INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

Name of the Student	:	TANUJ SRIVASTAVA
Roll Number	:	186103035
Programme of Study	:	Ph.D.

Thesis Title: Numerical and Experimental Investigations of Nonlinear Dynamics and Heat Transfer Deterioration in Supercritical Natural Circulation Loop

Name of Thesis Supervisor(s)	:	Dr. Dipankar Narayan Basu
Thesis Submitted to the Department/ Center	:	Mechanical Engineering
Date of completion of Thesis Viva-Voce Exam	:	30-09-2024
Key words for description of Thesis Work	:	Supercritical carbon dioxide, Natural circulation loop, Heat transfer deterioration, Buoyancy parameter

SHORT ABSTRACT

The natural circulation loop (NCL) efficiently transfers energy from a high-temperature source to a low-temperature sink without direct contact. The key driving force in natural circulation systems is buoyancy, caused by density differences. Single-phase NCLs face limitations from saturation temperature and low flow rates, while two-phase loops risk dry-out and complex flow regimes. Supercritical fluids offer an alternative, combining the benefits of both single- and two-phase systems. The concept of a supercritical natural circulation loop (sNCL) is important for Generation-IV nuclear reactors. This thesis evaluates sNCLs using CO2 through both numerical and experimental methods. Numerical studies analyze the steady-state and transient behavior of sNCL, using 3D simulations for steady-state and 2D/1D models for transient cases. Buoyancy and friction forces determine system behavior. As heating power increases, buoyancy dominates, leading to a rise in flow rate and heat transfer. However, friction eventually takes over, reducing flow rate and leading to flow-induced heat transfer deterioration (FiHTD). This phenomenon, which can be delayed but not avoided, is key to ensuring safe operation. Based on fluid temperature, four heat transfer zones were identified: low power, enhanced heat transfer, transition, and deteriorated heat transfer. 3D simulations using ANSYS Fluent confirmed the boundary of safe operation, with data fitting a power-law curve. Changes in friction factor along the heater section also signal the onset of FiHTD. The dissertation further explores static and dynamic instability in sNCL. Steady-state circulation shows a sharp decline, consistent with previous analyses, and exhibits Ledinegg instability at intermediate power levels. Both static and dynamic instabilities were identified, with results aligning across simulations. Under varying heat input, sinusoidal heating caused chaotic oscillations, while ramp heating remained stable due to gradual buoyancy generation. A 2D model explored startup transients, revealing the complex behavior of sNCL near the pseudocritical point. The system's bulk motion is influenced by phenomena like the piston effect, Rayleigh-Taylor instability, and adiabatic heating, which create hot fluid packets that drive system dynamics. Flow reversals and chaotic behavior result from intermittent fluid packet generation and disappearance. Experiments using CO2 examined the effects of sink temperature, pressure, tilt angle, and heating power for FiHTD. Flow rate peaked before declining, with the highest rates in vertical loops. No instability was observed under the test conditions, but the mass flow trends closely matched the simulations.