Abstract

Molten Salt Natural Circulation Loop (MSNCL) has been setup in BARC. It is a rectangular loop comprising of five components- heater, cooler, melt tank, expansion tank and loop piping. A steady state and transient analysis for the MSNCL has been performed using a one dimensional finite difference code, LBENC. Molten fluoride salt, eutectic mixture of lithium, sodium and potassium fluoride (FLiNaK) has been used as heat transfer medium for the analysis. Various transients such as startup of natural circulation, loss of heat sink, heater trip and step power increase have been analyzed for different orientation of heater and cooler.

Introduction

Present water cooled nuclear reactors have a limitation of temperature not going beyond 325°C. Increasing the system temperature increases the plant efficiency. Going beyond a certain temperature in case of water, need its pressurization which causes safety concern. Keeping in mind the cost and safety issues, researchers have a challenge to develop coolants for nuclear reactors which can be operated at higher temperature and low pressure. Molten fluoride salt mixtures have been considered as heat transfer media for core heat removal in advanced nuclear reactors as they have high boiling points. This allows reactors to be operated at high temperature and nearly atmospheric pressure. The high temperature heat is proposed to be used for generating hydrogen by thermo-chemical splitting of water.

Studies of natural circulation with water are abundant in literature. Both experimental and theoretical studies on the nature of unstable flow were performed by Vijayan et. al. [1]. There are some numerical studies for stability and other transient analysis of single-phase natural circulation loops [2-5]. Furthermore, the RELAP5, CATHARE2, and ATHLET system codes have been used in transient analysis for single-phase natural circulation loops [6-8].

The study of natural circulation in molten salt is still quite limited. Although a few analytical works exist for the thermal-hydraulics of molten salt cooled reactors [9], little experimental data have been published to demonstrate the thermal-hydraulic performance of molten salt-cooled systems.

The paper deals with the analysis performed for steady state and transient behavior of MSNCL, installed in BARC using FLiNaK salt mixture.

Natural Circulation Loop Detail

Molten salt loop is a 15NB uniform diameter rectangular natural circulation loop as shown in Fig. 1(a) and Fig. 1(b). It comprises basically four components- heater, cooler, melt tank and expansion tank. The height and
The total length of the loop are 2000 mm and 6800 mm respectively. The loop is designed in such a way that the orientation of heater and cooler can be changed to study its effect on natural circulation flow rate. Air is used as secondary side coolant.

Analysis for Molten Salt Natural Circulation Loop (MSNCL)

This analysis has been performed using one dimensional finite difference code LBENC [10]. The code is validated with water and liquid metal [11]. This study is performed for FLiNaK salt (eutectic mixture of LiF-NaF-KF), proposed as a candidate coolant for HTRs. For the sake of analysis, the loop geometries are divided into segments. Each segment is then divided into nodes. The number of nodes was taken as 20 for each segment of the loop. Pressure drop due to sudden expansion, contraction, bends etc. associated with each segment was accounted using suitable loss co-efficient. Temperature dependent thermo-physical properties [12] are considered for the analysis. The transients performed with the help of LBENC code include the loss of heat sink, heater trip and start-up of natural circulation. Analysis is performed for all four different orientations of heater and cooler i.e. Horizontal Heater & Horizontal Cooler (HHHC), Horizontal Heater & Vertical Cooler (HHVC), Vertical Heater & Horizontal Cooler (VHHC) and Vertical Heater and Vertical Cooler (VHVC). Prior to each transient analysis, steady-state conditions are usually established in the loop, which are the initial conditions of the subsequent transient analyses.

Steady state mass flow rate

Steady state mass flow rate is calculated for different heater power. Initially the fluid is in stagnant condition, heater power is zero and temperature of salt and the loop is 500°C. Heater power is then increased to 1000W in steps of 200W. Fig. 2 shows the calculated steady state mass flow rate at different power for all the four orientations. On applying the power at every step, the mass flow rate gives a steady...
state value. The power step is allowed to change after every 10000s. It is observed that the predicted steady state flow rate is highest in HHHC orientation and lowest in VHVC orientation at each power step. This is because the effective elevation difference between the hot and the cold leg, which is the driving force for natural circulation, is highest (2000 mm) in HHHC orientation and lowest (500 mm) in VHVC orientation. The effective elevation difference for HHVC and VHHC orientations are 1300 mm and 1200 mm respectively.

Start-up of natural circulation

Initially the fluid is in stagnant condition, heater power is zero and temperature of salt and the loop is 500 °C. Full power of 1000W is then applied to the heater in a single step at 0s. Fig. 3(a) shows the mass flow rate transient in start-up condition for all the four orientations. As the salt gets heated up, the mass flow rate starts increasing in the loop. At initial stage, the salt flow rate is low due to its inertia. Sudden application of full power causes a peak in mass flow rate which comes almost to steady state after 10000s. It can also be seen from Fig. 3(b) that after 10000s the temperature at inlet/outlet of heater and cooler reaches a constant value for VHHC orientation.

Loss of Heat Sink

This analysis is carried out at 1000W power. Initially the system is allowed to come in steady state at 1000W heater power and then secondary side heat transfer coefficient is set to 5W/(m2-K) at 10000s, a non-zero small value to account heat loss from cooler. Fig. 4(a) shows the transient mass flow rate variation for loss of heat sink case for all the four orientations. Due to unavailability of the cooler, the average temperature of the molten salt starts increasing. It can be seen from Fig. 4(a), after 10000s the mass flow rate suddenly decreases. This decrement in mass flow rate continues
and goes towards zero as expected. This is because after loss of heat sink the temperature difference between hot leg and cold leg decreases and hence the diving force. Figure 4(b), temperature transient, shows the sudden temperature rise in the molten salt after loss of heat sink for VHHC orientation. After t=10000s, the temperature difference between the heater and cooler decreases. The temperature of the loop suddenly increases and reaches to 1000°C in just 2000s.

![Fig. 4(a): Variation of mass flow rate during simulated loss of heat sink](image_url)

![Fig. 4(b): Heater and Cooler Inlet/Outlet Temperature Variation in VHHC orientation for simulated loss of heat sink](image_url)

**Heater Trip**

This transient is realized by removing the applied power from the heater. Initially a steady state was achieved at heater power of 1000W, then for the transient heater power was set to zero in single step at 10000s. Figure 6(a) and Fig. 6(b) show mass flow rate and temperature transients respectively following heater trip. Due to unavailability of the heater, molten salt temperature starts decreasing drastically. Mass flow rate also decreases continuously because of reduction in the available driving head i.e., temperature difference in hot leg and cold leg. The transient is stopped as soon as molten salt temperature reaches 454°C, the freezing point of the FLiNaK salt mixture.

![Fig. 5(a): Variation of mass flow rate during the simulated loss of heater trip](image_url)

![Fig. 5(b): Heater and Cooler Inlet/Outlet Temperature Variation in VHHC orientation for simulated heater trip](image_url)
Conclusions

A Pre-test analysis of MSNCL has been performed using LBENC code. Various transients such as: startup of natural circulation, loss of heat sink and heater trip has been analyzed. Steady state mass flow rate has been predicted for different heater power. Effect of orientation of heater and cooler on all the transients has been studied with the above analysis. The experimental results are awaited for the comparison of these results.

References