Risk Analysis of Domino Effect Due to Fire in Petroleum Plants

by

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21414

Dissertation submitted in partial fulfilment of
the requirement for the
Bachelor of Mechanical Engineering
With Honours

FYP 2
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Universiti Teknologi PETRONAS
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Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Mechanical Engineering Programme

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in partial fulfilment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(MECHANICAL)

Approved by,

(AP. Dr. Mohammad Shakir Nasif)

UNIVERSITI TEKNOLOGI PETRONAS

SERI ISKANDAR, PERAK

JANUARY 2020

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

ABDUL RASYID BIN ME’ERAJ

ABSTRACT

Fire accidents in petroleum plants are one of the common issues that happen in the industry nowadays. The facilities and equipment in petroleum plants have the risks to involve in accidents specifically fire accidents. These accidents first started as single event then they can spread leading to a domino accident. Fire domino accident have a great impact on a petroleum plant causing the loss of properties and fatalities. The common type of fire accidents that occur in the industry is pool fire. Fire domino can be categorized into three parts: primary event, escalation and secondary scenarios. There are a lot of detailed researches done on the primary and secondary scenarios during a fire accident but there are not many studies done on the escalation. Escalation effect is one of the important aspects in differentiating between an accident to be a normal accident or a domino accident. Then, there are also not many researches done on the impact of escalation during a fire accident in term of detailed loss of properties in a petroleum plant. This study focuses on analysing risks of domino effect due to fire in petroleum plants. The objectives of the study are analysing risks on escalation and the method used to analyse risks for this research is Quantitative Risk Analysis. This method consists of four steps: hazard identification, probabilistic analysis, consequence analysis and calculation of risks. Consequence analysis is done by doing a simulation of a fire accident in a petroleum plant by using Fire Dynamics Simulator (FDS) to evaluate the impact of heat radiation to the surrounding and the loss value of properties in a fire domino accident.

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1. INTRODUCTION

1.1 Background of Study

Several studies had been conducted throughout the decades on cause and consequences of domino effect in the industry. In various petroleum plants all around the world, there are many cases of domino effect due to fire that can affect and cause lot of damage to them. Fire domino effect had the highest chance to occur in petroleum plants due to the presence of highly flammable substances. Therefore, risk analysis had been conducted to identify the possibility and consequences of domino accidents. There are three concepts of domino effects: (1) A primary event, (2) Secondary accidents triggered and (3) Escalation effect, which the secondary accidents suffer more severe damage than the primary event. These three concepts must be presence for an accident to be categorized as "Domino Accident".

Quantitative Risk Analysis (QRA) is one of the tools of risk analysis. There are four steps in this method: hazard identification, frequency estimation, consequence analysis and measure of risk. This method focused on assessing on the potential risk by quantifying every risk and relying on probabilistic techniques.

Fire accidents are the most common types of accidents to occur in the industry. This is mostly because of the presence of flammable substances in a plant. Fire is an exothermic oxidation reaction occurring in the gas phase resulted from the mixing of flammable gases with air or other oxidative means. There are four categories of fires: pool fire, fire ball, jet fire and flash fire. The most common type of fire accident occurred in the industry is pool fire.

This study will focus on doing risk analysis to the escalation effect in a fire accident specifically pool fire and analyse the impact of escalation to a petroleum plant.

1.2 Problem Identification

In a fire domino effect, the fire on a primary event is transferred to the secondary equipment due to escalation effect. There are many studies done on describing detailed information on the primary event and secondary scenarios in a fire accident. There are not as many detailed studies on escalation effect in a fire domino accident done. Escalation effect is a major factor for a fire accident to be categorized as a fire domino accident.

Escalation triggered by fires resulting in domino scenarios was the cause of severe accidents in the industry. The escalation vector involved in fire accidents in petroleum plants is heat radiation. In order to evaluate the impact of heat radiation during a fire accident, risk analysis is performed.

1.3 Objectives

This study focuses on the escalation stage during a fire that can cause severe damage leading to domino effect in a petroleum plant. The objectives of this study:

1. To perform a risk analysis on the escalation effect during a fire accident that cause domino effect.

2. Evaluate the impact of heat radiation to the surrounding during a fire accident based on escalation using Fire Dynamics Simulator (FDS) software.

3. Evaluate the loss of properties in a petroleum plant after a domino fire accident.

1.4 Scope of Study

This study focuses on domino effect due to fire accidents in a petroleum plant that can cause a lot of damage on the plant. The fuel that will be focused is gasoline because gasoline is a common fuel in a petroleum plant. The type of fire that will be focused is pool fires. Pool fire is one of the most common fire accidents that occurs in petroleum plants and it usually causes the highest damage on the plant.

2. LITERATURE REVIEW

2.1 Risk Analysis

2.1.1 Risk

Risk is a possibility of exposure to danger or harm. Risk can also be defined as a product of probability of occurrence and consequence. According to Reniers and Faes (2013), there are three types of risks that can be recognized roughly. First type is risks where there are many historical data available. The consequences of this type of risks applies primarily to individual employees such as work-related accidents. Second type is risks that had very little history information available. This type of risks can impact an organization or large parts such as large explosions, domino effects, etc. Third type is risks that had no occurrence before. This type of risks may have unexpected and unparallel effect to the company and society. In summary, the first type can be regarded as “occupational accidents” as these accidents might occurred on mostly workers or employees only. The second and third types of risks can be categorized as “major accidents” because they could cause multiple fatality accidents and cause huge economic losses.

2.1.2 Quantitative Risk Analysis (QRA)

In order to avoid risks from becoming accidents that can cause losses, risk analysis is performed. Risk analysis is identifying and analysing potential issues that could impact negatively on a unit. One of a risk analysis tools is Quantitative risk analysis (QRA). Quantitative risk analysis (QRA) is a method comprised of four steps: hazard identification, frequency estimation, consequence analysis and measure of risk. Hazard identification is the most critical step because unquantified hazards can lead to underestimated risks. The techniques used to identify hazard include hazard indices, hazard and operability (HAZOP) studies, failure mode and effect analysis (FMEA), what-if analysis and checklists. The scope of a QRA is defined after the hazards are identified. Frequency estimation is quantifying the probability of each accident scenario. Third step, consequence analysis is aiming to measure the effects of the predicted accident scenario. The consequences are calculated in terms of total number of casualties or the number of injuries or estimating the total value of the loss of properties. Finally, the fourth step, which is measure of risk is the composition of step two and three. It can be used to calculate the actual risk of the accident (Khan, F., 2001).

2.2 Domino Effects

2.2.1 Domino Effect

Domino effect is any incident that began with a minor accident that can trigger a sequence of events that cause damage over a bigger area and lead to severe consequences.

Propagation effect is the main element that describes situations where a domino effect occurs. In a domino accident, to launch one or more secondary scenarios, the propagation of a primary accident scenario will take place. Therefore, in relation to the propagation component, to additional elements of a domino scenario can be identified: the existence of a primary scenario and one or more secondary scenarios. Figure 2.1 demonstrates alternate patterns of propagation that can be inferred in the domino scenario analysis. The concept of a simple propagation is one-to-one correspondence, a single primary scenario resulting in a single secondary scenario. A first accident scenario causes a second scenario in a multi-level domino chain, then triggering a chain reaction of scenarios. (Reniers, G. and Cozzani, V., 2013)

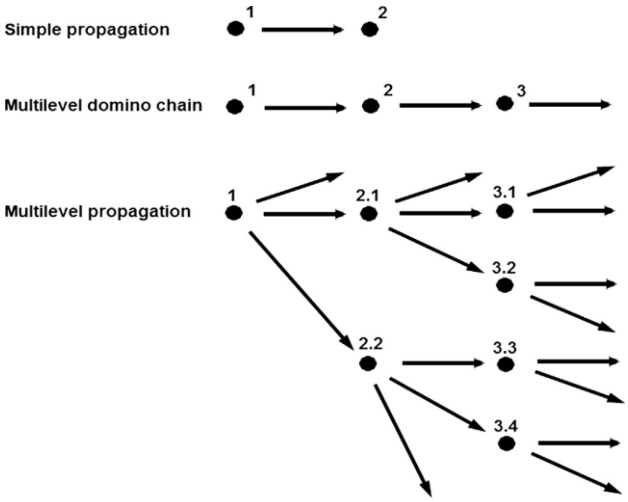


Figure 2.1: Examples of simple propagation, multiple-level domino chain and multilevel parallel propagation patterns (Reniers et. al., 2013).

According to Denti, J. et. al. (2017), there are three principles to be taken into account when assessing a domino effect incident: (1) primary event, (2) secondary target and (3) secondary scenario. A primary event is the case of the incident and its consequences are embodied in physical effects such as thermal radiation, overpressure and so on. Secondary targets are infrastructure that may be affected by the primary event and if destroyed, the secondary scenarios that caused by the primary event intensify further outcomes than the primary event, that is, the domino effect.

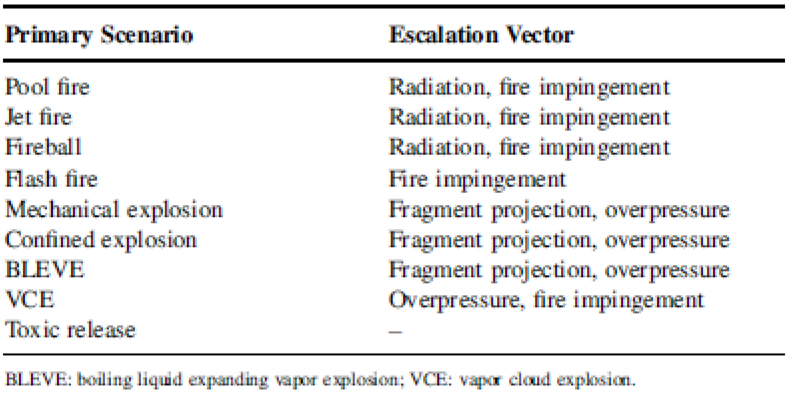
Different interpretations of domino effects have been proposed. An accident can be categorized as domino effect if there are these three concepts involved: (1) a “primary” event that occurs in a certain unit, (2) the propagation of the accident to one or more units, in which “secondary” accidents are triggered as a result of the primary event, (3) an “escalation” effect that results in overall increase in effects, with secondary accidents being more severe than the primary one (Darbra, R. et. al., 2010).

2.2.2 Escalation

Escalation is the intensification of the overall consequences of an accident. It is also one of the elements needed for a domino accident. The escalation vector, which means a vector of physical effects produced by the primary accident scenario such as heat radiation, overpressure and fragment projection, is another component required for a domino accident.

Escalation is a specific element of domino accidents. Propagation alone may not justify in considering a scenario as a domino accident. Frequently, a severe primary event involves other units besides the initiated accident. However, the damage afflicted on the secondary scenarios may not be as severe as the primary event itself. Escalation is required in order to consider an accident event to be domino accident. The overall consequences of the domino event should be expected to be more severe than the damage on the primary scenario. Propagation is therefore correlated with escalation of domino accidents and secondary scenarios lead to the overall consequences of the domino event. (Reniers, G. and Cozzani, V., 2013).

According to Reniers and Cozzani (2013), there are two main patterns identified for propagation and escalation: (1) direct escalation and (2) indirect escalation. Direct escalation is caused by the direct damage of target units because of radiation, blast waves and fragment projection. Table 2.1 shows the vector of escalation produced by different categories of primary scenarios.



Primary Scenario	Escalation Vector
Pool fire	Radiation, fire impingement
Jet fire	Radiation, fire impingement
Fireball	Radiation, fire impingement
Flash fire	Fire impingement
Mechanical explosion	Fragment projection, overpressure
Confined explosion	Fragment projection, overpressure
BLEVE	Fragment projection, overpressure
VCE	Overpressure, fire impingement
Toxic release	–

BLEVE: boiling liquid expanding vapor explosion; VCE: vapor cloud explosion.

Table 2.1: Escalation Vector Generated by Different Categories of Primary Scenarios (Reniers and Cozzani, 2013).

Indirect escalation scenarios can be caused by system or plant section control loss due to primary scenario impact. For example, a control room damage caused by a blast wave or the fleeing of untrained operators due to a toxic dispersion or fire can result in a system loss of control. These accidents are more likely to occur if the primary event involves a nearby plant, operated by a different company that predicts different types of accident scenarios.

2.3 Fire Accidents

2.3.1 Types of Fire Accidents

Fires and explosions are most critical and frequent causes of damage to facilities and industrial injuries and casualties. Fire accidents are most likely to occur in a petroleum plant because of the presence of flammable gases. The effects of fire accidents are too high that it can cause a great damage and loss to the plant. Fire is an exothermic oxidation reaction occurring in the gas phase, which is the product of combination of air or other oxidative means.

Four different models of fires have been developed: pool fire, fire ball, jet fire and flash fire. Pool fire is characterized as a turbulent diffusion fire burning over a horizontal pool of vaporizing flammable material in conditions where the initial momentum of the flammable material is very small. The duration of the pool fire is not immediate, depend on the quantity of the fuel evaporated. There are three categories of pool fires: confined and unconfined pool fires on land and fires on water. Confined pool fires on land have the most common occurrence in the industry. Fire ball resulted from a vast outflow and combustion of pressurized flammable gases. Fire balls radiated a very large amount of heat which caused damages, harm or injury to a larger area than the radius of the fire. The duration of a fire ball is very short or immediate. Jet fire is defined as turbulent dispersion arising from the combustion of continuously released flammable materials with considerable momentum in a particular direction. These factors differentiated a jet fire from a pool fire. The duration of a jet fire depended on the amount of fuel liberated. Flash fire resulted from a sudden combustion of a cloud of fuel gases, where due to the presence of barriers or the effect of turbulent dispersion, the flame is not accelerated. The flash fire shock wave is small, and the duration is limited, so the impact will only damage the facilities inside the cloud and had minimum damage to facilities outside of the cloud (Assael, M. and Kakosimos, K., 2010).

2.3.2 Fire Accidents Analysis

According to Darbra et. al. (2010), many industrial accidents are fire-based, accompanied by explosions and gas clouds. Fires and explosions caused subsequent accidents and a domino series was triggered by their physical effects. The scenario damage increased significantly due to the influence of a domino effect. Jet flame impingement, pool fires, vapor cloud explosion blasts and the effects of explosion missiles are the most common primary events that lead to more severe damage to facilities.

The properties of fire are influenced by leakage rates and depend on time, type of flammable substances, storage and discharge conditions, the surrounding structures and ambient wind conditions. Although there are many possible fire incidents, few industrial fire classes are relevant for escalation leading to domino effect. Table 2.2 shows the detailed characterization of fires ability to trigger escalation, evidencing the relevant features of the industrial fires and the potential secondary effects due to the ignition of flammable material involved in domino accidents (Landucci, G. et.al., 2013).

Features Relevant for Escalation		**Type of Fire**					
		Confined Jet Fire	**Open Jet Fire**	**Confined Pool/Tank Fire**	**Open Pool Fire**	**Fireball**	**Flash Fire**
Combustion mode		Diffusive	Diffusive	Diffusive	Diffusive	Diffusive	Premixed
Total heat load (kW/m^2)		150–400	100–400	100–250	50–150	150–280	170–200
Radiative contribution (%)		66.7–75	50–62.5	92–100	100	100	100
Convective contribution (%)		25–33.3	37.5–50	0–8	0	0	0
Flame temperature range (K)		1200–1600	1200–1500	1200–1450	1000–1400	1400–1500	1500–1900
Escalation criteria for fire impingement	Atmospheric equipment	Escalation always possible	Escalation always possible	Escalation always possible	Escalation always possible	$Q_{HL} > 100$	Flammable vapors ignition*
	Pressurized equipment	Escalation always possible	Escalation always possible	Escalation always possible	Escalation always possible	Escalation unlikely	Escalation unlikely
Escalation criteria for distant source radiation	Atmospheric equipment	$Q_{HL} > 15$	$Q_{HL} > 15$	$Q_{HL} > 15$	$Q_{HL} > 15$	$Q_{HL} > 100$	Escalation unlikely
	Pressurized equipment	$Q_{HL} > 40$	$Q_{HL} > 40$	$Q_{HL} > 40$	$Q_{HL} > 40$	Escalation unlikely	Escalation unlikely

Q_{HL}: thermal flow received by the fire in kW/m^2.
*For floating roof tanks.

Table 2.2: Classification of Fires in the Process Industry, Evidencing Escalation Criteria Based on the Heat Load Received by the Target (Landucci et. al., 2013).

Major causes of fire accident in storage tanks in petroleum plants are poor designs, poor operating procedures and poor management. The design flaws in a plant such as poor layout, pipe, vent and seal releases not properly designed can cause major setbacks on the plant and causing higher damage afflicted on the facilities during a fire accident. The maintenance and operator errors also could cause disastrous events toward a plant if the personnel assigned for the maintenance is not qualified or properly trained. Better procedures are required on the plant personnel so that there will not be technical errors that can cause a fire accident and lead to domino effect. The management also play an important role in managing the plant. Mistakes such as poor audits that fail to check the requirements for the designs according to proper standards. Then, management failure to supervise the maintenance and operating procedures according to specified standards can cause errors on the plant leading to an accident to occur (Zheng, B. and Chen, G., 2011).

3. METHODOLOGY

3.1 Research Methodology

3.1.1 Overview

Desk study

- Research on literature review.

Experimental investigation

- Study the facilities and equipments in a petroleum plant and modelling the plant in Fire Dynamics Simulator Software (FDS).
- Identifying the potential facility or equipment that have the potential to be a primary event for a fire.
- Run the simulation to evaluate the impact of heat radiation from the primary scene of the fire to the surrounding facilities and equipment.

Interpretation and conclusion

- Evaluation of the potential impact of the fire domino accident in a petroleum plant.
- Evaluation of the potential value loss of properties due to fire domino accident in a petroleum plant.

3.1.2 Research Flow

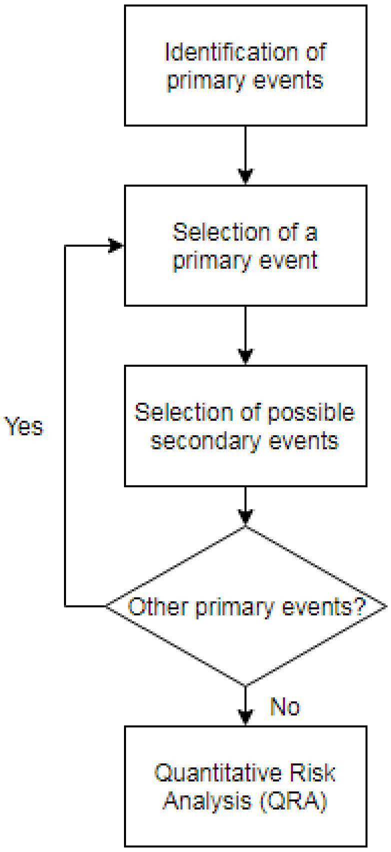


Figure 3.1: Flow Chart of Domino Accident Methodology

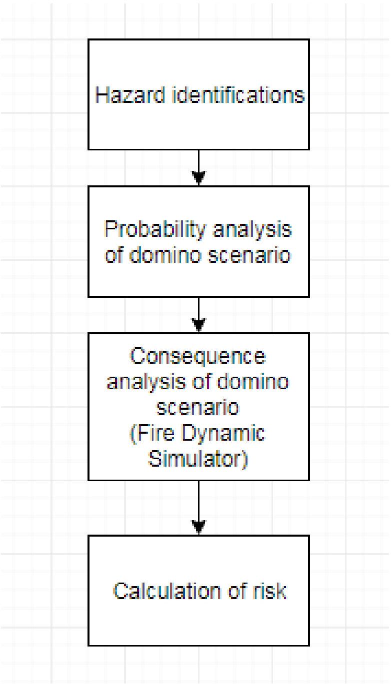


Figure 3.2: Flow Chart of Quantitative Risk Analysis (QRA).

3.1.3 Experimentation and Verification

The study will focus on petroleum plants so facilities and equipment in the plant will be modelled in the simulation software. The software that will be used to perform simulation for this study:

1. Fire Dynamics Simulator (FDS)

    - Model of fire-driven fluid motion Computational fluid dynamics (CFD).
    - Solves numerically a version of the Navier-Stokes equations suitable for low-speed, heat-driven flow, with a focus on smoke and heat transport from fires.

3.2 Plant Layout

3.2.1 Plant Layout Arrangement

The focus of the study is on the storage tanks in a petroleum plant. The storage tanks were modelled in PyroSim. The model was setup and the type of reaction fuel used in this project is gasoline, C_8H_{18}.

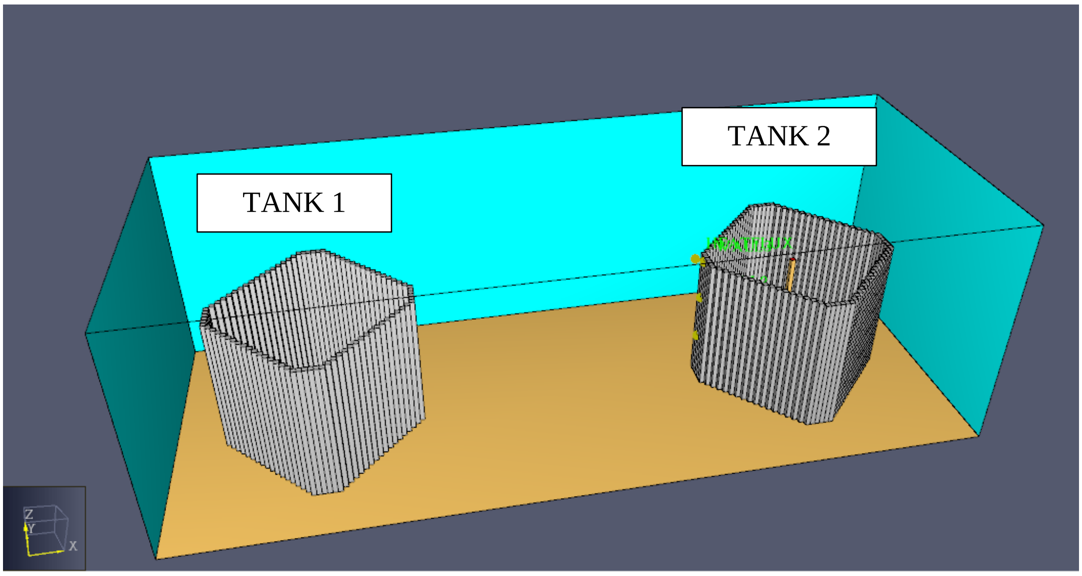


Figure 3.3: The Setup of the Tanks

The tanks were setup in parallel across each other. This is so to determine the chain reaction of fire between the tanks hence causing domino effect.

Model parameters: -

- Size of layout: 16m x 6m x 5m.
- Dimension of tank: Diameter= 4m, Height= 3m, Thickness= 0.1m.
- Distance between tanks wall to wall= 6m.

3.2.2 Fire Scenario

Tank 1 is chosen to be the primary event of the fire. For this study, two cases will be carried. Gas-phase sensor was set up in front of tank 2 facing tank 1 that was put on fire to record the heat flux of the fire. Solid-phase sensors were set up on the wall on tank 2 also facing the fire in order to record the wall temperature of tank 2. An auto-ignition sensor was set inside of tank 2 to indicate the ignition of gasoline fuel in tank 2. The type of fire used in this study is pool fire because it is the most common fire accident in the industry and have high probability on causing domino effect hence causing high damage to the affected plant.

For Case 1, the simulation will be carried without having external factors to the fire. The set up for Case 1 will be: -

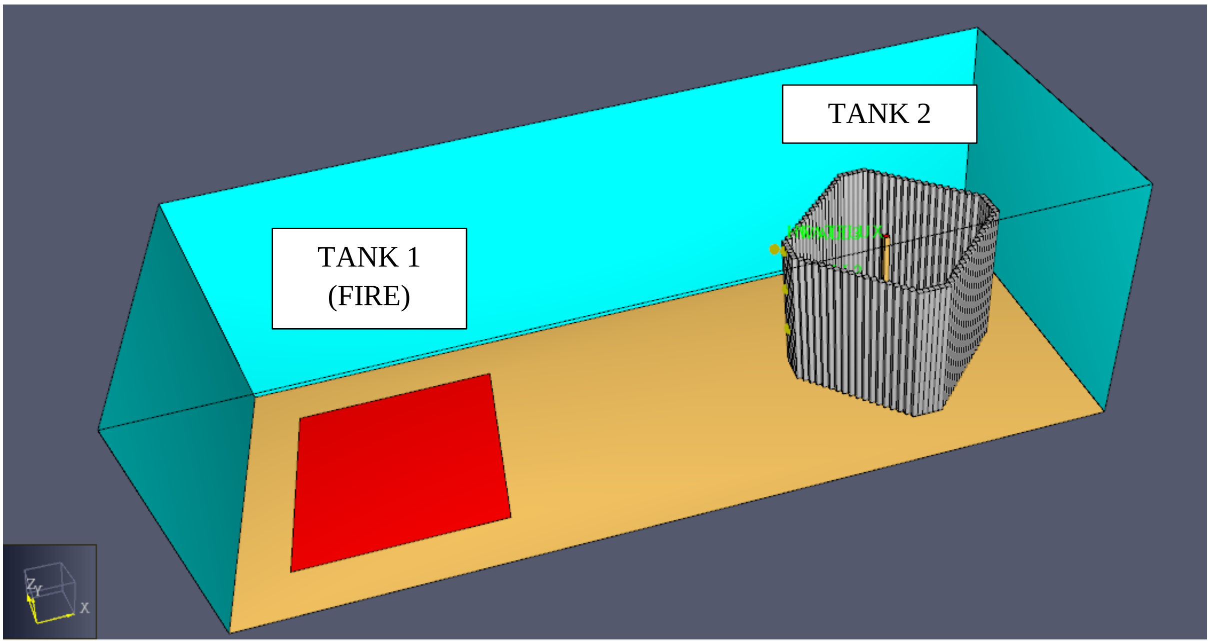


Figure 3.4: Fire Scenario Model for Case 1.

Then, the simulation for Case 2 will be carried with the external factor which is wind. The wind will be supplied at the velocity of 5m/s. The set up for Case 2: -

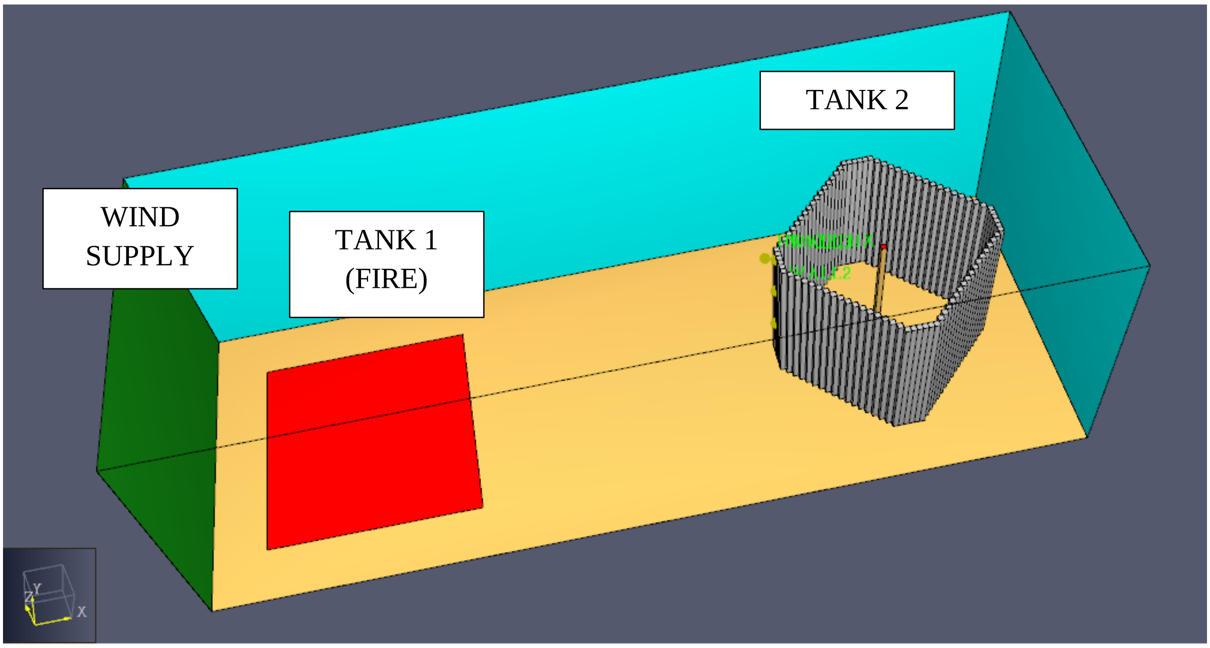


Figure 3.5: Fire Scenario Model for Case 2.

The simulations were carried out to determine the heat flux of the fire and to find out the damage caused by the domino reaction to the plant.

3.3 Gantt Chart and Key Milestone

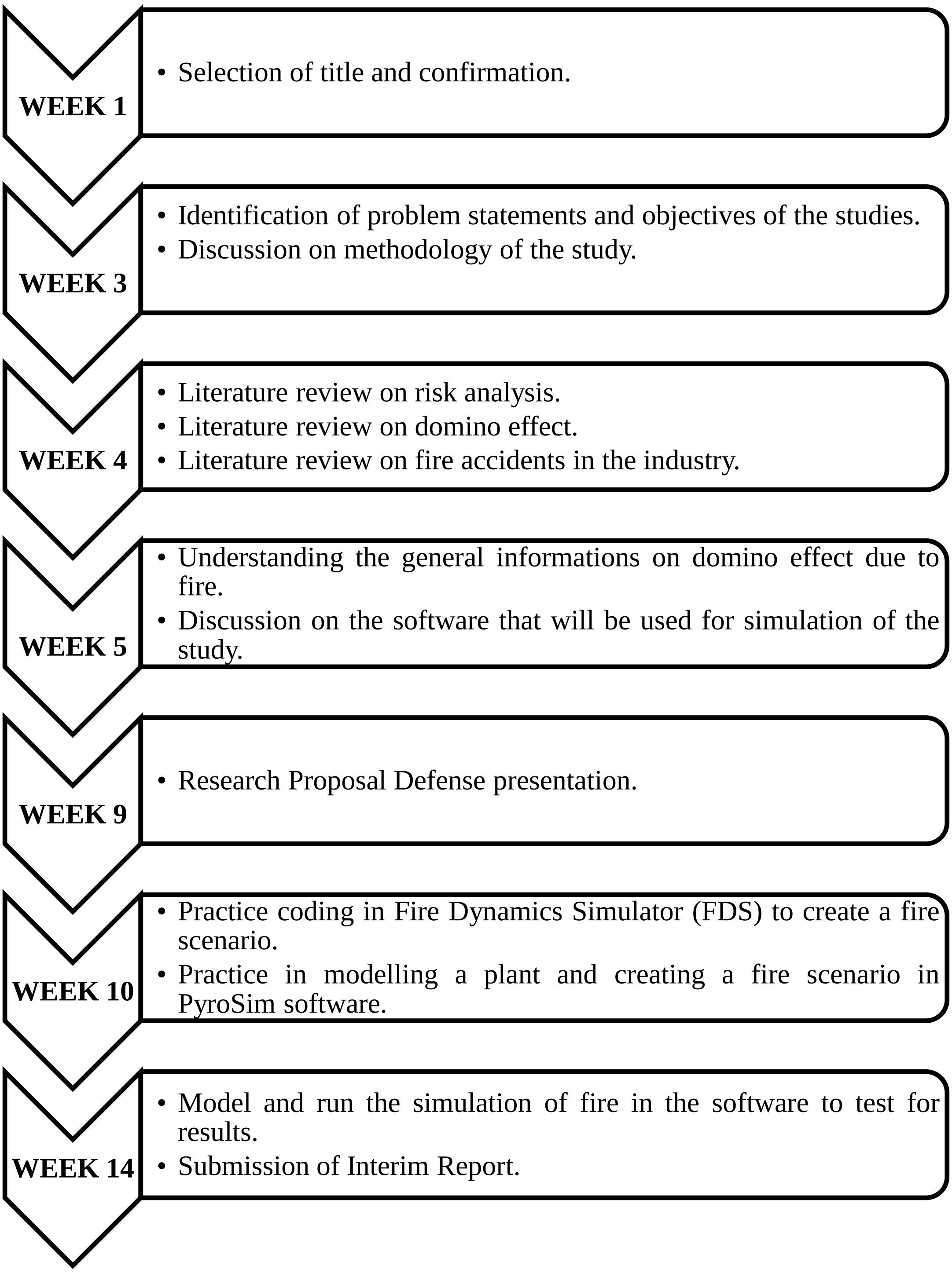
3.3.1 Gantt Chart for FYP 1.

Task	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project title selection and confirmation.	★	■												
Identification of problem statement and objectives of the study.		■	■											
Research on literature review: • Risk Analysis. • Fire Domino Effect.		■	■	■	■	■	■	■						
Research Proposal Defence presentation									★					
Improvisation of the project • Practice writing codes on Fire Dynamics Simulator (FDS) software. • Practice modelling in PyroSim software.							■	■	■	■	■	■	■	
Preparation of the project Interim report.									■	■	■	■	■	
Interim report submission														★

Table 3.1: Gantt Chart for FYP 1.

Key milestone: ★ Progress: ■

3.3.2 Key Milestone FYP 1



WEEK 1

- Selection of title and confirmation.

WEEK 3

- Identification of problem statements and objectives of the studies.
- Discussion on methodology of the study.

WEEK 4

- Literature review on risk analysis.
- Literature review on domino effect.
- Literature review on fire accidents in the industry.

WEEK 5

- Understanding the general informations on domino effect due to fire.
- Discussion on the software that will be used for simulation of the study.

WEEK 9

- Research Proposal Defense presentation.

WEEK 10

- Practice coding in Fire Dynamics Simulator (FDS) to create a fire scenario.
- Practice in modelling a plant and creating a fire scenario in PyroSim software.

WEEK 14

- Model and run the simulation of fire in the software to test for results.
- Submission of Interim Report.

Figure 3.6: Key Milestone FYP 1.

3.3.3 Gantt Chart for FYP 2.

Task	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Continuation of project on results and findings. • Simulation on project on Fire Dynamic Simulator (FDS) software. • Modelling in PyroSim software.	■	■	■	■	■	■	■							
Progress report submission.							★							
Project refinement for results and findings.							■	■	■	■				
Finalization of the project results.										★				
Project VIVA.														★

Table 3.2: Gantt Chart for FYP 2.

Key milestone: ★ Progress: ■

4. RESULTS AND DISCUSSION

4.1 Simulation

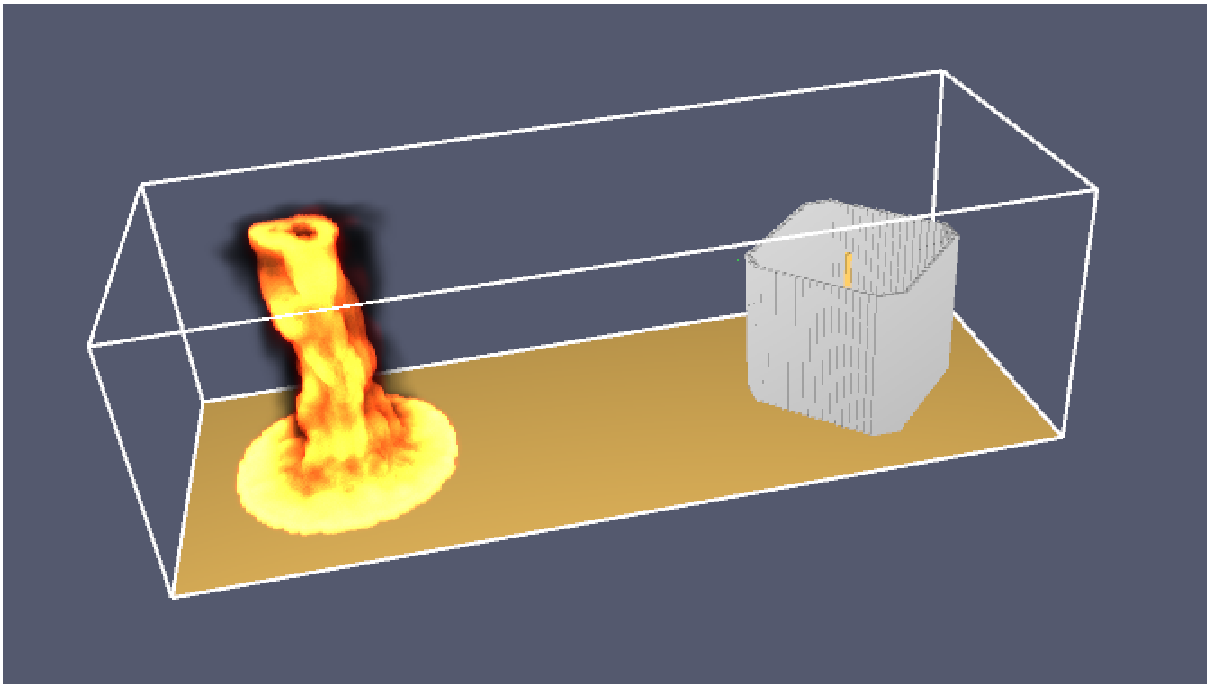


Figure 4.1: Simulation of Case 1.

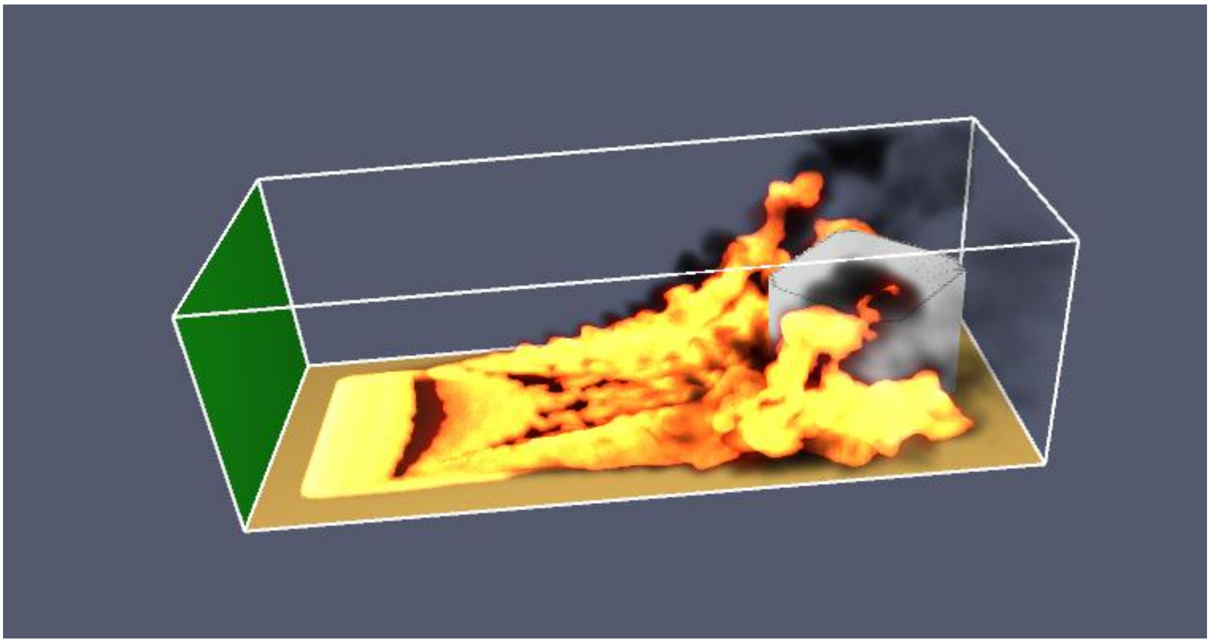


Figure 4.2: Simulation of Case 2.

4.2 Heat Flux

Heat flux is the rate of heat energy transfer through a surface. The gas-phase sensor was used to record the amount of heat flux transferred from the fire to tank 2. The gas-phase sensor was located in front of tank 2 facing the fire.

For case 1, the average heat flux for the simulation is 16.55 kW/m^2. Figure 4.1 shows the trend of the heat flux of the fire in case 1.

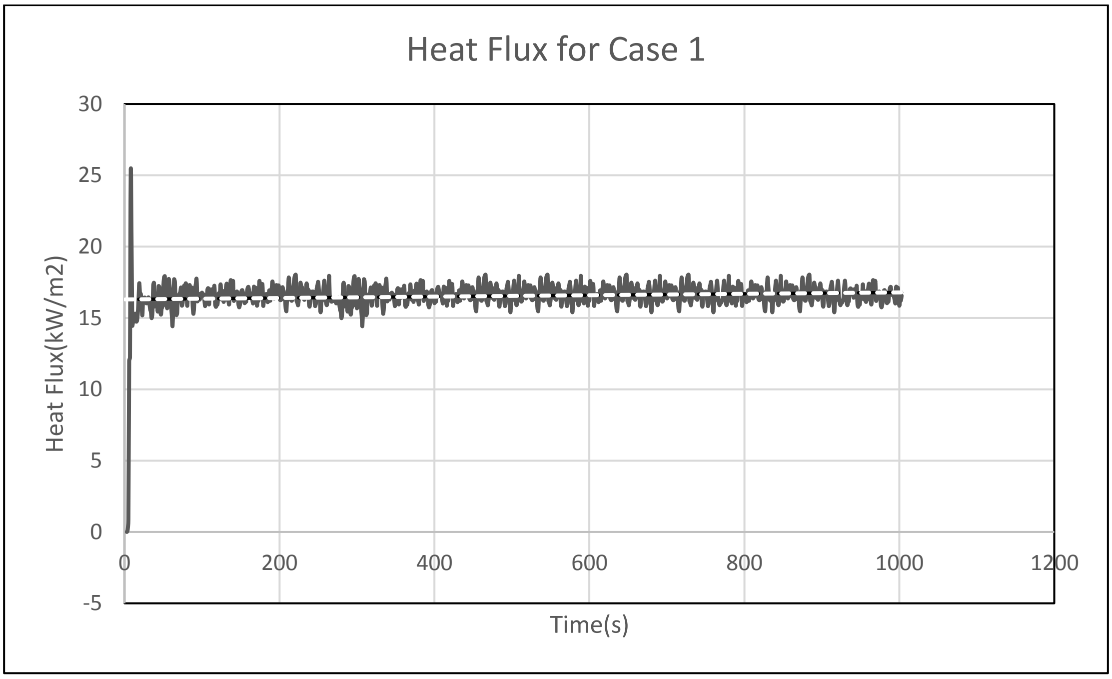


Figure 4.3: Heat Flux Graph for Case 1.

For case 2, the average heat flux for the simulation is 16.85 kW/m^2. Figure 4.2 shows the trend of the heat flux of the fire in case 2.

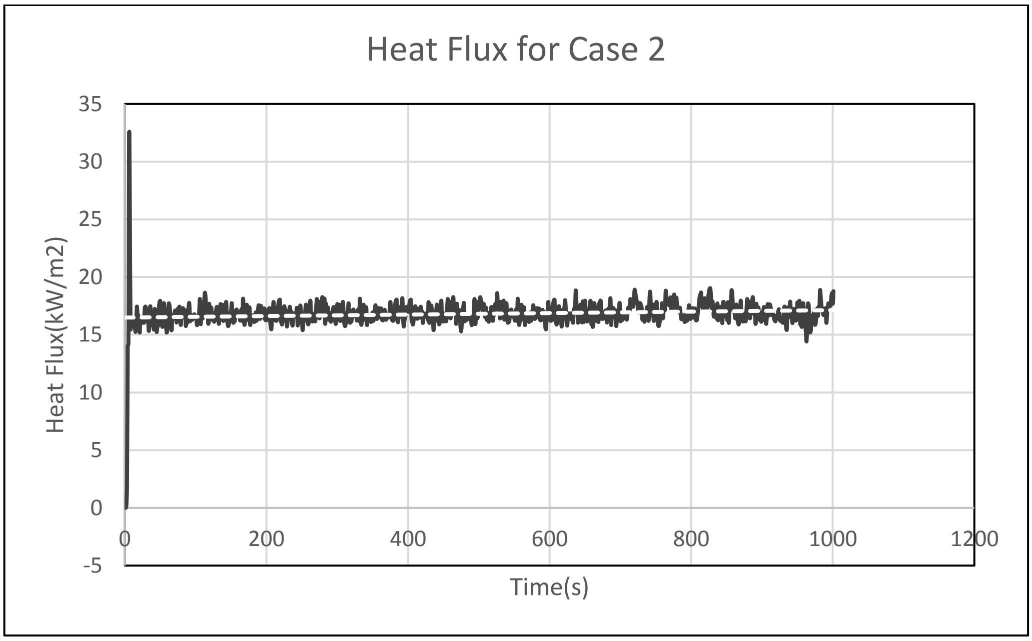


Figure 4.4: Heat Flux Graph for Case 2.

The transmission of heat flux is higher with the wind effect, so the fire radiation causes more damage to the surrounding buildings or secondary targets. Pool fire initially has zero or very low initial momentum but the characteristic of the fire change depending on wind velocity. So, pool fire accident that happen in presence of high velocity wind can cause a lot more damage than a normal pool fire.

4.3 Wall Temperature

There are three solid-phase sensors mounted on the wall of tank 2 that is facing the fire. The sensors are used to determine the temperature of the wall and find out whether the primary event of fire is going to spread and rupturing the wall of the tank causing fire domino effect on the storage plant. The sensors were located on the wall of the tanks at different heights: Wall Sensor 1= 1 meter, Wall Sensor 2= 2 meters, and Wall Sensor 3= 3 meters to determine the effect of the fire on different parts of the wall.

The ignition temperature for gasoline fuel is at 280°C. So, when the wall sensor reaches that temperature, the auto-ignition sensor inside the tank will ignite and burning the tank causing fire domino effect. The temperature for the metal tank to fail is 400°C so when wall temperature reaches the fail temperature, the tank is assumed to rupture.

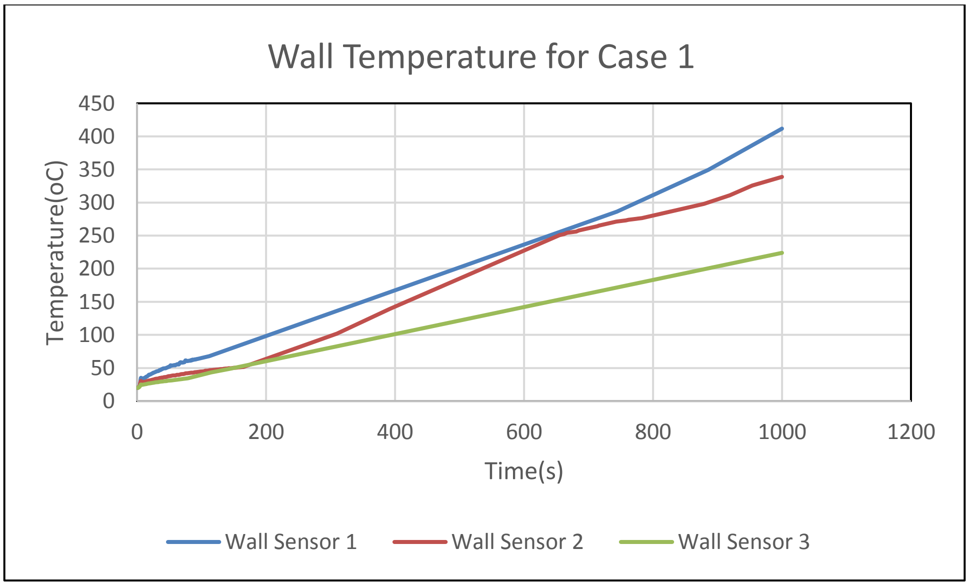


Figure 4.5: Wall Temperature for Case 1.

Case 1: -

Based on the temperature for Wall Sensor 1 in Case 1, the sensor reached the ignition temperature of gasoline at 750 seconds. This cause the auto-ignition sensors inside tank 2 to ignite and burn the tank. Then, Wall Sensor 2 also reached the ignition temperature of gasoline at 800 seconds causing the tank to burn faster. The pool fire from the primary event, which is tank 1 managed to spread and causing tank 2 to rupture, hence having the domino effect.

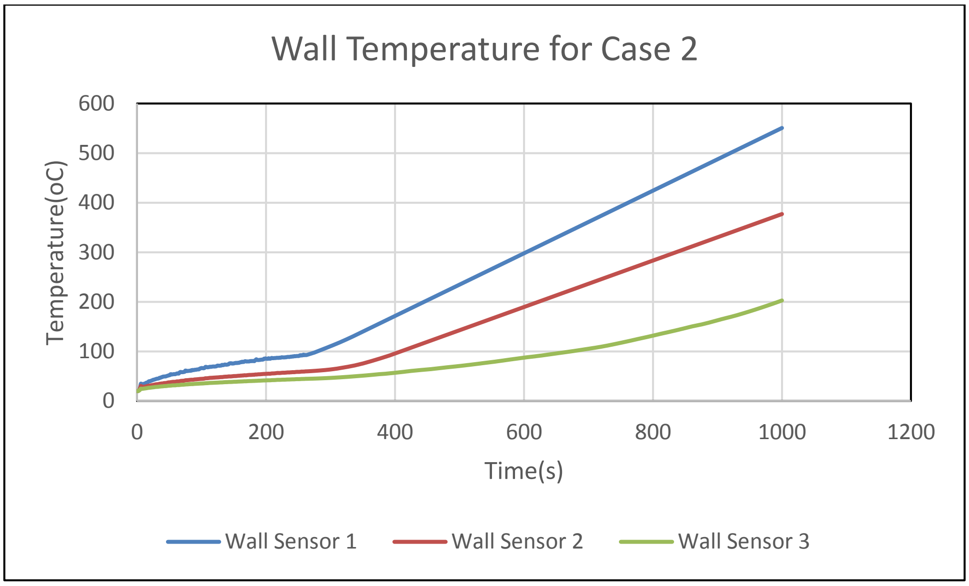


Figure 4.6: Wall Temperature for Case 2.

Case 2: -

For this simulation, wind effect is taken into consideration for the fire. The wind was supplied at 5m/s from the direction of the fire in tank 1 toward tank 2. The wind affected the motion of the fire since Wall Sensor 1 managed to get reading on the ignition temperature of gasoline at 590 seconds. Then, Wall Sensor 2 get to the ignition temperature at 800 seconds. The pace of the fire caused by the wind is faster and the fire can afflict more damage on the tank causing the tank to rupture, hence causing the domino effect reaction on the plant.

Based on the simulations, wind effect is a major factor in influencing the escalation of the fire. Heat flux difference from case 1 and case 2 show that wind can cause the increase in heat flux generated to the secondary targets. The faster pace of wall temperature rises in case 2 show that the time taken for ignition of fuel in secondary target is shorter so more damage can be afflicted on the secondary targets of the accident. Wind effect during a fire accident can cause the fire to spread faster to secondary targets in a plant hence causing higher damage to the plant.

5. CONCLUSION AND RECOMMENDATION

Domino accidents due to fire in a petroleum plant cause loss of properties and lives. Risk analysis is performed to minimize the probability of an accident to occur and prevent an accident from going domino. During a fire, escalation is a factor of causing domino effect.

Based on the previous studies, fire accidents in the industry become domino accidents because of the presence of escalation effect. Escalation is a main factor for an accident to be categorized as domino accident.

Therefore, the objectives that will be accomplished in this study is to perform a risk analysis to the escalation vector during the fire which is heat radiation. Facilities and equipment of a petroleum plant will be modelled in the Fire Dynamics Simulator (FDS) software, the impact of heat radiation to the surrounding of primary event based on escalation and the value of properties loss can be evaluated.

Upon completion of this study, all objectives will be achieved, and the results acquired will give solutions in understanding the escalation effect in domino accident due to fire in the industry. As recommendation, analysis and studies on domino effect and escalation effect should be continued so that the risk of having domino accidents in the industry can be minimized and avoiding the bad impact of the accidents.

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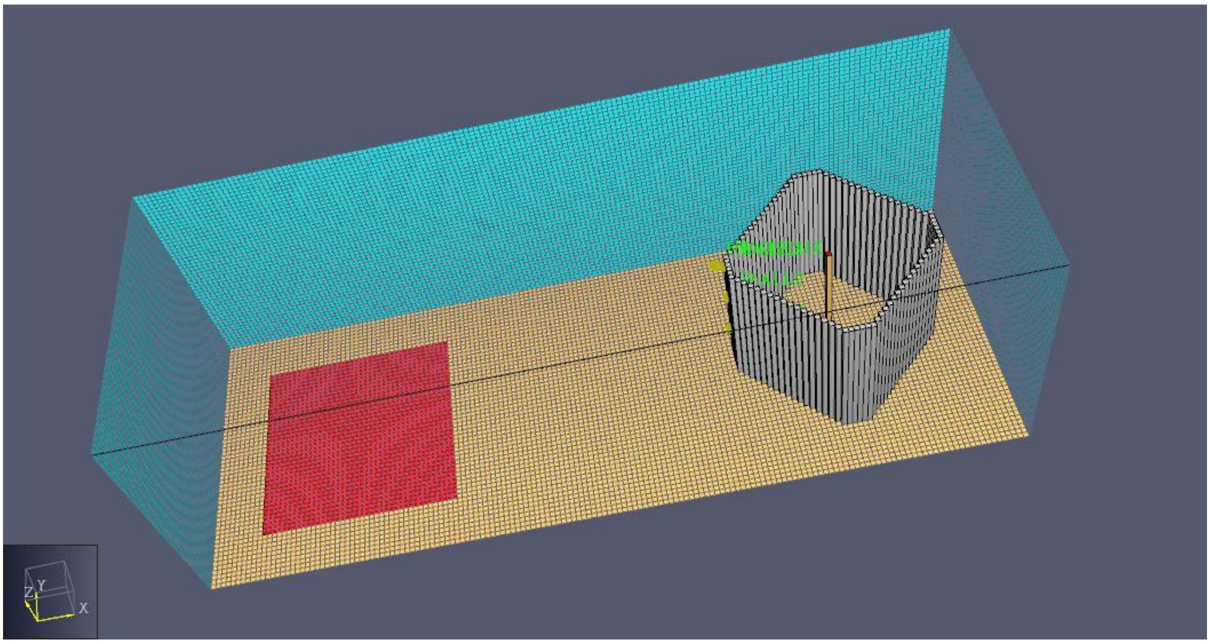
APPENDICES

Working Diagram of Case 1: -



Meshes (480,000)

Reaction Fuel (Gasoline)

Materials (Steel)

Surfaces: -

- INERT (YELLOW)
- OPEN (BLUE)
- STEEL (GREY)
- FIRE (RED)

Devices: -

- SOLID-PHASE SENSOR (WALL 1)
- SOLID-PHASE SENSOR (WALL 2)
- SOLID-PHASE SENSOR (WALL 3)
- GAS-PHASE SENSOR (HEAT FLUX)

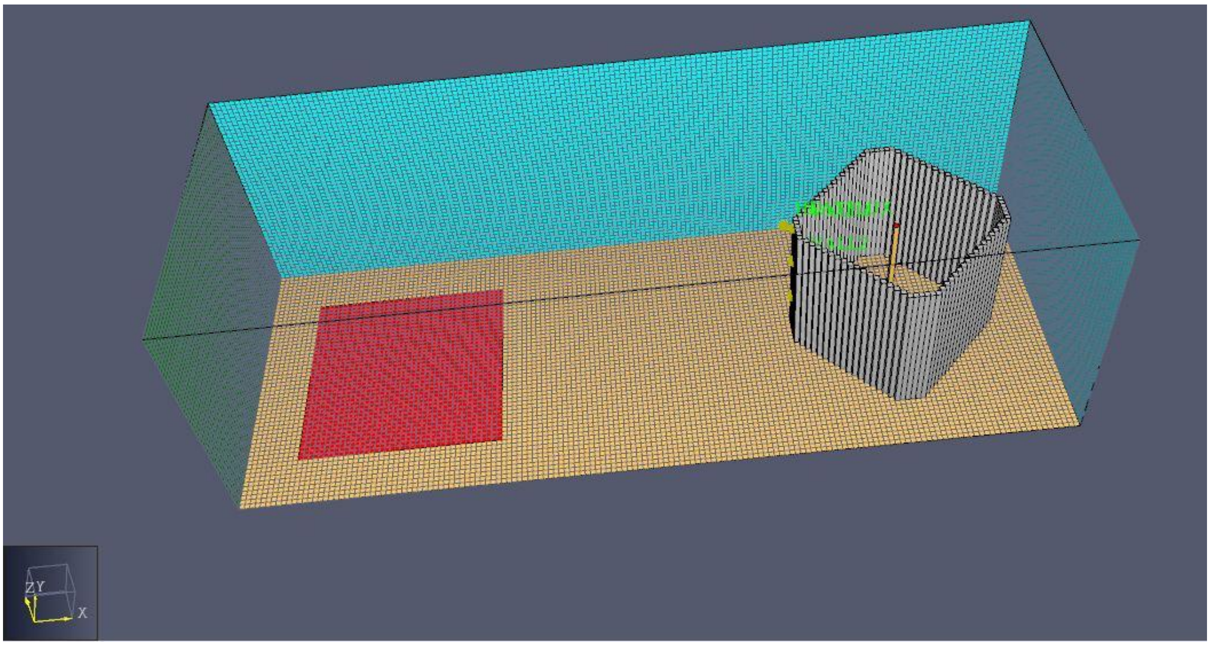
Control: -

- AutoIgnite (WALL 1 > 280^{O}C)

Vent: -

- Fire Vent (RED)

Working Diagram of Case 2: -



Meshes (480,000)

Reaction Fuel (Gasoline)

Materials (Steel)

Surfaces: -

- INERT (YELLOW)
- OPEN (BLUE)
- STEEL (GREY)
- FIRE (RED)
- WIND (GREEN) = 5 m/s

Devices: -

- SOLID-PHASE SENSOR (WALL 1)
- SOLID-PHASE SENSOR (WALL 2)
- SOLID-PHASE SENSOR (WALL 3)
- GAS-PHASE SENSOR (HEAT FLUX)

Control: -

- AutoIgnite (WALL 1 > 280^{O}C)

Vent: -

- Fire Vent (RED)