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Critical Heat Flux and power transients at low-pressure low-flow conditions in vertical flow boiling

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Critical Heat Flux and power transients at low-pressure low-flow conditions in vertical flow boiling

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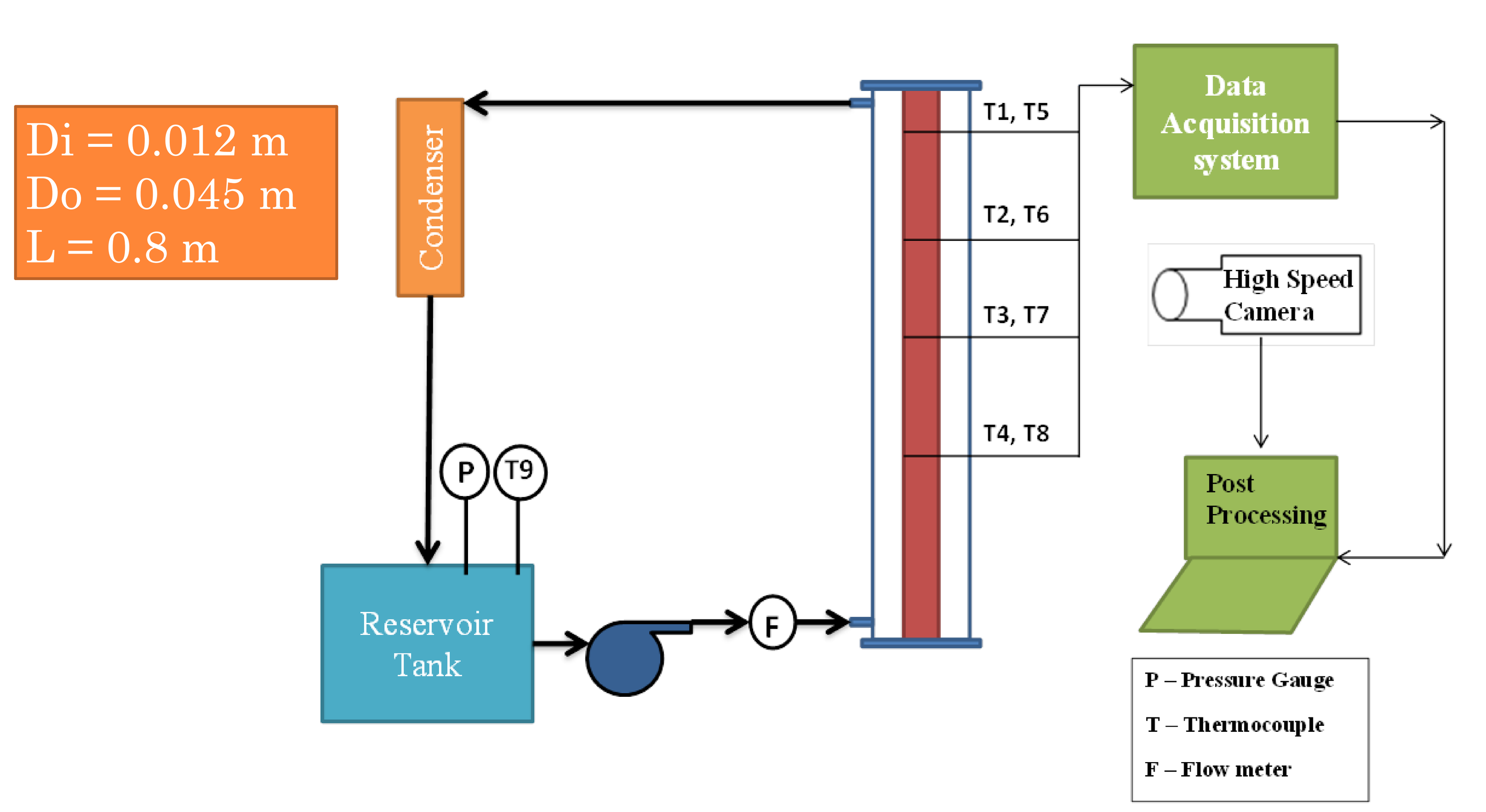
Abstract

In the advanced boiling water reactor concepts such as AHWR and ESBWR, the recirculation pumps are eliminated in order to simplify the design. During the start-up of such reactors, to establish the natural circulation, the primary coolant has to be heated up slowly in steady steps; it is quite important to determine the characteristics of boiling and critical heat flux (CHF) values in order to establish operational limits. Flow boiling experiments were conducted in an annular channel at very low flow rates and atmospheric pressure varying the inlet subcooling from 20 to 40^0 C. CHF occurred during the oscillatory flow pattern transition from slug to churn regime. Comparing the low- pressure and low-flow critical heat flux data with the present data has shown that CHF increased under oscillatory flow pattern transition from slug to churn. Power transient experiments were also performed at low-pressure and low-flow conditions. Flow regimes and the sequence of events leading to critical heat flux were visually observed using the high-speed camera.

Experiments Conducted

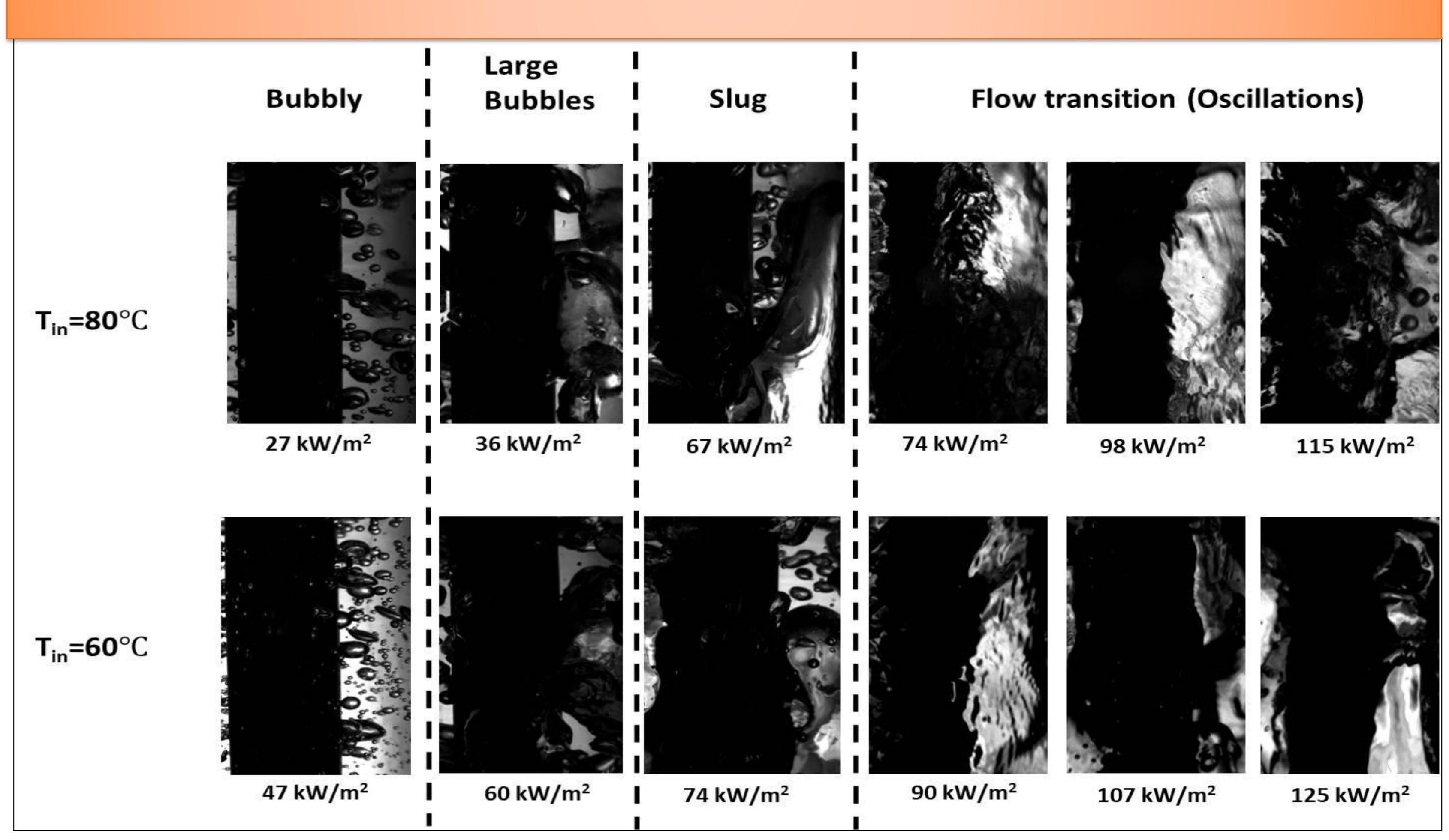
Experimental Setup



Test Conditions

	Mass Flux (kg/m^{2}s)	Inlet subcooling (°C)
Test-01	3	20
Test-02	3	40
Power Transient Experiments		
Test – 03	0	40
Test -04	3	40

Evolution of flow pattern with heat flux

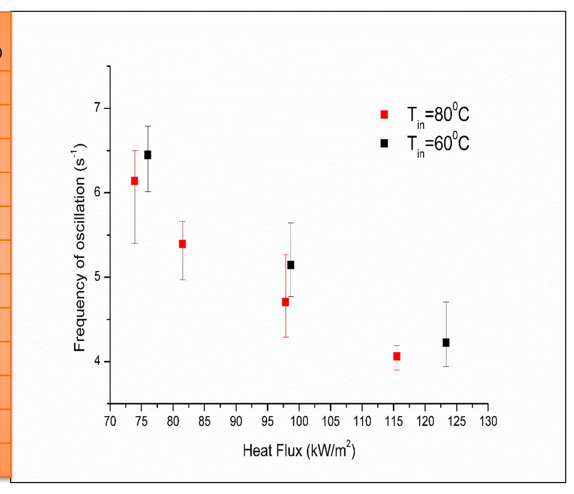


CHF results

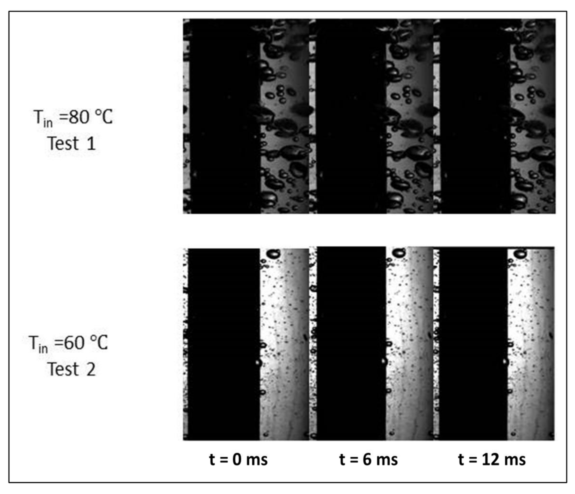
Comparison with existing CHF data

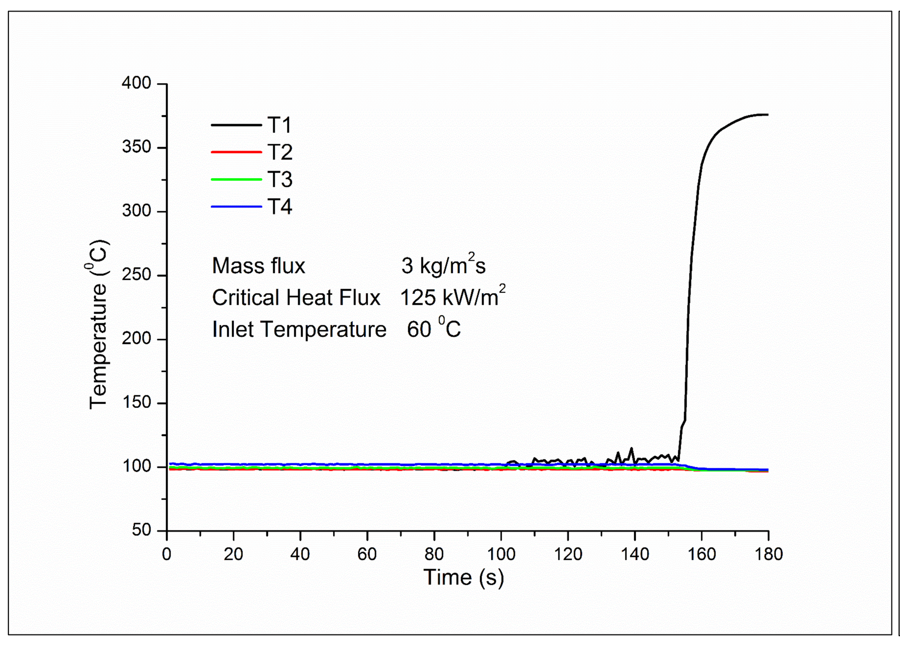
	D_o (m)	D_i (m)	L_h (m)	G (kg/m^2.s)	Δh_{in} (kJ/kg)	x_c	CHF (kW/m^2)
Present Work	**0.045**	**0.012**	**0.8**	**3.0**	**166.3**	**0.3**	**125**
	0.045	**0.012**	**0.8**	**3.0**	**82.5**	**0.31**	**115**
Park et al.	0.029	0.019	0.6	4.2	307.3	0.388	52.2
	0.035	0.019	0.6	1.3	311.9	0.985	62.3
	0.035	0.019	0.6	2.5	324.8	0.472	65.7
	0.035	0.019	0.6	4.9	296.8	0.250	79.8
	0.051	0.019	0.6	1.5	307.7	0.234	96.3
	0.051	0.019	0.6	3.0	304.3	0.131	122.3
Mishima	0.02	0.026	0.6	5.0	324.02	0.72	50.6
	0.02	0.026	0.6	4.6	167.65	0.85	51.1
	0.02	0.026	0.6	5.0	184.81	0.75	49.3
	0.02	0.026	0.6	4.6	307.29	0.75	48.8

Frequency of oscillation with heat flux

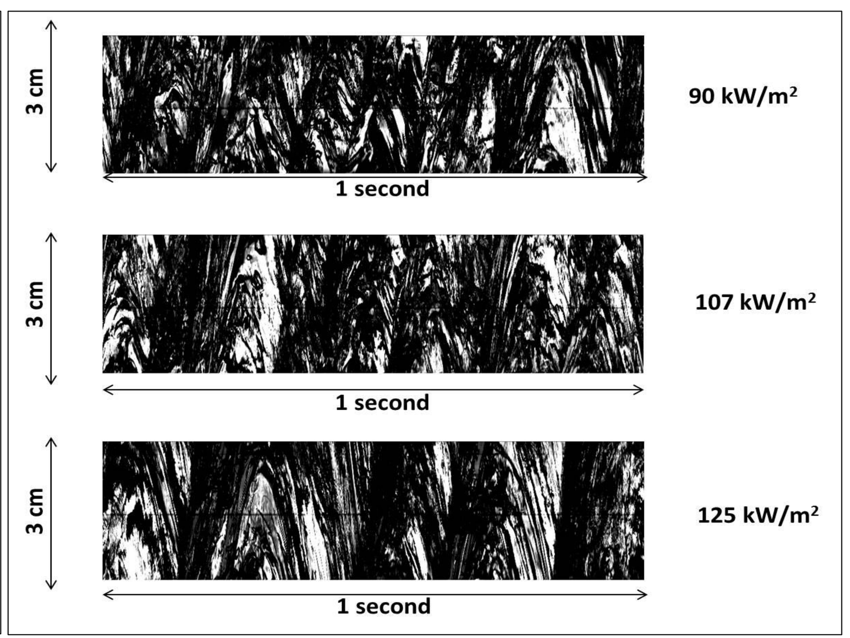


Effect of Inlet temperature (27 kW/m²)





CHF plot

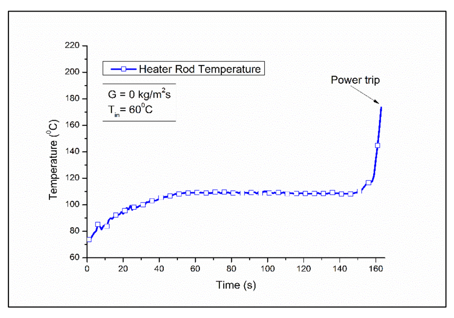


d-t plot

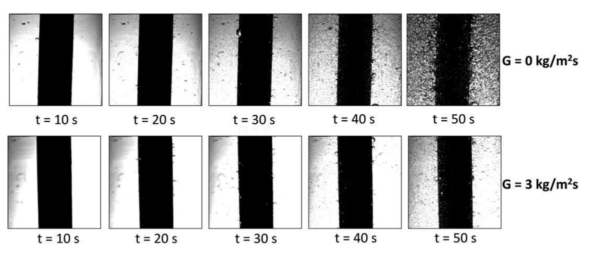
Discussions

✓Oscillations occurred during the flow transition from slug to churn flow due to combined effect of inherent instabilities in flow pattern transition and shorter exit length.
✓Oscillation frequency reduced with heat flux.
✓At CHF, the liquid film wetting the heater surface periodically was not sufficiently thick enough and the liquid film completely evaporates leaving the heater uncovered.

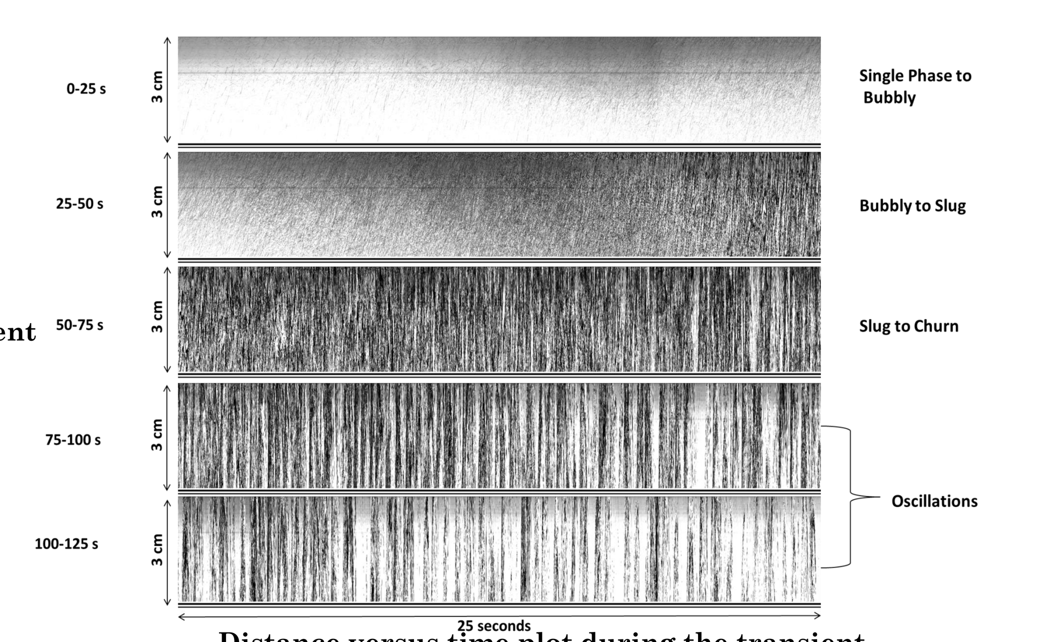
Power Transients



Rod temperature profile during the power transient



Global boiling structure with time



Distance versus time plot during the transient

Discussions

✓Initial 25 seconds is mostly dominated by single-phase convection,
✓Near 25 seconds small streak lines appeared which indicate the start of the bubbly flow.
✓At about 65 seconds, well-spaced thick dark bubbly lines appeared indicating the start of slug flow.
✓After 75 seconds the flow pattern is changed from slug to pulsating flow.

Conclusions

✓CHF occurred during flow transition from slug to churn flow.
✓The combined effect of inherent instabilities in flow pattern transition from slug to churn and shorter exit lengths lead to longer oscillations (pulsations).
✓In the power transient where the power was raised from 0.37kW to 3.77kW in 5 seconds, the rod burnout occurred at 160 seconds into the transient.
✓In the power transients, with a slight increase in mass flux, the bubble density decreased substantially. Higher bubble density was observed when the flow rate is zero.

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