Modelling and experimental validation of natural convection heat loss from a solar hot water storage tank

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BACKGROUND

- **Operating cycle of an active solar water heating system**
  - Charging
  - Static
  - Discharging

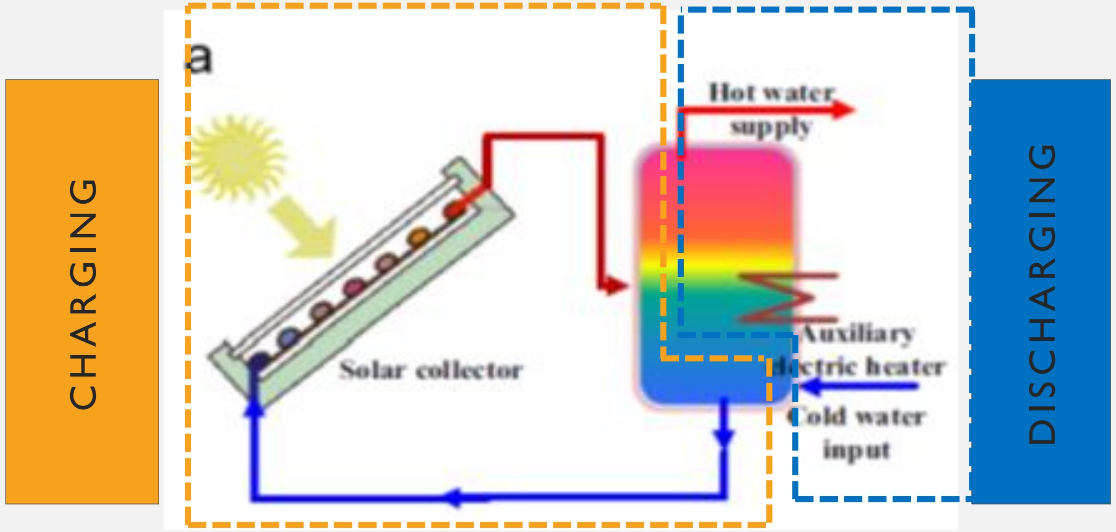
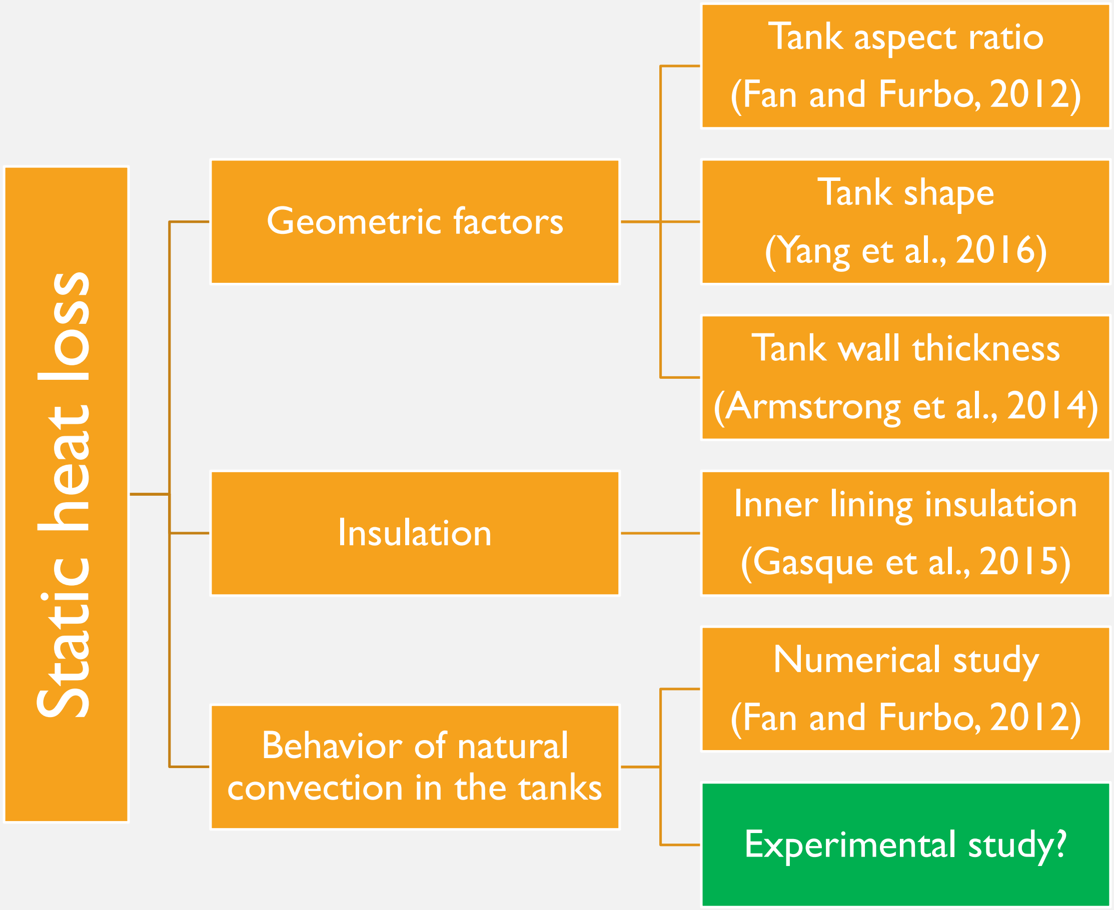


Figure 1. Operation of active-direct heating system (Li 2016)

LITERATURE GAP

- Thermal performance of solar hot water storage tanks



METHODOLOGY

- Experimental methodology
  - Transient heat loss during static operation
  - Initial condition
    - Hot water at uniform temperature (40˚C)
  - Boundary condition
    - Convection losses to still air
  - Measurements
    - Vertical temperature profile
    - Boundary layer velocity profile

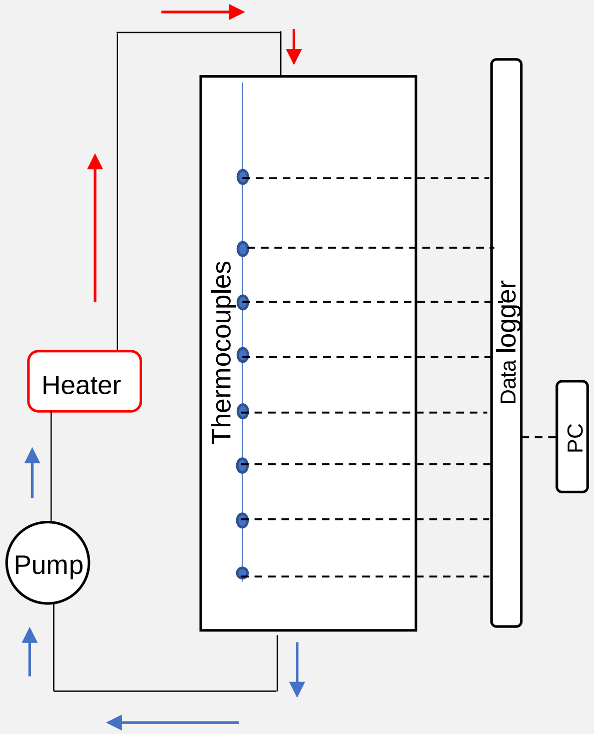


Figure 2. Experimental setup for temperature profile measurement

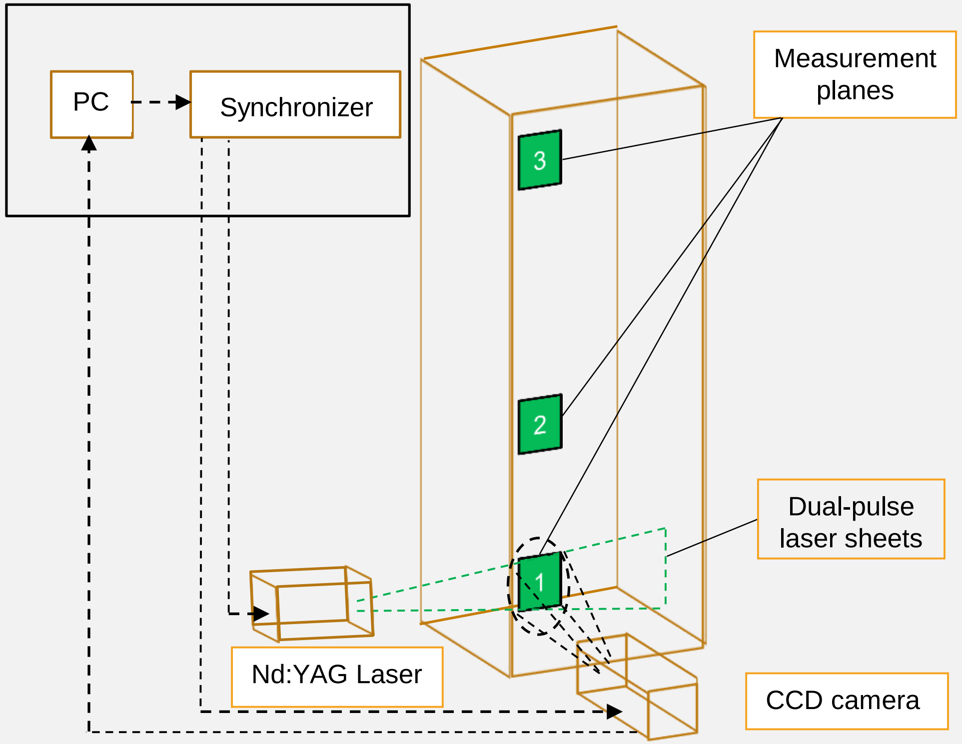


Figure 3. Experiment setup for boundary layer velocity profile measurement

METHODOLOGY

- Numerical methodology
  - 3-D Computation Fluid Dynamics (CFD) model
  - Initial condition
    - Hot water at uniform temperature (40˚C)
  - Boundary condition
    - Fitted experimental temperature data to specify the convective heat loss coefficients of each section
  - Flow regime
    - Laminar (Ra< 10^13)

      (Vliet and Liu, 1969; Kang and Chung, 2010)
  - Validation
    - Vertical temperature profile
    - Boundary layer velocity profile

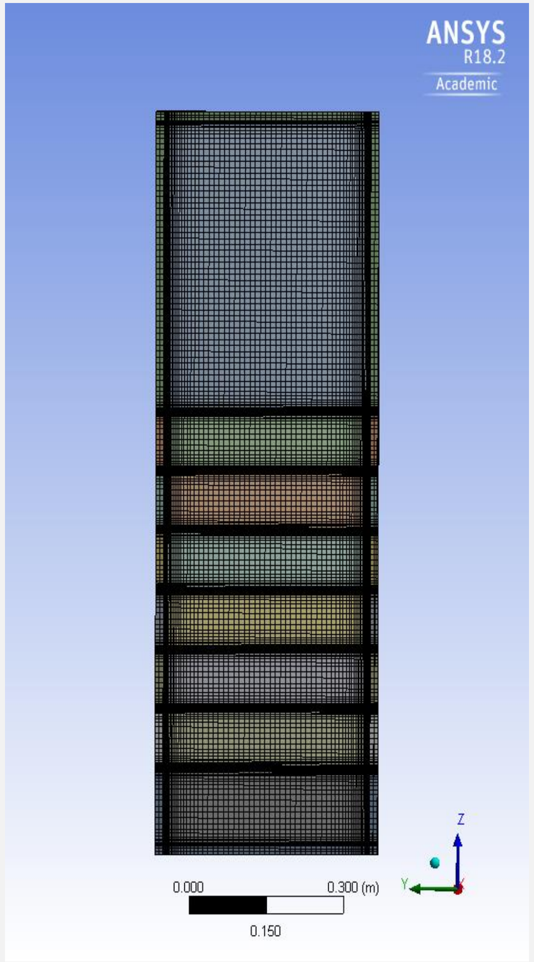


Figure 4. Numerical CFD model

RESULTS

- Vertical temperature profile

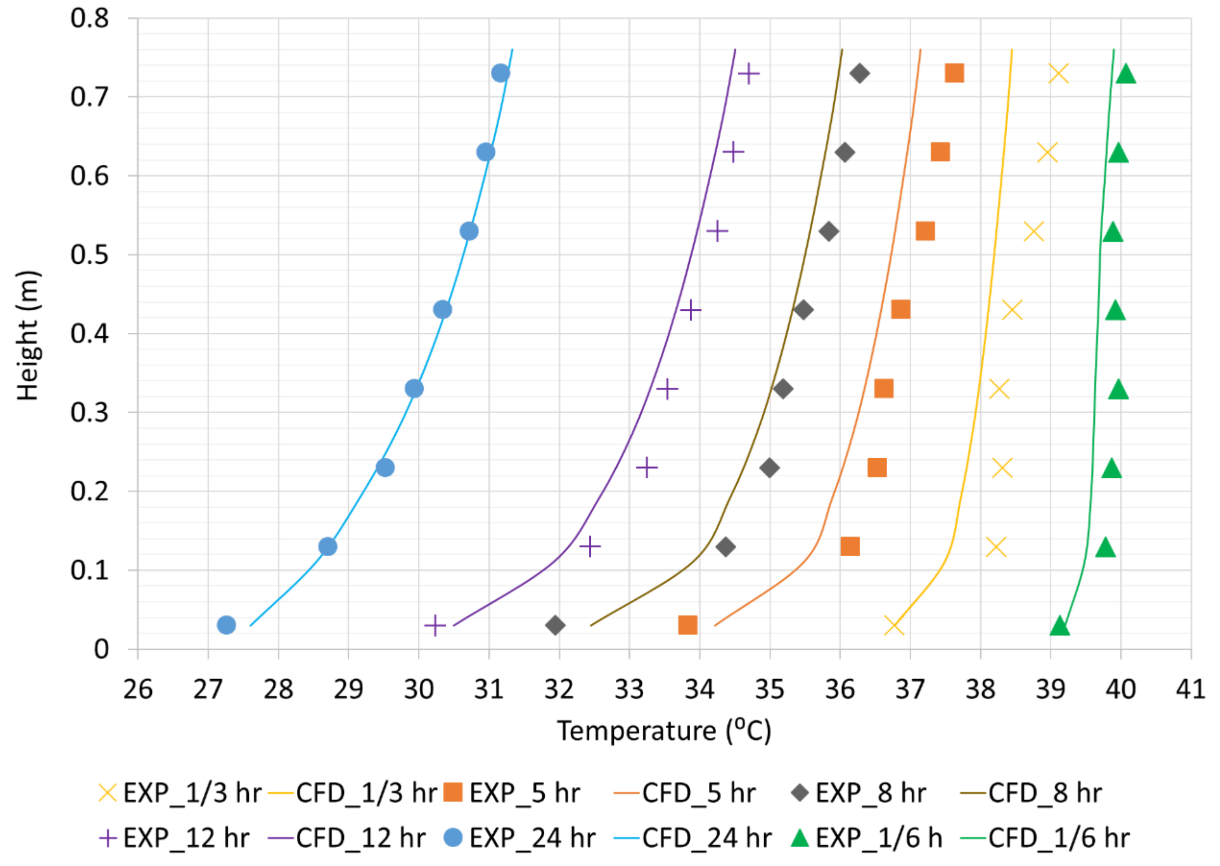


Figure 5. Vertical temperature profile validation of CFD model

RESULTS

- Boundary layer velocity profile
  - Detachment of boundary layer into the center (Bottom plane 1)

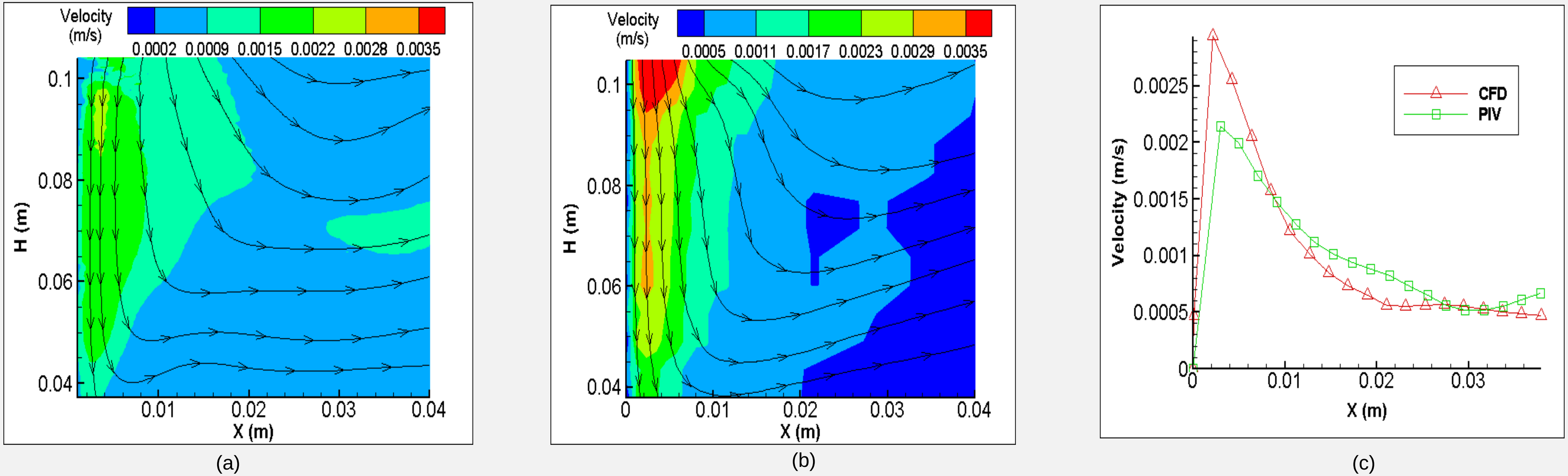
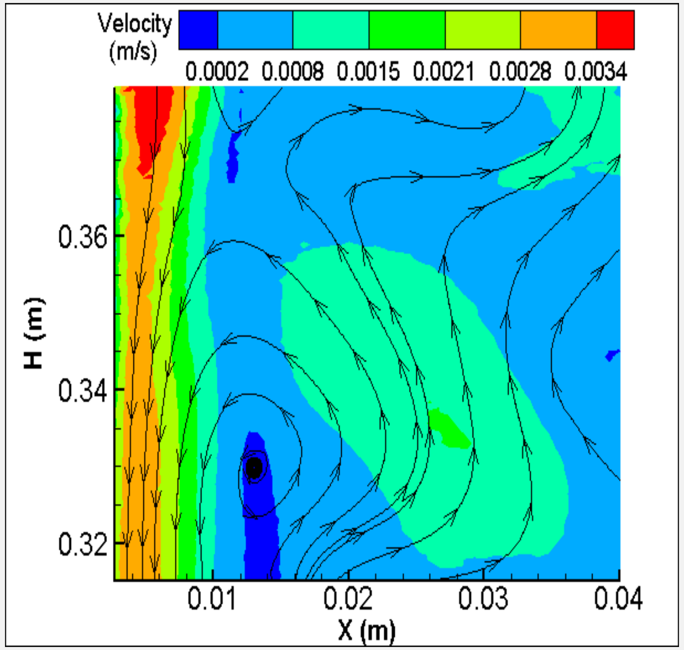


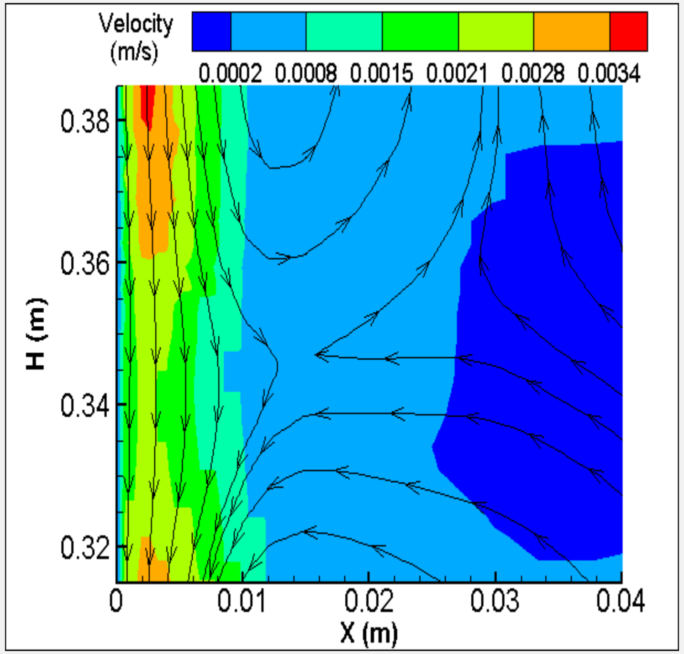
Figure 6. (a) Velocity field from experiment (left), and **(b)** CFD model (middle) at plane 1, **(c)** Velocity magnitude along X = 0-37 mm at H = 80 mm after 10 min of cooling

RESULTS

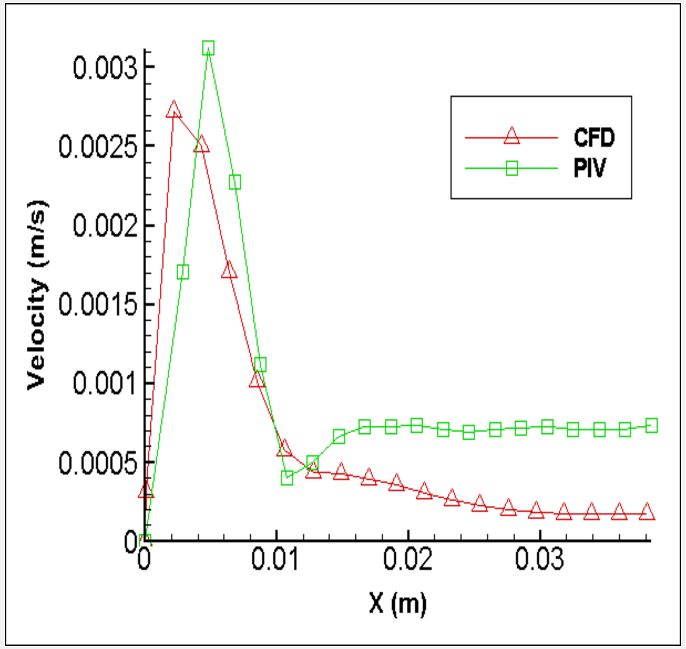
- Boundary layer velocity profile
  - A downward flow of cold water in the boundary layer and an upward flow of hot water far from the sidewall (Middle plane 2)



(a)



(b)

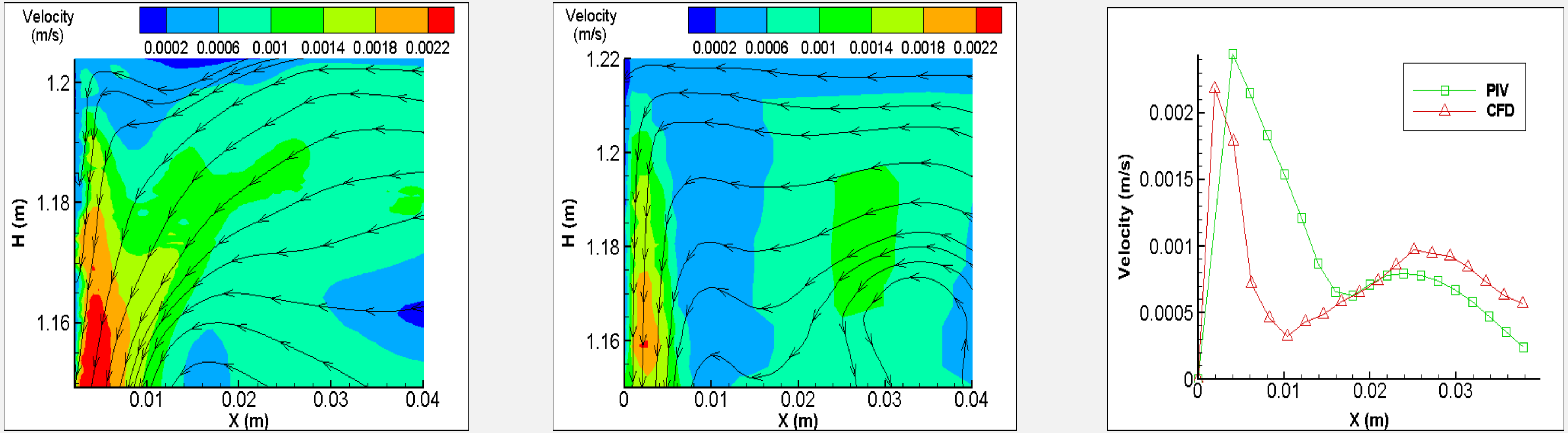


(c)

Figure 7. (a) Velocity field from experiment (left), and **(b)** CFD model (middle) at plane 2, **(c)** Velocity magnitude along X = 0-37 mm at H = 360 mm after 30 min of cooling

RESULTS

- Boundary layer velocity profile
  - Formation of the velocity boundary layer near the wall (Top plane 3)

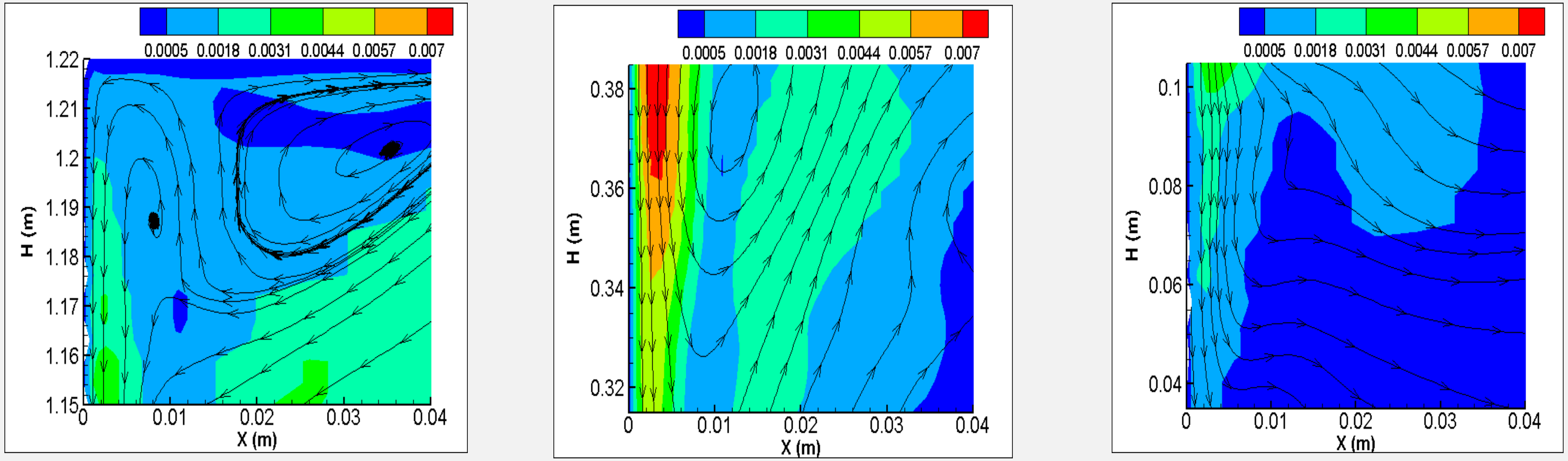


(a) (b) (c)

Figure 8. (a) Velocity field from experiment (left), and **(b)** CFD model (middle) at plane 3, **(c)** Velocity magnitude along X = 0-37 mm at H = 1160 mm after 80 min of cooling

RESULTS

- Flow characteristics of natural convection induced by static heat loss (CFD model)
  - Formation of velocity thin boundary layer at the top (1-3 mm/s)
  - A downward flow of cold water in the middle (3-7 mm/s) with thick boundary layer and an upward flow of hot water far from the sidewall
  - Detachment of thin boundary layer at the bottom (1-3 mm/s)



(a) (b) (c)

Figure 9. Velocity contours from CFD model after 10 min of cooling at **(a)** Plane 3, **(b)** Plane 2, **(c)** Plane 1

CONCLUSION

- Characterised natural convection behaviour in a rectangular storage tank subjected to static heat loss using PIV and a validated CFD model.
- Good agreement between predicted CFD model and experimental data
- Low flow velocities at the top and bottom of the tank, while in the middle, flow velocities are notably higher
- Thick boundary layer in the middle section, while at the top and bottom, it is thinner
- Observed variations could be very useful in developing new measures to reduce heat loss

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