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Variation of Concentration Profiles according to Flow Separation on Flat Plate Flow

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1. Introduction

Until now, many researches in field of aerospace have been studied to prevent a flow separation as main cause of stall. The flow separation on external flow decelerates main flow around a flight due to an abrupt increment of boundary layer thickness by the separation. Wake flow by the separation generates a vortex flow that results in flow instability.

Flow separation in calculation not only causes a numerical instability but also increases a calculating cost due to adapting many meshes into separation region.

Flow separation on internal flow may be generated by an effect of adverse pressure gradient (APG). The pressure gradient unavoidably exists in the elbow with the angle of 90° and the U-tube of 180°. Velocity and scalar fields are affected strongly by the separation flow generated from APG.

Recently, research projects are continuously progressed to settle a wall thinning problem caused by Flow Accelerated Corrosion (FAC) on feeder pipe in CANDU. The feeder pipes necessarily contain the APG region due to the S-shape made by connecting two elbows. The separation generated by the APG is affected a velocity profile on the opposite side. The variations affect a concentration profile of ferrous iron in coolant, simultaneously. The ferrous iron in oxidants on wall is fast diffused into bulk water with the strong dependence of the concentration gradient. The concentration field is strongly related with the FAC because the FAC is linearly proportional to the concentration gradient near wall. At the opposite site, the wall thickness of the pipe rapidly decreased due to the larger value of FAC rate than it of other sites [1].

Present study calculated two dimensional flat-plate flow to investigate such an affected concentration field owing to the separation on internal flow.

2. Numerical Analysis

Two dimensional flat-plate flow was calculated on the calculating domain as shown in Fig. 1. In order to generate a flow separation, APG on the bottom wall is adapted as wall boundary condition.

$$U_x(y) = 0.5\left[\frac{0.05-y}{0.05}\right]^{1/7} \quad (1)$$

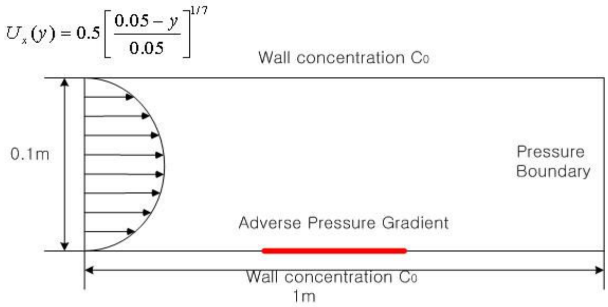

Figure 1. Computational domain and boundary conditions to calculate a flat plate flow

From Eq. (1), the initial velocity used the 1/7 law of Prandtl is adapted at inlet of rectangular conduit with 0.1 m of height and 1 m of length [2]. To visualize the effect of separation on the concentration field, concentration at both walls used the constant value of C_0 as the Dirichlet boundary condition. The solver used the commercial CFD solver, CFX 4.

3. Results and Discussion

Flow separation on 2-D flat-plate was generated by an artificial APG on the bottom wall. Figure 2 shows the generated APG and the streamlines under separation flow. In Figure 2, separation begins at APG and reattaches at the favorable pressure gradient (FPG).

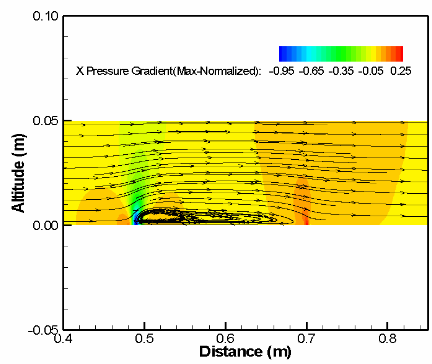

Figure 2. Contour of pressure gradient and stream lines

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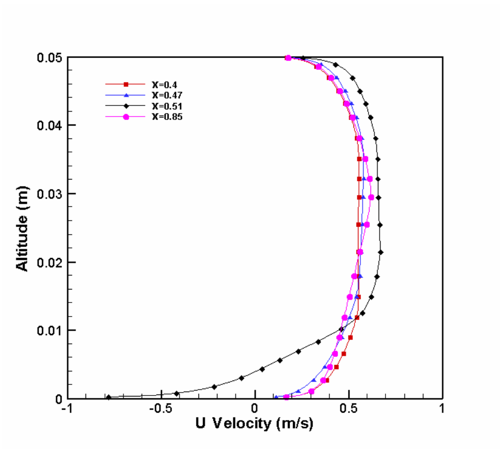

Figure 3. Comparisons of velocity profiles with locations; x=0. 51 is under affection of separation.

Flow separation on bottom wall also affects the velocity profile near the top wall without separation. As shown in Figure 3, the velocity gradient of Y-direction is more steep at the position, x=0.51, on the region of recirculation. The variation of velocity gradient is quantified from definition of shape factor in Equation (2) [2].

$$S.F = \frac{\delta_{\text{displacement}}}{\delta_{\text{momentum}}} = \frac{\int_0^{\delta}\left(1-\frac{u}{U}\right)dy}{\int_0^{\delta}\frac{u}{U}\left(1-\frac{u}{U}\right)dy} \quad (2)$$

Shape factor has the value of 1.9283 at the top wall within influence of separation and 2.9876 without separation. In comparisons with two shape factors, the velocity gradient on the top wall is steep as much as 46 % due to the separation.

Similarly, the effect of separation on concentration field is shown in Figure 4. Concentration gradient on top wall is also steep under influence of separation as similar as velocity field. Analogically about momentum thickness, the steepness of concentration gradient is also defined like Equation (3) with the modification of enthalpy thickness [3].

$$\text{Mass flux thickness} = \int_0^{\delta}\frac{u}{U}\left(\frac{C-C_\infty}{C_w-C_\infty}\right)dy \quad (3)$$

The thickness has the value of 0.0093 in case of affection of separation and 0.0043 without separation. The concentration gradient on the top wall is also steep as much as 46 % due to the separation.

4. Conclusion

In order to predict the FAC site on feeder pipe, fundamental calculation was performed in this study. This study suggested the evidence that concentration field is affected by the modified velocity profile due to separation. Both velocity and concentration gradient on the top wall is steeper because of separation. The phenomena can explain the migration of maximum wear site by FAC in CANDU.

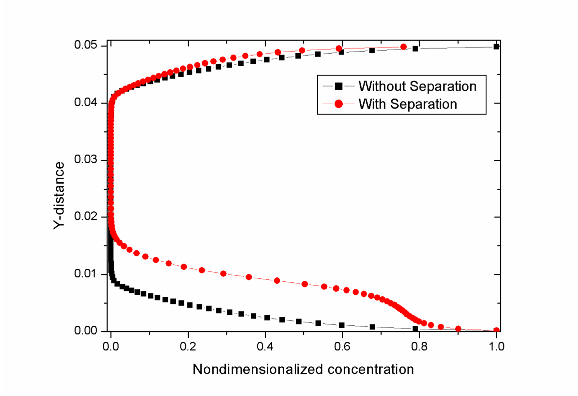

Figure 4. Comparisons of concentration profiles with locations; x=0. 51 is under affection of separation.

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