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Recovery of Heavy Fuel Oil from Sunken Ships by High Frequency Induction Heating Method

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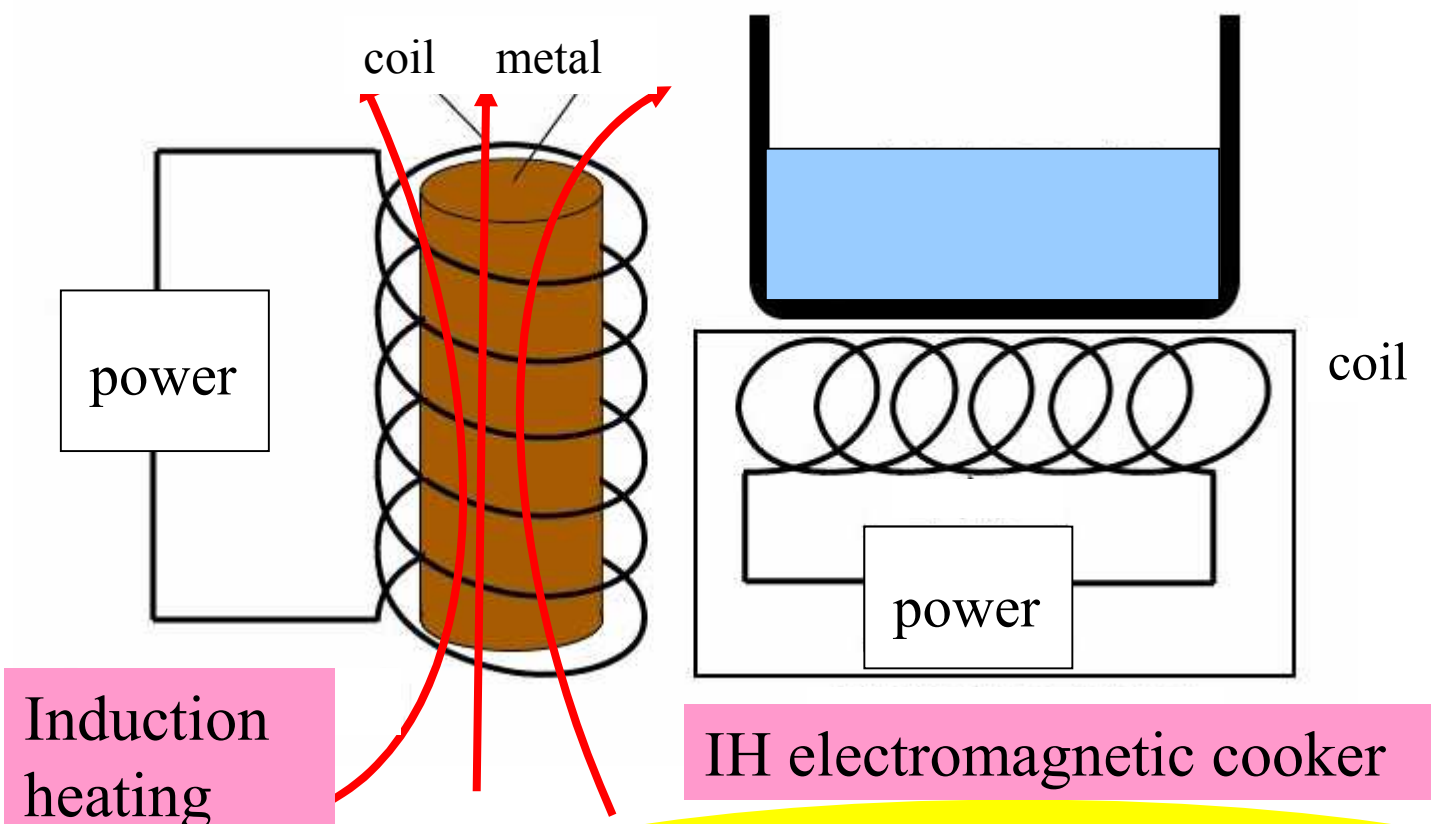
Necessity of recovering oil remained in the ship tank

- When the ship sinks loaded with the cargo oil or fuel oil due to marine disaster, the oil recovery is required because of the risk reduction of oil discharge and marine environment protection,
- The operation of the oil recovery from sunken vessels is extremely difficult in winter or in deep water, because the fluidity of oil in the tank is quite low.

Principle of technique
(High Frequency Induction Heating Method)



Induction heating principle

IH electromagnetic cooker

alternate current →magnetic flux change→eddy current→Joule heat generation

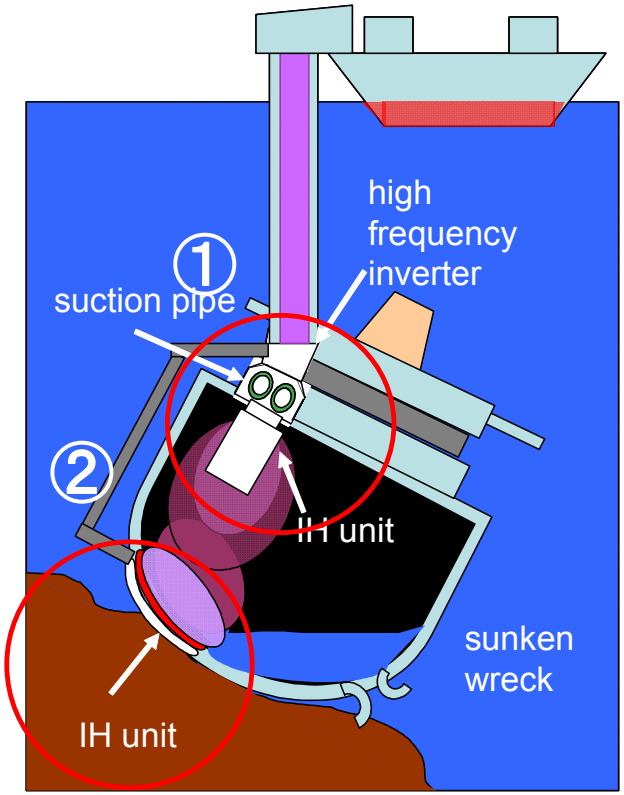
Heavy fuel oil recovery system

Heating system

①Direct heating unit: heating unit inside the hull

②Side hull heating unit: heating of heavy fuel oil outside the hull by heat transfer

Assuming the case of impossibility of direct heating inside the hull, the target is to develop the system for providing the heat from outside of the hull.



Schematic idea

Characteristics of heavy fuel oil recovery system

Advantage

- **The induction heating recovery system needs no large-scale facilities such as boilers.**

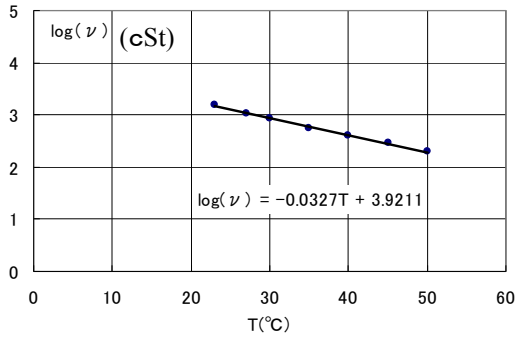
- **The power can sufficiently be supplied from auxiliary generator on the salvaging vessel.**

Outline of experiment

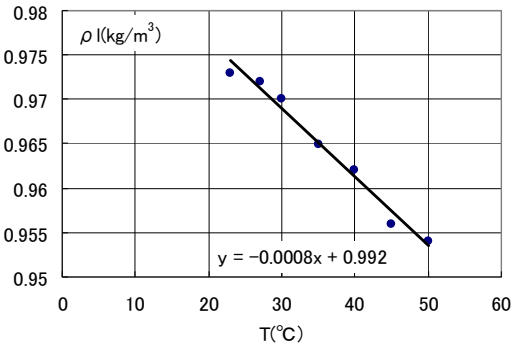
Physical property of heavy fuel oil

tank size:06x0.6x0.6m

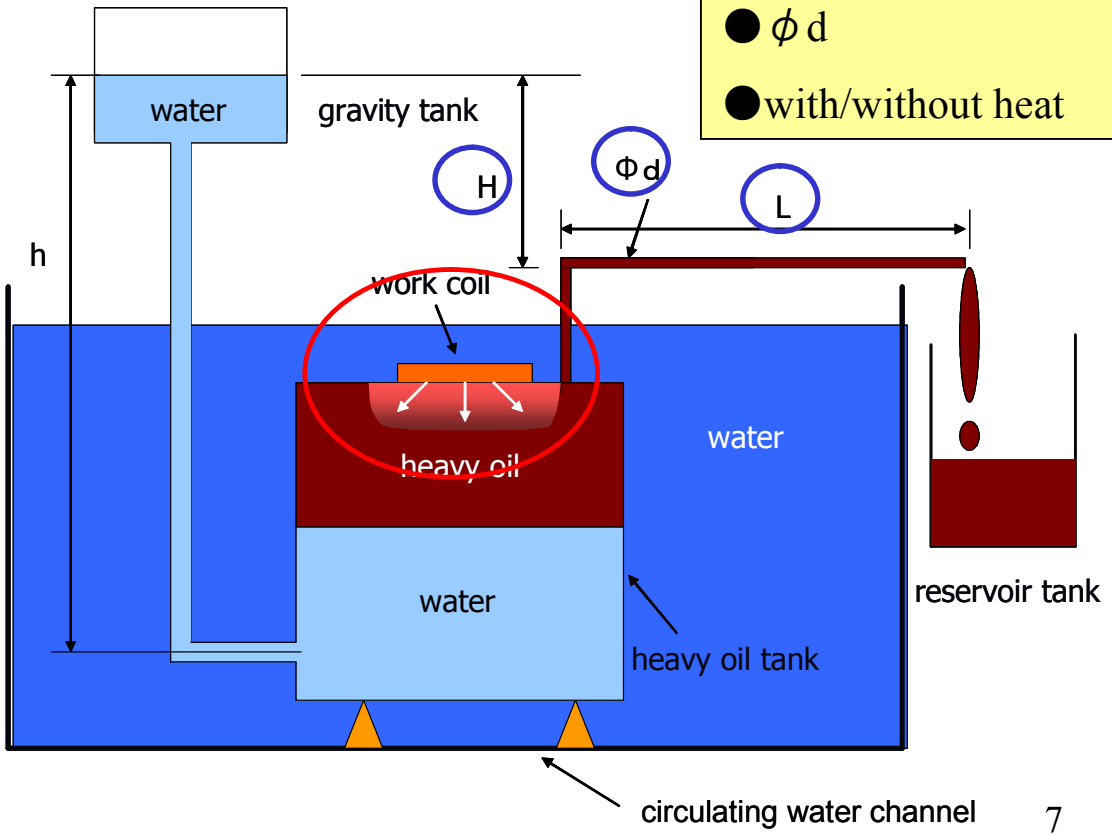
Experimental parameter
- H
- L
- ϕ d
- with/without heat



Logarithmic kinematic viscosity

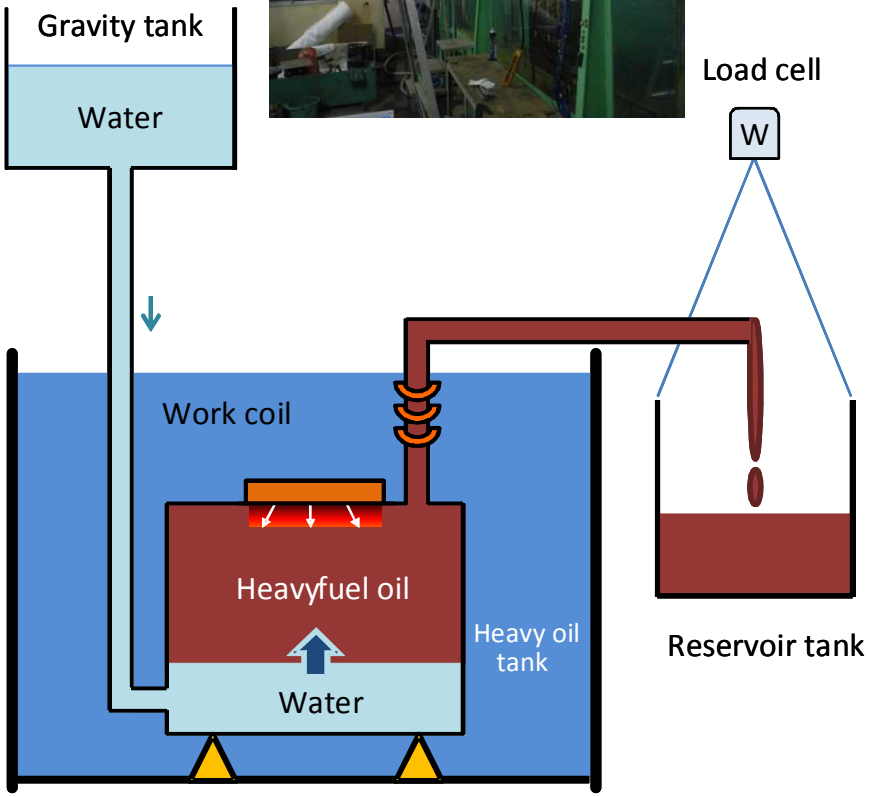


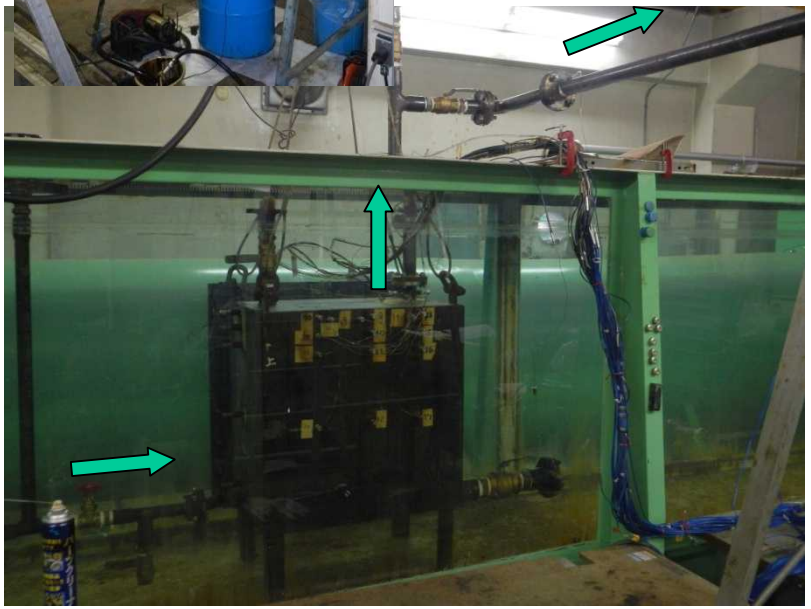
density



schematic idea of the experimental arrangement

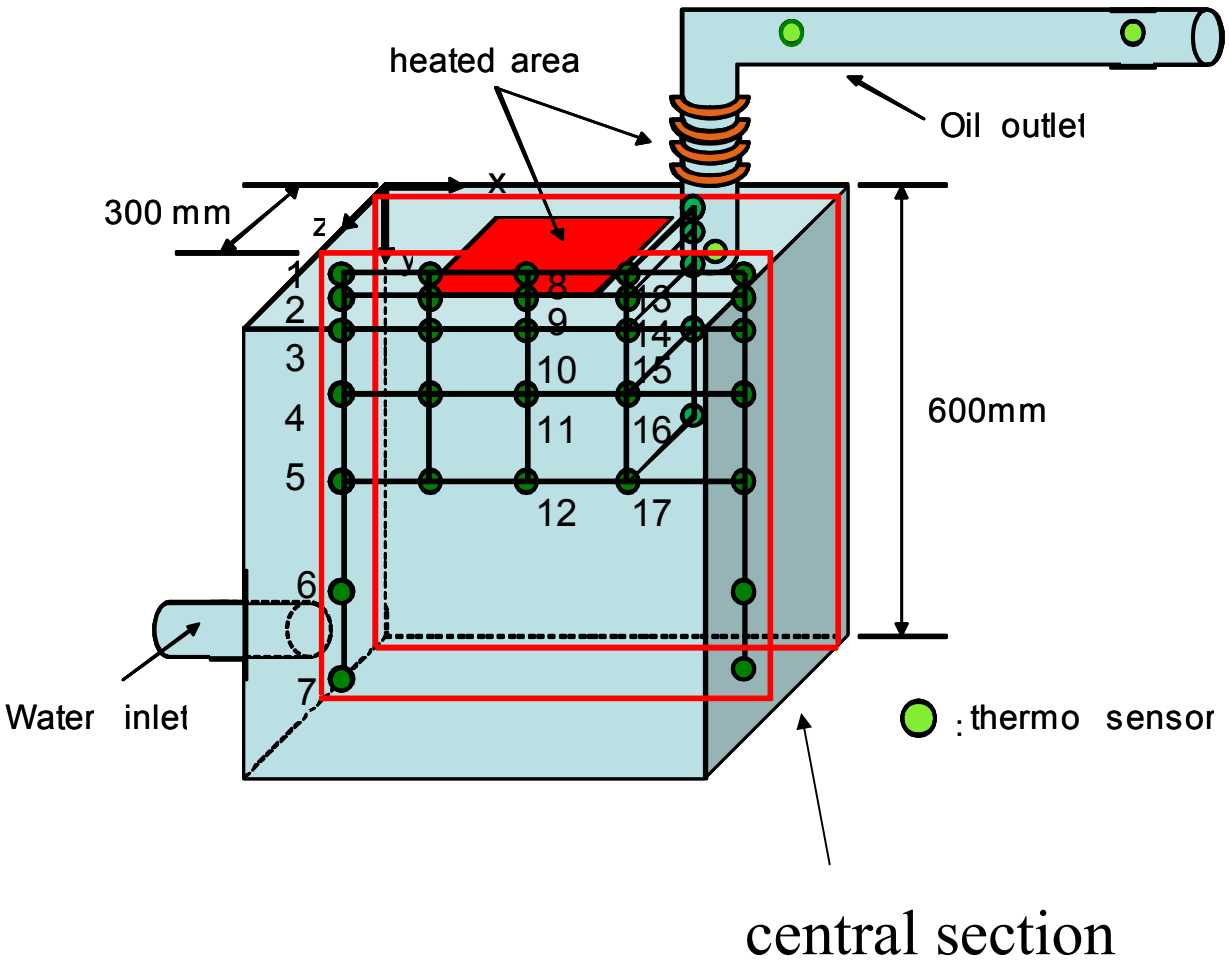
Outline of experiment





schematic idea of the experimental arrangement

Measurement by thermo couples



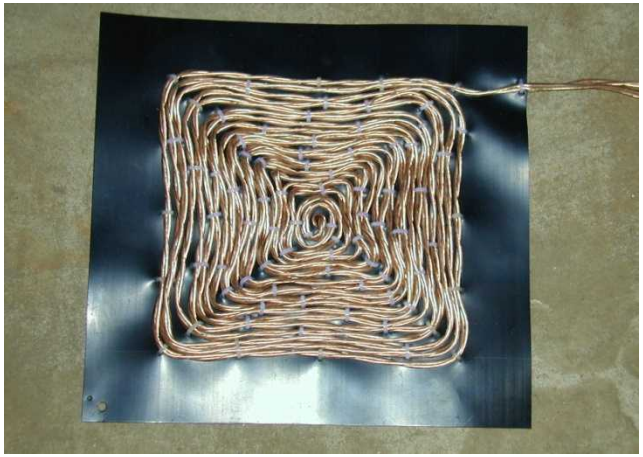
unit:mm

No	x	y	z
1	5	5	300
2	5	10	300
3	5	50	300
4	5	100	300
5	5	300	300
6	5	500	300
7	5	595	300
8	300	5	300
9	300	10	300
10	300	50	300
11	300	100	300
12	300	300	300
13	450	5	300
14	450	10	300
15	450	50	300
16	450	100	300
17	450	300	300
18	595	5	300
19	595	10	300
20	595	50	300
21	595	100	300
22	595	300	300
23	595	500	300
24	595	595	300
25	450	5	5
26	450	10	5
27	450	50	5
28	450	100	5
29	450	300	5
30-37	horizontal pipe		
41-48	heated pipe		

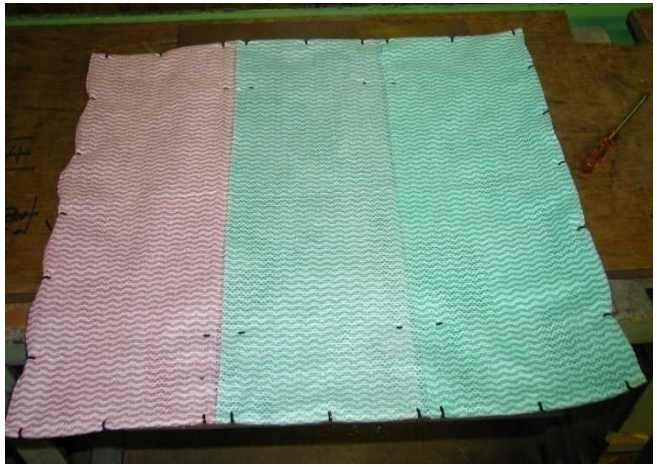
Experimental conditions

Exp.No.	Pipe length L(m)	Pipe diameterd Φ(mm)	Water pressure head h(m)	Heat time (min)	Mat size (m)	Water temperature (℃)	Atmosphere temperature (℃)	Oil temperature (℃)	Electric power before oil recovery (W)	Heating position during oil recovery	Electric power during oil recovery (W)	Recovery rate (kg/s)
1	4	25	4	—	—	28.2	—	—	—	—	—	0.0577
2	4	25	4	—	—	24.8	—	—	—	—	—	0.0539
3	2	25	4	—	—	28.0	—	—	—	—	—	0.1050
4	2	32	4	—	—	28.0	—	—	—	—	—	0.2310
5	4	32	4	—	—	27.9	—	—	—	—	—	0.1710
6	4	32	2	—	—	27.7	—	—	—	—	—	0.1090
7	2	32	2	—	—	27.7	—	—	—	—	—	0.1570
8	2	25	2	—	—	27.7	—	—	—	—	—	0.0699
9	4	25	4	—	—	27.4	—	—	—	—	—	0.0372
10	4	25	4	120	0.2	25.1	—	—	400	Top (Center)	400	0.0767
11	4	25	4	120	0.6	24.5	—	—	600	Top (Center)	600	0.0818
12	2	25	4	120	0.6	23.5	—	—	600	Top (Center)	600	0.1280
13	4	32	4	240	0.6	23.1	—	—	600	Top (Center)	600	0.1740
14	4	25	4	0	—	29.3	30.7	28.6	—	—	—	0.0771
15	4	25	4	10	0.2	28.8	28.9	28.6	400	Top (Center)	400	0.0813
16	4	25	4	30	0.2	29.1	27.8	28.7	400	Top (Center)	400	0.0803
17	4	25	4	60	0.2	28.1	27.8	28.2	400	Top (Center)	400	0.0808
18	4	25	4	120	0.2	27.3	26.9	27.1	400	Top (Center)	400	0.0705
19	4	25	4	120	0.2	27.1	26.4	26.7	400	Top (Recovery side)	400	0.0693
20	4	25	4	120	0.2	25.0	25.6	26.4	400	Side plate	400	0.0696
21	4	25	4	10	0.2	25.8	26.0	26.1	2000	Top (Center)	2000	0.0671
22	4	25	4	—	—	12.3	11.1	12.3	—	—	—	0.0118
23	4	32	4	—	—	11.7	11.0	11.7	—	—	—	0.0224
24	4	32	2	—	—	11.6	11.0	11.6	—	—	—	0.0119
25	4	25	2	—	—	11.6	11.7	11.6	—	—	—	0.0052
26	4	25	4	—	0.2	11.3	10.3	13.5	—	Pipe(Recovery side)	400	0.0144
27	4	25	4	—	0.2	11.1	10.3	13.2	—	Pipe(Recovery side)	1000	0.0181
28	4	25	4	—	0.2	11.2	10.1	12.7	—	Pipe(Recovery side)	2000	0.0230
29	4	25	4	120	0.2	11.4	9.6	11.5	2000	Top (Center)	2000	0.0085
30	4	25	4	120	0.2	10.9	9.8	12.2	2000	Top＋Pipe	4000	0.0305

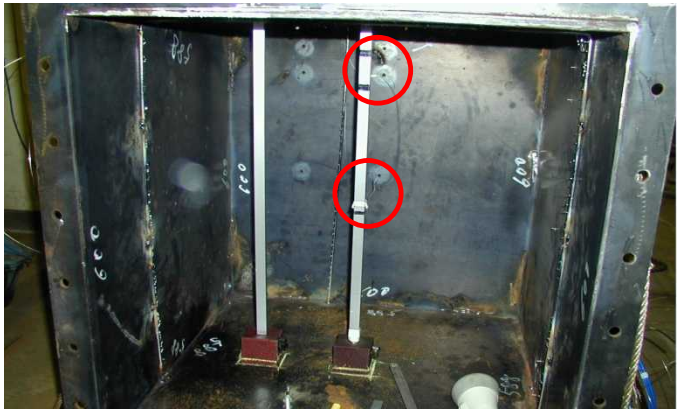
Experimental materials and instrument



work coil



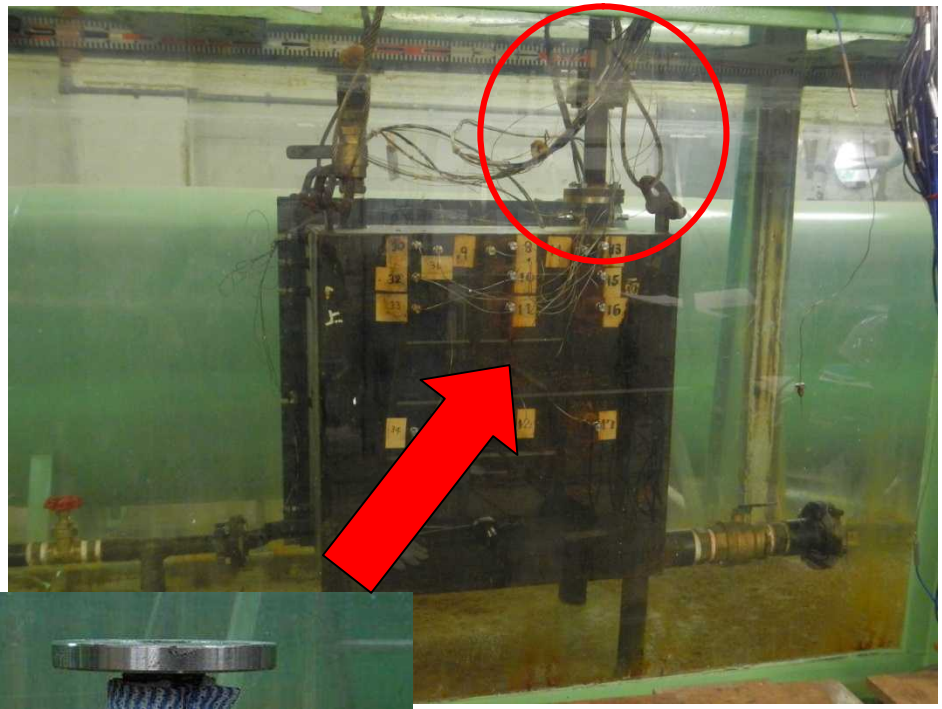
non-woven fabric

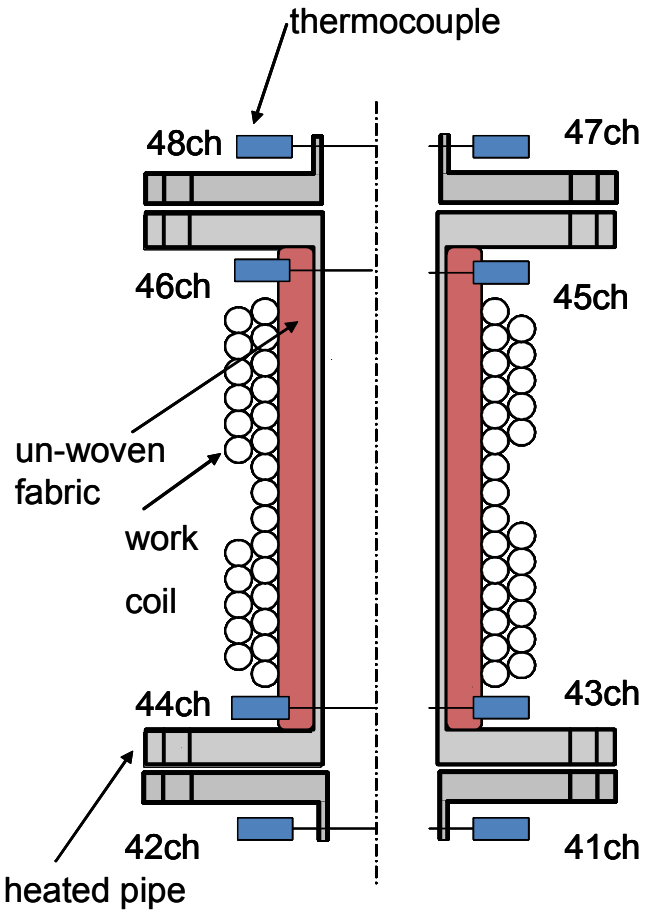


set-up of thermo couple

Inverter unit

Work coil of pipe type



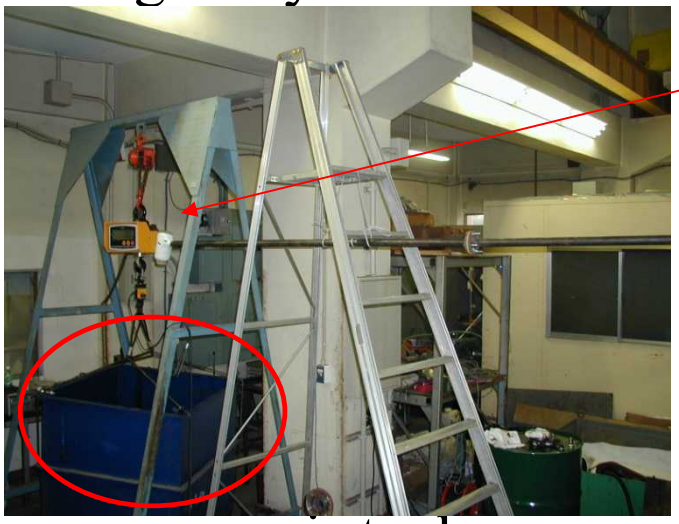


Gravity tank and reservoir tank

gravity tank

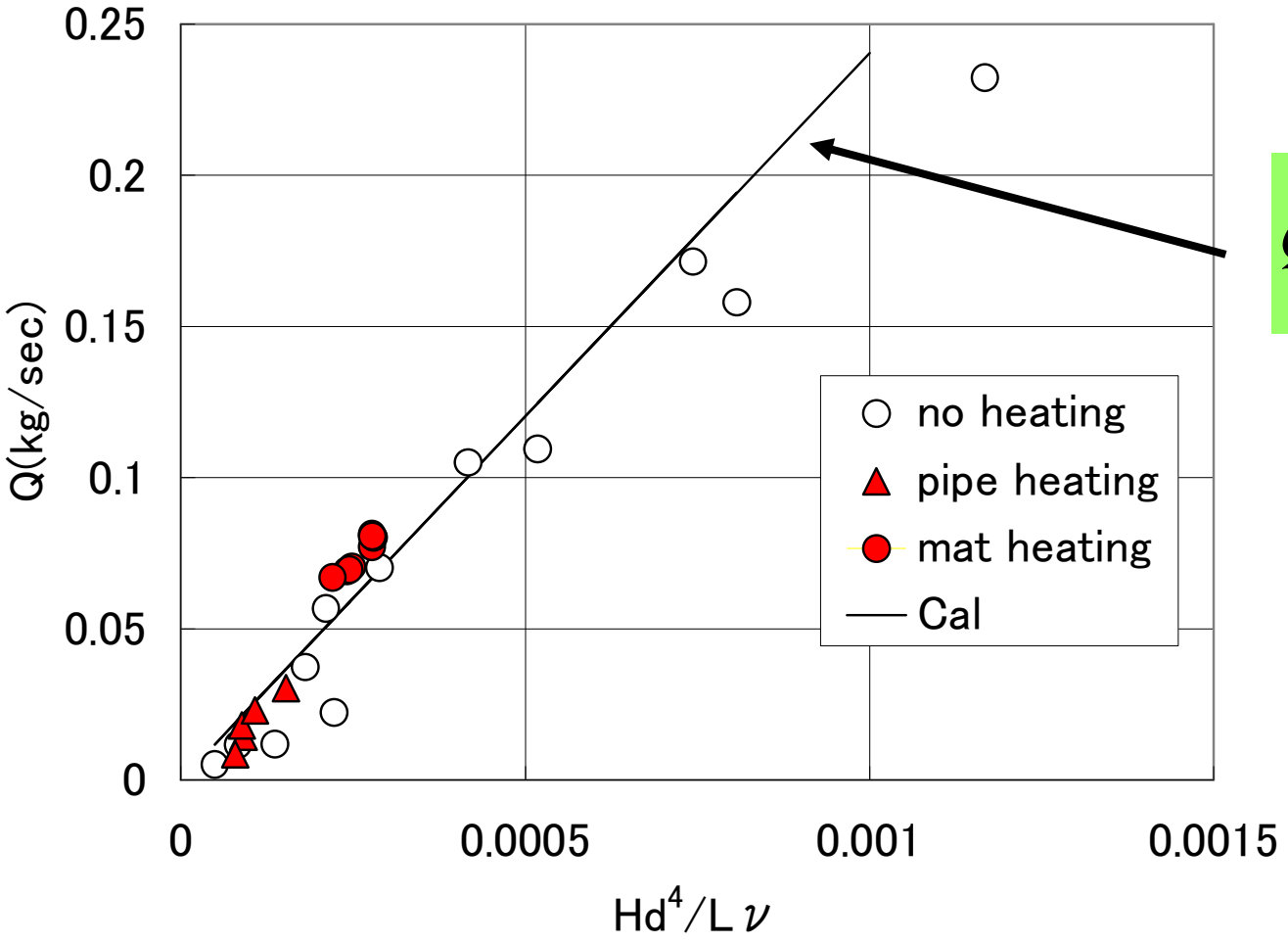
gravity tank

oil tank and pipe



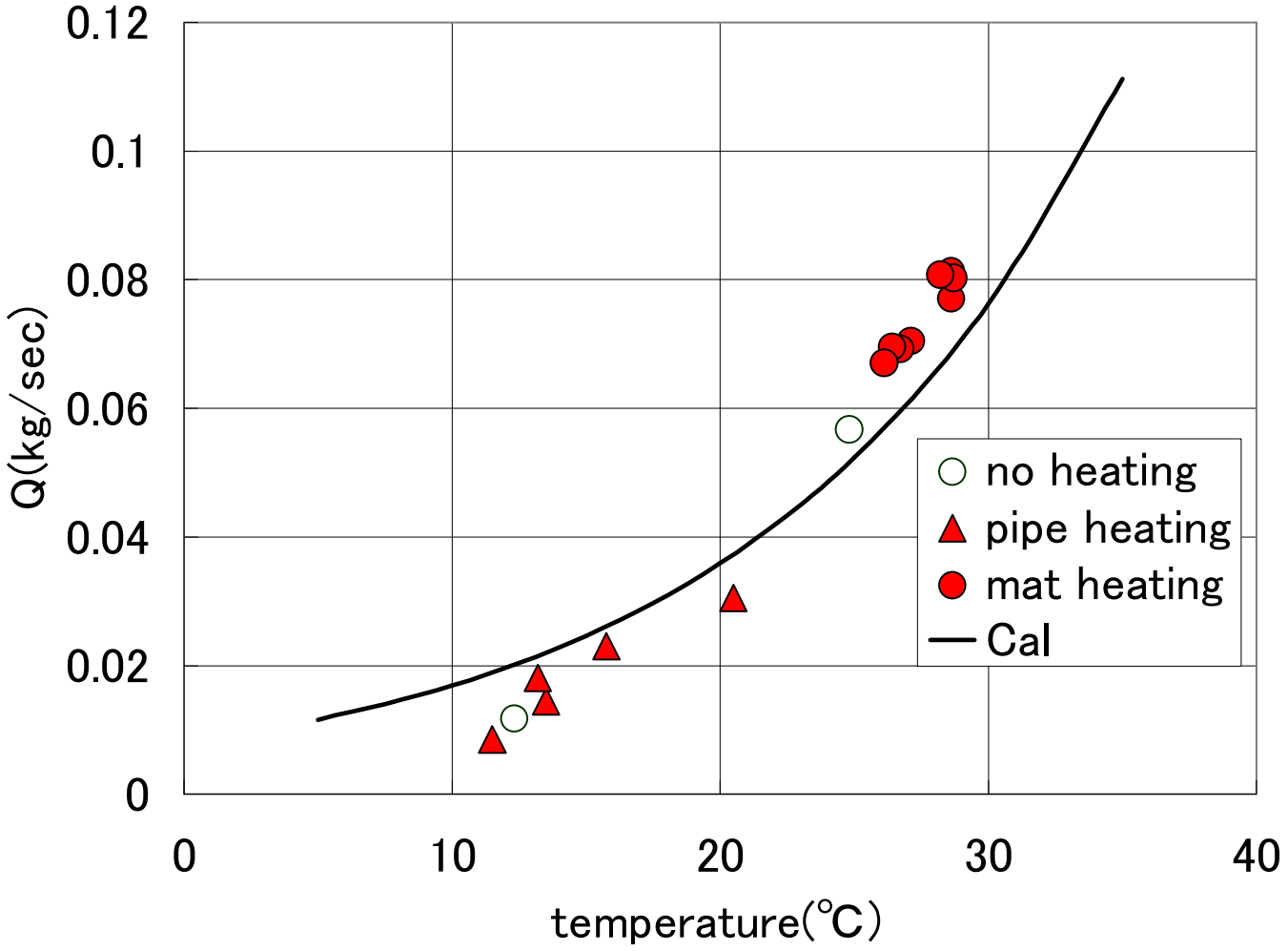
reservoir tank

Estimation of oil recovery rate with various experimental conditions

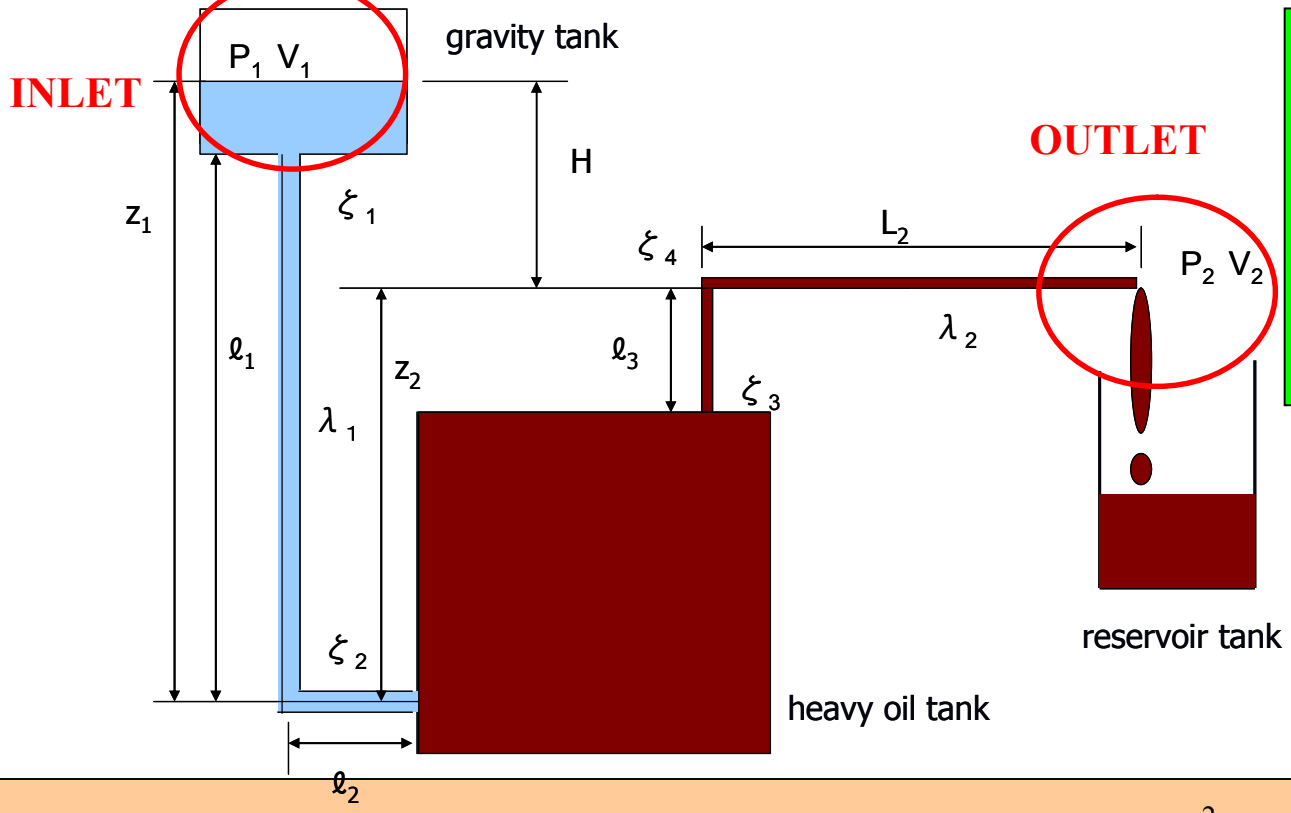


$$Q = \frac{\pi d^4 Hg\rho_w}{128\upsilon_o L}$$

Estimation of oil recovery rate concerning oil temperature on certain experimental condition



Friction loss factor



$\zeta_1, \zeta_2, \zeta_3$ friction loss coefficient of entrance

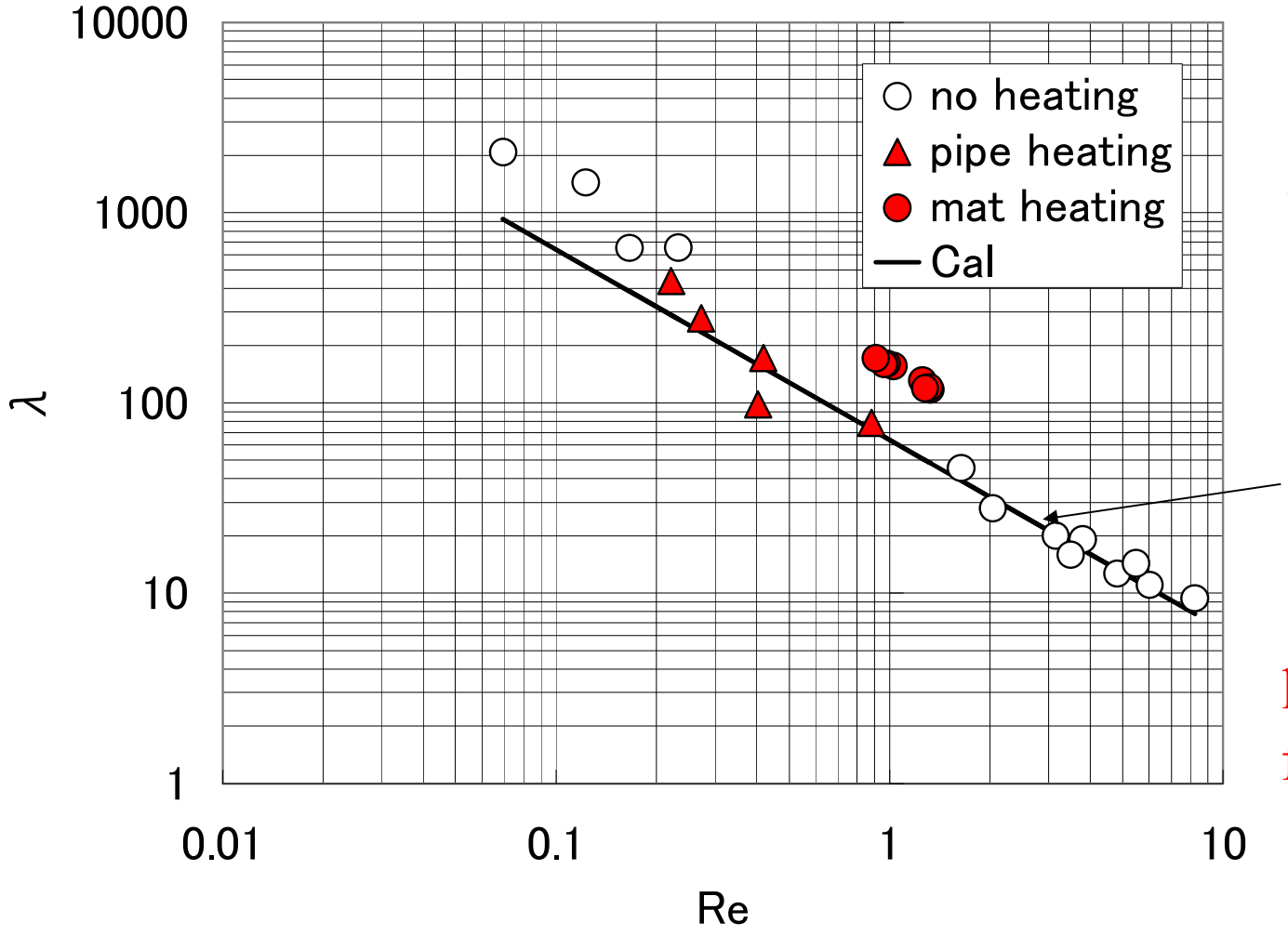
ζ_4 friction loss coefficient of elbow.

$$P_1 + \rho_w g z_1 + \frac{1}{2}\rho_w V_1^2 = P_2 + \rho_o g z_2 + \frac{1}{2}\rho_o V_2^2 + \zeta_1 \frac{\rho_w V_3^2}{2} + \zeta_2 \frac{\rho_w V_3^2}{2} + \lambda_1 \frac{L_1}{d_1} \frac{\rho_w V_3^2}{2} +$$

$$\zeta_3 \frac{\rho_o V_2^2}{2} + \zeta_4 \frac{\rho_o V_2^2}{2} + \lambda_2 \frac{L_2}{d_2} \frac{\rho_o V_2^2}{2}$$

Bernoulli's principle

Relation between Reynolds number and friction loss factor



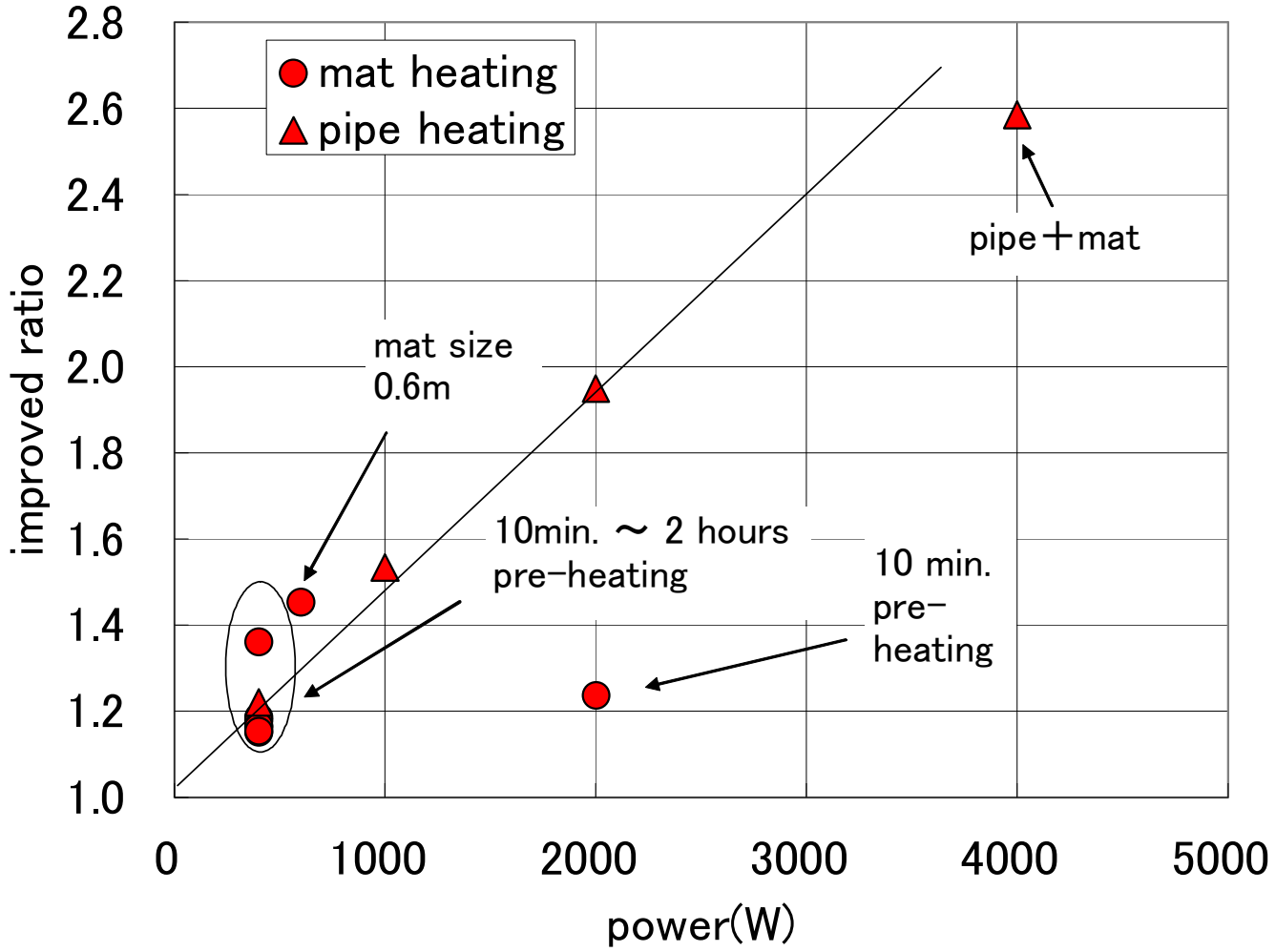
Exp.

$$\lambda = \frac{\rho_w g H}{\frac{L}{d}\frac{\rho_o V^2}{2}}$$

$$\lambda = \frac{64}{R_e} = \frac{64}{\frac{Vd}{\upsilon}}$$

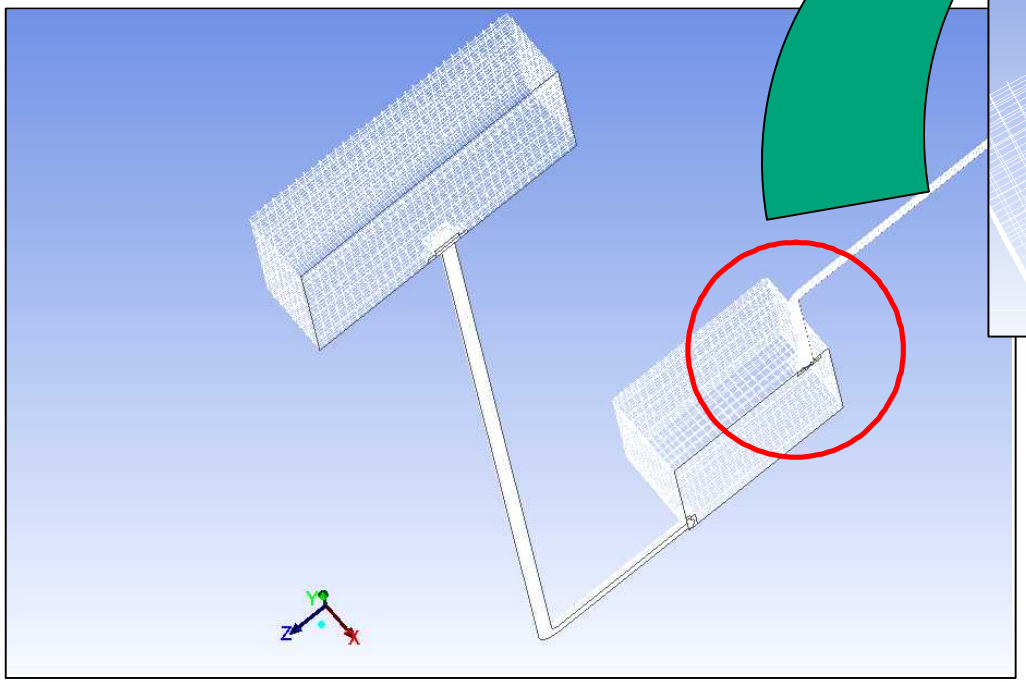
laminar flow

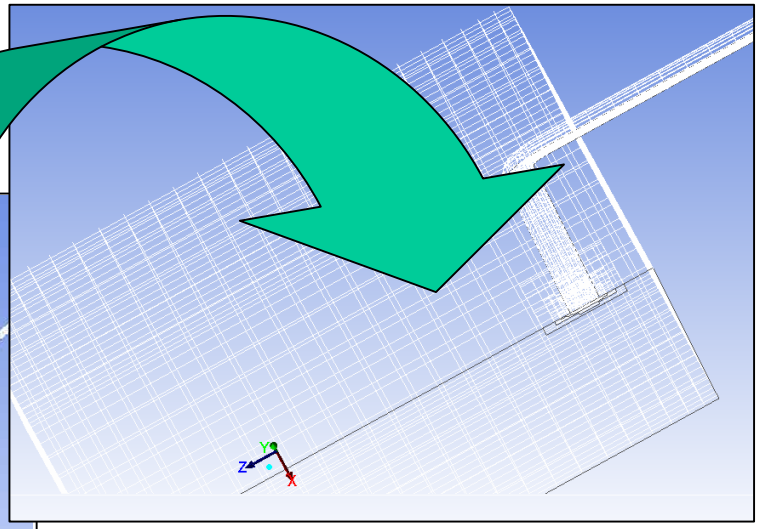
Relation between loaded electric power and improved ratio by heating



Numerical simulation

CFD tool : FLUENT



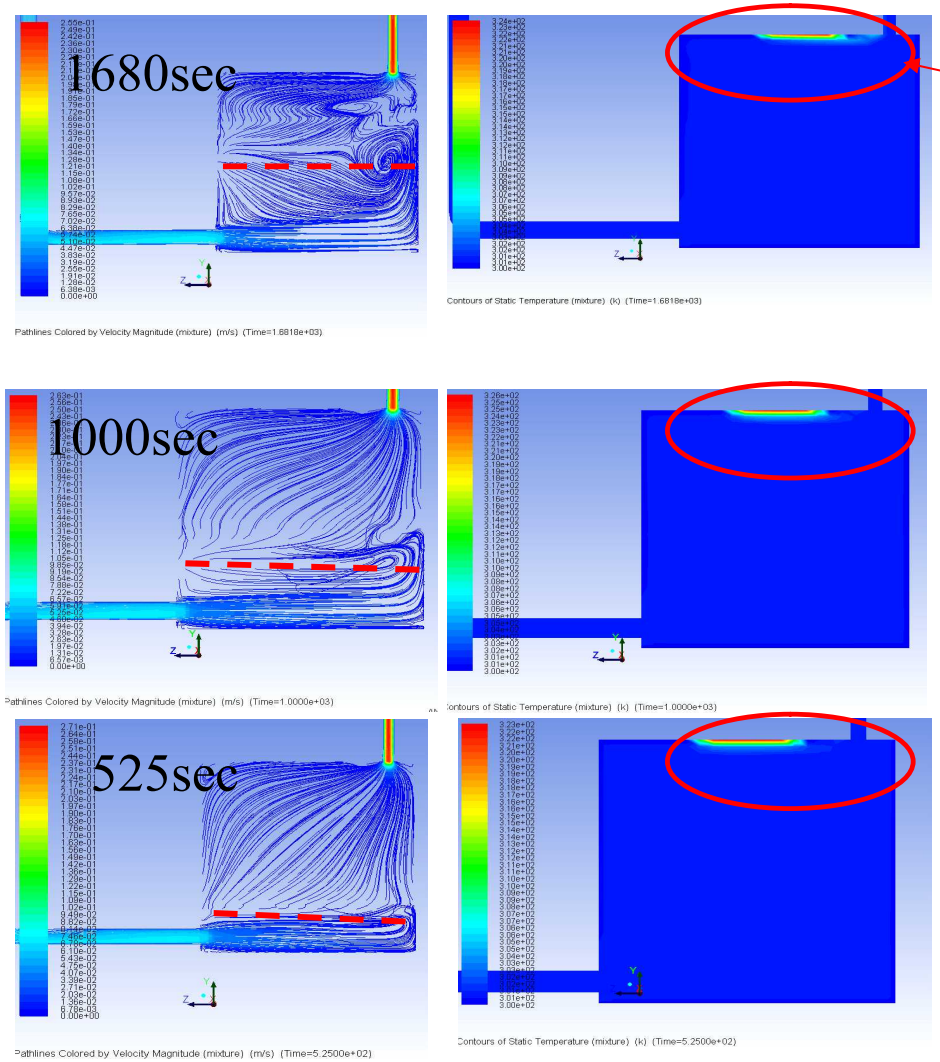


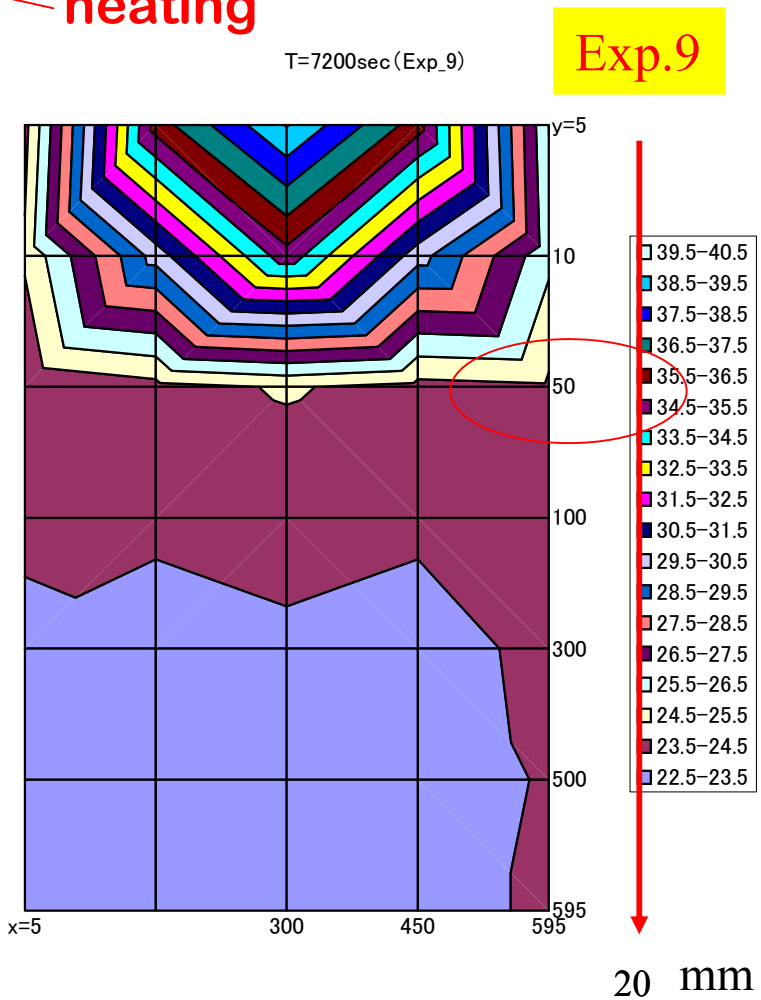
mesh for half model

physical properties of oil and iron

oil	density	977.2	(kg/m3)
	specific heat	2093.025	(kcal/kg℃)
	thermal conduction rate	0.1453	(kcal/mh℃)
	viscous coefficient	1.9544	(kg/ms)
	cubical expansion coefficient	0.00099	(/K)
iron	density	7850	(kg/m3)
	specific heat	498.13	(kcal/kg℃)
	thermal conduction rate	52.3256	(kcal/mh℃)

Particle trajectory and temperature distribution





Numerical results

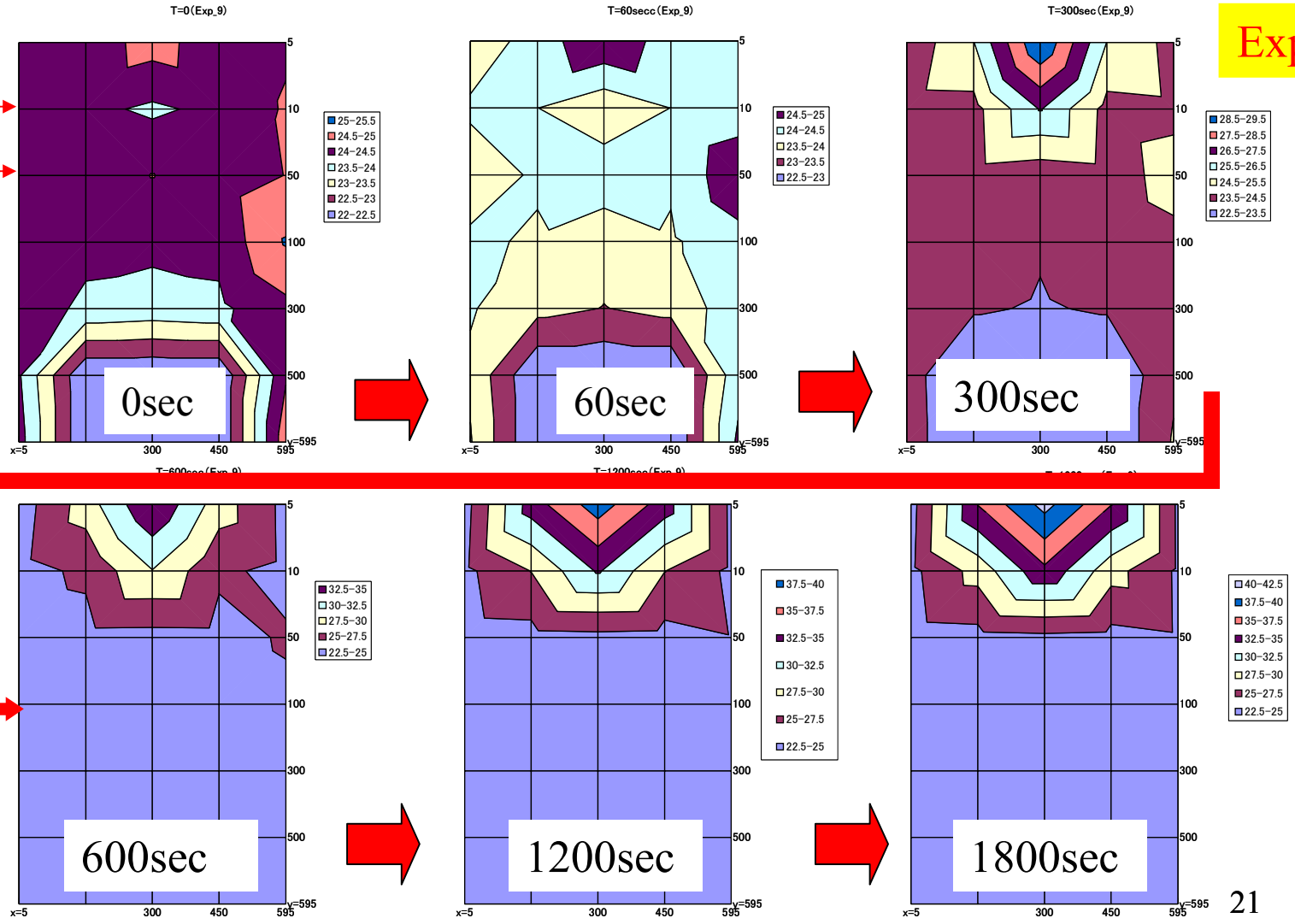
Experimental results

Change of temperature distribution

Exp.9

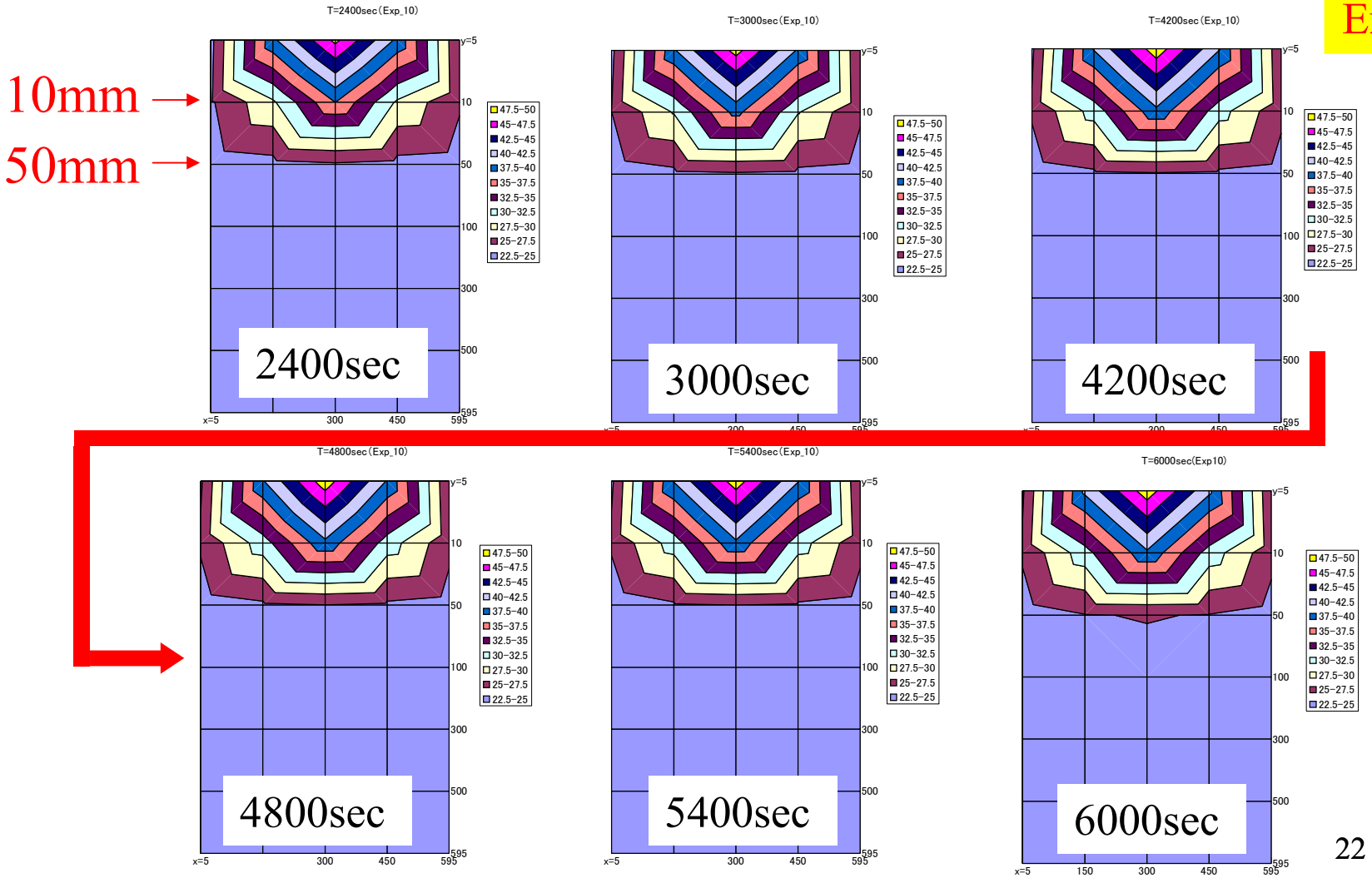
10mm →

50mm →



Change of temperature distribution

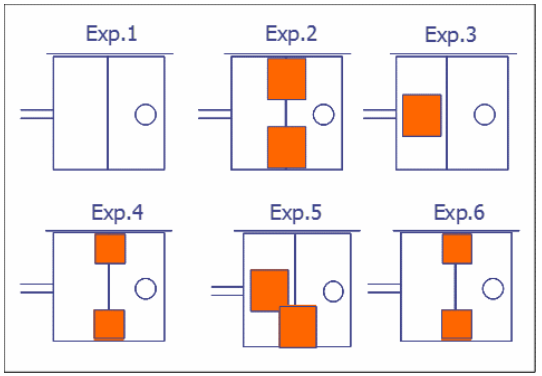
Exp.9



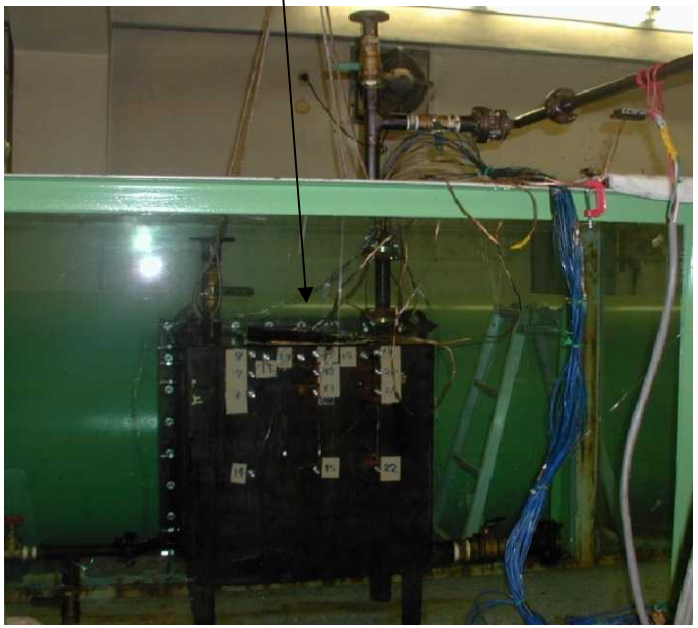
Arrangement of work coil In another experiment

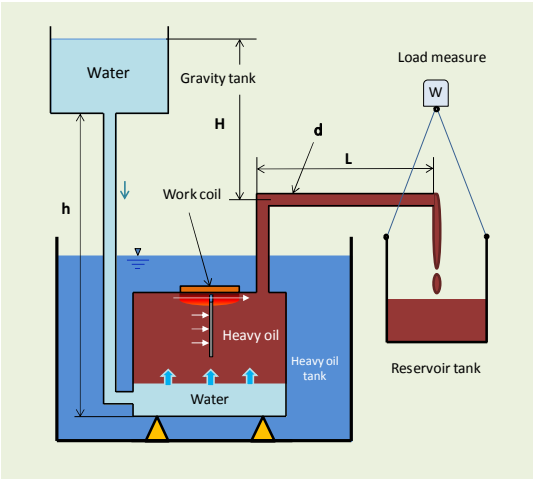
small coil（100×100mm）

large coil（150×150mm）



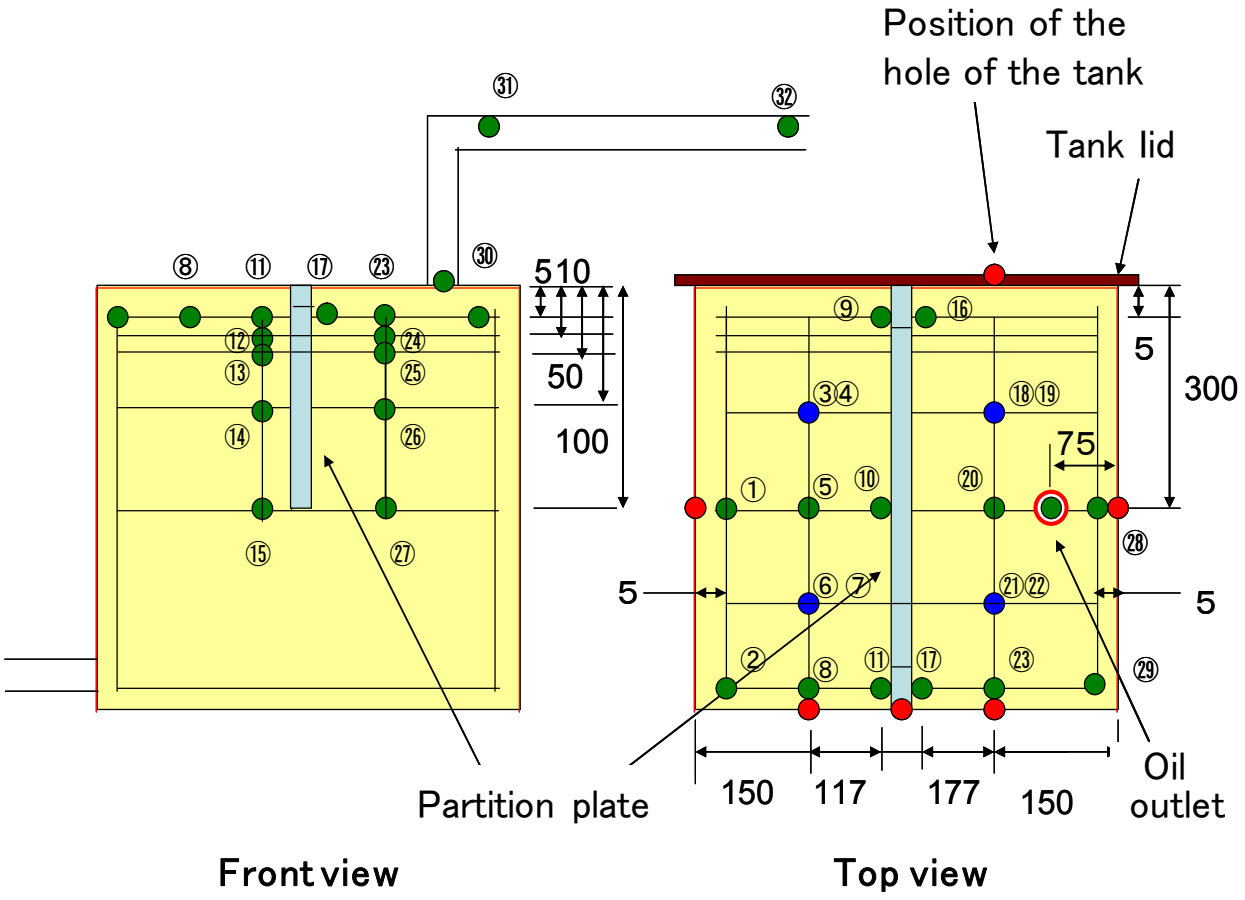
Coil arrangement on top plate





Oil recovery system

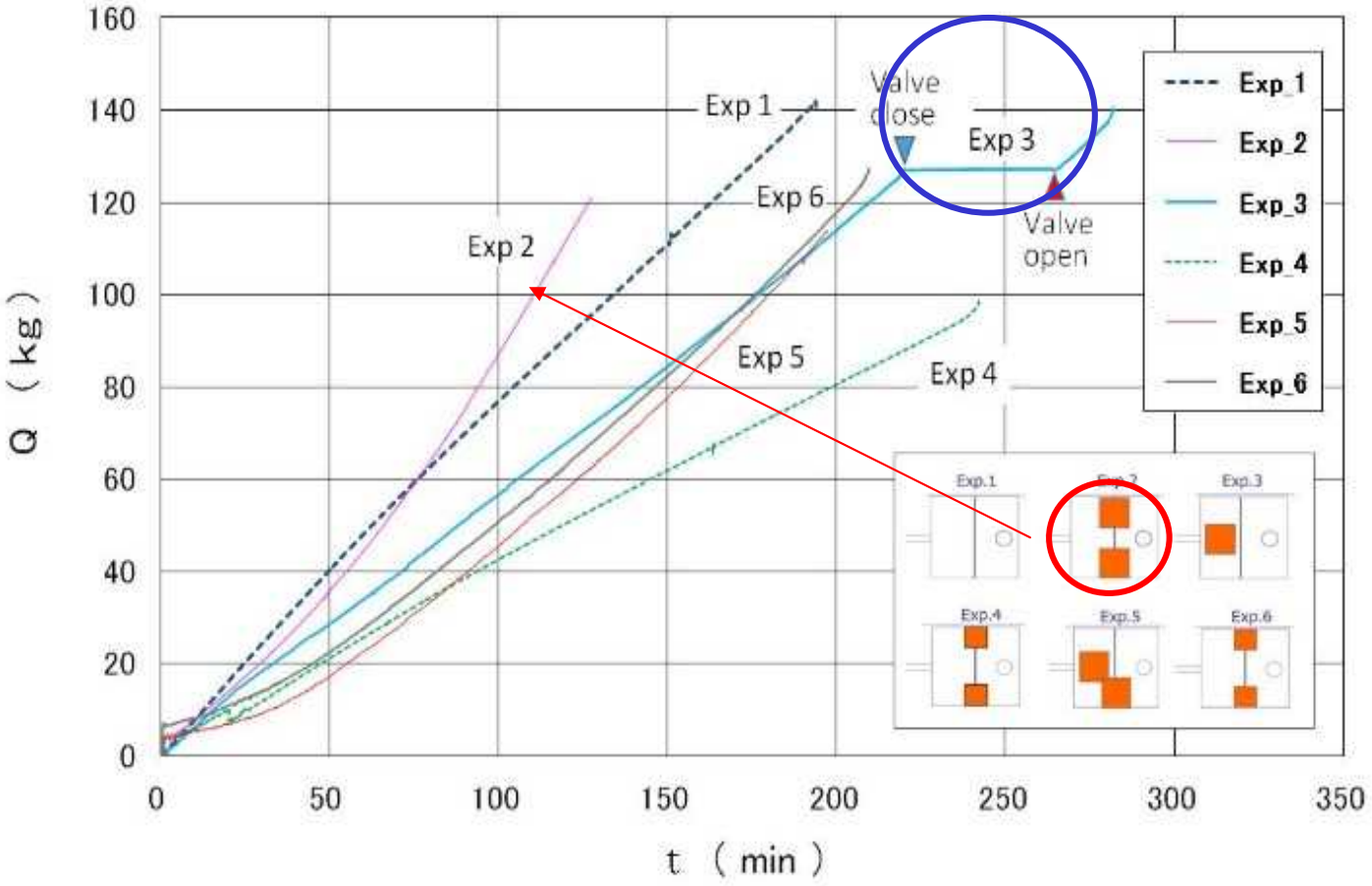
Measuring positions of thermo couples



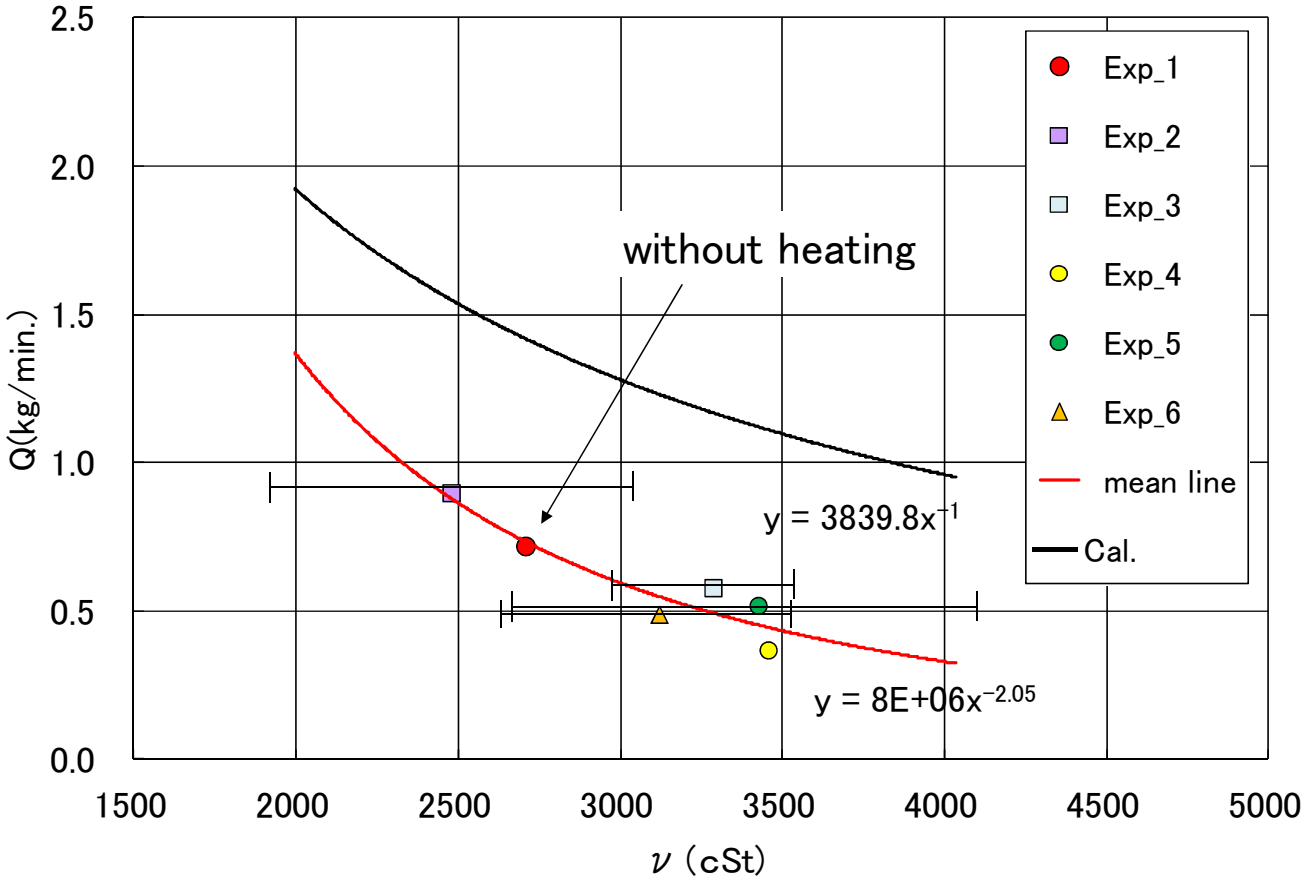
Experimental conditions and results

Exp. No.	Pipe length L(m)	Pipe diameterdd (mm)	Water pressure head h(m)	Heat time before Exp. (min)	Mat size & number of use(m) ×	Water temperature (℃)	Atmosphere temperature (℃)	Oil temperature (℃)	Heating position	Injection electricity (W)	Recovery rate (kg/min)
1	4	25	4	–	–	13.3	12.4	15.3	–	–	0.72
2	4	25	4	–	0.2×2	12.9	12.1	13.9	Central edge	2000	0.90
3	4	25	4	120	0.2×1	11.0	10.2	11.6	Center rear	2000	0.58
4	4	25	4	–	0.14×2	9.9	9.6	11.7	Central edge	2000	0.37
5	4	25	4	–	0.2×2	9.9	10.5	9.2	One side edge	2000	0.52
6	4	25	4	–	0.14×2	9.8	9.0	11.5	Central edge	2000	0.49

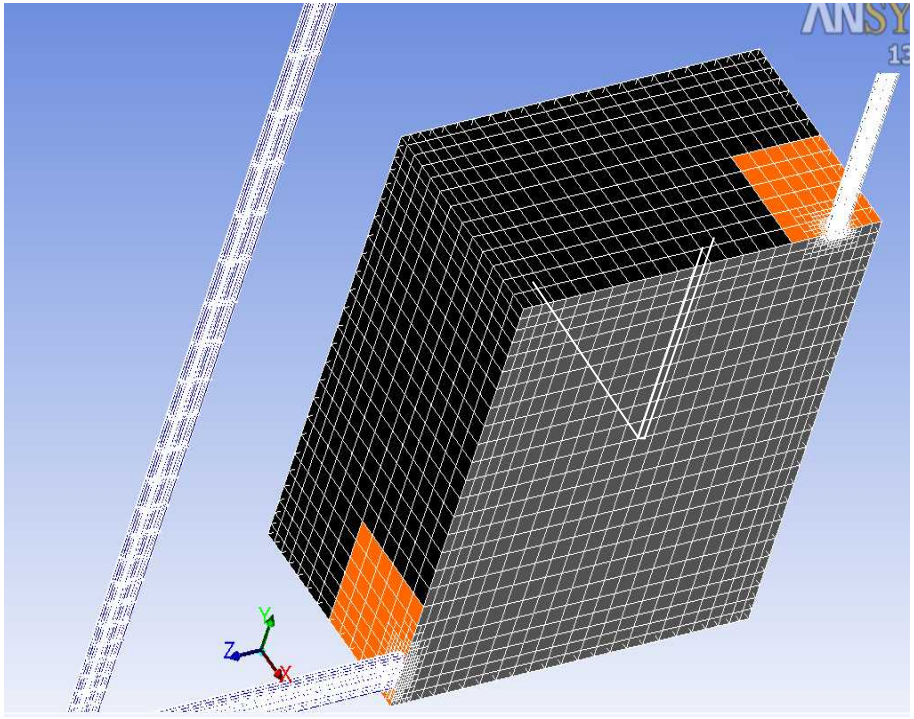
Time history of oil recovery weight in each case of experiments

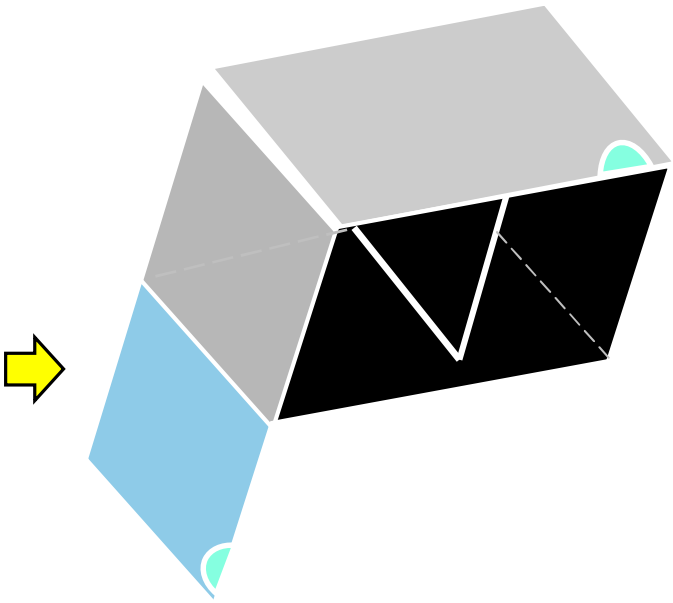


Relation between oil recovery rate and kinematic viscosity of oil

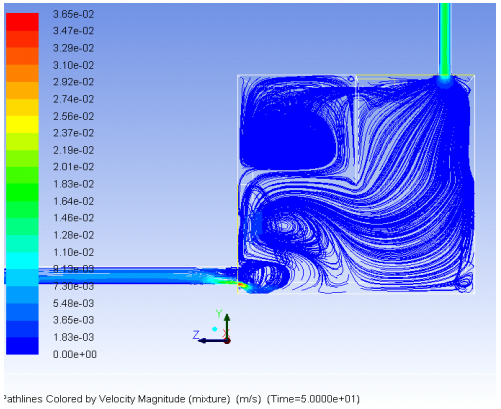


Modeling for computer simulation

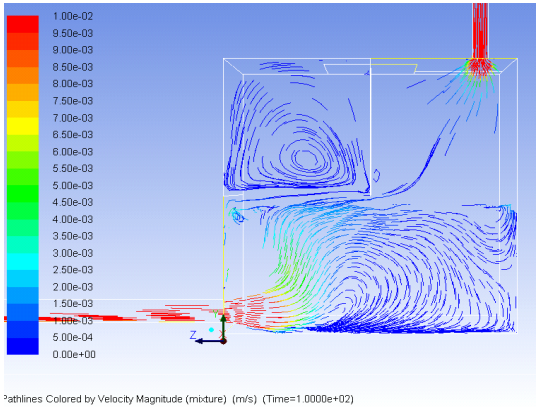




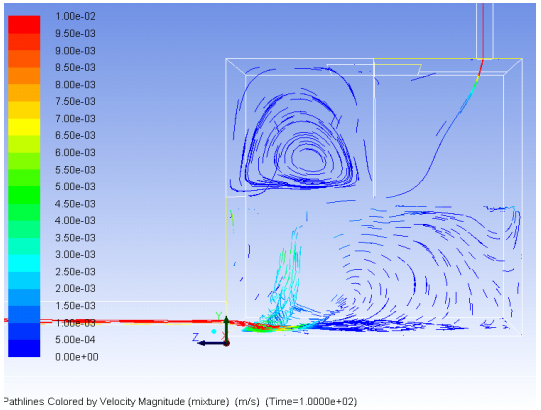
Streamline of oil and water inside the tank



Streamline of oil and water inside the model tank (Section distance : X=0.3m, t=50sec)



Streamline of oil and water inside the model tank (Section distance : X=0.15m, t=100sec)

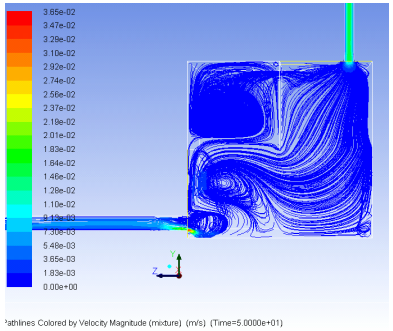


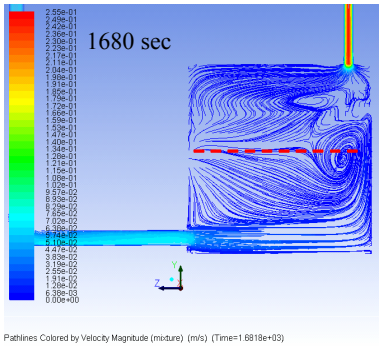
Streamline of oil and water inside the model tank (Section distance : X=0.3m, t=100sec)

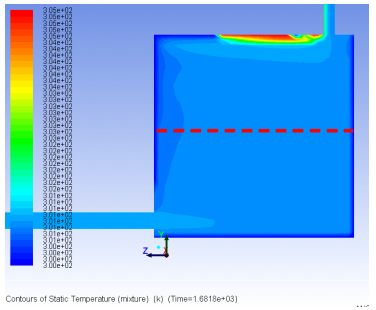
Comparison of streamline of oil and water inside the tank

With partition

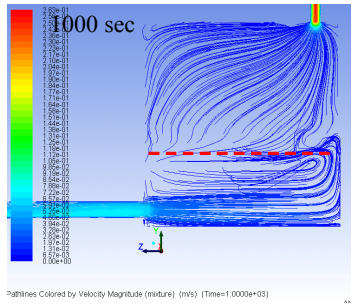
Without partition

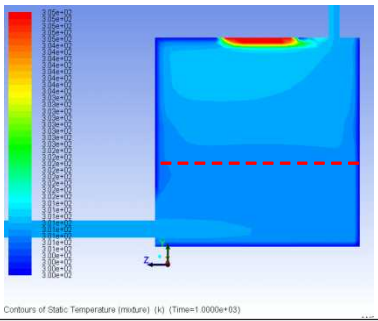


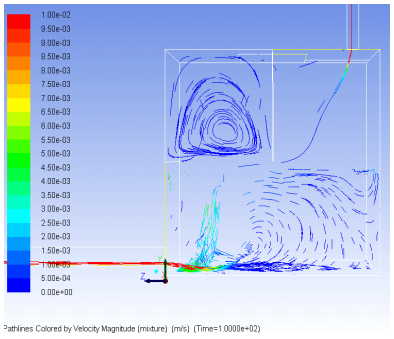


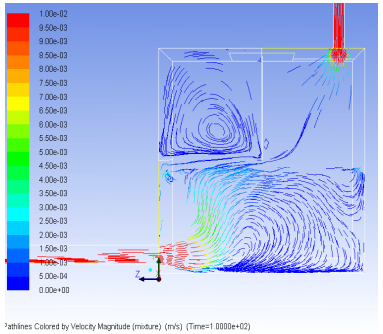


Streamline of oil and water inside the model tank (Section distance : X=0.3m, t=50sec)









Streamline of oil and water inside the model tank (Section distance : X=0.3m, t=100sec)

Streamline of oil and water inside the model tank (Section distance:X=0.15m, t=100sec)

Experimental conditions and oil recovery rate

Pipe length : 4 m
Pipe diameter : 25 mm
Water pressure head : 4 m
Water temperature : 25.1 ℃
Electric power before oil recovery : 400 w/2 hour

Conclusion

(1) The oil recovery rate has been estimated by the simple method using various parameters.

(2) The improved oil recovery rate comparing with the case of no heating as for the pipe type of heating increases linearly with the increase of electric power.

(3) The combination of pipe and mat type of heating can improve the oil recovery rate.

Conclusion

(4) The numerical calculation results of oil temperature inside the tank does not agree well with the experimental results and represent the natural convection of heat

(5) The heating at the cutout part of the partition plate does not improve the effect of fluidization.

(6) The size of the coil mat does not show the significant difference of the oil recovery efficiency.

(7) The partition plate prevents the oil from fluidizing because of making the route of water. This phenomenon is seen in the practical operation of salvage.

Thank you for
your kind attention.