FDS Analysis of Pool fire in Large Scale Flat Bottom Tank of Crude Oil

*Fire Dynamics Simulator (FDS) : Large eddy simulation model developed by NIST

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Outline

1. Introduction

2. Validation of FDS heat radiation analysis of large scale tank fire
   - ➢ Comparison of the result of heat radiation analysis by FDS and experiments

3. Investigation of the effects of tank diameter and oil level to flame behavior
   - ➢ Analysis of air entrainment to the base of flame

4. Comparison of the dangerous distances estimated by solid flame model and FDS analysis

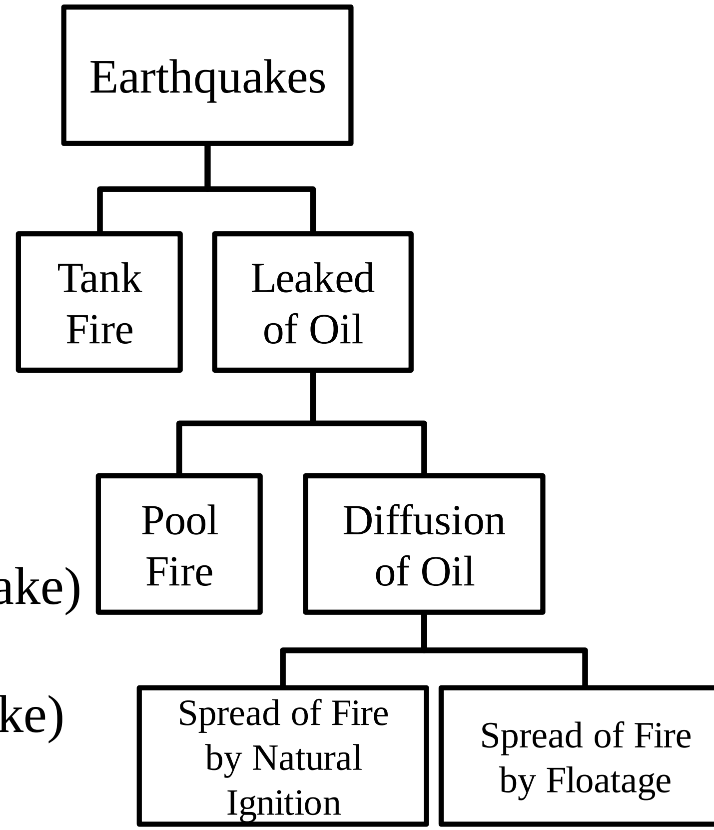
Background

➢ Huge oil storage tanks are increasing

In the case of large scale tank, it is difficult to do combustion experiment.

Tank fire caused by large earthquake
(28 Se9., 2003, Hokkaido, Japan)

Oil storage tanks of JX Energy Terminal in Tomakomai



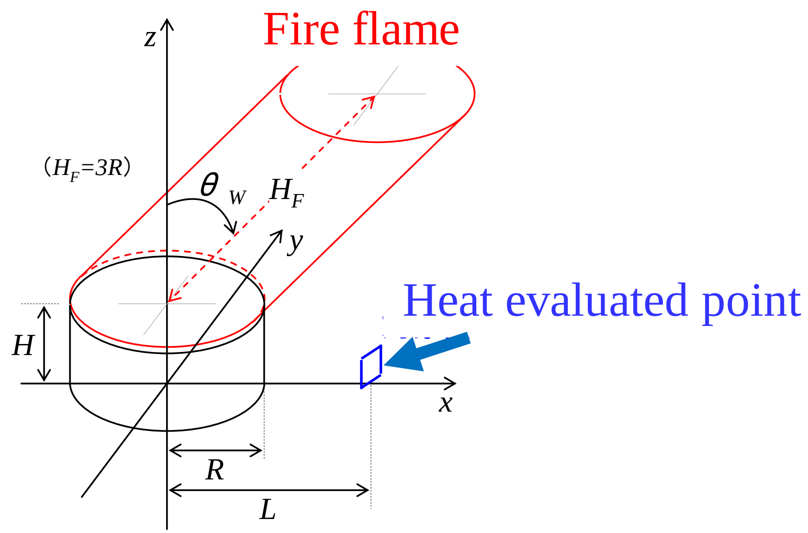
➢ Large earthquakes caused serious tank fire accidents

1964: Fire in a petro-chemical plant (Niigata Earthquake)
1983: Rim seal fire (Middle Japan Sea Earthquake)
2003: Whole surface tank fire (Tokachi-Oki Earthquake)
2011: LPG tank fire (Great East Japan Earthquake)

Quantitative estimation of heat radiation from tank fire and **disaster prevention plan** are required

Mathematical analysis method using solid flame model

- **Cylindrical model of tank fire by Yellow Book**



$$a = \frac{H_F}{R} \qquad b = \frac{L}{R}$$

$$A = \sqrt{a^2 + (b+1)^2 - 2a(b+1)\sin\theta}$$

$$B = \sqrt{a^2 + (b-1)^2 - 2a(b-1)\sin\theta}$$

$$C = \sqrt{1 + (b^2 - 1)\cos^2\theta}$$

$$D = \sqrt{\frac{b-1}{b+1}}$$

$$E = \frac{a\cos\theta}{b - a\sin\theta}$$

$$F = \sqrt{b^2 - 1}$$

- **Configuration factor ϕ: [Guideline by TNO Yellow Book, Netherlands]**

$$\pi\,\phi = -E\tan^{-1} D + E\left[\frac{a^2 + (b+1)^2 - 2b(1 + a\sin\theta)}{AB}\right]\tan^{-1}\left(\frac{AD}{B}\right) + \frac{\cos\theta}{C}\left[\tan^{-1}\left(\frac{ab - F^2\sin\theta}{FC}\right) + \tan^{-1}\left(\frac{F\sin\theta}{C}\right)\right]$$

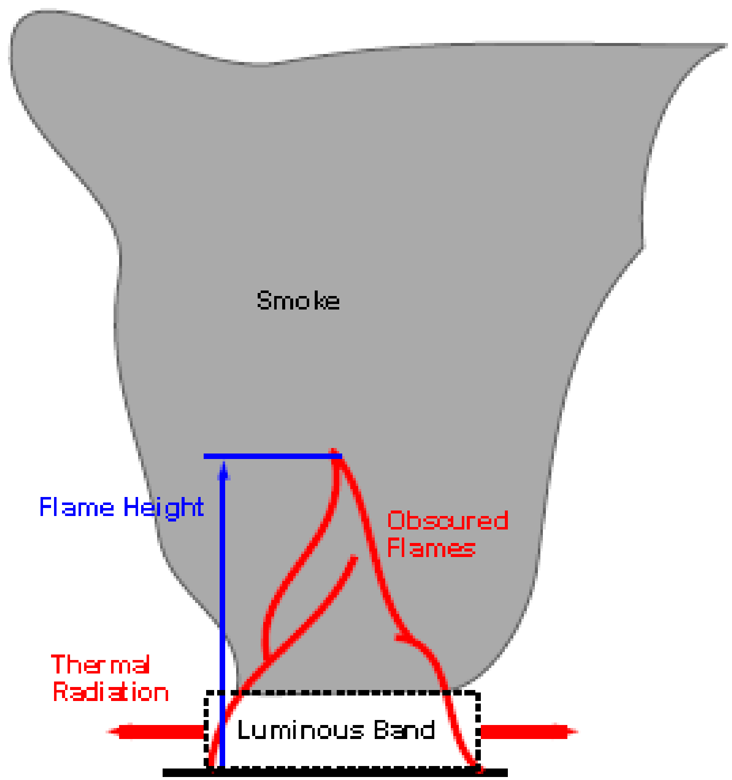
$$E = \phi \cdot \varepsilon \cdot \sigma \cdot T^4 = \phi \cdot R_D$$

[ϕ : Configuration factor, R_D Heat radiant emittance (W/m^2)]

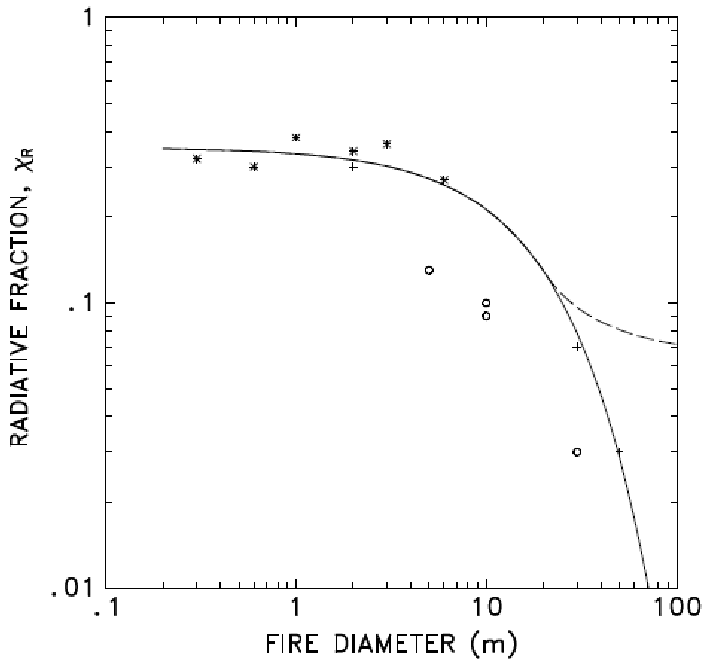
Fuel	Crude oil	Gasoline	LNG (Methane)	Ethylene	Propane
R_D (kW/m^2)	41	58	76	134	74

The effects of tank diameter to the soot formation

Thermal shielding by black smoke which increase with size of tank diameter※



The relation between diameter of flame and radiative fraction※



The solid line is a fitted curve:

$$\chi = 0.35\exp(-0.05D)$$

Oxygen supply into the flame become insufficient in the case of large diameter tanks, which causes incomplete combustion

※K.McGrattan,"Thermal Radiation from Large Pool Fires",Fire Safety Engineering Division,2000

The effects of length from pan lip to oil surface

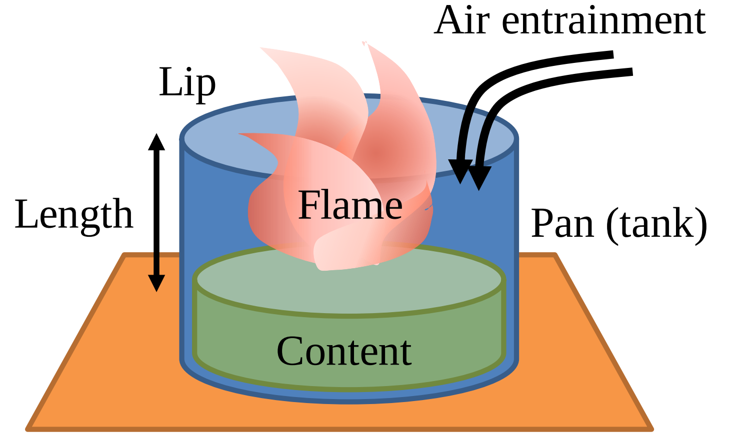
A) There are a number of edge effects due to the “lip” of a pan, which exists where the pan extends above the fuel surface to confine the liquid.

- Greater turbulence near the base of the flame
- Shorter flame height
- Higher gas emissivity

(Hall,1972)

B) These changes are consistent with an enhancement in the burning rate. (Orloff,1981)

These studies showed that air entrainment have great effects to the flame behavior.



Hall, A.R., Pool Burning: A review, Rocket Propulsion Establishment: Westcott, 1972
Orloff, L. Simplified Radiation Modeling of Pool Fires. *Proc. 18th Symp. (Int.) on Combustion, Waterloo, Ontario, The Combustion Institute, Pittsburgh, PA, 1981*.

Purpose

- Analysis of the effects of tank diameter to the fire behavior
- Analysis of the effects of length from pan lip to oil surface

It is important to notice that air entrainment largely affect the flame behavior and heat radiation.

FDS is used to analyze heat radiation from pool fire in large scale flat bottom tanks

Fire Dynamics Simulator (FDS)

FDS is a large eddy simulation model, which was developed by the National Institute of Standards and Technology.
The software solves numerically a form of the Navier-Stokes equations appropriate for low-speed, thermally-driven flow, with an emphasis on smoke and heat transport from fires.

Purpose

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Estimate the distances to the points at where receiving radiation of 2.3 kW/m^2 from the wall of the tank estimation

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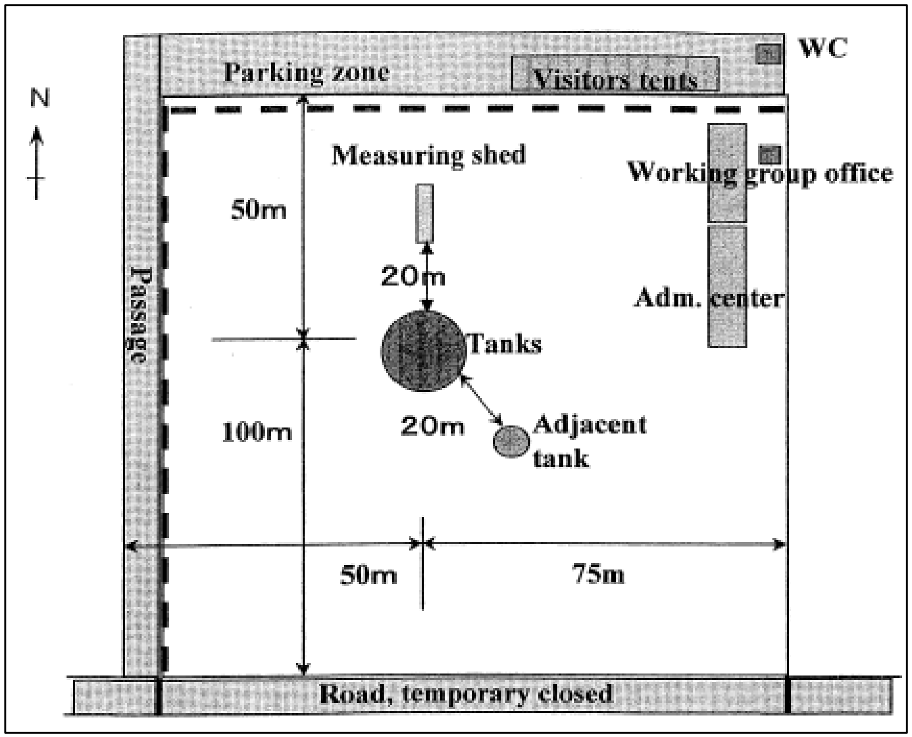
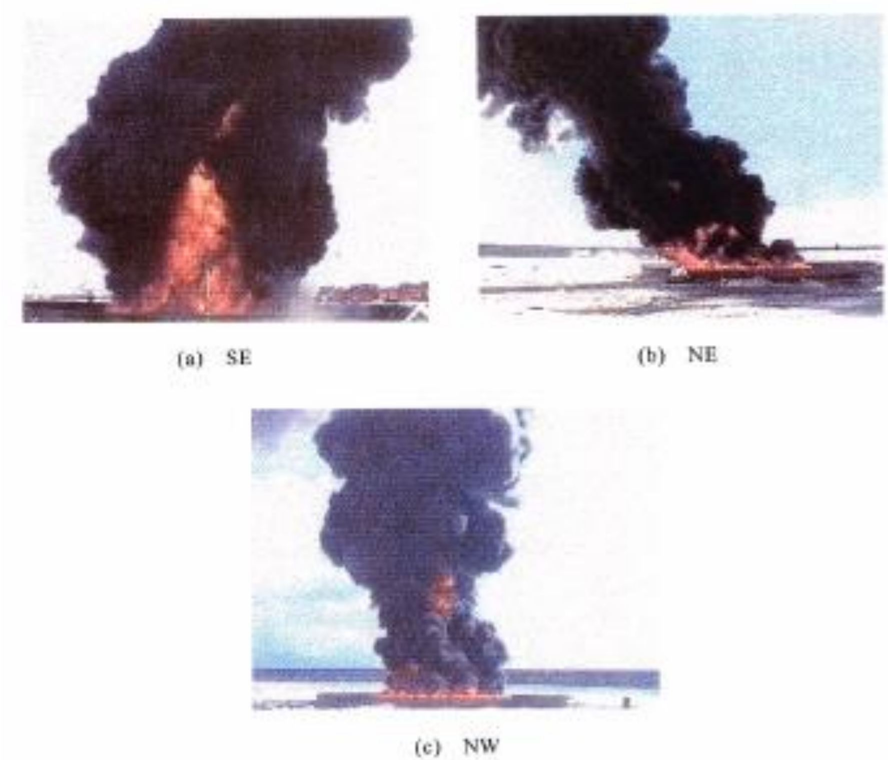
Experiments of large scale pool fire (1998, Japan)※

Japan national oil corporation in Tomakomai

Horizontal view of experimental allocation



Flame behaviors (tank diameter D=10m)



※ Hiroshi Koseki, Yusaku Iwata, "Tomakomai Large Scale Crude Oil Fire Experiments", Fire Technology, Vol.36 No.1, 2000

Environmental conditions

Experiment

Date	Pan	Time	Remarks	Burning site Temp. ℃	Humid %	Wind	Wind spd m/s
Jan. 26	20m-pan	7:00	10min before ignition	-14.7	90.7	N	1.35
		7:10	Ignition	-14.3	90.9	N	0.94
		7:15	5min after ignition	-11.7	79.3	NNE	1.28
		7:20	10minafter ignition	-12.3	78.7	NE	1.40
		7:25	15min after ignition	-11.8	81.6	ENE	0.54
		7:30	20min after ignition	-13.1	84.4	ENE	0.80
		7:40	10min after extinguish	-13.7	87.0	ENE	1.05

Jan.26	10m-pan	12:20	10min before ignition	-3.3	51.5	NW	0.73
		12:30	Ignition	-3.4	61.7	WNW	2.12
		12:35	5min after ignition	-2.2	51.0	NNW	1.21
		12:40	10min after ignition	-2.9	55.5	N	1.68
		12:45	15min after ignition	-4.4	63.4	NNE	2.31
		12:50	20min after ignition	-3.9	60.7	N	2.58
		12:55	25min after ignition	-4.0	62.7	N	4.41
		13:00	10min after extinguish	-4.4	60.9	NNE	2.52

FDS analysis

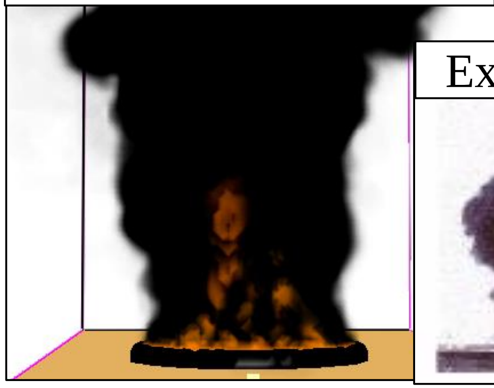
20m-tank: Temperature:**-15℃**, Wind velocity:**1m/s**

10m-tank: Temperature: **-5℃**, Wind velocity:**4m/s**

Comparison of the results of FDS analysis and experiment

Formation of soot (D=10m)

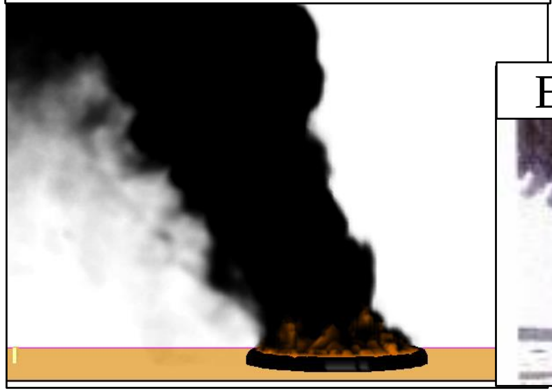
FDS result



Experimental result

View from leeward

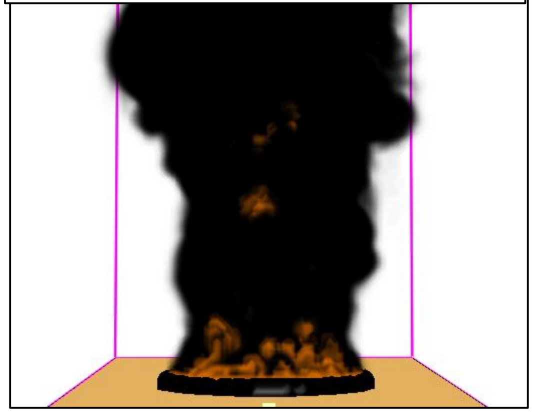
FDS result



Experimental result

Side view of the flame

FDS result



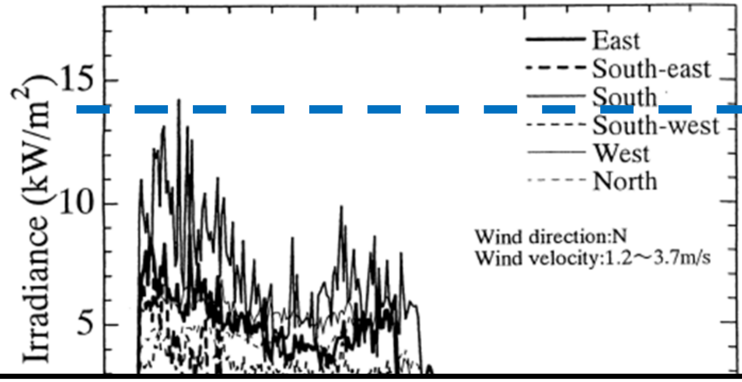
Experimental result

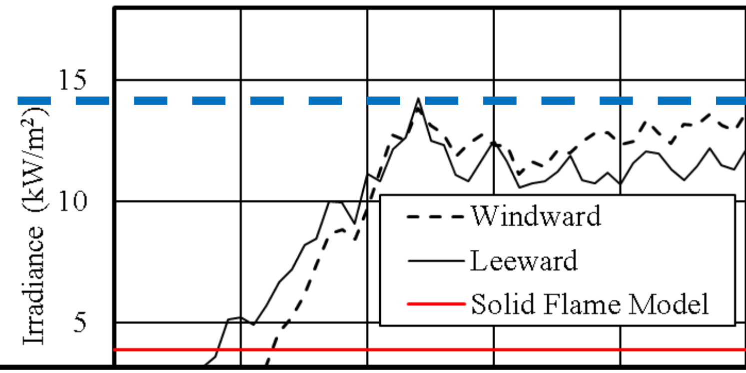
View from windward

Comparison of the results of FDS analysis and experiment

Experiment | FDS analysis

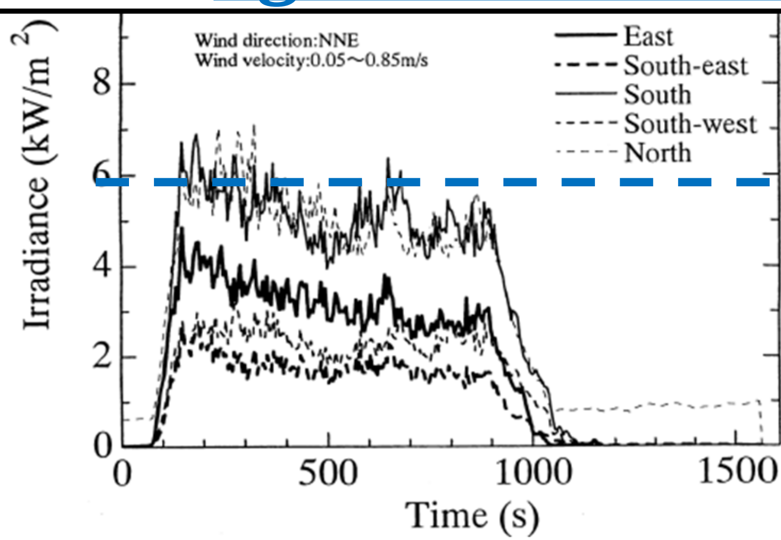
D=10m

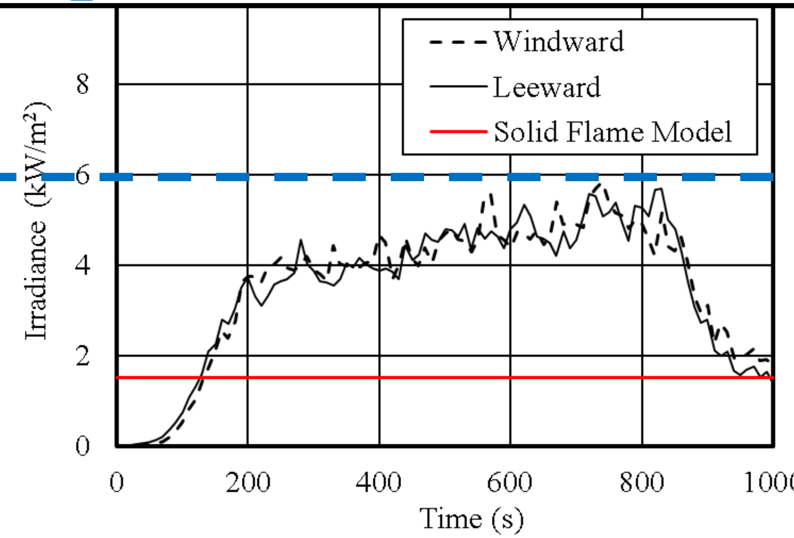




Max value of heat radiations show good agreement with experiment

D=20m





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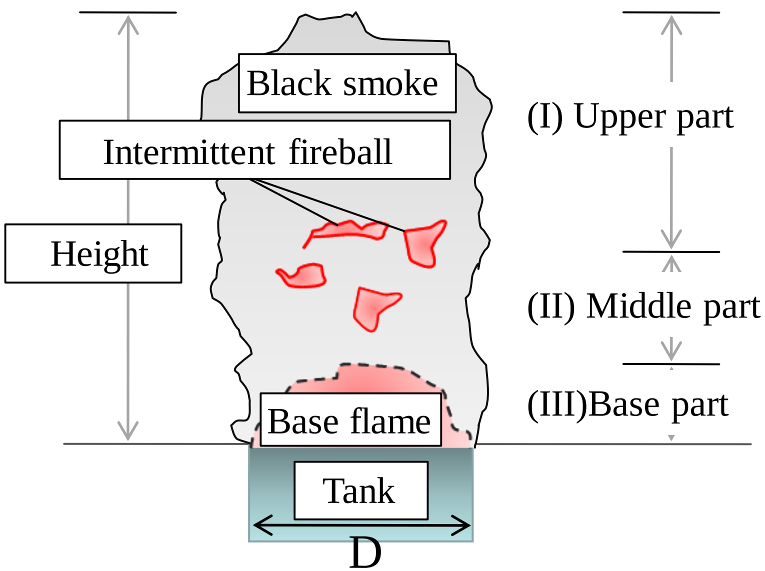
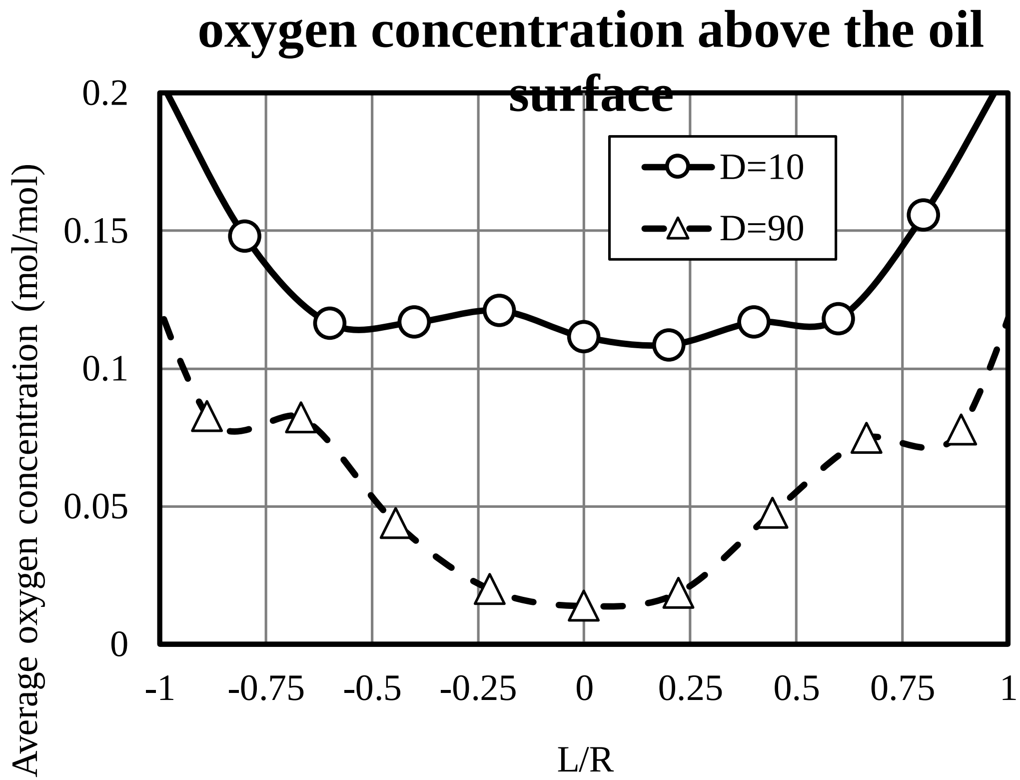
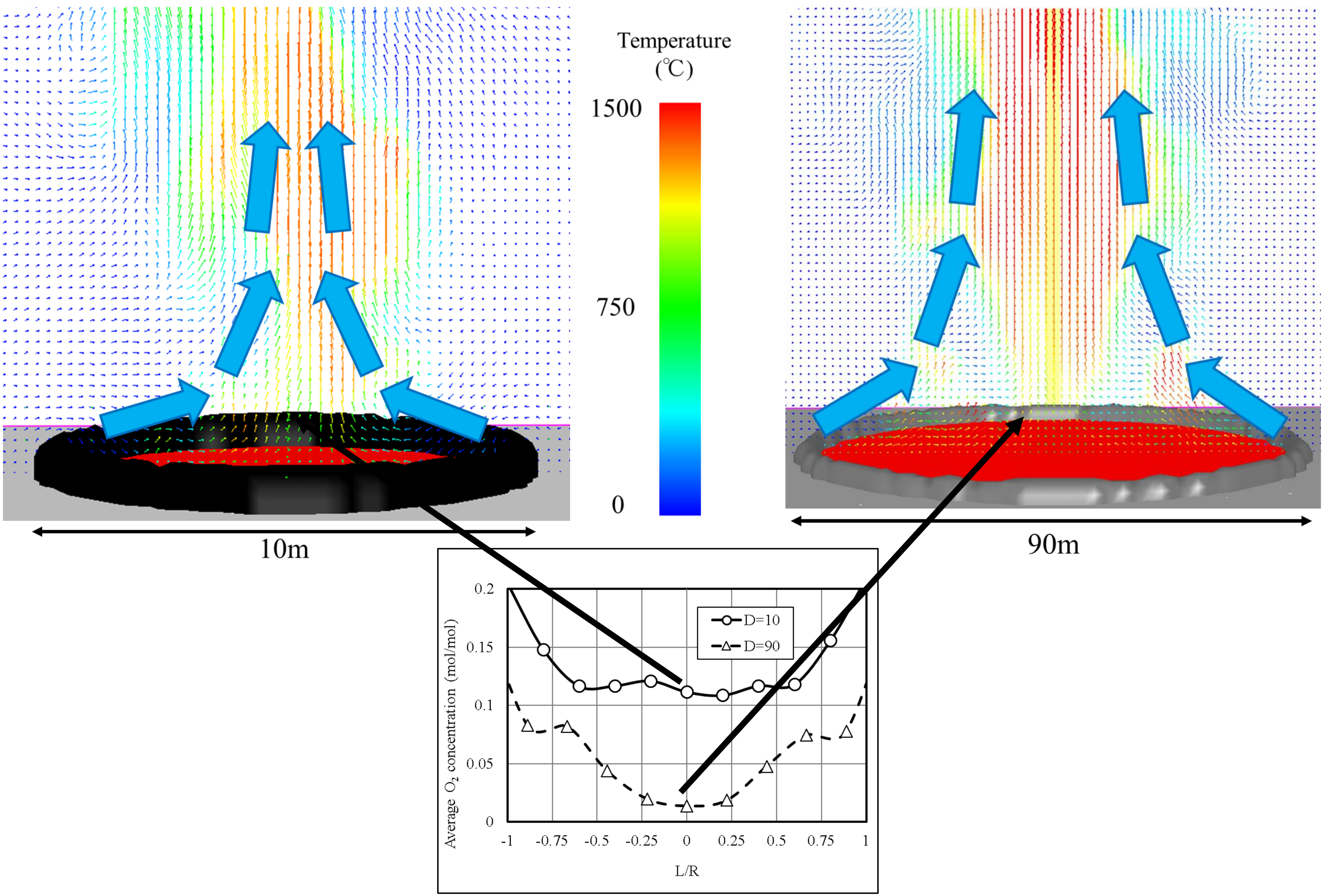
The effects of tank diameter to air entrainment



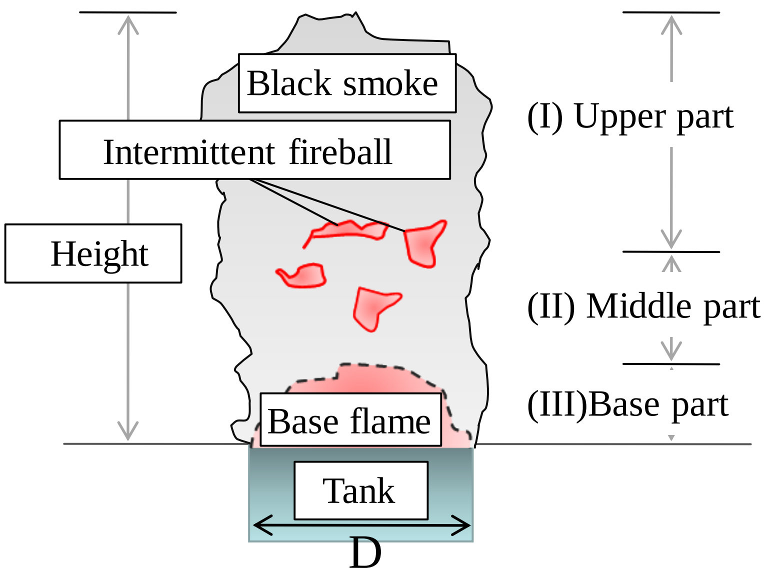


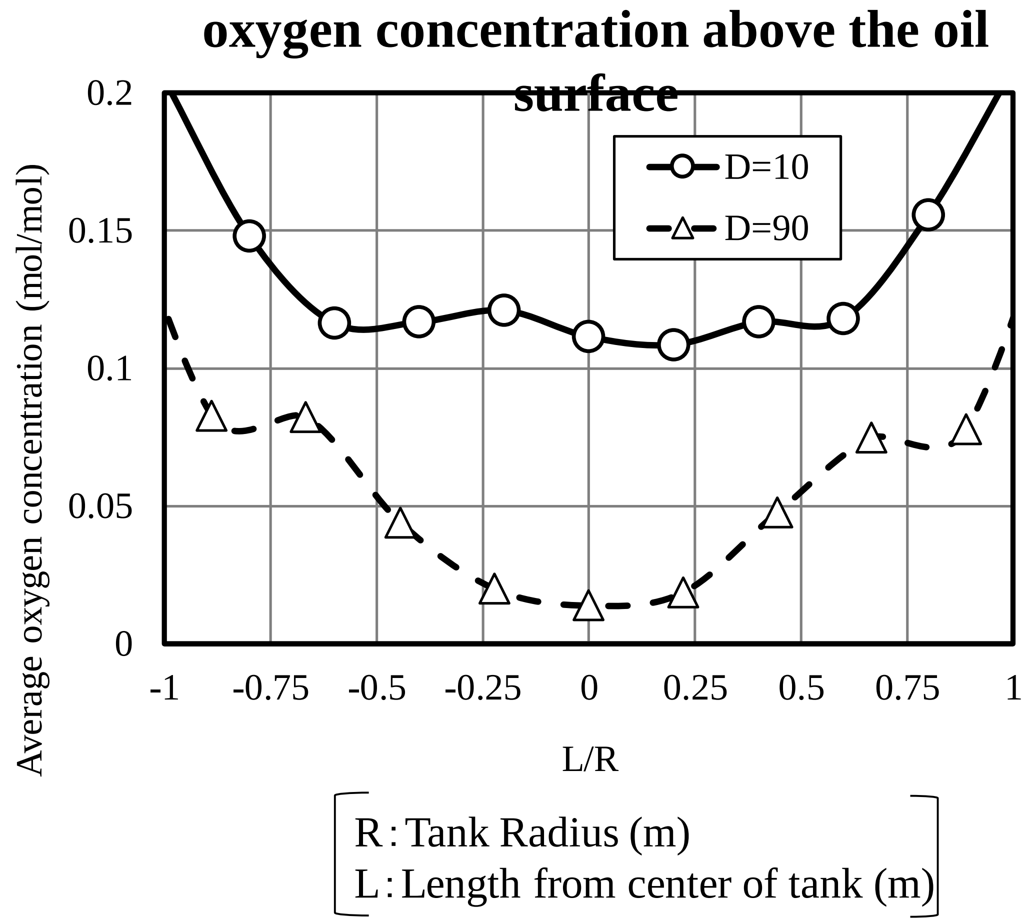
R : Tank Radius (m)
L : Length from center of tank (m)

Air flow and Temperature distribution around the flame



The effects of tank diameter to air entrainment

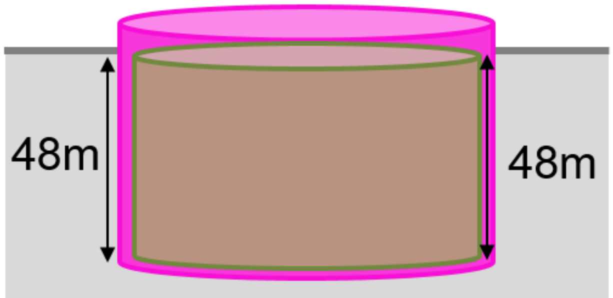




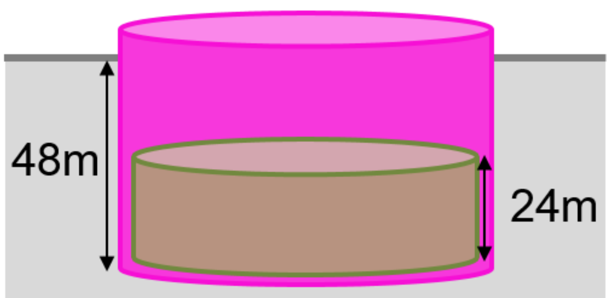
Combustion efficiency goes down with decreasing of oxygen supply and that results formation of massive black smoke

The effects of length from pan lip to oil surface

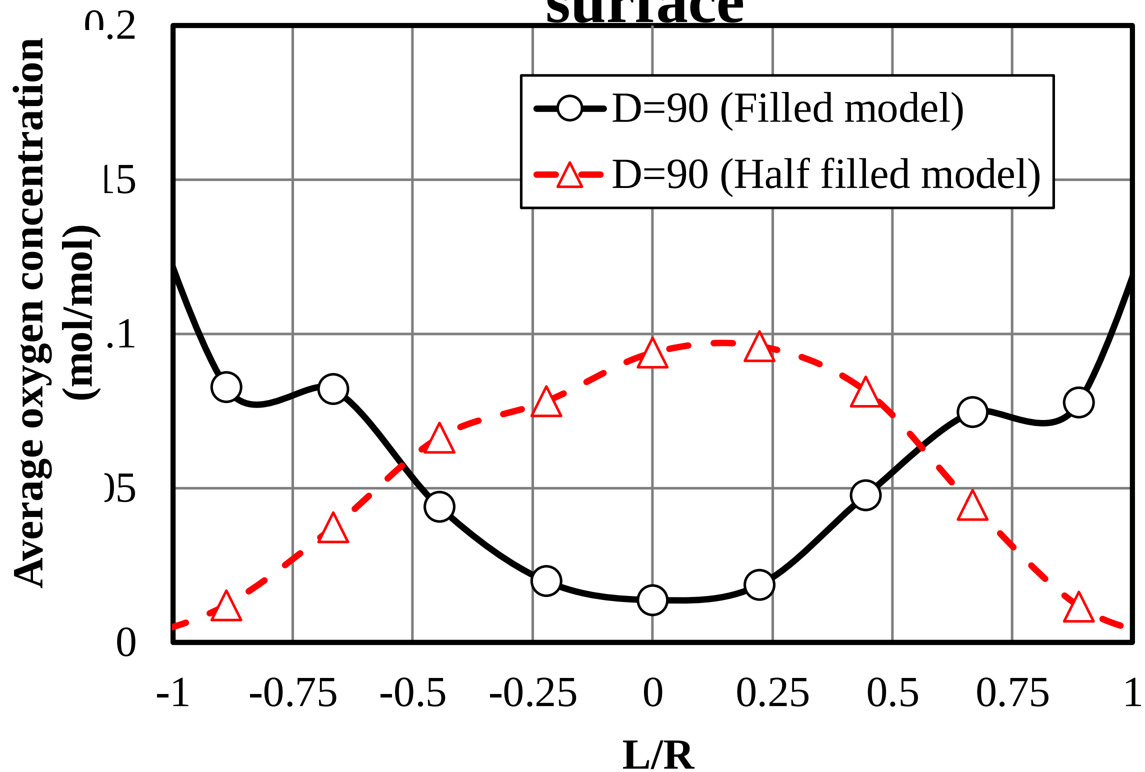
Fully filled model



Half filled model

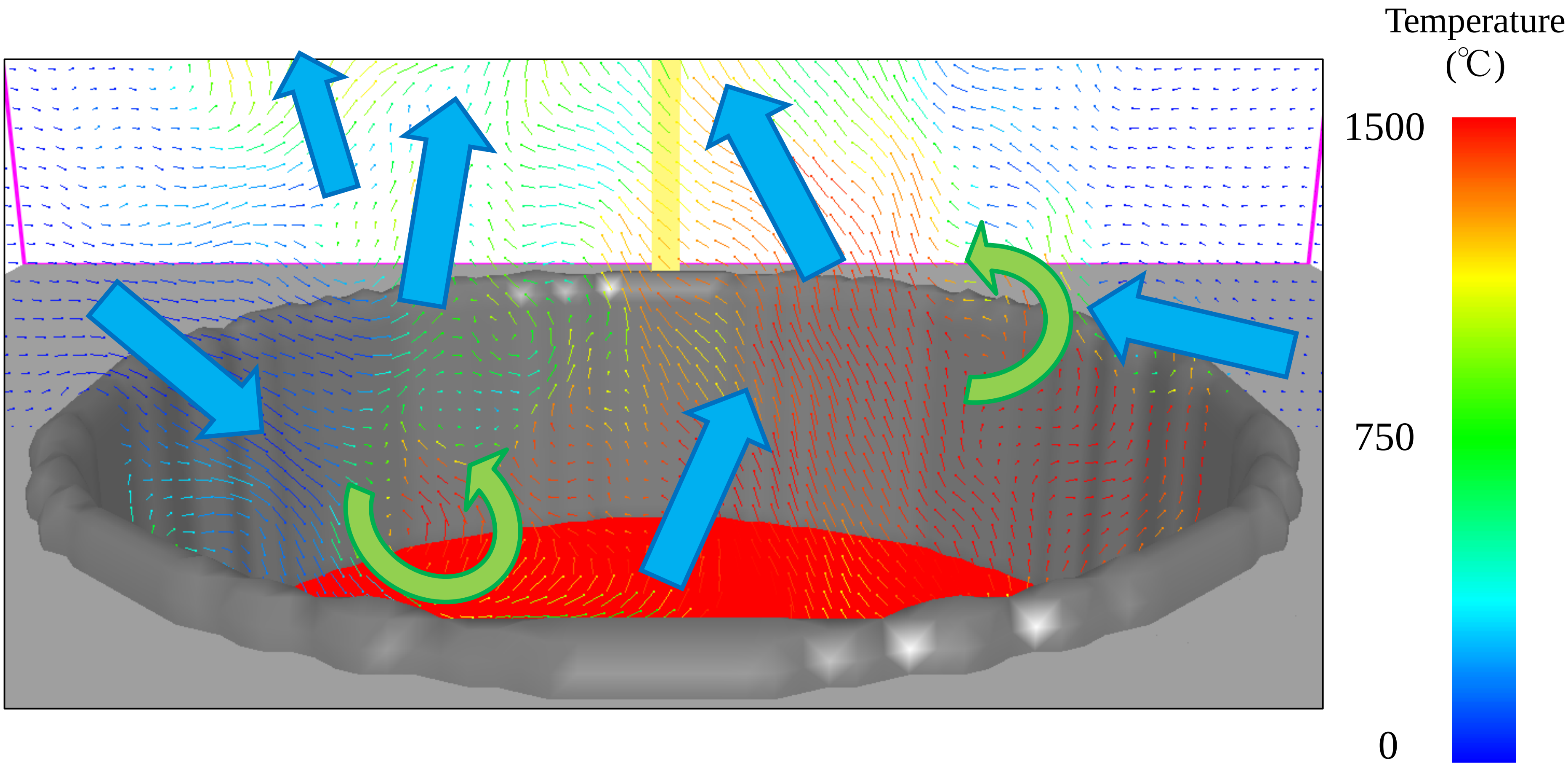


oxygen concentration above the oil surface



R : Tank Radius (m)
L : Length from center of tank (m)

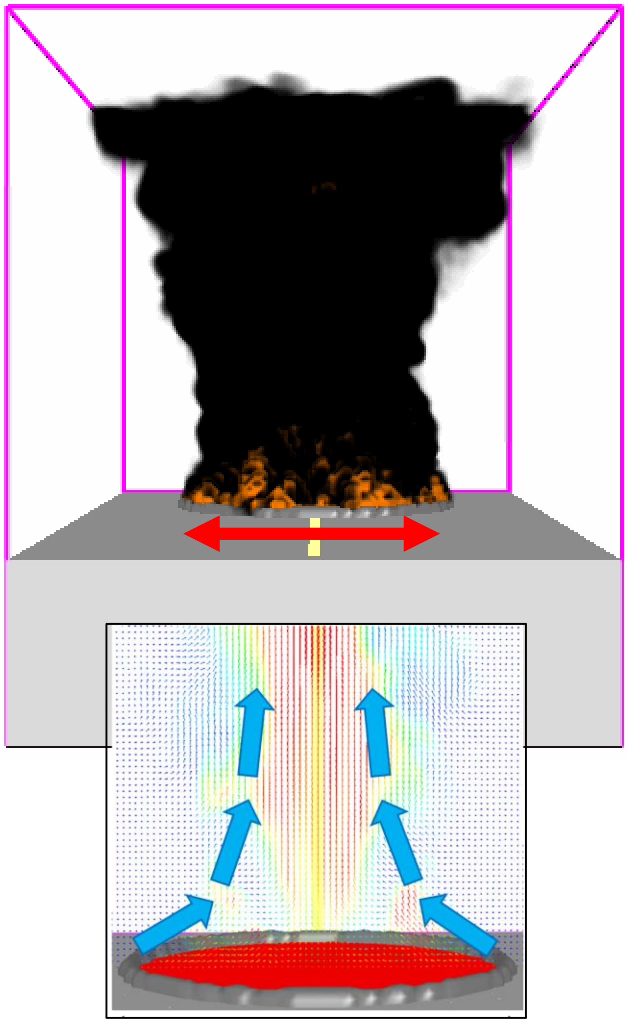
Turbulence flow in firing tank



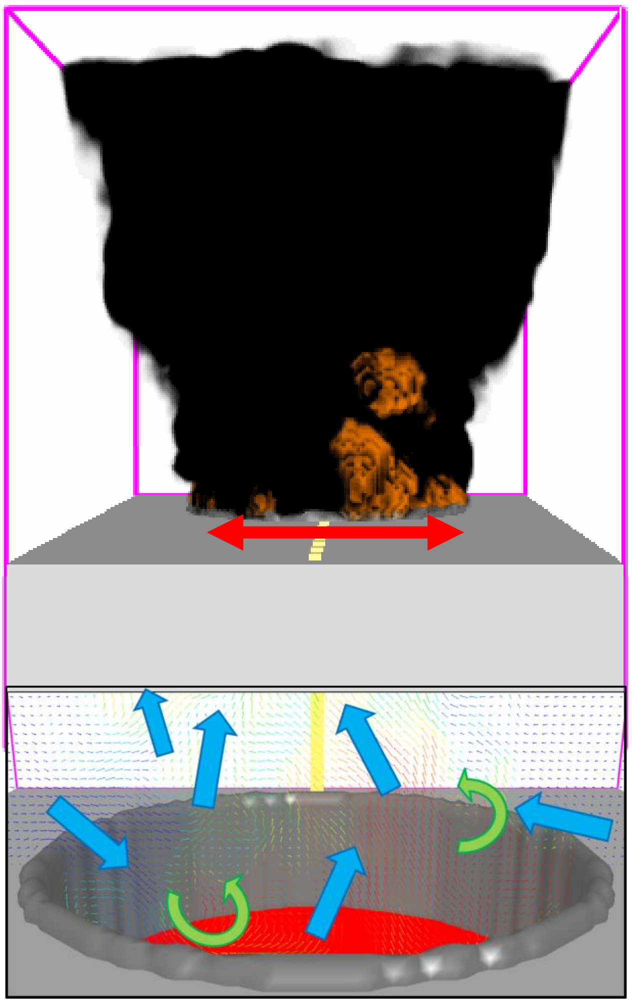
Irregular turbulence flow occur in the firing tank

Flame behavior of underground-tank fire

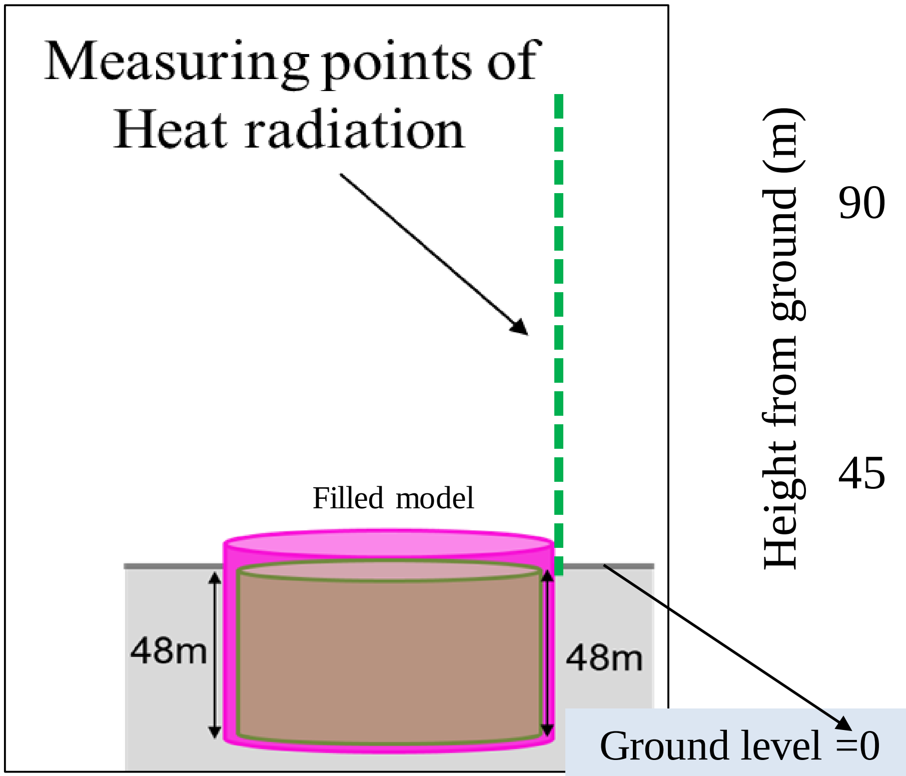
Fully filled model

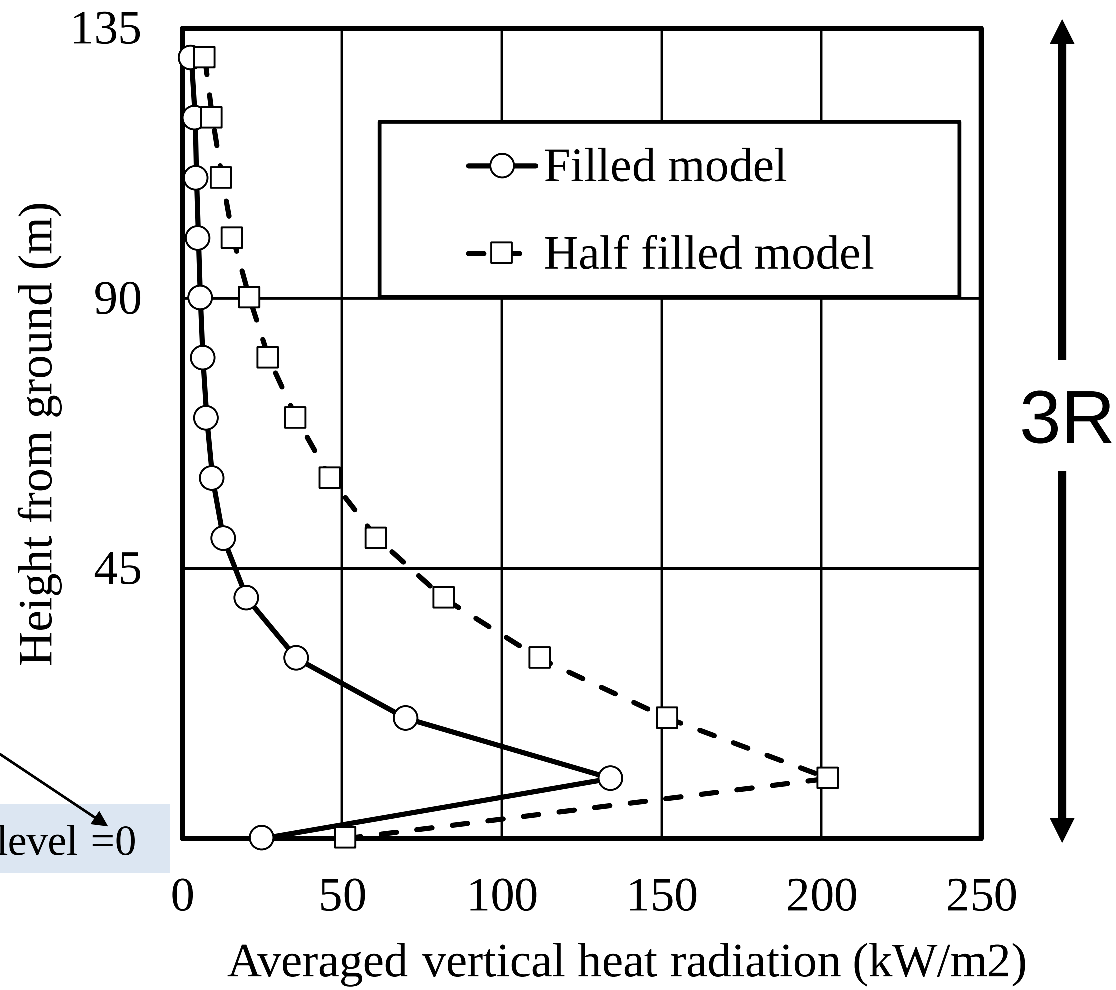


Half filled model



Distribution of vertical heat radiation





Half filled tank is more dangerous than fully filled tank in the case of wholly surface pool fire

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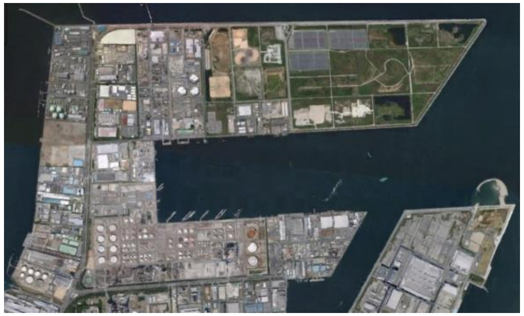
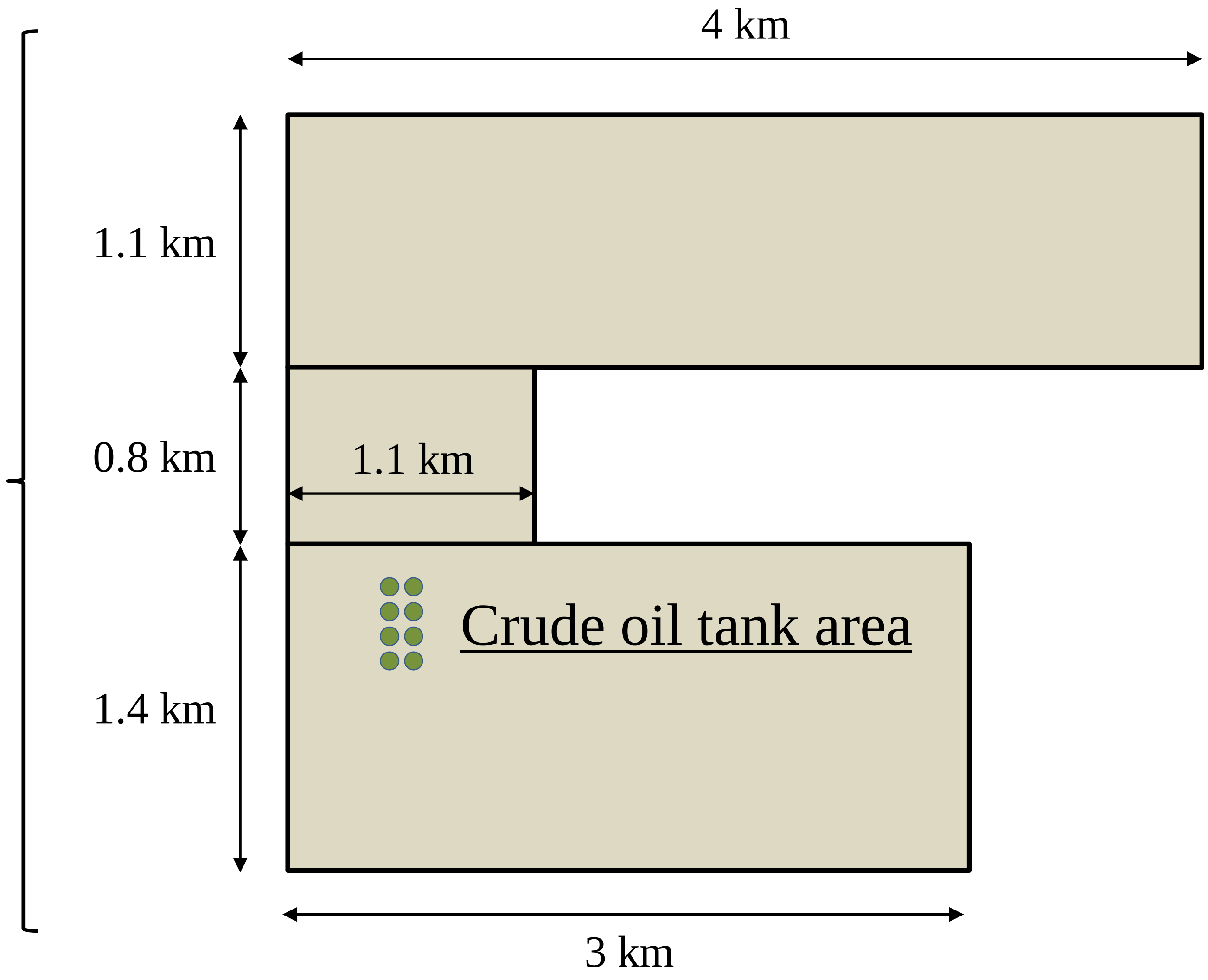
Heat radiation analysis in the simulated tank in Sakai

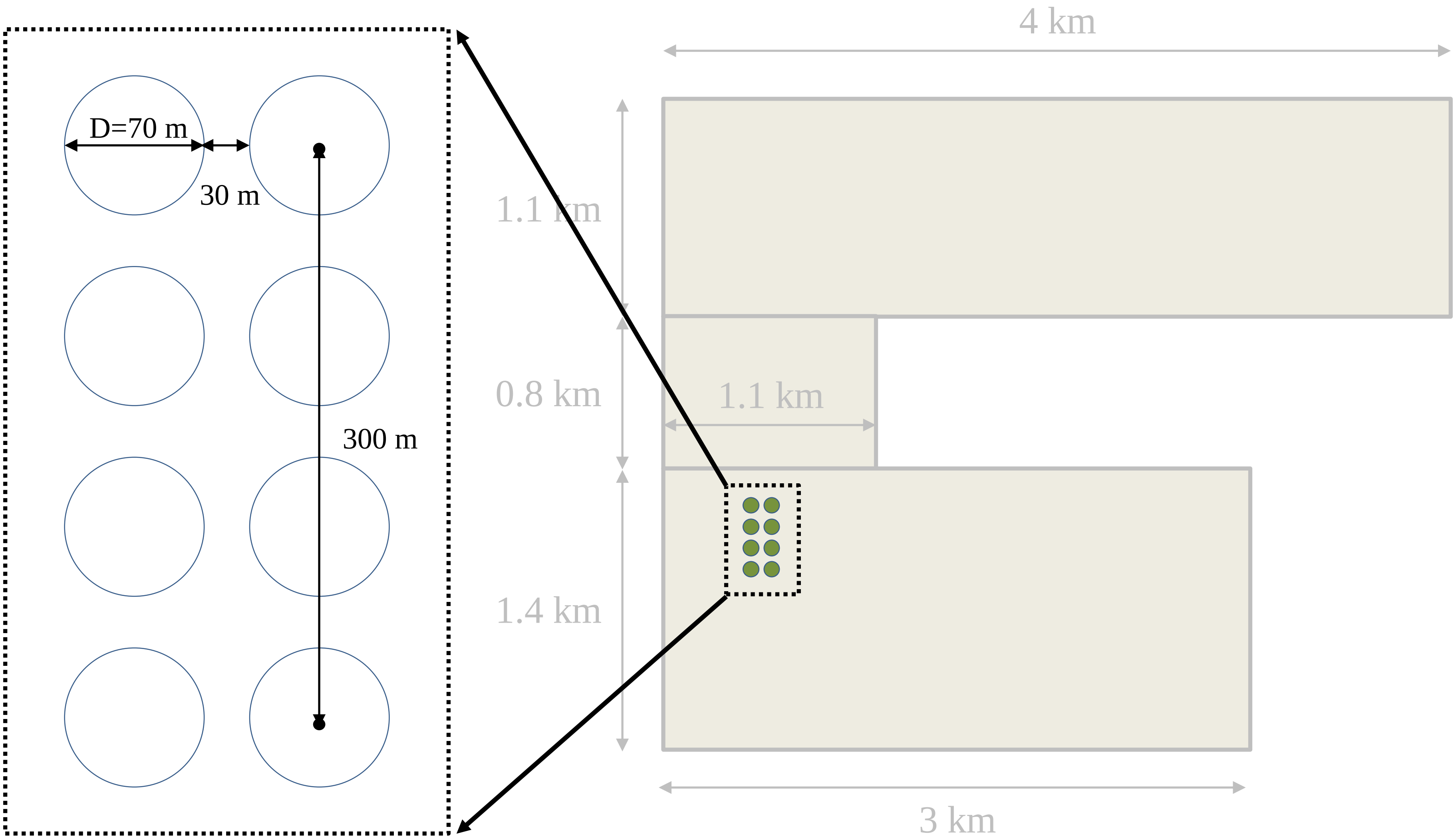
Allocation of simulated model tank



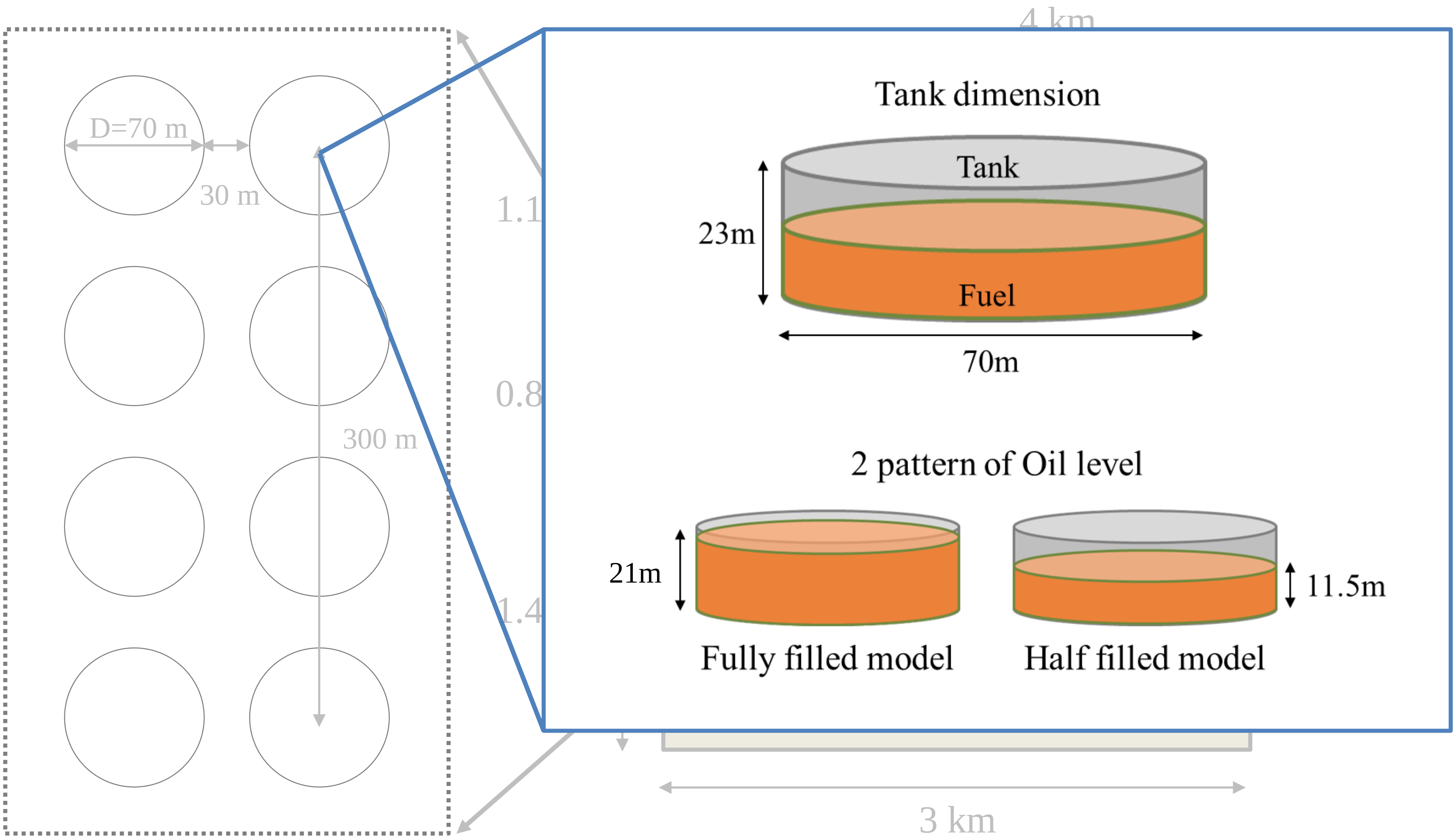
Plant Area



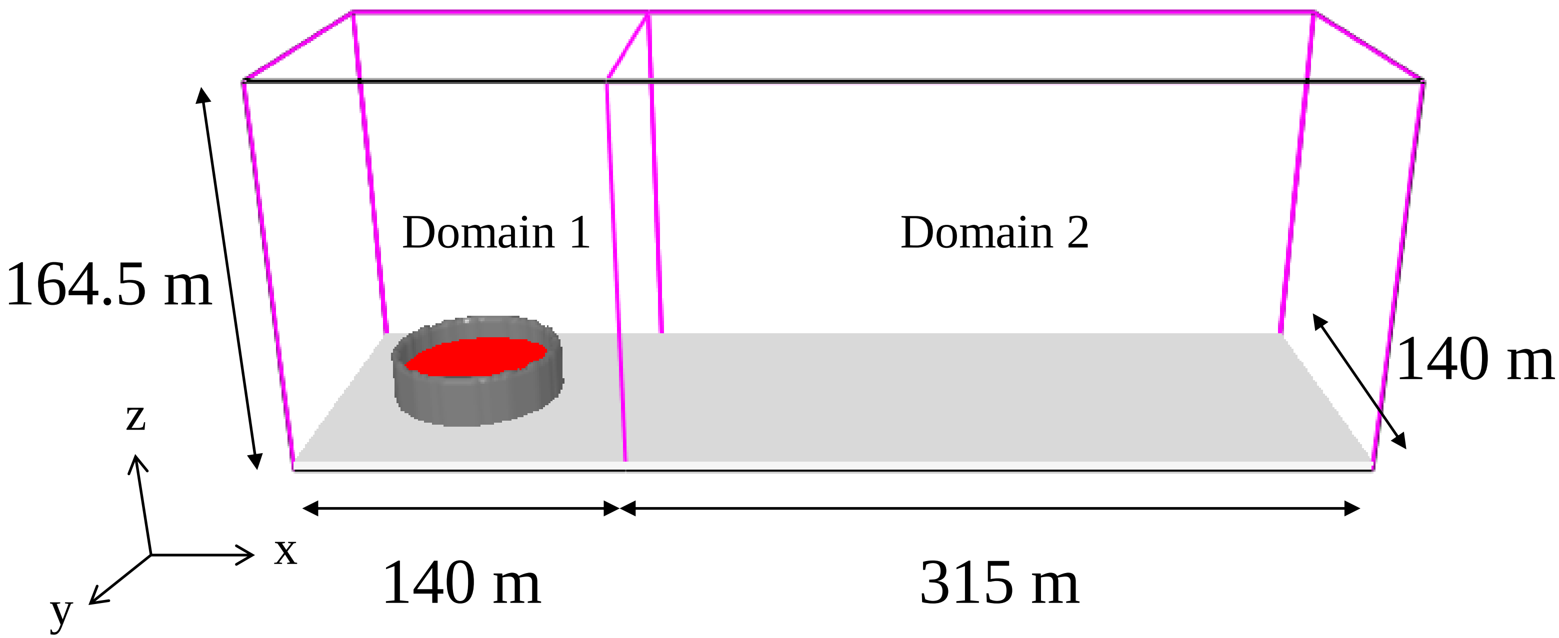
Allocation and dimension of simulated tank



Allocation and dimension of simulated tank



Analysis domain and conditions

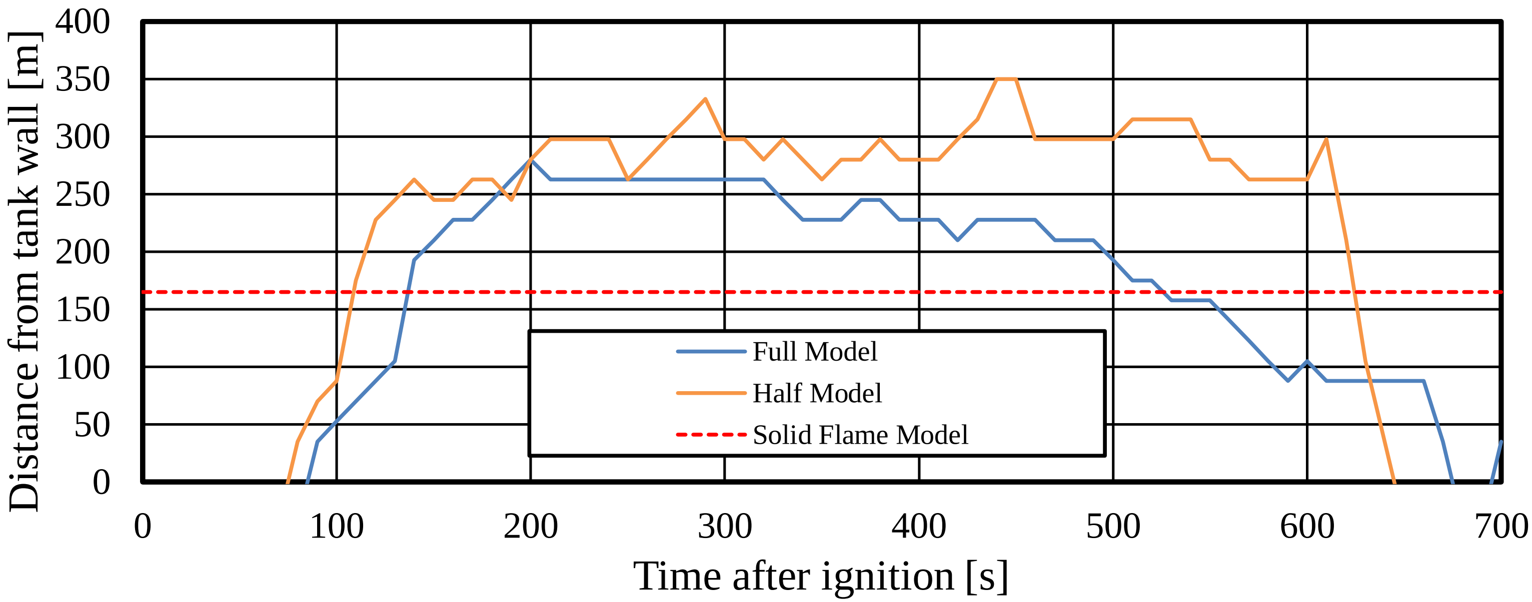


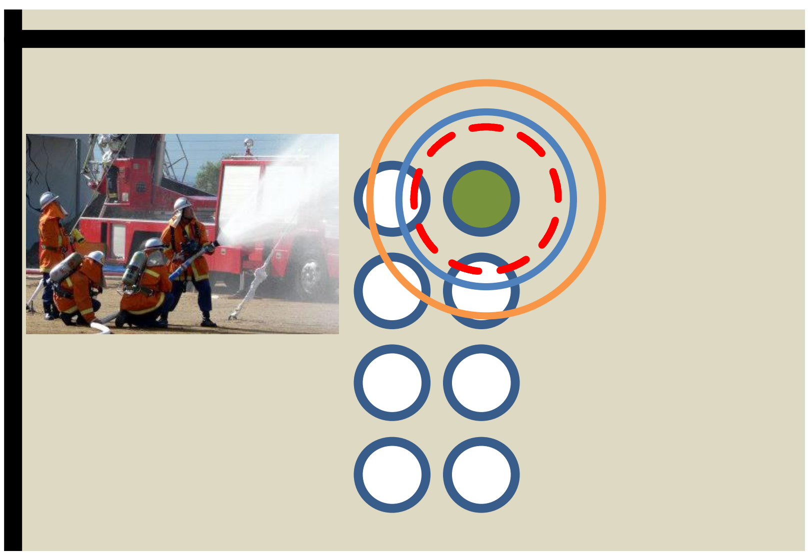
【Analysis conditions】

Content： Crude oil (Combustion heat: 45000kJ/kg)
Wind velocity：0m/s
Temperature： 20℃
Number of mesh： Domain 1：80×80×96 (1.75m-cubic mesh)
Domain 2：90×40×48 (3.5m-cubic mesh)

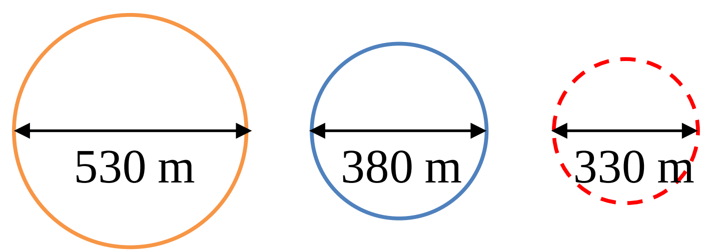
Distance from tank wall to the critical heat radiated point

Distance from tank wall to critical heat radiation point (2.3kW/m^2)





Area of the average value of the distance of critical heat radiation point



Summary

- FDS analysis of pool fire in large scale flat bottom tank showed good agreement with experiment.
- The tank diameter and the oil level had effects on flame behaviors which include flame shape and heat radiation.
- The air entrainment from the tank rim into the flame bottom is considered to have principle effect to behavior of flame and soot formation.

Future Work

In the case of TSUNAMI disaster, fire on sea surface is very important, and we are trying investigation of the burning mechanism on the sea surface.

Thank you for your kind attention