Effects of Mixing Vane Design on Hydraulic Flow Fields in Subchannel

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1. Introduction

A series of flow visualization testing is performed to characterize the hydrodynamic flow field produced by the various mixing vane within a 5x5 rod bundle including ACE7^{TM} (previously NGF) geometry.

Particle Image Velocimetry (PIV) allows the full-field measurement of in-plane velocities in a flow field. The basic principle used to measure the velocity field is to obtain two images of the same seed particles by some imaging technique. The distance and the direction that the particles move correspond directly to the local fluid velocity within carefully controlled time span between the two images. The requirement of this technique is that the particles are small enough to follow the flow and a specific gravity close to that of water.

2. Test Methodology

2.1 Test Loop

The flow housing accommodates a 5x5 test bundle assembled on a 0.496-inch pitch with 0.374-inch rod diameter. This is a typical 17x17 fuel lattice. Major components of the loop include a constant head tank, pump, motor and frequency controller, flow meter (turbine-type) and appropriate piping/valves. The closed-loop piping system is open to the atmosphere at the constant head tank and provides for re-circulation of filtered water. An adjustable frequency controller provides speed control for the pump motor and allows precise control of the flow rate ranged from 95 to 285 GPM (bundle velocity of 8 to 24 ft/sec). This loop is installed and operated by Thermal-Fluid Sciences Laboratory at Clemson University.

2.2 Flow Visualization

Video recording of the flow field employed the flow housing, and a flow visualization technique using a laser light source (Argon-Ion Laser) and seeded flow. Lateral flow visualization is achieved at numerous axial locations using traversing mechanisms that allow the laser light to be directed to the appropriate axial location in the desired subchannel. A borescope is used to transit information to the camera and VCR.

2.3 PIV Process

A laser sheet illuminates the particles in the plane of the light created by the pulsed laser (Nd : YAG). Two images are generated, and small regions of the image analyzed to assign a velocity vector. Conceptually each vector represents the average velocity in an interrogation region. Mathematically, this process uses a cross-correlation of the intensity matrix for each interrogation region. Thirteen image pairs are acquired to create instantaneous velocity fields. These velocity fields are combined to yield the time-averaged flow field.

3. Test Articles and Setup

The 5x5 grids tested are ;
- Baseline (17x17 RFA)
- C01 (vane design for 16 ACE7)
- C02 (vane design for 17 ACE7)

Figure 1 [1] shows the schematic of vane designs tested. Note that the vane angle for all of above is same. The 5x5 typical rod bundles are three spans in length, on full spacing, 20-inch. Pressure drops are measured at the second and the third span to avoid inlet effects. Lateral velocity PIV data is taken downstream of the third grid.

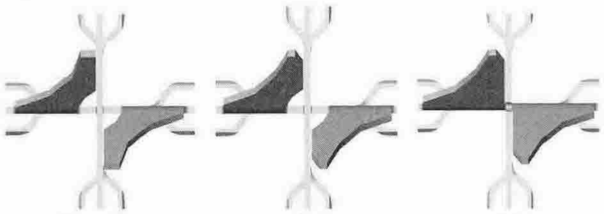

Figure 1.Schematics of vane design tested

4. Test Results

4.1 Pressure Drop

Pressure drop measurements determine the pressure losses due to friction drag along the rods and the combined effect of friction and form drag of the grid. By comparing the data measured at each of grid span, the effect of multiple grid as well as magnitude of pressure loss of each grid tested can be justified.

The results from two consecutive grids serially aligned showed that the pressure loss of second measured grid span, downstream of first measured grid span, is slightly higher than that of first grid by 0.02 to 0.07 psi. The higher flowrate results in the larger difference between them especially for friction drag. The relative pressure loss between grid type is ; Baseline < C01 < C02.

4.2 Lateral Velocity Flow Fields

PIV data is taken for channels 6 and 10 (subchannels 15 and 21 for 5x5 CHF data analysis model) based on following reasons (except for baseline) ;

- central channels to be as far away as possible from the wall effect
- balance of counter-clockwise swirl (channel 6) and clockwise swirl (channel 10) with current vane pattern
- to be consistent with 2-channel CFD models
- conventionally limiting subchannels in CHF tests or equivalnet

The region of main interest is 6 to 10 inch (150 to 250 mm) downstream of vane base. As stated, PIV data for baseline is taken from channel 6 (subchannel 15) only. Qualitatively, the strong vortex (swirl) is pertained to 200 mm downstream of vane base. Even though there is no data above 200 mm for baseline, it can be inferred that vortex is extended further downstream.

Figure 2 shows the lateral flow fields for vane design of 16 ACE7 (C01) at region of interesting. Even though there are central swirl to 200 mm downstream, it can be characterized by rod swirl dominant similar to that of baseline. At 250 mm downstream, most of swirl is decayed out in channel 6. Above 250 mm downstream, at 300 mm downstream, the flow field is mainly axial with small lateral velocity.

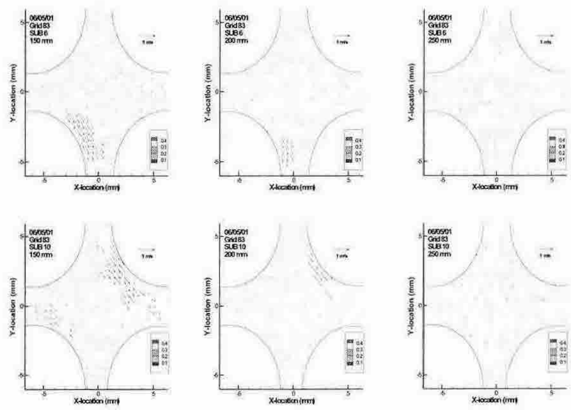

Figure 2. PIV data for C01 (6 to 10-inch downstream)

Figure 3 shows the lateral flow fields for vane design of 17 ACE7 (C02) at region of interesting. Central swirl is dominant at 150 mm downstream of vane and it is switched to rod swirl after 200 mm downstream. Rod swirl is pertained at 250 mm downstream. Above 250 mm downstream, at 300 mm downstream, central swirl still retains in channel 6 with small lateral velocity. Flow in the rod gap is mainly axial with small lateral flow.

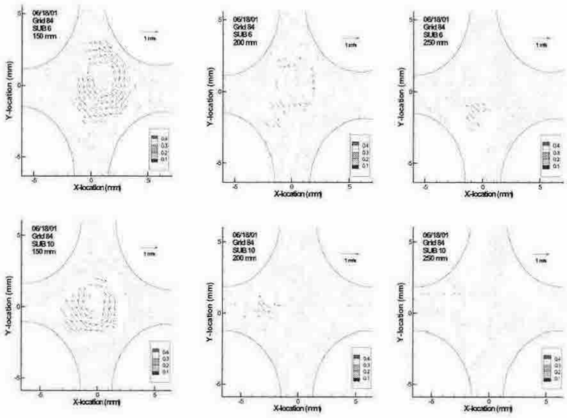

Figure 3. PIV data for C02 (6 to 10-inch downstream)

5. Conclusion

Based on flow visualization, the characteristics of swirl at region of interesting is identified. While conventional split-vane (baseline & C01) shows rod swirl up to 200 mm downstream, C02 shows unique central swirl above 200 mm downstream. There is a transition between two types of swirl (rod to central for C01, central to rod for C02) at 150 or 200 mm downstream. Central swirl is thought to be effective to minimize enthalpy gradient within channel. Due to weak strength of swirl above 250 mm downstream, it is not recommended to use any of vane design for limiting span of application with full span (20-inch) to achieve designated performance.

For the actual fuel lattice, there are guide thimbles which can alter flow characteristics or structure. To extend the results to the general application, testing and CFD benchmarking with thimble geometry including the effects of deteriorated vane are required and planned.

RFERENCES

[1] K.H. Kim, et. al., 17 NGF Grid Concepts and Scoping Analysis (T/H related), Proceeding KNS Autumn Meeting, Yongpyong Korea, October 2002.

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