Japan-US Workshop on
Fusion Reactor Design and Critical Issues of Fusion Engineering
28-31 Mar. 2022@ZOOM

TOHOKU UNIVERSITY

# Molten salt application for a cooling system in a fusion reactor

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# Outline

**1. Background**

1.1 Divertor in a fusion reactor

1.2 Liquid Flibe Divertor

**2. Objectives and action items**

**3. Experimental apparatus**

**4. Flow visualization experiment**

5.1 Experimental method & conditions

5.2 Experimental results

**5. Heat transport experiment**

5.1 Experimental method & conditions

5.2 Experimental results

**6. Summary**

# 1. Background
# 1.1 Divertor in a fusion reactor

**Role**

・Particle control in a fusion core plasma (evacuation of impurities)

**Key issues**

・An excessive heat load due to incident high energy particles
・Thermal fatigue by cyclic heat load originated from ELM, and increase in impurities by sputtering

Table Fusion reactor and its power, steady heat load on divertor[1]

| Fusion reactor | Fusion power | Steady heat load on divertor |
|---|---|---|
| ITER | 500 MW | 10 MW/m$^2$ |
| Slim-CS (DEMO) | 3 GW | 30 MW/m$^2$ |

**Solid wall divertor**

- Tungsten is one of the candidate materials due to high melting temp.
- An excessive heat load will cause cracks due to fatigue even in using W.

**Liquid divertor**

- Use of flowing liquid metal, molten salt could keep the plasma-facing surface clean and sound.
- An excessive heat load could be removed by the flowing surface.

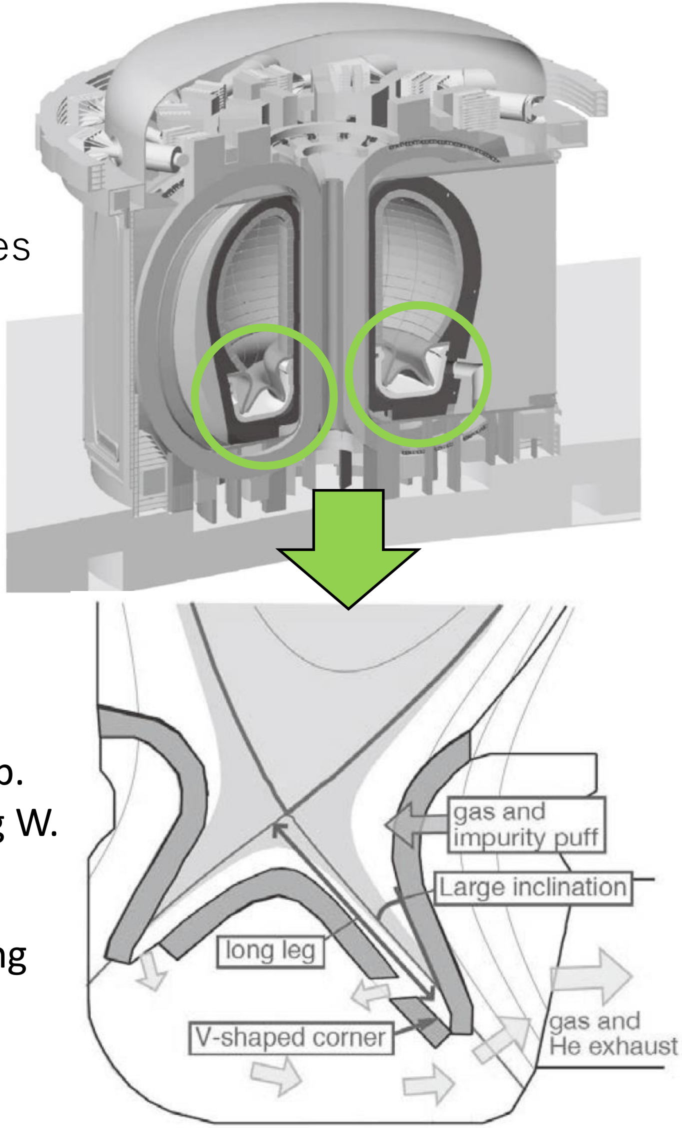



Fig. Divertor in SlimCS[1]



[1] Tobita, et al., Conceptual Design of the SlimCS Fusion DEMO Reactor (2010) JAEA-Research 2010-019

# 1. Background
# 1.2 Liquid Flibe Divertor

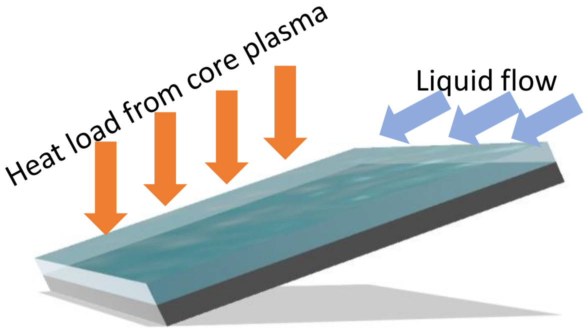



Fig. Image view of liquid divertor

Table. Characteristics of Flibe and Li [2] [3]

| Liquid material | Chemical stability | Melting point @ 1 Pa [K] | Boiling point @ 1Pa[K] | Electric cond. [1/(Ωcm)] | MHD Pressure loss |
|---|---|---|---|---|---|
| **Flibe** | High | 731 | 940 | 2.2 | Very small |
| **Li** | Low | 452 | 797 | 27000 | Large |

**Flibe:** Mixed salt of LiF and $BeF_2$ (typical composition → LiF:$BeF_2$=2:1)

MHD pressure loss generated in flowing Flibe is very small.
⇨ Flibe has big advantage compared to liquid metal.

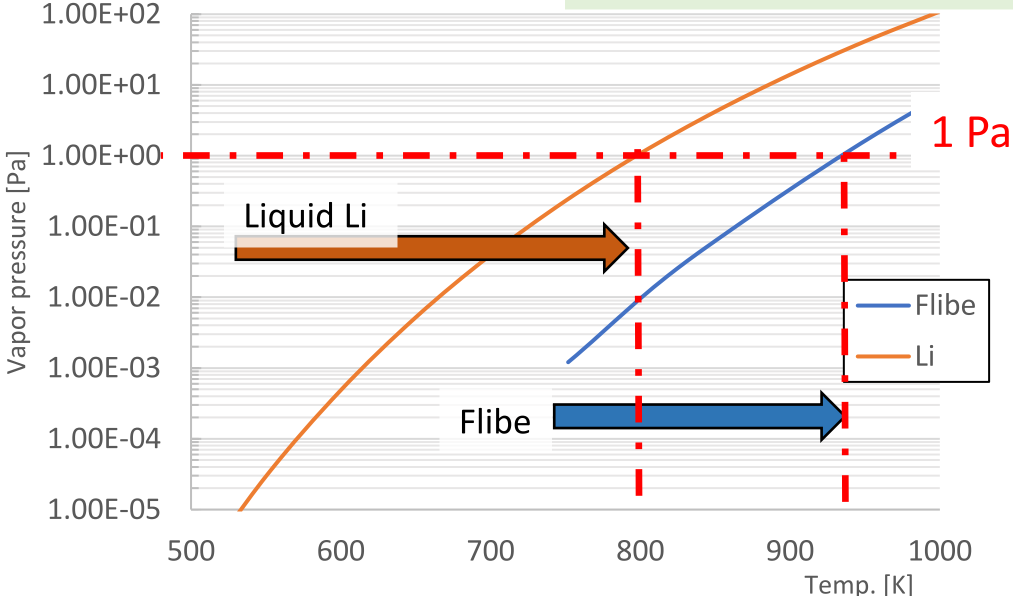



Fig. Vapor pressure of Flibe and Li [2] [3]

Vapor pressure of Flibe is lower than liquid Li.
⇨ Particle contamination in plasma can be reduced.

Fig. Picture of pebble-arrayed bed

Low surface temp. is required for lower vapor pressure. ➔ Pebble-arrayed bed as a turbulent promoter to enhance heat transport on a free surface.

[2]DAI-KAI SZE and ZHANHE WANG, 1998, FLIBE DATA, ARGONNE NATIONAL LABORATORY
[3]Vapor Pressure Calculator < http://www.iap.tuwien.ac.at/www/surface/vapor_pressure > 2020. 2. 9. Access

# 2. Objectives and action items

**Objectives** : Feasibility study of Flibe liquid divertor by flow and heat transport experiments using water as a simulant

## Action items

**Experiments using water**

- Flow visualization experiment
- Heat transport experiment

↓

Experiment with changes in flow velocity and water depth

**Optimization in geometry**

**Evaluation using a mock-up**

**Experimental evaluation using Flibe**

**Realization of Flibe liquid divertor**

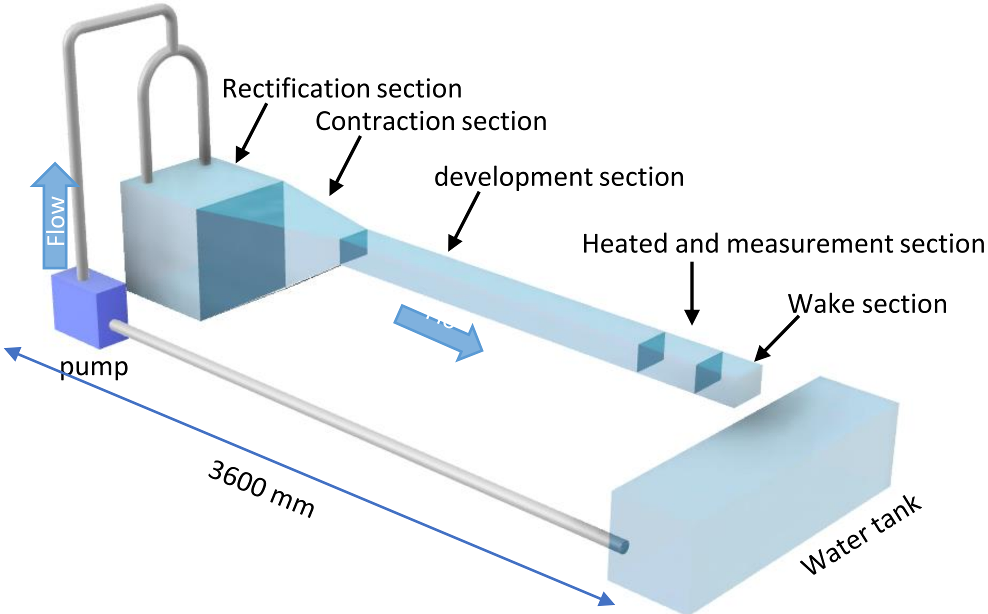



Fig. Image view of the experimental water loop

# 3. Overview of experimental apparatus

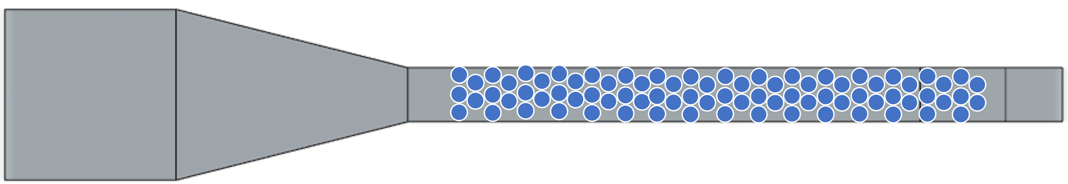


Fig. Image view of the experimental water channel from the topside

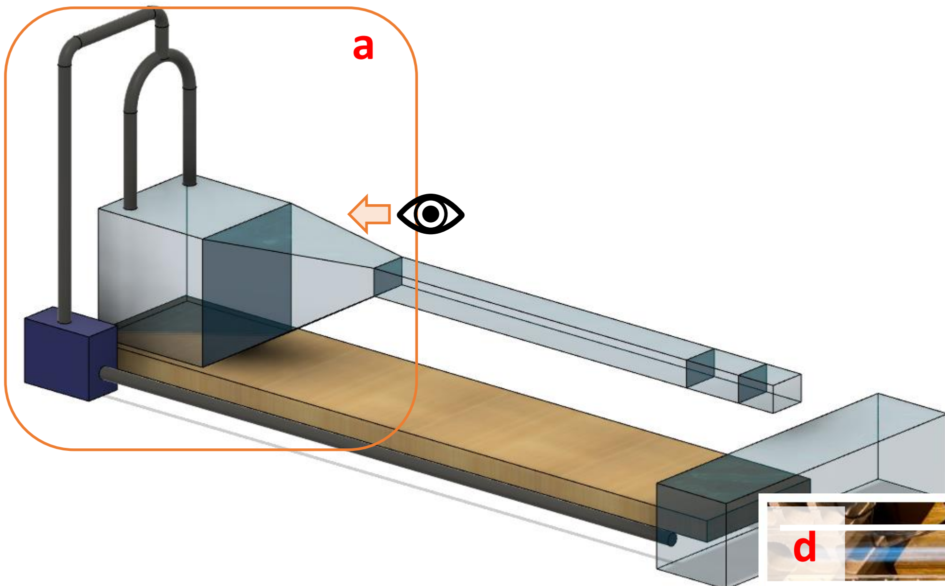



Fig. Image view of the experimental water loo

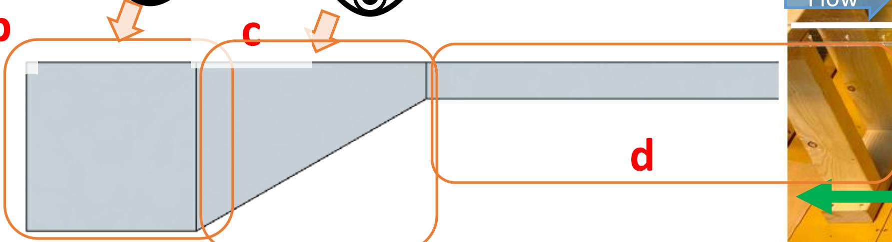
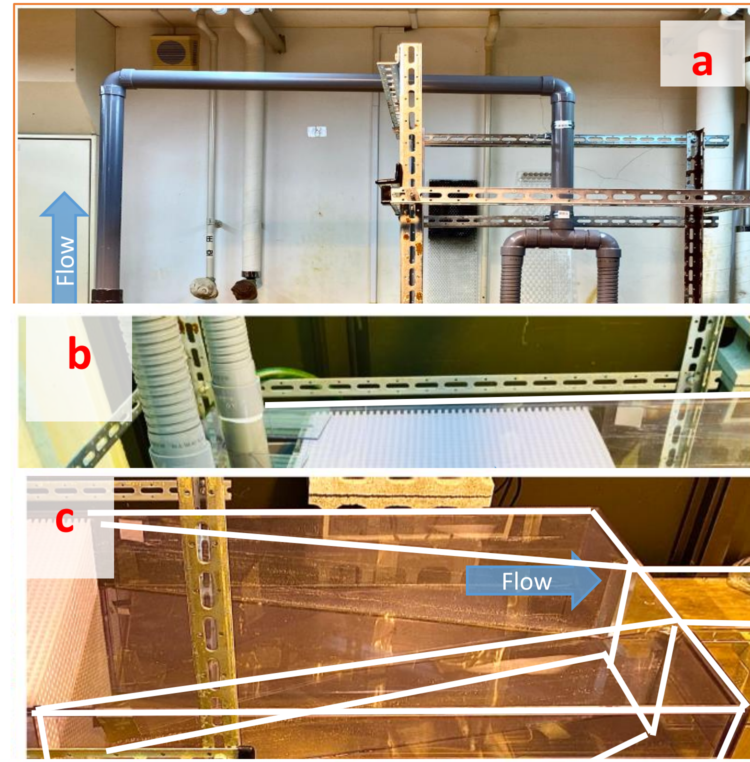



Fig. Image view of the experimental water channel



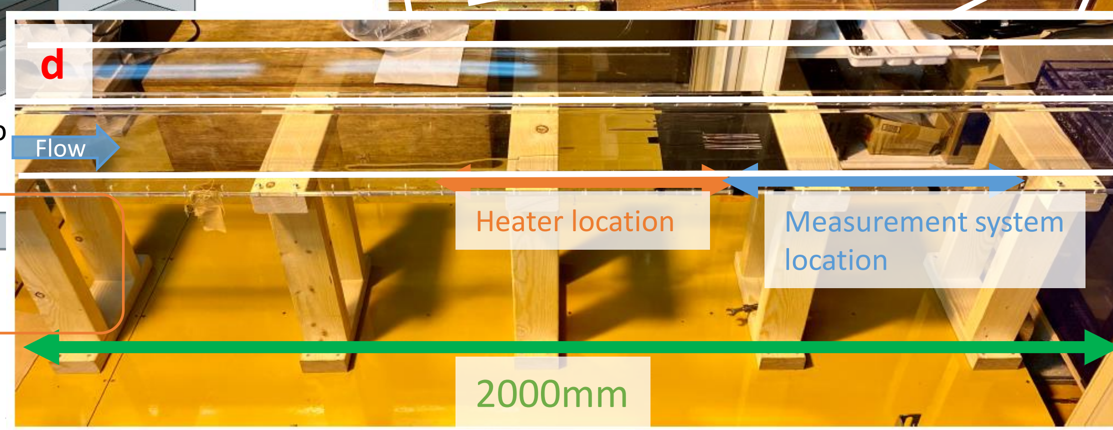




Fig. Development and measurement section

# 3. Overview of experimental apparatus

**Position of heated area** is 300 mm in length and located 1500 mm downstream of the end of contraction section

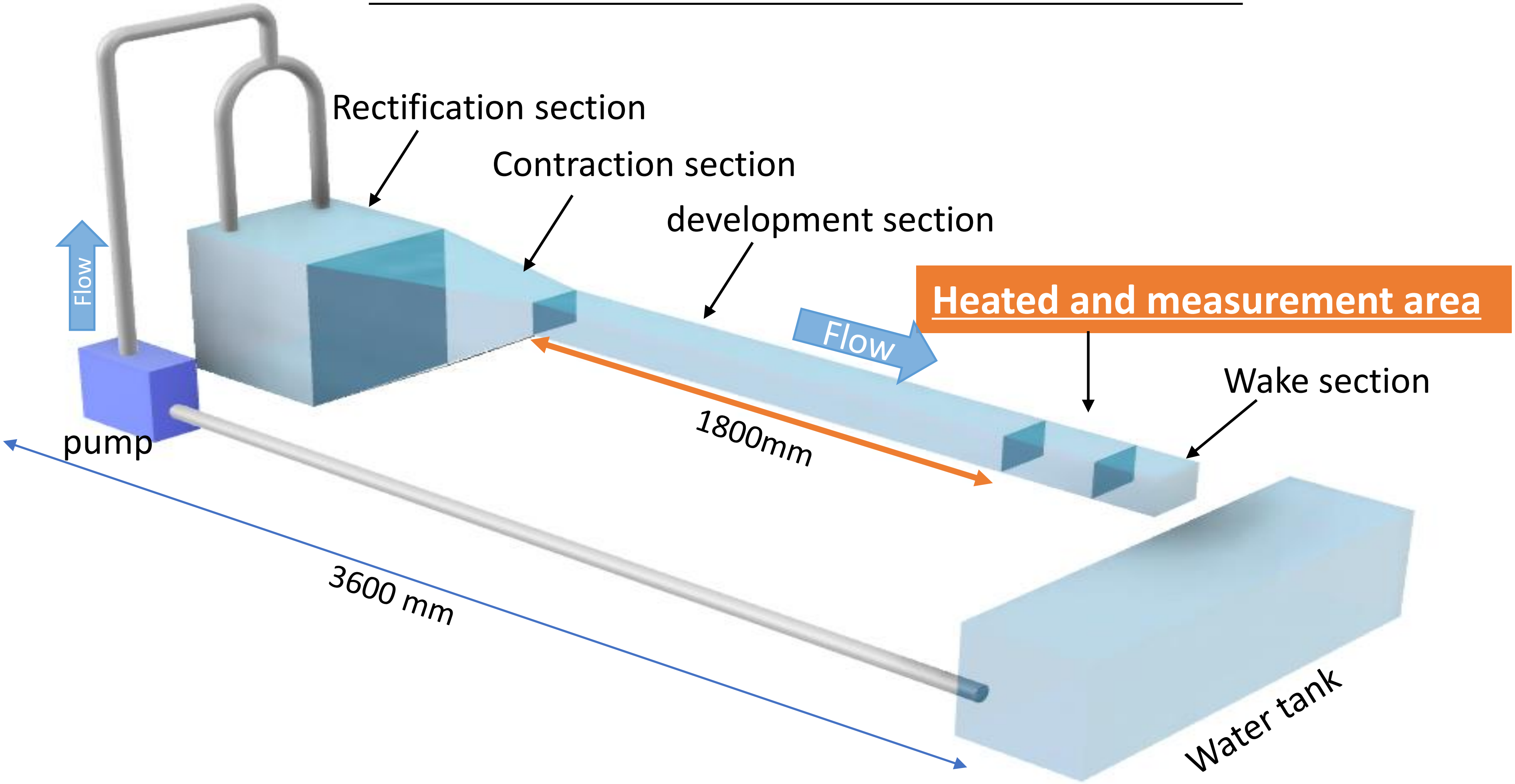



Fig. Location of the heater

# 4.1 Experimental method & conditions

**PIV parameters**

Camera resolution : 1 280 x 1 024
Frame rate : 500 fps
The num. of sample : 2 048 (1 024 pair images)
Tracer particle : nylon (20 μm in diameter)
Laser : Diode laser with wavelength of 808 nm
Laser duration : 250 μs, 300 μs

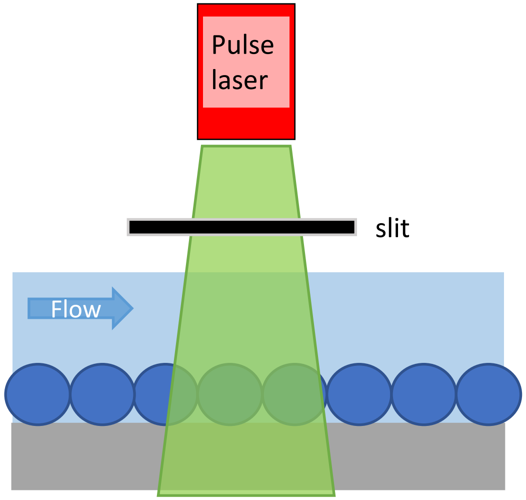


Fig. Image view of the laser

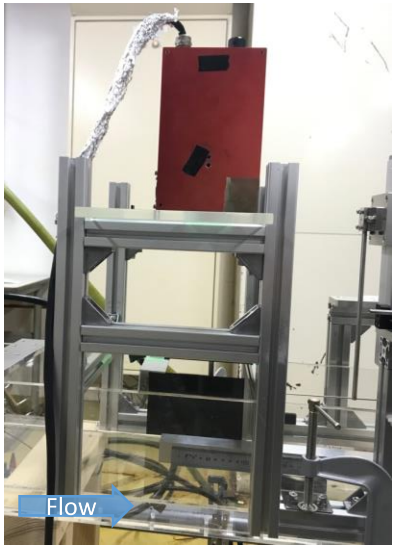


Fig. Picture of the laser equipment

**Experimental conditions**

Water depth : 30 mm
Flow velocity : 0.3, 0.5 m/s
Pebble diameter : 40 mm (OR without pebbles)

The definition of water depth : h

- From surface to channel bottom in the case without pebbles
- From surface to pebble top in the case with pebbles

Table Conditions of flowing water

| U [m/s] | h [mm] | d [mm] | Re [-] | $\theta$ [deg] |
|---|---|---|---|---|
| 0.28 | 30 | 0 | 6361 | 0.15 |
| 0.25 | 31 | 40 | 6043 | 0.30 |
| 0.46 | 34 | 0 | 12019 | 0.80 |
| 0.49 | 30 | 40 | 11348 | 0.80 |

U : Average flow velocity, h : Flow film thickness, Re : Reynolds number, $\theta$ : Inclining angle

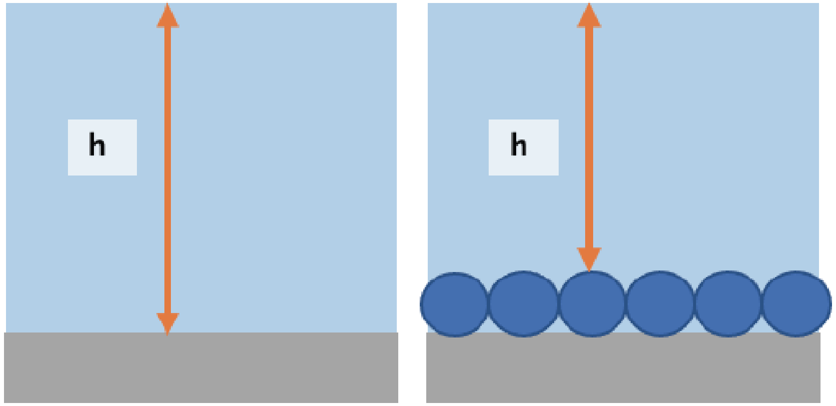


Fig. Definition of the h(flow film definition)

# 4. Flow visualization experiment
# 4.2 Experimental results

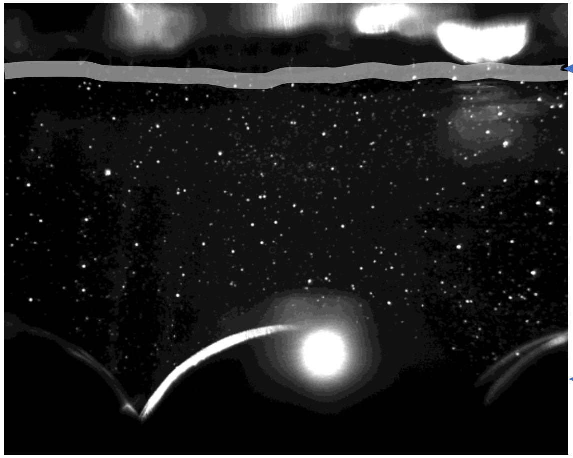



Fig. Particle image of PIV

**Velocity profiles (time-averaged)**

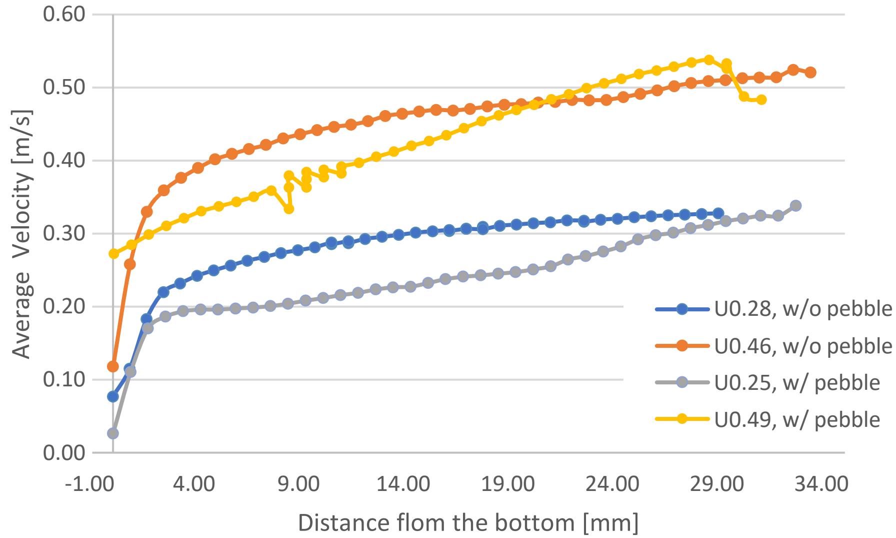



Fig. Average velocity

- Water free surface is wavy and difficult to recognize its position precisely.
- Some reflection of laser light from free surface and pebbles disturb PIV analysis.
- In the pebble cases, velocities monotonically increase with the distance.
- As for turbulent intensity, the value in the case of U=0.49, d=40 doesn't show large value compared to the case without pebble.

→ Needs to redo and re-evaluate.

**Turbulent kinetic energy (normalized by mean velocity)**

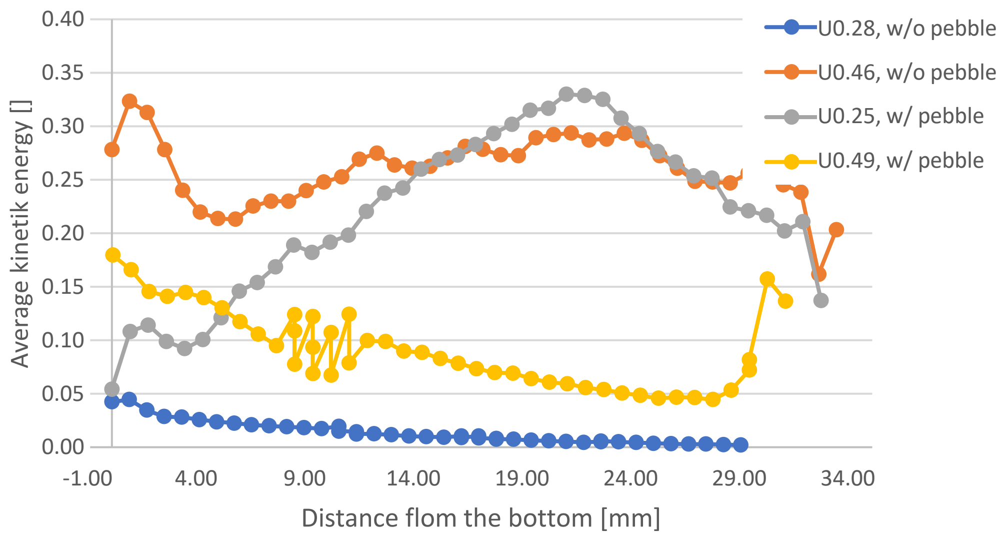



Fig. Kinetic turbulence energy

# 5. Heat transport experiment
# 5.1 Experimental method & conditions

## Temperature measurement device with XYZ stages

| | |
|---|---|
| Range of motion | X:128mm, Y:50mm, Z:150mm |
| Min. measurement interval | 0.1 mm |
| Temp. measurement | TC with sheath (o.d. 0.5 mm) |
| TC Sleeve | 2 mm in o.d. |

*Location of TC is recorded in a data logger as well as temp.

## Temp. measurement area

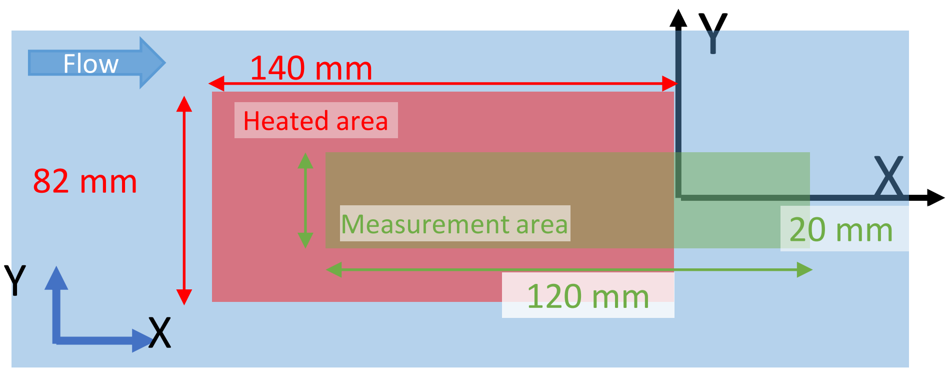



Fig. Location of the measurement area

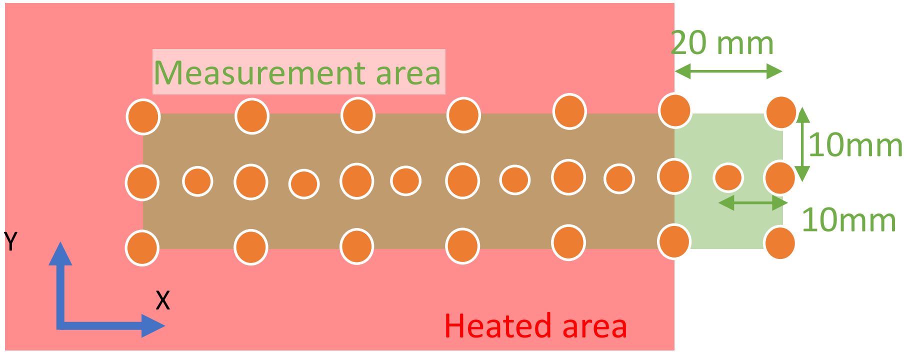



Fig. Location of the measurement points

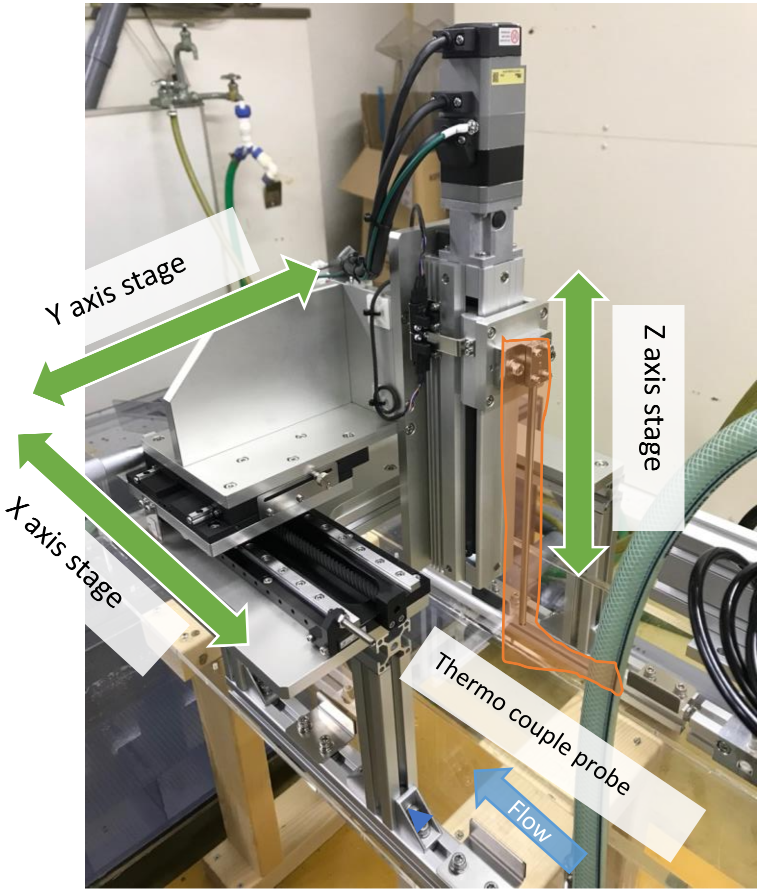



Fig. Picture of the XYZ stage temperature measurement unit

Table Measurement area and pitch

| axis | Max. | min. | pitch |
|---|---|---|---|
| X[mm] | 20 | -120 | 10(center y=0), 20(Y=-10, 10) |
| Y[mm] | 20 | -20 | 10 |
| Z[mm] | 0 | -15 | 1 |

# 5. Heat transport experiment
# 5.1 Experimental method & conditions

Measurement interval in Z direction : 1 mm

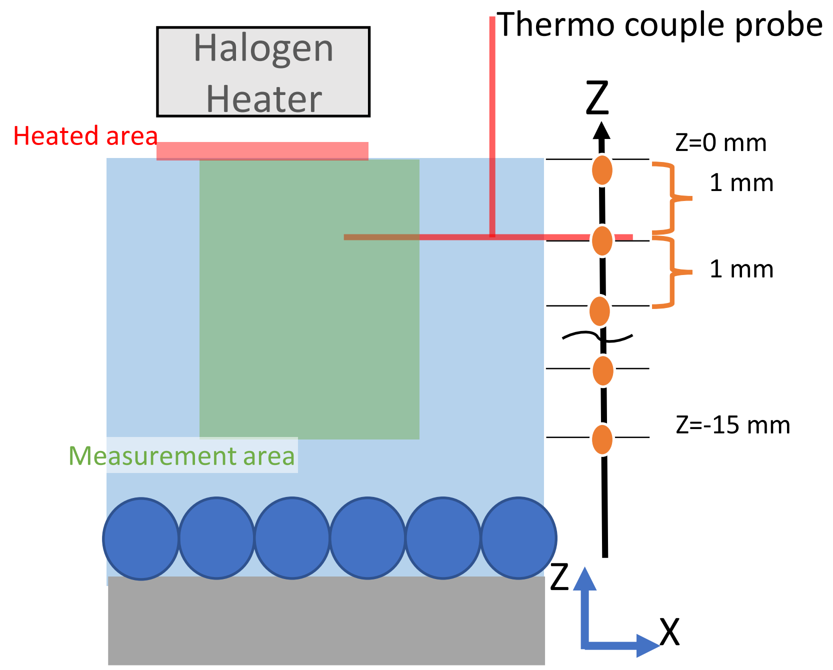



Fig. Location of the measurement area on Z axis

When X, Y=0, TC is located above the top of a pebble.

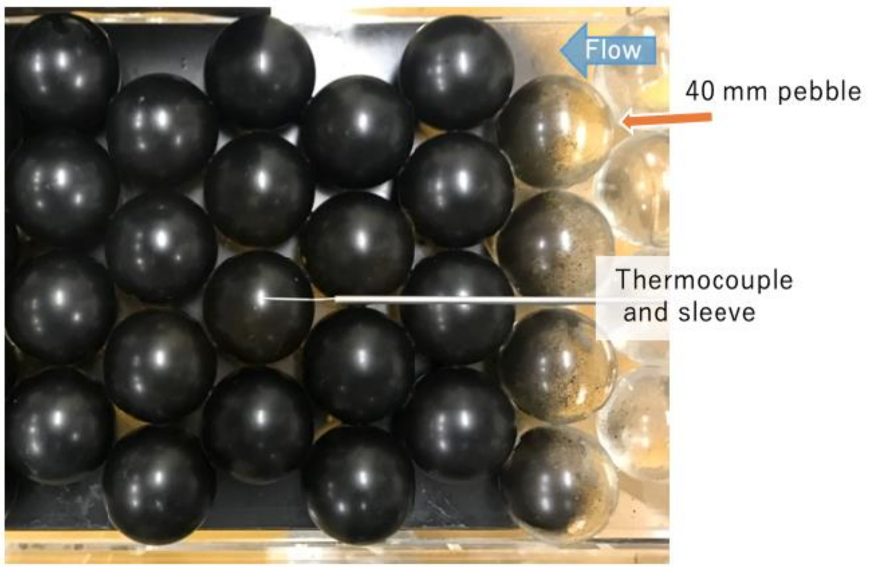



Fig. Location of the thermocouple (x, y=0)

Experimental conditions
Measurement time : 10 s
Heater power : 3.3 kW
Distance from heater to water surface :30 mm

*Flow conditions are the same with PIV experiment.

Table Conditions of the experiment

| U [m/s] | h [mm] | d [mm] | Re [-] | $\theta$ [deg] |
|---|---|---|---|---|
| 0.28 | 30 | 0 | 6361 | 0.15 |
| 0.25 | 31 | 40 | 6043 | 0.30 |
| 0.46 | 34 | 0 | 12019 | 0.80 |
| 0.49 | 30 | 40 | 11348 | 0.80 |

U : Average flow velocity, h : Flow film thickness, Re : Reynolds number, $\theta$ : Inclining angle

# 5.1 Experimental results

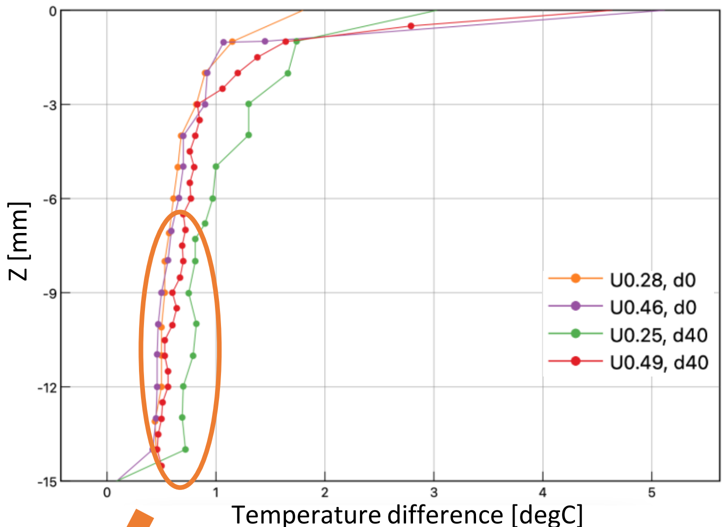



Fig. Distribution of temp. difference from the inlet (X=0)

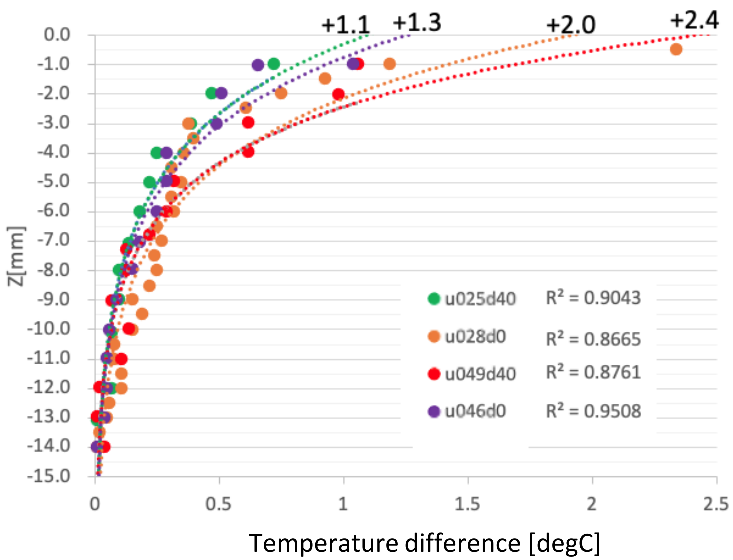
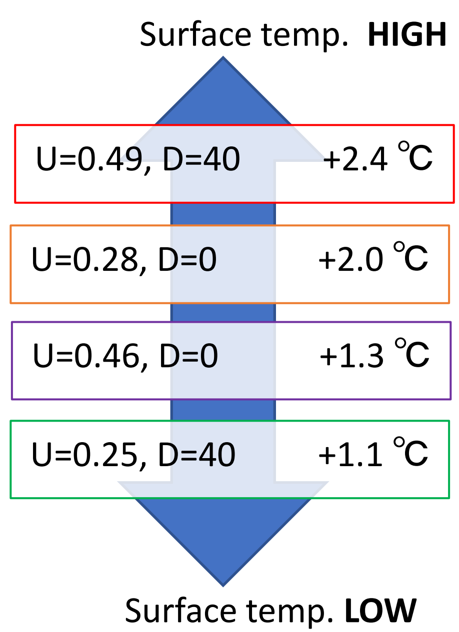



Fig. Surface temperature increase (X=0)

**Evaluation method**

1. Temperature distributions are averaged in Y direction.
2. The distributions approximated by an exponential function.
3. Surface temperatures are assumed.




Temp. increase in the case of U=0.25, D=40 is the lowest. Compared to the similar velocity case without pebble (U=0.28, D=0), temp. increase decreases by 50 %.

On the other hand, temp. increase in the case of U=0.28, D=40 becomes largest even in using pebbles.
→ Needs to redo and re-evaluate.

# 6. Summary

**Objectives** :
Feasibility study of Flibe liquid divertor by flow and heat transport experiments using water as a simulant

Flow visualization experiment

- Water free surface is wavy and difficult to recognize its position precisely.
- Some reflection of laser light from free surface and pebbles disturb PIV analysis.
- The experiment has to be continued and re-evaluated due to being some physically inconsistent.

Heat transport experiment

- Temp. increase of surface could be reduced by 50 % by using pebbles as turbulence promotor.
- The experiment has to be continued and re-evaluated due to being some physically inconsistent.

**Future task**

More precise experiments are needed to evaluate surface temp. increase and influence of pebble-arrayed bed.
Flow visualization experiment and heat transport experiment has to be redone and re-evaluated carefully.

Thank you for your attention.