N-TAC
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Hydrogen Flow in Moderators

Japan Atomic Energy Research Institute
(JAERI)

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Development of Cold Moderator Vessels

- Neutronics design
  (modeling to secure high neutronic performance)
- Mechanical strength design
- Thermal-hydraulic design
- Total system design

To Maintain the mechanical strength of the moderator vessel under supercritical hydrogen conditions of 20K and up to 1.5MPa

To prevent boiling of hydrogen and to suppress hot spots affect neutronic performance such as neutron intensity excessively.

- Utilize impinging jet to removal high heat depositions generated vessel bottom wall near the target
- To suppress the temperature rise of hydrogen in the vessel within 3K, it is necessary to reduce of recirculation and stagnant flows, which cause hot spots in the hydrogen flow.

To prove the feasibility of this concept, thermal-hydraulic analyses, as well as experiments were carried out.

Overview of Flow Visualization Experiments

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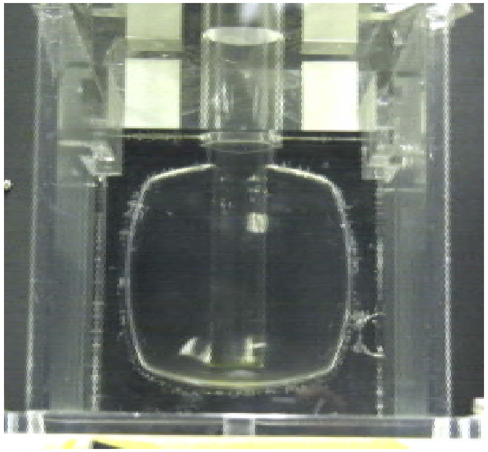
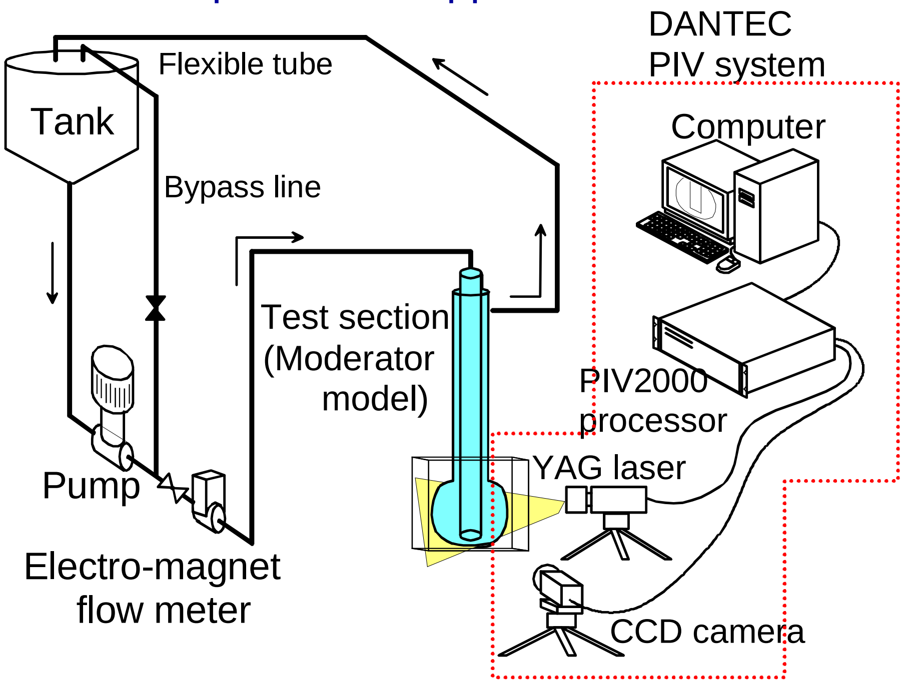
Object

- To clarify the flow pattern
  Flow situations such as recirculation and stagnant flows
- To verify the analysis code
  for good prediction of temperature distributions in the vessel

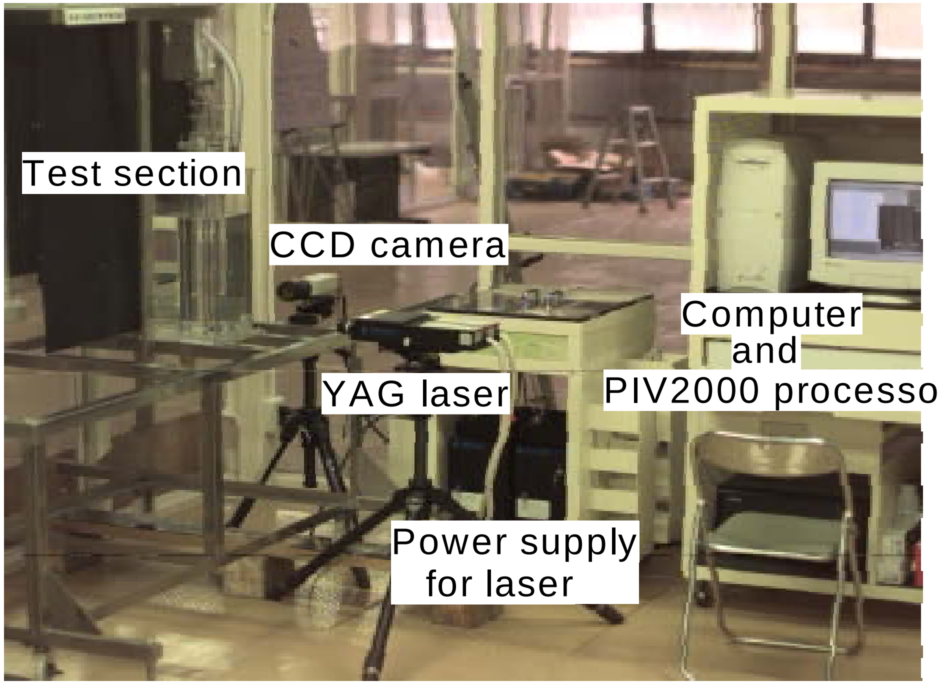
Acrylic models of decoupled(left) and coupled(light) moderator



Experimental apparatus



PIV system overview



Flow Visualization Experiments

(Flat type vessel)

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Experimental conditions

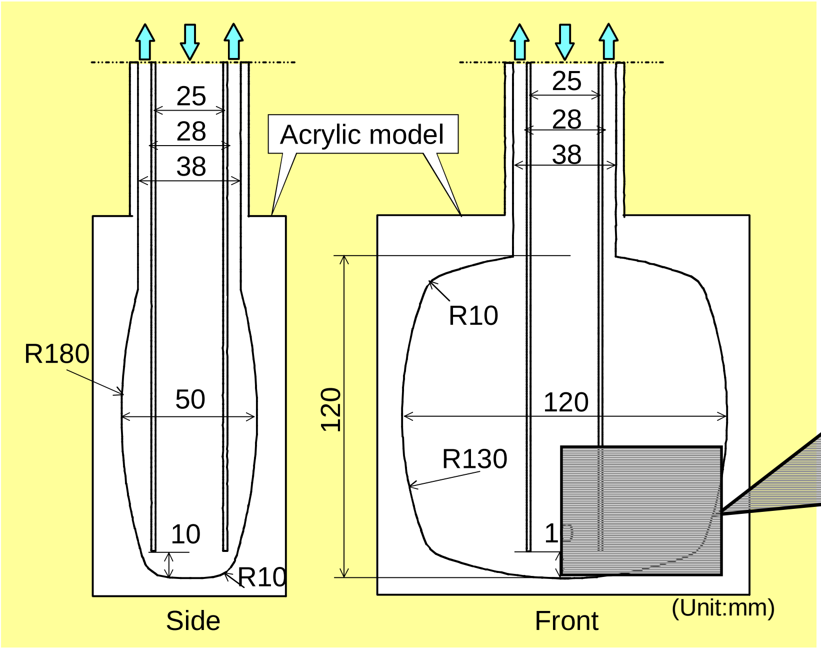
Inlet flow rate :0.25〜1.25L/s
(Inlet flow velocity :0.5〜2.5m/s)
(Reynolds number :1.4×10^4〜7.0×10^4)
Height of inlet pipe :10, 30, 50mm

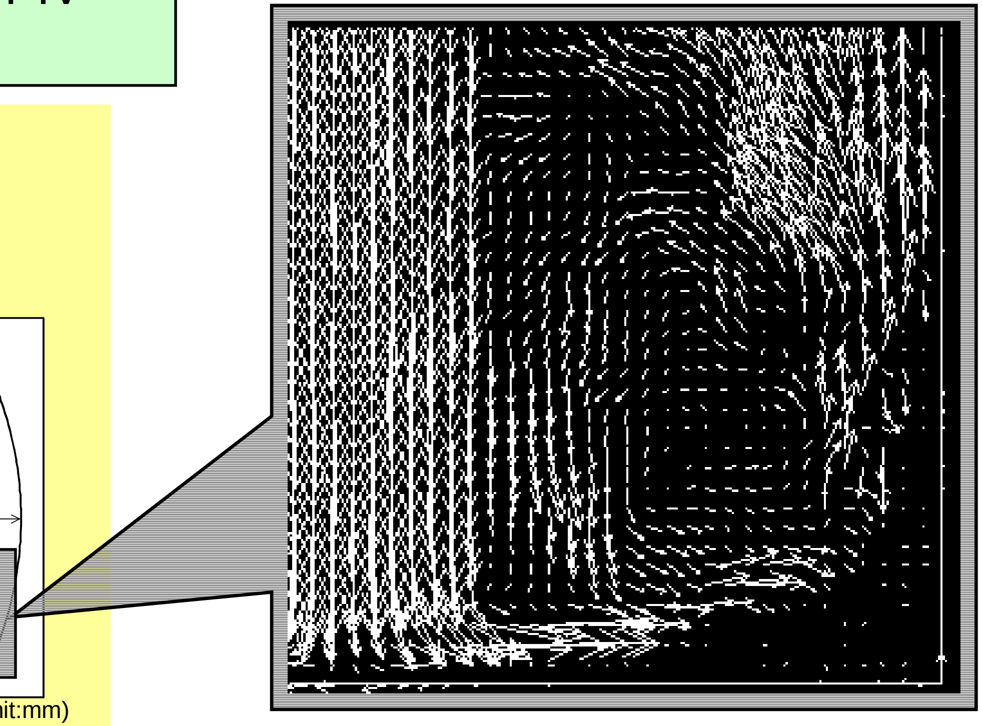
Data processing

100 vector maps measured with PIV were averaged by EXCEL

PIV conditions

Direction of flow	:Parallel with light sheet
Measurement area	:123.8×125.0mm
Lens	:f=60mm
Illuminant	:YAG laser 15mJ/pulse
Pulse interval	:〜100μs
Tracer	:Vinylidene chloride/ acrylonitril particle (ave. 10μm)





An example of vector sampling

Flow Analyses (Flat type vessel)

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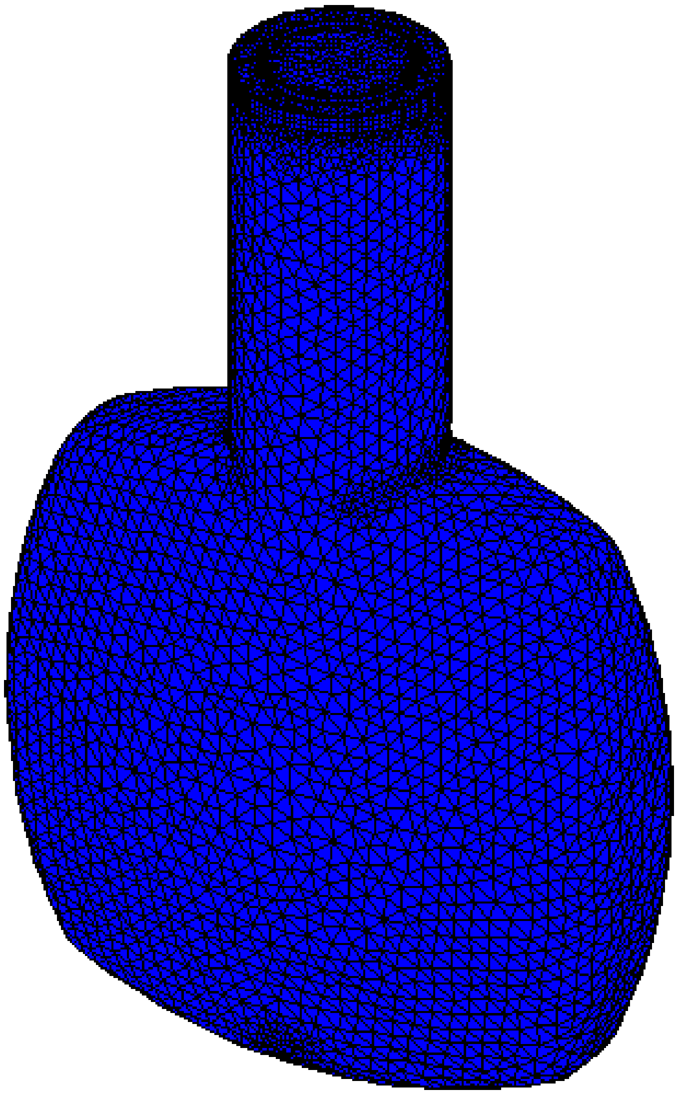
Analytical conditions

Inlet flow rate :0.25〜1.25L/s
(Inlet flow velocity :0.5〜2.5m/s)
(Reynolds number :1.4×10^4〜7.0×10^4)
Height of inlet pipe :10, 30, 50mm

Analytical code :STAR-CD
Analytical scheme :Finite volume method
Solution algorithm :SIMPLE method
Spatial discretisation scheme :MARS
Wall boundary condition :Low of the wall
Turbulence model :(1)Standard k- ε model
(2)RNG k- ε model
(Renormalization Group)
Cell number :〜200,000

Analytical model



Flow Analyses (Flat type vessel)

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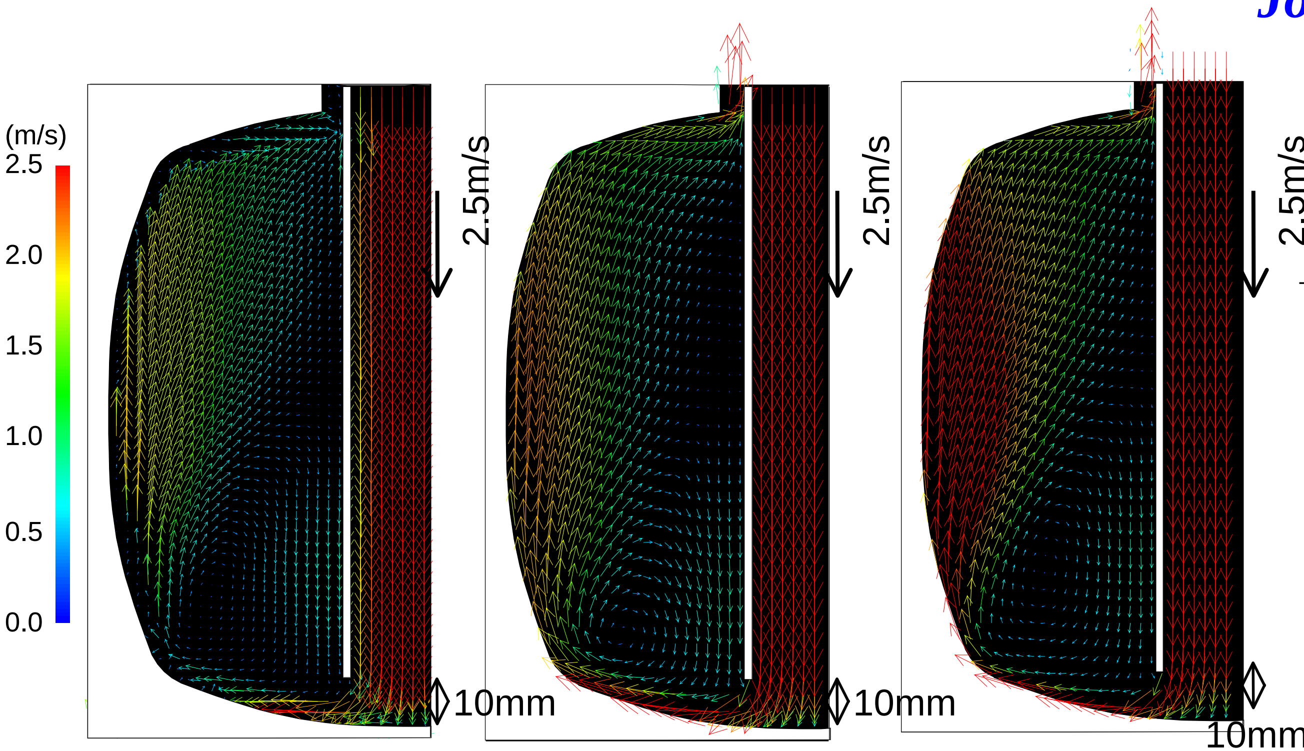
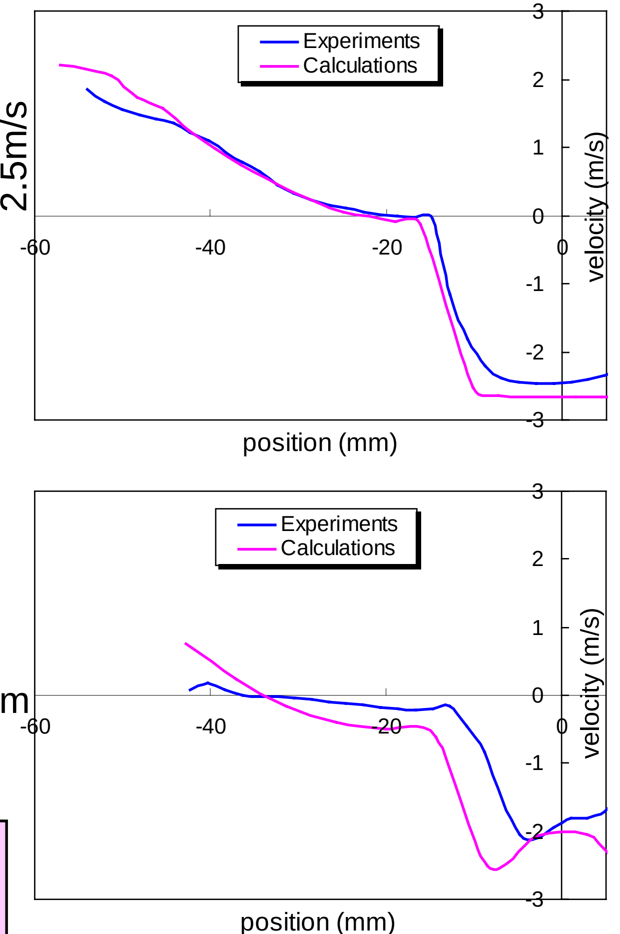


Experimental result
Analytical result ((1)Standard k- ε model)
((2)RNG model)



- Flow patterns (recirculation flow and stagnant region) were clarified.
- Analytical results obtained using standard k- ε model agreed well with experimental results.
- Velocity distributions obtained using RNG k- ε model tended to be higher than experimental results.

Comparison of experimental and analytical velocity distributions at 10mm(down), 60mm(up) in height from bottom of vessel (analysis: standard k-e model)

Thermal-hydraulic Analysis for New Designed Vessel

Based on these experimental and analytical results, the hydrogen velocity and temperature distributions in the moderator vessel of the current design were analyzed under 1MW proton beam condition.

- Analytical conditions

Analytical code :STAR-CD

Analytical scheme :Finite volume method

Solution algorithm :SIMPLE method

Spatial discretisation scheme :MARS

Wall boundary condition :Low of the wall

Turbulence model :Standard k- **ε** model

Size : Optimized dimension

Fluid : Liquid hydrogen

Inlet temperature : 20K

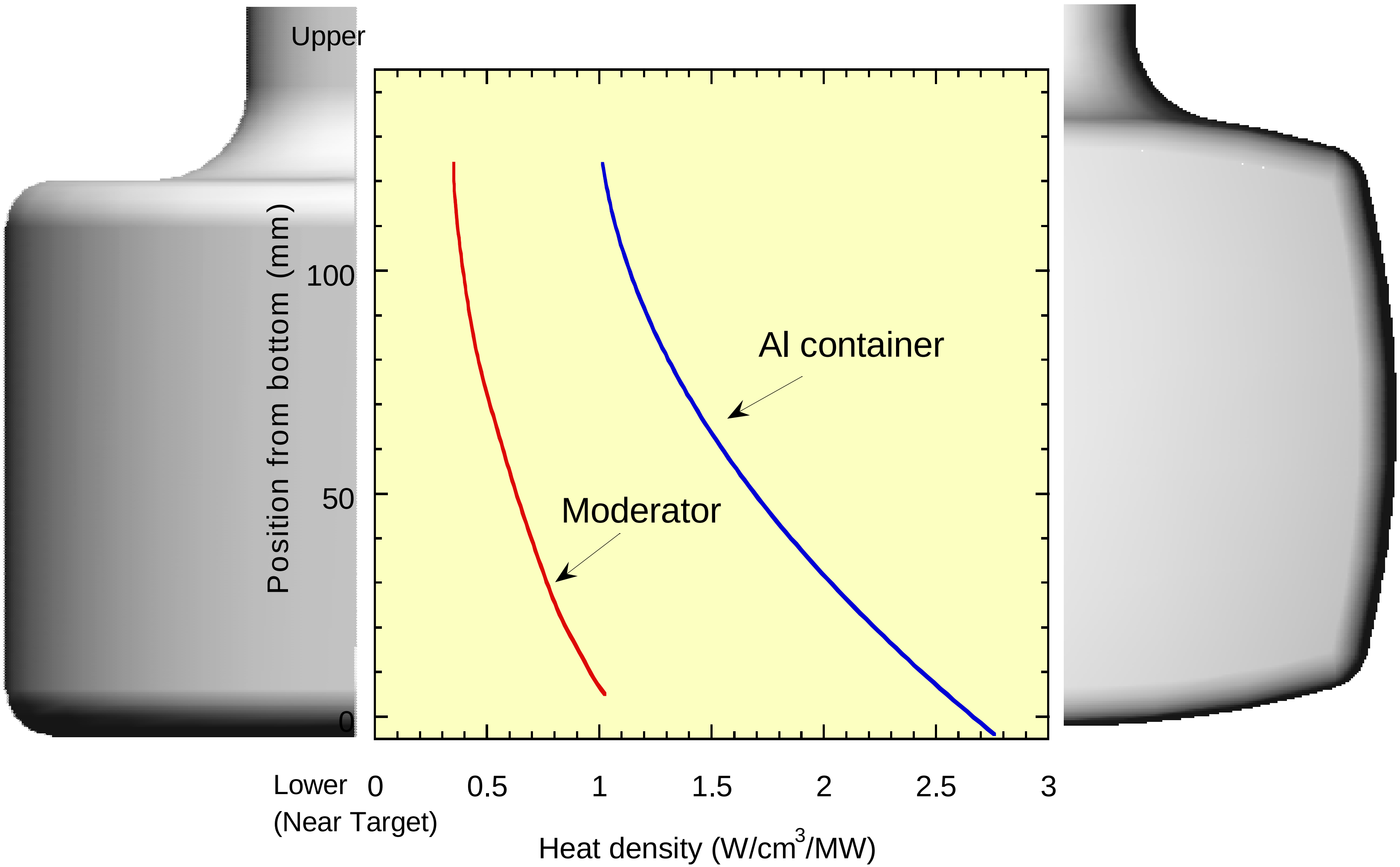
Inlet velocity (Flow rate) :

Coupled moderator 2.36m/s (1.25L/s)

Decoupled moderator 3.73m/s (0.75L/s)

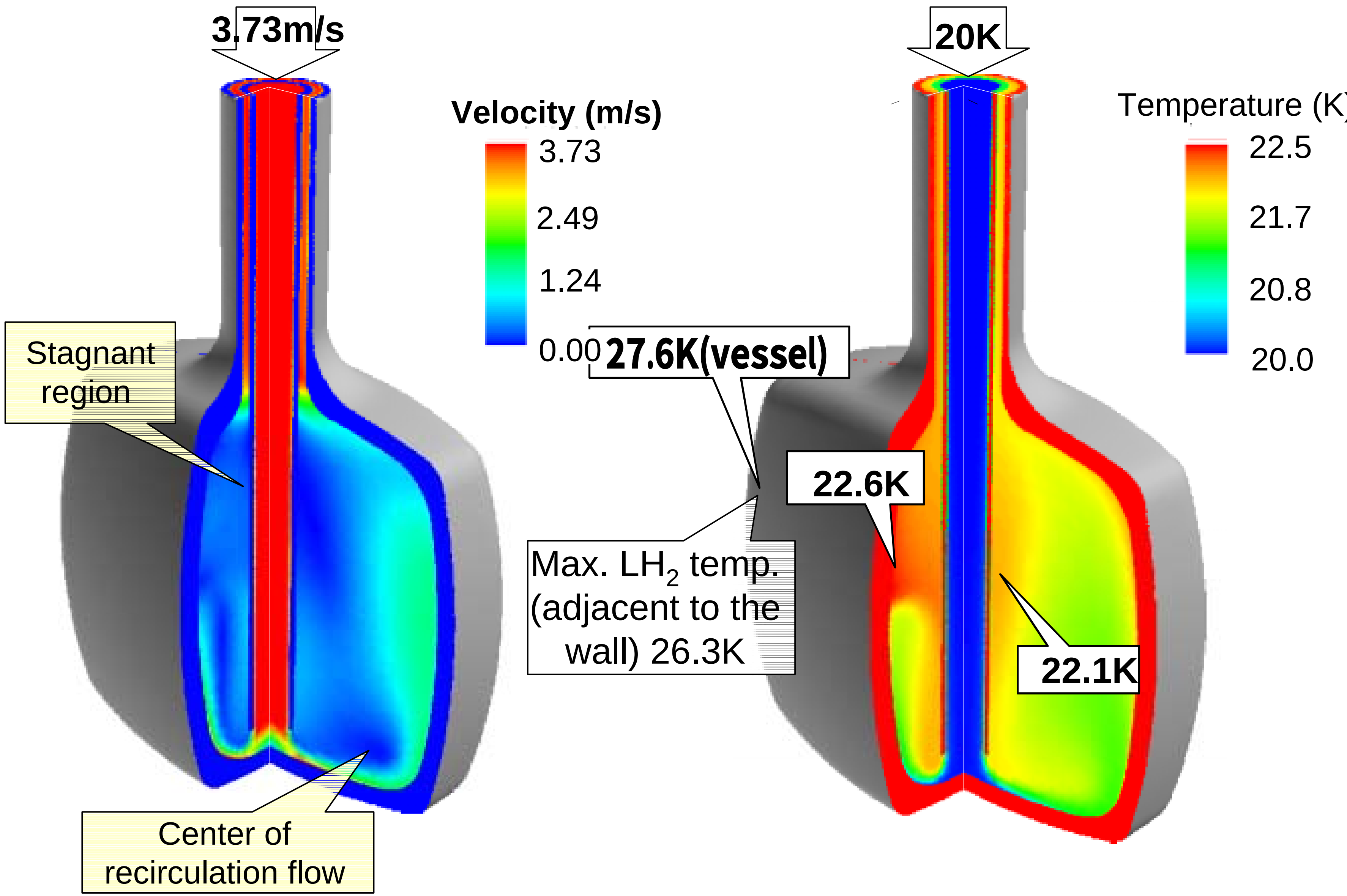
Input heat density of hydrogen and aluminum alloy under 1MW proton beam operation.

Thermal-hydraulic Analysis for New Designed Vessel



Heat density of hydrogen and aluminum alloy under 1MW proton beam operation

Thermal-hydraulic Analysis for Decoupled Moderator Vessel



Thermal-hydraulic Analysis for Coupled Moderator Vessel

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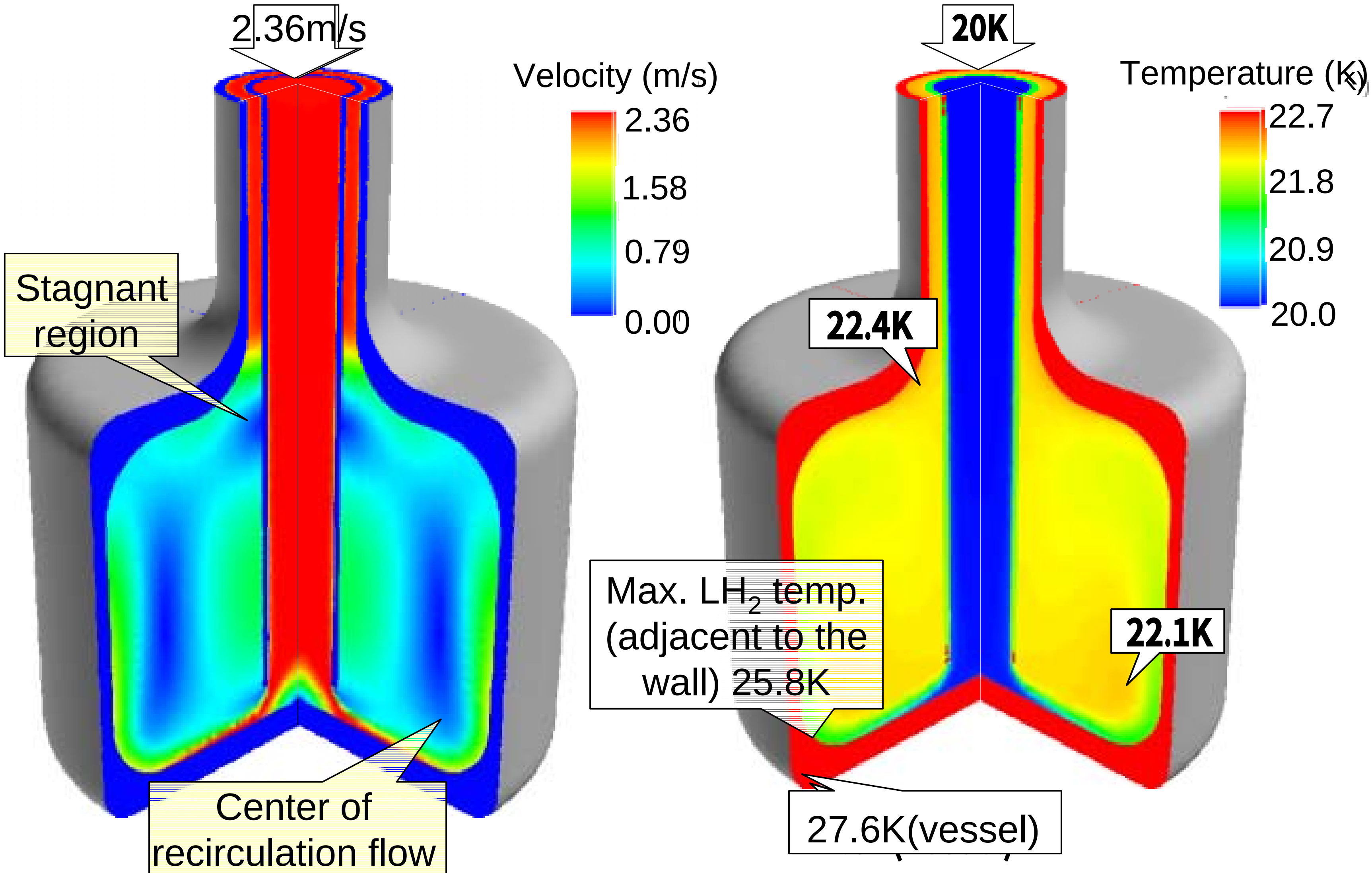

We are going to reanalyze with improved analytical models to estimate temperature distributions more accurately.

Summary

- From results of thermal-hydraulic analyses in the moderator vessels, it was verified that the local temperature rise in the recirculation and stagnant flow regions could be suppressed within 3K. The hydrogen temperature was increased up to 26K adjacent to the vessel surface due to nuclear heating of the vessel, but this hot layer would not affect the neutronic performance because its thickness was very thin (less than 0.3mm).

- We are going to evaluate to analyze using optimized analytical conditions such as turbulent model, calculation raw of near wall and properties of hydrogen.

Appendix

Flow Visualization Experiments
(Flat type vessel)

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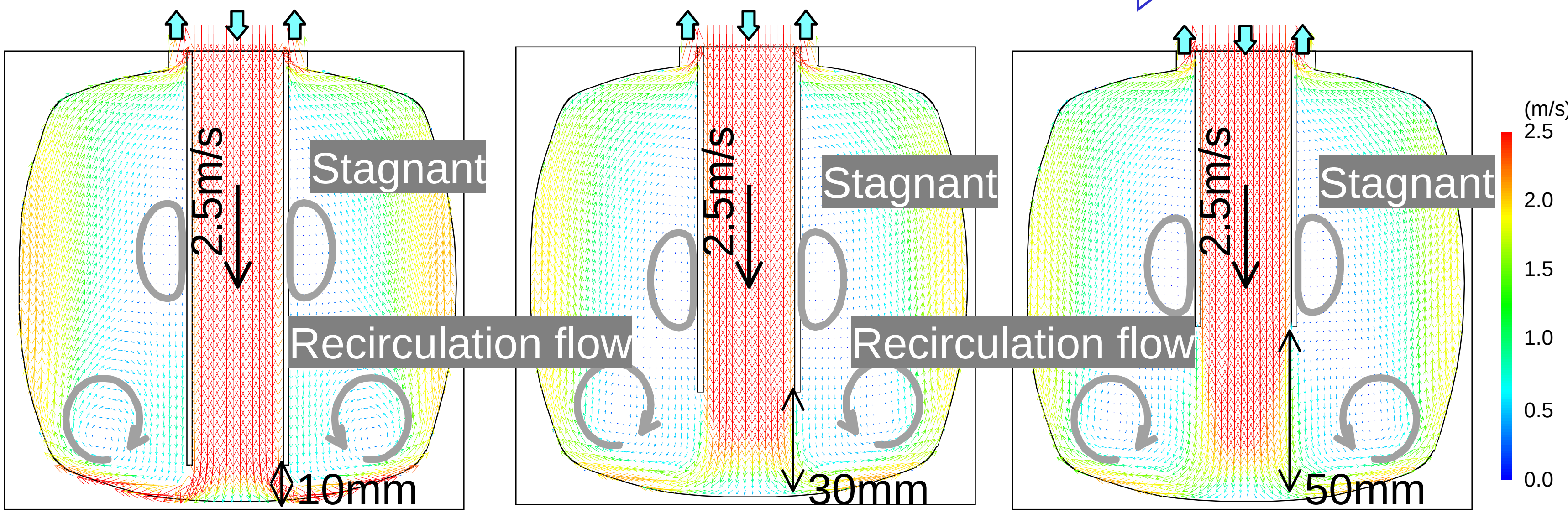
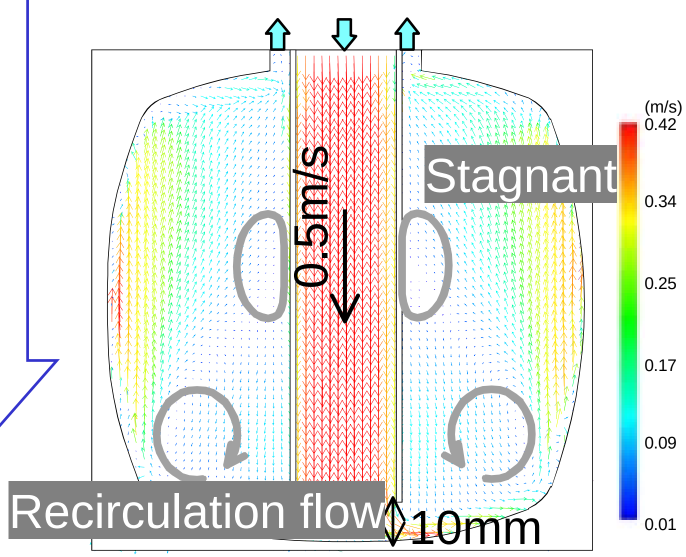
Parameter

Height of inlet pipe

Jet velocity





- Flow patterns (recirculation flow and stagnant region) were clarified.
- There was no significant difference in relative flow patterns with changing parameters.
- However, heat removable performance will be reduced by reduction of velocity around bottom and wall with high inlet pipe or low jet velocity.

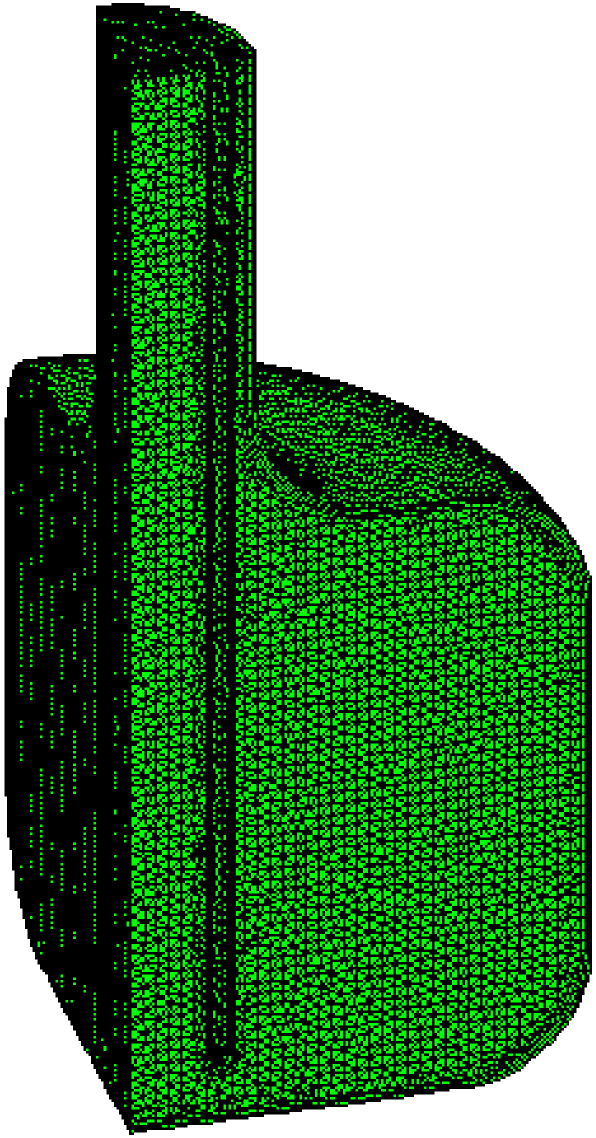
Flow Analyses (Cylindrical type vessel)

Experimental conditions

Inlet flow rate :0.5～1.5L/s
(Inlet flow velocity :1.0～3.0m/s)
(Reynolds number :2.8×10^4～8.4×10^4)
Height of inlet pipe :5～50mm
Inner dia. of inlet pipe :10, 25mm

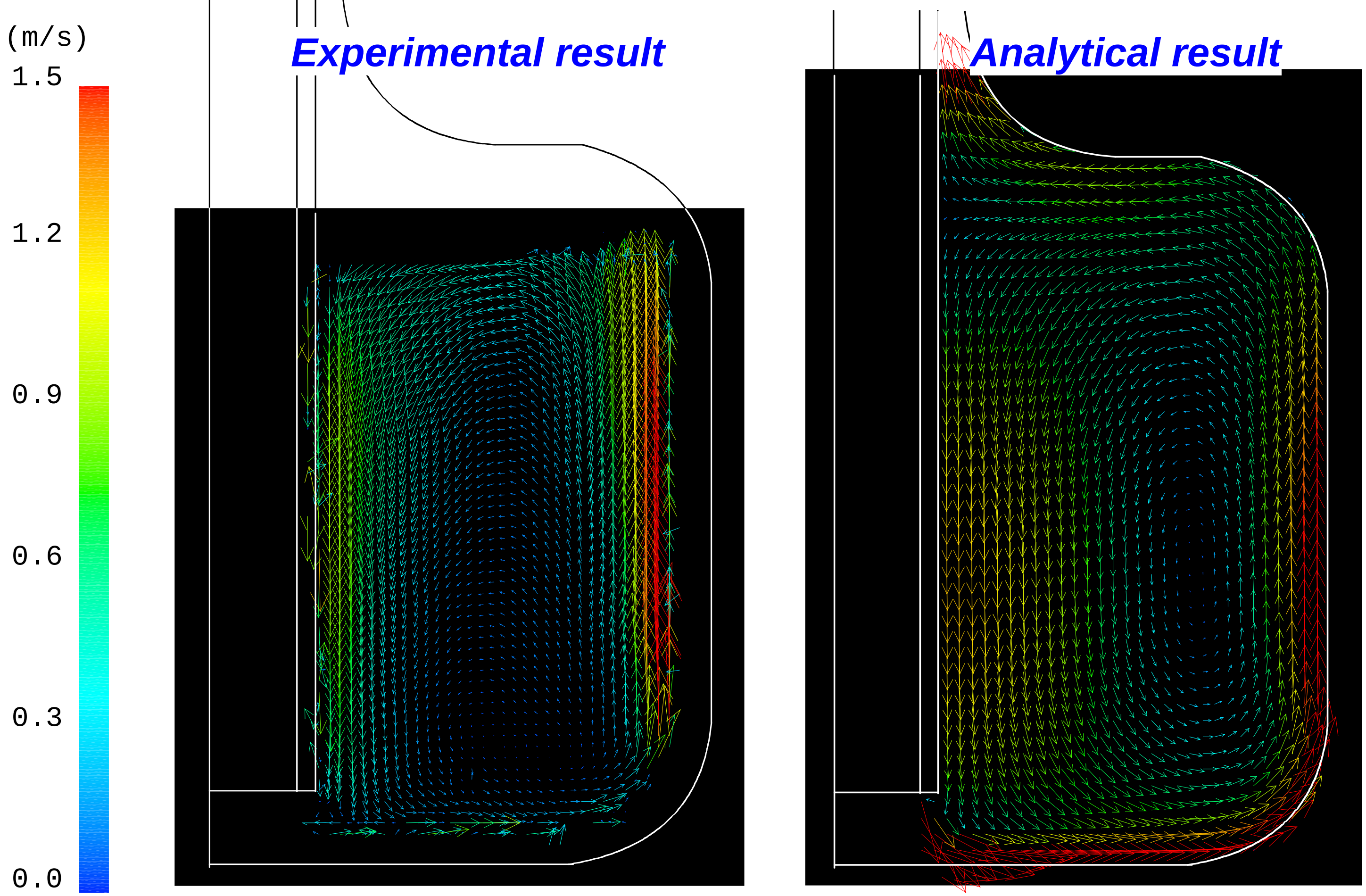
Analytical code :STAR-CD
Analytical scheme :Finite volume method
Solution algorithm :SIMPLE method
Spatial discretisation scheme :MARS
Wall boundary condition :Low of the wall
Turbulence model :Standard k- ε model
Cell number :～390,000

Analytical model



Experimental and Analytical Results of Velocity Distributions (1)

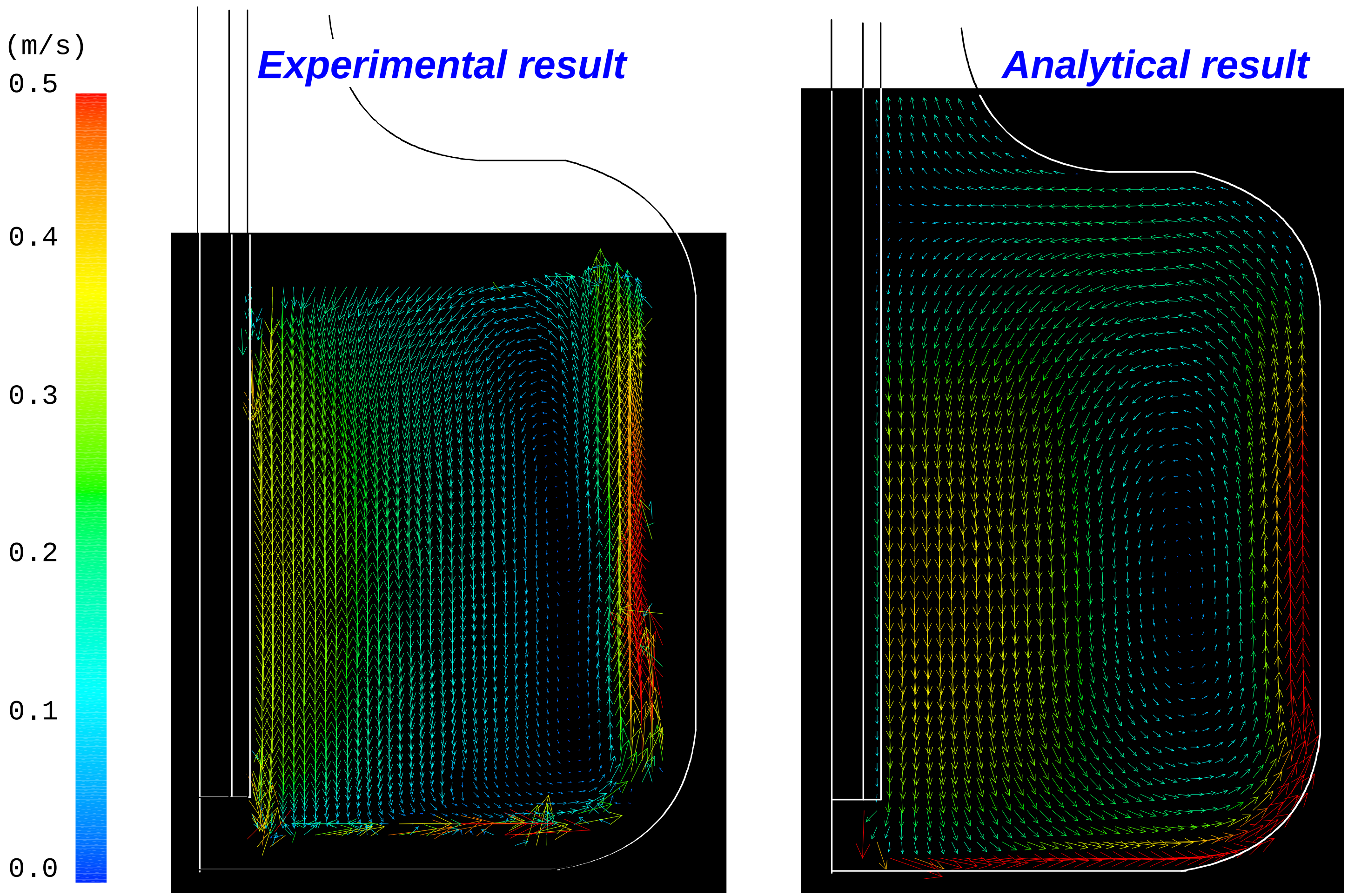
Inlet flow rate :1.5L/s (v=3m/s, Re= 8.4×10^4 at inlet-pipe outlet)
Inner diameter of inlet pipe :25mm , Height of inlet pipe :10mm



Experimental result does not agree well with the analytical result.
We are going to improve the analytical model by using other turbulent models such as the RNG and nonlinear models.

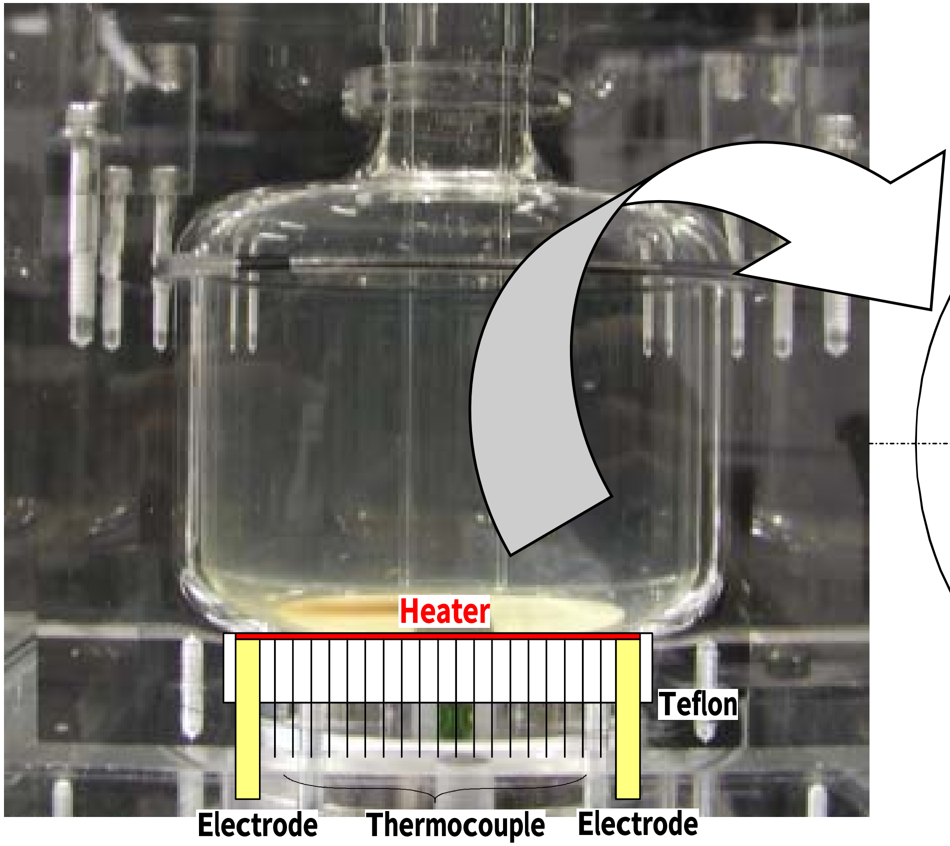
Experimental and Analytical Results of Velocity Distributions (2)

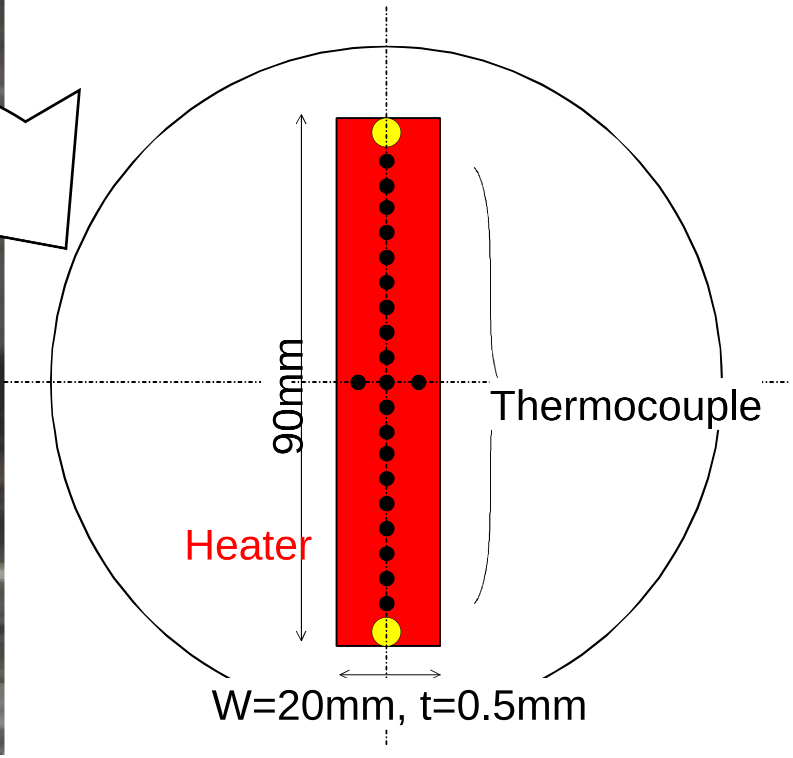
Inlet flow rate :0.23L/s (v=3m/s, Re= 3.4×10^4 at inlet-pipe outlet)
Inner diameter of inlet pipe :10mm, Height of inlet pipe :10mm



Heat Transfer Experiments under Impinging Jet in Limited Space

Heat transfer experiments on the bottom surface is being carried out with a real-scale model to verify analytical temperature distributions obtained under the flow field combined with impinging jet and its induced flow.



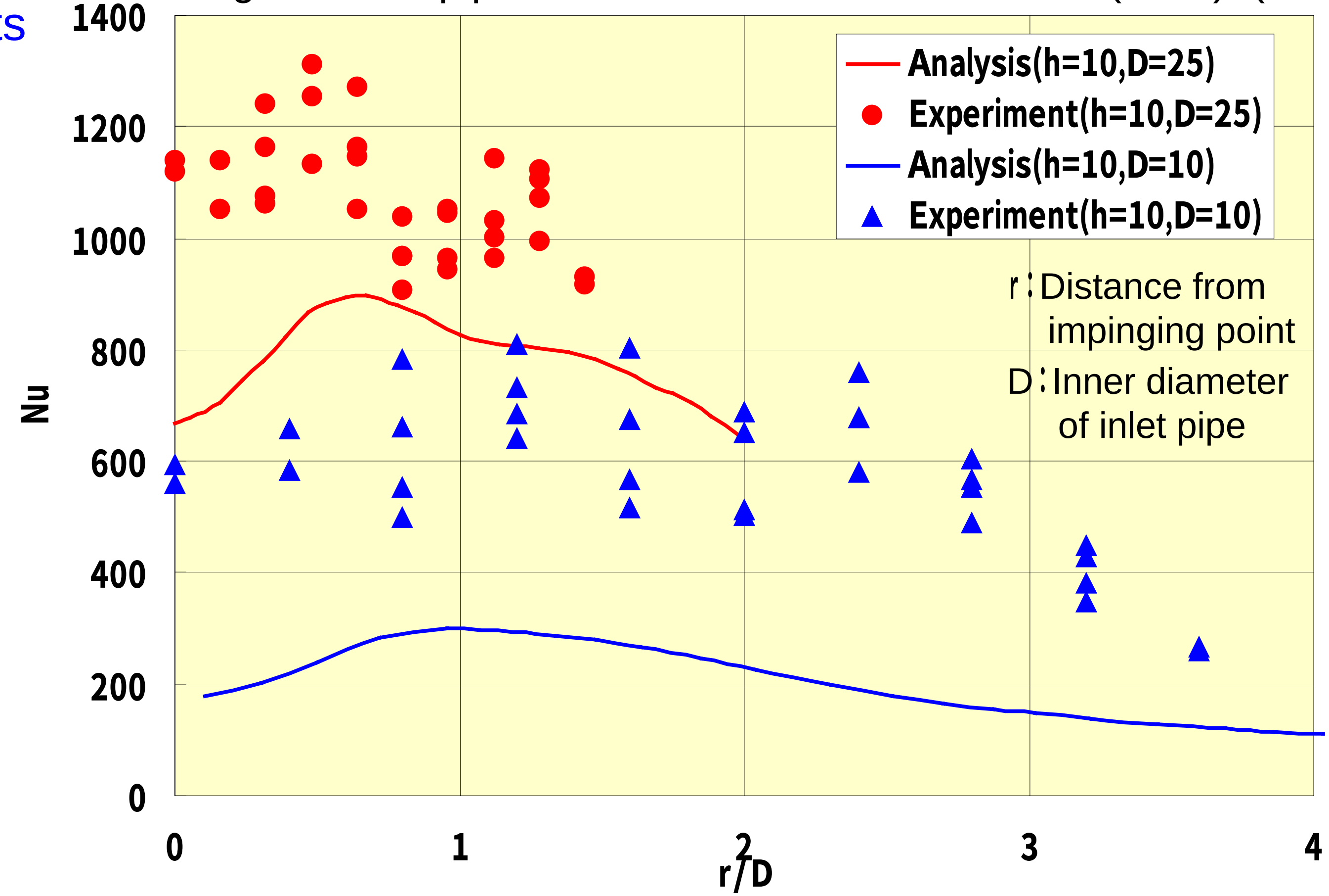


Preliminary Experimental and Analytical Results

- Conditions

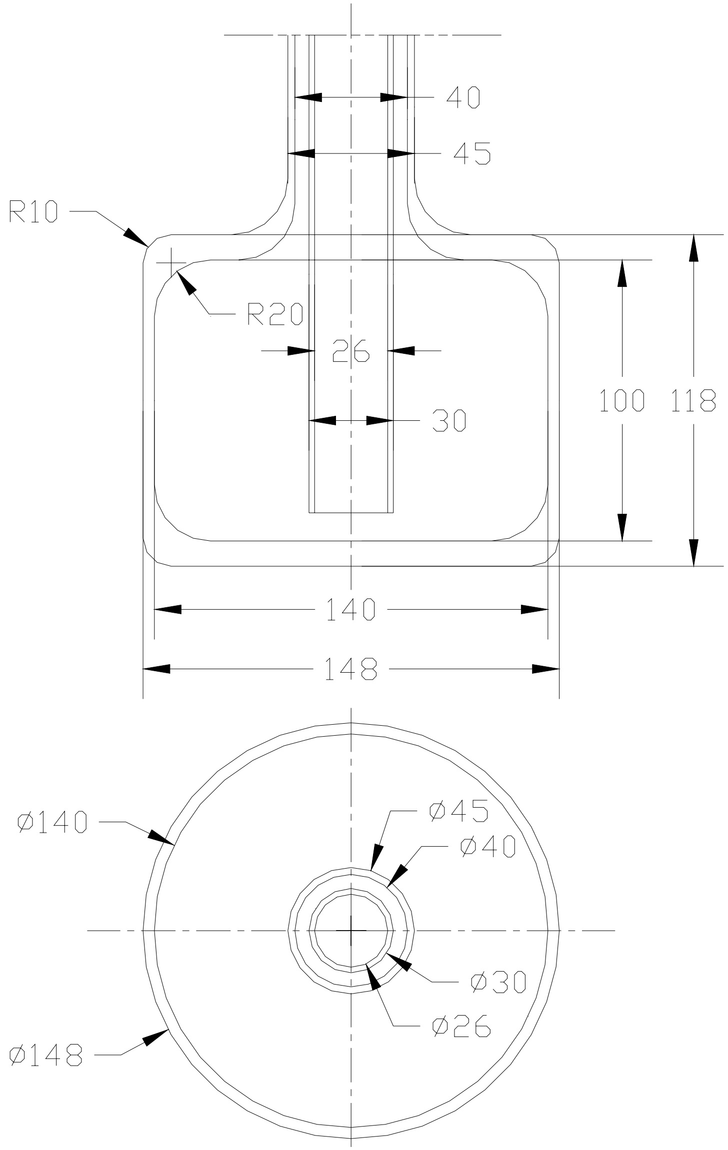
Inlet flow rate : 1.5L/s (Inner diameter of inlet pipe :25mm)
0.23L/s (Inner diameter of inlet pipe :10mm)
Height of inlet pipe : 10mm, Heater Current :120A(max.) (～260W)

- Results



Analytical results obtained with the standard k-e turbulent model were lower than the experimental results (conservative results). We are going to improve analytical models so as to estimate flow and temperature fields clearly on the basis of experimental results.

Drawing of Coupled Moderator Vessel



Drawing of Decoupled Moderator Vessel

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