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Study on Flow Field in the Core Inlet of PGSFR

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1. Introduction

PGSFR (Prototype Sodium-cooled Fast Reactor, PGSFR) is now under development by KAERI (Korea Atomic Energy Research Institute) with the aim of construction by 2028. PGSFR is far different from conventional PWRs (Pressurized Water Reactors), and resultantly the flow and pressure distribution in the core is expected much different each other. The flow and pressure distribution in the core is essentially important in the evaluation of the core thermal margin, and eventually the safety of the core.

In section 4.4 of NUREG-0800 (Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plant: LWR Edition) the flow and pressure distribution test is highly recommended, and appendix 4A of SAR (Safety Analysis Report) also requires the test result of core flow and pressure distribution[1]. For large conventional PWRs, there have been several core flow and pressure distribution tests such as for CE's System 80+, KAERI's APR+, and so on. And for an integral light water reactor, the test for SMART was carried out by KAERI. Most of these tests were scaled down by around 1/5, and the technical background of the scaling is based on Hetstroni(1976)[2,3]. For PGSFR the test is on the way by KAERI.

However, studies on the flow field distribution in the core inlet are rare, in spite that the flow field is closely related with the core flow and pressure distribution. This study is on the flow field test near the core inlet for PGSFR. The flow field in the core inlet was measured using PIV (Particle Image Velocimetry) system.

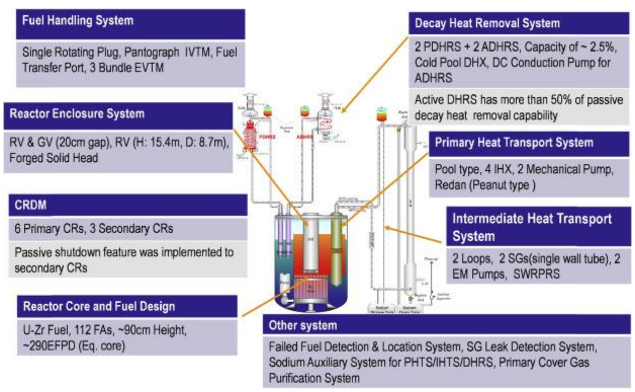

Fig. 1. Outline of PGSFR and Its Design Features

2. Brief Description of PGSFR

PGSFR is pool-type reactor as shown in Fig. 1, and the core is honeycomb arrangement as shown in Fig. 2. The honeycombs including fuel assemblies (FAs) are categorized into 12 groups according to the mass flowrate. The 10th, 11th, and 12th groups have totally around 1.2%, so these groups are ignored in the test.

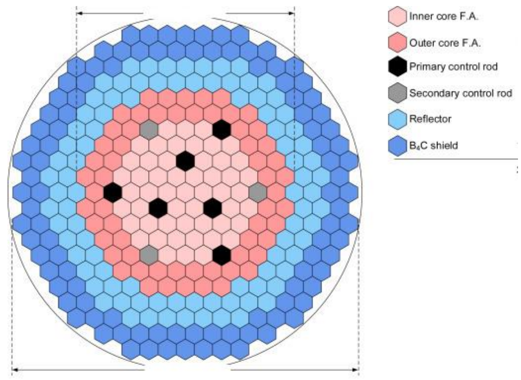

Fig. 2. PGSFR core assembly arrangement

3. Experiments

3.1 Scaling Analysis

According to Hetstroni [3] and Hong et al. [4] Euler (Eu) number should be conserved both in prototype and model even in the place where the geometrical similarities are not fully conserved. Conservation of Eu number means that the pressure drop constraint is imposed on that. Fluid velocity is not constrained, if the free surface (or gravity) is not importantly considered. Free surface phenomenon mathematically produces Froude (Fr) number in scaling analysis, which constrains the model velocity.

Geometrical scaling constraint is length scale, 1/5, and the same aspect ratio. The fluid velocity scale was set 1/2, and this is similar to $1/\sqrt{5}$, which comes from the conservation of Fr number. The working fluid was determined as water instead sodium.

3.2 Single Tube Test

In order to set the required pressure drop for each FA according to its group, orifices were used and the pressure drop was checked by a single tube test facility as shown in Fig. 3. The pressure drop vs. flowrate test results are shown in Fig. 4 for group 1 as a representative test results. Every test for the other flow groups was also performed. The maximum pressure drop err over the all groups lies between 1.6% and 4.9%.

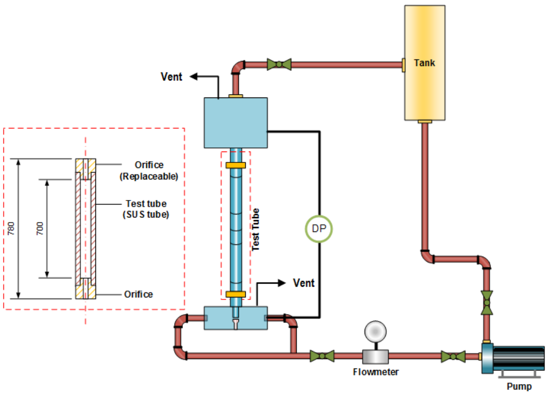

Fig. 3. Outline of Single Tube Test Facility

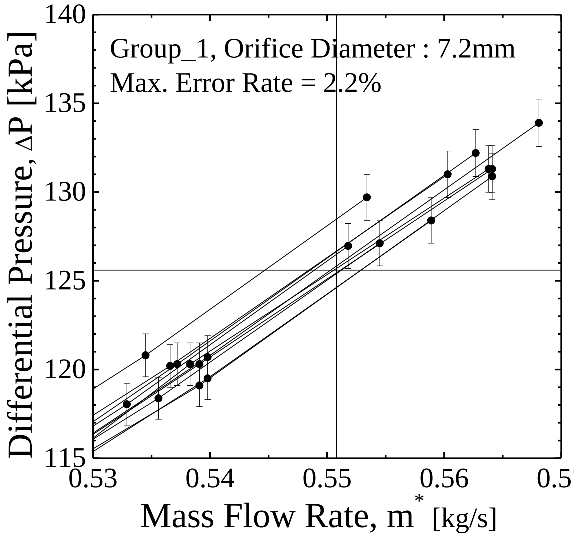

Fig. 4. Pressure Drop vs. Flowrate for group 1

3.2 Core Inlet Flow Simulator Test

Test facility for the core inlet flow field constructed and PIV measurement system was setup as shown in Fig. 5 and Fig. 6. 4 circulation pumps and 4 flowmeters were installed. In the lower plenum receptacles were simulated even in the place where the 10^{th}, 11^{th}, and 12^{th} groups are located above, but the middle parts were removed for the PIV measurement. So the laser slit can go through the removed part. Selected some important specification for the used PIV is arranged in Table I.

The velocity measurement error was estimated as 7.27mm/sec.

Tests were conducted for 5 cases; 1) 100% flow (full power operation), 2) 30% flow (shutdown operation), 3) 50% flow, 4) One pump100%, flow, and the other 90% flow, and 5) One pump100%, flow, and the other stops. Each result is shown in Fig. 7 to Fig. 11. Overall results look reasonable in qualitative point. Cases 4 and 5 are asymmetric conditions and the flow fields also show the asymmetric fields.

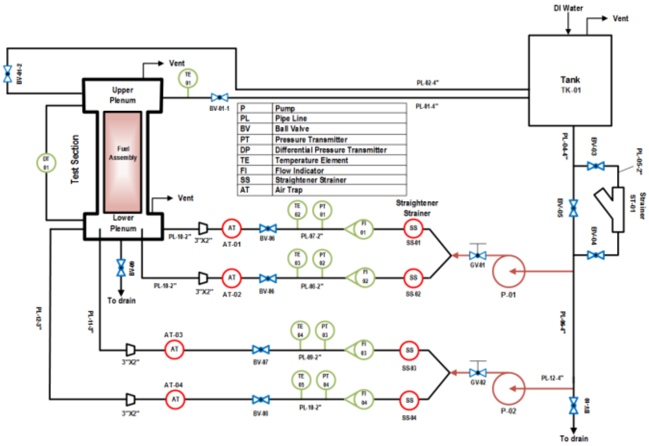

Fig. 5. Core Simulator Test Facility Flow Diagram

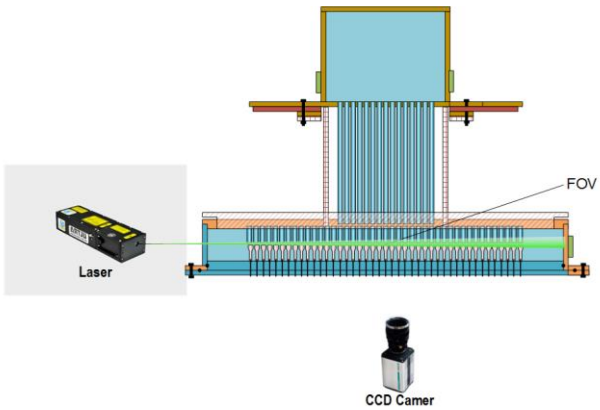

Fig. 6. PIV Setup in Core Simulator Test Facility

Table I. PIV System

Items	Specification
Laser generation	Nd: YAG Laser 532nm, 200mJ×2 energy, 15Hz
Synchronizer	1ns resolution
CCD camera	1600×1200 pixel, 32 Lenz Nikon 50mm/F1.2, F-mount
Software	Insight3G-SEC
Computer	Quad-Core Xeon 2.66GHz Processor, 4Gb ram

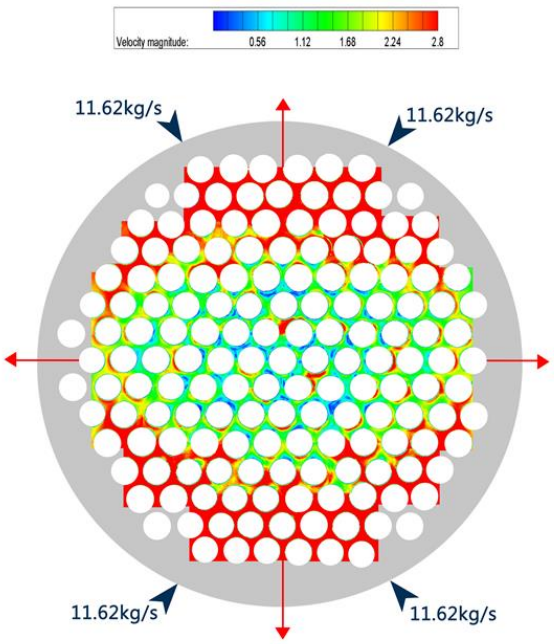

Fig. 7. Flow Filed Image Measured by PIV (100% flow)

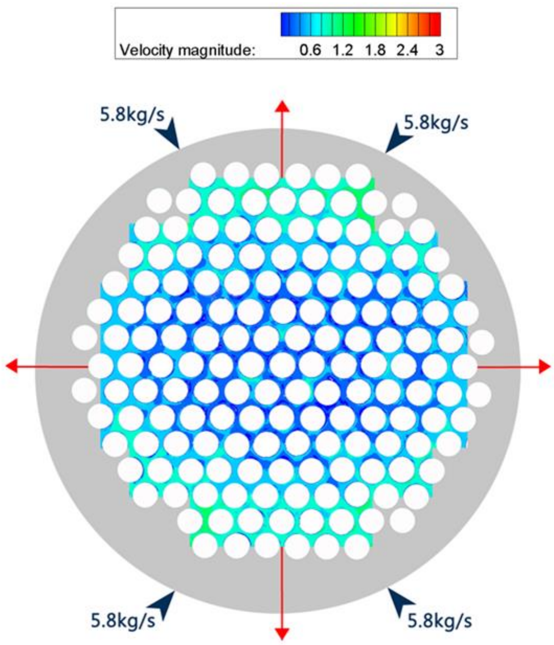

Fig. 9. Flow Filed Image Measured by PIV (50% flow)

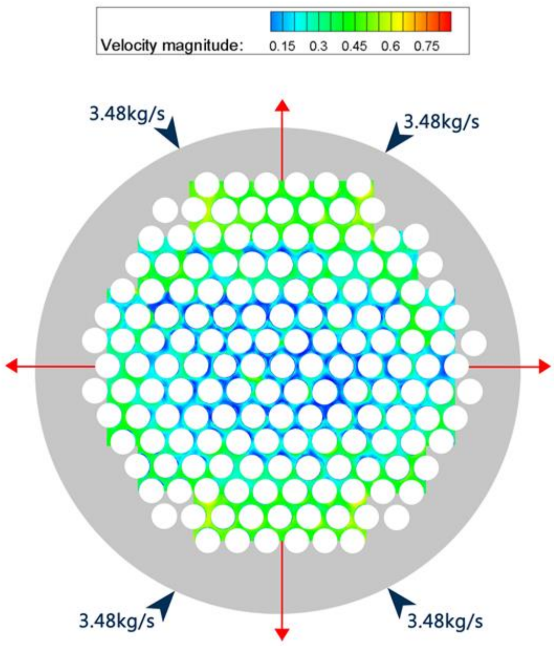

Fig. 8. Flow Filed Image Measured by PIV (30% flow)

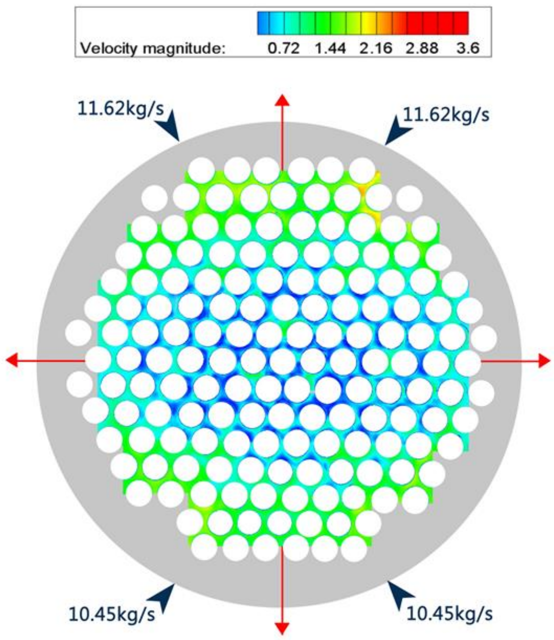

Fig. 10. Flow Filed Image Measured by PIV (One pump100%, flow, and the other 90% flow)

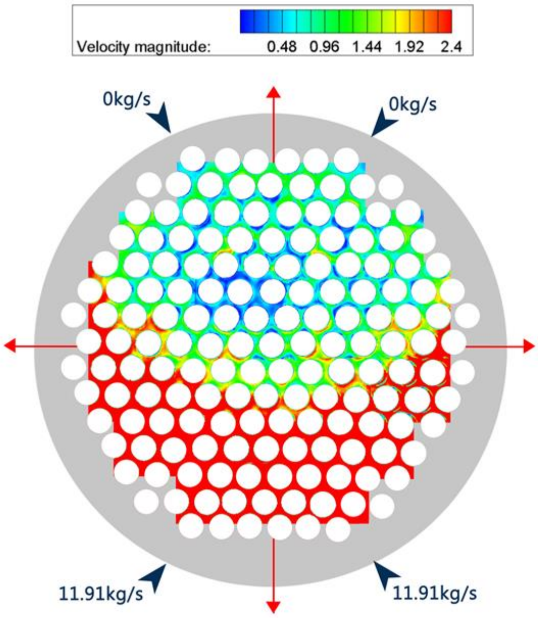

Fig. 11. Flow Filed Image Measured by PIV (One pump100%, flow, and the other stops)

5. Conclusions

A core inlet flow field test facilities for PGSFR were designed and PIV measurement was performed to obtain the flow field information in the core inlet. At first a single tube facility was designed to select and verify the orifices design which is applied into fuel assembly simulator for the pressure drop relation between prototype and model. And then a core inlet flow simulator facility was designed based on linear scaling law in order to preserve the flow characteristics of the core inlet and the fuel assemblies in prototype reactor. The length scale was employed as a 1/5 of prototype and 1/2 of prototype velocity, which is conventional method and which is expected to minimize the flow distortion in the reduced scale of the facility. In order to perform the visualization of the core inlet flow field, PIV method was selected. Several tests for the various flow conditions were performed, and the results show reasonable velocity contours in qualitative point. These test results of flow fields are expected to give additional information to the core flow and pressure distribution test results.

In further study, CFD (Computational Fluid Dynamic) analysis is to be conducted. This will give the direct information on the FA flow distribution, and direct comparison with KAERI's core flow and pressure distribution test results.

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[1] NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plant: LWR Edition".

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[4] Soon Joon HONG, Jung Hui HA, Taehoo LEE, Ji Woong HAN, Study on the Scaling of Core Flow Distribution Test, Transactions of the Korean Nuclear Society Autumn Meeting, Pyeongchang, Korea, October 30-31, 2014.