Reduction of Critical Heat Flux due to steep power transients on PFCs

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ABSTRACT

- Assessment of CHF margin is crucial in the design of Plasma Facing Components (PFCs) for ensuring safe operation.
- Sudden changes in thermal hydraulic conditions could also lead to CHF occurring prematurely.
- CHF is seen to occur earlier when the power is applied instantaneously as compared to a gradual increase in the power for identical themal-hydraulic conditions.
- Experiment results reported here shows, possibly for the first time, CHF induced due to the onset of flow instability (OFI) for one sided heating conditions.
- The ratio of the CHF obtained for the steady state CHF condition to the transient CHF condition is seen to be ~1.13 which could be significant when considering a safety factor of 1.4 typically taken for PFC design.

BACKGROUND

- Selection of thermal hydraulic parameters must be made not just with respect to the CHF value, but also transient effects such as the flow instability criteria and power distribution.
- These transient effects can also cause mechanical vibrations and damage the coolant system as well as induce CHF prematurely.
- Most of the correlations and experiments for OFI for flow boiling have been performed at low pressure or on micro-channels.
- Limited data is available in the range of 10 – 50 bars and high velocities [1].
- CHF tests were carried out at the HHFTF to demonstrate capabilities of the facility.

EXPERIMENTAL SETUP

Table 1: Schematic of High Heat Flux test facility [2],[3]

Electron beam system	200 kW at 45 kV
Vacuum Chamber	D shaped, double walled 2.5m x 1.5m
Diagnostics	IR camera (RT – 3000 C) One color pyrometer (350 °C – 3500 °C) Two color pyrometer (350 – 3000 °C) Diff. Press Transmitter (0.7 mbar – 7 bars) RTD – (0 °C – 250 °C) Accelerometer – (1 Hz – 10 kHz)
Cooling system	Pressure – upto 60 bars Temperature – upto 160 °C Flowrate – upto 300 lpm

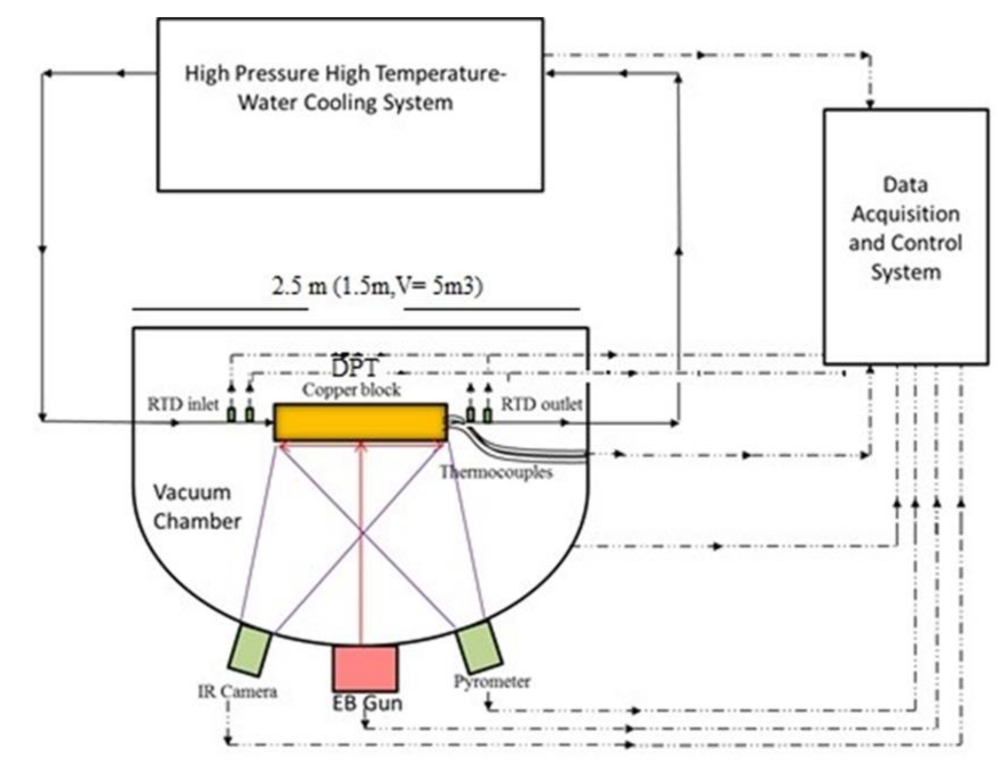
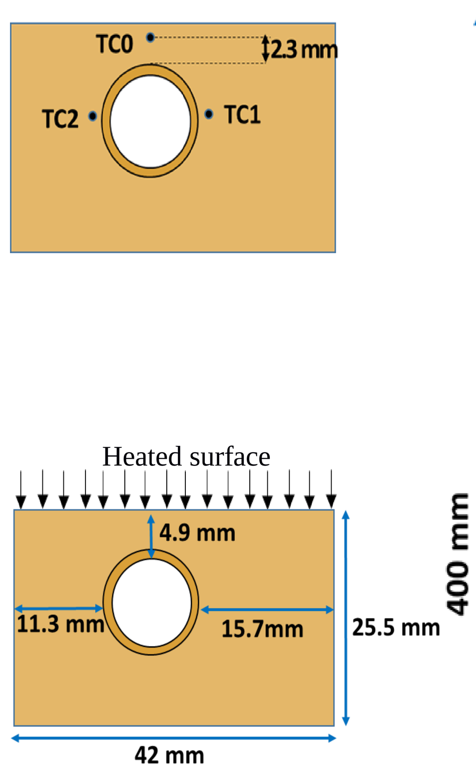


FIG 1: Schematic of High Heat Flux test facility



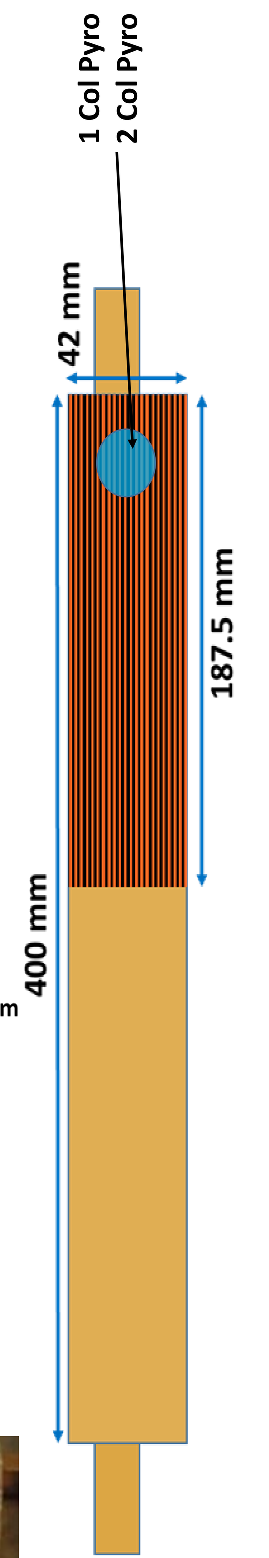


FIG 2: Dimensions of test mockup along with TC locations (top). Heated length along with pyrometer viewing locations (Right)

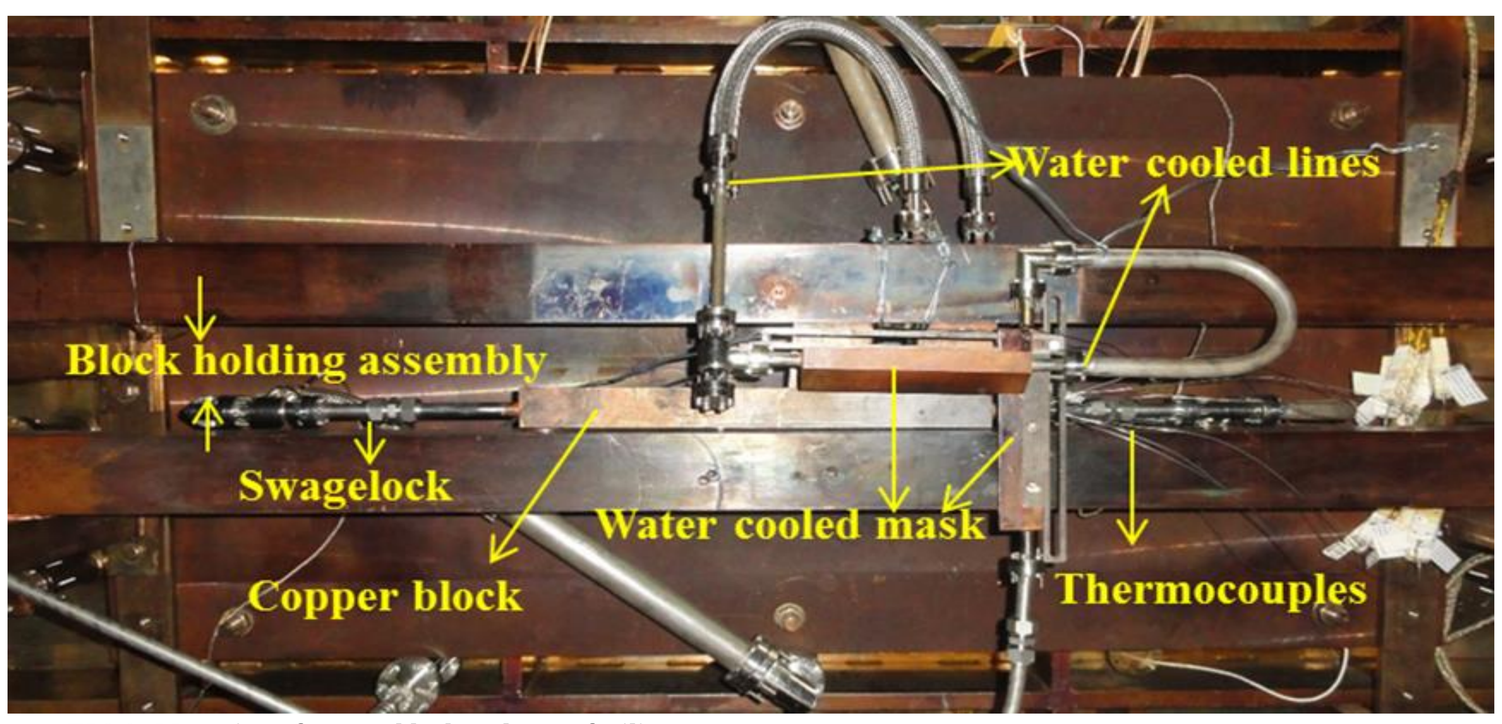


FIG 3: Mounting of copper block at the test facility.

- Pyrometers set to detect surface temperature at outlet side, IR camera used for monitoring surface temperature distribution
- EB power is gradually increased in steps of 2 – 5 kW, kept constant for at least 30 s to ensure steady state conditions.
- CHF is detected when there is a sudden temperature excursion for a small change in the heat load.
- DAQ is set to trip when temperature detected by pyrometer crosses 1050 °C.

CRITICAL HEAT FLUX TESTS

Table 2: Thermal hydraulic conditions and CHF value obtained at 45 lpm

Pressure (bars)	Coolant velocity (m/s)	Heated length (mm)	Inlet temp (°C)	Beam power (kW)	CHF value MW/m²
9.5	6.6	187.5	80 - 100	55 – 91	8.15 – 8.6

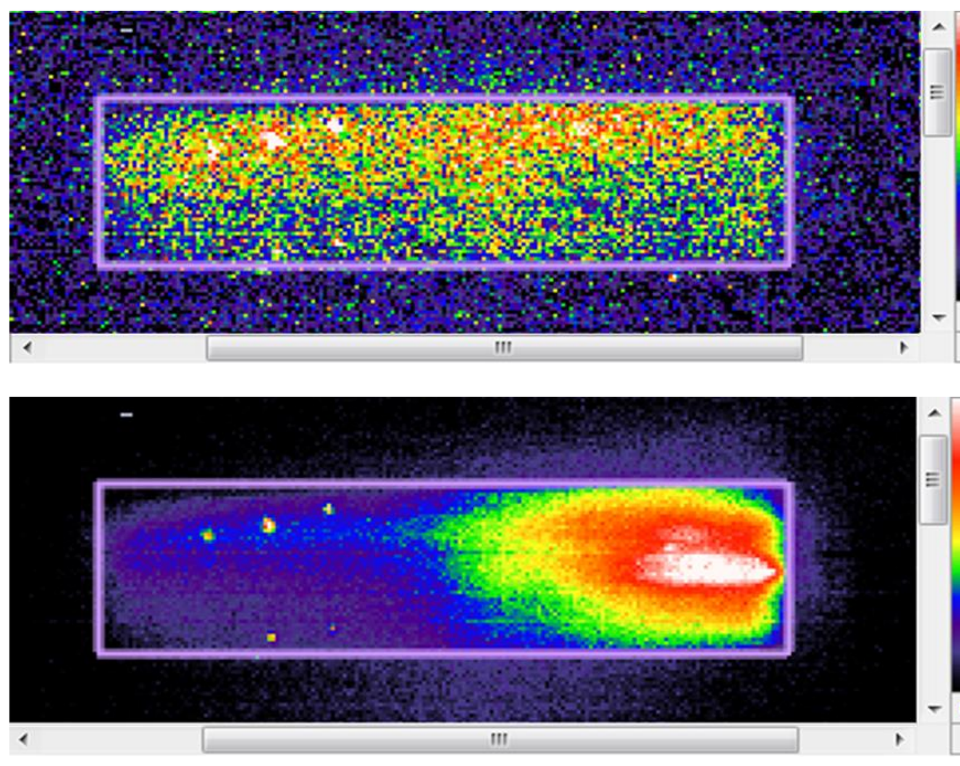


FIG 5: surface temperature distribution before CHF (top) and at CHF condition just before EB is tripped (bottom)

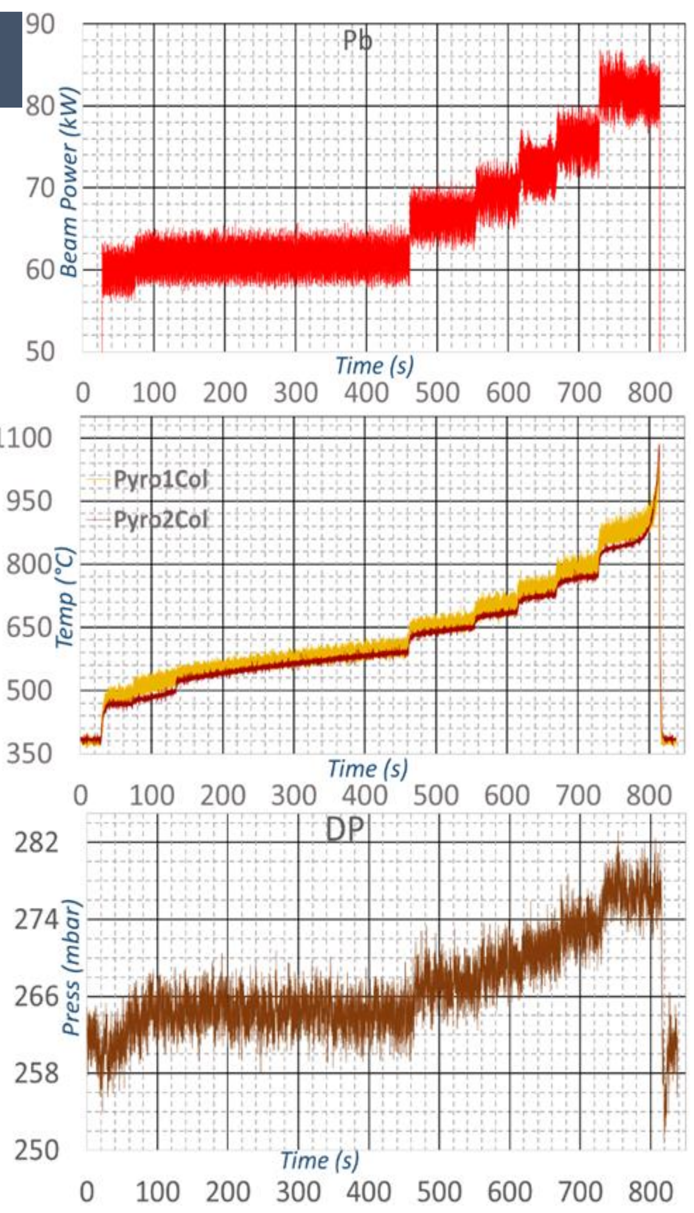


FIG 6: Timing graphs of the beam power, pyrometer and differential pressure.

CRITICAL HEAT FLUX DUE TO POWER TRANSIENTS

- CHF experiments performed with identical thermal-hydraulic conditions, one with power gradually increasing upto CHF and the other applied instantaneously.
- CHF is seen to occur at higher heat fluxes in the steady state case as compared to the transient case.
- Large amplitude mechanical vibrations observed preceding CHF indicates that CHF is limited by the onset of flow instability (OFI) [4] region shown in FIG 8.
- This has also been reported in [5] where high frequency pressure fluctuations with mechanical vibrations were observed for water at 40 bars pressure, however, without the occurrence of CHF.

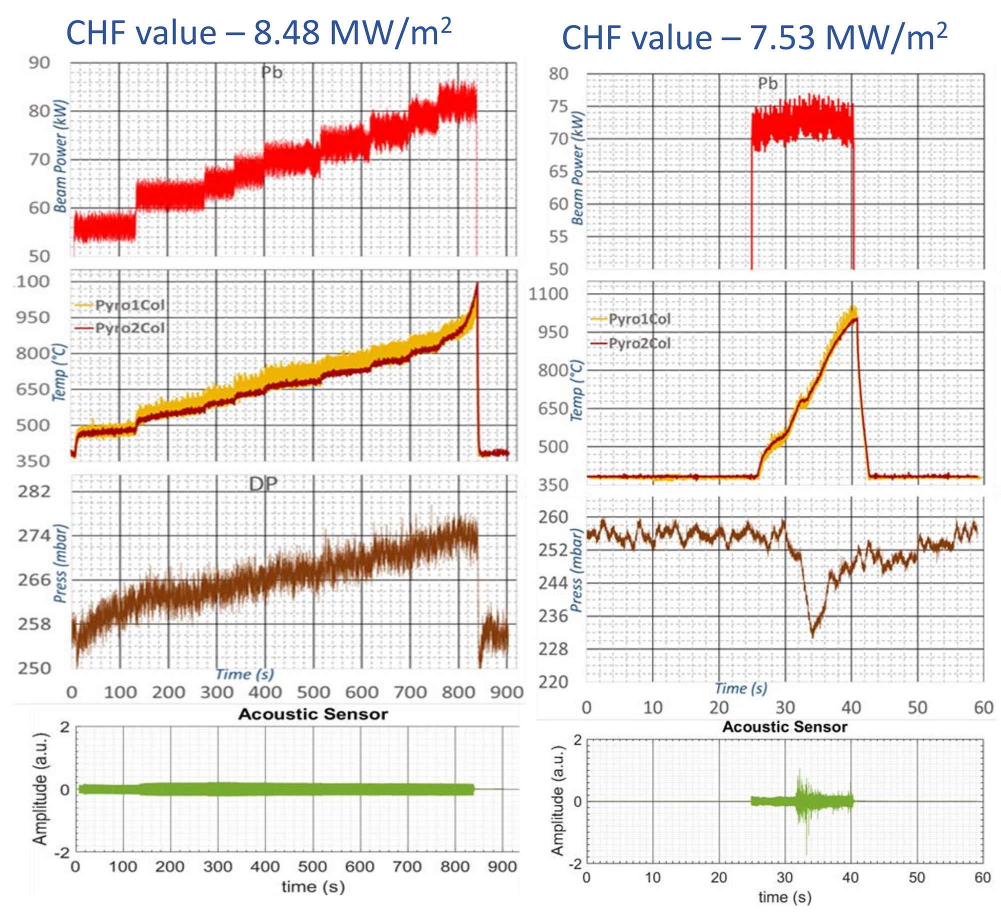


FIG 7. Data from two shots having the same thermal hydraulic parameters. On the left (a) the beam power is gradually increased in steps upto CHF, and on the right (b) heat load applied as a sudden transient. In (a) CHF is seen to occur at 81.1 kW beam power, corresponding to a heat flux of 8.48 MW/m2. In (b) CHF is seen to occur earlier at 72.2kW corresponding to IHF of 7.53MW/m2. Also shown are pressure drop data.

- CHF value obtained from Tongs-CEA correlation – 8.6 MW/m².
- Ratio of steady state to transient CHF values ~ 1.13.
- OFI estimated from Saha-Zuber correlation occurs ~ 2.5 MW/m². Experimentally observed values lie between 5 – 7 MW/m².

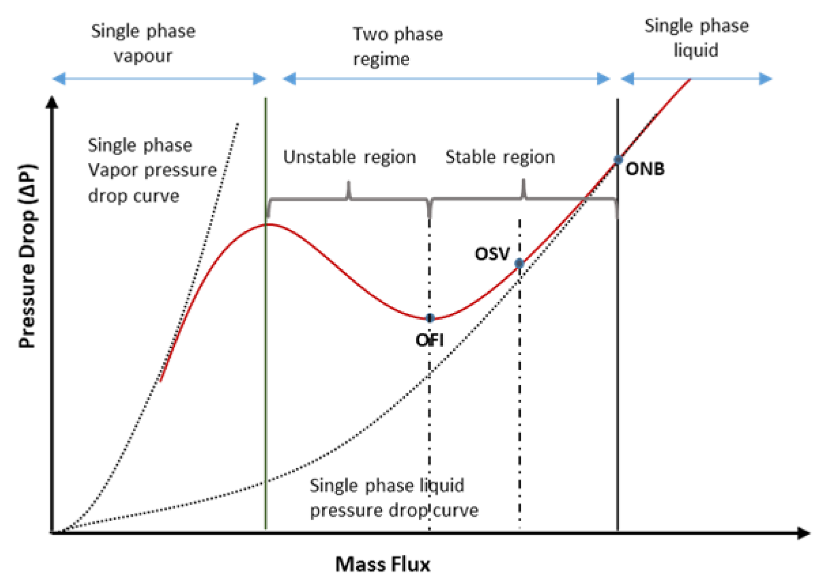


FIG 8: Pressure drop vs Mass flux curve showing the stable and unstable regions wrt to the onset of flow instability (OFI)

CONCLUSION

- Transient effects leading to flow instabilities have been observed causing CHF to occur prematurely.
- The margin of CHF is lower by a value of 1.13 for the experimental conditions considered for the tests. The CHF obtained is lower than that predicted from Tongs-CEA correlation [6]
- CHF limited by OFI must be studied for thermal-hydraulic ranges 10 – 40 bar, at different flow rates and heated lengths for a stiff pressure system, particularly for parallel channels such as the ITER Divertor to check stability.
- CHF testing for PFCs should not be limited to small size test specimens as the heated length could also affect CHF limits.
- Further experiments are planned to check the effect of flow instability at higher pressures and heated lengths.

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