Direct Contact Heat Exchange Interfacial Phenomena for Liquid Metal Reactors
Part II: Void Fraction

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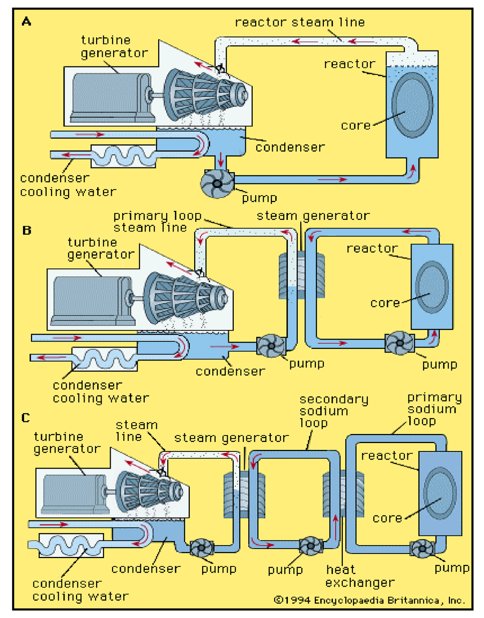
1. Research Objective:

One concept being considered for steam generation in innovative nuclear reactor applications, involves water coming into direct contact with a circulating molten metal. The vigorous agitation of the two fluids, the direct liquid-liquid contact and the consequent large interfacial area can give rise to large heat transfer coefficients and rapid steam generation. For an optimum design of such direct contact heat exchange and vaporization systems, detailed knowledge is necessary of the various flow regimes, interfacial transport phenomena, heat transfer and operational stability.



Scope of the Current Study

1. Fuel-Coolant interactions envelope
2. Flow regime boundaries
3. Void fraction
4. Different zone lengths
5. Heat transfer coefficients

2. Previous Investigations:

The previous investigations can generally be divided into two main categories:

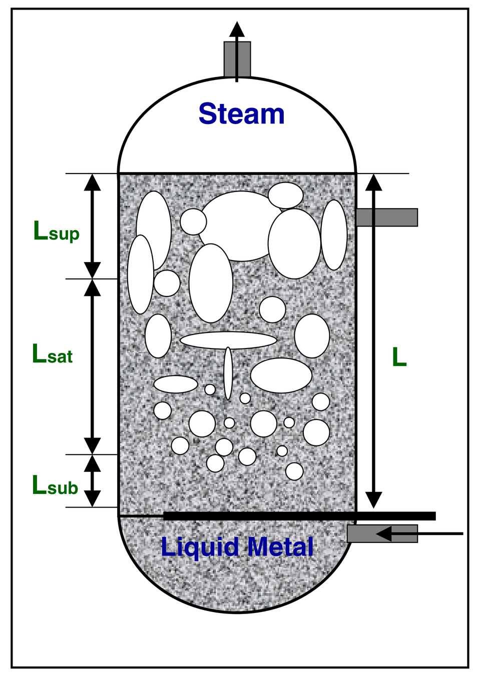
I. Water/Light, low boiling point pair:

Sideman & Taitel (1964), Sideman & Gat (1966), Blair et al. (1976), Smith et al.(1982), others

II. Liquid metal/Water pair:

El-Boher et al. (1988), CRIEPI (1995-97), Boungiorno et al. (2000)

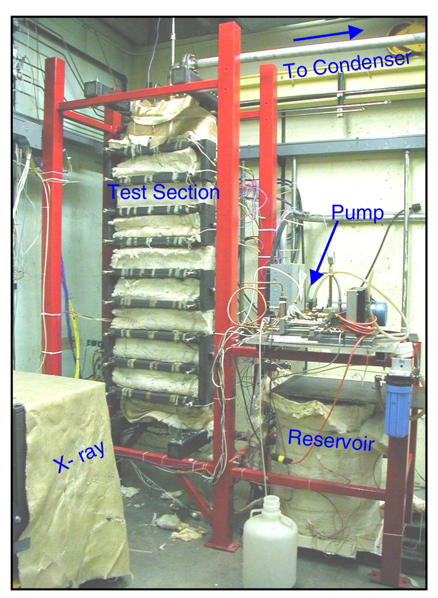
The main objective for most of the previous investigations was to find the overall volumetric heat transfer coefficient for the exchanger.

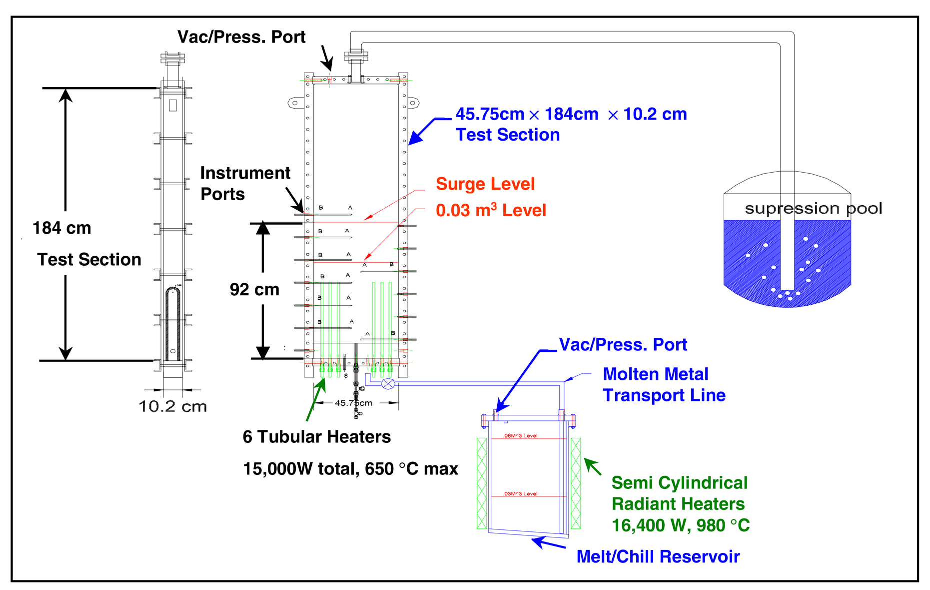


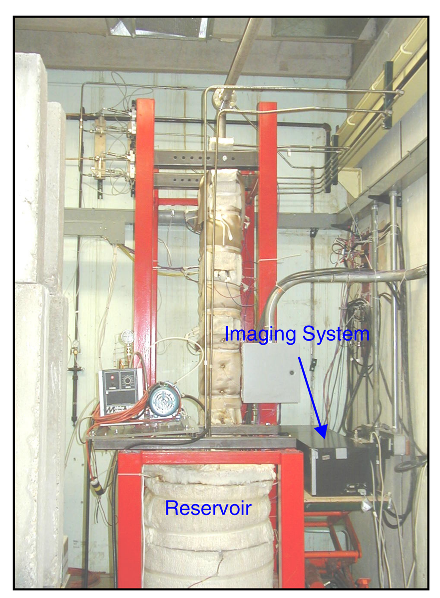
3. Experimental Facility:

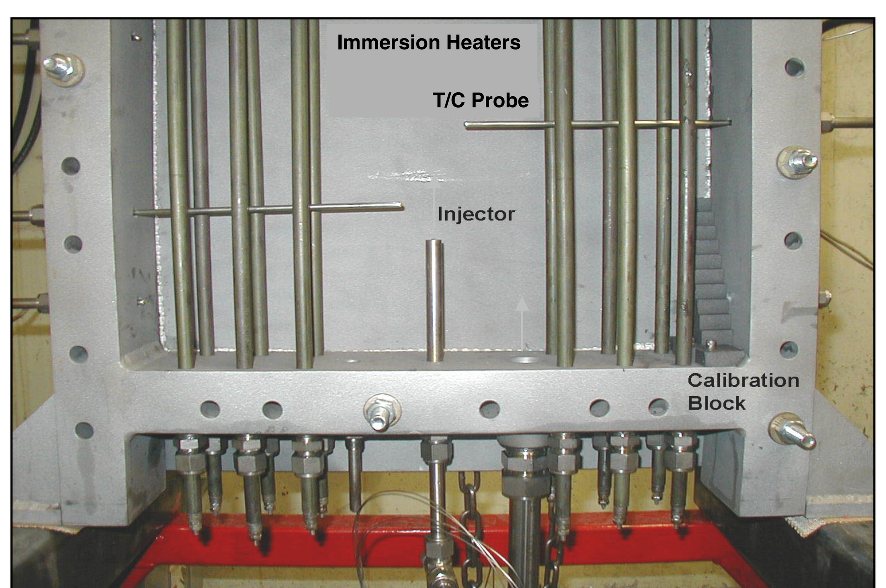
An experimental facility has been designed and constructed at UW-Madison. It consists mainly of three components, namely,

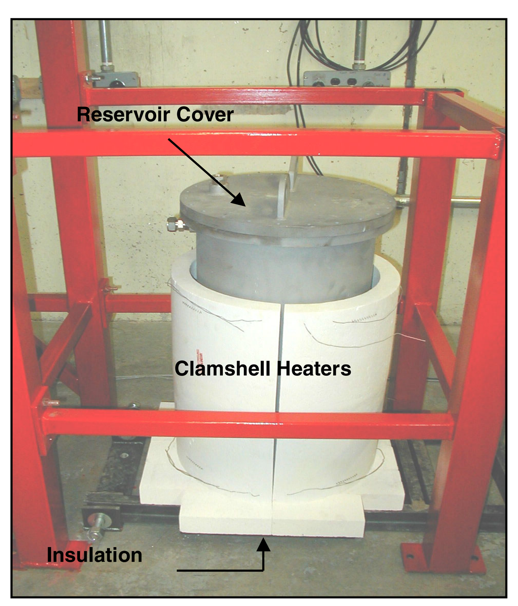
1. Liquid Metal Reservoir
2. Test Section
3. Condenser

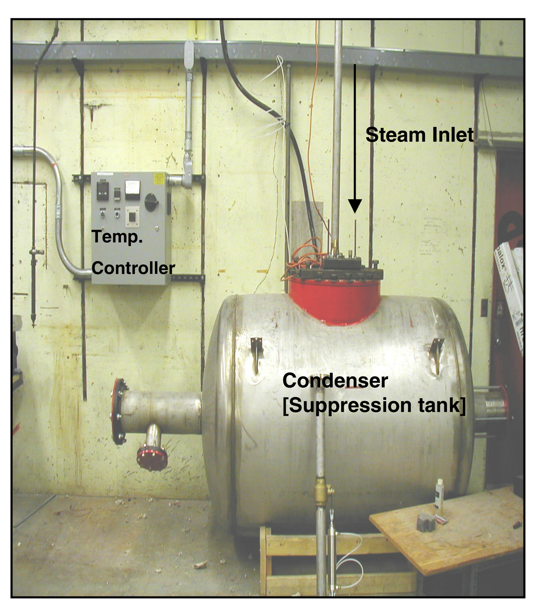








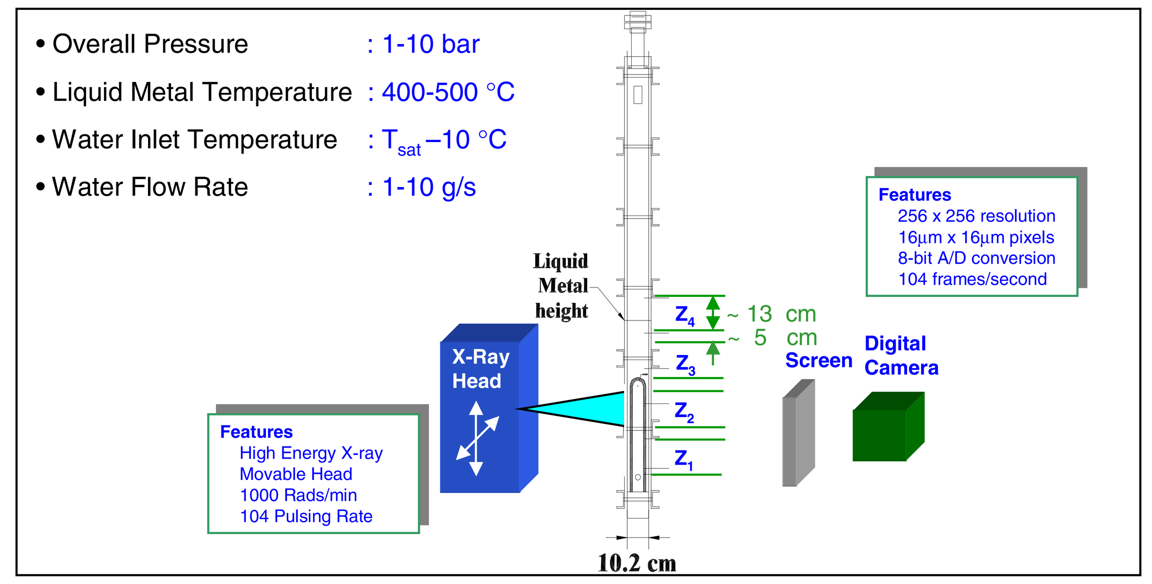


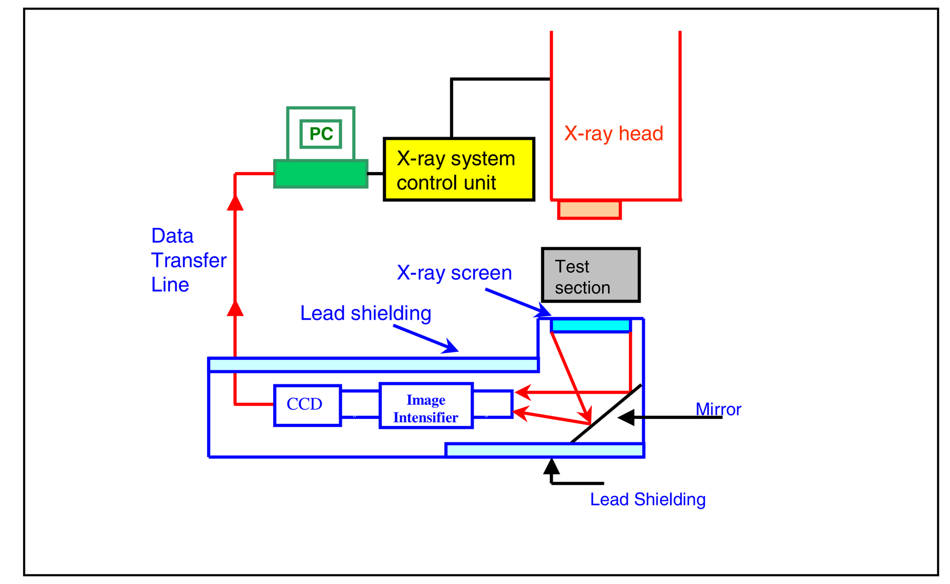


Water — Liquid Metal

4. Test Conditions:

- Overall Pressure : 1-10 bar
- Liquid Metal Temperature : 400-500 °C
- Water Inlet Temperature : T_{sat} −10 °C
- Water Flow Rate : 1-10 g/s



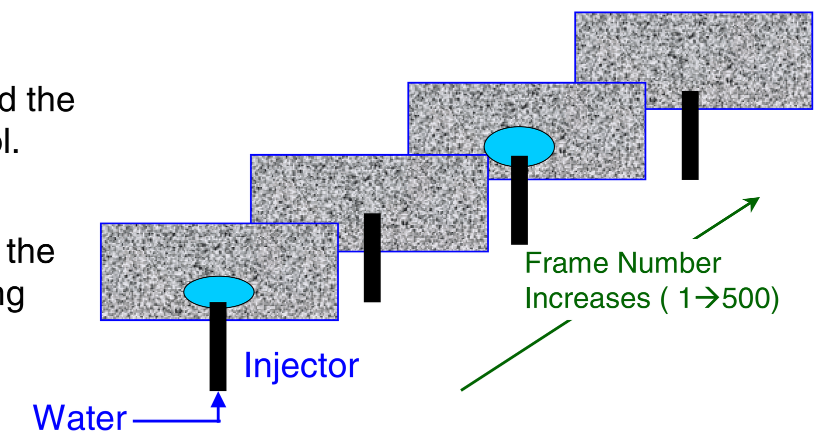


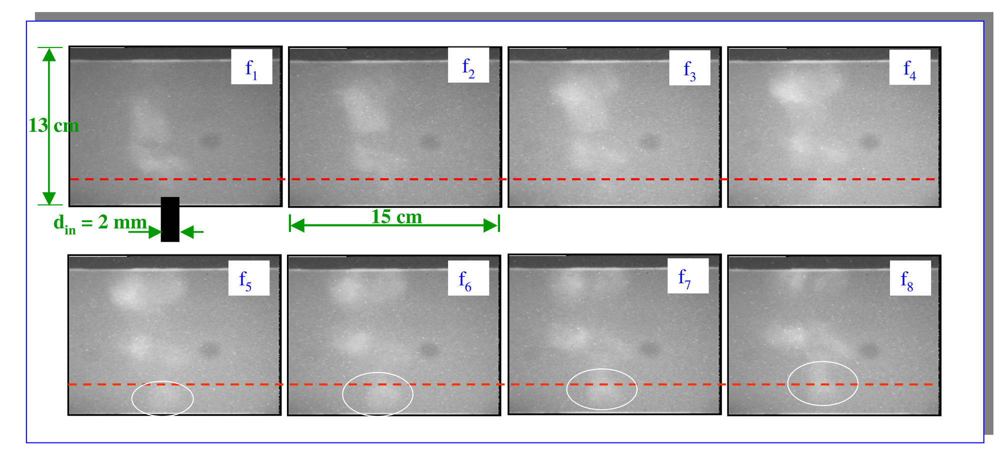
5. Results:

- **Production Time:**

- Time it takes to build a bubble around the injector before its departure to the pool.

- $F_{buoyancy} < F_{surface\ tension}$
- Analysis of the 500 images taken for the injector tip during one experiment along with the framing rate gives the bubble production time.



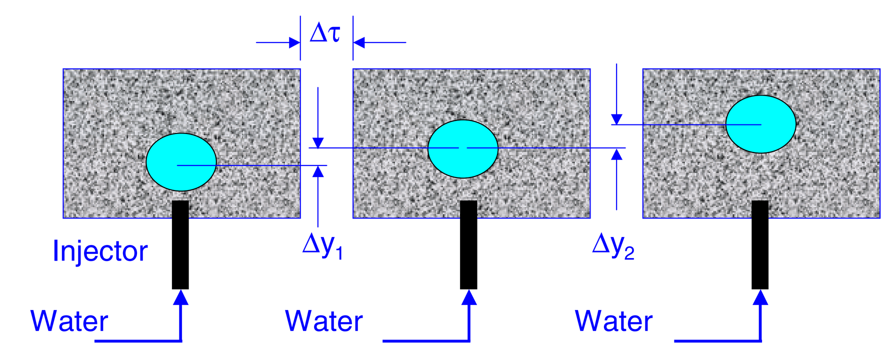


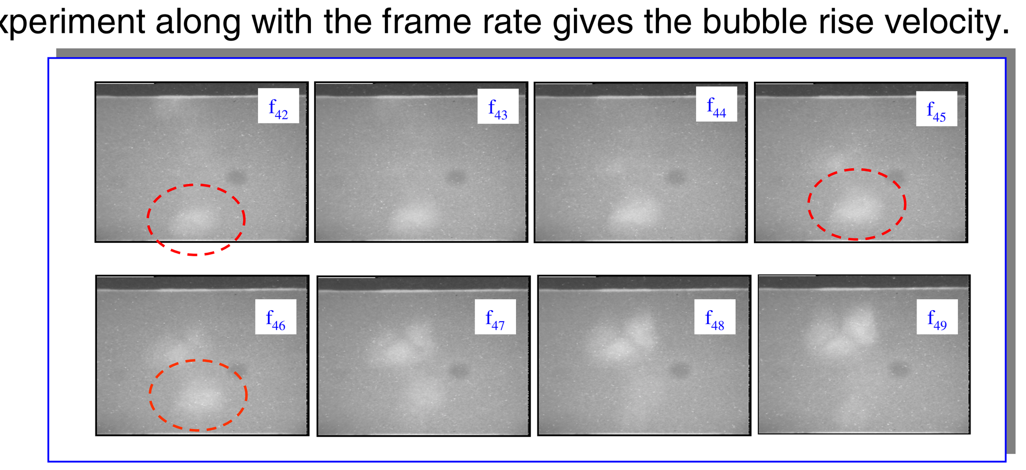
Test Conditions:

Single injection
$d_{injector} \cong 2$ mm
flow rate ≅ 1 g/s
$T_{inj,\ water} \cong 100$ °C
$T_{steam,exit} \cong 380$ °C
$T_{LM} \cong 500$ °C
X-ray imaging window ≅ 5 sec.

- **Rise Velocity:**

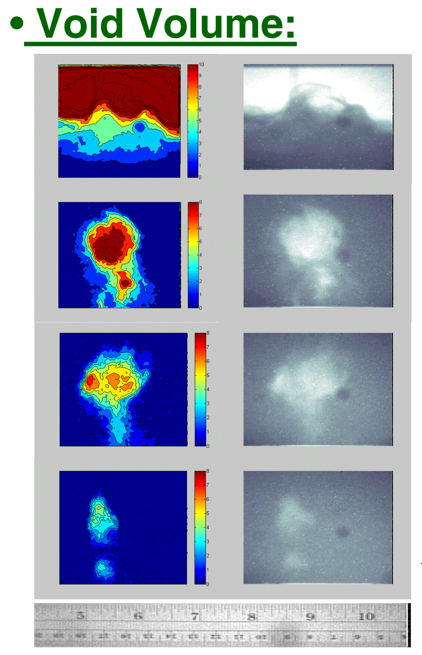
Analysis of the 500 images taken for each imaging zone during one experiment along with the frame rate gives the bubble rise velocity.

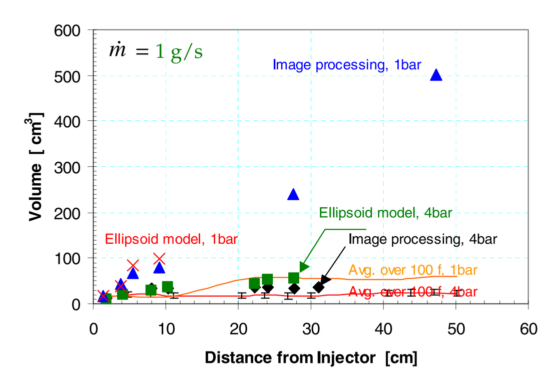


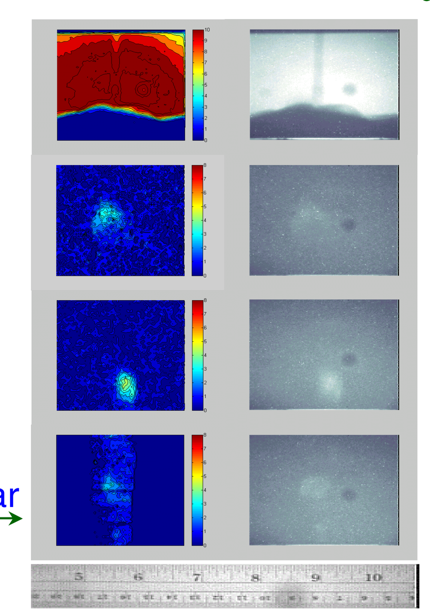


Zone	V_{rise} [m/s]
1	0.59
2	0.93
3	1.42

- **Void Volume:**







P = 1 bar — P = 4 bar

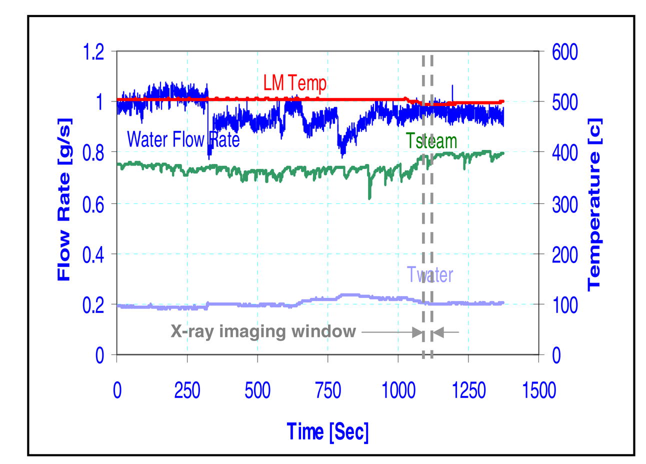
- **Volumetric Heat Transfer Coefficient:**

$$U_v = \frac{\dot{m}(i_{exit} - i_{inlet})}{V\,\Delta T_{l,m}}$$

Subcooled water inlet: $i_{inlet} = f\,(T_{inlet}, P_{inlet})$

$$\Delta T_{l,m} = \frac{T_{exit} - T_{inlet}}{\ln\left(\frac{T_{lm} - T_{inlet}}{T_{lm} - T_{exit}}\right)}$$

Superheated steam exit: $i_{exit} = f\,(T_{exit}, P_{exit})$



6. Summary and Future Plans:

- An experimental facility has been designed and used successfully to measure the void fraction at different heights within the liquid metal pool.
- The overall volumetric heat transfer coefficient based on the liquid metal level swell could be estimated
- Bubble production time and bubble rise velocity have been estimated from the X-ray images taken for the liquid metal/water pool
- The local heat transfer coefficient at different pool heights will be estimated using the following procedure:
- The test facility provides the means to estimate the void volume and void interfacial area within the pool.

1. Evaluate the bubble production time [x-ray image analysis]
2. Calculate the injected water mass: $m_w = \dot{m}_w \times production\ time$
3. Calculate the specific volume: $v_{z_1} = \frac{Vol_{bubble}}{m_w}$
4. Calculate the quality: $x = \frac{v_{z_1} - v_f}{v_{fg}}$
5. Calculate the enthalpy: $i_{z_1} = i_f + x\,i_{fg}$
6. Calculate local HTC: $h_{z_1} = \frac{\dot{m}_w \times production\ time \times (i_{z_1} - i_f)}{A_{interfacial} \times (T_{lm} - T_w) \times rise\ time}$