

***STUDY ON EFFECTIVENESS OF COMMERCIAL
AND RESIDENTIAL NATURAL GAS ODORISATION
SYSTEM IN PENINSULAR MALAYSIA***

**SIMULATION STUDY:
CFD AND FLACS RESULTS**

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ST Office*

COMPUTATIONAL FLUID ANALYSIS (CFD) RESULTS

Simulation at Selected Pre-Determined Condition

Figures 6.1 and 6.2 below illustrate a simple horizontal main pipe with two sets of branch pipe gas layout arrangement, i.e. vertical and horizontal, that has been modelled to simulate gas transport of natural gas (i.e. methane) and odorant vapour (80 wt% TBM and 20 wt% DMS) mixture.

Figure 6.1:
A Horizontal
Branch Gas
Pipe Layout

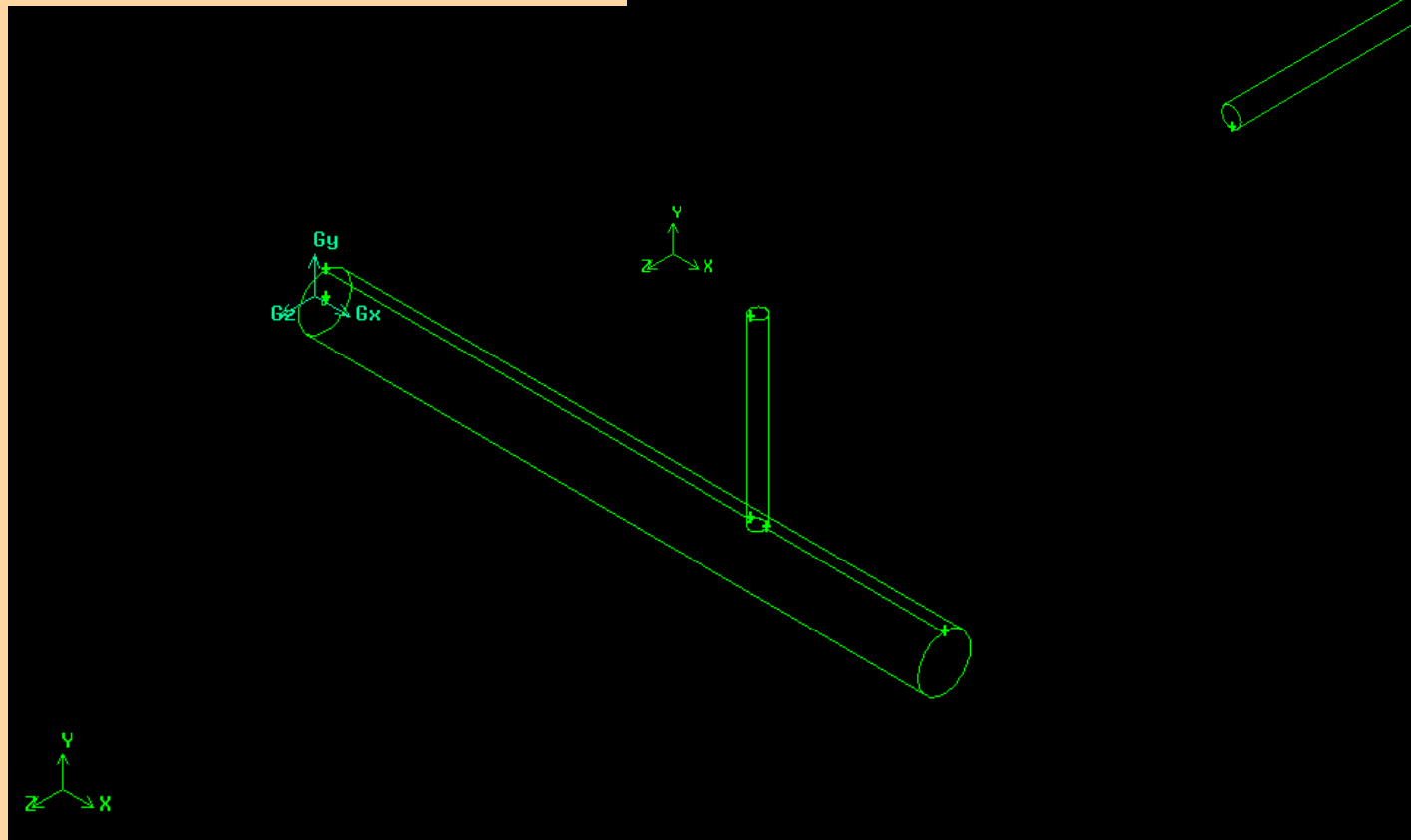
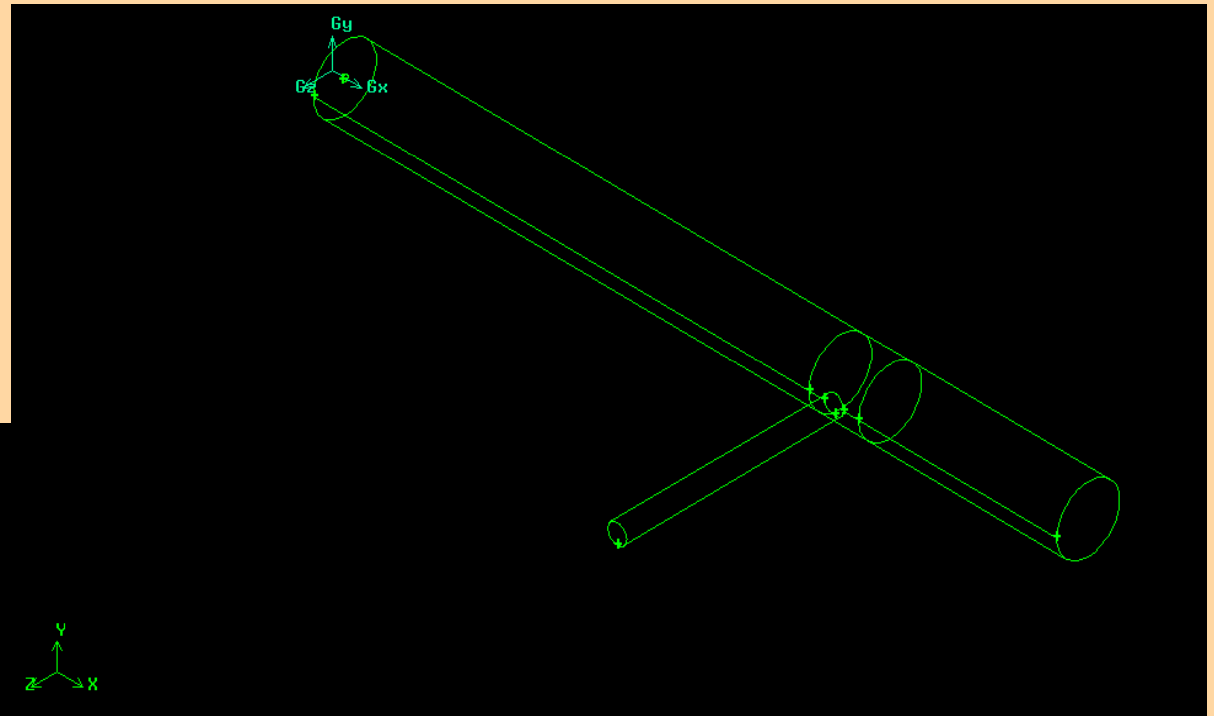


Figure 6.2:
A Vertical
Branch Gas
Pipe Layout

- Table 6.1 below summarises the average mass fraction of TBM and DMS measured at the gas exit points of main pipe and of two branch pipe gas models, i.e. vertical branch and horizontal branch.
- Natural gas and odorant flow rates were set at 0.25 kg/s and 0.0025 kg/s, respectively, thus simulating 1 % of odorant concentration (i.e. average mass fraction of 0.0099 kg odorant/kg gas mixture) in flowing gas. *T*
- *the outlet gas flow rates at the main and the branch were set at 90 % and 10 % of the inlet gas flow, respectively.*
- The simulation was performed assuming high flow gas conditions with steady-state flow, standard k-e turbulent model and default CFD values.

Table 6.1: Average Mass Fraction of TBM and DMS *

Reference	Average Mass Fraction at Gas Outlet (kg odorant/kg natural gas-odorant mixture)					
	TBM			DMS		
	Main (Horizontal)	Branch (Vertical)	Branch (Horizontal)	Main (Horizontal)	Branch (Vertical)	Branch (Horizontal)
Figure 6.1	0.00812		0.00766	0.00203		0.00192
Figure 6.2	0.00826	0.00510		0.00207	0.00127	

* (Simulated High Gas Flow ; the outlet gas flow rates at the main and the branch were set at 90 % and 10 % of the inlet gas flow, respectively)

- Comparison of the average mass fraction of TBM at the main and branch outlets for both pipe layouts clearly show higher TBM concentration at the former, thus indicating more odorant being transported along a horizontal pipe at a high gas flow rate.
- The average mass fraction of TBM for the main outlet of both pipe layouts is quite similar, however higher TBM concentration at the horizontal branch is demonstrated. This again shows the significant effects of higher TBM specific gravity and pipe elevation on the odorant distribution pattern.
- Detailed explanation for this phenomenon has been discussed in the previous section. The same phenomenon is also demonstrated for DMS.

- Table 6.2 below summarises the average mass fraction of TBM and DMS measured at the gas exit points of main pipe and of two branch pipe gas models, i.e. vertical branch and horizontal branch.
- Natural gas and odorant flow rates were set at 0.25 kg/s and 0.0025 kg/s, respectively, thus simulating 1 % of odorant concentration (i.e. average mass fraction of 0.0099 kg odorant/kg gas mixture) in flowing gas.
- *The outlet gas flow rates at the main and the branch were set 50 % and 50 % of the inlet gas flow, respectively.*
- The simulation was performed assuming high flow gas conditions with steady-state flow, standard k- ϵ turbulent model and default CFD values.

Table 6.2: Average Mass Fraction of TBM and DMS *

Reference	Average Mass Fraction at Gas Outlet (kg odorant/kg natural gas-odorant mixture)					
	TBM			DMS		
	Main (Horizontal)	Branch (Vertical)	Branch (Horizontal)	Main (Horizontal)	Branch (Vertical)	Branch (Horizontal)
Figure 6.1	0.00797		0.00834	0.00199		0.0021
Figure 6.2	0.00827	0.00813		0.00207	0.00203	

* (Simulated High Gas Flow; The outlet gas flow rates at the main and the branch were set at 50 % and 50 % of the inlet gas flow, respectively)

- Comparison of the average mass fraction of TBM at the main and branch outlets for both pipe layouts clearly show approximately identical values, thus indicating uniform TBM concentration were present in both horizontal and vertical pipes.
- The average mass fraction of TBM and DMS at the both branch outlets was higher, in particular TBM at vertical branch outlet, than that as compared the predicted values in Table 6.1.
- This shows that as long as the gas flow rate are high enough to carry the odorant along with natural gas, the effects of pipe elevation on the odorant distribution pattern is insignificant.
- Detailed explanation for this phenomenon has been discussed in the previous section.

- Table 6.3 below summarises the average mass fraction of TBM and DMS measured at the gas exit points of main pipe and of two branch pipe gas models, i.e. vertical branch and horizontal branch.
- Natural gas and odorant flow rates were set at 0.025 kg/s and 0.00025 kg/s, respectively, thus simulating 1 % of odorant concentration (i.e. average mass fraction of 0.0099 kg odorant/kg gas mixture) in flowing gas.
- The outlet gas flow rates at the main and the branch were set at 90 % and 10 % of the inlet gas flow, respectively.
- The simulation was performed assuming low gas flow conditions, steady- state flow, laminar model and default CFD values.

- Comparison of contours of TBM mass fraction in Figures 6.3 - 6.6 show more uniform odorant concentration for horizontal branch compared to the vertical branch.

Table 6.3: Average Mass Fraction of TBM and DMS *

Reference	Average Mass Fraction at Gas Outlet (kg odorant/kg natural gas-odorant mixture)					
	TBM			DMS		
	Main (Horizontal)	Branch (Vertical)	Branch (Horizontal)	Main (Horizontal)	Branch (Vertical)	Branch (Horizontal)
Figure 6.1	0.00783		0.00365	0.00196		0.000912
Figure 6.2	0.00515	2.17e-08		0.00129	5.4e-09	

* (Simulated Low Gas Flow; The outlet gas flow rates at the main and the branch were set at 90 % and 10 % of the inlet gas flow, respectively)

- Comparison of the average mass fraction of TBM at the main outlet for both pipe layouts clearly show higher TBM concentration at the former, thus indicating more odorant being transported along a horizontal pipe at a lower gas flow rate.
- The most interesting results from the simulation are the marked difference in TBM and DMS concentrations for the horizontal and vertical branch outlets.
- Significant levels of TBM and DMS are predicted to be present at the horizontal branch outlet, however, virtually no TBM and DMS is present at the vertical branch outlet.
- This again shows the significant effect of higher odorant specific gravity and pipe elevation on the odorant distribution pattern. Detailed explanation for this phenomenon has been also discussed in the previous section.

- Table 6.4 below summarises the average mass fraction of TBM and DMS measured at the gas exit points of main pipe and of two branch pipe gas models, i.e. vertical branch and horizontal branch.
- Natural gas and odorant flow rates were set at 0.025 kg/s and 0.00025 kg/s, respectively, thus simulating 1 % of odorant concentration (i.e. average mass fraction of 0.0099 kg odorant/kg gas mixture) in flowing gas.
- The outlet gas flow rates at the main and the branch were set 50 % and 50 % of the inlet gas flow, respectively.
- The simulation was performed assuming low gas flow conditions, steady- state flow, laminar model and default CFD values

Table 6.4: Average Mass Fraction of TBM and DMS *

Reference	Average Mass Fraction at Gas Outlet (kg odorant/kg natural gas-odorant mixture)					
	TBM			DMS		
	Main (Horizontal)	Branch (Vertical)	Branch (Horizontal)	Main (Horizontal)	Branch (Vertical)	Branch (Horizontal)
Figure 6.1	0.0085		0.0081	0.0021		0.002
Figure 6.2	0.01357	0.0005		0.0034	0.00014	

* (Simulated Low Gas Flow; The outlet gas flow rates at the main and the branch were set at 50 % and 50 % of the inlet gas flow, respectively)

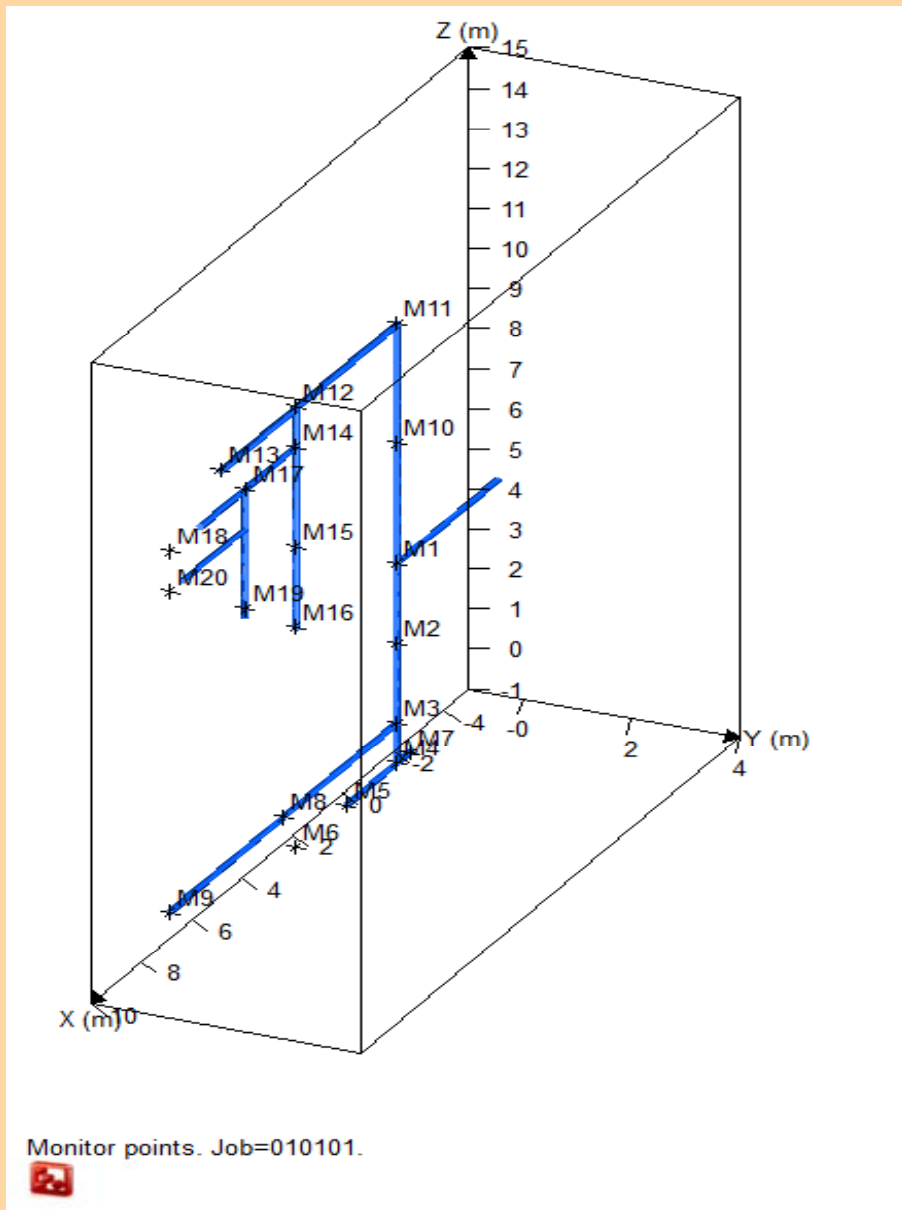
CFD Conclusion

- The most interesting results from the simulation is the marked increase in TBM and DMS concentrations for the horizontal and in particular vertical branch outlets as compared to the values in Table 6.3.
- This again shows the significant effect of gas flow condition on the odorant distribution pattern. Detailed explanation for this phenomenon has been also discussed in the previous section.
- The analysis of CFD simulation data significantly supports the odorant measurement during the site visit in July and September 2012.
- Two very important factors, i.e. gas consumption rate and pipe gas elevation, which contribute to significant odorant fade especially in pipe gas supply line at high rise buildings such as at Hampshire Park (Ampang) and Harmony Putra Flats (Putra Jaya) have been identified experimentally and computationally.
- Nevertheless, the CFD simulation indicate that gas consumption rate play a more important role as compared to pipe elevation, i.e. as long as gas consumption rate is high enough, adequate odorant concentration levels can be achieved eventhough at high elevation point of consumption.

FLAME ACCELERATION SIMULATOR (FLACS) RESULTS

Case 1: Glenmarie Horizontal Dispersion

Simulation at Selected Pre-Determined Condition



No.	X	Y	Z	Status
1	0.00	0.00	5.00	Open
2	0.00	0.00	3.00	Open
3	0.00	0.00	1.00	Open
4	0.00	0.00	0.00	Open
5	2.00	0.00	0.00	Open
6	4.00	0.00	0.00	Open
7	-0.50	0.00	0.00	Open
8	4.50	0.00	1.00	Open
9	9.00	0.00	1.00	Open
10	0.00	0.00	8.00	Open
11	0.00	0.00	11.00	Open
12	4.00	0.00	11.00	Open
13	7.00	0.00	11.00	Open
14	4.00	0.00	10.00	Open
15	4.00	0.00	7.50	Open
16	4.00	0.00	5.50	Open
17	6.00	0.00	10.00	Open
18	9.00	0.00	10.00	Open
19	6.00	0.00	7.00	Open
20	9.00	0.00	9.00	Open

Figure 7.2: The Overall Monitor Points for the Case Study Adopted

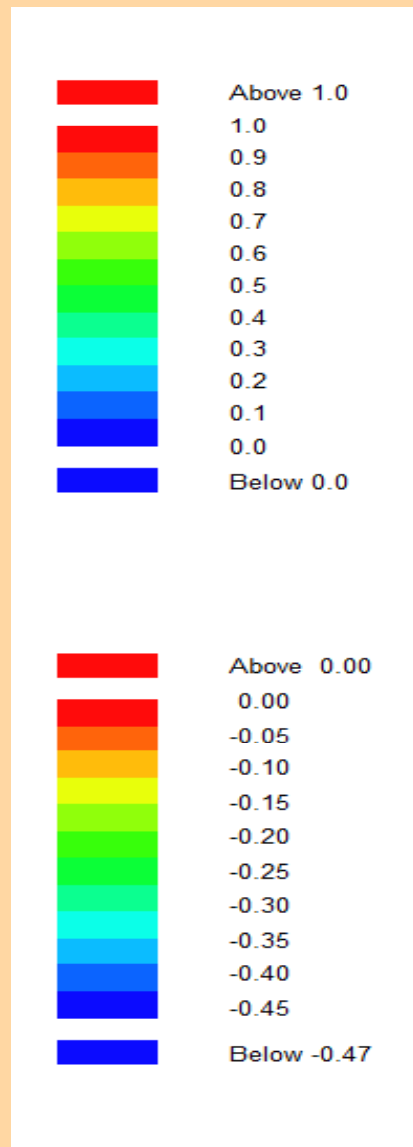
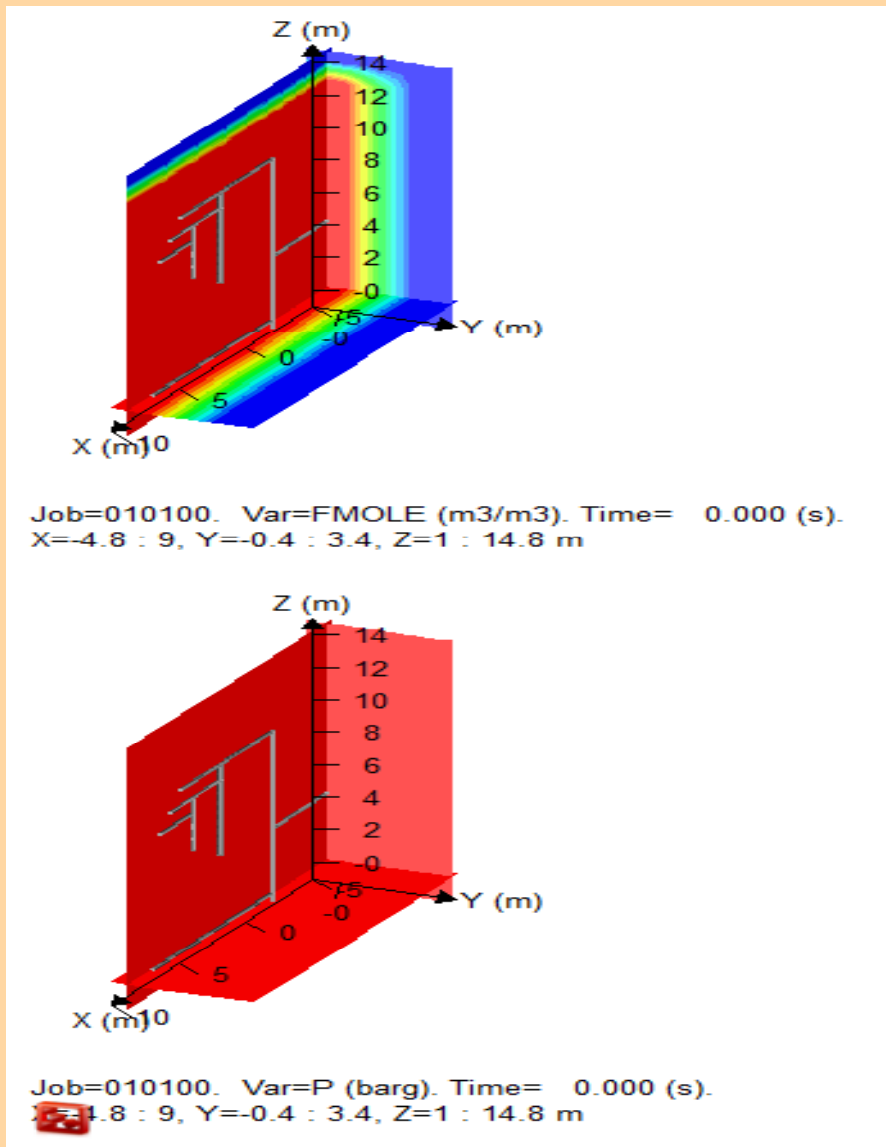
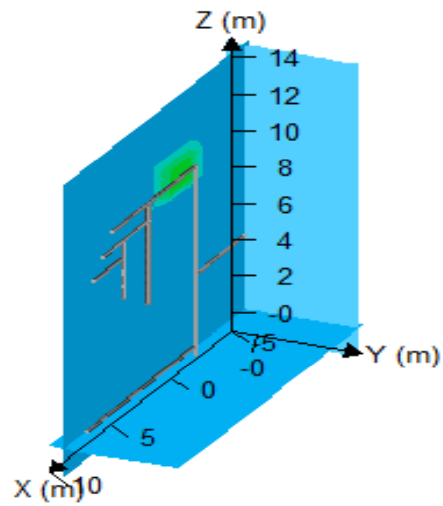
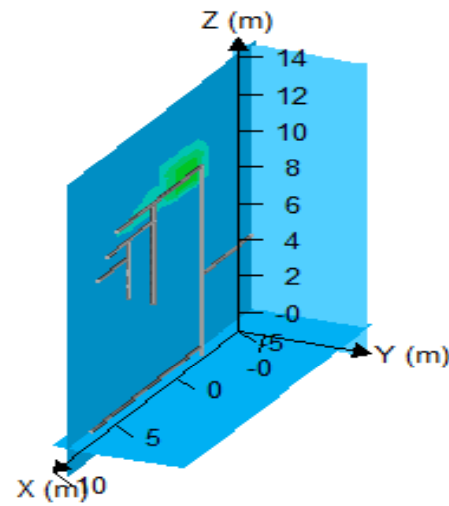


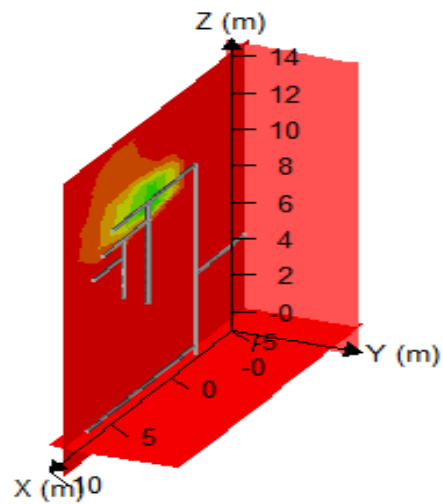
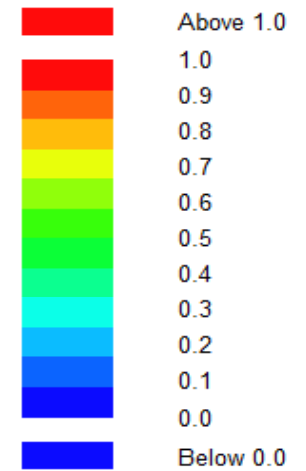
Figure 7.4: Pressure, P and Mole concentration FMOLE profile on Time Step



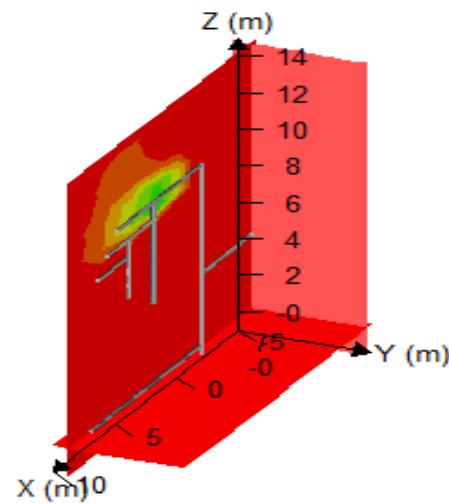
Job=010100. Var=FMOLE (m3/m3). Time= 19.996 (s).
 X=-4.8 : 9, Y=-0.4 : 3.4, Z=1 : 14.8 m



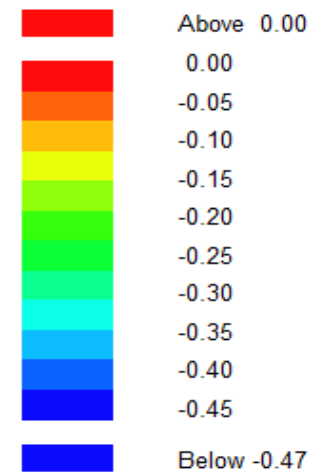
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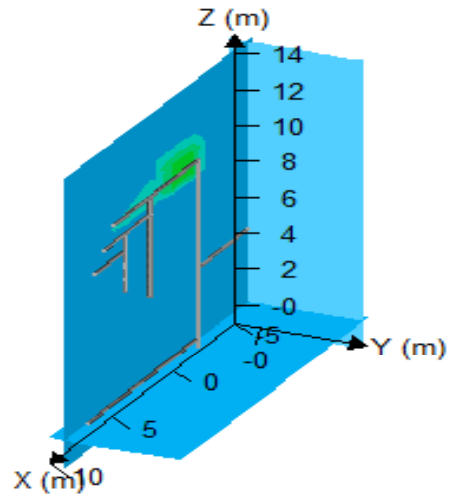


Job=010100. Var=P (barg). Time= 19.996 (s).
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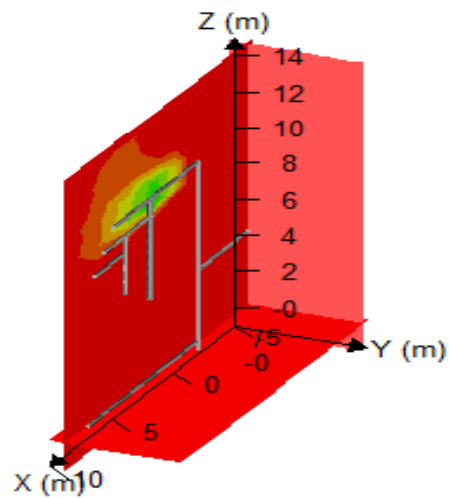
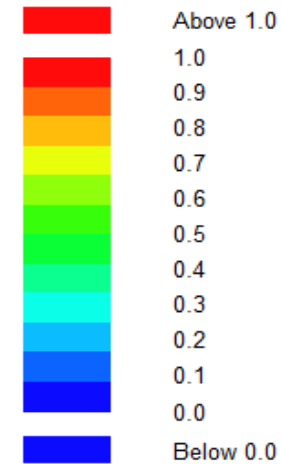


Job=010100. Var=P (barg). Time= 40.000 (s).
 X=-4.8 : 9, Y=-0.4 : 3.4, Z=1 : 14.8 m

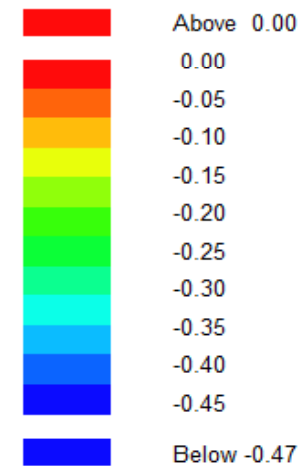




Job=010100. Var=FMOLE (m3/m3). Time= 100.000 (s).
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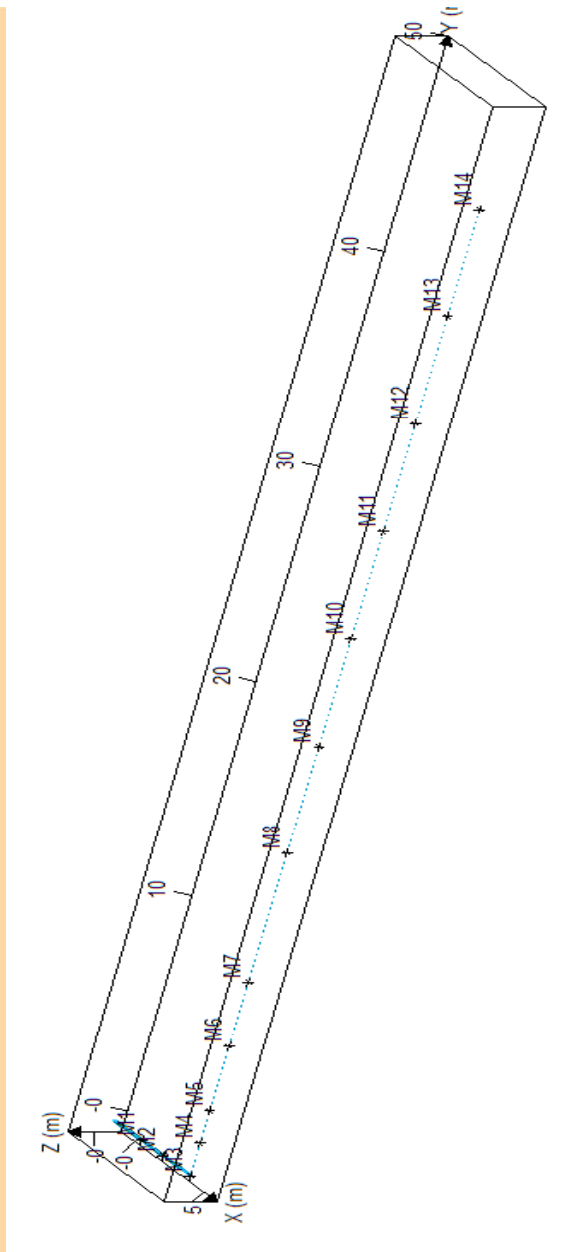
Job=010100. Var=P (barg). Time= 100.000 (s).
 X=-4.8 : 9, Y=-0.4 : 3.4, Z=1 : 14.8 m



FLAME ACCELERATION SIMULATOR (FLACS) RESULTS

Case 2 : High-Rise Building Dispersion

Simulation at Selected Pre-Determined Condition



No.	X	Y	Z	Status
1	2.00	0.00	0.00	Open
2	3.50	0.00	0.00	Open
3	5.50	0.00	0.00	Open
4	5.50	1.50	0.00	Open
5	5.50	3.00	0.00	Open
6	5.50	6.00	0.00	Open
7	5.50	9.00	0.00	Open
8	5.50	15.00	0.00	Open
9	5.50	20.00	0.00	Open
10	5.50	25.00	0.00	Open
11	5.50	30.00	0.00	Open
12	5.50	35.00	0.00	Open
13	5.50	40.00	0.00	Open
14	5.50	45.00	0.00	Open

Figure 7.7: Monitor Points of Pipe Configuration

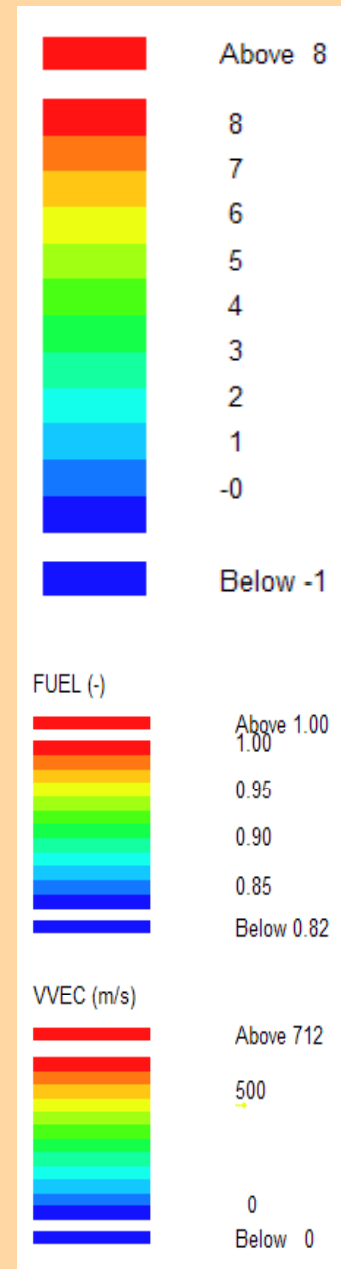
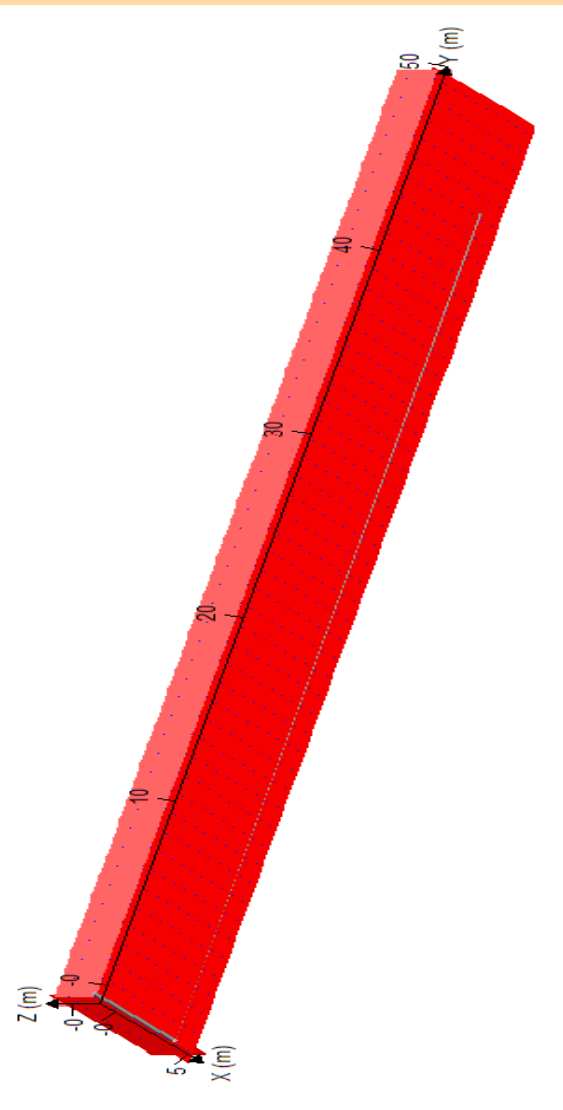
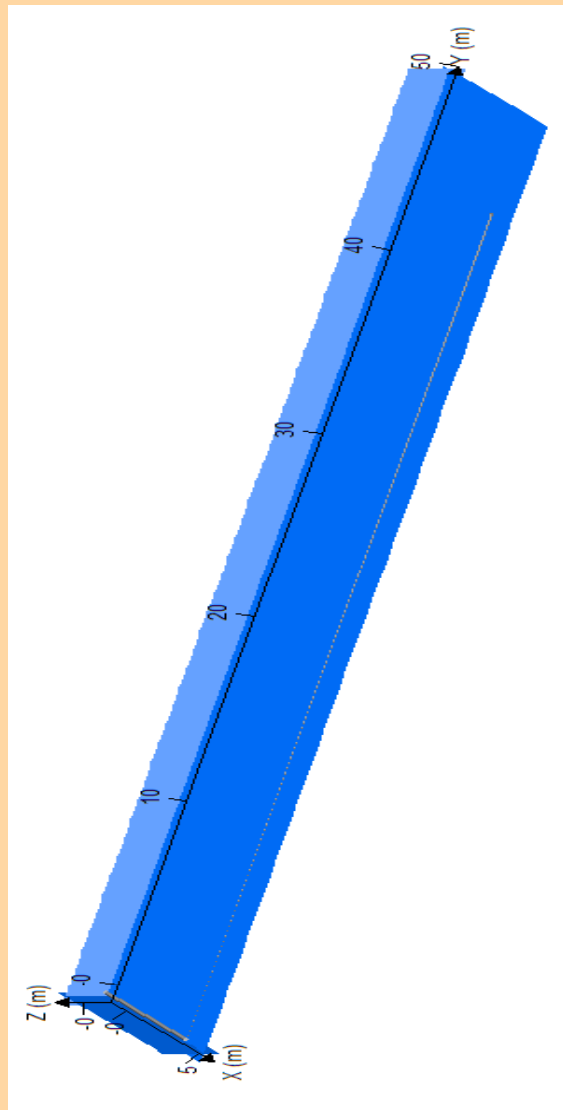


Figure 7.8: Fuel, Pressure and VVEC Profile in a Step Time at $t = 0$ s

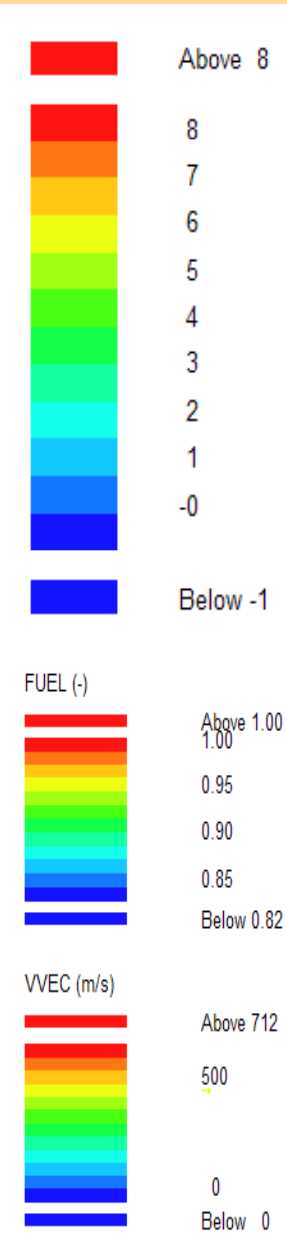
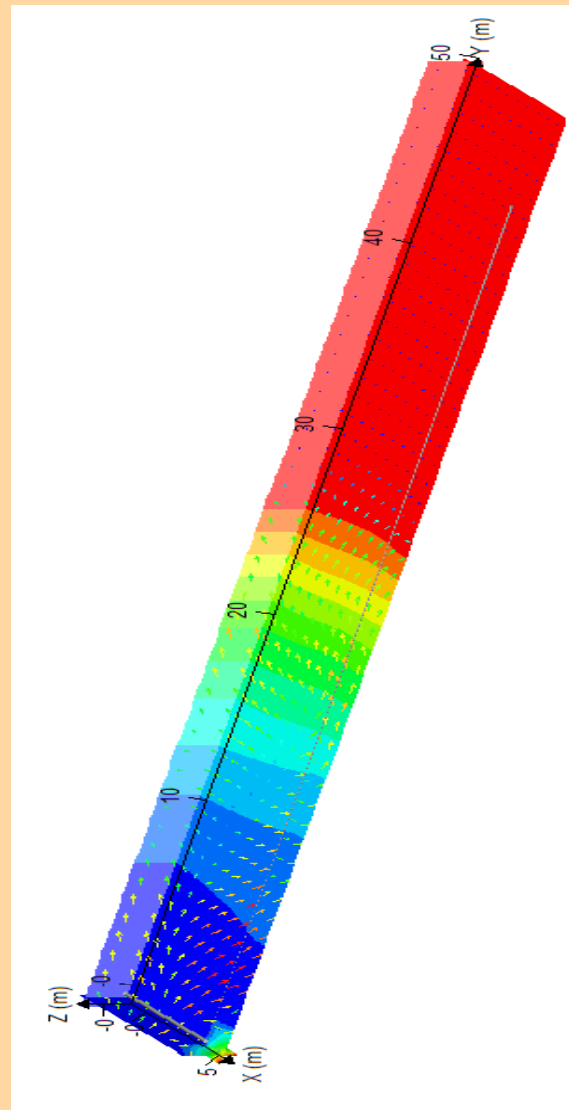
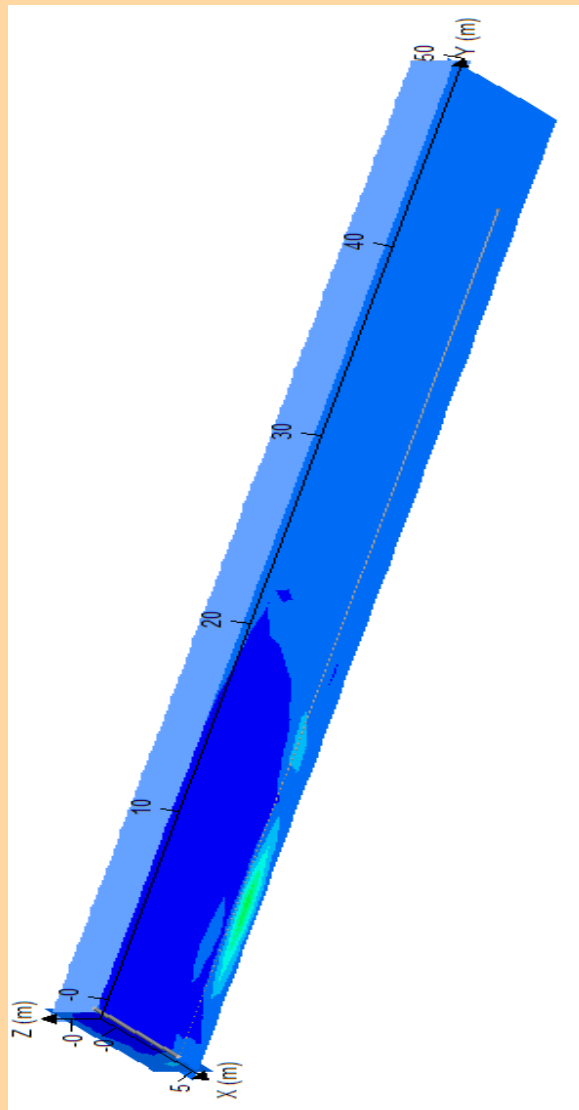
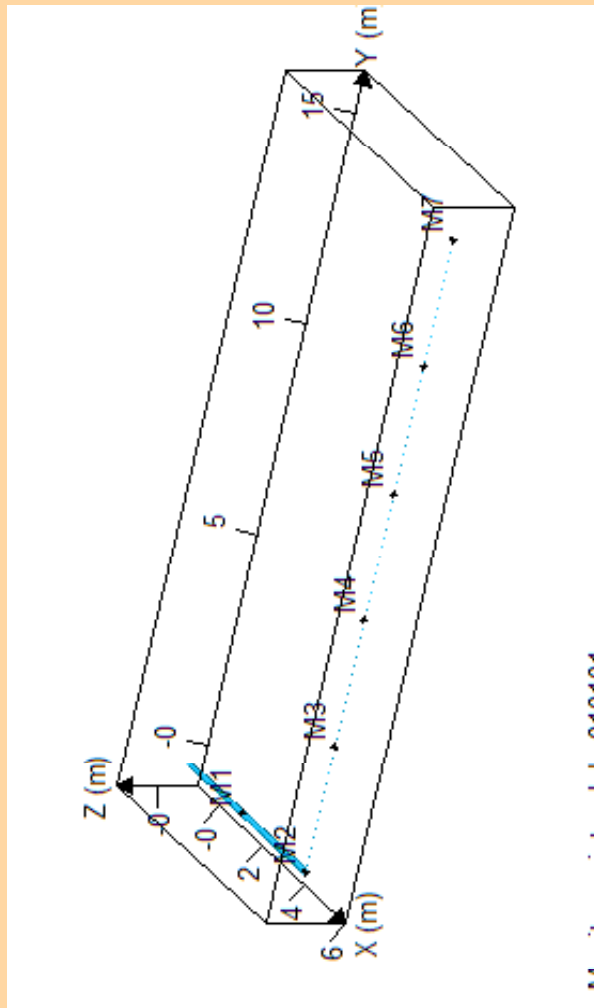


Figure 7.9, Pressure and VVEC Profile in a Step
Time at $t = 4.985$ s



No.	X	Y	Z	Status
1	2.50	0.00	0.00	Open
2	5.50	0.00	0.00	Open
3	5.50	3.00	0.00	Open
4	5.50	6.00	0.00	Open
5	5.50	9.00	0.00	Open
6	5.50	12.00	0.00	Open
7	5.50	15.00	0.00	Open

Figure 7.10: Monitor points for 15 m Height Building

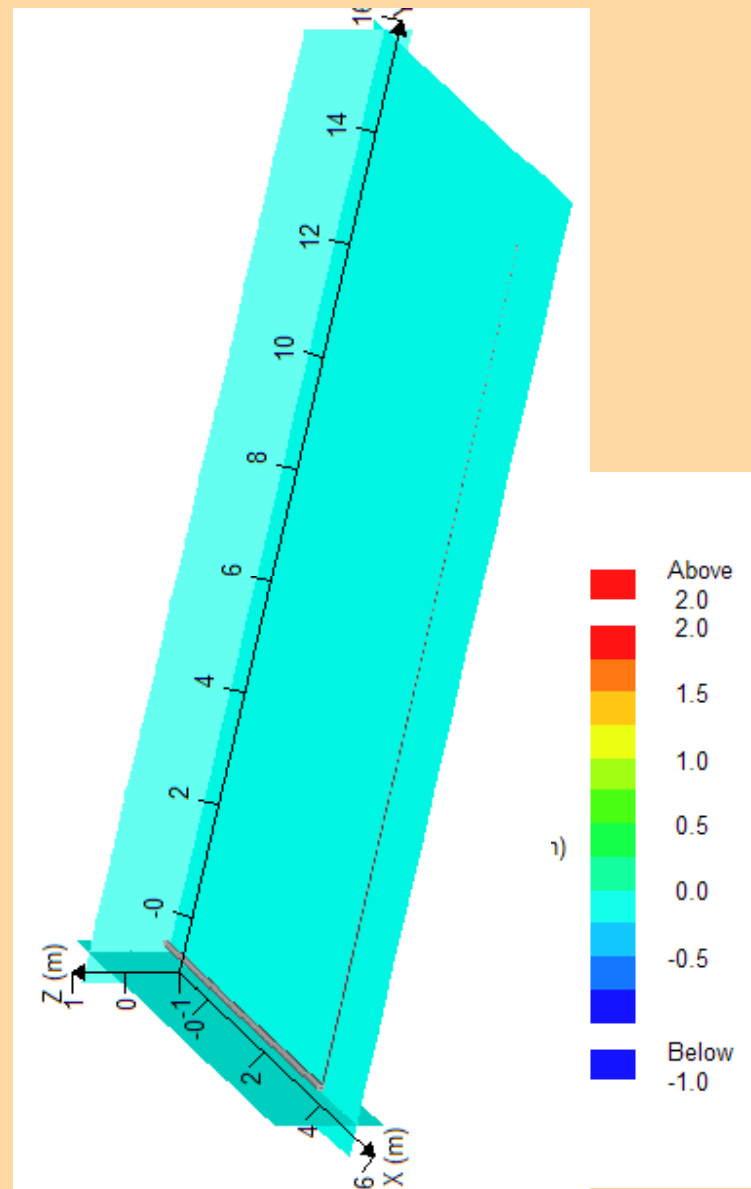
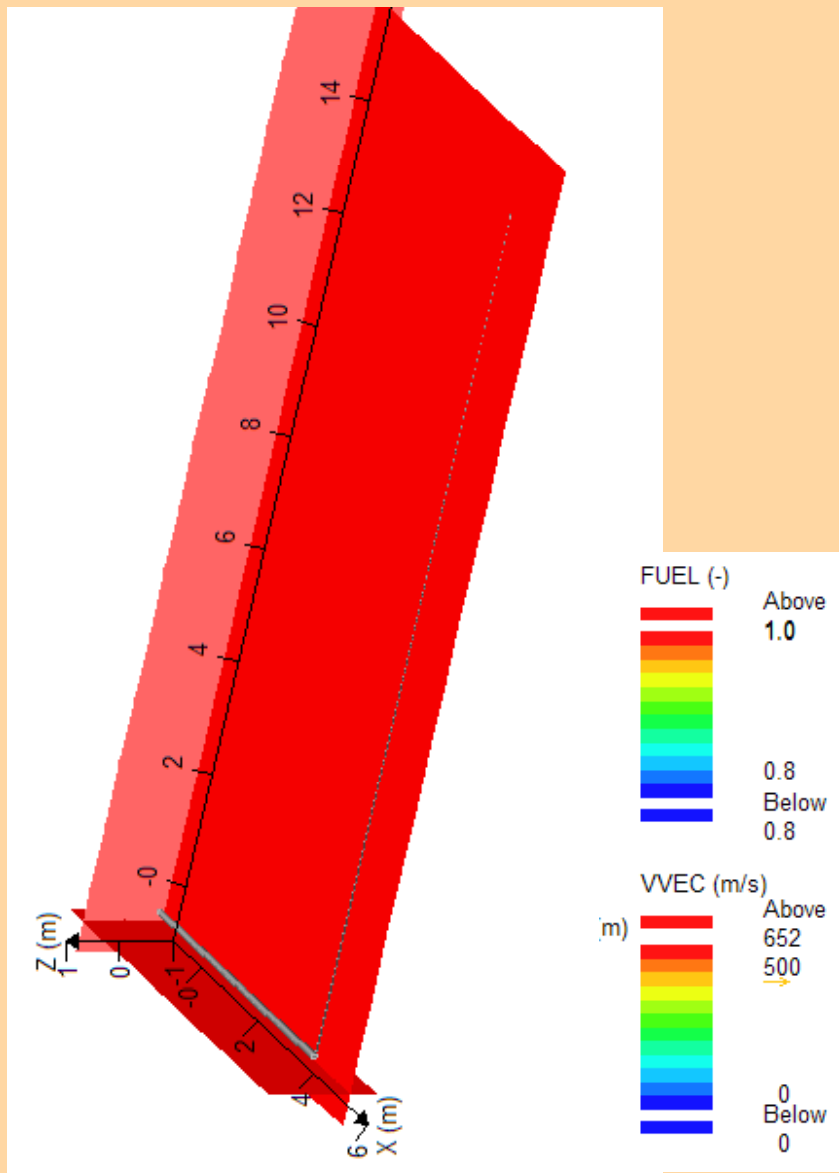


Figure 7.11a : Fuel, Pressure and VVEC Profile in a Step Time at $t = 0$ s for 15 m height building

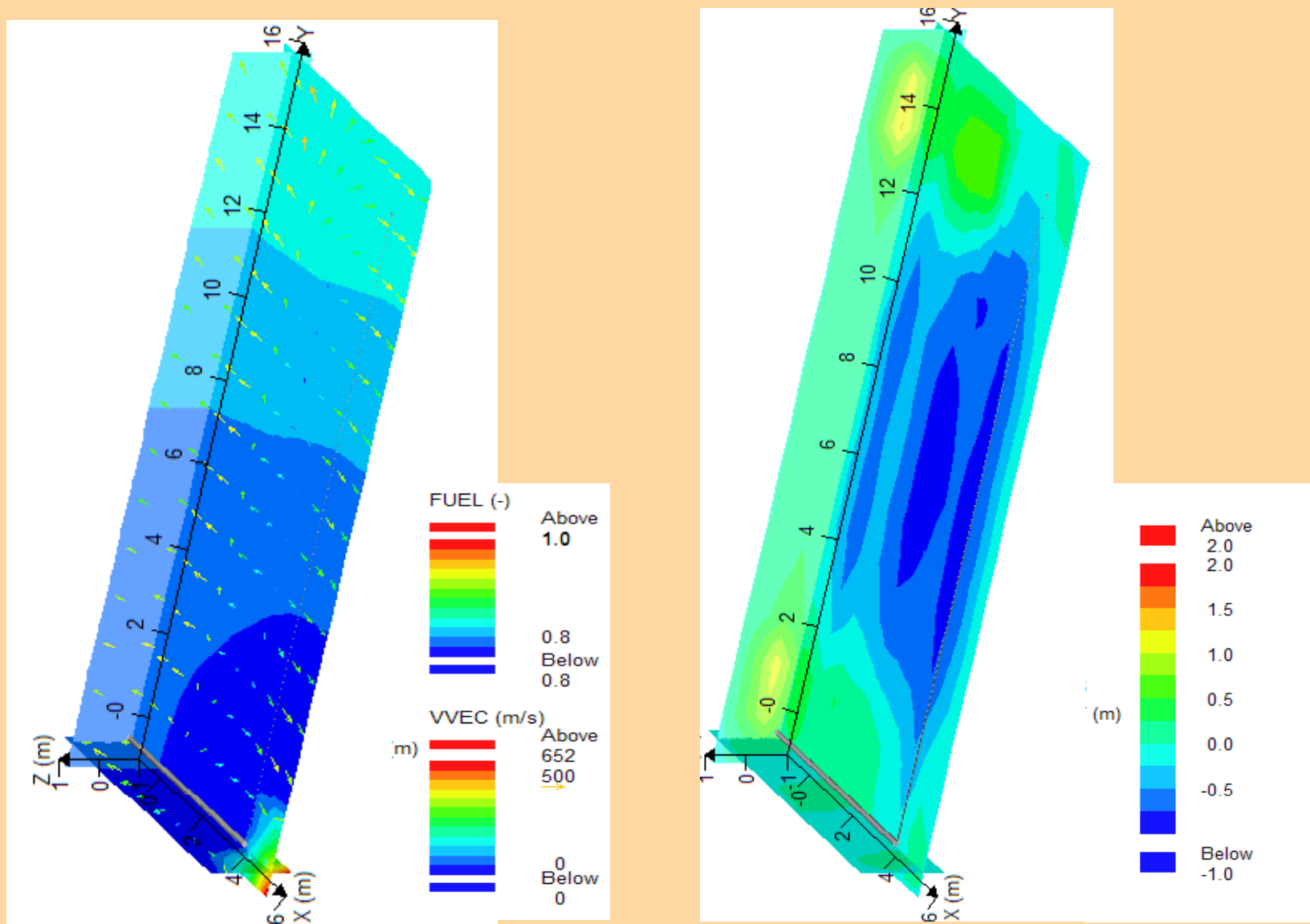
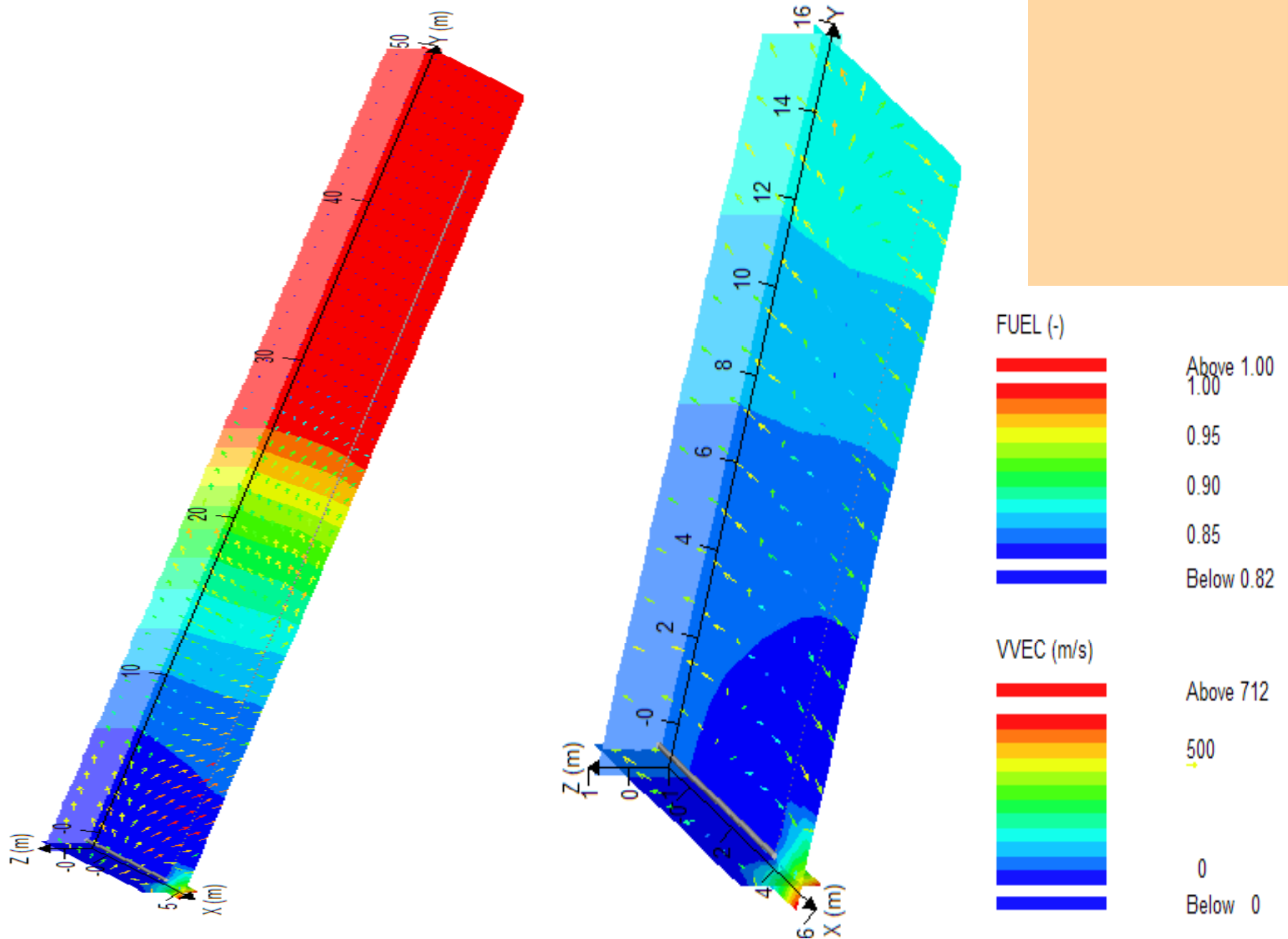


Figure 7.11b : Fuel, Pressure and VVEC Profile in a Step Time at $t = 5.034s$ for 15 m Height Building

Comparison between 15 and 45-m height building



Solution for Odor Fade System

- The various factors which affect odorant losses from gas streams in steel pipe include temperature, pressure, gas flow rate and iron oxide concentration.
- Generally, the lower the temperature, the greater the odorant loss. This is explicable since the rate of adsorption of gaseous molecules is inversely proportional to temperature [6].
- Adsorption is directly proportional to pressure at constant temperature. Thus, higher line pressures result in additional adsorption of odorant molecules.
- At higher flow rates the diffusion of odorant molecules to a pipe surface is less probable, resulting in decreased adsorption and possible subsequent oxidation of the odorant molecules at active sites.
- The iron oxide concentration is a function of the cleanliness of pipe. The cleaner the pipe the smaller the iron oxide concentration.

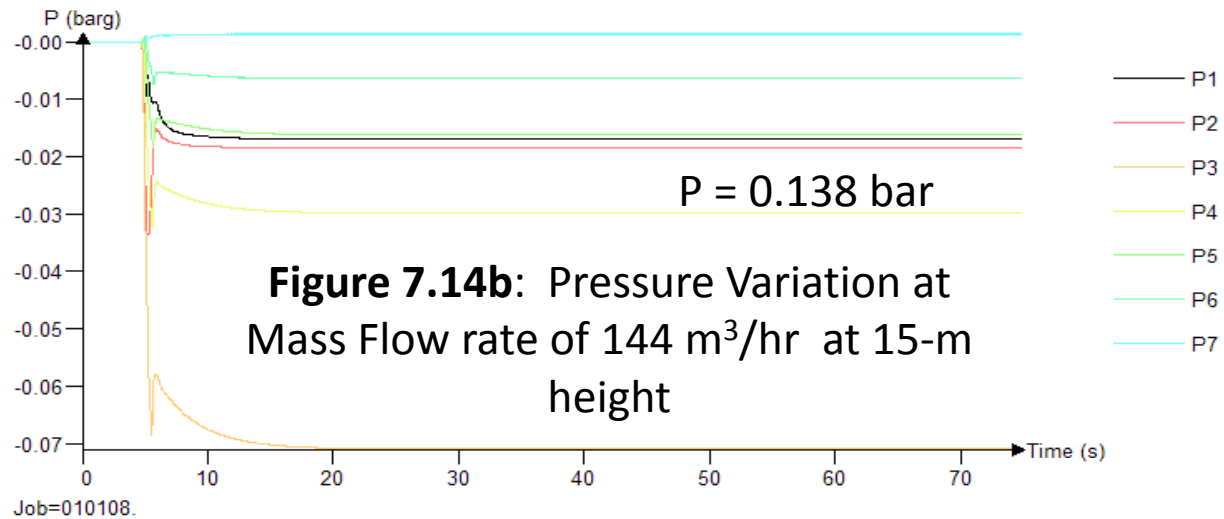
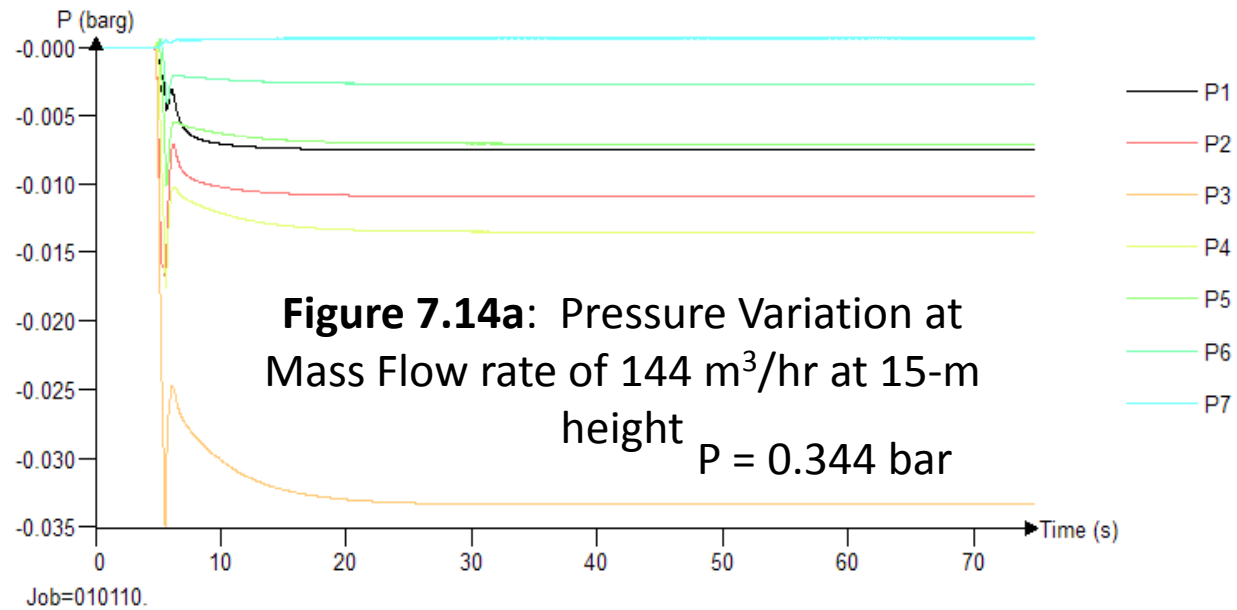
In order to justify the hypothesis given in literature, simulations were conducted by varying pressure and flow as follows:

- For 15-m height building;

P = 0.344 bar	Flow rate m³/hr		
	0.36	18	144
Flow rate = 36 m³/hr	Pressure, bar		
	0.138	0.344	0.689

- For 45-m height building;

P = 0.344 bar	Flow rate m³/hr			
	3.6	10.8	18	144
Flow rate = 36 m³/hr	Pressure, bar			
	-	0.138	0.344	0.689



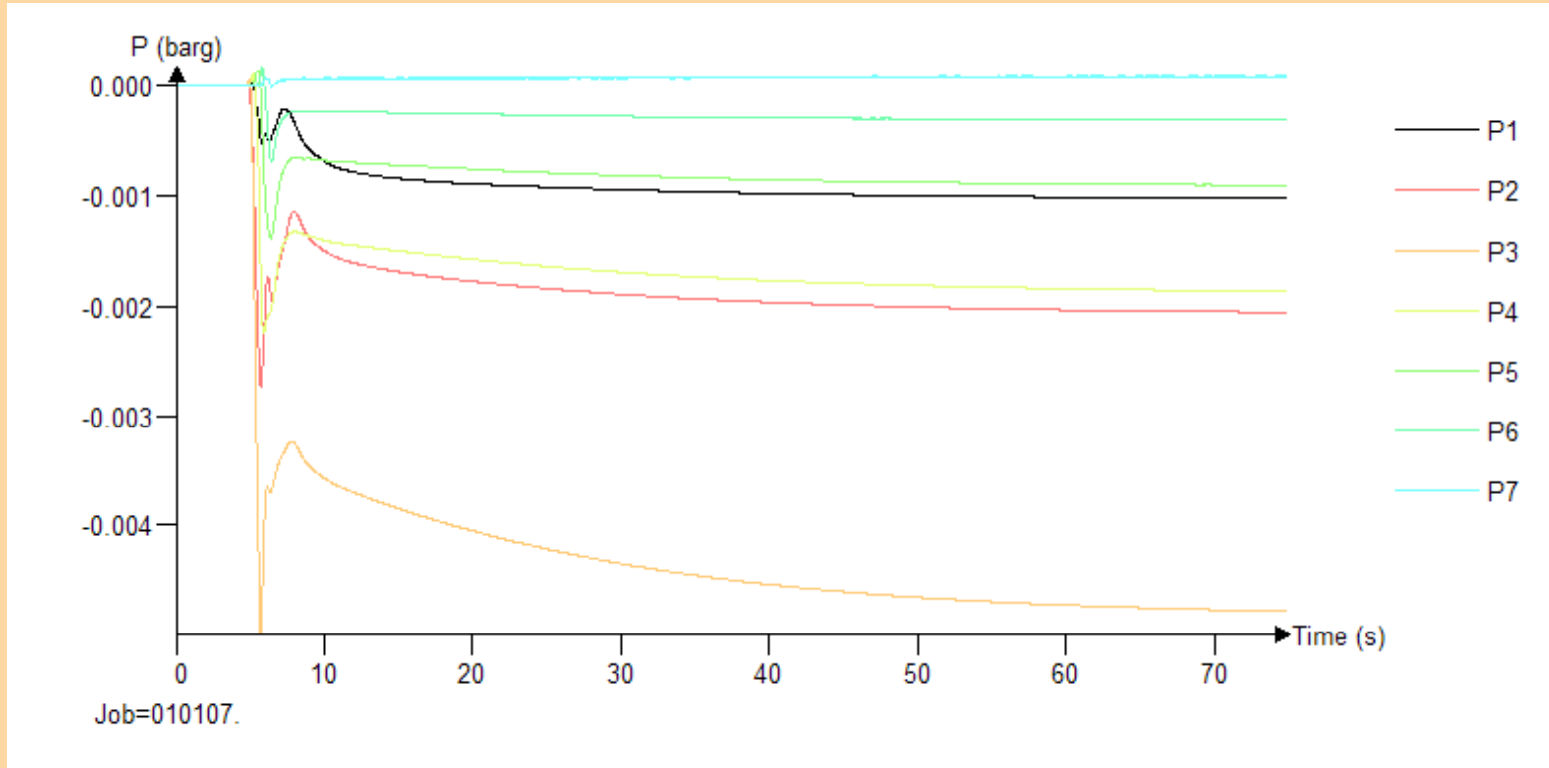
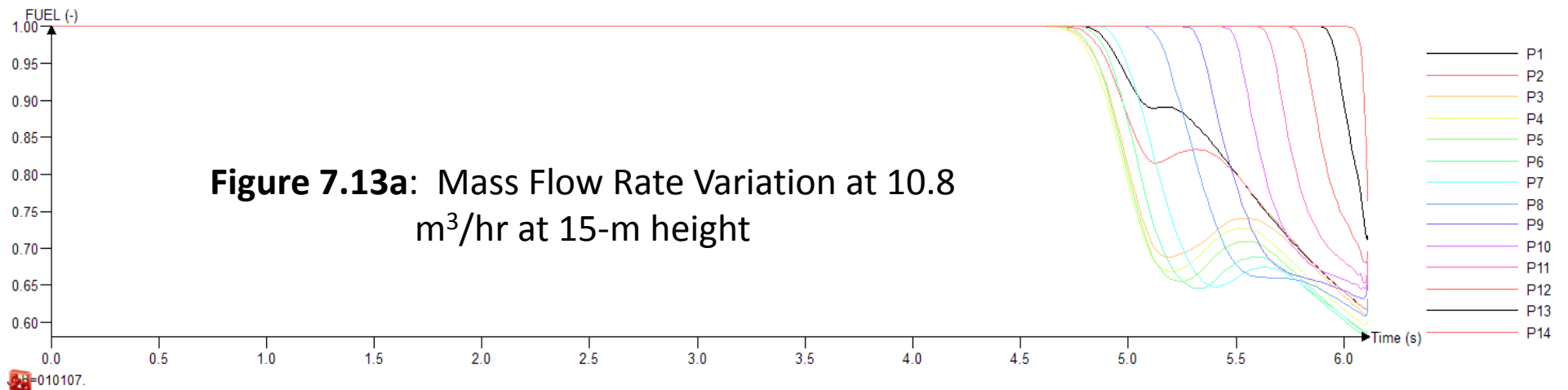
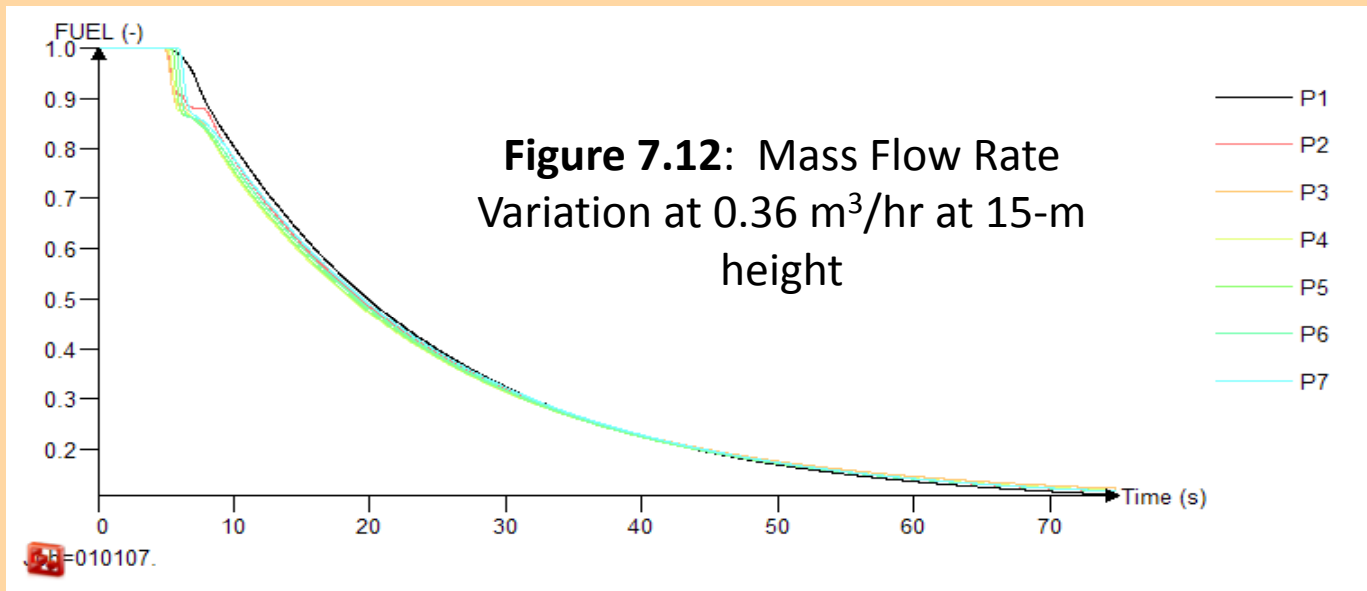
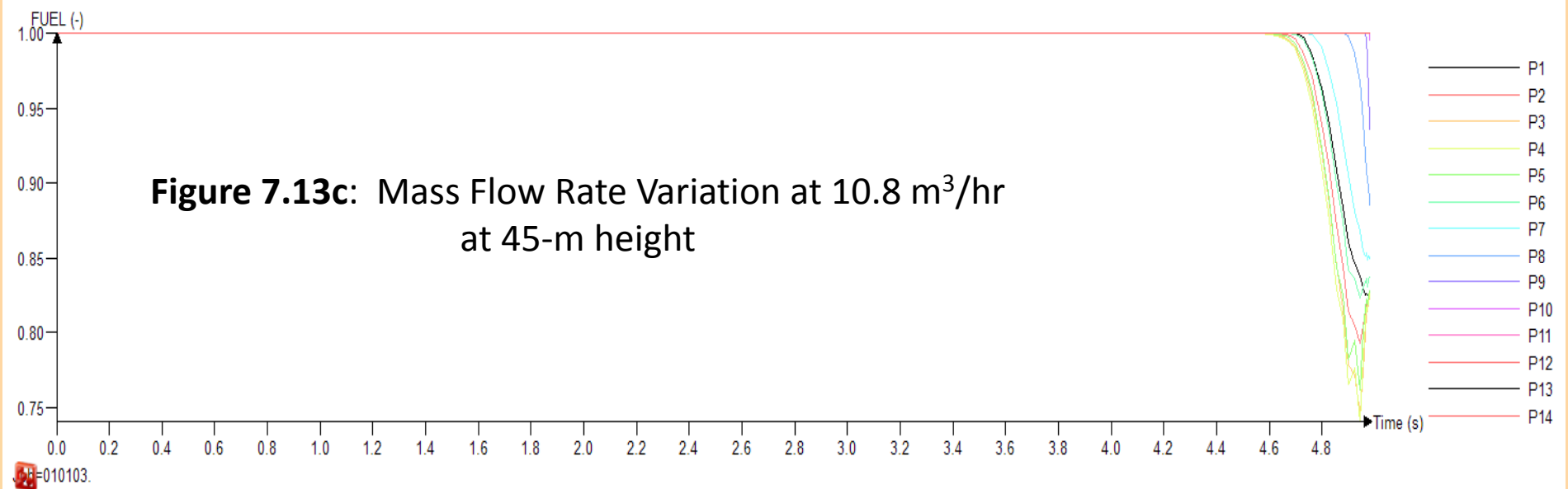
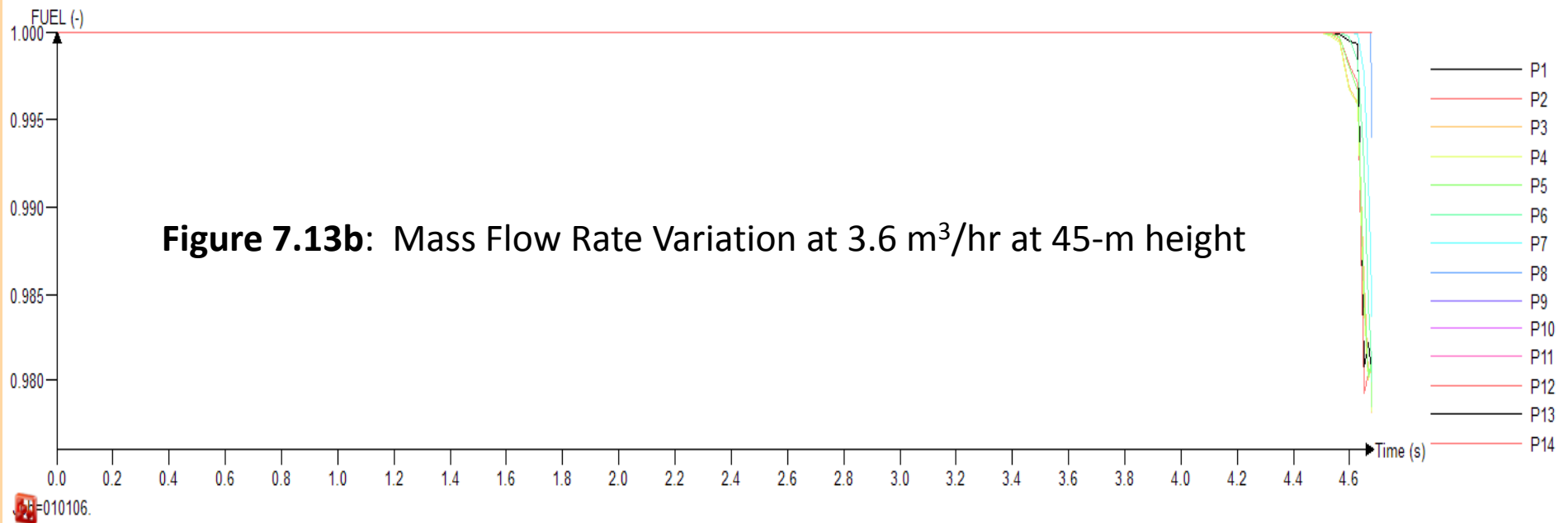


Figure 7.14c: Pressure Variation at Mass Flow rate of 144 m³/hr at 15-m height





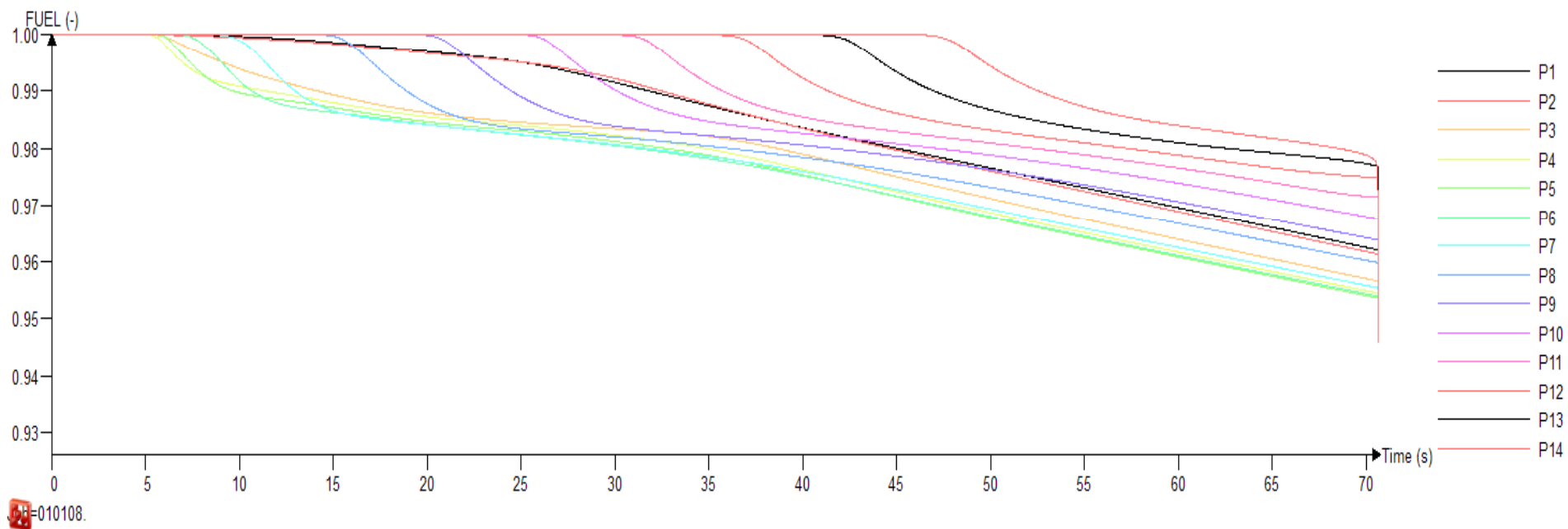


Figure 7.13d: Mass Flow Rate Variation at 144 m³/hr s at 45-m height

FLACS Conclusion

- Simulation exercise has been conducted on cases concerning the odor fade in natural gas pipeline distribution system within Lembah Kelang regional area.
- Three cases were investigated involving the wide area coverage to include the distribution system for Glenmarie and Serdang odorization Stations; and case involving high rise building.
- A good agreement between predicted results and in-situ measurement of dispersion profile of odorant in gas pipeline was obtained.
- By increasing the gas flow rate in upward sloping pipes, an increasingly fine balance between the frictional and gravitational contributions to the loss of momentum.

OVERALL CONCLUSION

The overall conclusion derived on the factual findings via site measurement, CFD and FLACS analyses

The following conclusions are deduced from detailed findings and factual outcomes obtained from the study conducted from 1st May, 2012 till 31st December, 2012:

- The odorant concentration was found sufficient at odoriser stations (Glenmarie's and Serdang's location) and provide adequate sufficiency up to service stations.
- Two important factors were identified to have direct effect towards odorant loss namely rate of gas consumption and altitude level. However, the rate of gas consumption is considered as dominance in contributing highest losses of odorant.

- At a lower gas flowrate the loss of odorant is most significant at high elevation consumption point especially at high-rise residential building.
- From survey conducted, the majority of high-rise residential gas customers are under utilise the gas facilities that contribute towards lower gas consumption rate.
- The findings indicate that the present odorant concentration at 80 % TBM and 20 % DMS provides adequate natural gas odorization.
- The CFD results qualitatively indicate good agreement with the site-measurement data.
- The effect of altitude changes towards odorant losses was demonstrated clearly by means of FLACS simulation results.

- High flow or active gas lines (e.g. SS, RS or AS) experience lower % odorant loss. In addition, the magnitudes of odorant loss between gas stations are quite significant.
- Odorant loss is more prevalent in residential areas where gas consumption rates are relatively lower compared to commercial areas.
- Comparison of % odorant loss at different levels of medium (DMC) and high rise flat (PHF) or condominium (SHC) shows the combined effects of low gas consumption and high altitude contribute to even higher odorant loss.

RECOMMENDATION

The overall conclusion derived on the factual findings via site measurement, CFD and FLACS analyses

- Since the gas lower consumption rates are experienced by the majority of the high-rise building residential customers, it is highly recommended that each residential customers unit be installed with natural gas leak detection system.
- It is recommended that further study need to be conducted by the gas utility company (GMB) to look upon possibility of installing Back-Checked Valve along the pipe route in high-rise building to provide better retention of odorant at higher level altitude.
- Extra injection be introduced at level higher than 15-storey, perhaps located at the roof side of the building.

- It is recommended that the future piping system should be designed with no dead-end connectivity as such the gas will be trapped and remains stagnant should there be no significant consumption. By having continuous pipe connection with more active customers further downstream, the gas is expected to induce sufficient steadily amount of odorant in the pipe flow regime.
- To integrate scheduled monitoring of odorant levels especially at high-rise building residential customers.
- To increase the level of usage among high-rise building residence occupants through continuous promotion of natural gas integrated safety and its continuous benefit.
- The use of CFD and FLACS software could provide additional niche in determining in-line odorant dispersion and losses at critical region.

ACKNOWLEDGEMENTS

The group is extending its sincere gratitude to the Energy Commission (EC) for providing great management and financial assistance, the staff of Gas Malaysia Berhad (GMB) for their commitment, coordination and enabling data sharing, the staff and project members of GASTEG for their full dedication, enthusiasm, hard-working, discipline and efforts that had enabled the completion of the project.

THANK YOU