ICARST 2017

ID: B01-04

Application of Radioactive Particle Tracking (RPT) and Densitometry for Measuring Liquid Velocity Fields and Void Fraction in Convective Boiling Flows

Ashutosh Yadav[1], Harish Jagat Pant[2] and Shantanu Roy[1]

1: Department of Chemical Engineering, Indian Institute of Technology - Delhi, New Delhi 110016, India

2: Isotope and Radiation Application Division, Bhabha Atomic Research Centre, Mumbai 400085, India

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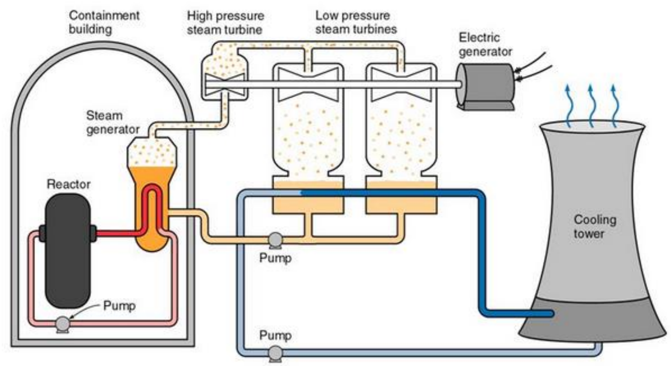
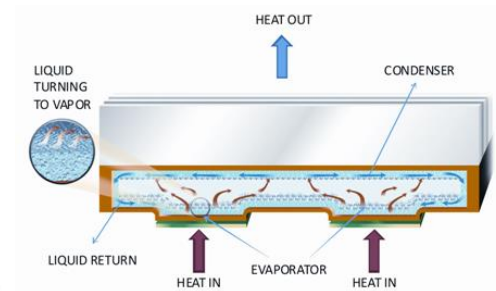
Introduction

- Boiling flows are observed in evaporators, boilers, distillation towers, chemical reactors, condensers, oil pipelines, nuclear reactors, electronic cooling.



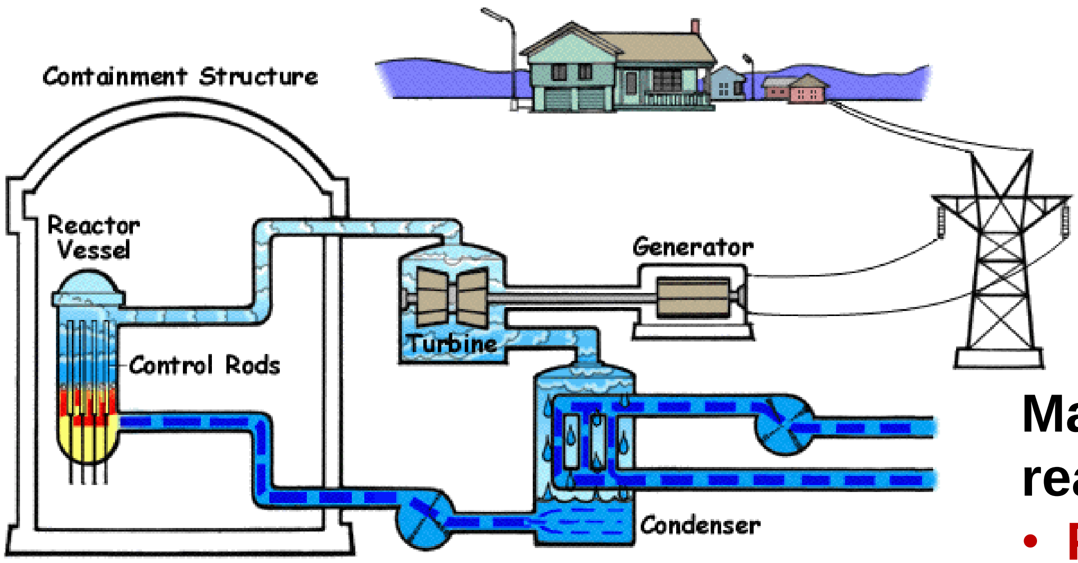


- Phase change by boiling or evaporation is a highly efficient heat transport mechanism.
- Boiling flow is a complex multiscale phenomena.

*http://www.thermacore.com/news/cooling-high-power-electronic-components-in-small-packages-1.aspx
http://www.engineeringoil.com/page.php?cateid=908

Nuclear Power Reactors

Nuclear reactors produce thermal energy that can be converted into mechanical energy and ultimately, into electrical energy with the help of steam turbines.



Main components:

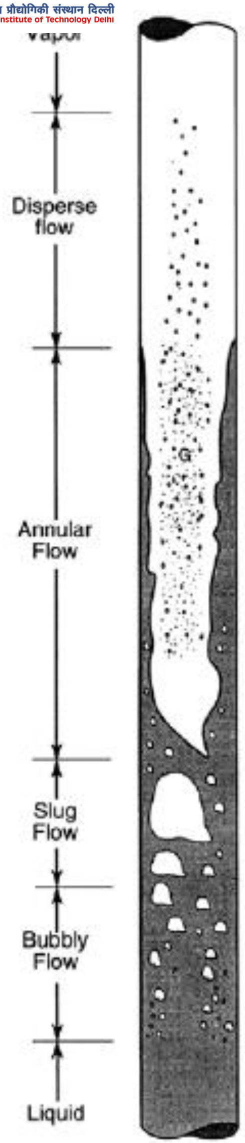
i. Core
ii. Coolant
iii. Containment
iv. Moderator

Main commercial nuclear reactors:

- **Pressurized Water Reactor (PWR)**
- **Boiling Water Reactor (BWR)**
  - **Forced Circulation**
  - **Natural Circulation**

http://www.nrc.gov/reading-rm/basic-ref/students/animated-bwr.html)

Forced Convective Boiling Flow



Vapor single-phase flow

The liquid phase is completely evaporated.

Mist flow

A sharp decrease in the heat transfer coefficient.

Annular flow

Core of the flow consists of vapor only, and liquid adjacent to the walls.

Slug flow

Bubbles coalesce into slugs of vapor. Moderate mass qualities.

Bubbly Flow

Individual bubbles.

Liquid single-phase flow

Liquid is sub-cooled and heat transfer to the liquid is by forced convection.

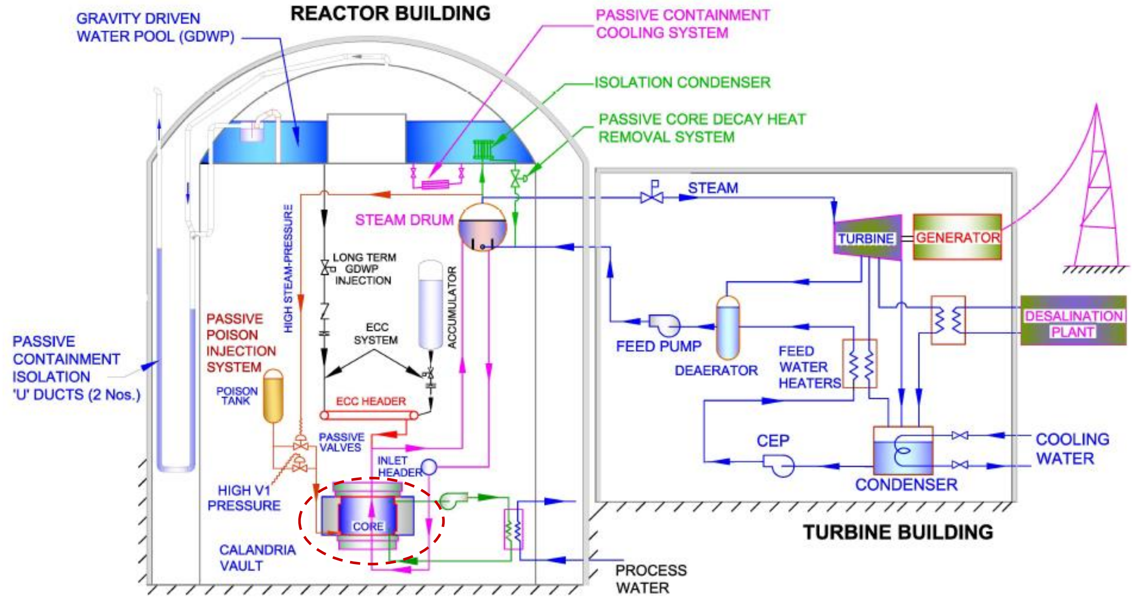
N. I. Kolev, *Multiphase Flow Dynamics 4: Nuclear Thermal Hydraulics,* Springer (2009).

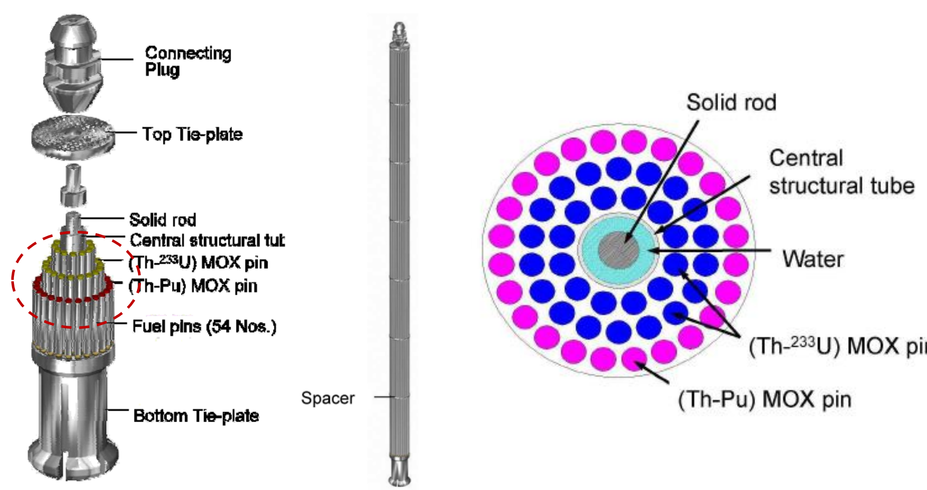
Advanced Heavy Water Reactor (AHWR)

- **India has developed the (AHWR), based on boiling water NC cooling, for exploiting the huge thorium reserves**

- **No need for the installation, operation and maintenance of pumping devices, e.g. recirculation pumps**

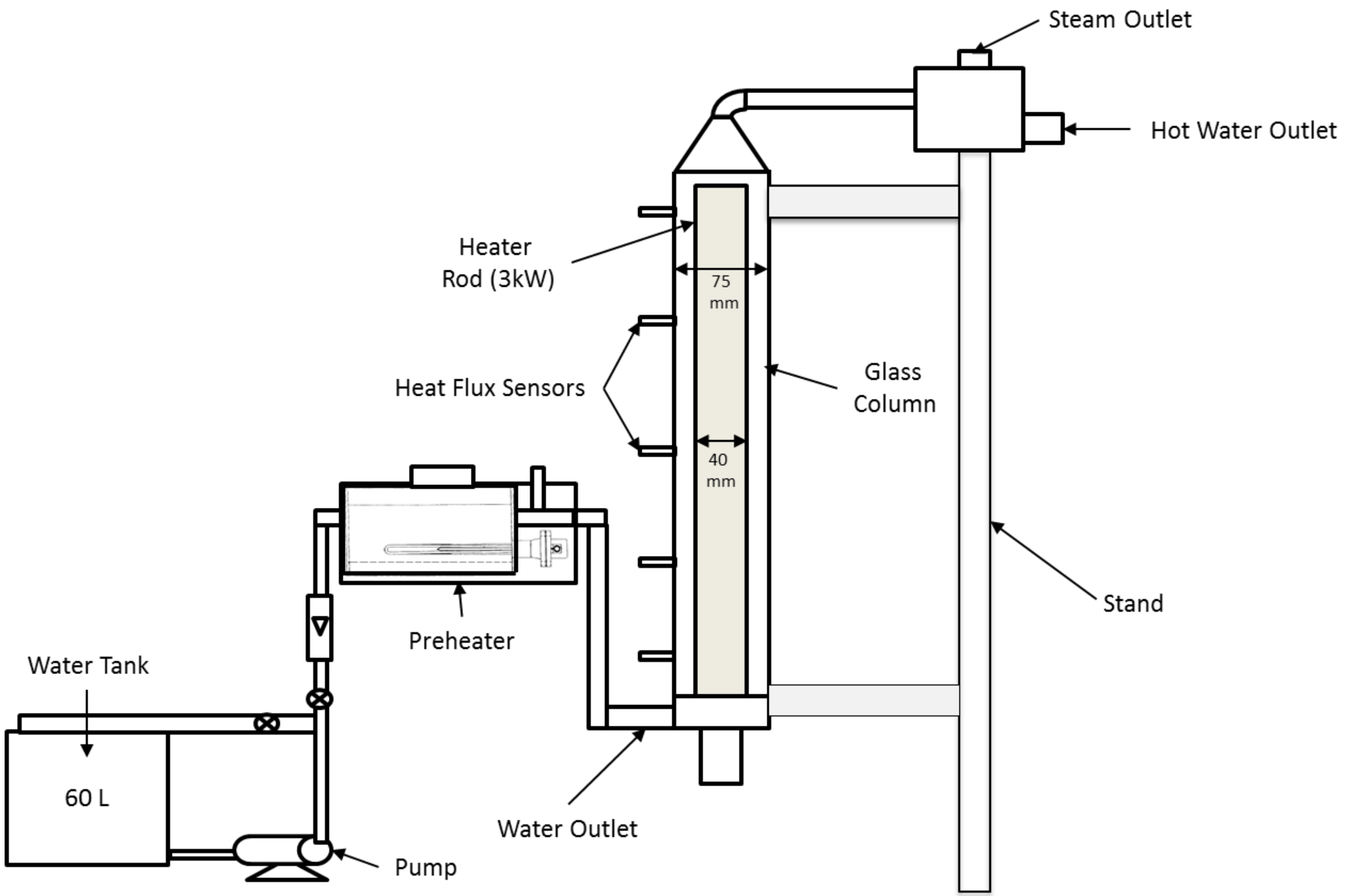
- **Large heat sink in the form of Gravity Driven Water Pool with an inventory of 7000 m^3 of water**





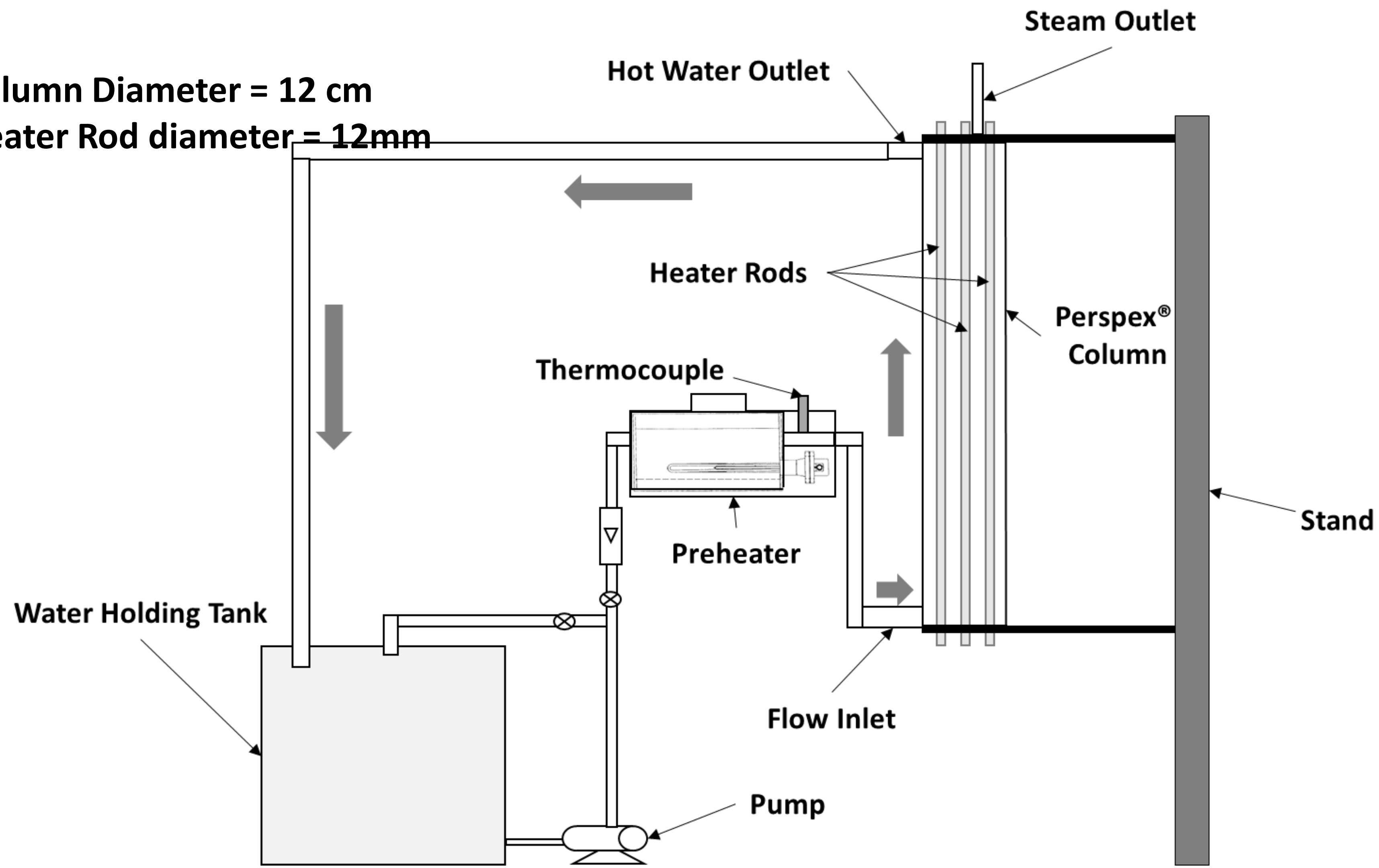
Sinha, R.K., and A. Kakodkar, "Design and development of the AHWR the Indian Thorium fuelled innovative nuclear reactor", *Nucl. Eng. Des.*, 236, 683(2006).

Experimental Setup-I

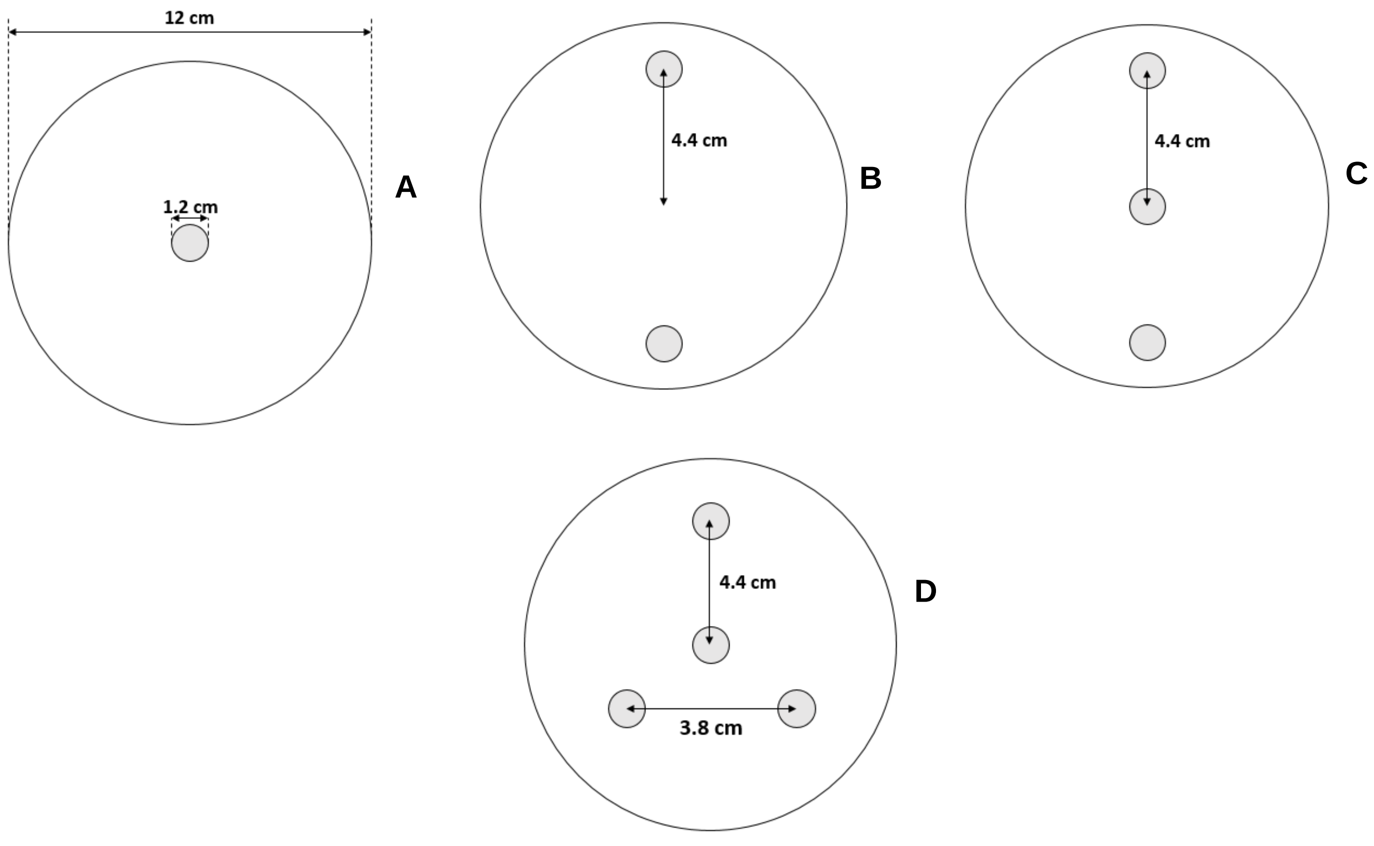


Experimental Setup-II

Column Diameter = 12 cm
Heater Rod diameter = 12mm

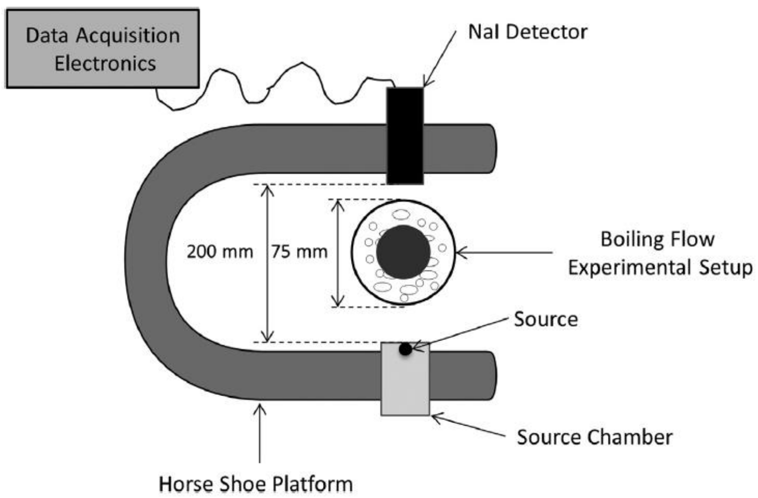


Heater Rods Arrangements (Experimental Setup-II)

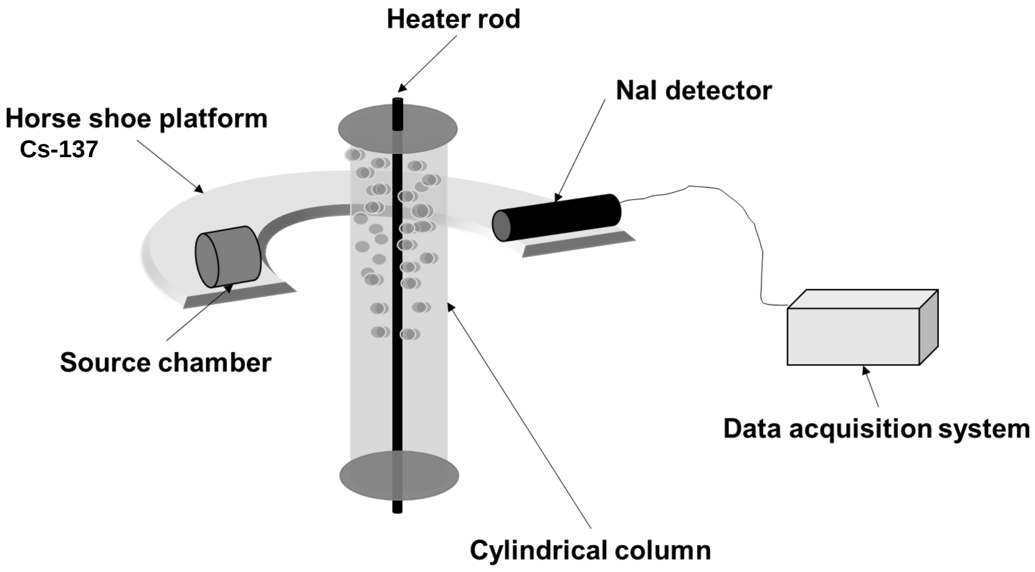


Gamma-ray Densitometry

$$\frac{\ln(I_{TP}) - \ln(I_{liq})}{\ln(I_{vap}) - \ln(I_{liq})} = \varepsilon$$



2D schematic representation



3D schematic representation

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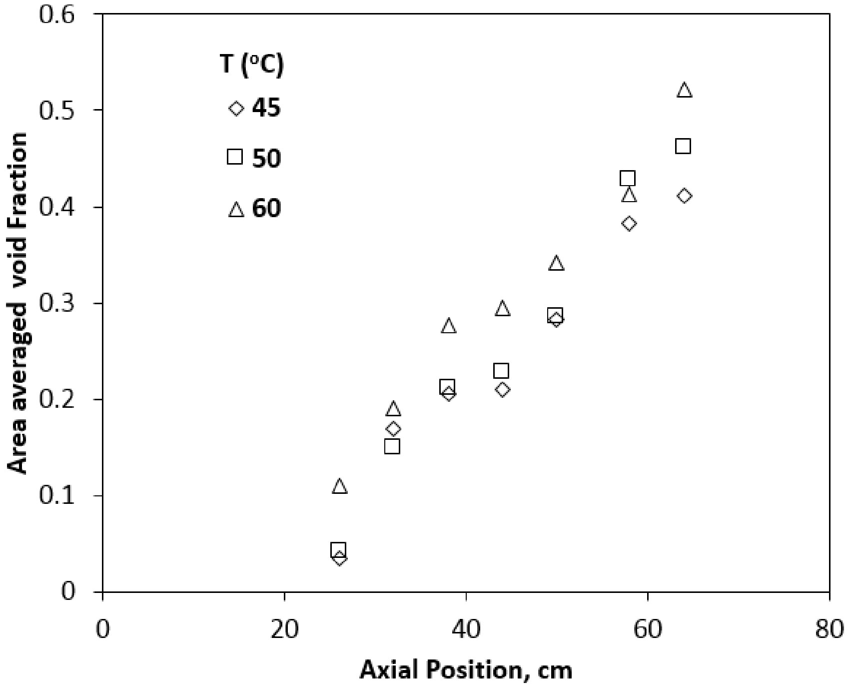
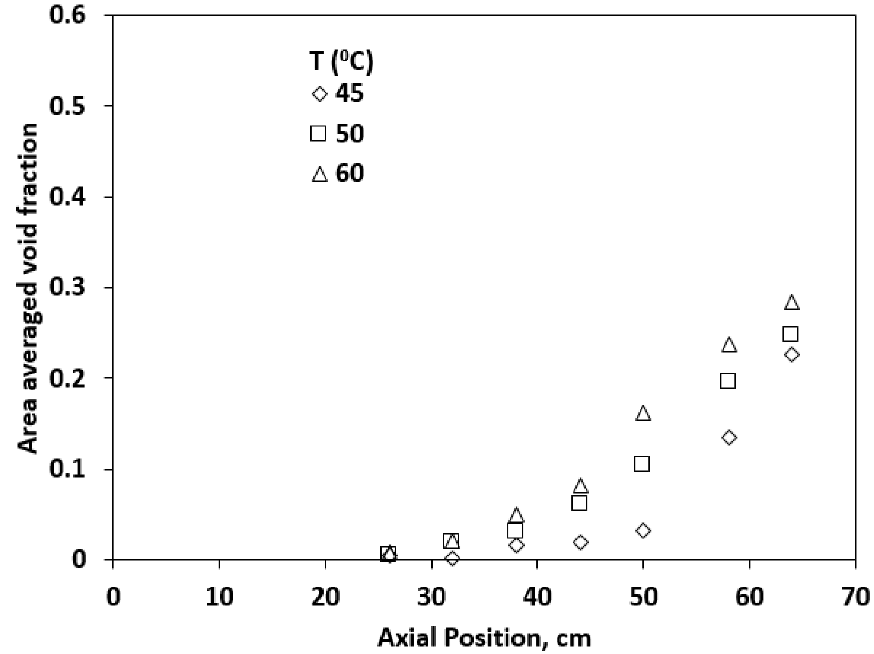
Void Fraction Measurement (Experimental Setup-I)



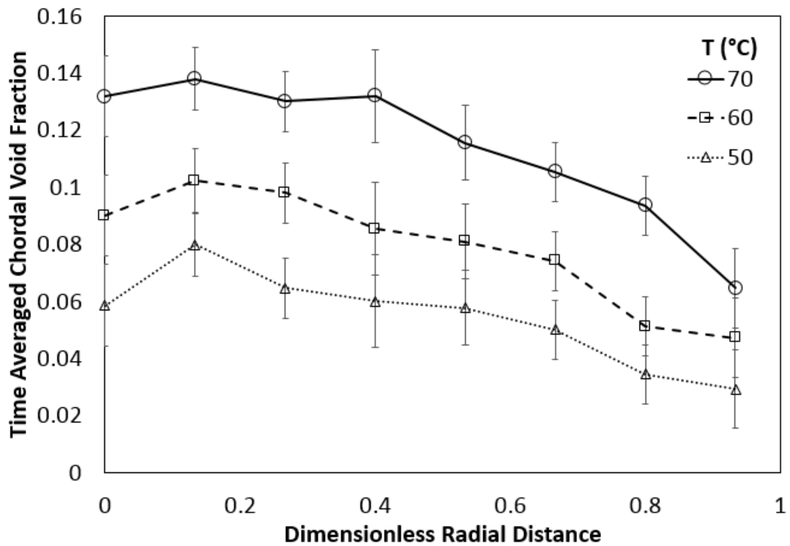
(a)



(b)

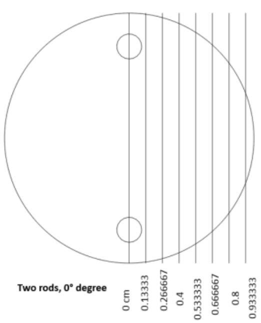
Axial development of void fraction for q''=22.7 kW m^{-2} as function of different inlet liquid temperatures and inlet liquid mass flux of: (a) *G*=2.89 kg m^{-2} s^{-1} (b) *G*=6.94 g m^{-2} s^{-1}.

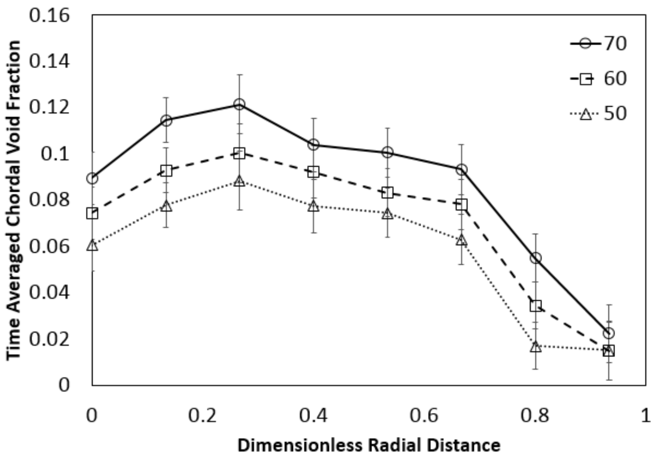
Void Fraction Profiles (Single and Two Heater Rods)



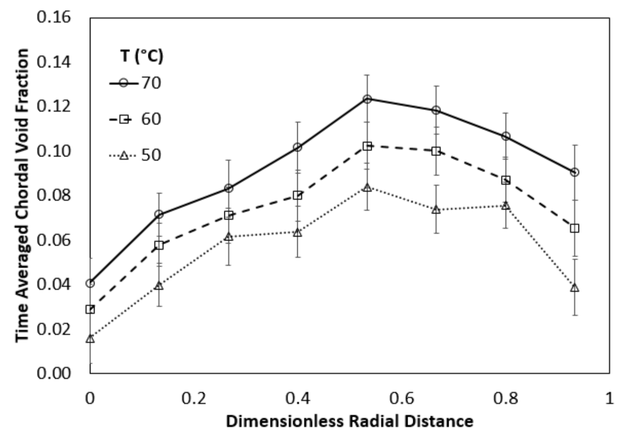
Single heater rod

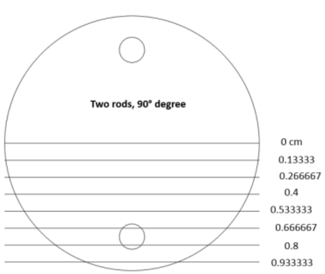
Two heater rods





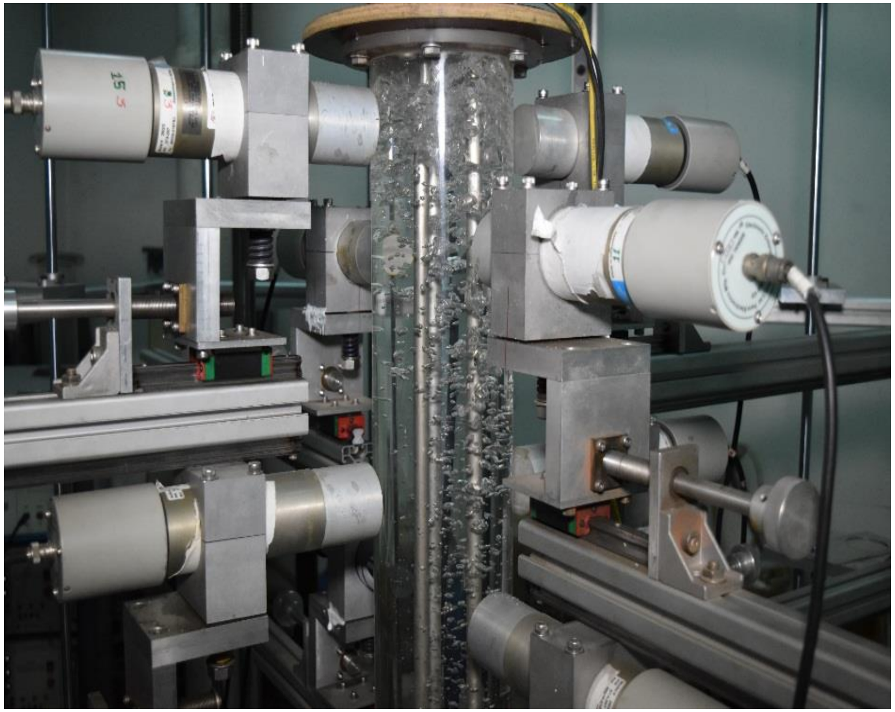
0° plane

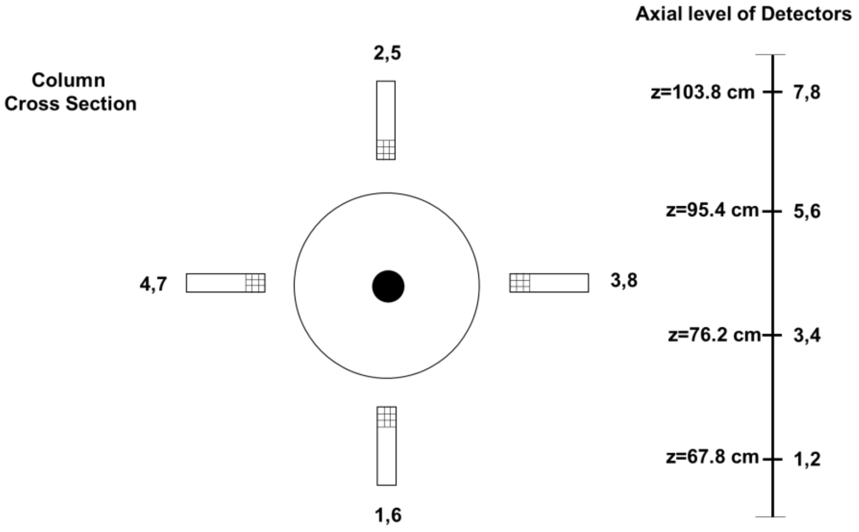




90° plane

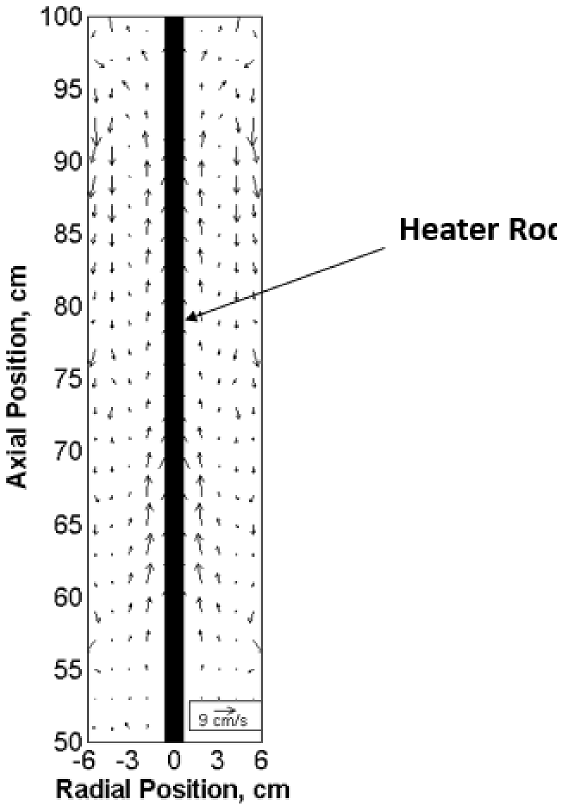
Experimental setup for RPT Measurements

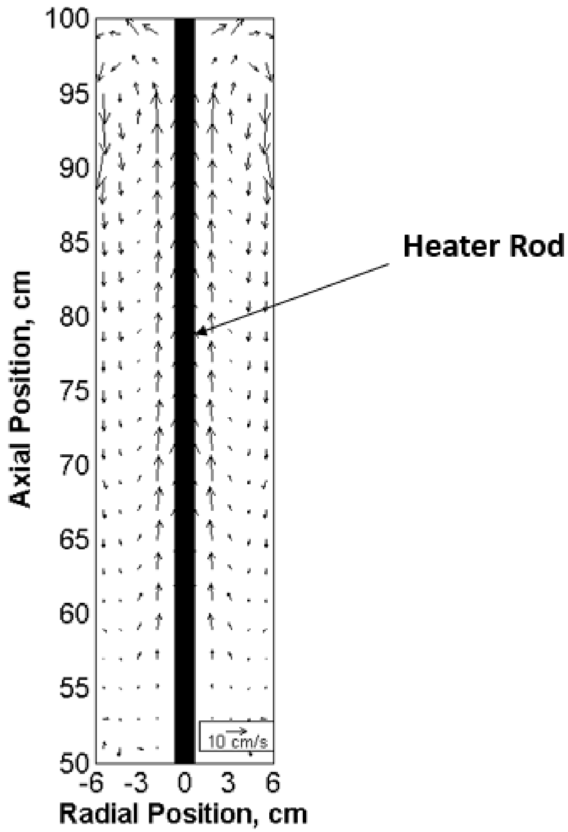




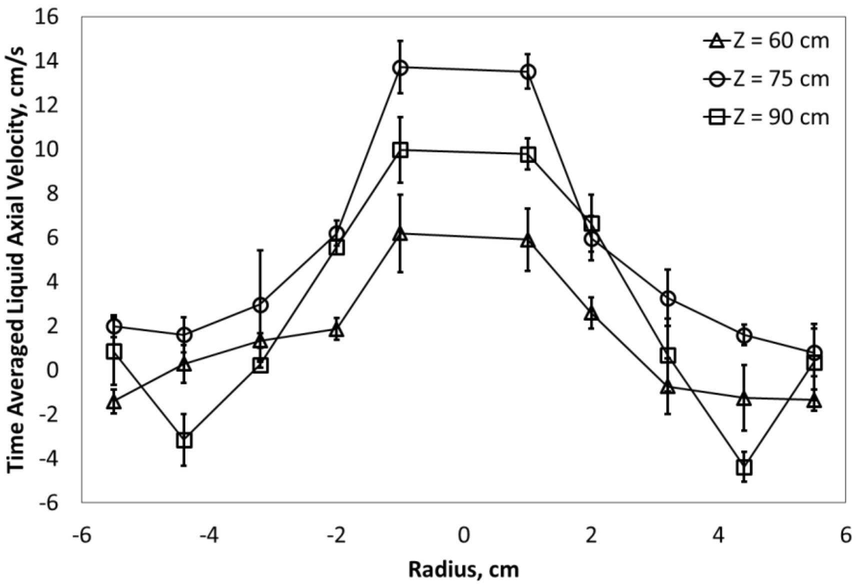
Liquid Velocity Measurements Using RPT (Vector Plots)

Velocity vectors arrangement at inlet flow rate of 5LPH (a) T^{in}= 50°C (for single heater rod), (b) T^{in}= 70°C (for single heater rod).

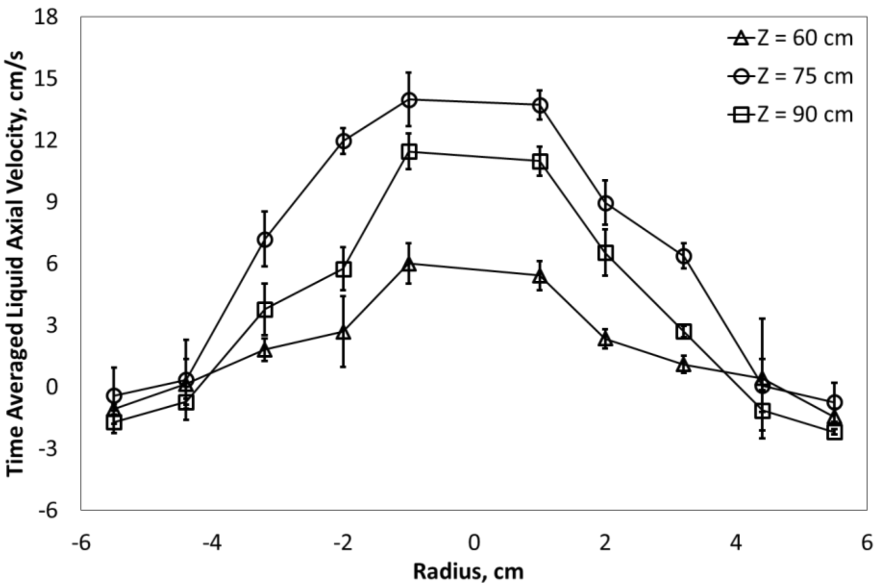




Velocity Profiles (Single Rod-Setup-II)



$T^{in} = 50^{\circ}C$



$T^{in} = 70^{\circ}C$

Inlet liquid flowrate=0.01 cm/s

Conclusions

- Maximum void fraction was observed away from the heater wall suggesting that vapor bubbles after departing from heater wall grows in size.
- With increase in liquid temperature or decrease in liquid flow rate the void fraction increased.
- Void fraction profiles in case of single rod were flatter as compared to other heater rods configurations.
- Peak in the axial liquid velocity profiles is observed in the region near to the central heater wall and axial liquid velocity decreases in a region away from the central heater wall region.
- Magnitude of axial liquid velocity as well as liquid kinetic energy increases with increase in inlet liquid temperature for both heater rods configuration.
- Recirculation of the liquid phase results in negative velocity magnitude for single and three heater rods configuration.


Thank You