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Simulation of Dispersion and Explosion in Petrol Station using 3D Computational Fluid Dynamics FLACS Software

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ABSTRACT

Petrol station are areas that have a high level of risk of fire (Major Hazard Accident), which is a large industrial accident with very detrimental consequences, both human life and other material losses. Cases of fire or accidents at gas stations are still common, recorded during 2016-2018 around 120 cases that resulted in losses for both entrepreneurs and consumers and the community. In this research, simulation and explosion modelling will be carried out using the CFD FLACS software. The case used in this research is at Petrol station X with input variables (wind direction, surface roughness, and day and night conditions). The dispersion simulation results show that the dispersion that occurs cause kidney damage. The explosion simulation results show that the highest overpressure is 0.0064 barg, which is in the scenario of north wind direction, night conditions, and surface roughness of 0.03 m. The overpressure does not cause any damage.

1. Introduction

Petrol station is an area that has a high level of risk of fire (Major Hazard Accident), which is a large industrial accident with very detrimental consequences, both human life and other material losses. Cases of fire or accidents at gas stations are still common, recorded during 2016-2018 around 120 cases that resulted in losses for both entrepreneurs and consumers and the community [1]. In United States, based on the National Fire Protection Association, it was recorded during 2014-2018, there were accidents at public gas stations that left an average of 3 people dead, 43 people injured and losses reaching 30 thousand US dollars. Some examples of cases of explosions and fires at petrol stations is shown in Table 1.

When fuel is accidentally released, fuel density becomes a very important parameter for the formation of flammable cloud vapor. When lighter-than-air gases, such as hydrogen, have bouyancy, the cloud vapor rises to the top, and in its open state to the environment, the gas rises and disperses relatively quickly. While heavier solid gases will float along the ground surface and not disperse as

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quickly as lighter gases. Solid gases can drift past buildings, tunnels, culverts or other confined areas [2,3]. Therefore, a dense gas release has a higher potential for a larger fuel vapor cloud to form than a light gas release [3,4].

An explosion can be characterized by a sudden release of energy and a shock wave or blast wave that travels rapidly outward from the source of the explosion toward its surroundings [5-7].

Table 1
Explosion and Fire Cases

Date of time	Location	Type accidents	Number of victims
2011	Labuhan Batu, Indonesia	Explosion	2
2012	Jakarta, Indonesia	Explosion	2
2015	Jakarta, Indonesia	Fire	-
2016	Pontianak, Indonesia	Explosion	7
2016	Jakarta, Indonesia	Fire	1
2016	Solo, Indonesia	Explosion	2
2017	Aceh, Indonesia	Fire	-
2018	Surabaya, Indonesia	Explosion	4
2018	Bogor, Indonesia	Fire	1
2018	Trenggalek, Indonesia	Fire	1

This research was conducted to simulate an explosion in general refueling using FLACS software in order to predict how big the impact would be so as to minimize the impact of the explosion [8,9]. The previous research from "Simulation of Dispersion and Explosion of Natural Gas in Vented Enclosures Using 3D Computational Fluid Dynamics Flacs Software". In this research, modeling of deployment and blasting scenarios was carried out using FLACS software with the variables defined, namely grid, geometry, natural gas composition, and leakage conditions. While the manipulated variables are leak holes, wind direction, obstructions, and day and night conditions. Verification in this study is to compare the results of the simulations and experiments by reviewing the maximum pressure generated during the simulation against previous data experiments based on the variable methane-air concentration, the area of the leak hole, and the ignition point used. has been determined [10]. If there is an error, then the modeling will be re-analyzed and if the simulation results are appropriate or close to the experimental results, then proceed with the next variable. The error tolerance value in this study is considered good because the resulting error is below 30% so that it can be used to create research scenarios. The next variables after the validation stage are dispersion and explosion, where the simulation results obtained will be reviewed based on the overpressure value, where overpressure is the increased pressure above the dispersed gas and the surrounding atmosphere [10]. Comparison of the simulation results with the experiments results is presented in Table 2.

Table 2
Comparison of verification variable overpressure to overpressure simulation

Running	Overpressure experiment (bar)	Overpressure simulation	Error
1	0.017	0.028	0%
2	0.027	0.044	3.7%
3	0.051	0.054	11.76%
4	0.045	0.05	15.5%
5	0.07	0.068	2.85%
6	0.079	0.058	26.58%

2. Methodology

2.1 Dispersion and Explosion Simulation Flowchart

In this study, a 3D CFD simulation of octane explosion was carried out on a dispenser using FLACS software with the following steps:

2.1.1 Geometry design and scenario modeling

Geometry design (refer to Figure 1) is based on the reference design of Petrol station X then the design is exported to FLACS software. Next configure the grid, and the gas composition. There are three input variables, which is wind direction, surface roughness, and day-night conditions. From these three variables, it can be identified that there are 16 scenarios. All scenarios identification is base from all possibility that can happen. In this research there are four wind direction that we use: north, south, east and west. With wind direction we can conclude that what is the wind direction that have worst scenario effect. Surface roughness is the condition when if the gas station have obstacle or not. Day night condition can affect the stability of dispersion.

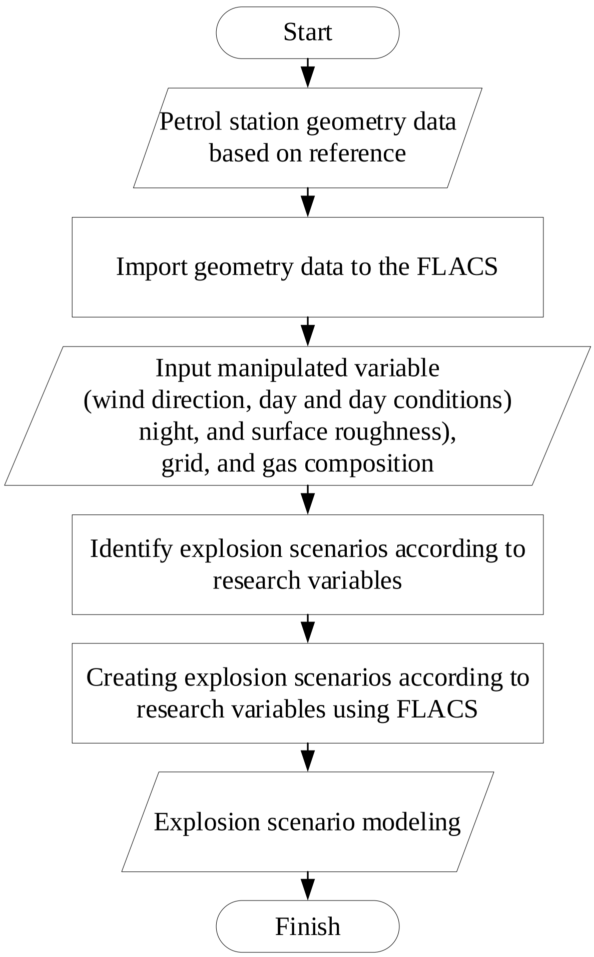

Fig. 1. Geometric design flowcharts and scenario modeling

2.1.2 Dispersion scenario

For dispersion simulation (refer to Figure 2), input data type, location, time and duration of leakage, Single Field 3D Output, NPLOT, DPLOT, MODD, CFLC, CFLV, maximum simulation time, NDUMP and TDUMP, ignition and boundary conditions into the dispersion scenario modeling that has been made previously. Then run on the Run Manager section in order to obtain the simulation results. The simulation results are then analyzed by comparing the input variables to determine the effect of the input variables on the dispersion and impact of gasoline exposure.

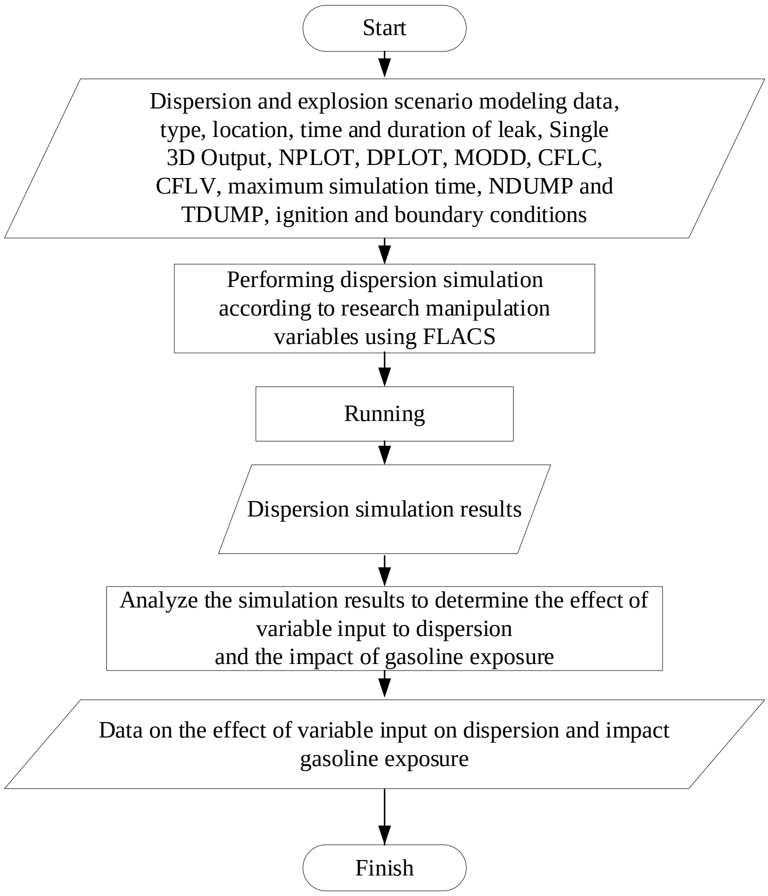

Fig. 2. Dispersion scenario flowchart

2.1.3 Explosion scenario

For explosion simulation (refer to Figure 3), input position and ignition timing, NLOAD, monitor point parameters, Single Field 3D Output, NPLOT, DLPOT, and boundary conditions into the previously created dispersion simulation results. Then run on the Run Manager section in order to obtain the simulation results. The simulation results are then analyzed by comparing the input variables to determine the effect of variable inputs on explosions and the impact of overpressure on buildings, and humans.

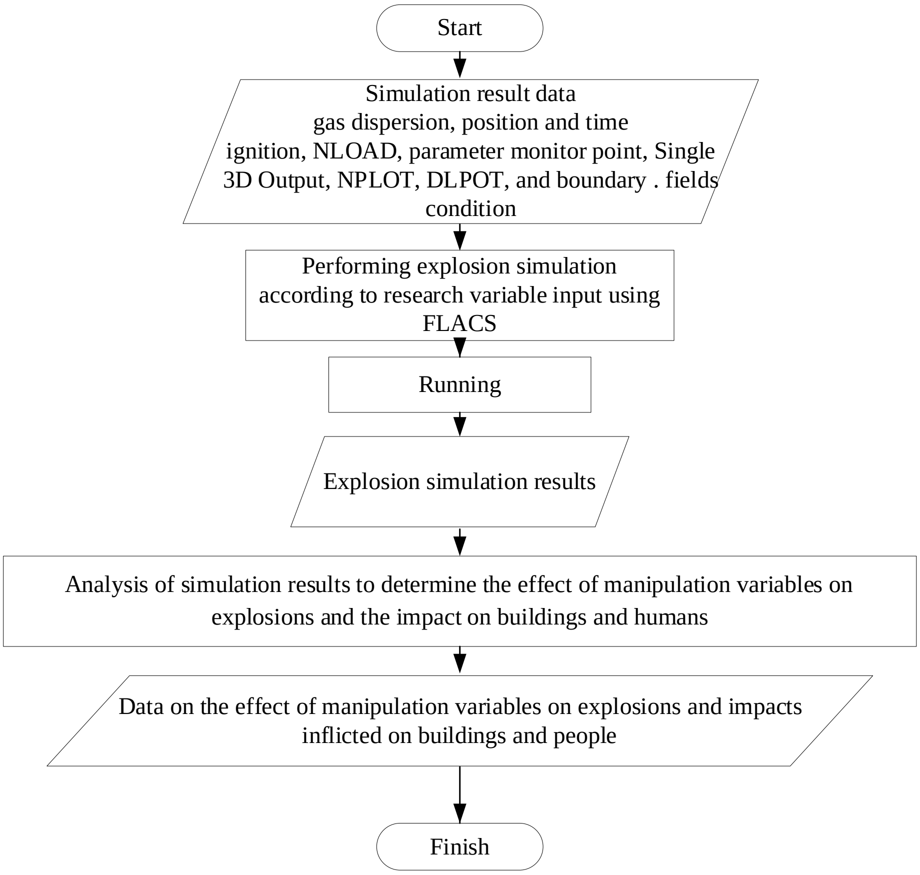

Fig. 3. Explosion scenario flowchart

2.2 Geometry of Petrol Station

Case study at Petrol station X. Here is the layout of the Petrol station X at Cianjur Regency. The location is rural state.

Figure 4 shows the layout of a petrol station consisting of 3 dispensers. As well as public building areas such as offices and minimarkets. Then, recreate geometry base on reference using FLACS. there is the result at Figure 5.

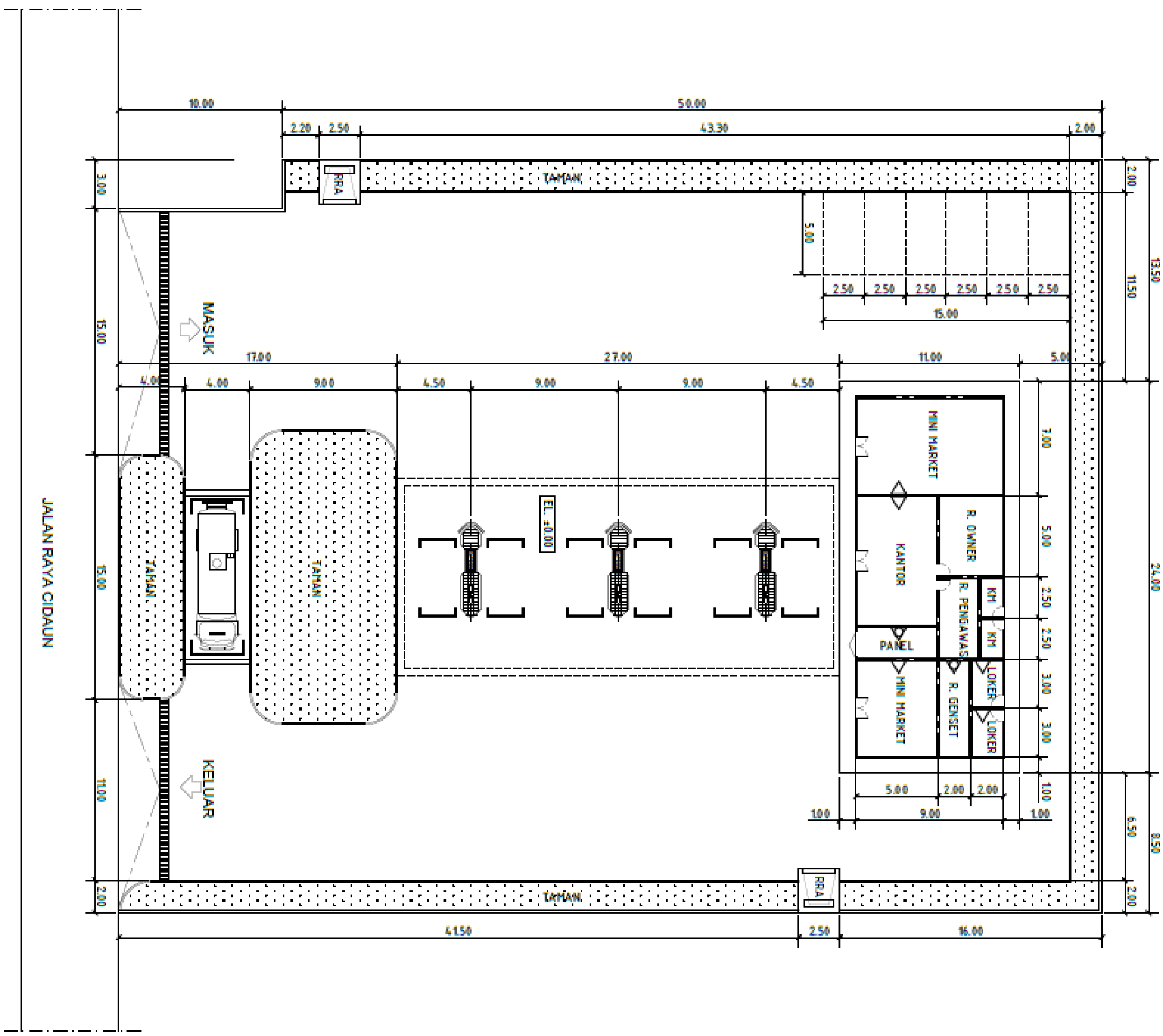

Fig. 4. Petrol station X layout

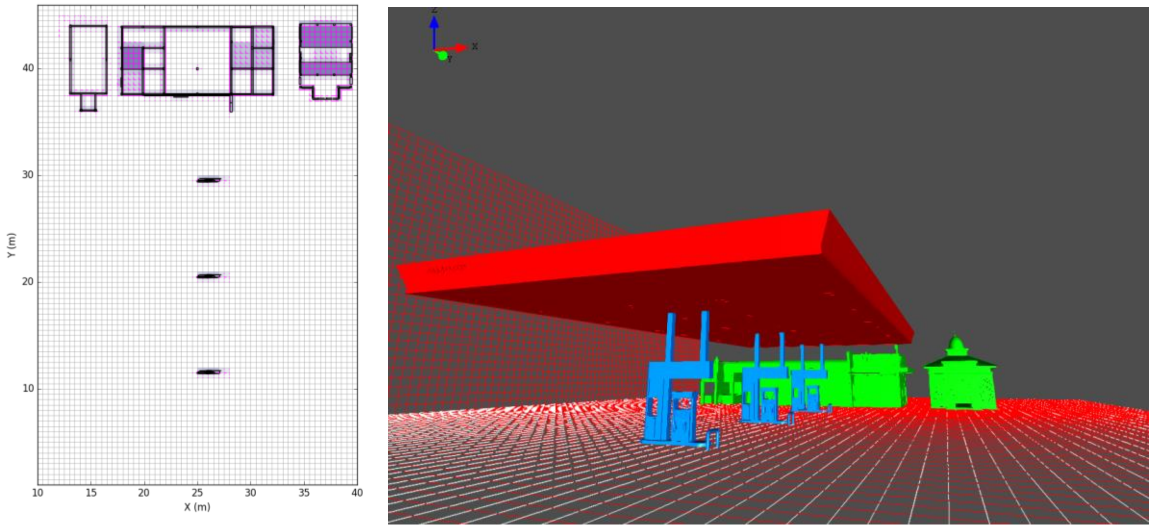

Fig. 5. Petrol station X layout

2.3 Input Variable

The variables of this research include:

i. Wind direction

The wind direction was chosen based on the worst-case scenario, which is heading north towards minimarkets, cafes, and mosques where people are usually there. In addition, the wind directions to the south, west, and east were also selected to determine the highest explosion effect (refer to Figure 6).

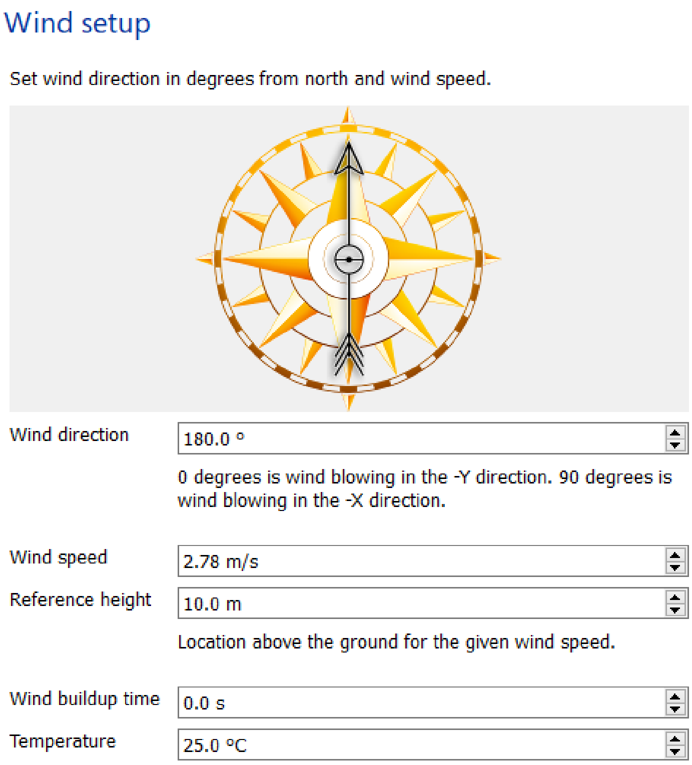

Fig. 6. Wind setup

The wind direction was chosen because the wind direction affects the motion of the gasoline vapor fluid, so the wind direction is a vector quantity.

Here is the dispersion equation

$$c(x,y,z) = \frac{q}{u_a} F_y(x,y) F_z(x,z) \tag{1}$$

ii. Surface roughness

The greater the surface roughness, the more dispersed the gas will be. So that the greater the surface roughness, the lower the pressure will be due to the smaller the concentration (refer to Table 3).

In this study, surface roughness of 0.03 m and 0.005 m were used. The length of this roughness was chosen because it adapts to the condition of the gas station which has vehicle barriers, dispensers, and consumer vehicles.

Table 3
Surface roughness length parameter z0 [11]

Terrain description	z0 (m)
Open water, fetch at least 5 km	0.0002
Mud flats, snow; no vegetation, no obstacles	0.005
Open flat terrain; grass, few isolated obstacles	0.03
Low crops; occasional large obstacles	0.10
High crops, scattered obstacles	0.25
Parkland, bushes, numerous obstacles	0.5
Regular large obstacles coverage (suburb, forest)	1

To calculate the surface roughness using the Eq. (2)

$$u = \frac{u^*}{k} ln \frac{z}{z_0} \tag{2}$$

The constant k, which is the Von Karman constant, has a value of 0.35 on smooth surfaces and 0.4 on most other surfaces [5].

iii. Day-night condition

Day and night conditions are based on temperature and wind speed. Temperature and wind speed data were taken from BMKG on December 24 2021, in Surabaya (refer to Table 4). The following is data on temperature and wind speed from BMKG.

Table 4
Temperature and wind speed data [5]

Condition	Day	Night
Temperature (deg C)	32	25
Wind Speed (m/s)	8.33	2.78

The state of day and night is based on influencing the stability of the atmosphere, thus affecting fluid motion. as stated in the following equation

$$\sigma_y(\mathrm{x}) = \mathrm{a}\, x^b \tag{3}$$

and

$$\sigma_z(\mathrm{x}) = \mathrm{c}\, x^d \tag{4}$$

2.3.1 Grid

Configure the grid as follows (refer to Figure 7):
Core domain:
Minimum (10; 1; 0) m
Maximum (40; 46; 15) m
Cell size: 0. 5 m

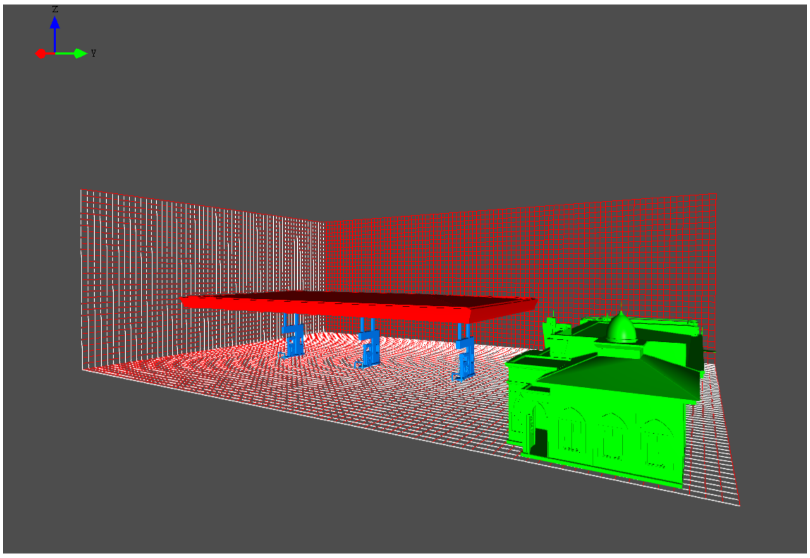

Fig. 7. Grid visualization

2.3.2 Gas composition

The composition of the gas used is 27.1% Butane, 40.9% Pentane, 18.8% Hexane, 2% Heptane, 4% Octane, 0.2% Nonane, 0.2% Decane (refer to Table 5). That composition is selected base on common gasoline.

Table 5
Temperature and wind speed data [11]

Carbon number	Whole baseline gasoline (%Volume)	Vapor equilibrium at 130 °F (%Volume)	Baseline gasoline vapor condensate (%Volume)
3	0	0	0.1
4	4.7	27.1	20.6
5	16.3	40.9	46.4
6	18.5	18.8	21.6
7	19.1	2.0	9.0
8	20.2	4.0	2.2
9	10.6	0.8	0.2
10	6.0	0.2	0
11	2.8	0	0
12	1.8	0	0

2.4 Gas Dispersion Simulation Configuration
2.4.1 Type

The type of leakage used is diffusion, where the gas releases without momentum (the leaking gas has the same velocity as the flow around it). In this case, it is simulated that there is a leak in the pipe from the buried tank to the dispenser, gas comes out through the bottom of the dispenser due to construction damage to the dispenser container. The buried tank is in an open state so it cannot maintain the temperature and pressure that keeps gasoline in a liquid state, which is 77 oF and 4.6 psia [2]. Gas leak visualization is shown in Figure 8.

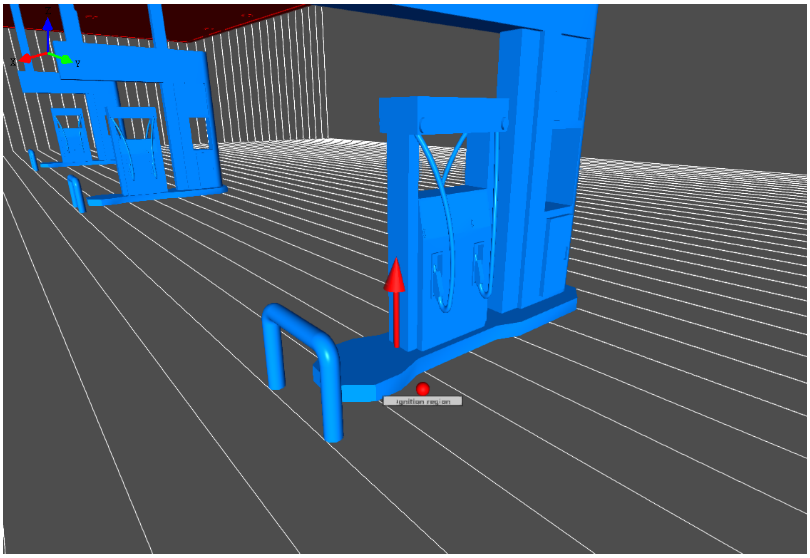

Fig. 8. Gas leak visualization

2.4.2 Single Field 3D Output

Single Field 3D Output serves to determine the output variables and to know the graphs and plots of the simulation results. For the dispersion scenario, the variable FMOLE (m^3/m^3) or the concentration of mole fraction of gasoline is selected.

2.4.3 NPLOT

This is a parameter that can be used to determine how often data for field plots is written to a file during simulation: data is stored at a given fuel level where NPLOT is the number of fuel levels equidistant between zero and maximum. The fuel level is defined as the total mass of the current fuel divided by the total initial mass of the fuel. This output mechanism is not active in the case of simulated gas dispersion (leakage determined). So that NPLOT 0 is used in the dispersion simulation. This variable does not affect the simulation results, only the amount of data stored [2,11].

2.4.3 DPLOT

DPLOT is the time interval (in seconds) for the field outputs. This is useful in gas dispersion simulations and also in gas explosion simulations when frequent outputs are required. This variable does not affect the simulation results, only the existing data is stored. In the dispersion simulation used DPLOT 0.025 s [2].

2.4.4 MODD

MODD is a parameter that can be used to determine how often data for scalar-time plots is written to the results file during a simulation: data is stored every MODD time steps. The MODD value used in CASD is the default value, which is 1. This variable does not affect the simulation results, only affects the amount of data stored [2].

2.4.5 CFLC

The CFLC is a Courant-Friedrich-Levy number based on the speed of sound. The CFLC value relates the simulation time step length to control the volume dimension through the speed of signal propagation (in this case the speed of sound). In this study, for dispersion, the default value set by CASD is 5.0. The simulation results may change with this parameter. Therefore, it is not recommended to change this value for simulated explosions because the validation job is aborted [2].

2.4.6 CFLV

CFLV which is Courant-Friedrich-Levy number based on fluid flow velocity. The CFLV value relates the simulation time step length to control the volume dimension through the signal propagation speed (in this case the fluid flow velocity). In this dispersion simulation study, the default value set by CASD is 0.5. The simulation results may change with this parameter. Therefore, it is not recommended to change this value for simulated explosions because the validation job is aborted [2].

2.4.7 Maximum simulation time

Simulation lasts 20 seconds

2.4.8 NDUMP and TDUMP

Dump / Load Setting used in dispersion scenarios.
NDUMP : 1
TDUMP : 7

2.4.9 Ignition

In dispersion, because we do not want ignition, we do not need to fill in the position and volume, while the time of ignition is 9999 second, which means that we do not want ignition.

2.4.10 Boundary condition

For the gas dispersion simulation, the nozzle boundary condition is used because it is in accordance with the characteristics of subsonic fluid flow (relatively constant density).

2.4.11 Initial condition

The initial conditions (refer to Table 6) that were varied were temperature and wind speed (variable day-night conditions), surface roughness (0.03 m, 0.005 m), and wind direction (north, south, east, west).
When t = 0, c(t((x,y,z))=0
Determination of air pressure and composition using default values from FLACS
The composition of the air is 79.05% Nitrogen and 20.95% Oxygen
Ambient pressure = 1 bar

Determination of wind speed and temperature based on BMKG data in Surabaya
Temperature: 32°C (Day), 25°C (night)
Wind speed: 8.33 m/s (day), 2.78 m/s (night)

Table 6
Initial condition

Parameter	Value
Time	0
Concentration	0
Air composition	79.05% Nitrogen, 20.95% Oxygen
Ambient pressure	1 bar
Wind speed	8.33 m/s (day), 2.78 m/s (night)
Wind temperature	32°C (day), 25°C (night)

2.5 Explosion Simulation Configuration
2.5.1 Ignition

The explosion occurred shortly after 15 seconds of leakage, so the ignition was configured as follows:

Size : (0 x 0 x 0) m
Location : (27.5; 30.25; 0) m
Time of ignition : 15 s

Ignition time is set at 15 seconds, because at this time most of the LFL – UFL flash points are close to the maximum condition. If it is less or more than 15 seconds then there is a moment where the flash point value is less than LFL.

2.5.2 Single Field 3D Output

Single Field 3D Output serves to determine the output variables and to know the graphs and plots of the simulation results. In this study, the variable P_3D (barg) was selected.

2.5.3 NPLOT

NPLOT is a parameter that can be used to determine how often data for field plots is written to a file during a simulation: data is stored at a given fuel level where NPLOT is the number of fuel levels equidistant between zero and maximum. The fuel level is defined as the total mass of the current fuel divided by the total initial mass of the fuel. This output mechanism is not active in the case of simulated gas dispersion (leakage determined). So NPLOT 0 is used in the explosion simulation. This variable does not affect the simulation results, only the amount of data stored [2].

2.5.4 DPLOT

DPLOT is the time interval (in seconds) for the field outputs. This is useful in gas dispersion simulations and also in gas explosion simulations when frequent outputs are required. This variable does not affect the simulation results, only the existing data is stored. In the dispersion simulation used DPLOT 0.025 s [2].

2.5.5 NLOAD

Dump / Load Settings used in the explosion scenario are:
NLOAD : 1

2.5.6 Maximum simulation time

Simulation lasts 20 seconds

2.5.7 Boundary condition

In the explosion simulation it is recommended to use the Euler boundary, because the Euler boundary is suitable for solving the continuity equation and momentum equation, so the Euler boundary is used in this explosion simulation [2].

2.5.8 Running

Running scenarios using FLACS software in the Run Manager section. From the simulation results obtained, then an analysis is carried out.

3. Results

3.1 Dispersion Simulation Results based on Wind Direction

In this study, the manipulation variables used are north and south directions. The selection of the north wind direction is based on the worst-case scenario, that is the wind direction that leads to the area of public facilities such as minimarkets, cafes, and mosques. The following (refer to Figure 9) are the results of dispersion simulations based on wind direction with fixed variables, namely roughness 0.03 and conditions at night and at 15 seconds.

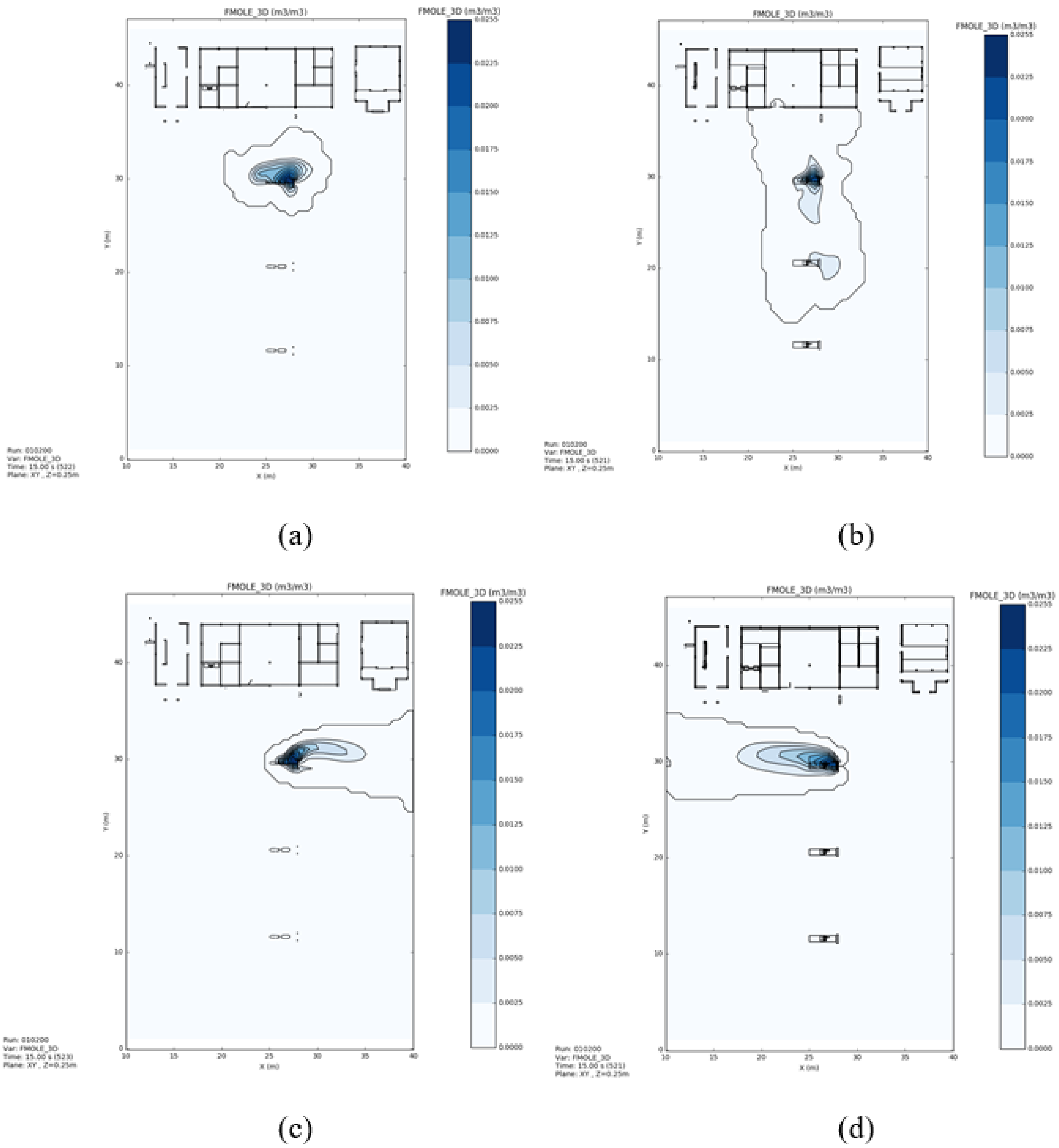

Fig. 9. Dispersion visualization by north (a), south (b), west (c), east (d) wind direction

The difference in wind direction causes the concentration of gasoline vapor to be dispersed in the atmosphere. In the north wind direction, the dispersed gasoline vapor spreads to the north towards the building. In the southerly direction, gasoline vapours tend to be dispersed southward away from the building. In the westerly direction, the dispersion is towards the west. In the east wind direction, the dispersion is towards the east. Based on references from the Northeast States for Coordinated Air Use Management, the dose of gasoline vapor in the air that can cause liver damage in humans is 2^{-10} m^3 gasoline/m^3 air. So, it can be concluded that all colours of gasoline vapor dispersion indicators can damage human kidneys.

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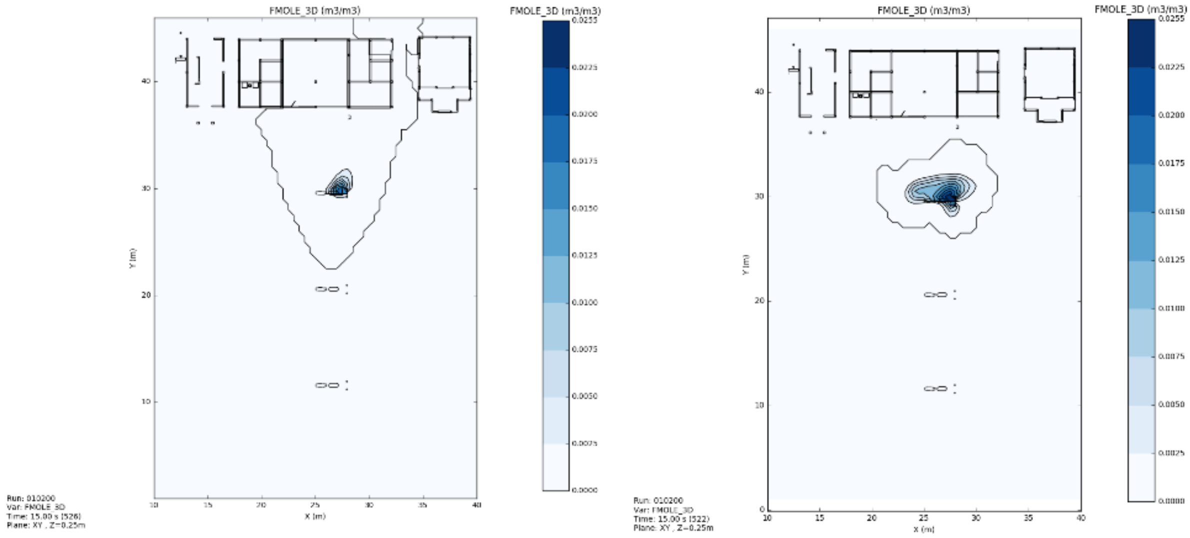
3.2 Dispersion Simulation Results based on Day or Night conditions

In this study, the input variables used are conditions during the day and night, with parameters namely temperature and wind speed. The following (refer to Figure 10) is the result of visualization of dispersion with fixed variables, namely north wind direction and surface roughness at a value of 0.005 m.



(a) (b)

Fig. 10. Dispersion visualization based on daytime (a) and night (b) conditions

During the day, the air below the atmosphere tends to be high so that the density of the air below the atmosphere becomes smaller than the air above the atmosphere. This causes an upward buoyant force of air. Thus, the air that has a warmer temperature will rise to the location of the air that has a cooler temperature until it reaches equilibrium. At sunset (at night) if the weather is clear, the air at ground level will be cooler than the air above, so the atmosphere is more stable [12].

Wind speed also affects the stability of the atmosphere, the higher the wind speed, the more unstable the atmosphere (refer to Table 7).

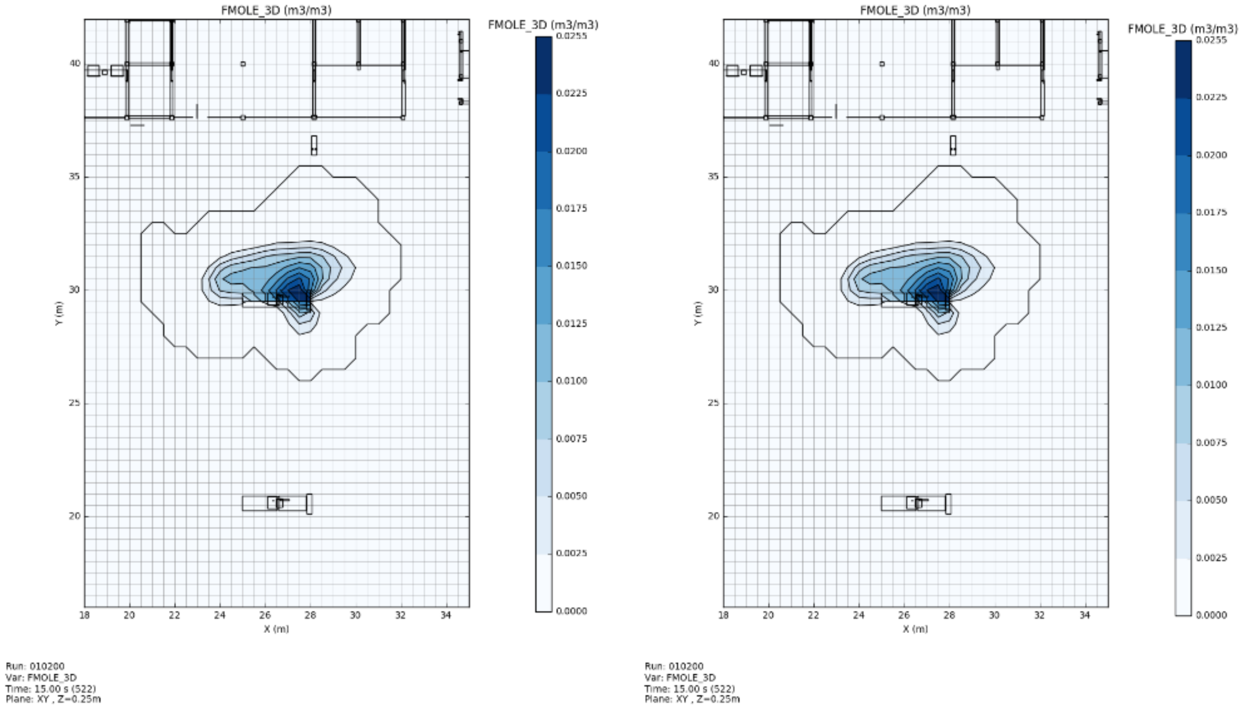
Table 7
Effect of wind speed on atmospheric stability

Wind speed at 10 m (m/s)	Insolation			Night	
	Strong	Moderate	Slight	≥ 4/8 Cloud	≤ 3/8 Cloud
2	A	A-B	B	F	F
2-3	A-B	B	C	E	F
3-5	B	B-C	C	D	E
5-6	C	C-D	D	D	D
6	C	D	D	D	D

From the simulation results, it can be seen that during the day, the dispersion area is greater than the dispersion area at night. This is because during the day the surface temperature is higher than the temperature above the atmosphere, so the air tends to rise. Meanwhile, at night, the surface temperature is lower than the temperature above the atmosphere so that the air does not rise and tends to be stable on the surface. The impact of exposure to gasoline during the day is more dangerous than at night, this is because the dispersion range is wider and tends to hit buildings around petrol stations.

3.3 Dispersion Simulation Results Based on Surface Roughness

In this study, the variables used were 0.03 m and 0.005 m. The following (Figure 11) is a visualization of the dispersion with a fixed variable, namely at night and the north wind direction.



(a) (b)

Fig 11. Dispersion visualization based on surface roughness (a) 0.005 m (b) 0.03 m

From the simulation results, it can be concluded that the greater the surface roughness value, the smaller the dispersion range.

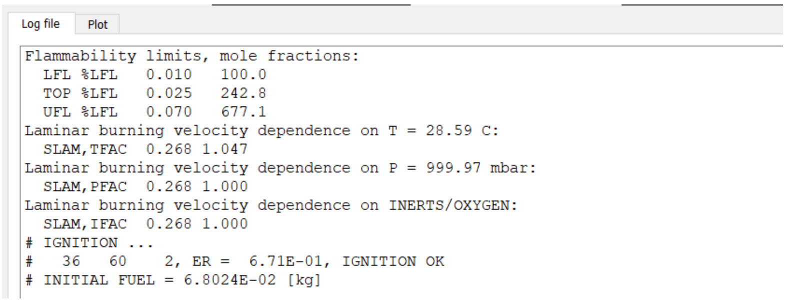
3.4 Explosion Simulation Results

The results of the explosion simulation will be reviewed based on the overpressure value, where Overpressure is the pressure that increases above the dispersed gas and the surrounding atmosphere. The results of this research simulation can be seen in Table 8.

Explosions can occur because the concentration is at the LFL and UFL values. A vapor-air mixture will ignite and burn only at a certain concentration. The vapor-air mixture will not burn when the concentration is lower than the Lower Flammable Limit (LFL) or when the concentration is too high, namely when it is above the Upper Flammable Limit (UFL)[13]. Vapor-air mixtures are flammable only if their composition is between LFL and UFL. LFL and UFL values can be viewed from the FLACS log file. The following are the LFL and UFL values in this study (refer to Figure 12).

Table 8
Explosion simulation results

No	Wind direction	Condition	Roughness (m)	Run	Overpressure (barg)
1	North	Day	0.005	success	0.001244
2	North	Night	0.005	success	0.001642
3	North	Day	0.03	success	0.001056
4	North	Night	0.03	success	0.001483
5	South	Day	0.005	Failed	-
6	South	Night	0.005	success	0.0009802
7	South	Day	0.03	Failed	-
8	South	Night	0.03	success	0.00098
9	East	Day	0.005	Failed	-
10	East	Night	0.005	success	0.003329
11	East	Day	0.03	Failed	-
12	East	Night	0.03	success	0.002622
13	West	Day	0.005	Failed	-
14	West	Night	0.005	success	0.002335
15	West	Day	0.03	Failed	-
16	West	Night	0.03	success	0.002235



Log file Plot

```
Flammability limits, mole fractions:
  LFL %LFL   0.010   100.0
  TOP %LFL   0.025   242.8
  UFL %LFL   0.070   677.1
Laminar burning velocity dependence on T = 28.59 C:
  SLAM,TFAC  0.268 1.047
Laminar burning velocity dependence on P = 999.97 mbar:
  SLAM,PFAC  0.268 1.000
Laminar burning velocity dependence on INERTS/OXYGEN:
  SLAM,IFAC  0.268 1.000
# IGNITION ...
#   36   60     2, ER =  6.71E-01, IGNITION OK
# INITIAL FUEL = 6.8024E-02 [kg]
```

Fig. 12. LFL and UFL value

From Figure 12, we can determine, is position of ignition between LFL and UFL value or not. It can describe on Figure 13.

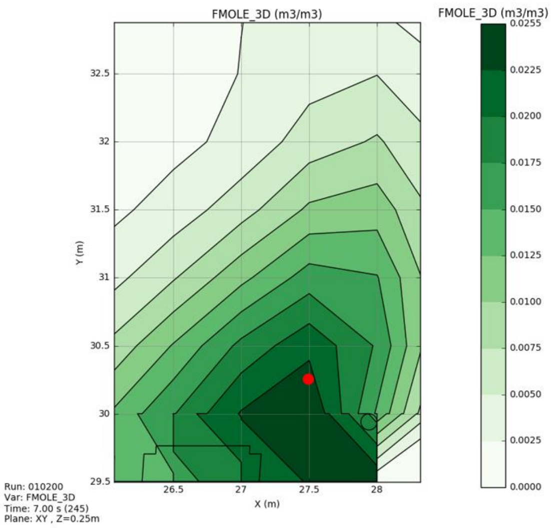


Fig. 13. Ignition location

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In scenario 2 for example, the ignition used is in the range of 0.0225-0.0255, the optimum value of LFL is at 0.025 so that the ignition point is close to the optimum range so that explosion can happen.

3.5 Explosion Simulation Results Based on Wind Direction

In this study, the input variables used in the explosion simulation are north and south wind directions. The following is the result of visualization of explosions based on wind direction with fixed variables, that is surface roughness of 0.005 m, and conditions at night.

From Figure 14, it can be seen that the difference in wind direction affects the overpressure of the explosion. Based on Table 8, the results of the explosion simulation in the north wind direction are at 20 s, which is 0.001642 barg, while in the south wind direction, overpressure occurs at 20 s and is 0.0009802 barg. In the east wind direction, the overpressure that occurs is 0.003329 barg. In the west wind direction, the overpressure that occurs is 0.002335 barg.

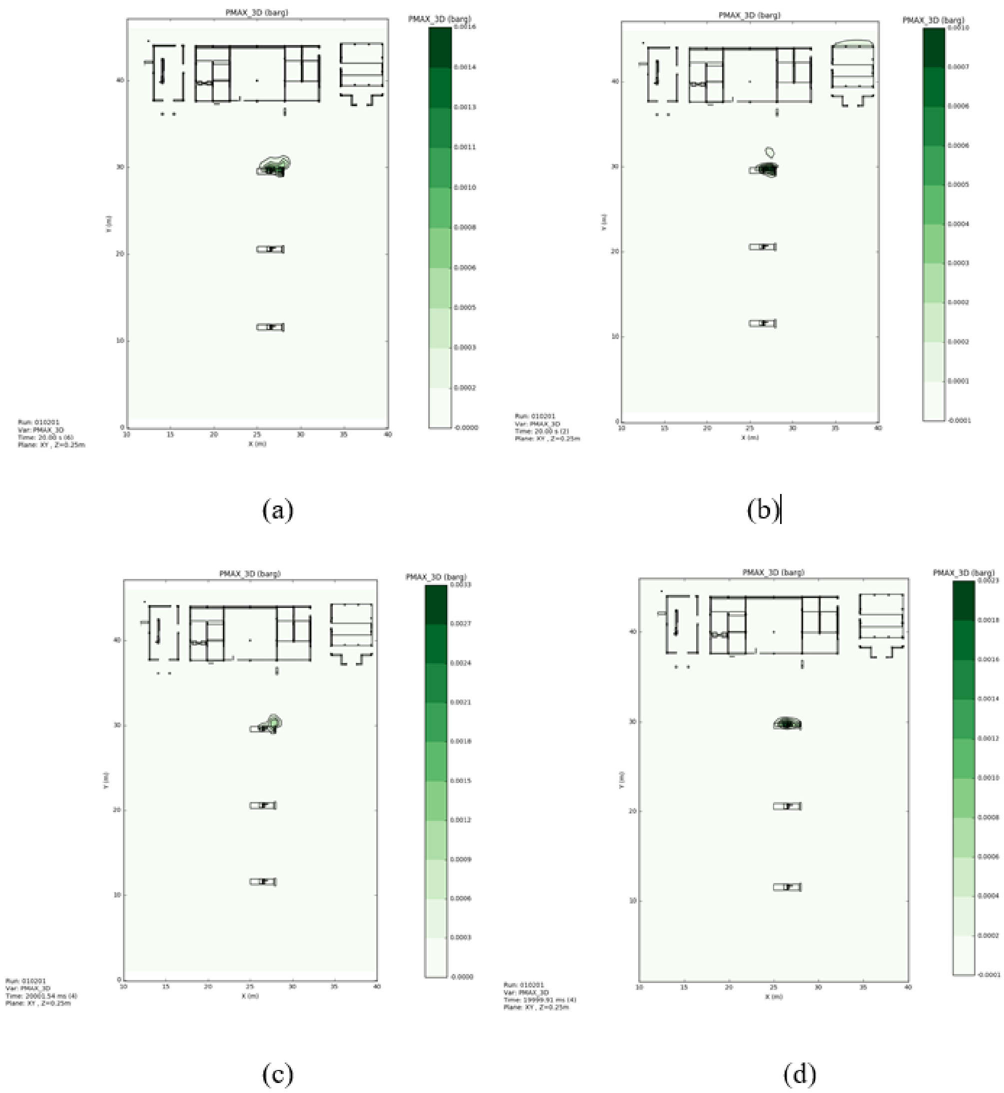


Fig. 14. Explosion visualization based on north (a), south (b), east (c), and west (d) wind directions

In the east wind direction, the overpressure is greater than other wind directions, this is because the east wind direction causes turbulence which causes concentrated concentration so that it can increase the explosion pressure [8]. The high concentration is also reflected in the dispenser building so that it enlarges the explosion.

The impact of the damage that occurs can be known through the overpressure value. The following is the impact of damage that occurs in buildings based on overpressure.

From Table 9, it can be concluded that the lowest explosion in the west wind direction (0.0483 psig) can cause glass shattering, cause sonic booms, and can interfere with the human sense of hearing.

Table 9
Relationship of pressure value and damage caused

Pressure (Psig)	Damage
0.02	Annoying noise (137 dB if of low frequency, 10-15 Hz)
0.03	Occasional breaking of large glass windows already under strain
0.04	Loud noise (143 dB), sonic boom, glass failure
0.1	Breakage of small windows under strain
0.15	Typical pressure for glass breakage
0.3	"Safe distance" (probability 0.95 of no serious damage below this value); projectile limit; some damage to house ceilings; 10% window glass broken
0.4	Limited minor structural damage
0.5-1	Large and small windows usually shatter; occasional damage to window frames
0.7	Minor damage to house structures
1	Partial demolition of houses, made uninhabitable
1-2	Corrugated asbestos shatters; corrugated steel or aluminum panels, fastenings fail, followed by buckling; wood panels (standard housing), fastenings fail, panels blow in
1.3	Steel frame of clad building slightly distorted
2	Partial collapse of walls and roofs of houses
2-3	Concrete or cinder block walls, not reinforced, shatter
2.3	Lower limit of serious structural damage
2.5	50% destruction of brickwork of houses
3	Heavy machines (3000 lb) in industrial buildings suffer little damage; steel frame buildings distort and pull away from foundations
3-4	Frameless, self-framing steel panel buildings demolished; rupture of oil storage tanks
4	Cladding of light industrial buildings ruptures
5	Wooden utility poles snap; tall hydraulic presses (40,000 lb) in buildings slightly damaged
5-7	Nearly complete destruction of houses
7	Loaded train wagons overturned
7-8	Brick panels, 8-12 in thick, not reinforced, fail by shearing or flexure
9	Loaded train boxcars completely demolished
10	Probable total destruction of buildings; heavy machine tools (7000 lb) moved and badly damaged, very heavy machine tools (12,000 lb) survive
300	Limit of crater lip

Furthermore, analyzing the impact of damage that occurs to humans based on overpressure through Table 10. From Table 10, it can be concluded that the explosion poses no danger to humans.

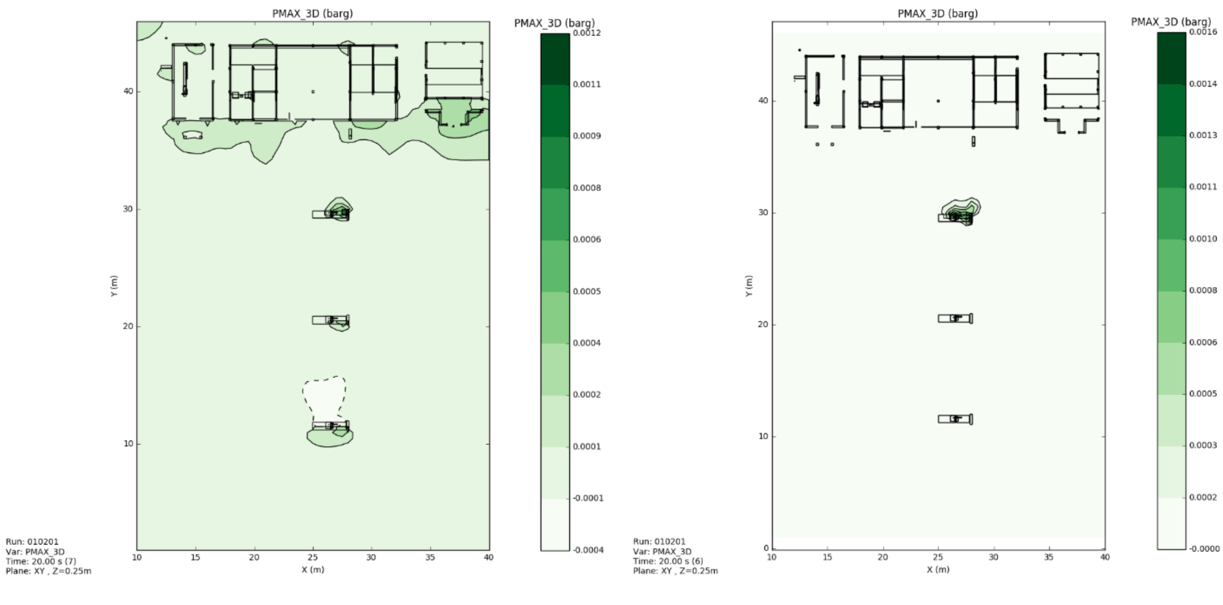
Table 10
Relationship between pressure value and damage caused [14]

Overpressure (barg)	Wind Speed (mph)	Effect on the human body
0.069	38	Light injuries from fragments occur
0.138	70	People injured by flying glass and debris
0.207	102	Serious injuries are common, fatalities may occur
0.345	163	Injuries are universal, fatalities are widespread
0.69	294	Most people are killed
1.389	50	Fatalities approach 100%

3.6 Explosion Simulation Results Based on Day and Night Conditions

In this study, the input variables used in the explosion simulation are day and night conditions. The following are the results of explosion visualization based on day and night conditions with fixed variables, namely surface roughness of 0.005 m, and north wind direction.

From Figure 15, it can be seen that the difference in wind direction affects the overpressure of the explosion. Based on Table 8, the highest explosion simulation results were obtained at night, namely at 20 s, which was 0.001642 barg, while during the day, overpressure occurred at 20 s and 0.001244 barg. At night, the overpressure is greater than during the day due to the greater concentration of gasoline vapor dispersed, and the dispersion range is smaller, which causes the overpressure effect of the explosion to be more concentrated in one area and the overpressure value is greater than during the day.



(a) (b)

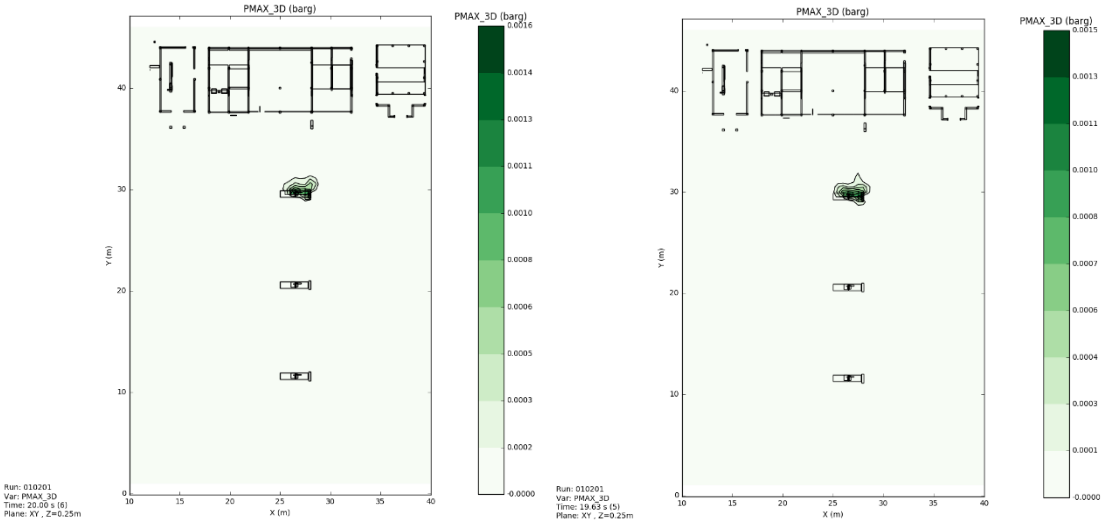
Fig. 15. Explosion visualization by day (a) and night (b)

From tables Table 9 and 10, it can be concluded that explosions can cause sounds that interfere with the human sense of hearing.

3.7 Explosion Simulation Results Based on Surface Roughness

In this study, the condition variable used in the explosion simulation is surface roughness, namely the surface roughness of 0.03 m and 0.005 m. The following is the result of visualization of explosions with fixed variables, that is the type of north wind direction, and night conditions.

From Figure 16, it can be seen that the difference in surface roughness affects the overpressure of the explosion. Based on Table 8, the highest explosion simulation results obtained at a surface roughness of 0.005 m, namely at a time of 20 s, which is 0.001642 barg, while at night, overpressure occurs at a time of 20 s and is 0.001483 barg.



(a) (b)

Fig. 16. Explosion visualization based on a surface roughness of 0.005 m (a) and a surface roughness of 0.03 m (b)

The results of this study are contrary to previous research which states that surface roughness affects the overpressure of an explosion where the smaller the surface roughness, the greater the overpressure of the explosion [14]. This is because the smaller the surface roughness the smaller the dispersion that occurs. So, the gas concentration becomes greater. This causes the resulting explosion to be larger and the range to be greater [15]. In this study, the concentration at the ignition point was greater at a surface roughness of 0.005 m than at a concentration of 0.03 m so that the explosion was greater at a surface roughness of 0.005 m. it shown at Figure 17.

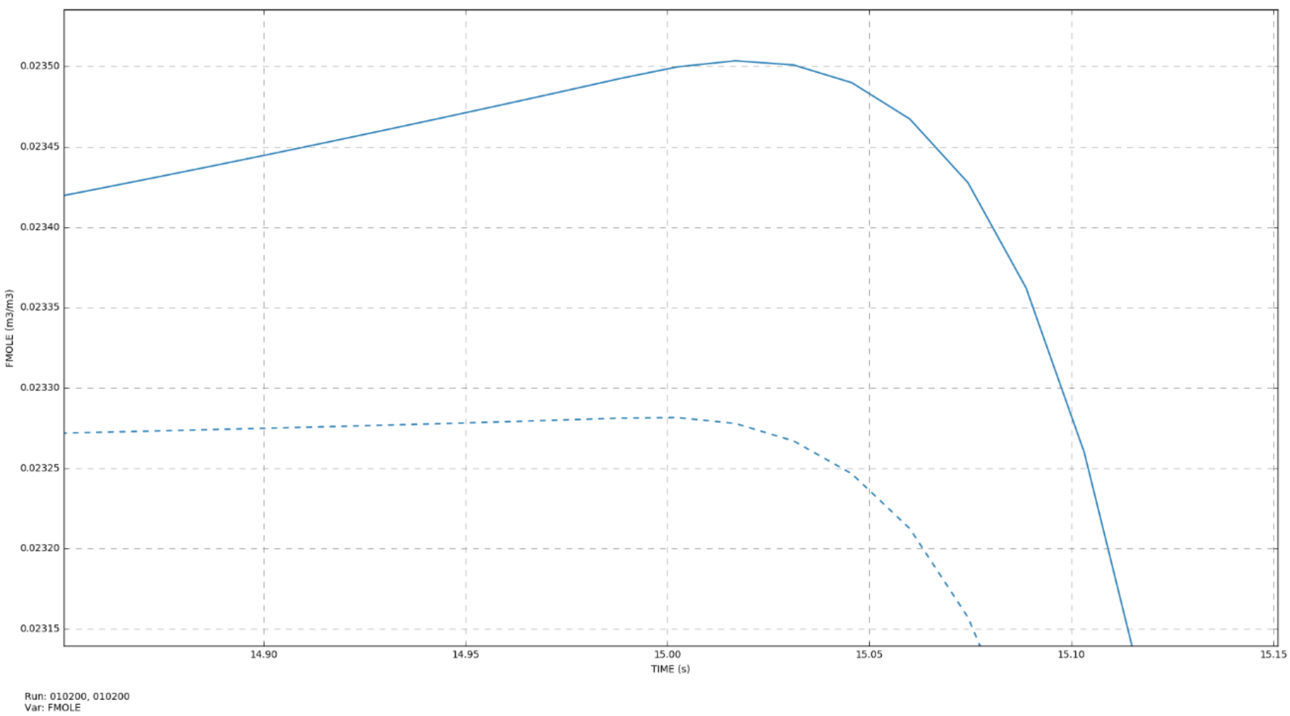


Fig. 17. Relationship of concentration Vs time at ignition point at surface roughness 0.005 m (connecting line) and at surface roughness 0.03 m (dotted line)

From tables Table 9 and 10, it can be concluded that explosions can cause sounds that interfere with the human sense of hearing.

4. Conclusions

The results of the dispersion simulation at gas stations X variables are divided based on:

i. Wind direction
The difference in wind direction will cause differences in the concentration of gasoline vapor dispersed in the atmosphere, as well as the location and how the gas will be dispersed.
ii. Day – night condition
Day and night conditions are affected by temperature, and wind speed. Conditions during the day are more unstable than at night, which is indicated by the air temperature and wind speed being greater, causing the dispersion rate to be faster and the dispersion distance to be wider.
iii. Surface Roughness
The smaller the surface roughness, the greater the wind speed, causing the range of each gas in each range to be farther and wider and the concentration of gasoline vapor dispersed is smaller.

The explosion simulation results show that the highest overpressure is 0.003329 barg, that is in the scenario of east wind direction, night conditions, and surface roughness of 0.005 m. This happens because the building reflects the last explosion at night and the large surface roughness causes a small dispersion area so that the gasoline vapor concentration increases. The impact of the resulting explosion can break the glass and cause a sound that disturbs the human sense of hearing.

From 16 simulated scenarios, there are 6 scenarios that fail to explode, this is because the concentration of gasoline vapor is not in the UFL and LFL.

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