CFD simulation of water curtain for gas dispersion

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Outline

- Current situation of the Japanese chemical industry
- Conventional methods of gas diffusion analytical
- Gas diffusion analysis using numerical method

  -The effects of gas density and wind speed

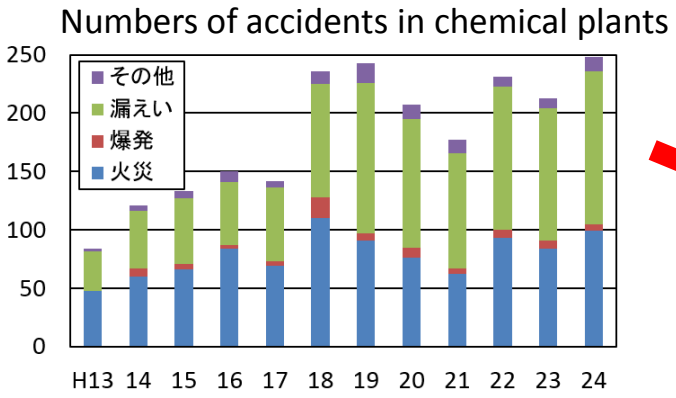
  -The effects of mitigation equipment
- Summary

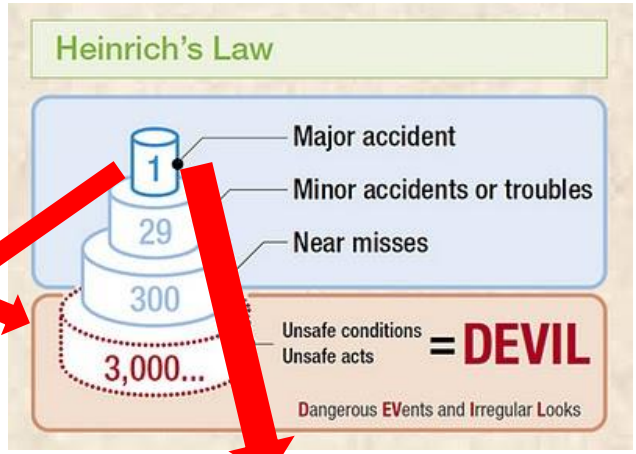
Current situation of the Japanese Chemical industry

Situation of accident in chemical plant in Japan

■In recent years, disasters and accidents occur frequently

■The main cause of the damage expansion is spreading and diffusion of stored items





Flixborough disaster(Cyclohexene)

28 deaths
36 serious injuries

Bhopal Disaster

500,000+ injuries
8000+ deaths

Large leakage accidents make a serious impact on the surrounding area due to toxic or explosive characteristic of storaged substances

Analysis of the leaked gas diffusion

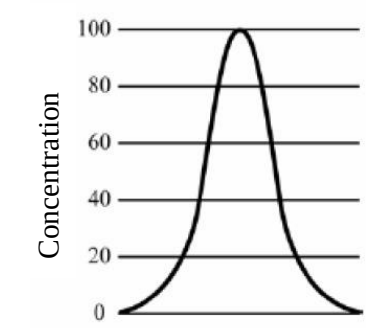
Close distances from factory areas to residential areas

Precise analysis of leaked gas diffusion is required

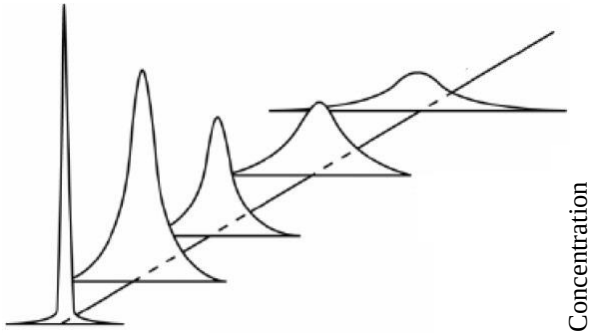
Analytical methods of gas diffusion analytical

Examples of conventional diffusion analytical methods

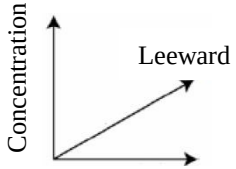
Density of leaked gas is analogized with Gaussian distribution



Distance direction perpendicular to the wind



Outflow source



Direction perpendicular to the wind

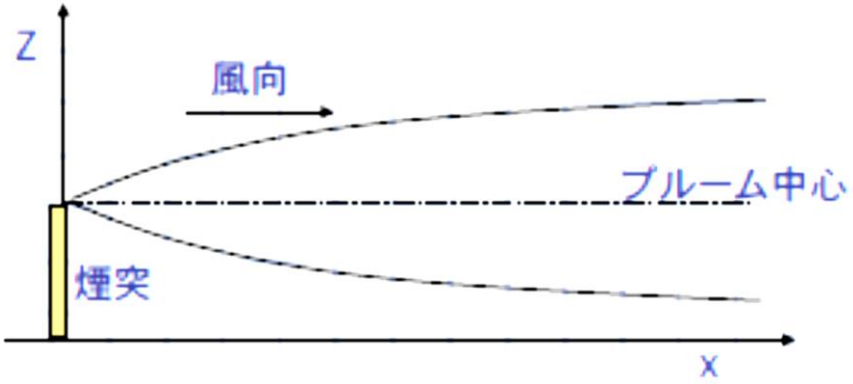
The 2 of most commonly used analytical methods

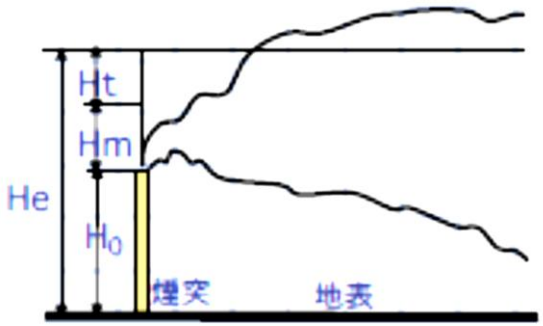
- Analytical solution model
  - Plume Model
  - Puff Model

Analytical method based on the Gaussian distribution

Plume Model

→Applied when neutral gas is continuously discharged in a sufficiently large space, and diffuses under one direction with constant velocity.





H_0:煙突高,Hm:運動量による上昇高
Ht:浮力による上昇高,He:有効煙突高

$$C = \frac{q}{2\pi\sigma_y\sigma_z u}\exp\left(-\frac{y^2}{2\sigma_y^2}\right)\left[\exp\left\{-\frac{(z-He)^2}{2\sigma_z^2}\right\}+\exp\left\{-\frac{(z+He)^2}{2\sigma_z^2}\right\}\right]$$

C=gas concentration (kg/㎥) σy:horizontal standard deviation of the emission distribution(m)
q=gas source emission rate (kg/s) σz:vertical standard deviation of the emission distribution(m)
u=horizontal wind velocity along the plume centerline(m/s)
He=height of emission plume centerline above ground level(m) x,y,z = measuring point

Study gases and analysis conditions

Gas	Gas Density	Source Strength	Wind Speed		
Neutral Gas(CO)	**1.25 kg/m³**	**10 m³/s**	1m/s	3m/s	6m/s
Lift Gas (Ammonia)	**0.771 kg/m³**	**10 m³/s**	1m/s	3m/s	6m/s
Heavy Gas(Propane)	**1.882 kg/m³**	**10 m³/s**	1m/s	3m/s	6m/s

3 cases of wind speed

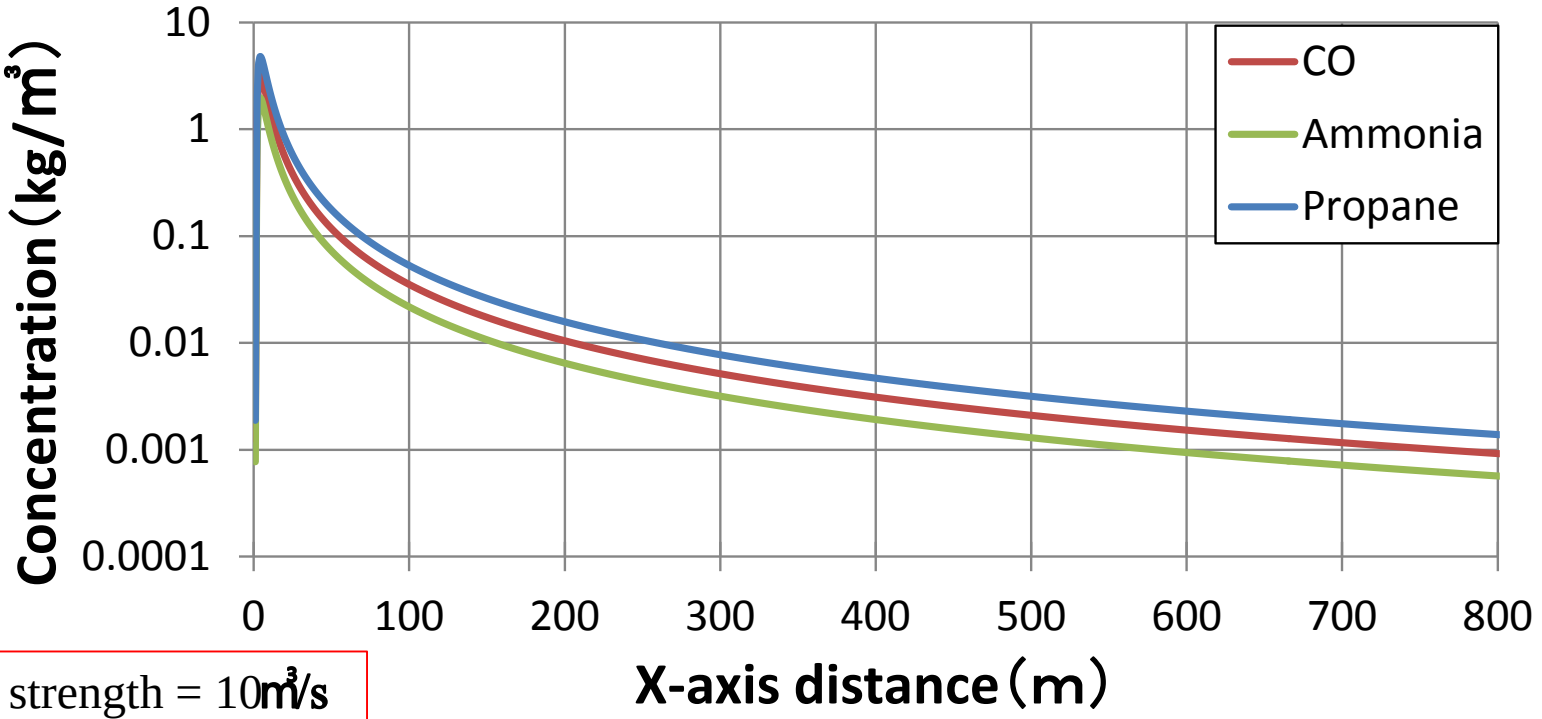
3 different density gas

Air density = 1.18 kg/m³

Height of gas source from ground = 0.5m

The effects of different density

Gas concentration at ground along x axis(leeward direction) at wind speed=3m/s



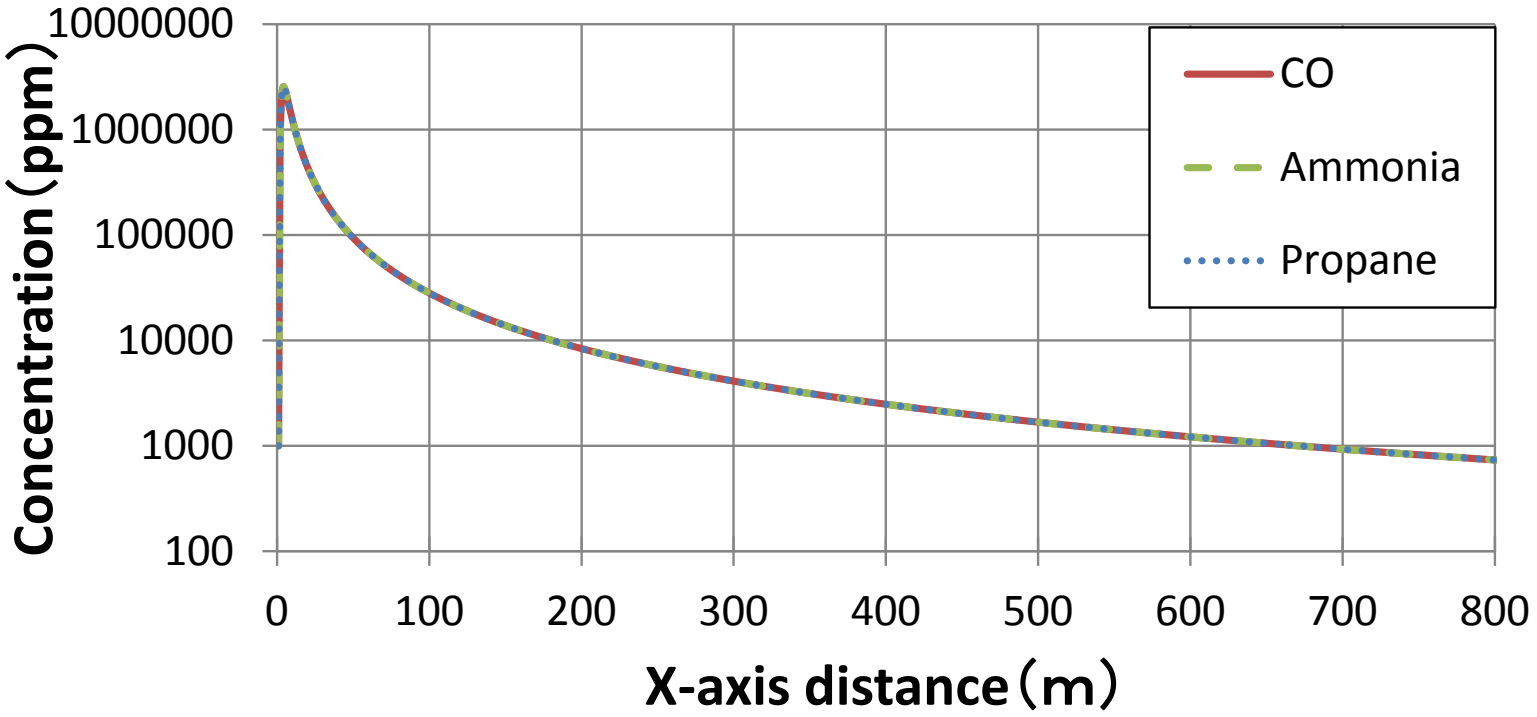
Source strength = 10m³/s

q=gas source emission rate (kg/s)

$$C = \frac{q}{2\pi\sigma_y\sigma_z u}\exp\left(-\frac{y}{2\sigma_y^2}\right)\left[\exp\left\{-\frac{(z-He)^2}{2\sigma_z^2}\right\}+\exp\left\{-\frac{(z+He)^2}{2\sigma_z^2}\right\}\right]$$

The effects of different density

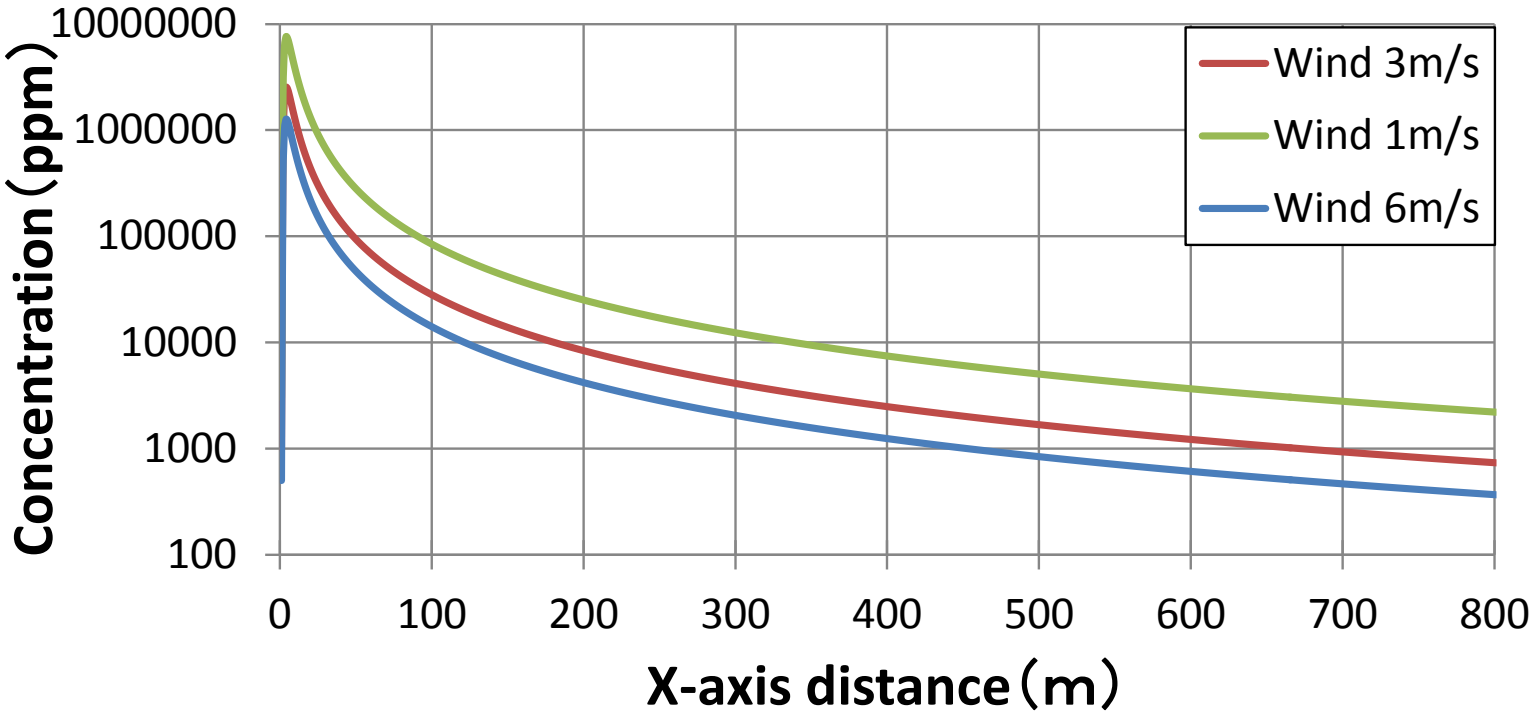
Gas concentration at ground along x axis(leeward direction) at wind speed=3m/s



- **Plume model does not considers the effects of density**

The effects of wind speed

Gas concentration at ground along x axis(leeward direction)
at wind speed=1m/s , 3m/s , 6 m/s



・**Gas concentration only changes with wind speed by ratio**

⇒ Plume model can not considers the effects of wind speed on gas diffusion behavior

Limit of plume model

-Does not considers

- **the effects of density**
- **the effects of wind speed on gas diffusion behavior**

-Can not evaluate properly at near the gas source

-Not be able to considers the effects of mitigation equipment

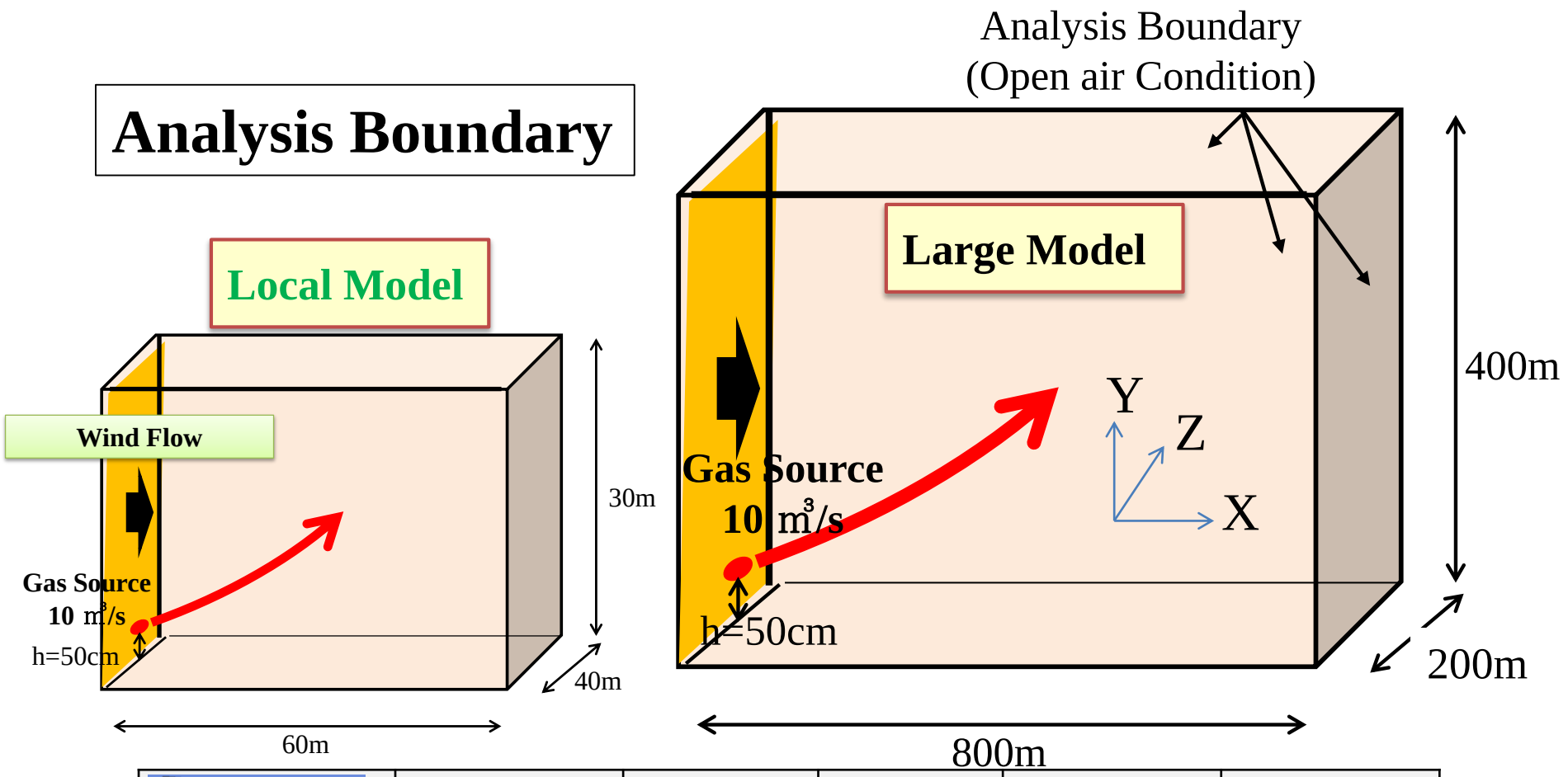
⇒We employed numerical method for this research

Gas diffusion analysis using numerical method

Gas diffusion analysis using numerical method

- CFD simulation software: ANSYS-CFX R16

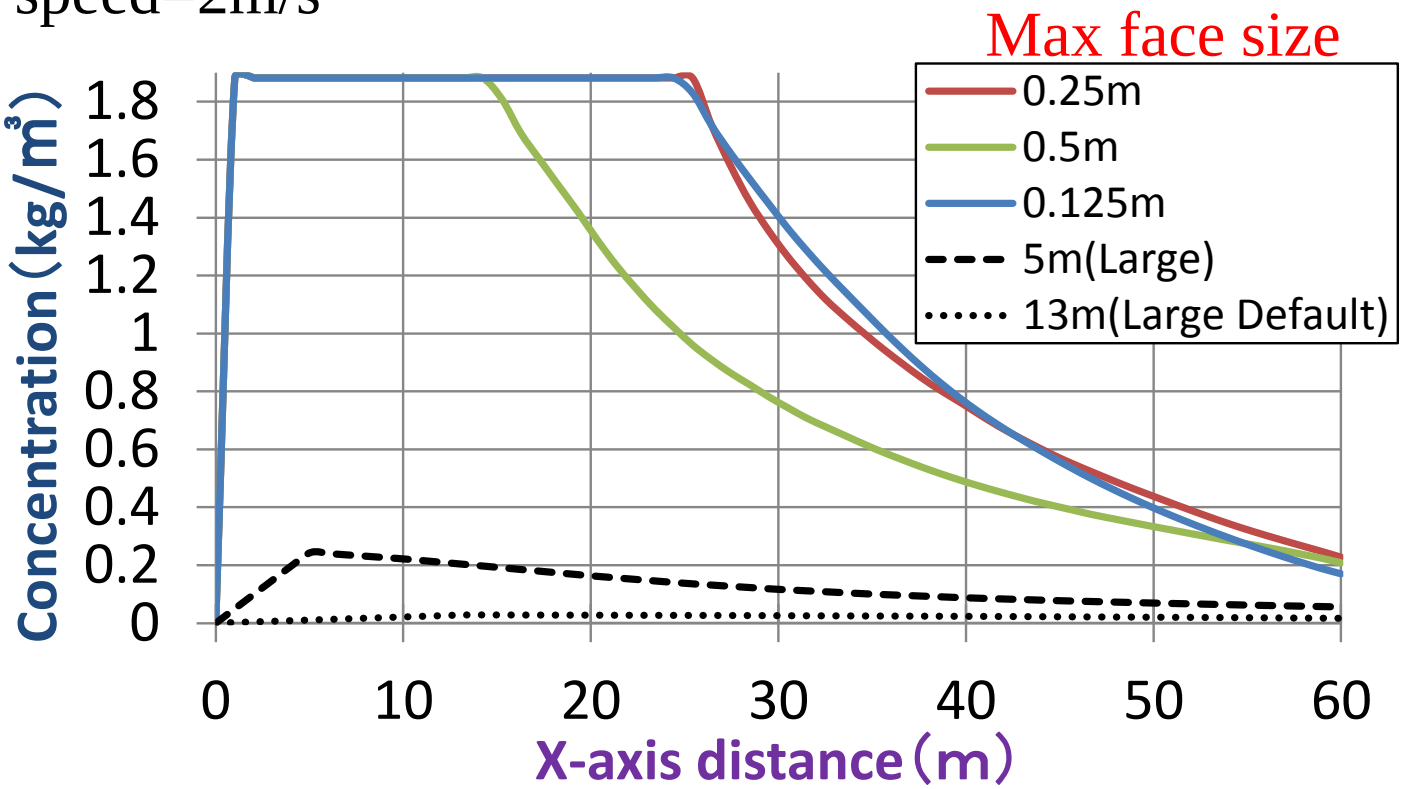
Mesh size effect



	Local 1	Local 2	Local 3	Global 1	Global 2
Max mesh face size	**0.125m** *Height 30m→20m Leght60m→40m	**0.25m**	**0.5m**	**5m**	**13.38m (Default)**

Mesh size effect

Propane gas concentration at ground along x axis(leeward direction) at wind speed=2m/s



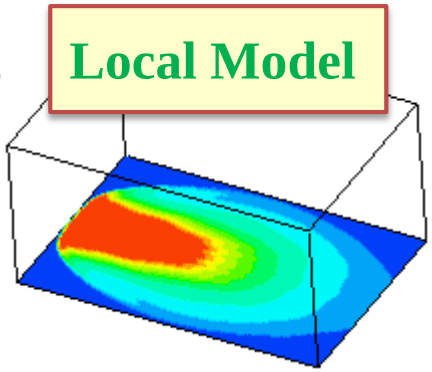
Mesh size has large effect to the gas concentration

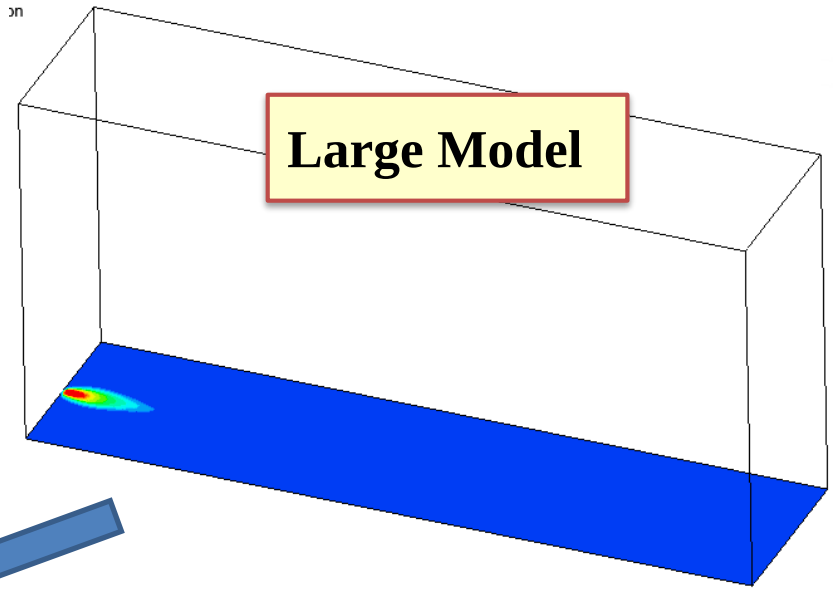
⇒To estimate gas concentration in wide area , It is a future challenge to adapt local model with large model.

Mesh size effect

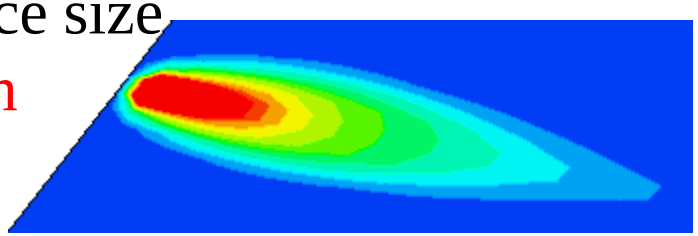
Propane gas distribution at ground along x axis(leeward direction) at wind speed=2m/s

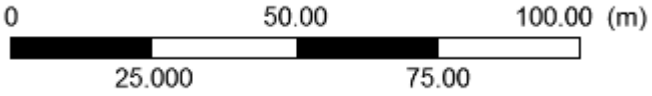
Max face size
0.25m





Max face size
5m



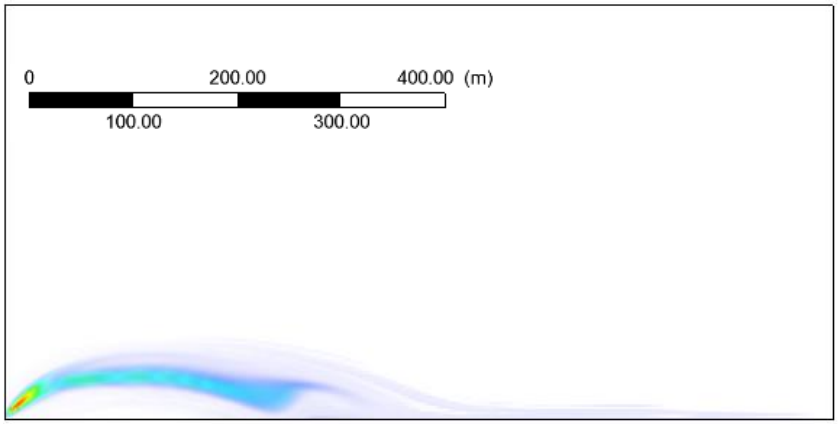


Even it is different mesh size ,
it is still be able to get similar result of gas dispersion

Mesh size effect

Ammonia gas dispersion at wind speed=3m/s

Max face size
2.676m



Large Model

Max face size
13.38m (Default)

Large Model

Be able to observe gases behavior by using rough model

Study gases and analysis conditions

Purposes of study

1)Study the effects of density and wind speed on gas diffusion behavior

2)Simulate leaked gas dispersion with considering the effect of water spray curtain

	Gas	Gas Density	Source Strength	Wind Speed			Absorption Level
①	Neutral Gas(CO)	**1.25 kg/㎥**	**10 ㎥/s**	1m/s	3m/s	6m/s	No Curtain
①	Lift Gas (Ammonia)	**0.771 kg/㎥**	**10 ㎥/s**	1m/s	3m/s	6m/s	No Curtain
①	Heavy Gas(Propane)	**1.882 kg/㎥**	**10 ㎥/s**	1m/s	3m/s	6m/s	No Curtain
②	Supposed Gas A	0.771kg/㎥	**10 ㎥/s**	3m/s			**No Curtain**
②	Supposed Gas B	0.771kg/㎥	**10 ㎥/s**	3m/s			**None**
②	Supposed Gas C	0.771kg/㎥	**10 ㎥/s**	3m/s			**High**

Gas diffusion analysis using numerical method

① The effects of wind speed and gas density

①Study gases and analysis conditions

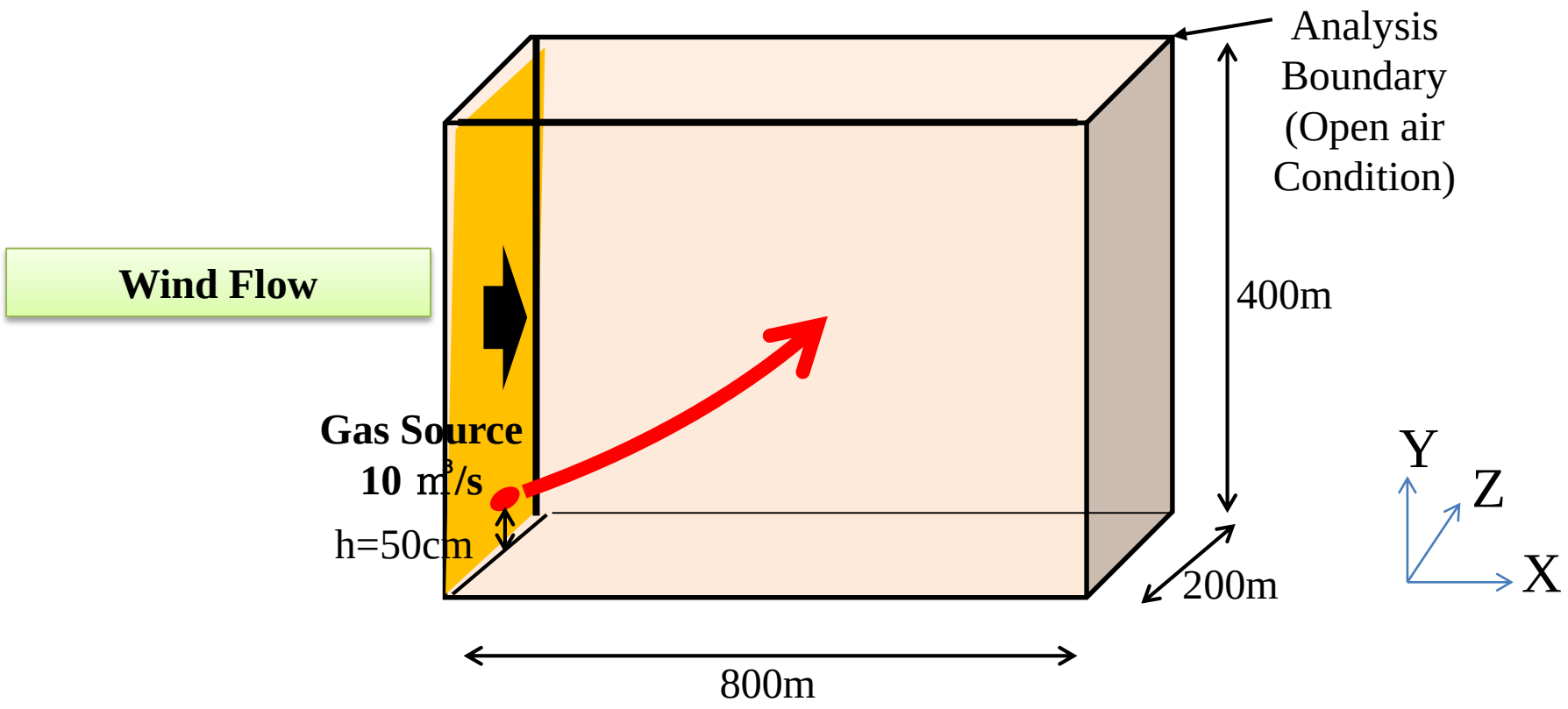
Gas	Gas Density	Source Strength	Wind Speed		
Neutral Gas(CO)	1.25 kg/㎥	10 ㎥/s	1m/s	3m/s	6m/s
Lift Gas (Ammonia)	0.771 kg/㎥	10 ㎥/s	1m/s	3m/s	6m/s
Heavy Gas(Propane)	1.882 kg/㎥	10 ㎥/s	1m/s	3m/s	6m/s

3 cases of wind speed

3 different density gas

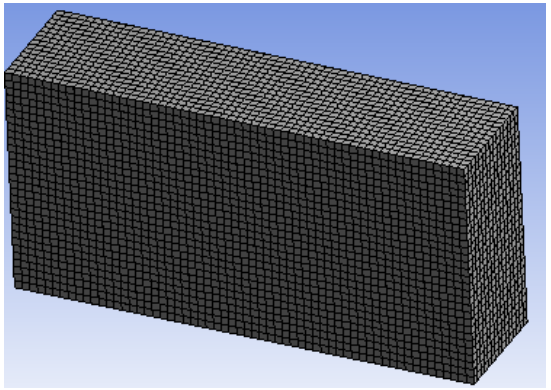
Air density = 1.18 kg/㎥

Analysis Boundary



Air Temperature	25℃
Anylysis time	Until 800s

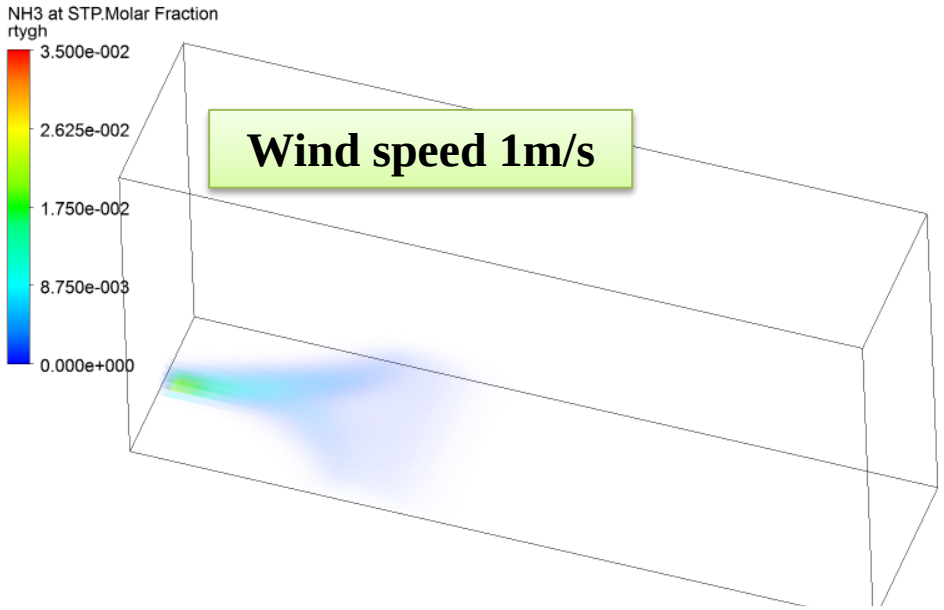
MESH

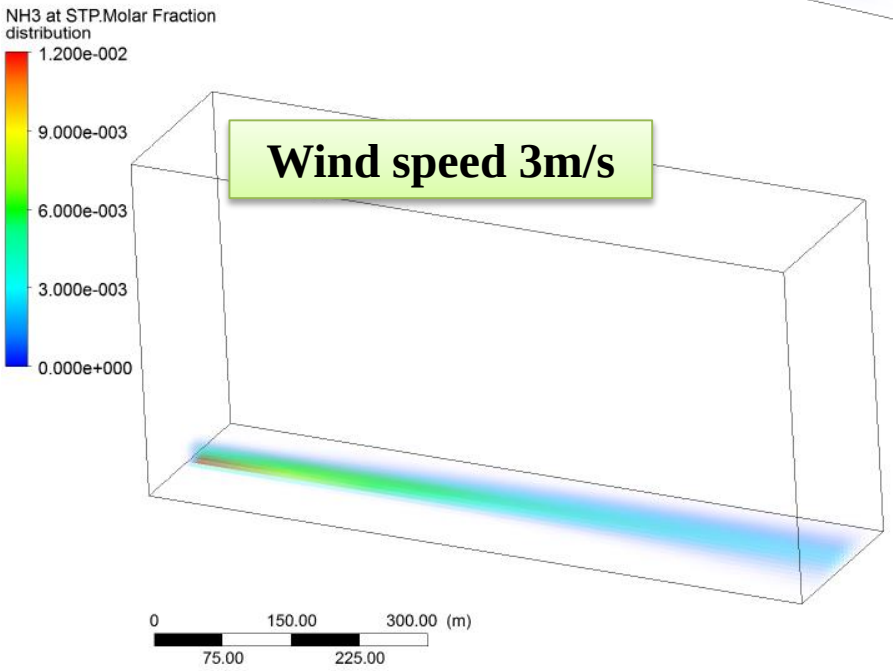


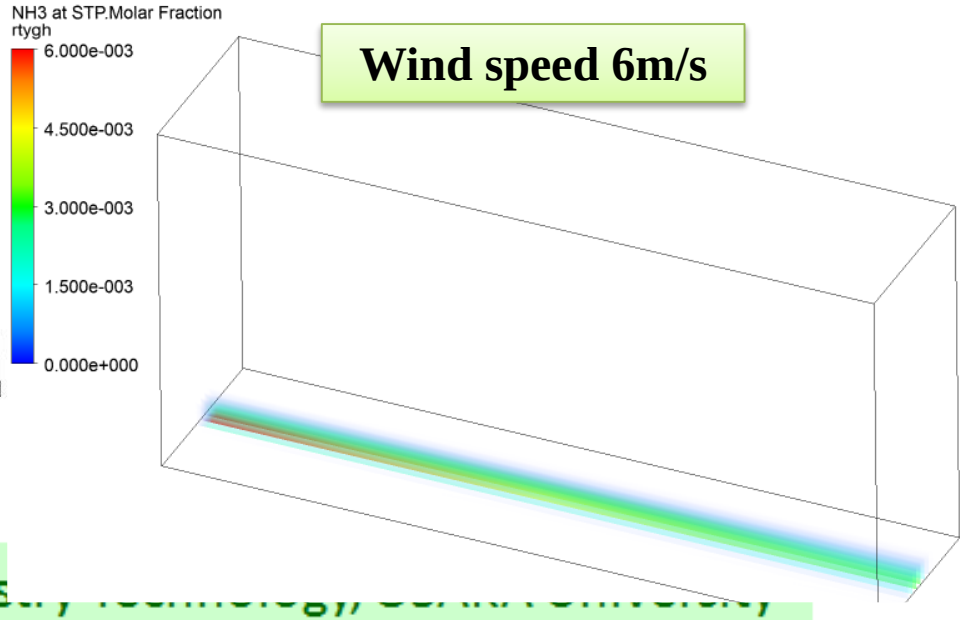
Statistics	
Nodes	30256
Elements	27000
Sizing	
Use Advanced Size Function	On: Curvature
Relevance Center	Fine
Smoothing	High
Transition	Slow
Span Angle Center	Fine
Curvature Normal Angle	Default (18.0 °)
Min Size	2.4e-002 m
Max Face Size	Default (13.380 m)
Max Size	Default (26.760 m)
Growth Rate	Default (1.20)
Minimum Edge Length	200.0 m

The effects of wind speed

Ammonia

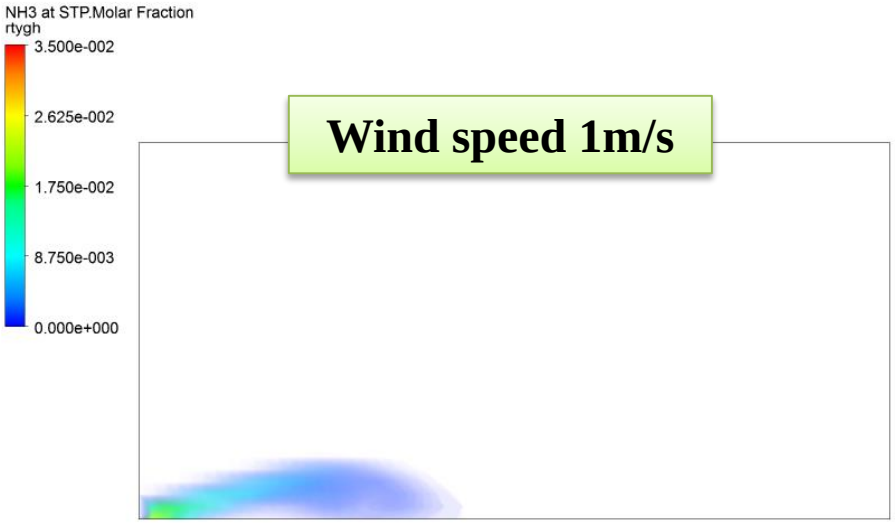


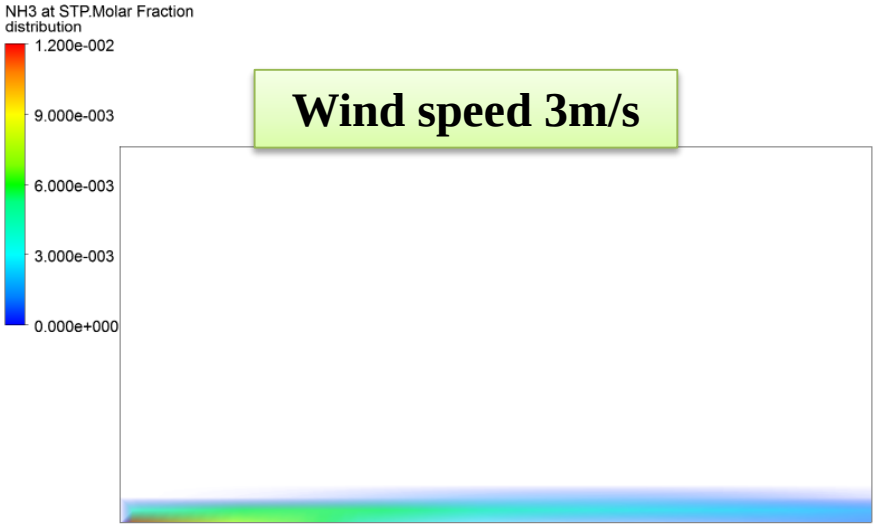


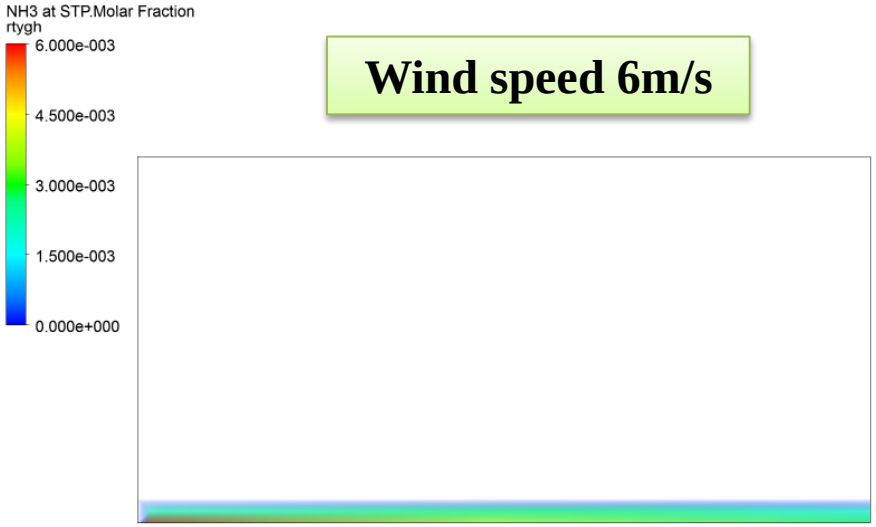


The effects of wind speed

Ammonia



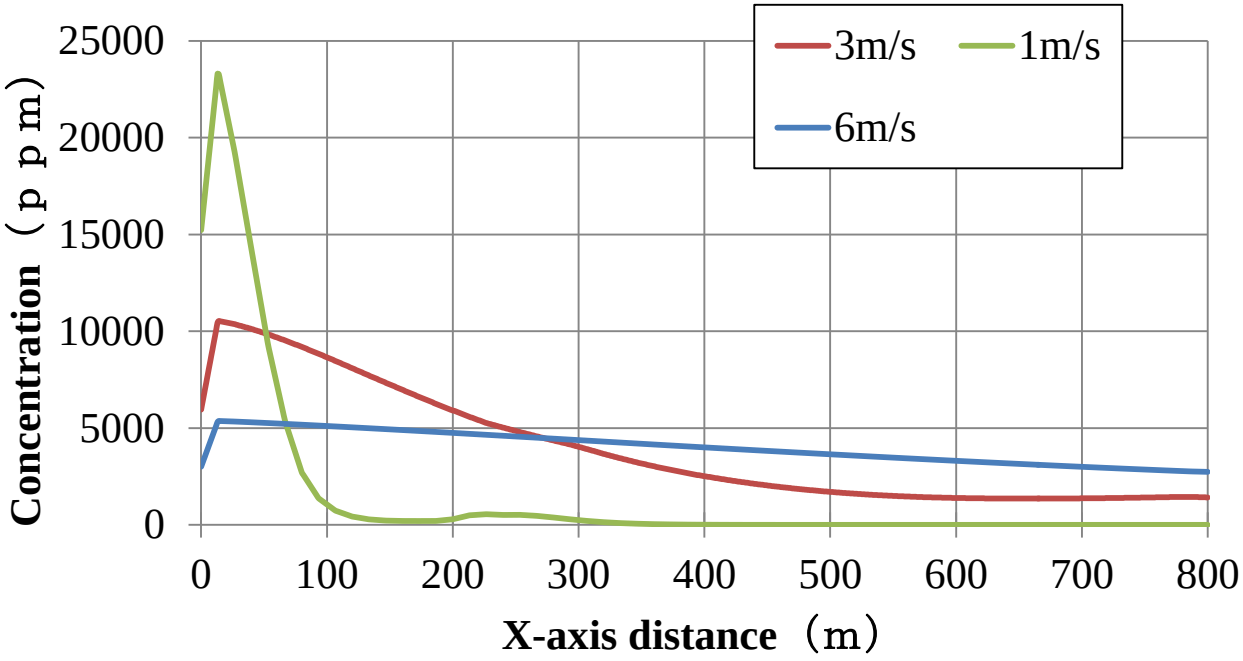


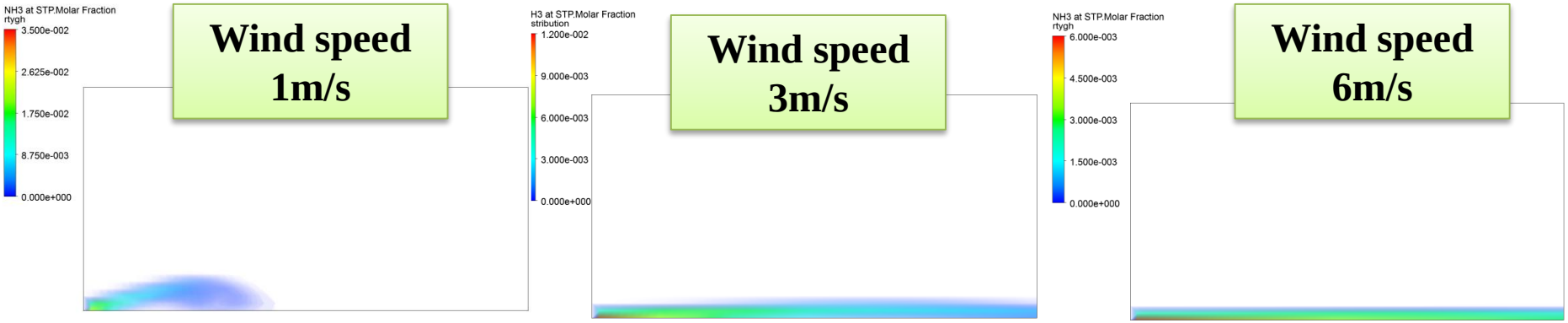


0 150.00 300.00 (m)
75.00 225.00

The effects of wind speed

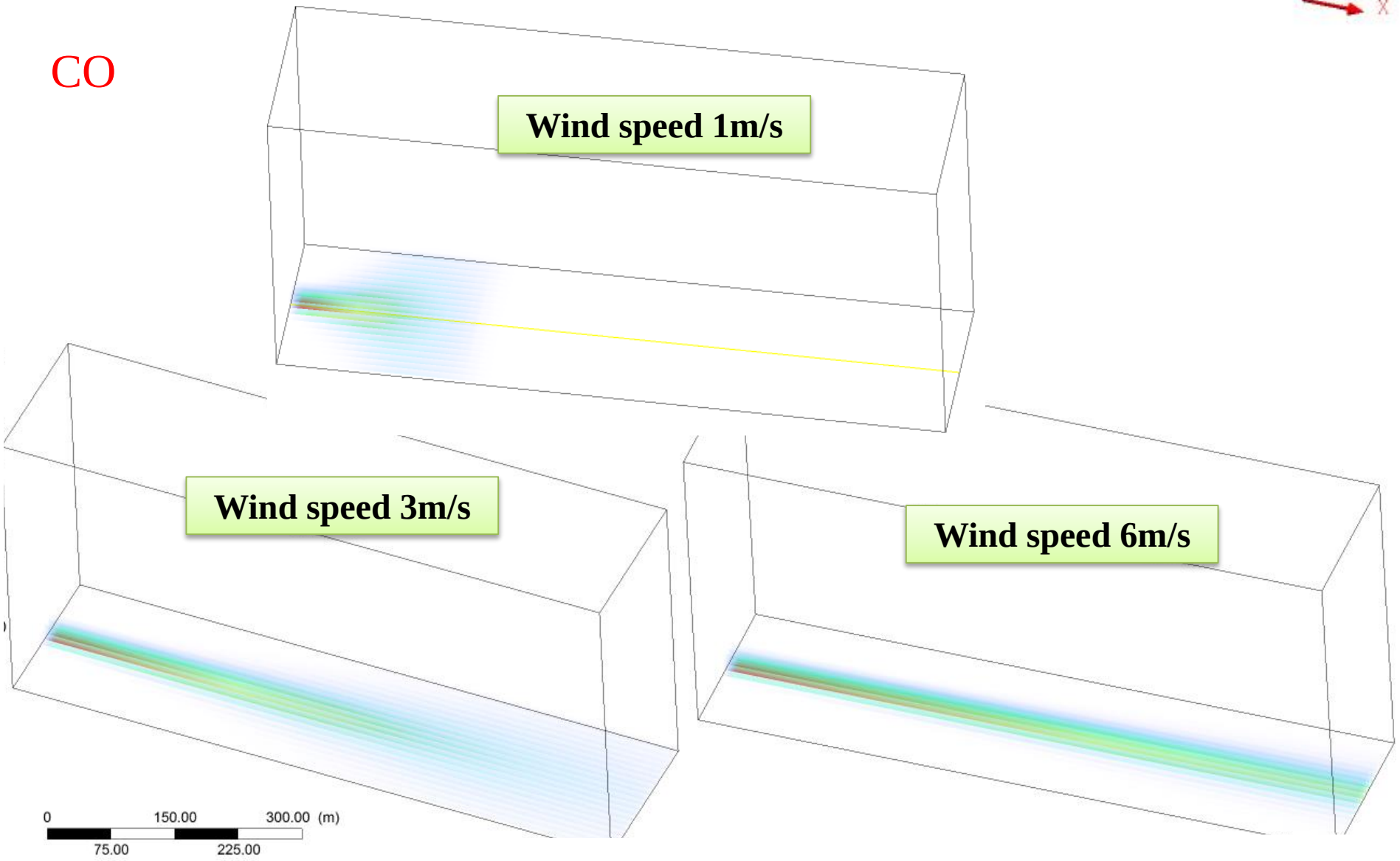
Ammonia





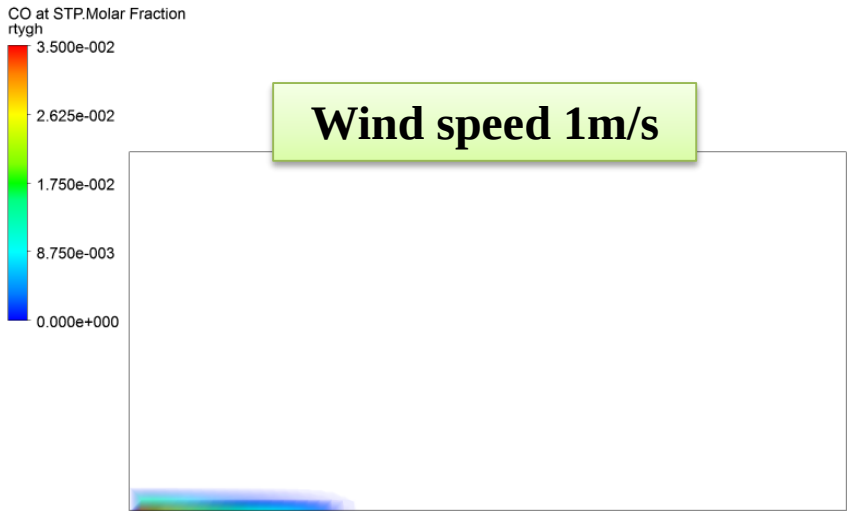
The effects of wind speed

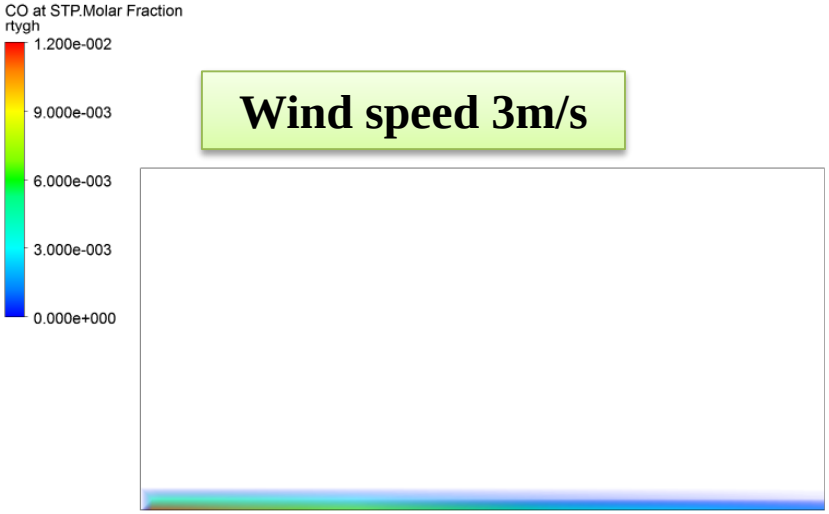
CO

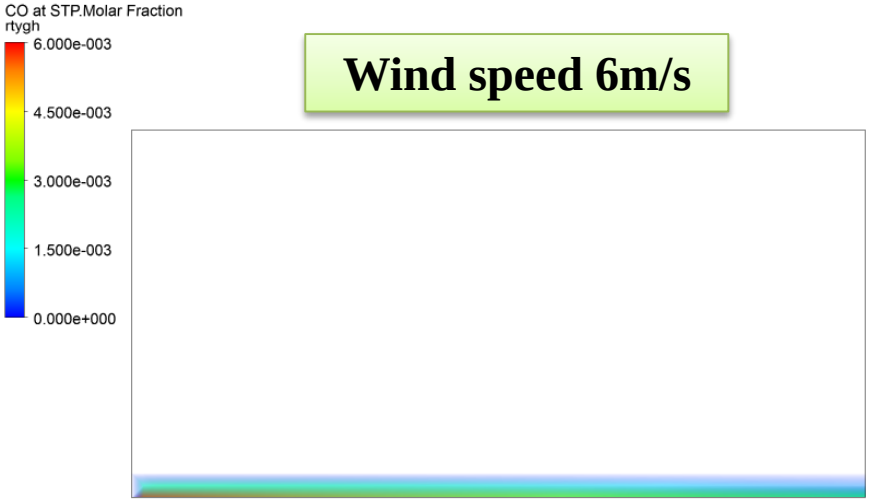


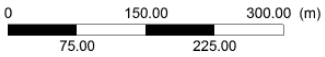
The effects of wind speed

CO









The effects of wind speed

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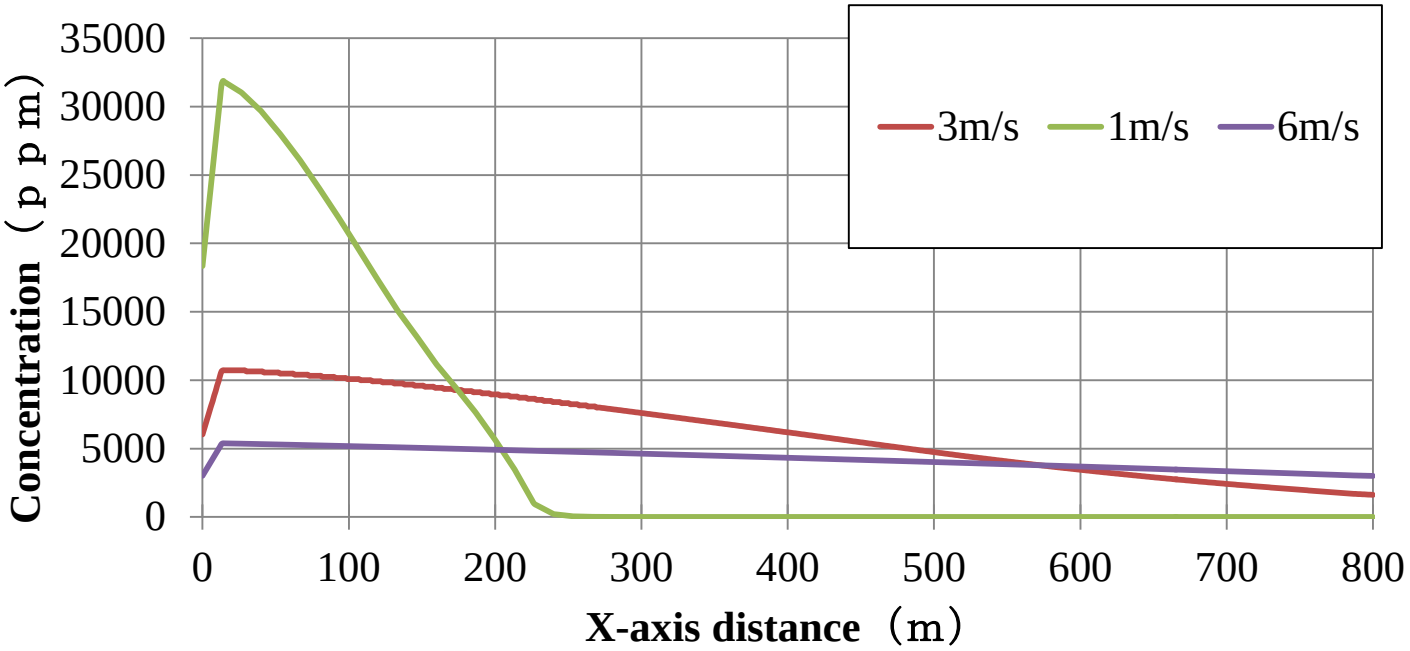
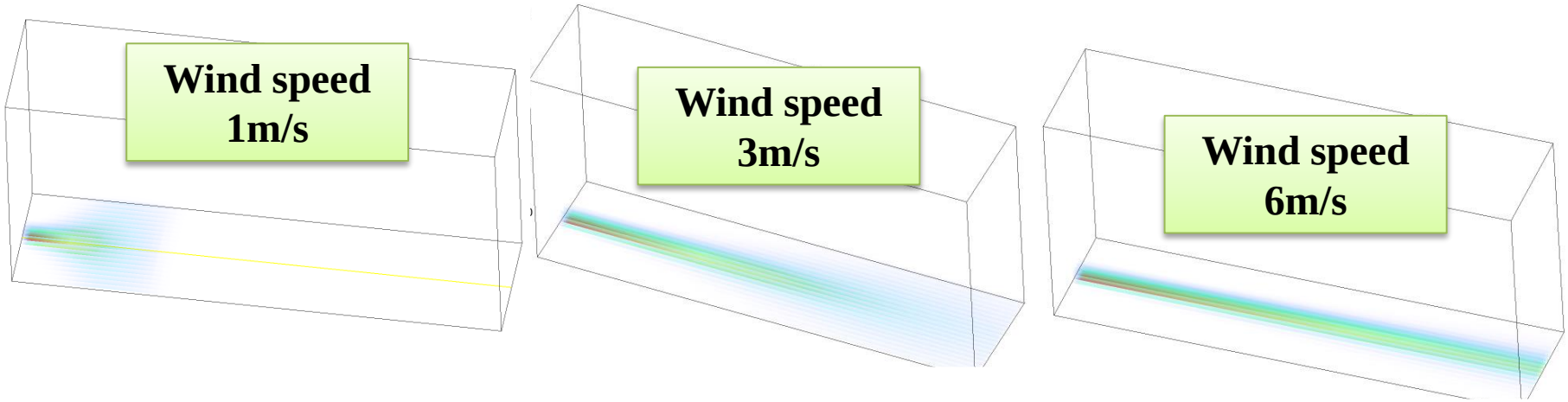
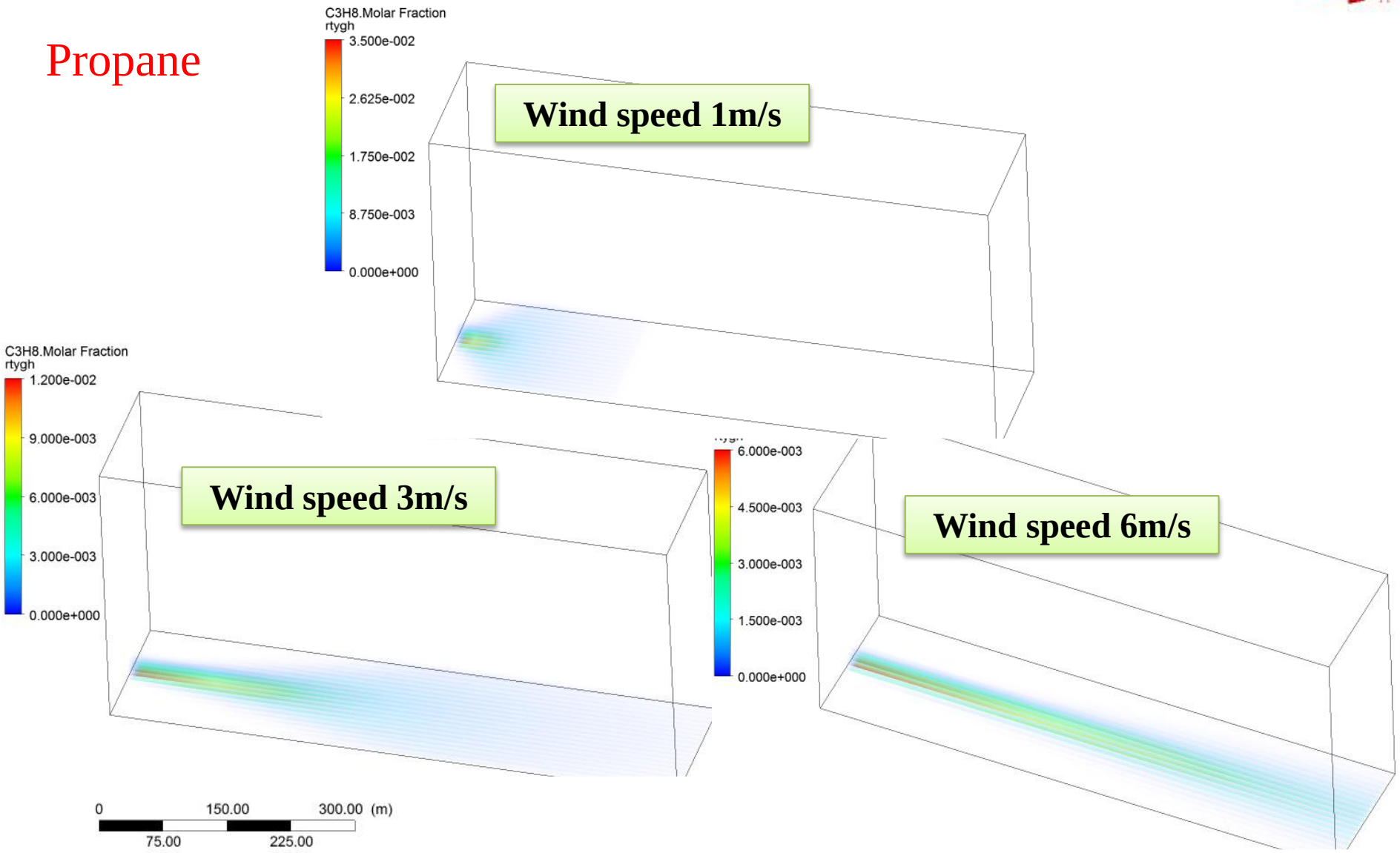




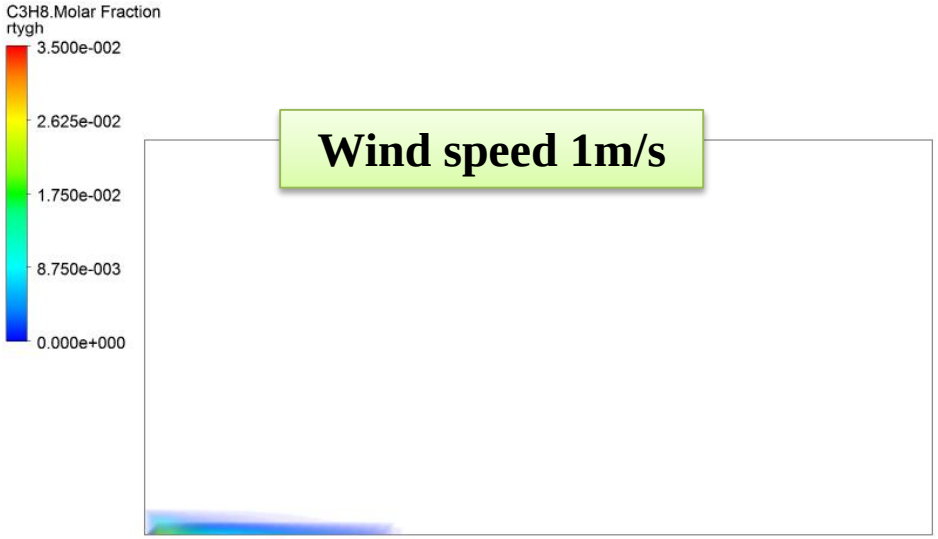
The effects of wind speed

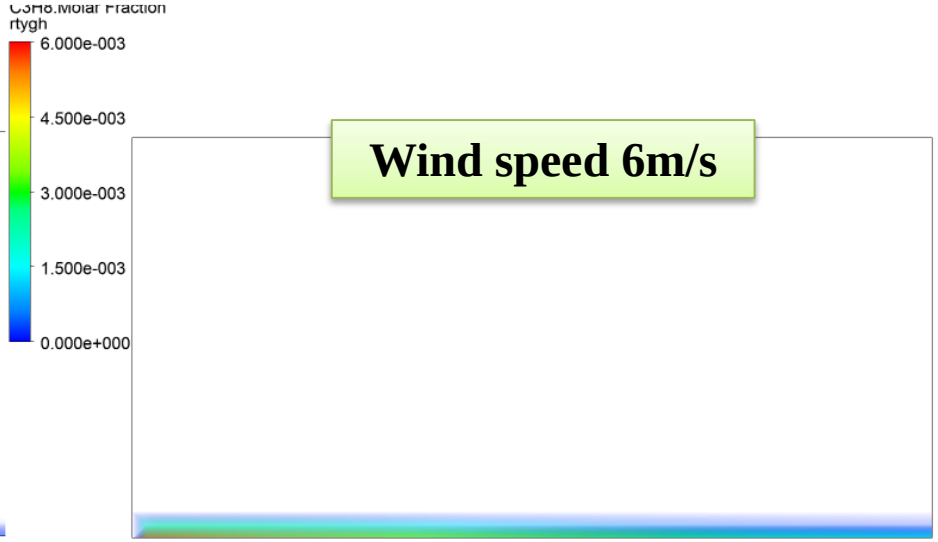
Propane



The effects of wind speed

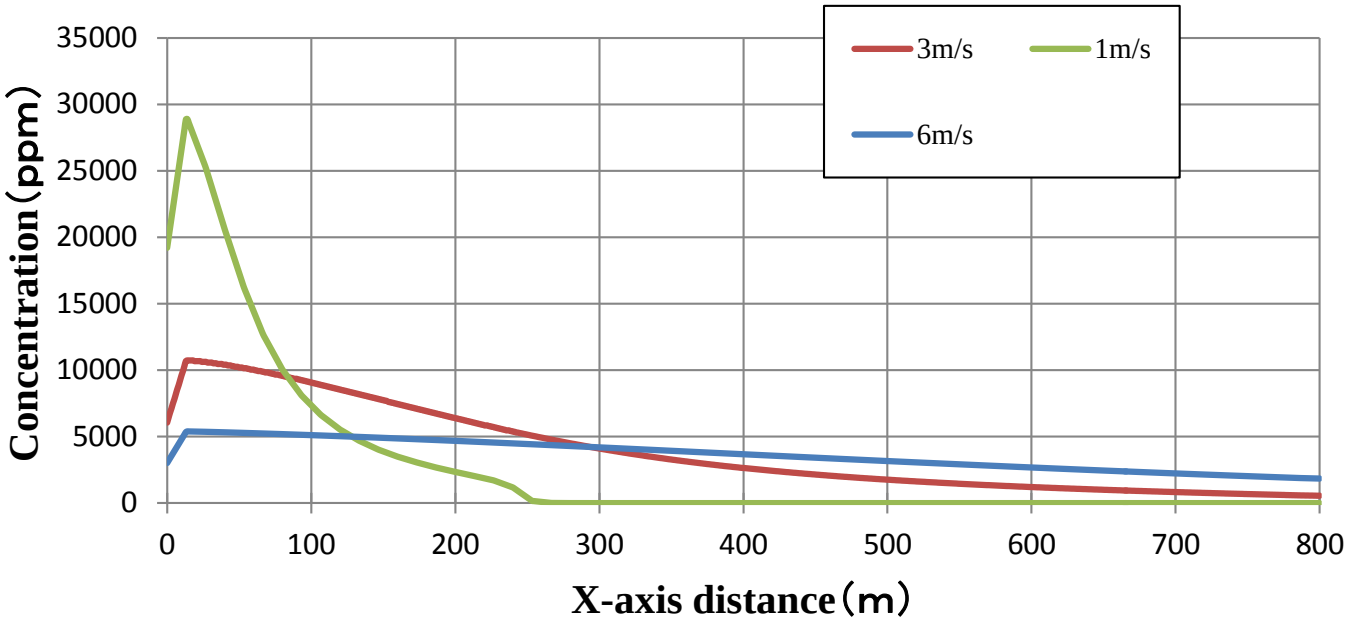
Propane

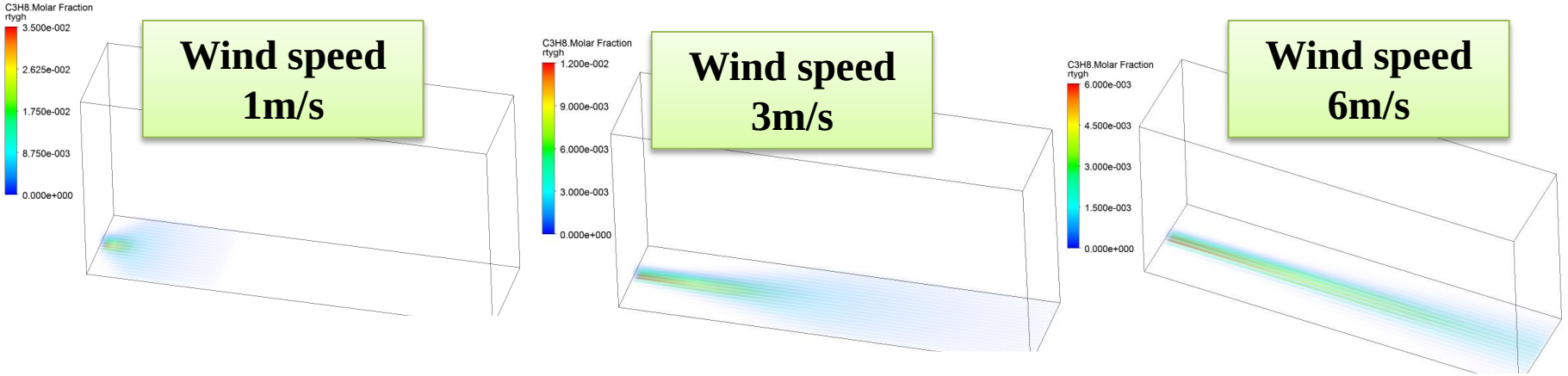




The effects of wind speed

Propane

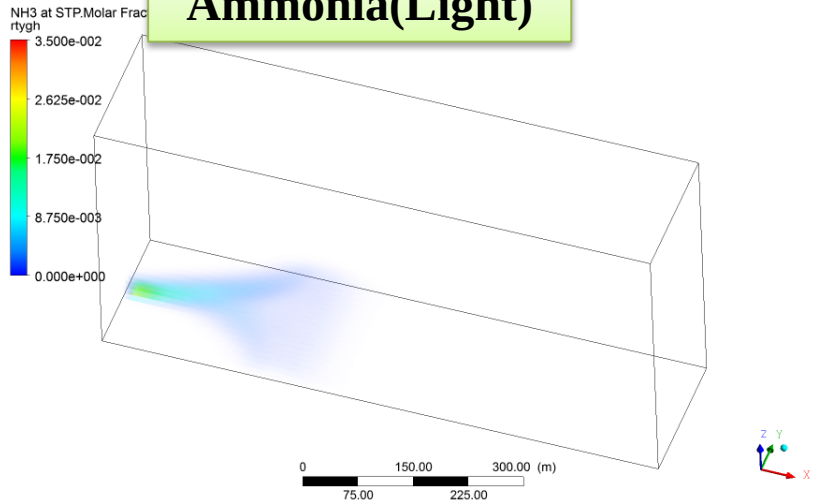




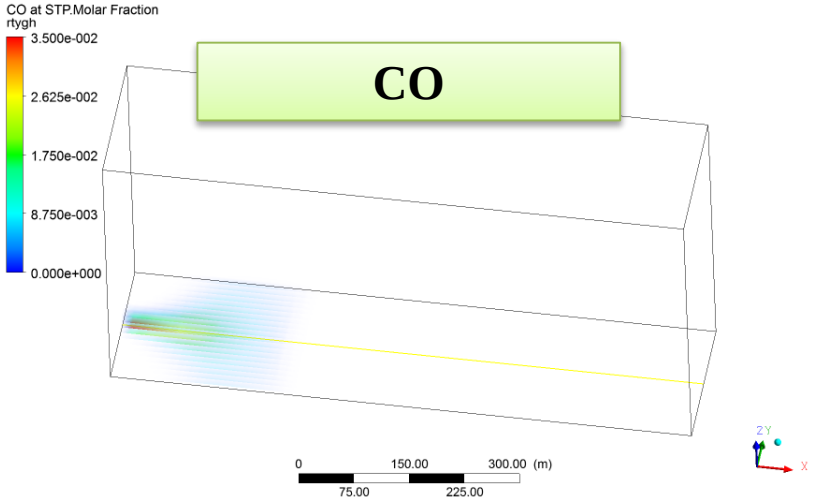
The effects of different density

The distribution of gas concentration (side view)
at wind speed=1m/s

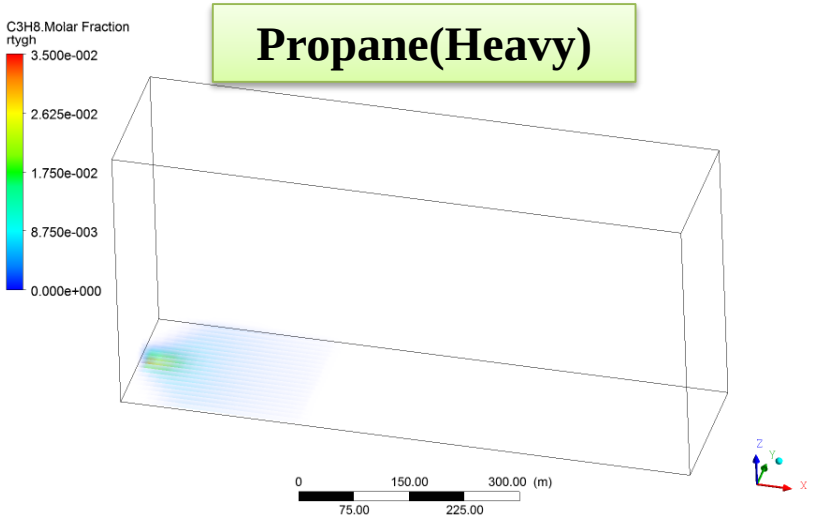
Ammonia(Light)



CO

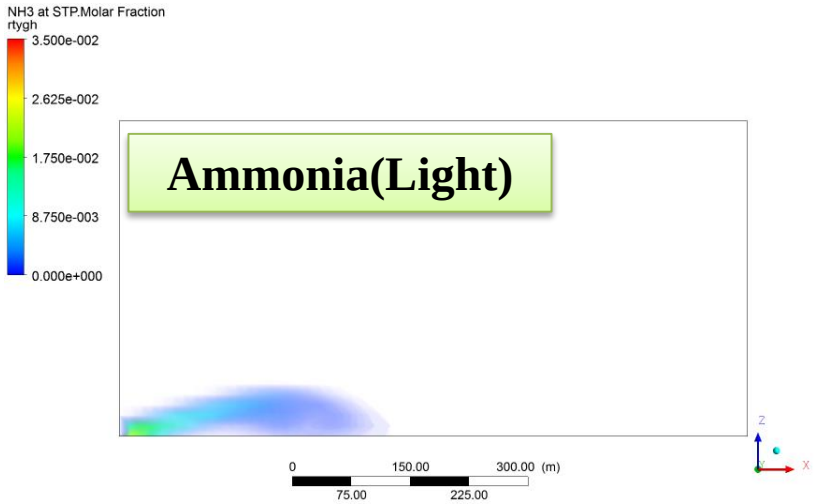


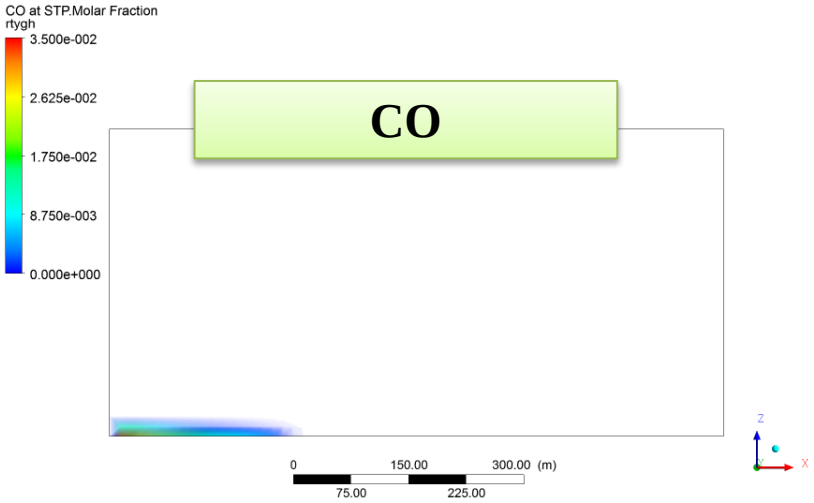
Propane(Heavy)

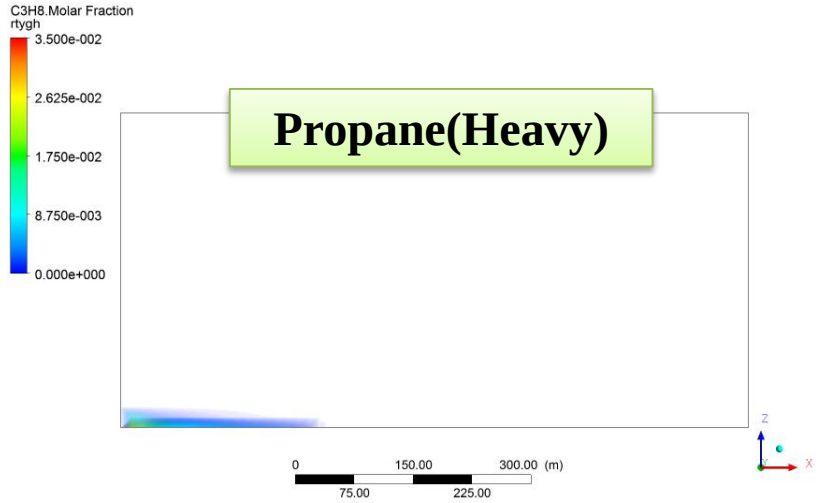


The effects of different density

The distribution of gas concentration (side view)
at wind speed=1m/s

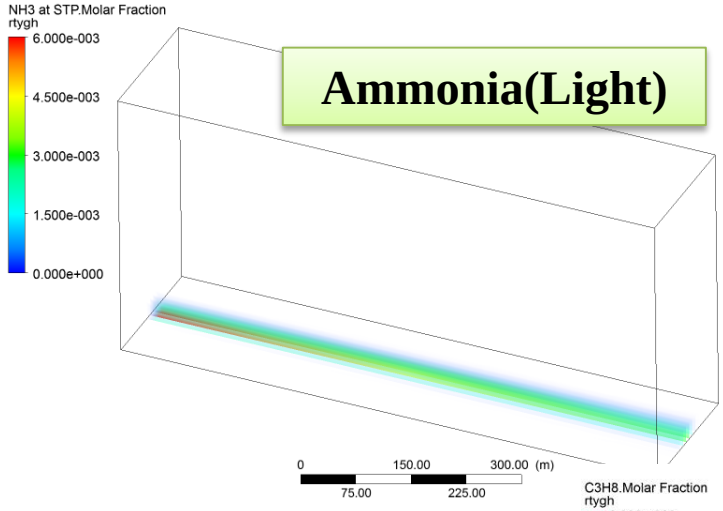


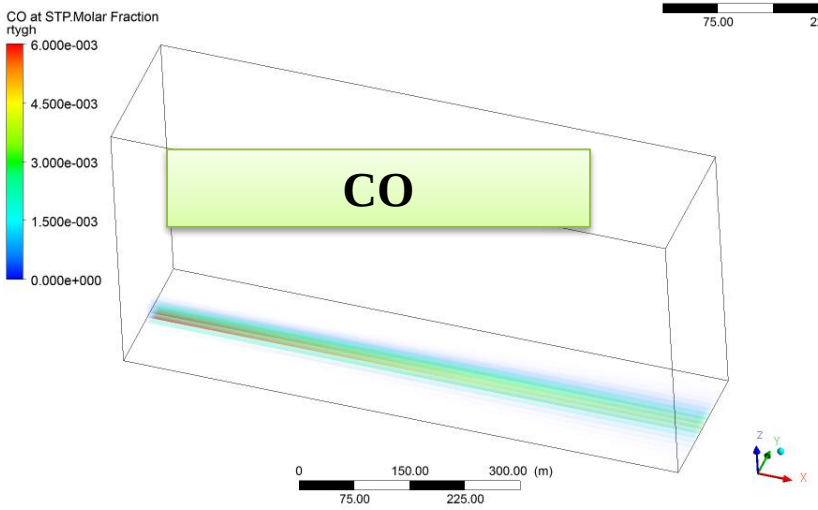


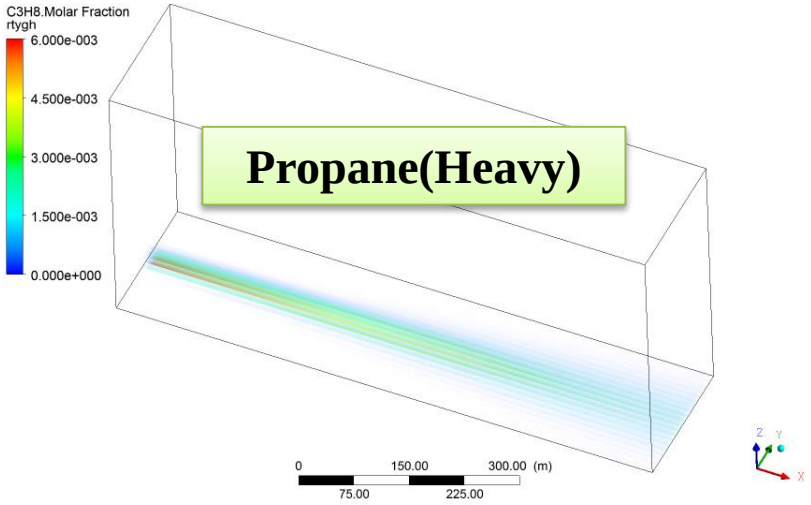


The effects of different density

The distribution of gas concentration (side view)
at wind speed=6m/s







The effects of different density

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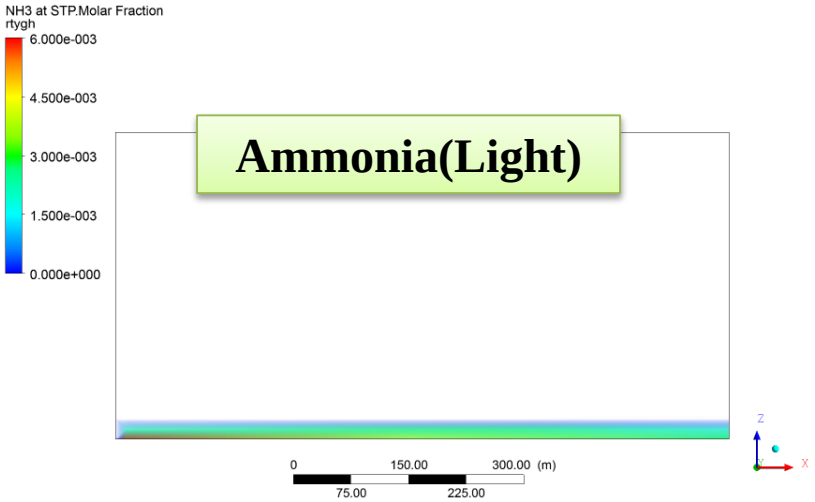
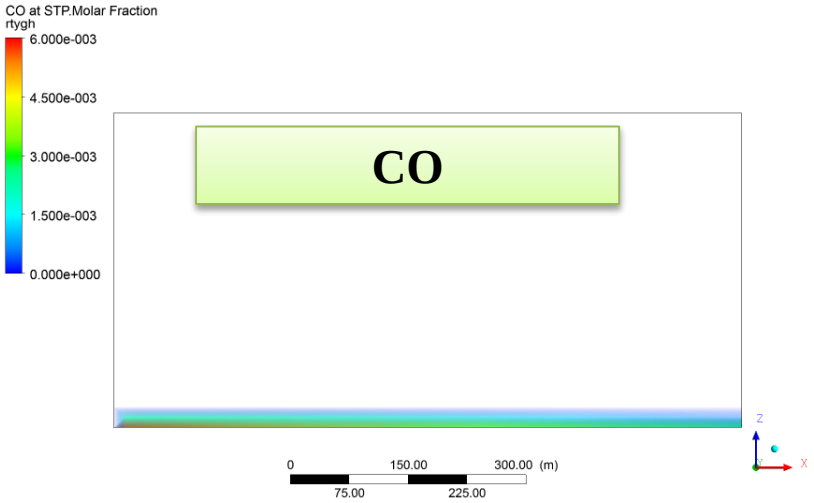
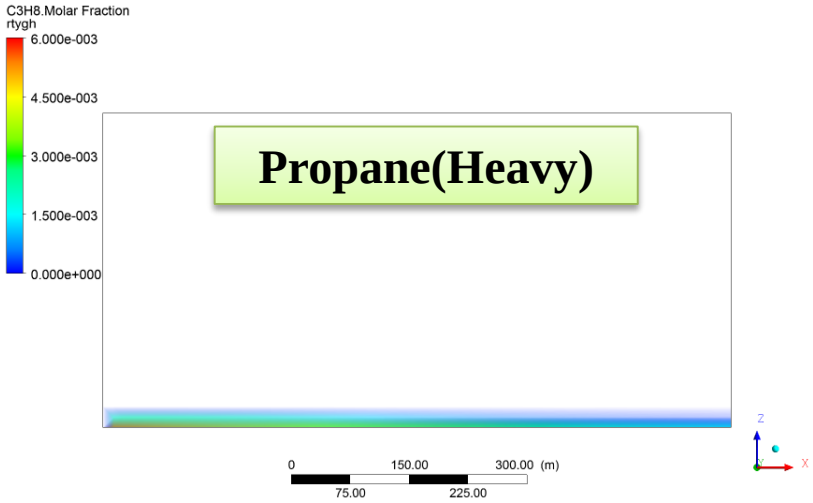






Gas diffusion analysis using numerical method

②The effects of mitigation equipment "Water spray curtain"

Examples of mitigation methods

Absorption Tower

Adsorption Tower

Gas Scrubber

Conventional diffusion analysis models are not able to consider
the effect of mitigation measure

The effects of water curtain

Efficacy : **Reduction of the leeward side concentration**

Effects caused by the water curtain

Dispersion of diffused gas

-Change of gas dispersion caused by the water curtain

Absorption of diffused gas

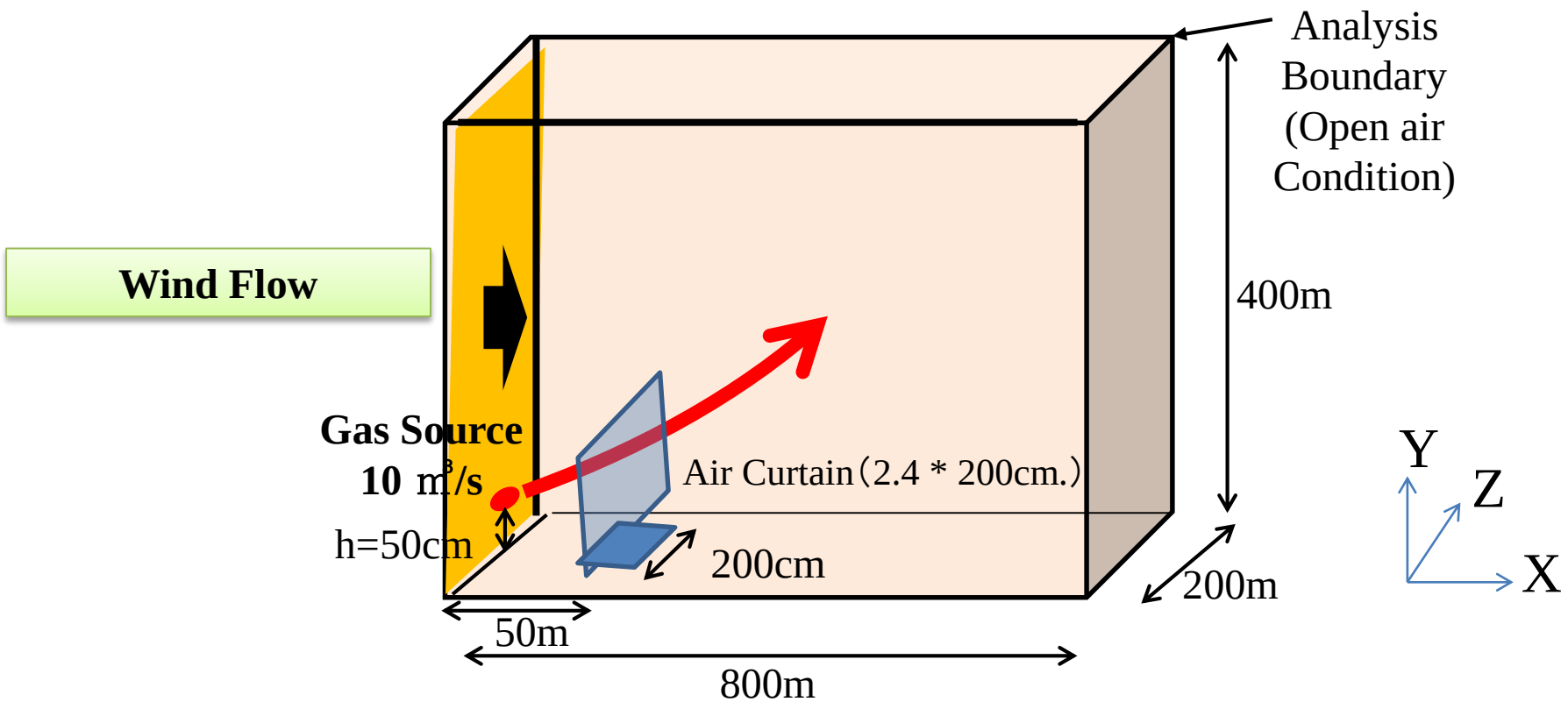
-The effect that soluble substances dissolve into the water curtain

To estimate gas dispersion area correctly we have to consider these both effects.

②Study gases and analysis conditions

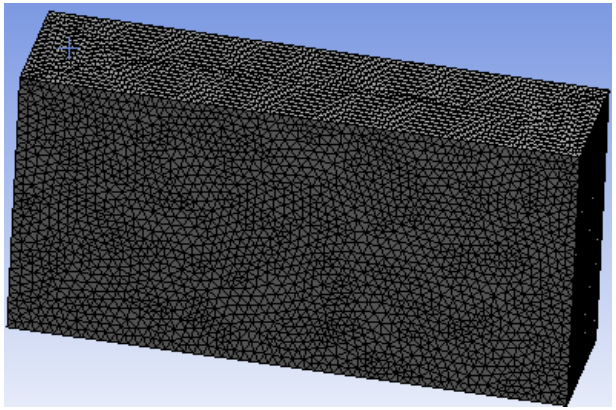
Gas	Gas Density	Source Strength	Wind Speed	Absorption Level
Supposed Gas A	0.771kg/㎥	**10 ㎥/s**	3m/s	**No Curtain**
Supposed Gas B	0.771kg/㎥	**10 ㎥/s**	3m/s	**None**
Supposed Gas C	0.771kg/㎥	**10 ㎥/s**	3m/s	**High**

Analysis Model



Air Temperature	25℃
Nozzle water pressure	7 bar

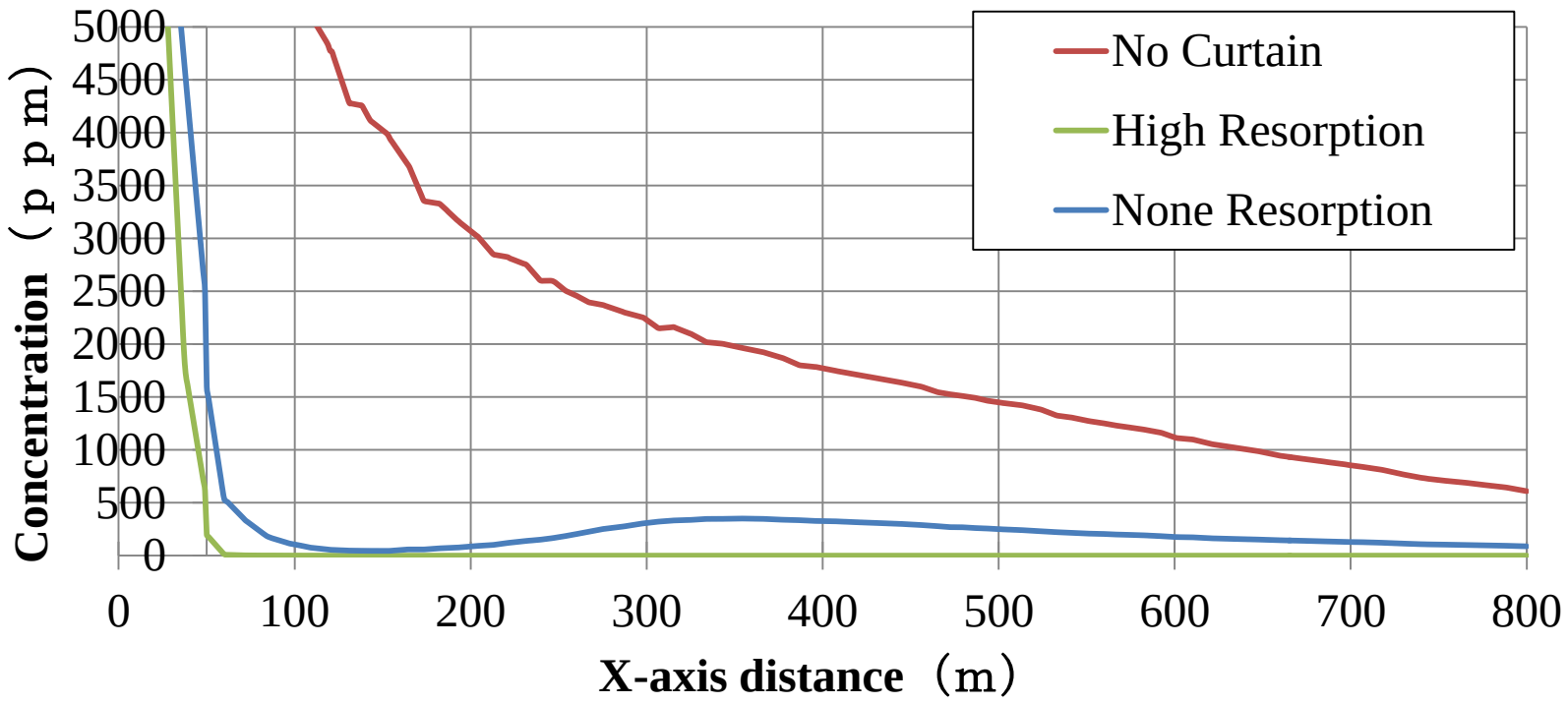
MESH



Statistics	
Nodes	25765
Elements	133557
Sizing	
Use Advanced Size Function	On: Curvature
Relevance Center	Fine
Smoothing	High
Transition	Slow
Span Angle Center	Fine
Curvature Normal Angle	Default (18.0 °)
Min Size	1.e-003 m
Max Face Size	Default (13.380 m)
Max Size	Default (26.760 m)
Growth Rate	Default (1.20)
Minimum Edge Length	4.e-002 m

The efficiency of water curtain

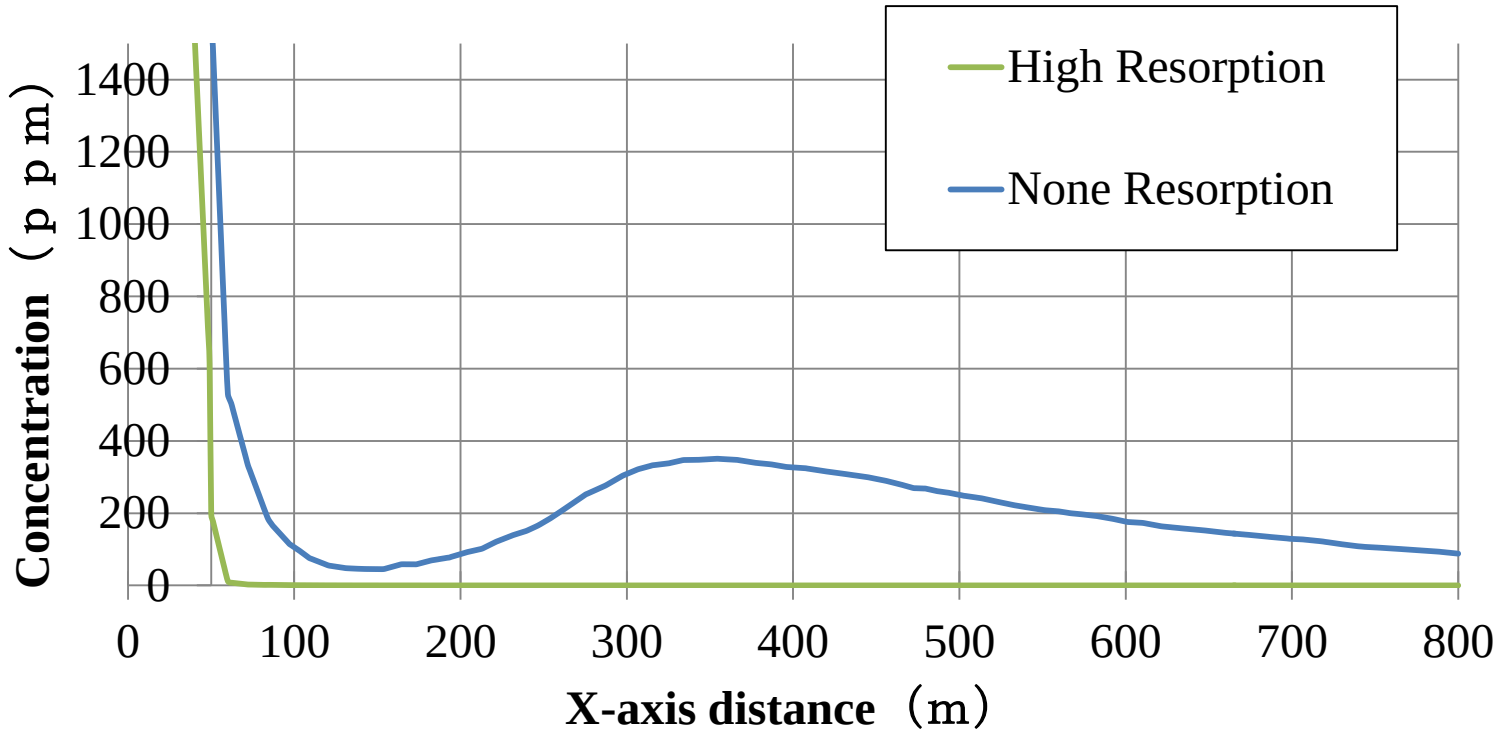
Gas concentration at ground along x axis(leeward direction)



Gas concentration is largely reduced by water curtain

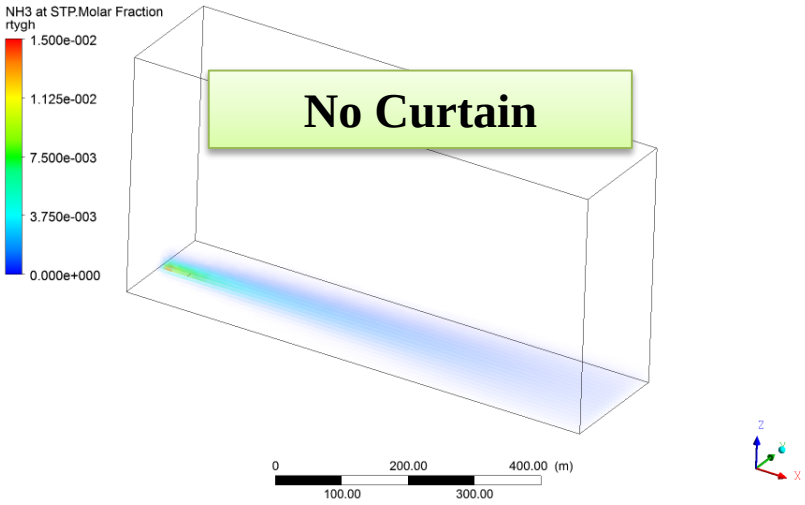
The efficiency of water curtain

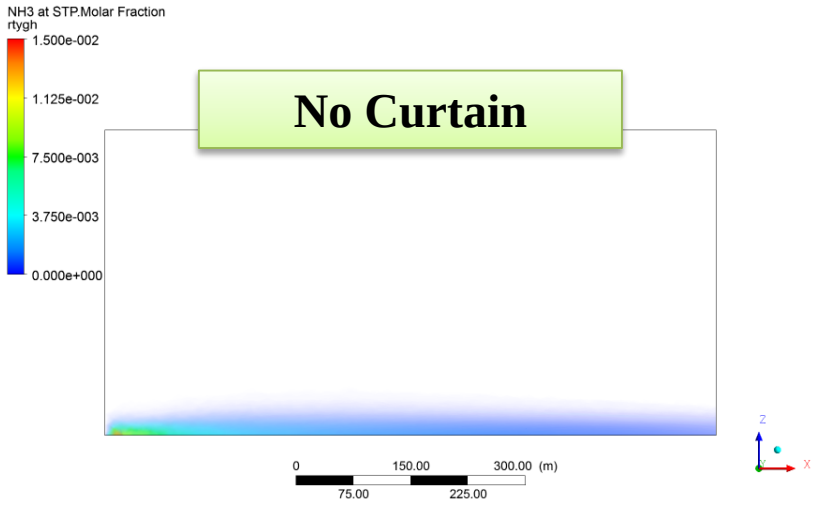
Gas concentration at ground along x axis(leeward direction)

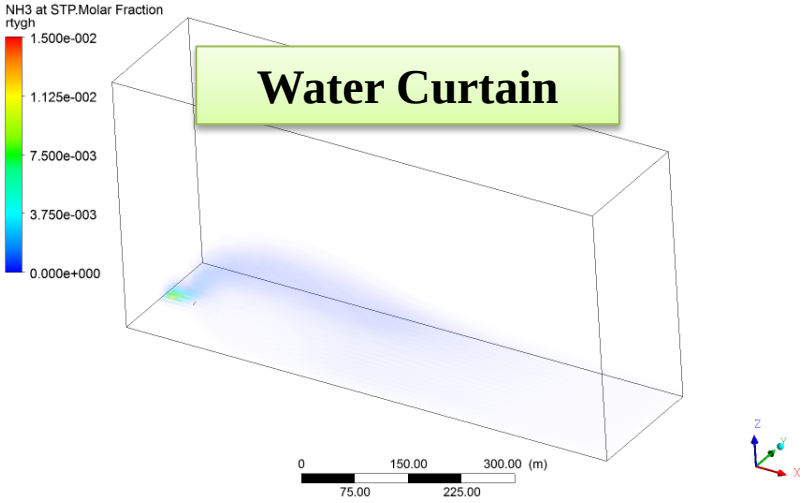


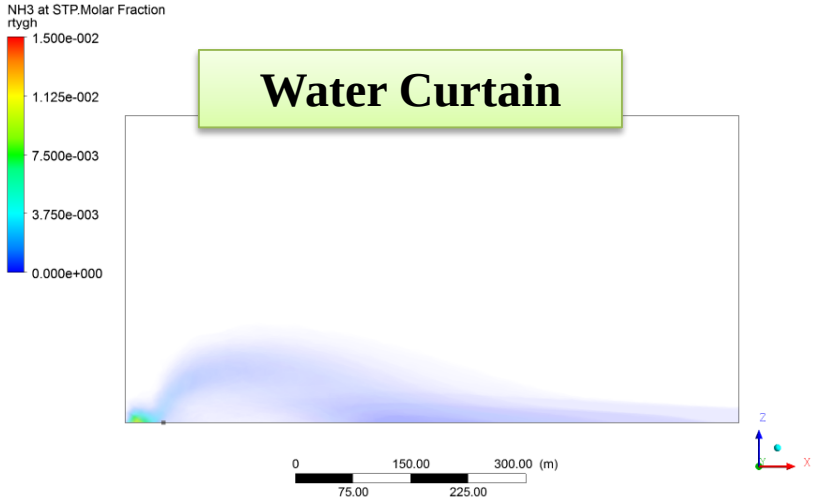
The efficiency of water curtain can be increased by the absorption rate of liquid of curtain

Results (Concentration Distribution Image)

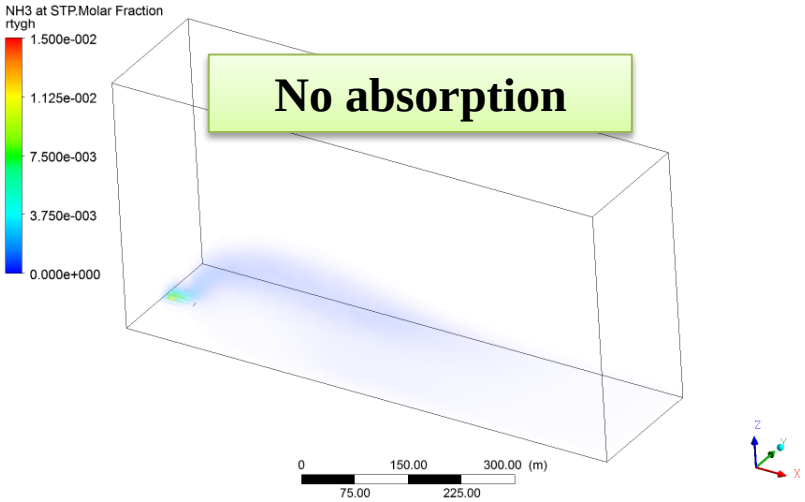


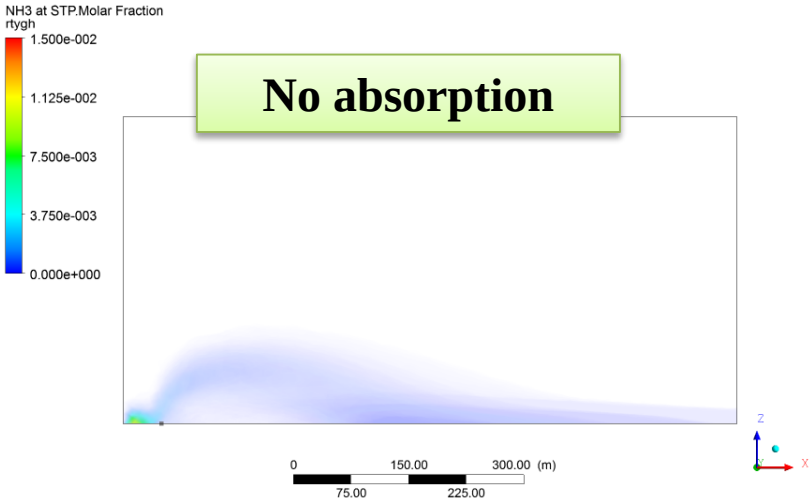


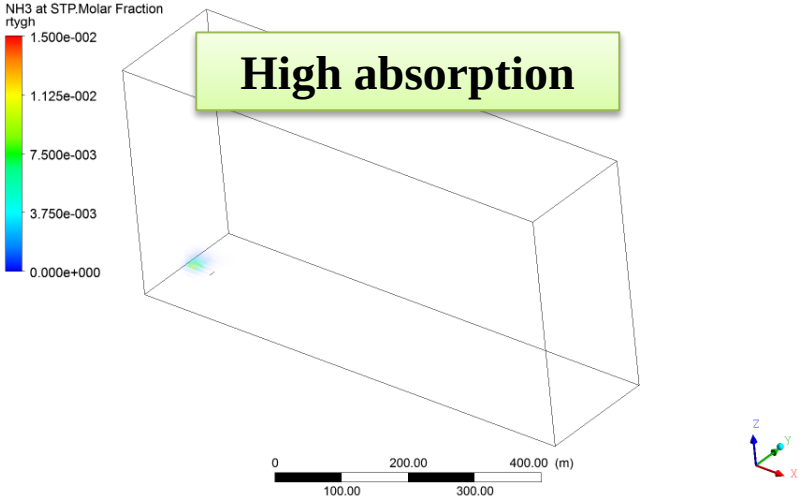


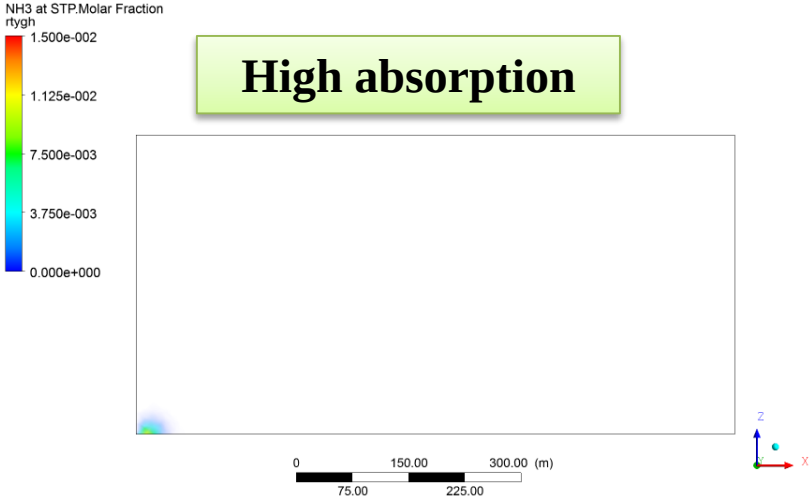


Results (Concentration Distribution Image)









Summary

Overall Summary

① The effects of wind speed and density

-Problems of plume model

-The important of mesh size for future study on CFD

-The effects of wind speed and density on gas diffusion behaviors

②The effects of "Water spray curtain"

-Evaluated the effect of water spray curtain by simulated model

-The important of absorption level

Thank you very much,

ありがとうございました。

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