Annals of Nuclear Energy 102 (2017) 255–267

Contents lists available at ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene

# Hydraulic characteristics of a fast reactor fuel subassembly: An experimental investigation

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ARTICLE INFO

*Article history:*
Received 10 May 2016
Received in revised form 11 November 2016
Accepted 21 December 2016

*Keywords:*
Fast breeder reactor
Fuel subassembly
Rod bundle
Top blockage
Pressure drop
Laminar and turbulent flows
Water model

ABSTRACT

Fuel subassemblies of a fast reactor consist of fuel pin bundle with helically wound spacer wires, arranged in a triangular pitch within a hexagonal wrapper. The fuel pins are located within the subassembly. Further the subassembly comprises of a diffuser where the cross section changes from cylindrical to hexagonal, mixing plenum before the exit of pin bundle and a specially designed blockage adapter. Accurate assessment of the pressure drop in the fuel subassembly is essential to ensure adequate core cooling and design of sodium pump. Experimental determination of pressure drop characteristics in the subassembly by simulating the hydraulic condition in the subassemblies of the reactor core is considered essential as a better choice as correlations reported in the literature cannot be directly used for all the complex regions present in the subassembly. This is due to the fact that flows in the interconnecting sections are highly under developed. Further, the flow regime in a fuel subassembly varies from laminar (during shutdown heat removal under natural convection) to completely turbulent under full power condition.

To understand the hydraulic characteristics of the 500 MWe Proto type Fast Breeder Reactor (PFBR) fuel subassembly, an experimental facility has been commissioned. Experiments on full scale subassembly with dummy fuel pins have been performed using water as simulant. Experiments have been conducted covering a wide range of Reynolds number encompassing laminar, transition and turbulent regimes. In the rod bundle, no abrupt changes in friction factor were observed when the flow changes from laminar to turbulent. The experimental results have been transposed using Euler number similarity, to determine the pressure drop for sodium flow in the reactor. Possible uncertainties in the experimental data have been quantified. Useful pressure drop correlations have been proposed for various section of the subassembly of a fast breeder reactor. Finally the results for fuel pin bundle region are compared with the data reported in the literature and a satisfactory agreement has been observed.



## 1. Introduction

The Prototype Fast Breeder Reactor (PFBR) is a 500 MWe pool type sodium cooled reactor which is in its advanced phase of commissioning at Kalpakkam, India. It is designed to have two secondary loops with each loop having one Secondary Sodium Pump (SSP) and two Intermediate Heat Exchangers (IHX). Reactor core comprises of various types of subassemblies resting inside the grid plate sleeves through which primary sodium coolant is fed to all the individual subassemblies by two Primary Sodium Pumps (PSP) operating in parallel. The heat generated in core is transported by primary sodium to the secondary sodium in the Intermediate Heat Exchangers. Finally, the secondary sodium transfers heat to water in the steam generator leading to production of superheated steam to generate power (Chetal et al., 2006). The schematic flow sheet of PFBR is depicted in Fig. 1. The primary circuit of PFBR consists of inner vessel surrounded by main vessel housing grid plate, reactor core, control plug, IHX and pump assembly apart from other components as depicted in Fig. 2. The core consists of various types of subassemblies, viz., fuel, blanket, reflector, storage, shielding etc. A core plan showing all these subassemblies is depicted in Fig. 3. About 90% of the thermal power is generated in fuel region which consists of 181 subassemblies grouped into seven zones based on the flux pattern and the associated flow requirements to get a nearly uniform sodium outlet temperature. The geometrical details of the fuel subassembly are listed in Table 1. The subassembly is complex in geometry having radial entry, axial exit and pin bundle

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http://dx.doi.org/10.1016/j.anucene.2016.12.025
0306-4549/

**Nomenclature**

| | |
|---|---|
| A | cross section area ($m^2$) |
| f | Darcy friction factor |
| D | diameter (m) |
| K | loss coefficient |
| L | length of the bundle (m) |
| $\Delta P$ | pressure drop (Pa) |
| Re | Reynolds number |
| Q | volumetric flow rate ($m^3/h$) |
| V | velocity of flow in fuel bundle (m/s) |
| $\epsilon$ | surface roughness (m), |
| $\upsilon$ | kinematic viscosity of fluid ($m^2/s$) |
| P | density of fluid ($kg/m^3$) |

*Subscripts*

| | |
|---|---|
| m | model |
| p | prototype |
| t | total |
| f | foot |
| h | hydraulic |
| en | entry |
| b | bundle |
| ex | bundle exit |
| se | subassembly exit |
| exp | experiment |

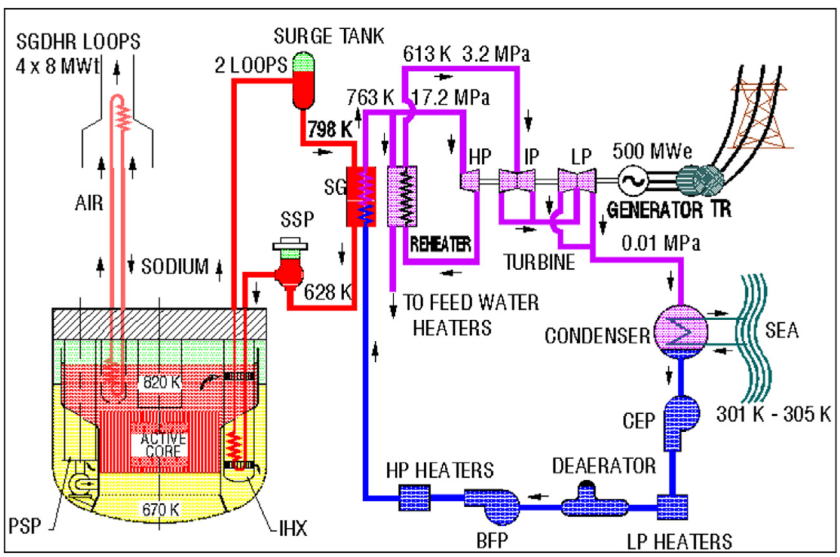


**Fig. 1.** Heat transport flow sheet of a pool type FBR.

with helical spacer wire. It also has a number of varying cross sections along the length.

The fuel pins are supported on rails. The subassembly comprises of a diffuser where the cross section changes from cylindrical to hexagonal, mixing plenum at the bundle exit and a blockage adapter before subassembly exit. Knowledge of pressure drop in various regions of subassembly and across the subassembly is critical for determining the primary pump head, and to quantify the extent of additional pressure drop required using devices such as orifices as well to understand the hydraulic behaviour during various operating scenarios. Because of the complex geometry of the subassembly and highly underdeveloped nature of flow in various sections, any estimate, of pressure drop using literature correlations is prone to uncertainties.

Even though many correlations are reported in literature to determine pressure drop, the ranges of applicability of them are different for various geometrical configurations present in the subassembly. Hence, it is necessary to experimentally measure the pressure drop on a full scale subassembly and assess its characteristics. It may be highlighted that the flow from grid plate to the foot of the subassembly is through multiple inlet holes in the grid plate sleeves. The flow enters in the foot of the subassembly through 12 slots provided in the foot of the subassembly. In order to minimize the effect of blockage from top of the subassembly head, provision of six blockage adaptor holes (one in each face of the hexcan) have been provided at the subassembly top. This provision avoids complete flow from top even in case of fall of some heavy objects at top of the subassembly. But when the subassembly top is blocked, reduced flow will take place through blockage adaptor holes. Hence it is essential to determine the flow through the blockage adaptor holes for the purpose of safety analysis. These form the motivation for the present experimental investigation.

To achieve the above objectives, an experimental loop was designed, fabricated and erected for conducting the hydraulic studies using water as the test medium. A 1:1 scale dummy fuel subassembly, was fabricated and experiments have been conducted for various operating conditions of the reactor and the results were transposed to the reactor condition using appropriate similarity laws. This paper describes the details of the subassembly, objective of the tests, similarity criteria followed for the experiment, experimental methodology, instrumentation involved and the results obtained from the experiments with their transposability to the reactor conditions. As already indicated, both the normal subassembly and the subassembly with axial exit completely blocked have been tested.