NUMERICAL ANALYSIS OF TURBULENT UNSTEADY FORCED CONVECTION IN CIRCULAR DUCTS

Mahmut D. Mat[*], Yuksel Kaplan[*], Sadik Kakaç[**]
[*]Mechanical Engineering Department, Nigde University, 51100 Nigde, Turkey
[**]University of Miami, Coral Gables, Florida 33124

Unsteady forced convection may occur in a various devices such as in heat exchangers, computers and electronic devices that have heat producing chips. The uncontrolled thermal transients may results thermal stresses, reduced thermal performance even mechanical failure. Therefore, it is essential a detailed knowledge on transient thermal response in such system for an effective control. In this study, turbulent flow in a pipe with a periodic inlet temperature numerically investigated. Forced convection with a periodically varying inlet temperature is extensively studied in the literature. Kakac and Yener[1] obtained an analytical solution for transient energy equation for laminar forced flow in a pipe assuming a constant velocity or slug flow in the pipe. Kakac[2] extended the analytical solution to turbulent flow between two parallel plates and obtained a general solution for energy equation for fully developed turbulent flow with a sinusoidally varying inlet temperature. Kakac and Li[3] extended the analytical solution to forced convection in a rectangular channel with a periodic inlet temperature. Their theoretical results slightly deviated from experimental results. This deviation was attributed to a simple turbulence model assumed in the study.

Although an extensive literature on the forced convection in channels, relatively little done determination thermal responses when the flow is turbulent. Specifically, a constant eddy viscosity concept which is usually employed in such studies is not adequate to capture turbulence characteristics in turn heat transfer rate in such systems. Therefore the objective of this study is to apply an advance turbulence model to forced flow in a pipe with periodic variation of inlet temperature and compare the result with experimental data. Since range of Reynolds number considered in the experiments between 10 000 and 20 000 a low Reynolds number extention of k-ε turbulence model namely Lam-Bremhorst[4] model is employed.

The estimated centerline temperature amplitude history at several locations along the pipe is presented in Figure 1. Due to periodic nature of the problem, one cycle adequately represent the temporal evolution in the system. It is seen that the temperature amplitude progressively decreases at the downstream locations. This behavior is a result of heat transfer between and the boundary wall. A phase lag which time of maximum and minimum amplitude shifts along the pipe is evident in this figure. The phase lag is results of heat capacity of the fluid and wall. The theoretical and experimental results of Kakac and co-workers[5-6] clearly indicate that the phase lag is a strong function of Reynolds number especially in laminar flows. For the Reynolds number range considered in this study the phase lag is expected to be not to much significant as seen in Figure 1.

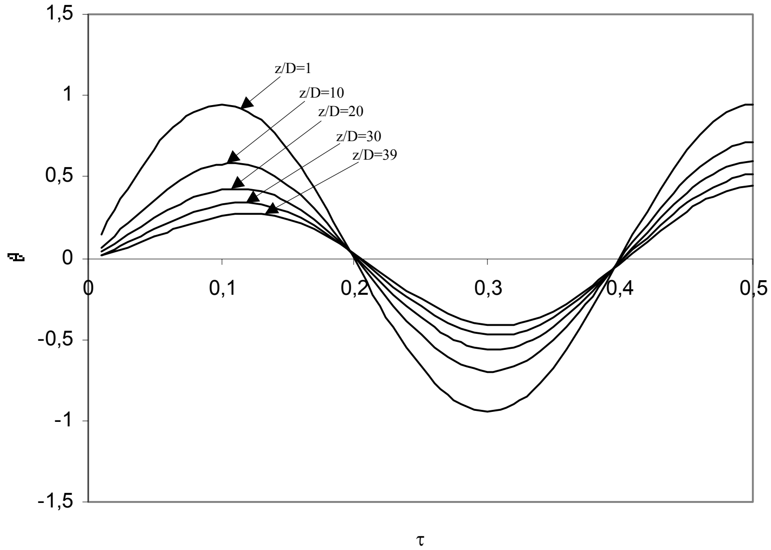

Figure 1. Estimated dimensionless centerline temperature histories at several locations (Re=16114)

The variation of average Nusselt number is shown in Figure 2. The periodic nature of the problem is also evident in this figure. It is seen that Nusselt number varies between a maximum and minimum points. These points correspond to times, beginning and end of the cycles. The minus Nusselt number reflects the times that the fluid is heated from energy accumulated at the boundary walls. The average quasi steady state value of average Nusselt number is less than one calculated using Dittus-Boelter correlation.

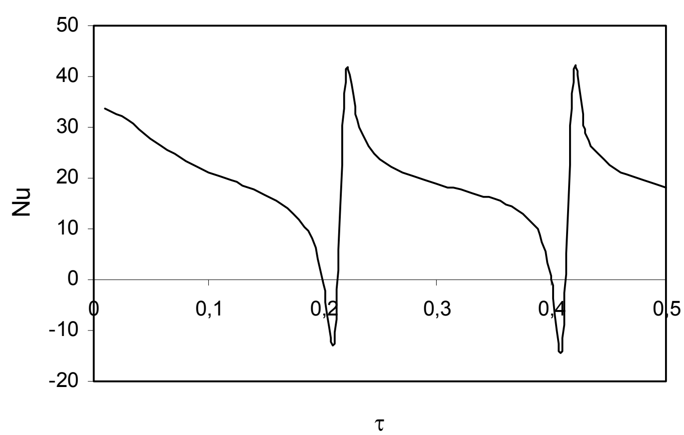

Figure 2. Evolution of average heat transfer coefficient (Re=16114)

The predicted dimensionless temperature amplitude is found to be close agreement with experimental data. The predicted turbulence characteristics such as turbulence energy production and dissipation rate are similar to the data in the literature.

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