THREE DIMENSIONAL FLOW DISTRIBUTION IN A HEADBOX MANIFOLD

Lu Hua, Pingfan He, Eric Bibeau*, Martha Salcudean and Ian Gartshore
Department of Mechanical Engineering, The University of British Columbia, Vancouver, BC V6T 1Z4
*Process Simulation Limited (PSL), #204, 2386 East Mall, Vancouver BC V6T 1Z3

INTRODUCTION

The flow modelling of a tapered manifold flowspread, similar to those used in paper machine hydraulic headboxes, has been investigated. Tapered manifolds are commonly used in hydraulic-type headboxes in the pulp and paper industry. Stock is admitted at the larger end and flows across the width of the machine to the smaller end. A portion of the stock is recirculated. The recirculation ratio is adjusted until there is no apparent flow in the indicator tube that is connected across the headbox. An array of small diffuser tubes connects the manifold section to the rectifier region located upstream of the slice. Until recently, the complexity of the geometry and the three-dimensional turbulent flow field did not allow for complex flow calculations in headbox manifolds. There have been few numerical calculations of flows in headbox manifolds [1–4]. These studies have known limitations. The diffuser tubes were either ignored, modelled in two dimensions, or assumed to have single tube behavior. These models cannot account for the flow non-uniformities existing across the diffuser tubes.

NUMERICAL MODEL

The three-dimensional incompressible Reynolds averaged Navier-Stokes equations are solved. Turbulence closure is obtained by the use of the standard $k - \varepsilon$ model with the usual wall function treatment. A domain segmentation method in conjunction with curvilinear grids is used in the present study. The manifold is decomposed into the tapered duct region and a number of diffuser tube regions. A solution is obtained by repeatedly applying a single-domain solution solver to all the computational blocks, and cycling through all the blocks until the residuals are sufficiently small. Validation cases for manifold applications can be found in Reference [6].

RESULTS

The simulated headbox manifold consists of a tapered rectangular duct and a bank of diffuser tubes. The inlet duct diameter is $0.6 \, \text{m}$ and the outlet duct diameter is $0.40 \, \text{m}$. Each diffuser tube is $0.5-\text{m}$ long with an inlet diameter of $0.1 \, \text{m}$. The hexagonal outlet diffuser tubes are in contact. The flow in the manifold is assumed steady and incompressible. An outlet boundary condition of zero-gradient is used at the diffuser tubes exit to avoid calculation of the rectifier and slice regions. The complete calculation of the headbox will be considered in another study. It is further assumed in this study that the headbox manifold is limited to 30 diffuser tubes distributed in three rows. Figure 1 shows one half of the coarse grid computational domain used in the present study. There are 31 segments, one segment for the tapered manifold duct and 30 segments representing the diffuser tube bank. Taking advantage of flow symmetry, only half of the flow domain is calculated: half of the manifold duct, the first row of tubes and half of the tubes in the second row. A rectangular type grid is used for the tubes instead of cylindrical grids to obtain a continuous grid at the interface. The grid shown here contains $125 \times 13 \times 25$ grid nodes for the main segment and $5 \times 5 \times 27$ grid nodes for each diffuser tube. A finer grid was also used containing $165 \times 19 \times 25$ grid nodes for the main segment and $7 \times 7 \times 27$ grid nodes for each diffuser tube. The finer grid was used to verify that the solution is grid independent. Each grid is generated using a combination of an elliptic grid generation method and an algebraic generation grid method.

Results were obtained using water and an inlet manifold flow velocity of $1 \, \text{m/s}$. Imposing a zero-gradient condition at the outlet of the manifold resulted in a recirculating flow ratio of 39.5%. Although the zero-gradient condition results in a relatively high recirculation ratio, this condition was imposed to differ from the velocity boundary condition also imposed at the outlet which requires less numerical iterations to obtain rapid convergence.

Figure 2 presents the calculated flow velocities at the symmetry plane passing through the second row of diffuser tubes. For this particular manifold geometry, the flow direction in the tapered duct near the entrance of the first few tubes tends to be parallel to each diffuser tube while the flow direction in the last several tubes tends to be more aligned with the main flow in the duct. This flow distribution causes more fluid to circu-
late through the diffuser tubes near the manifold entrance as compared to diffuser tubes located towards the manifold exit.

Figure 3 shows the predicted pressure field in the manifold and diffuser tubes at the symmetry plane. It can be seen that the pressure drop near the tube entrance is large when compared to the pressure drop occurring elsewhere in the flow field. A three dimensional view of the overall flow field is shown in Figure 4. The flow rate distribution for the first and second row of tubes is shown in Figure 5. As mentioned earlier, it can be seen that the flow rate is slightly higher for diffuser tubes located near the manifold entrance.

CONCLUSIONS

A computational model is presented for the numerical flow simulation of headbox manifolds. The model uses block-structured curvilinear grids to allow the treatment of the complex geometry occurring in headboxes. The model is applied to simulate the flow distribution in a manifold. Computation of the headbox manifold demonstrates that the computational method developed has the ability to model headbox manifolds with complex geometries and has the potential to be an important and attractive analysis tool for the design and optimization of pulp and paper headboxes.

References


