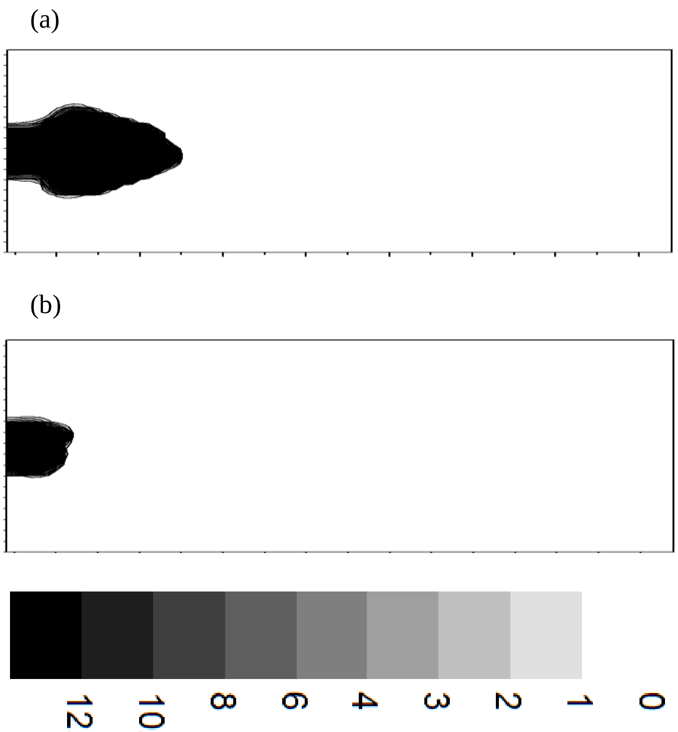

Figure 7 hazard Area: Maximum hazard Area
(a) 10% (b) 50%

Table 1 Flame images: After 30 seconds

kW/m²	Time for Severe Pain (sec)	Time for 2nd Degree Burn (sec)
1	115	663
2	45	187
3	27	92
4	18	57
5	13	40
6	11	30
8	7	20
10	5	14
12	4	11

Which is located in the center of the reformer wall. Grid system based on the Hexagonal mesh was configured with 770,000 hexahedron grids. The reformer is includes 8 burners with fuel flow rate is 0.125 ℓ/sec. Rupture section of the tube is one point. Leakage gas flow rate is 4.2 ℓ/sec.

CFD Technique and Boundary Condition

In this study, numerical analysis was performed using FDS. FDS code is employed to calculate turbulent flow for LES. The program package consists of two parts, the simulation program fire dynamics simulator (FDS) which is developed by national institute of standards and technology (NIST) and the visualization program Smokeview. The FDS predicts smoke and/or air flow caused by fire, wind and ventilation systems. It consists of major modules: A computational fluid dynamics module, which solves the Large-Eddy form of the turbulence equations using the Smagorinski model and the low Mach number approximation. This turbulence model has been shown to be appropriate for low-speed, thermally driven flows of smoke and hot gases generated in a fire with an emphasis on smoke and heat transport from fires. This module is using the Eulerian approach. An improved combustion model for the fire dynamics including pyrolysis of a mixture fraction combustion model. A module for heat transfer by conduction, convection and radiation. And a module for the simulation of sprinkler sprays using a Lagrangian approach by tracing a large number of droplets [6]. FDS has been used for many types of problems like sprinkler activation in warehouse fires, tunnel fires, tenability in residential fires, and smoke concentration in outdoor fires [7]. 8 burners were set to fuel flow rate of 0.125 ℓ / sec. 1 leakage point was set to fuel flow rate of 4.2 ℓ /sec. The scenario of leakage gas is set to be stop at 60 seconds. Wall boundary condition is applied to a standard wall function. Radiation model was used for Wide band model [7].

RESULTS AND DISCUSSION

The Numerical analysis is performed to examining the usage of Low Mach number of FDS code and understanding the combustion characteristics in a high-temperature flue gas. The flame was maximized in 22.5 seconds. The shape of the flames from 22.5, 30 and 60 seconds as shown in Figure 4. The outlet is on the right at the top, with the result that the flame is seen spread to the outlet direction from the center of the lower ignition points. The flame shape is maintained to be similar until the analysis time is ended. Numerical analysis results shown that the features of large flame formation from leakage point in case of high-temperature flue gas is better than ambient temperature air. Maximum Mach number is generated in the vicinity of the leak point; the value is 0.3. Therefore, it was confirmed that the numerical value can be interpreted as low Mach number code of FDS.

Performed analysis the case of destroyed right wall for accident Severity analysis including a damage range on the leakage accident. The maximum size of the flame shape is shown in Figure 5 it is represented in 24, 12, 15 seconds when the hole size of the wall is 10%, 50% and 100 % respectively. When the cases of hole size are 10% and 50%, the wall surface are formed with flame while the shape is floating vertically. In this case, the right wall completely destroyed. The recirculation flow is the flame development in a diagonal direction in the downstream direction.

The shape of the flame of 30 seconds is shown in the Figure 6. In this case, only a part of the wall is destroyed at the time 30 seconds, also the size of the fire is decreased. However, it seems a characteristic flame spreads in the width direction when only a portion of the fracture wall. On the result that, it is necessary to analyze the damage range and maximum flame time.

The maximum size of the hazard area is shown in Figure 7. The maximum hazard area was calculated by the reference [8]. The maximum hazard area is represented in 53.75 ㎡ when the hole size is 10% of the wall area and 13.75 ㎡ when the hole size is 50% of the wall area.

CONCLUSION

The numerical analysis of the combustible gas leakage accident due to the internal pipe damage of the reformer show that the large flame is formed in the leaking direction from the initial time of leakage. Therefore, in this case, the gas in the piping leakage is confirmed that the risk of damage to the wall direction of leakage is high. The lifted flame shape of the flame due to buoyancy occurs when the walls of the reformer damage is more than 10%. In this case, the wall is completely destroyed while the air flows inside the reformer and the flame generated in a diagonal direction. Smaller damage happen on the wall of a reformer is show that the flame spreads to a wide range and increase the hazard area. Therefore, it was confirmed that a small damage earlier on the wall of a reformer caused the highest risk of damage to the wall.

ACKNOWLEDGMENT

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