**INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI**
**SHORT ABSTRACT OF THESIS**


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Thesis Title: Computational and Experimental Assessment of Supercritical Natural Circulation Loop: Steady-state Thermalhydraulics and Stability Aspects

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**SHORT ABSTRACT**

Despite the mathematical intricacy, the natural circulation loop (NCL) proposes a convenient route of energy and species transport from a high-temperature source to a low-temperature sink, without them in direct contact. The buoyancy force originating from the density gradient is the prime driving force of any natural circulation system. Operating regime of single-phase NCLs is limited by the constraints of saturation temperature and low flow rate, whereas the possibility of dry-out and appearance of different flow regimes with contrasting heat transfer behavior are of great concern in two-phase loops. Supercritical fluid offers a potent alternative due to its good heat transport capability and large volumetric expansion, thereby coupling the advantages of single- and two-phase versions. Accordingly the concept of supercritical natural circulation loop (SCNCL) has evolved in the present millennium as one of the most important initiatives under generation-IV nuclear reactors.

Both numerical and experimental appraisal of SCNCL is presented in the current thesis. Thorough numerical investigation have been performed to explore the steady-state, as well as transient, behaviour of SCNCL. The mode of heating is a critical factor on steady-state thermalhydraulics of SCNCL. Both Dirichlet and Neuman type modes are of equal importance, according to the design of system. Thus, several subsequent steady-state studies have been performed, where, heating is envisaged in both constant temperature and constant heat flux modes and cooling is always through a constant temperature sink. To find out a complete observation on the thermalhydraulic of SCNCL, influence of various operating parameters, like system pressure, source and sink temperature, working fluids, inclination angle, heating power, and various geometric dimensions have been studied meticulously. Steady-state analysis of SCNCL begins with the study of thermalhydraulic comparison of water, $CO_2$ and R134a as the working fluids under identical set of operating conditions. Effort is made to identify the best working fluid from heat transfer point of view.

An interesting observation was found for the variation in loop flow rate with power under steady-state. Mass flow rate was identified to increase with rise in heater power till a maxima, followed by a rapid deterioration in both flow rate and heat transfer coefficient, and a hike in the fluid temperature level. This phenomenon was identified as a natural circulation version of heat transfer deterioration (HTD), which is a well-explored topic for forced flow channels. For such systems, it is common to have tubes or annular channels with known wall heat flux, and the HTD is characterized by a rapid increase in the wall temperature, owing to the failure in the wall-to-fluid heat transfer mechanism. For SCNCL, however, the nature of the phenomenon is different, the similarity being in the deterioration of the heat transfer coefficient and occurrence around the pseudocritical point. To recognize this difference, and also the role of the reduction in flow rate in lowering the heat transfer coefficient, the terminology is modified as the flow-induced heat transfer deterioration (FiHTD). That leads to a drastic deterioration in heat transfer coefficient and hence can be identified as a practicable limit of operation. Power level corresponding to the appearance of FiHTD can be increased by raising pressure and lowering sink temperature. A mechanism can also be devised to maneuver the sink temperature with heater power for delaying the appearance of such deterioration. Supercritical CO2 based SCNCL can be a superior choice, as long as the power level can be limited to the FiHTD, owing to the higher flow rate and lower fluid temperature levels. However, if the expected power range of operation goes beyond the FiHTD constraint, single-phase water-based loops are a safer option, due to the consistent behavior. Asymmetric temperature and velocity profiles can be observed across flow sections, particularly with larger source-to-sink temperature differential, due to the local buoyancy effects.

It is apparent that the steady-state thermalhydraulics of an SCNCL is dominated by the geometric parameters. That necessitates a comprehensive study to understand the role of geometric variables on the thermalhydraulic characteristics of SCNCL in general and FiHTD in particular. Influence of several parameters, including loop diameter, height, width, inclination angle, heating and cooling length and their orientation, has been explored with the objective being the identification of a set of guidelines corresponding to a safer design.

SCNCLs being prone to system instabilities, systematic stability appraisal is mandatory to identify the condition for stable operating zone. In the present thesis, therefore, a comprehensive transient analysis and dynamic performance evaluation have been carried out to observe the stability performance of SCNCL. Consequently, a 2D computational model of rectangular NCL is developed and used to explore the transient nature of the same. The system exhibited both stable and unstable performance. Despite the absence of exclusive phase change, SCNCL can experience a huge density variation for a small temperature change around the pseudocritical point. This is the likeliest of reasons that may push the system towards instabilities quite similar to the two-phase versions. Influence of sink temperature on transient analysis of SCNCL is thoroughly investigated and a stability map is prepared accordingly. A Lorenze like chaotic flow is observed in the unstable zone of operation of SCNCL.

To enlarge the corresponding experimental database for SCNCL, experiments have been performed using R134a as the working fluid. R134a exhibits a low critical pressure, which makes it relatively easier to achieve supercritical condition with compared to water. The motivation of the present experimental study is to identify the thermalhydraulic characteristic and stability behaviour of SCNCL. Influence of sink temperature, operating pressure, tilt angle and input heating power are thoroughly investigated. Pressure and sink temperature are found to be the most influencing parameters for operation of SCNCL. Loop mass flow rate has been found to increase with the increase in power for all chosen conditions. Mass flow rate gradually changes with tilt angle, with the highest mass flow rate appearing for the vertical loop. There is no instability observed for the selected range of operating condition.

This dissertation reports, both numerical and experimental evaluation of the thermalhydraulic behavior and stability aspects of SCNCL. Several gaps from the literature have been identified and effort is made to address a few, with the identification of FiHTD being the most significant contribution. The goal of transient analysis is achieved by producing a detailed stability map for sink temperature. Both experimental observations and numerical predictions are found to be in consensus, with the maximum deviation being limited to 15%.