Design constraints – Outlet temperature of coolant & Pressure drop

K.S. Rajan

Professor, School of Chemical & Biotechnology

SASTRA University

Table of Contents

This short lecture is continuation of the previous lecture in which constraints with respect to coolant velocity were discussed. This lecture will focus on design constraints with respect to the outlet temperature of coolant and pressure drop in the core for coolant flow. Constraints with respect to height to diameter ratio of the core will also be discussed briefly.

1 Outlet temperature of coolant

With the view of achieving higher thermodynamic efficiency, the temperature of coolant leaving the core must be as high as possible. Two challenges must be met while increasing the coolant outlet temperature to higher values:

(i) Maximum allowable temperature coolant temperature has to be fixed taking into consideration of thermo-mechanical resistance of materials. Increasing the coolant outlet temperature beyond this may lead to structural damages to components of reactor or cooling circuits
(ii) The distribution of coolant across the core must ensure minimal occurrences of hot spots

1.1 Coolant flow distribution

Coolant flow distribution is an important aspect of cooling circuits of fast reactor. It must be designed to ensure the following:

(i) adequate cooling of each subassembly
(ii) homogeneity of core outlet temperature profile, i.e. the variation in coolant outlet temperatures in radial direction must be minimized

To facilitate the above, subassemblies in the core are classified into different flow zones. This classification is based on the maximum linear power rating of each subassembly, which in turn determines flow rates of coolant in each flow zone. Hence all subassemblies in a specific flow zone are in thermal contact with the same coolant flow rate.

The flow rate in each zone is fixed to ensure that its hottest part is cooled to the desired lower temperature. This is a conservative approach to prevent overheating of subassemblies. Hence there are parts in each flow zone that are slightly overcooled.

1.2 Pressure drop in core

The pressure drop in the core for flow of sodium determines the energy required for pumping. More important aspect is the maximum pressure drop for the required flow rate of primary sodium. Under steady state or in normal operating conditions, primary sodium flow is maintained by sodium pumps. In the case of transients due to loss of flow due to malfunctioning of pump, the sodium flow is to be maintained by natural convection. The sodium flow by natural convection is due to the reduced density as sodium heats up. Lighter hot sodium moves up the core and leaves at the top while relatively cold sodium enters the core at the bottom. Too a higher-pressure drop would provide higher resistance for flow to be established by natural convection. Hence maximum pressure drop in the core is restricted to 5.4 atm in Prototype Fast Breeder Reactor.

1.3 Core height to diameter ratio

Height and diameter of core play an important role in the overall design with respect to safety and economy. With the core of larger length, the cost of subassembly is high apart from increased sodium void coefficient. Higher cost is attributed to difficulty in fabrication of fuel and due to increased subassembly length. With increase in core height, the volume fraction for the fuel is reduced for a fixed pressure drop for coolant flow. Hence both from the perspective of economy and safety, shorter cores are desirable.

But a constraint arises due to the use of shorter cores. The fissile fuel inventory required is larger; hence more number of pins and a larger diameter core are required. The reactor control becomes difficult with too a larger diameter core. Similarly, radial flux flattening for larger diameter core is relatively difficult. Hence, a trade-off needs to be achieved for optimum core height and diameter. In other words, an optimum core height to core diameter ratio needs to be worked out. For most fast reactors, a core of 1 m height is considered to represent this tradeoff satisfactorily, with the height-to-diameter ratio of 0.2 for large diameter cores.

2 Reference/Additional reading

1. Sodium Fast Reactor Design: Fuels, Neutronics, Thermal-Hydraulics, Structural Mechanics and Safety, in: Vol. 21, Handbook of Nuclear Engineering, Dan Gabriel Cacucu (Ed. In Chief), Springer