Experimental study on bubble curtain for blocking and eliminating drifting oil in port area

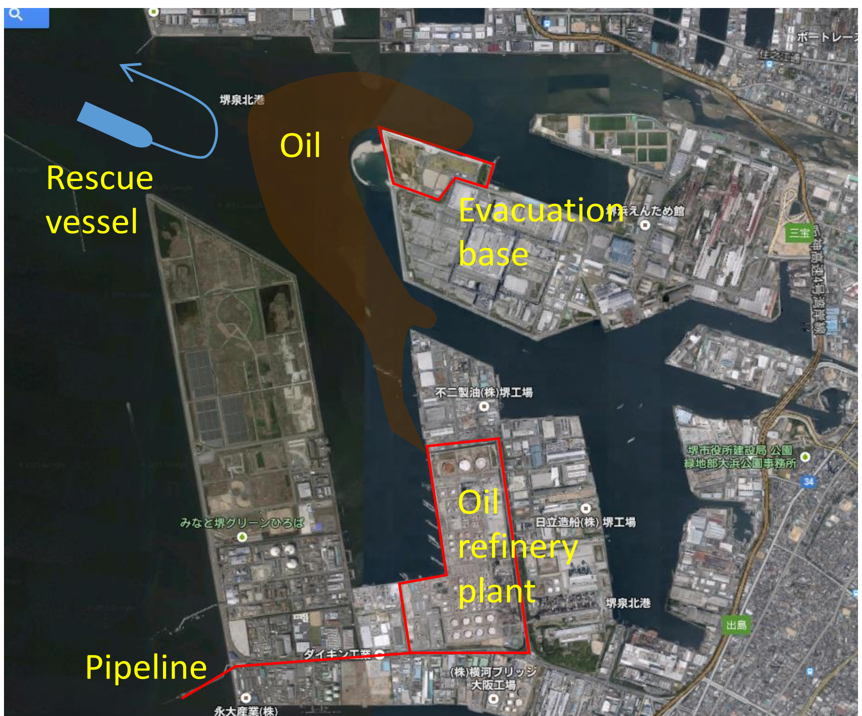
Isamu Fujita

[1]National Research and Development Agency

Port and Airport Research Institute, Japan

Research background

- In Japan, port areas are highly concentrated with industrial facilities. In some cases, oil refinery plants and a disaster evacuation base locate near to each other.
- Once an oil spill incident is triggered by a natural disaster such as earthquake or tsunami, the spilt oil from the plant may cover the sea surface around the evacuation base and impede rescue vessel access to the evacuation base.
- Oil skimming mission by OSR vessels is hardly expected just after the disaster in chaotic situation, so the evacuation base should have some autonomous measure to prevent the oil from accessing to the base, or to eliminate the oil from the quay and navigation channel by itself for enabling the rescue vessel's immediate access



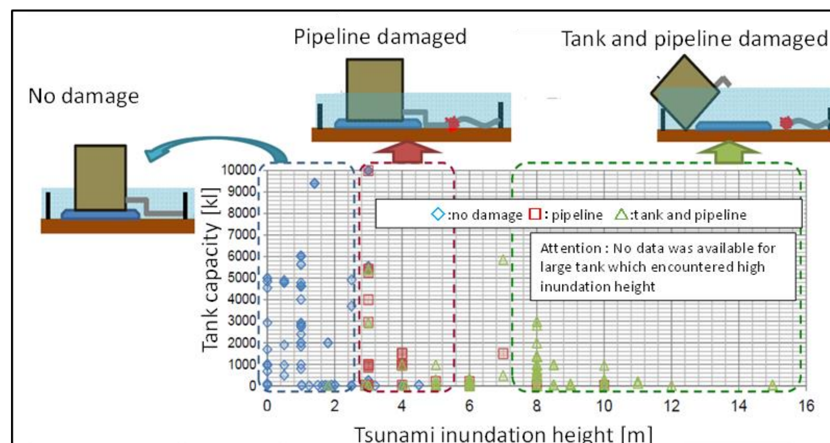
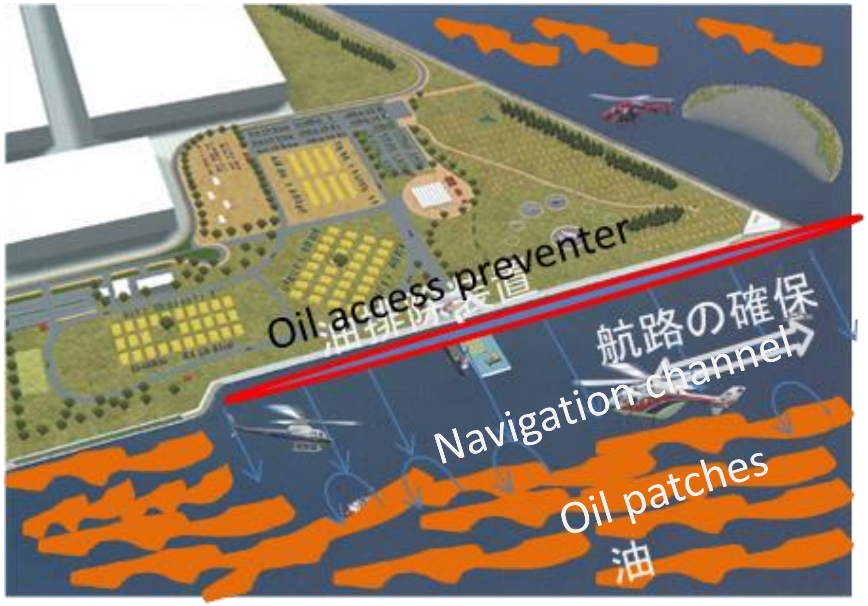
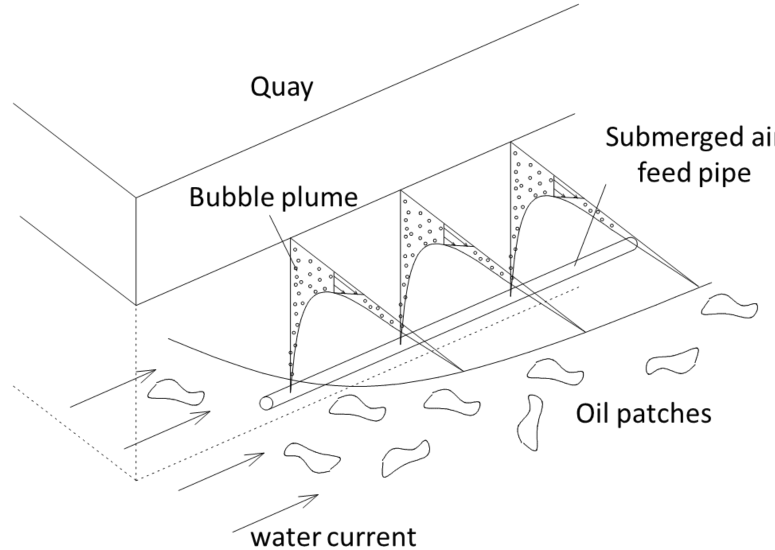
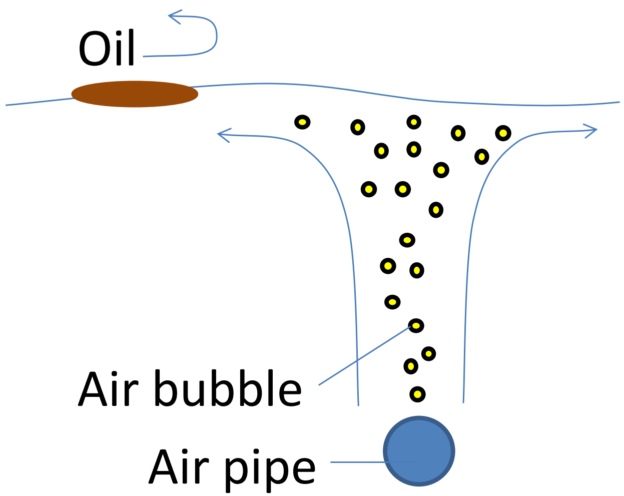


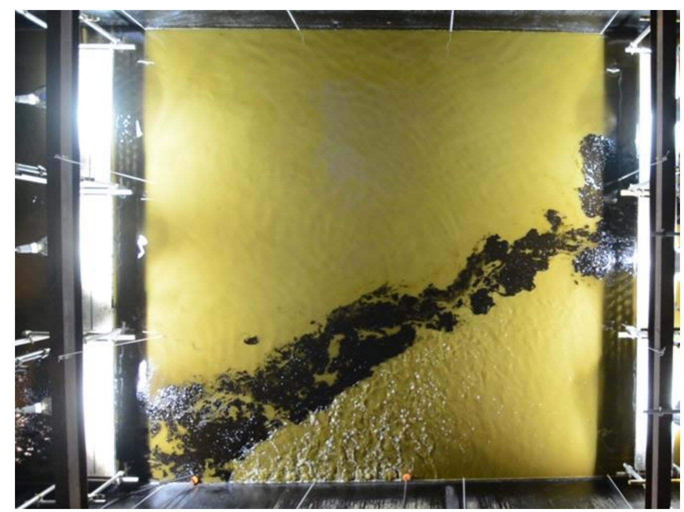
Figure derived from FDMA (Fire Disaster Management Agency)

Concept of autonomous oil access prevention





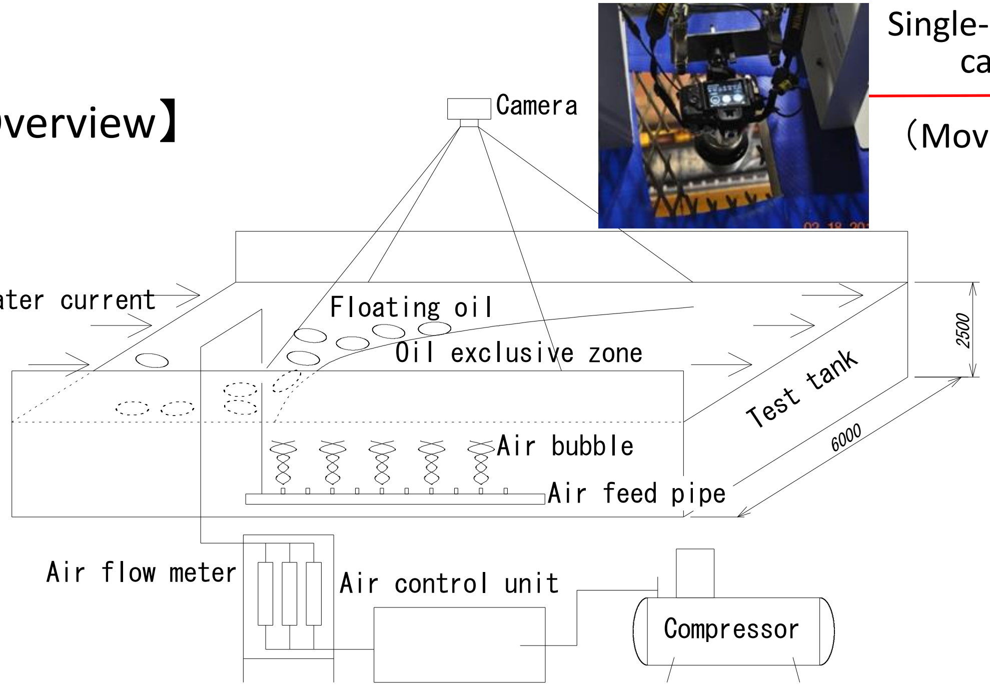




In this study we focused on the bubble curtain with a vertical wall in the near field intended for application to an autonomous equipment for blocking or eliminating drifting oil patches from the quay.

Experimental setup and procedure

【Overview】



Single-lens reflex camera

（Movie mode）

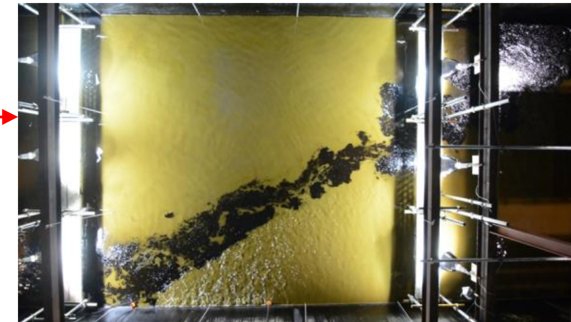
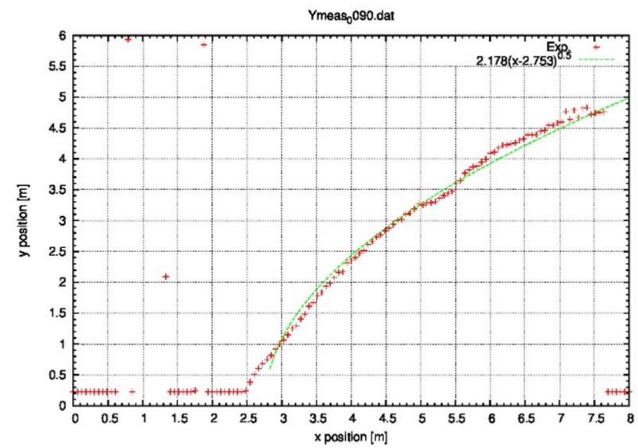
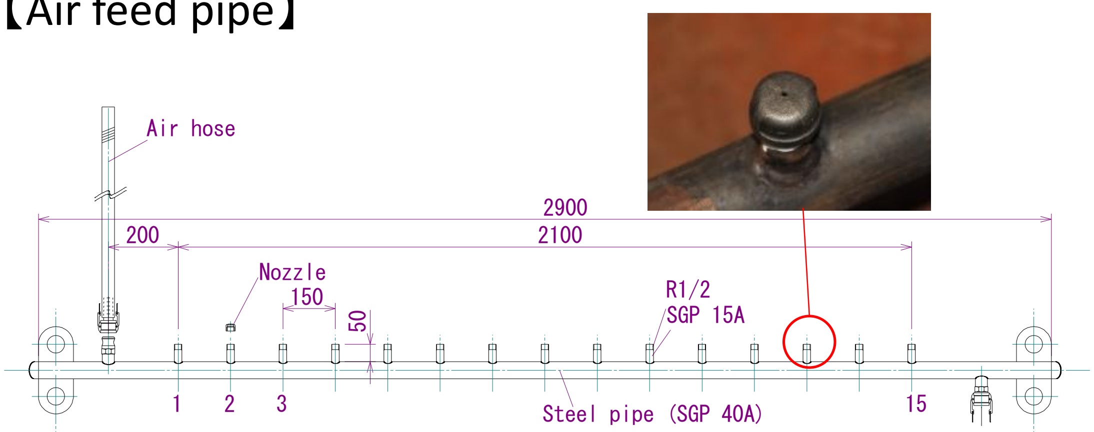


Image processing
(OpenCV)



Test tank : 6m（Width）x2.5m（Depth）× 20m（Length）

【Air feed pipe】

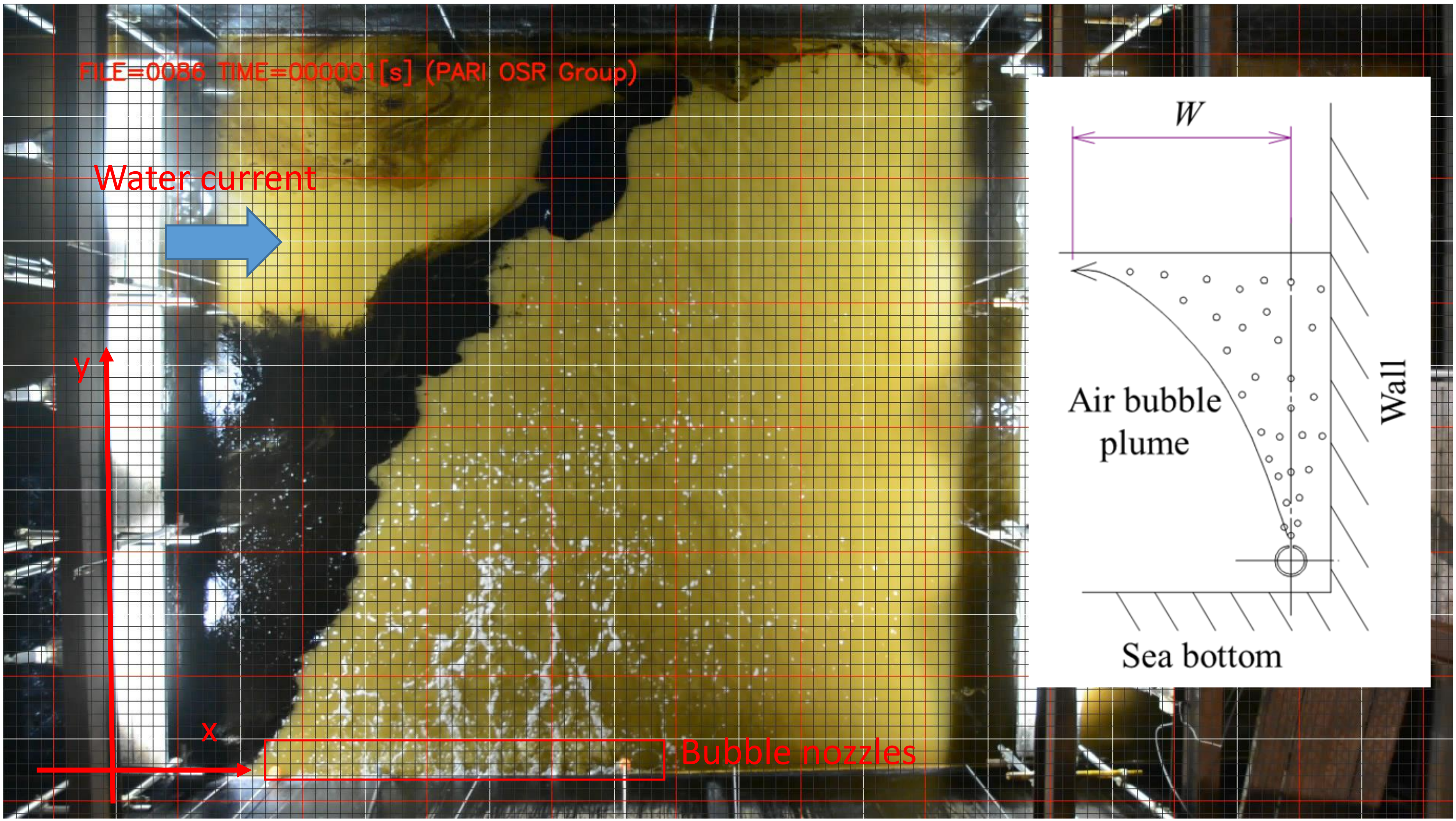


Pipe: SGP 40A, 2900mm（Length）

Nozzle : Φ2mm x 15, 150mm(pitch)

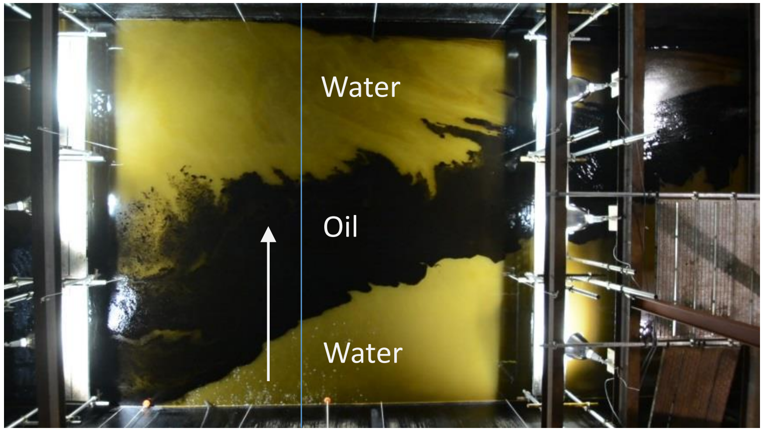
Test example

- ✓ Air pipe depth : 2.35m
- ✓ Air feed rate : 165 l/min
- ✓ Water current: 7cm/s
- ✓ Test oil : C-heavy oil

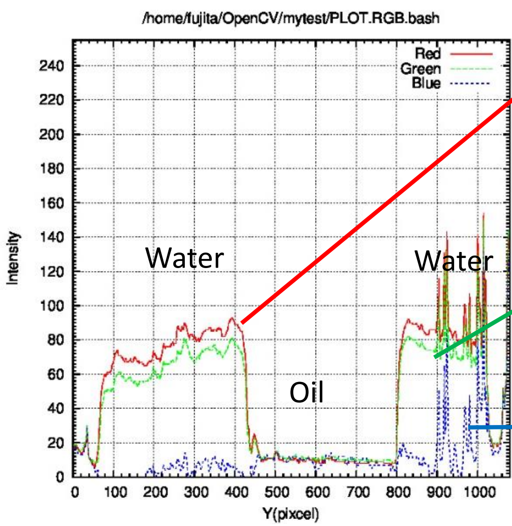


Post process (Image processing using OpenCV)

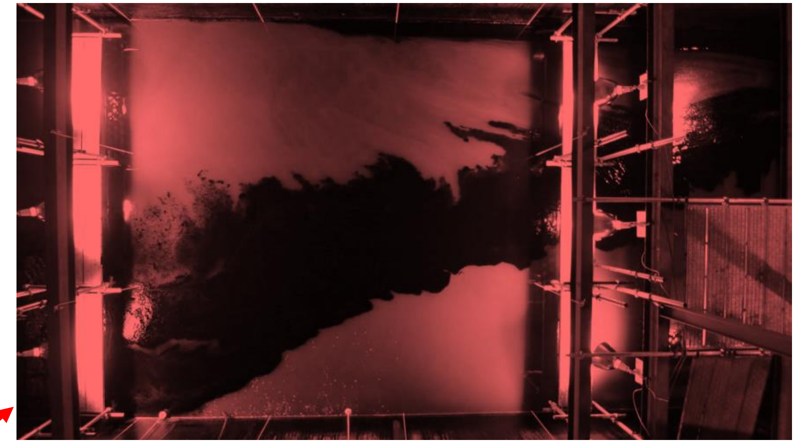
STEP1: RGB decomposition

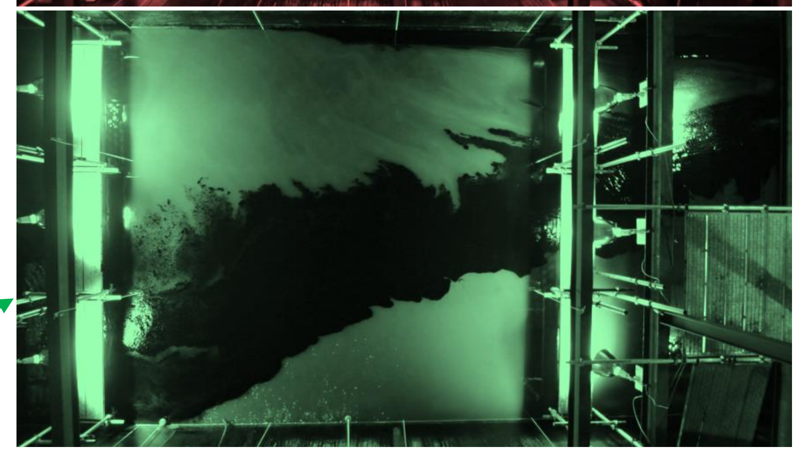


RGB decomposition



Red gives the highest contrast between w/o





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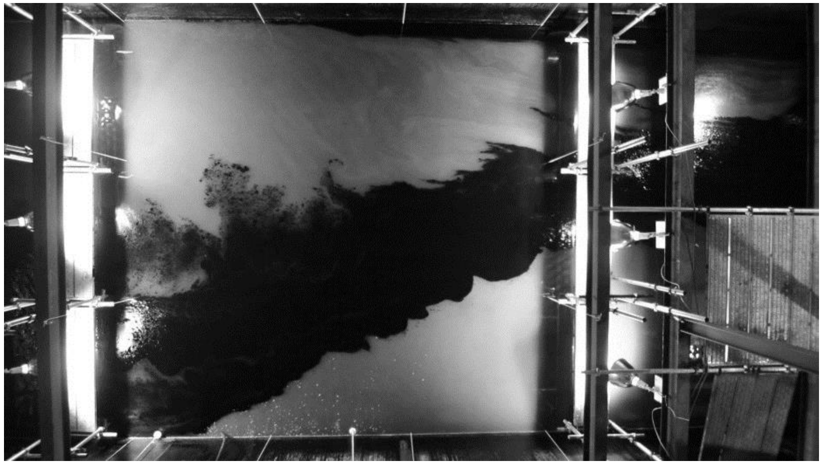
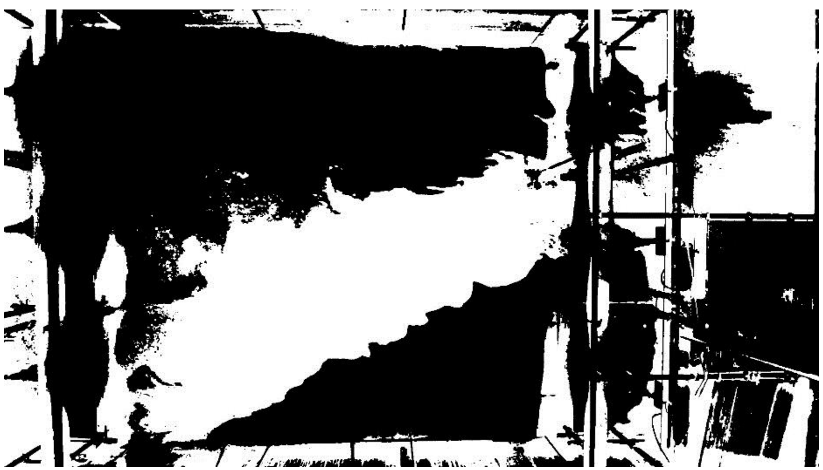
Post process (Image processing using OpenCV)

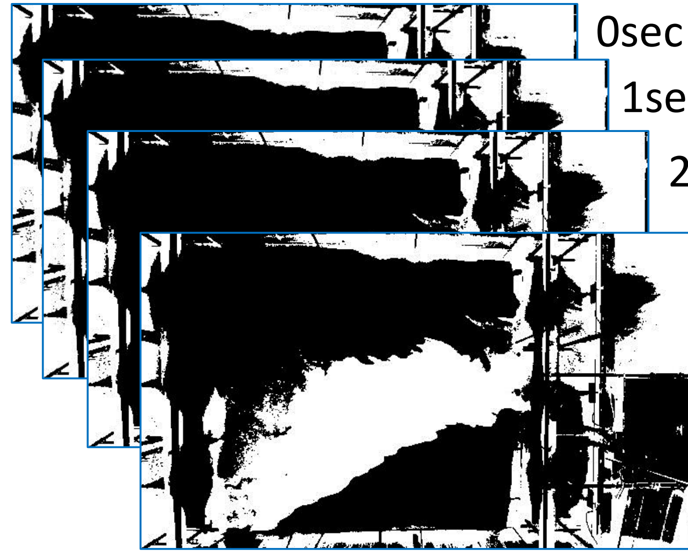
STEP2: Luminance inversion and binarization



$$I_n = 255 - I_n < \mathit{Threshold}\ ?\ 0 : 255$$



STEP3: Time averaging



0sec

1sec

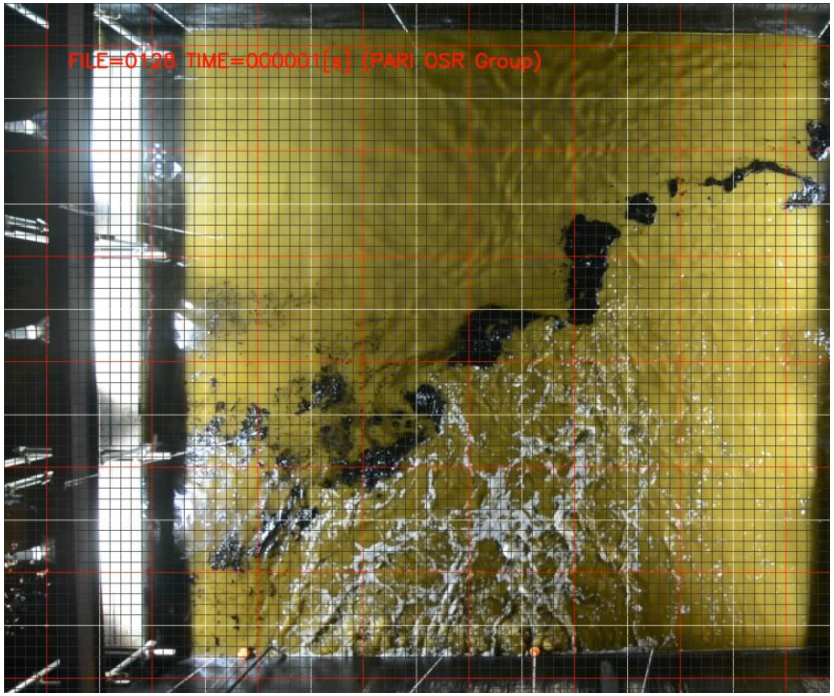
2sec

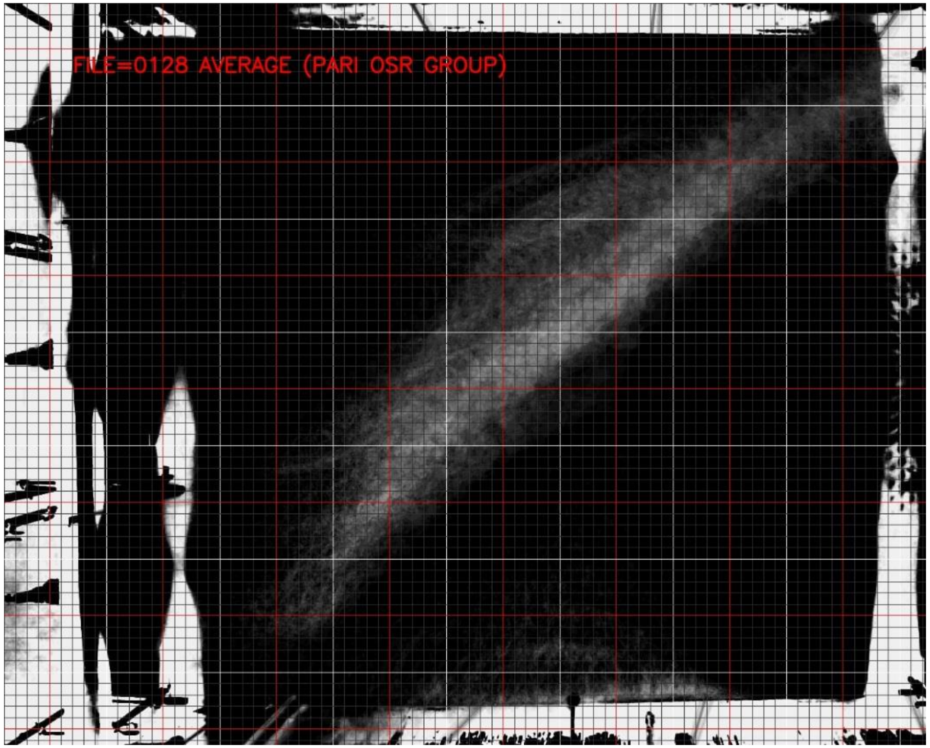
N-1sec

$$I = \sum_n I_n / N$$

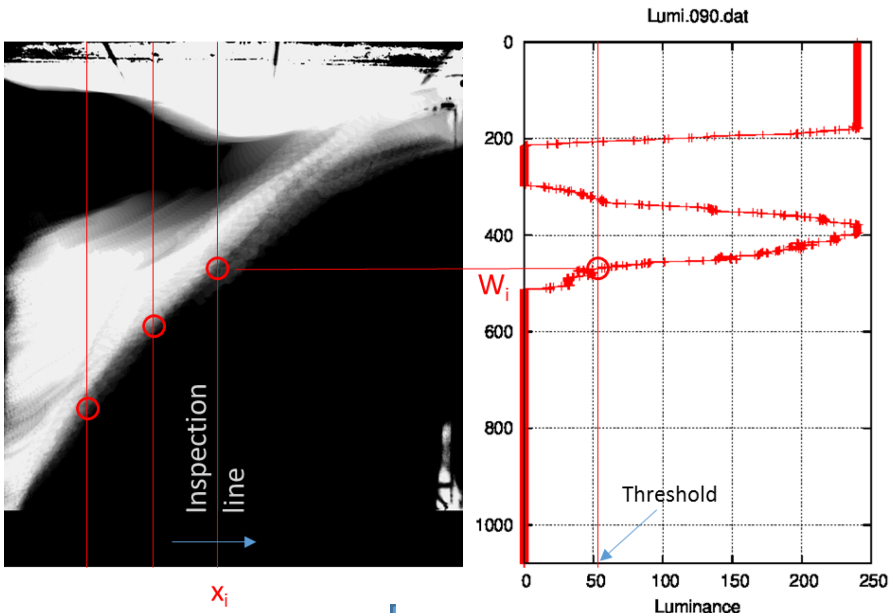
Superimpose with weight

Post process (Image processing using OpenCV)

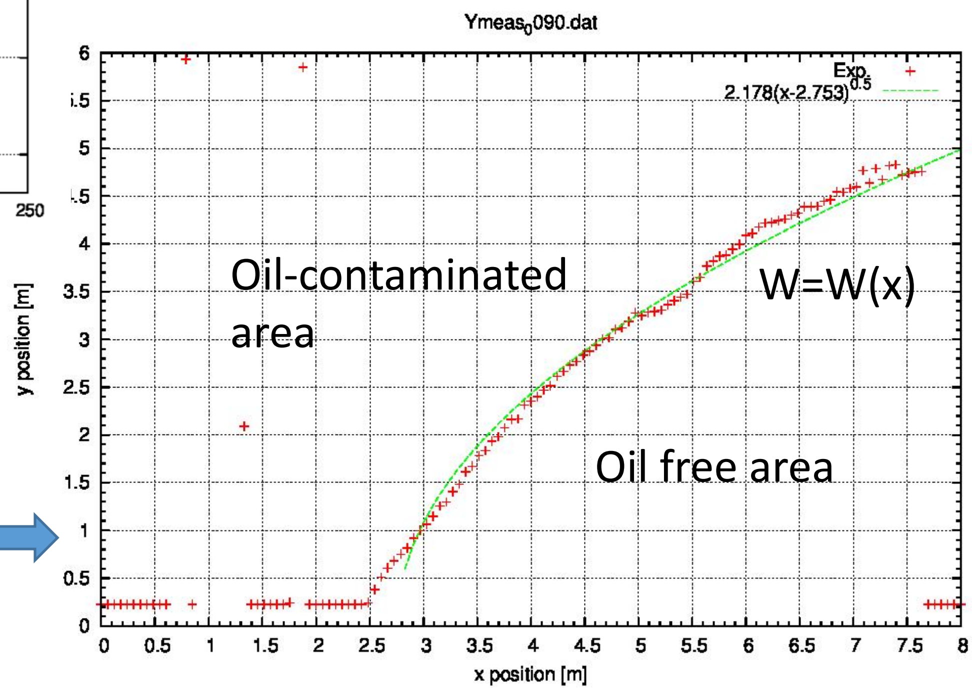




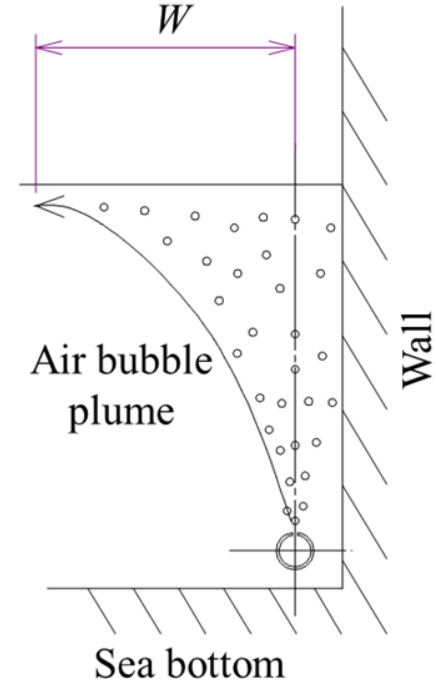
STEP4: Edge detection and line fitting



(x_i, W_i) i=0～N



Experimental Condition and Data Analysis



Experimental conditions

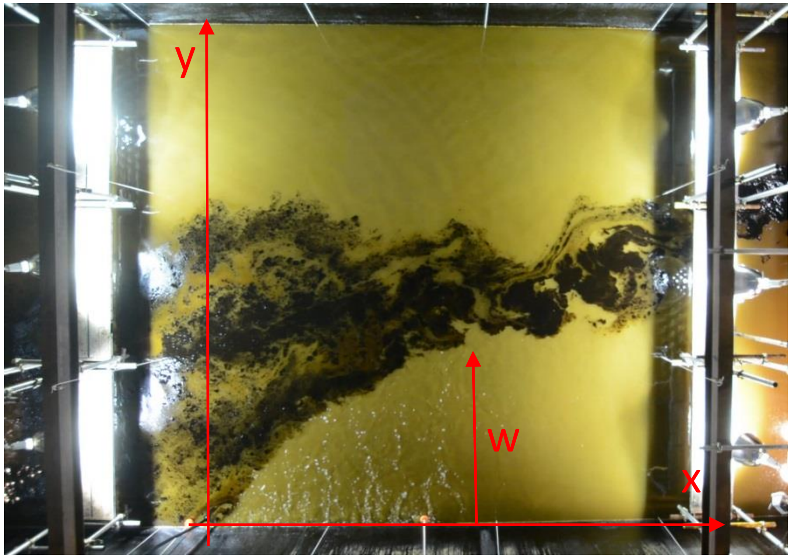
- Nozzle diameter：Φ2mm
- Nozzle number：15
- Nozzle pitch：150mm
- Nozzle arrangement : along the wall and parallel to water current
- Nozzle depth：0.85-2.35m（4patterns）
- Water velocity：0.07-0.35m/s
- Air feed rate：0-1700L/min (0-113 L/min/nozzle)

Purpose: Oil elimination width(W)

How the W depends on parameters?

W=W（x，D，U，Q）?

- x：x location
- D：Nozzle depth
- U：Water velocity
- Q：Air feed rate



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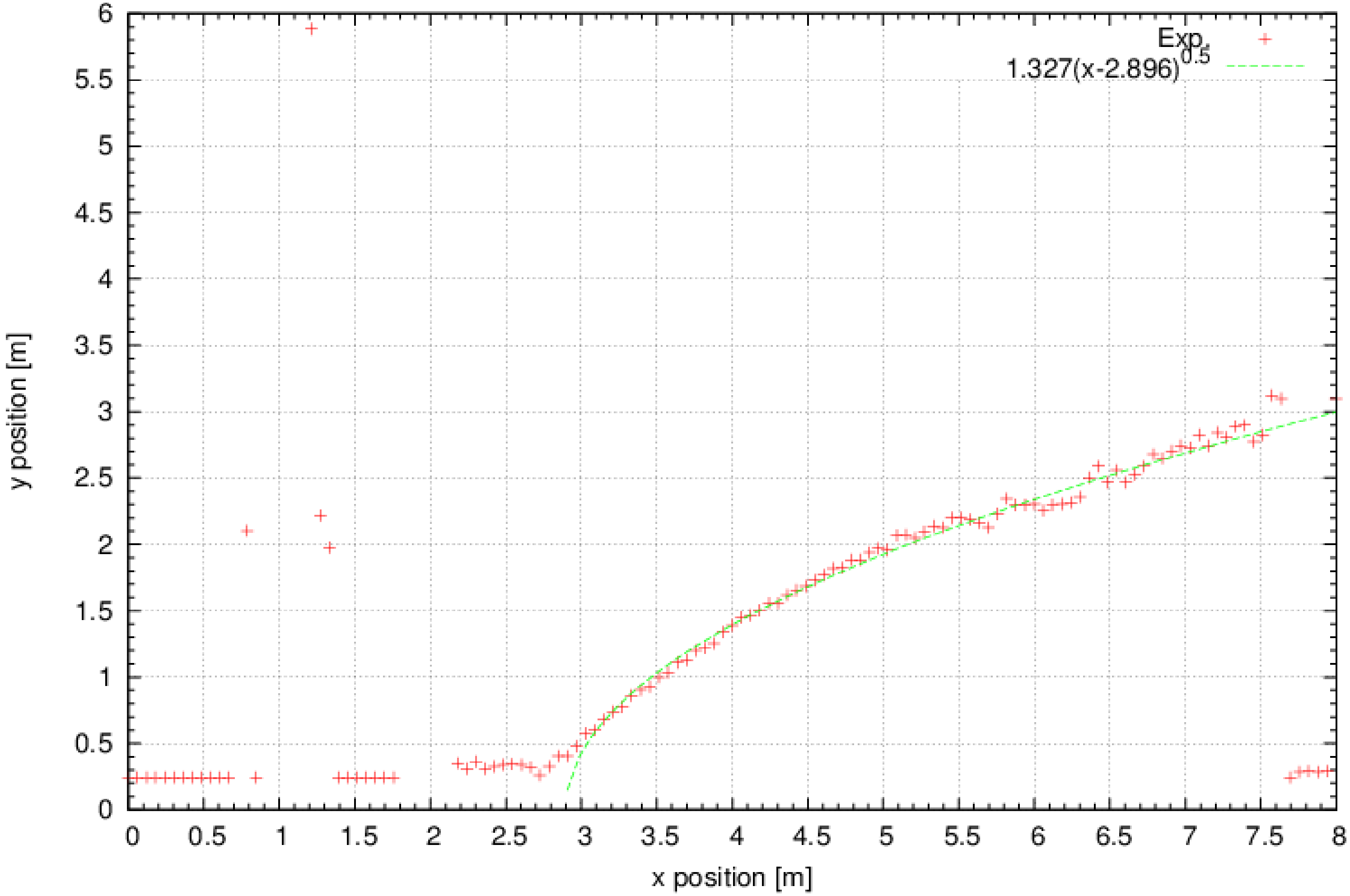
Oil elimination by Bubble curtain

Relation between W and x



$$W = c\sqrt{(x - x_0)}$$ gives good approximation

Oil elimination width (W) dependency on parameters

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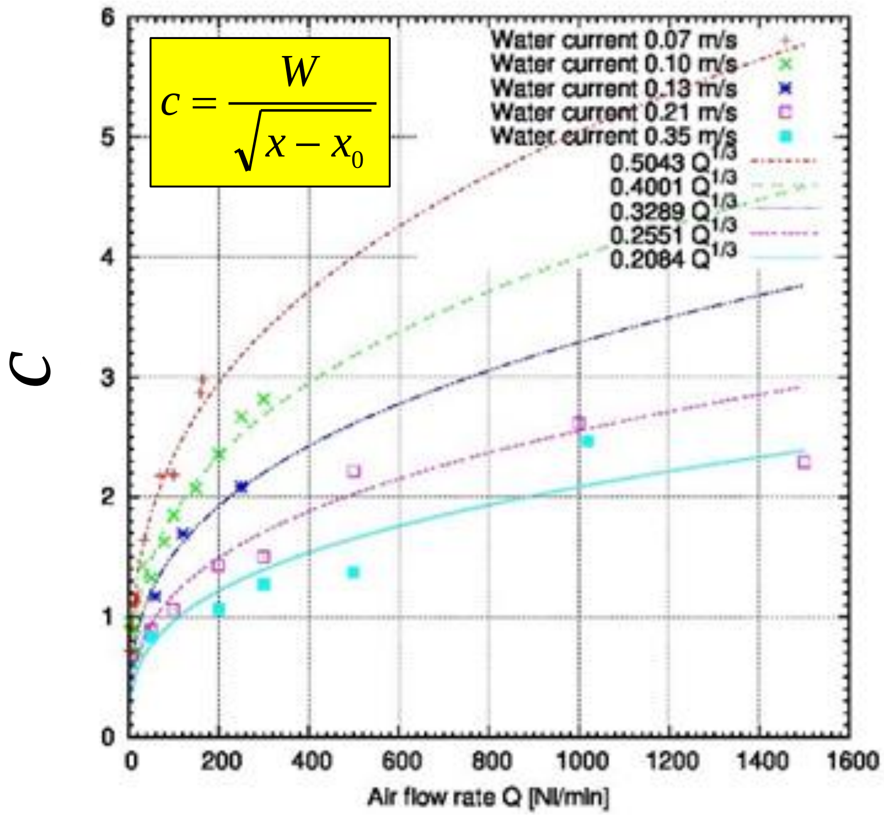
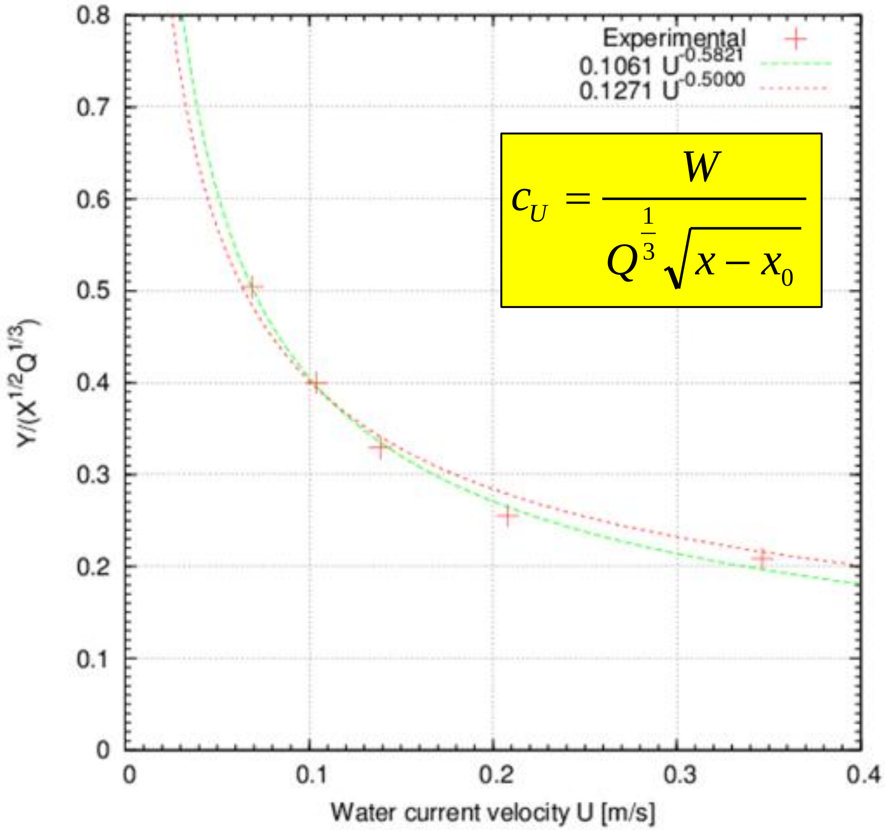
1)Air feed rate effect



$W \propto Q^{1/3}$

2)Water current velocity effect

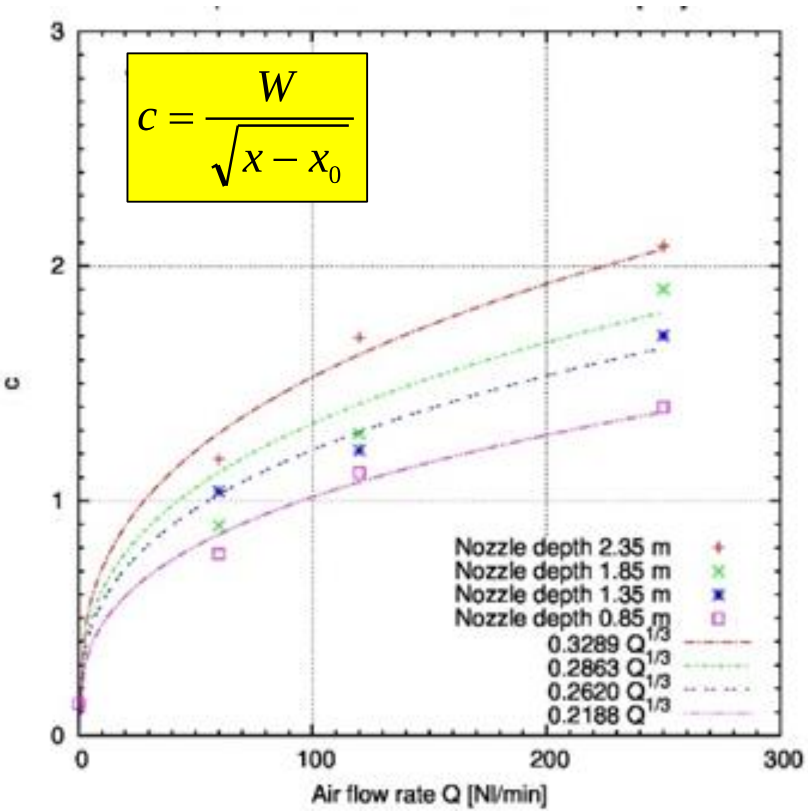


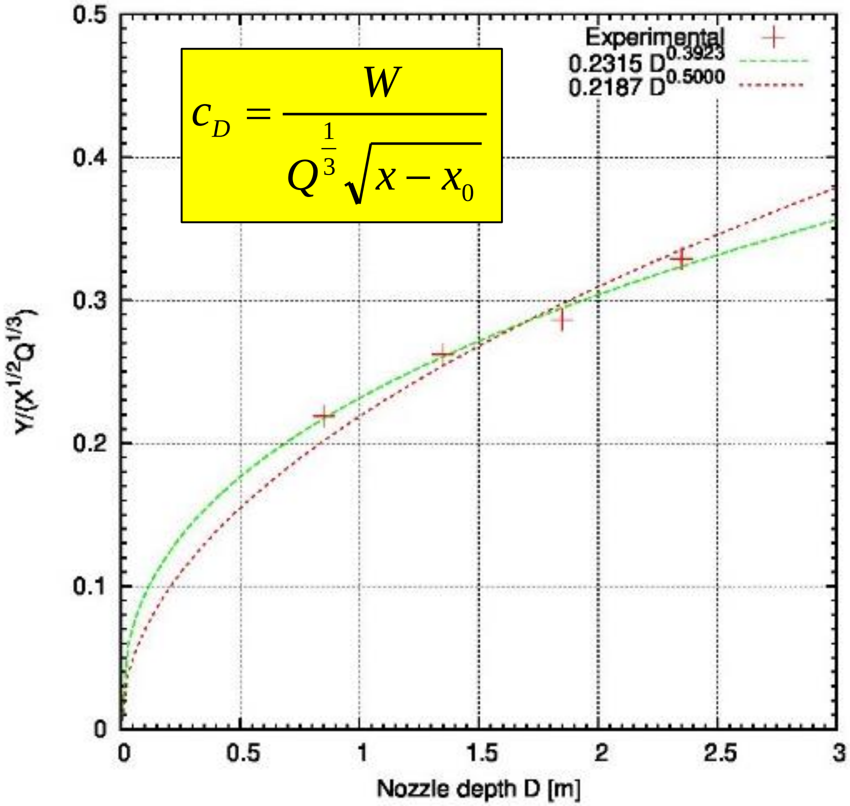
$W \propto U^{-1/2}$

Bulson : Surface current velocity induced by the bubble curtain is in proportion to the cube root of the air feed rate.

Oil elimination width (W) dependency on parameters

3)Nozzle depth

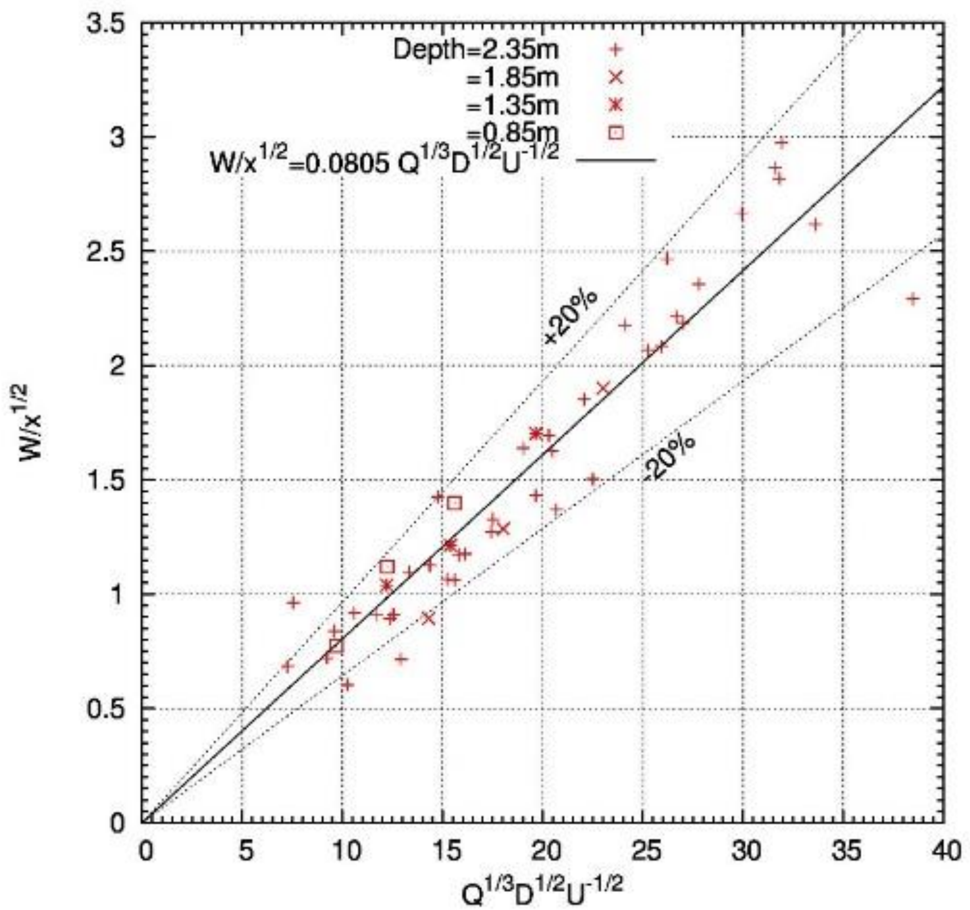




$W \propto D^{1/2}$

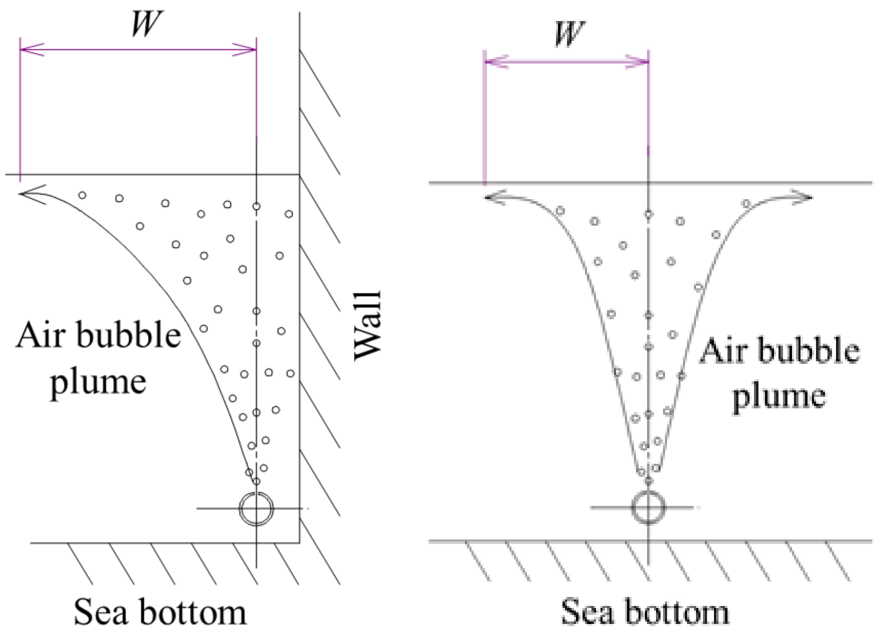
Oil elimination width (W) dependency on parameters

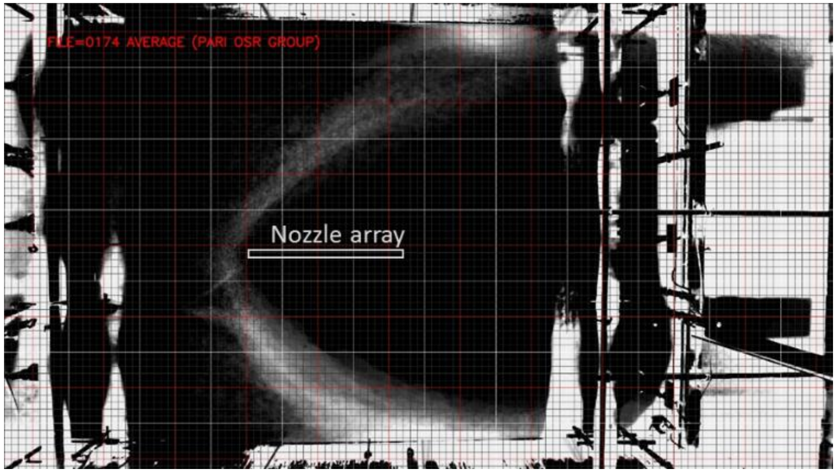
Proposed model (overall): $$\frac{W}{x^{1/2}} = cQ^{\frac{1}{3}}\sqrt{\frac{D}{U}}$$

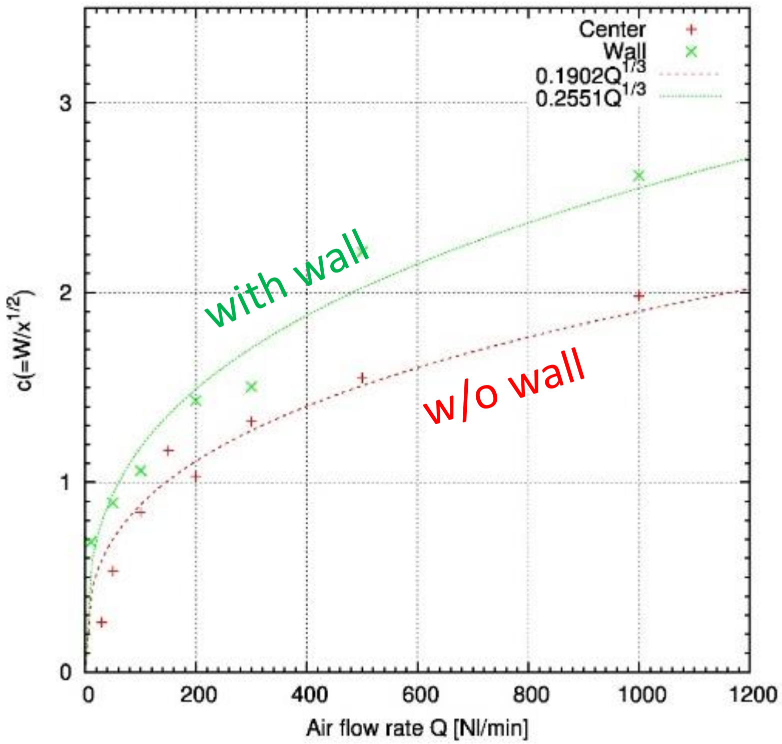


→Good agreement is observed between the experiment and the proposed model

Wall effect







One-sided elimination width

Air feed pipe arrangement and their barrier effect in the current

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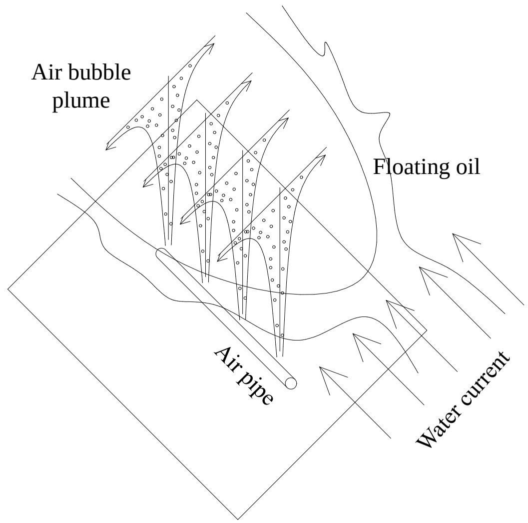
CASE1)Parallel arrangement



Proposed model:

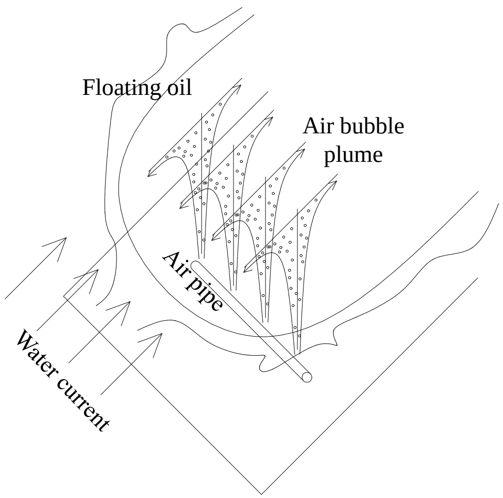
$$\frac{W}{x^{1/2}} = cQ^{\frac{1}{3}}\sqrt{\frac{D}{U}}$$

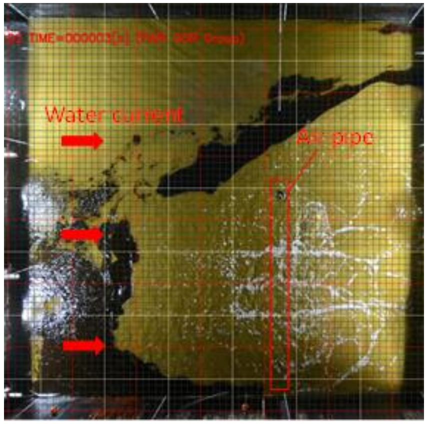
To keep the oil blocking width constant, Air flow rate required

$$Q \propto U^{3/2} \quad \cdots\cdots (1)$$

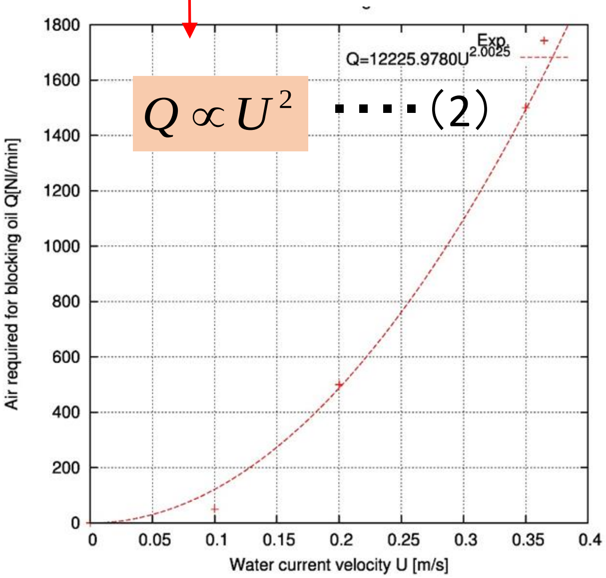
Parallel arrangement has a smaller power index on the U.
Parallel arrangement may better for blocking oil…

CASE2)Perpendicular arrangement





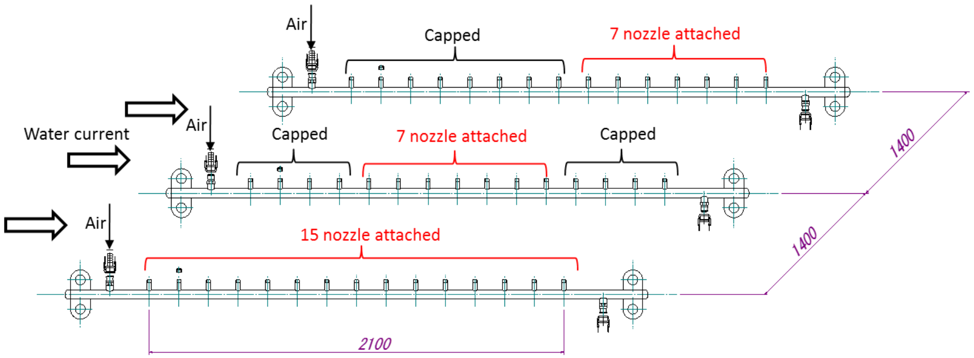
$$Q \propto U^{2} \quad \cdots\cdots (2)$$

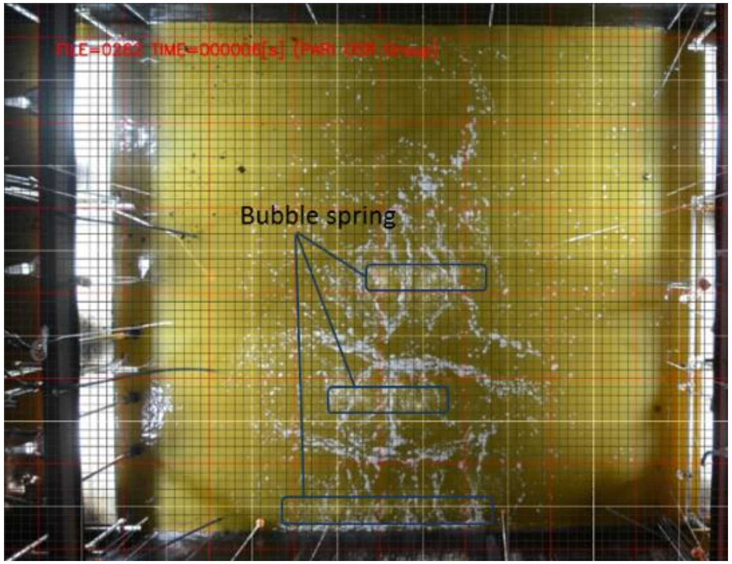


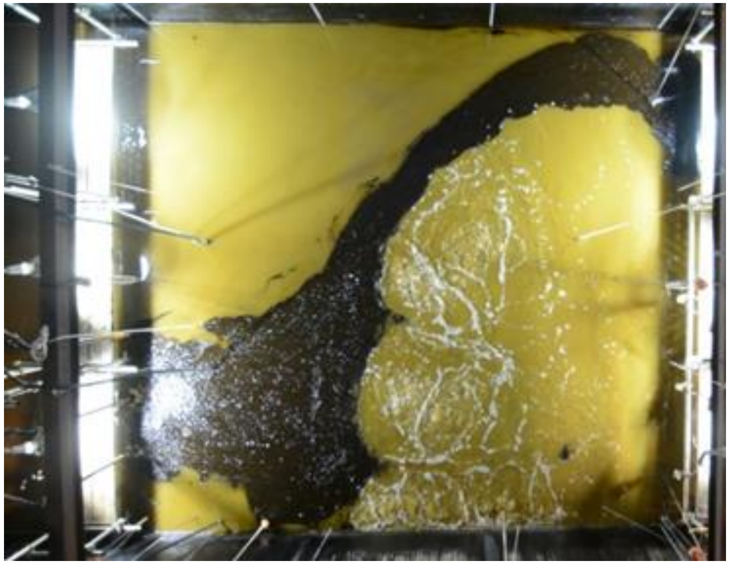
Air flow rate required for blocking oil（visual obs.）

Multiple line test

Oil blocking test using multiple air feed pipes

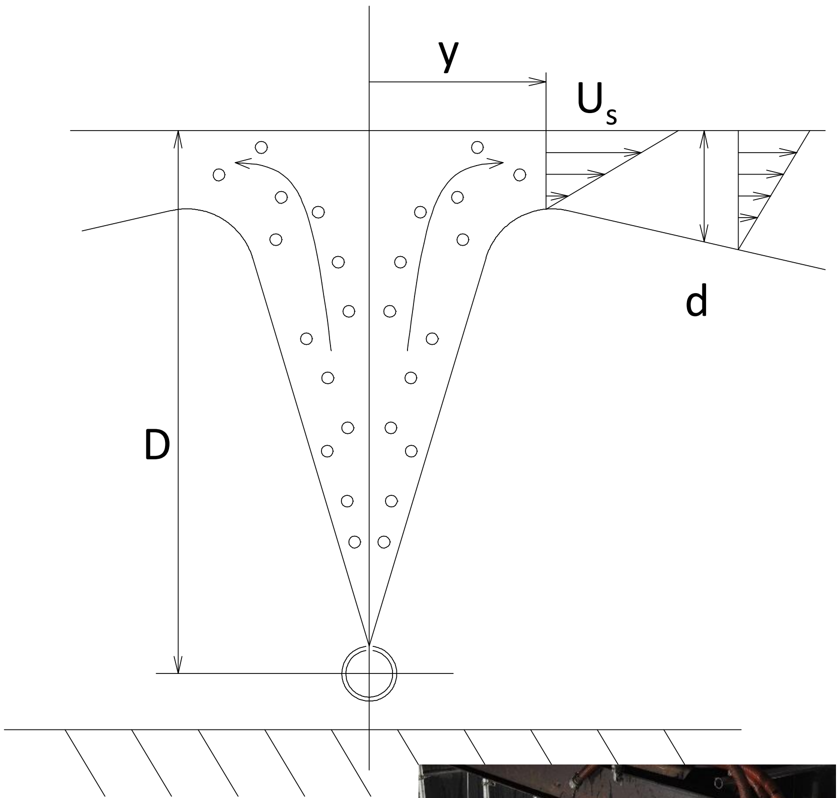


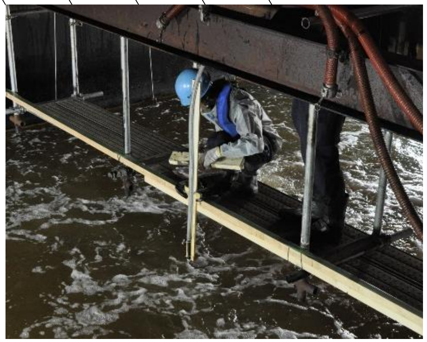


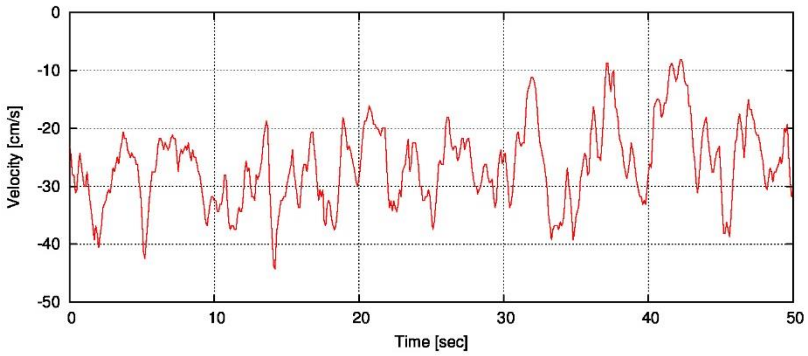


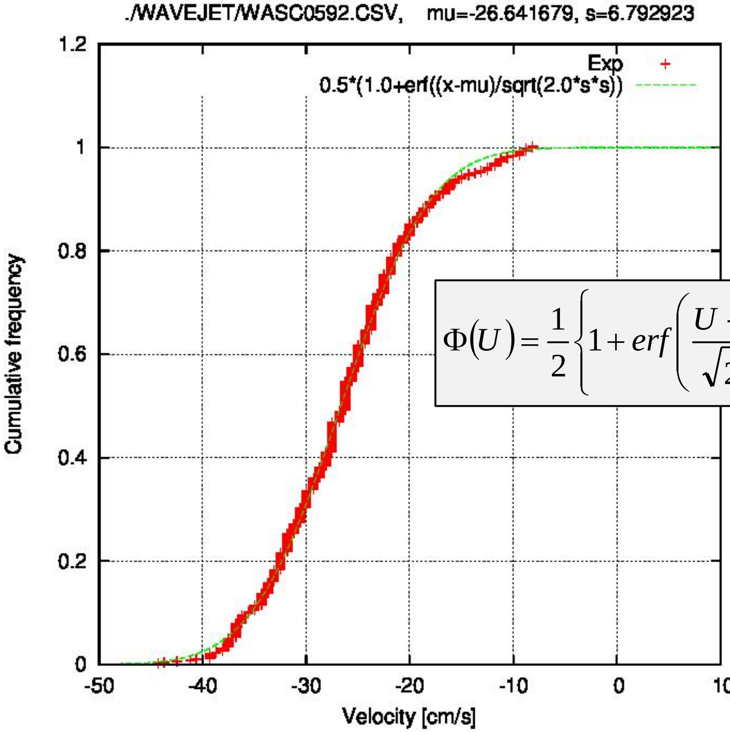
Multiple pipes can extend the elimination width.

Surface current measurement and discussion









$$\Phi(U) = \frac{1}{2}\left\{1 + erf\left(\frac{U - U_s}{\sqrt{2\sigma^2}}\right)\right\}$$

Horizontal velocity was measured using an electromagnetic current meter

Surface current measurement and discussion

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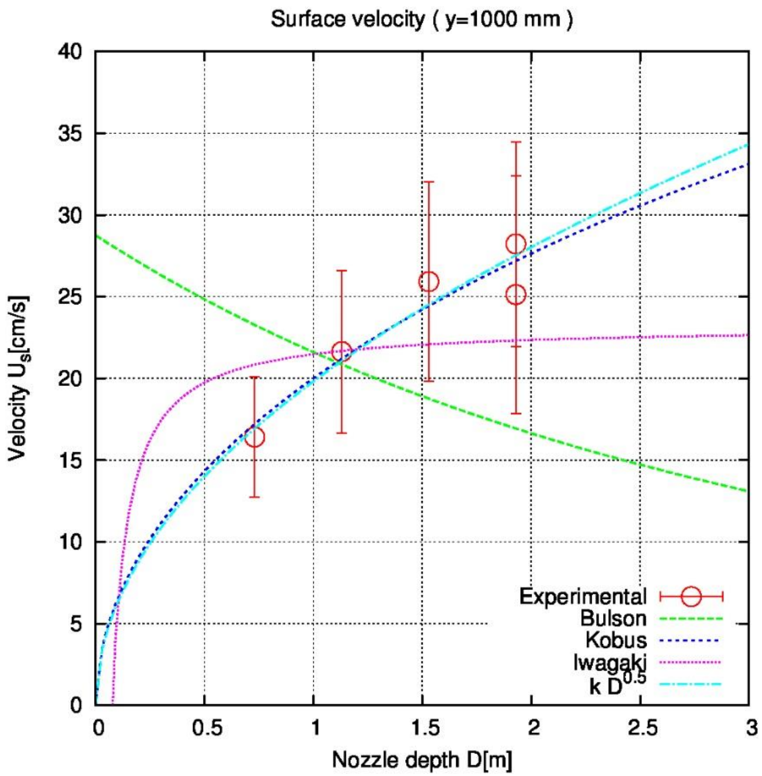
Experimental result



Previous studies

Bulson(1968): $U_s \propto Q^{\frac{1}{3}} \left(\frac{P_0}{P_0 + D} \right)^{\frac{1}{3}}$

Kobus(1972): $U_s \propto Q^{\frac{1}{3}} \left\{ \frac{P_0}{D + z_0} \ln\left(1 + \frac{D}{P_0} \right) \right\}^{\frac{1}{2}}$

Iwagaki(1983): $U_s \propto Q^{\frac{1}{3}} \left(1 - \frac{0.075}{D} \right)$

U_s: surface velocity
P_0: atmospheric pres. in meter
D: nozzle depth
Q: Air feed rate

Requirement

1) $U_s \to k\sqrt{D} \quad (D \to 0)$ Our observation

2) $U_s \to const.$ or $0 \quad (D \to \infty)$

-Bubbles reach the terminal velocity → const.
-Momentum disperses before reaching surface → 0

Kobus model is good, since his mode has asymptotic form:

$$U_s \propto Q^{\frac{1}{3}} \sqrt{\frac{D}{z_0}} \quad (D \to 0)$$

which satisfies our observation

Concluding remarks

- In this study, we conducted experimental study on bubble curtain for blocking or eliminating drifting oil near a quay wall.
- We found that the bubble curation is good option for this purpose.
- We proposed a quantitative equation which gives the oil exclusive zone which the bubble curtain generates.
- We compared bubble curtain arrangement. The parallel configuration may better than the perpendicular configuration.
- Multiple pipes can widen the oil free area.
- As for the horizontal velocity by bubble curtain, Kobus model (1972) gives good representation in shallow water.