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Mixing of hot and cold fluid inside a square chimney model for a pool type research reactor – An experimental study

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ABSTRACT

Mixing of hot and cold fluid inside a scaled down model of chimney structure for a pool type nuclear research reactor was studied experimentally. Chimney structures are often used in pool type reactors to prevent mixing of radioactive water from reactor core and reactor pool water. This helps in reducing radiation field at the reactor pool top so that the pool top area can be accessible during reactor operation. During normal operation, chimney top opening serves as the inlet for the cold fluid from the reactor pool and the chimney bottom opening serves as the inlet for the hot fluid from core outlet. The chimney structure considered in the present work has two arms which act as the outlets for the mixed flow of core outlet water and pool water. These arms are connected to the pump suctions of two independent recirculation loops of the primary coolant system. Depending on the reactor operation with one loop or two loops, outlet flow from the chimney structure to the pump suction will take place either through single arm or through both the arms. To study the difference in mixing behaviour for one-loop operation and two-loop operation, experimental investigations were carried out inside a 2/9th scaled down model of the chimney structure of a pool type research reactor being developed at BARC. The bypass flow was varied from 0 to 15% of the core flow. Flow visualization of the mixing zone was carried out using dye injection and vortex spread height was observed. Fluid temperatures were measured in the mixing region and temperature profile was obtained. It was observed that increase in bypass flow reduces vortex spread height and pool temperature front height. Larger mixing zone and higher temperature front height were found for one-loop operation than that for two-loop operation. It was observed that minimum bypass flow should be 10% of the core flow in case of one-loop operation and minimum chimney height should be six times the hydraulic diameter of chimney.

1. Introduction

Pool type nuclear research reactors are often preferred for carrying out various irradiation experiments and production of radioisotopes due to its simple design having easy accessibility from the reactor pool top. In order to meet increasing demand for radioisotopes of high specific activity, the design envisages compact reactor with higher power density. A typical example is High Flux Research Reactor (HFRR) being developed at BARC. The reactor is cooled by forced upward flow to remove heat from the reactor core. The coolant velocity in the fuel channels is about 9 m/s and the pressure drop across the core is about 1.9 bar. The reactor pool is open and the water level above the core is about 10 m to facilitate handling of the fuel assemblies as well as the irradiation assemblies. The coolant flow direction is from bottom to top as shown in Fig. 1. The hot water from core outlet is guided through a chimney and is drawn by a set of primary coolant pumps through the two side outlet nozzles of the chimney. Each outlet nozzle caters to one loop of the primary coolant system. There are two loops in the high flux research reactor. For each loop, core outlet water is passed through delay tank in order to decay down the radioactivity level mainly caused by the N^{16} radio-nuclide. Subsequently primary coolant water is circulated through the heat exchangers where heat is transferred to the secondary coolant. Cold primary coolant water from the outlet of the heat exchangers is fed back to the inlet plenum at the bottom of the reactor core. Since top of the reactor core is kept open for handling of fuel/irradiation assemblies and direction of coolant flow is from bottom to top, the radioactive coolant

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Nomenclature

D	side of square chimney (m)
H	height of chimney (m)
h_s	vortex spread height (m)
h_T	temperature front height (m)
R	bypass flow ratio, $\frac{W_{in}}{W_{bp}}$
Re	Reynolds number, $\frac{\rho U_{in} D}{\mu}$
T	water temperature (°C)
T*	dimensionless temperature $(T-T_c)/(T_h-T_c)$
U	upward fluid velocity ($m.s^{-1}$)
W	mass flow rate ($kg.s^{-1}$)
y	height along upward direction (m)
y*	dimensionless height (y/D)

Symbols

μ	viscosity ($kg.m^{-1}.s^{-1}$)
ρ	fluid density ($kg.m^{-3}$)

Subscripts

bp	bypass flow
in	inlet
p	pool

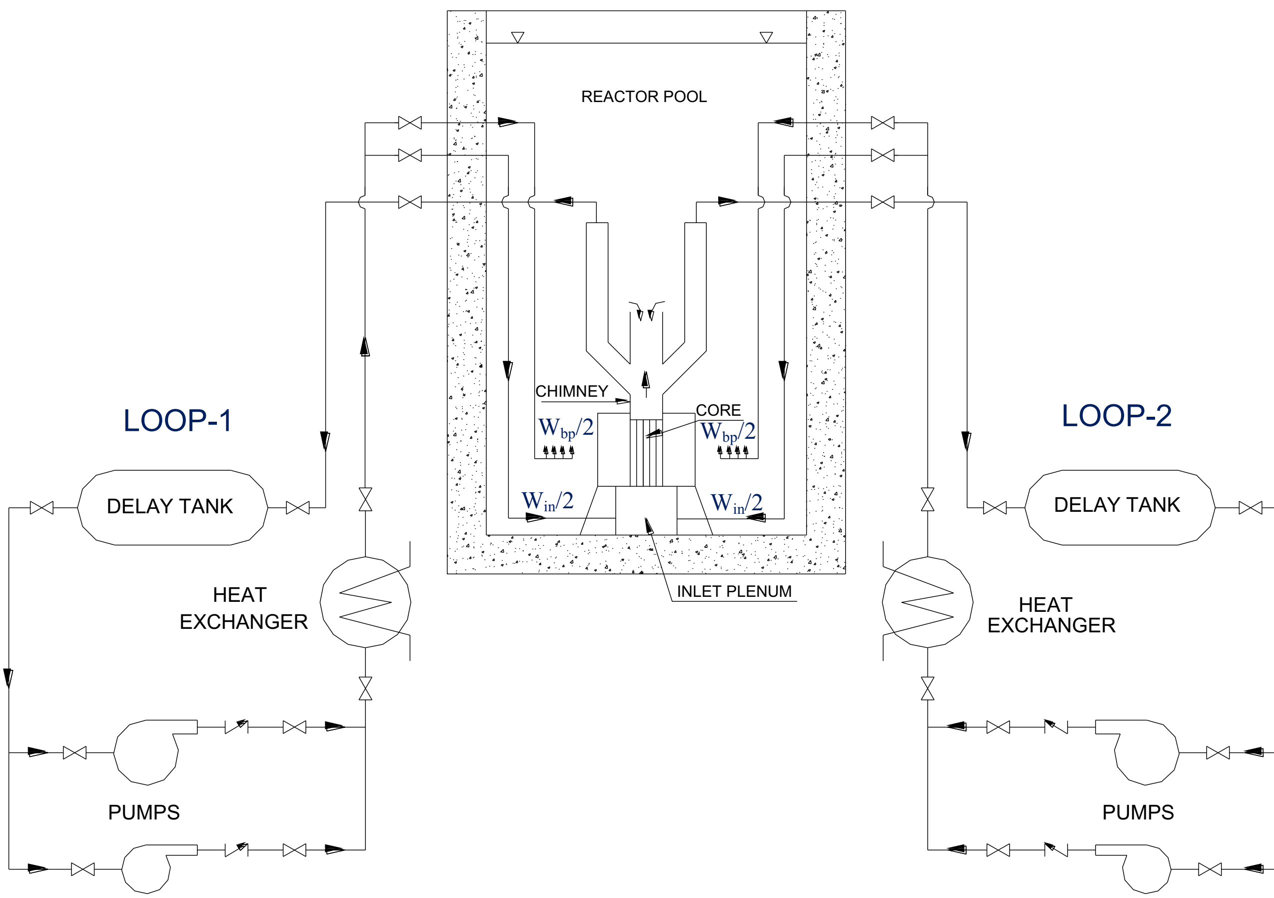

Fig. 1. Simplified process flow diagram of primary coolant system of HFRR.

from core outlet has a tendency to reach towards the top of the reactor pool. The pool top radioactivity level needs to be well below a specified limit to provide accessibility to the reactor pool top. In order to achieve this objective, a chimney structure is provided at the reactor core outlet. This chimney structure guides the radioactive water from the reactor core towards the side outlet nozzles and simultaneously draws water from the reactor pool through the chimney top in the downward direction. This downward flow through the chimney is compensated by providing core bypass flow to the reactor pool. A dynamic mixing between the two opposing flows – hot radioactive water from core outlet and cold water from pool takes place inside the chimney which decides the maximum height up to which the radioactive water (hot water) will rise inside the chimney.

Experiments were carried out in a scaled (2:9) model of the chimney structure to understand the turbulent mixing phenomena of hot upward flowing fluid and cold downward flowing fluid for different operating conditions of the reactor. Since the reactor has two loops and two pumps in each loop, during reactor start up operation, pumps need to be started one by one. When the first pump will be started, coolant flow through one loop will be taking place. Therefore, it is essential to know during this one loop operation, whether upward fluid will come out of the chimney or to what extent of chimney height this upward flow will reach. As per operational procedure, the next pump (i.e., second operating pump) will be started from the other loop. Now the coolant flow will be taking place through both the loops and both the arms of the chimney will be participating during this operation. How this