学位論文の要旨

Abstract of Thesis

研究科 School	Graduate School of Natural Science and Technology
専　攻 Division	Industrial Innovation Sciences
学生番号 Student No.	51426354
氏　名 Name	Anup Kumer Datta

学位論文題目 Title of Thesis（学位論文題目が英語の場合は和訳を付記）

Numerical Study of Helical Pipe Flow　ヘリカル管内流の数値解析

学位論文の要旨 Abstract of Thesis

Flows and heat transfer in helical pipes have attracted considerable attention not only because of their ample applications in chemical, mechanical, civil, nuclear and biomechanical engineering but also their physical interest of secondary flow patterns and soon. In this dissertation, three dimension (3D) direct numerical simulations (DNS) of viscous incompressible isothermal (without heat transfer) and thermal (with heat transfer) laminar and turbulent fluid flows through a helical pipe with circular cross section are presented, where the wall of a helical pipe is heated for thermal case. Note that the case of turbulent flow through a helical pipe, we also used three different turbulent models based on the Reynold averaged Navier-Stokes equation (RANS). Numerical calculation were carried out over a wide range of Dean number, Dn, curvature, δ, torsion parameter, β, the Prandtl number, Pr, and the Reynolds number, Re, for both the laminar and turbulent flow cases.

OpenFOAM was used as a tool for the numerical approach. To generate a suitable mesh in the flow domain, an appropriate mesh system with 3D orthogonal helical coordinates was successfully created to conduct accurate DNSs and turbulence models of helical pipe flow using an FVM-based open-source computational fluid dynamics package (OpenFOAM).

First, the laminar flow in a helical pipe with circular cross section was investigated. The instability of the steady solutions of the helical pipe flow was studied instead of the linear stability

Name	Anup Kumer DATTA

analysis. We found the neutral curve of the critical Reynolds numbers of the laminar to turbulent transition by observing unsteady behaviors of the solution. The present results of the critical Reynolds number nearly agree with the two-dimensional (2D) linear stability analysis (Yamamoto et al. (1998)) except for the lowest critical Reynolds number region, where the present study gave the critical Reynolds numbers much less than those by the 2D linear stability analysis and showed explosive 3D instability occurred slightly in the marginal instability state. It is interesting that we found a close relationship between the disturbances of unsteady solutions (such as nearly 2D state, nonlocal 3D modification, highly nonlinear behaviours, continuous nonperiodic oscilation), and the vortical structure of steady solutions in helical pipe flow.

Then, the effect of torsion on the friction factor of helical pipe flow was investigated. Well-developed axially invariant regions were obtained where the friction factors were calculated, and good agreement with the experimental data was obtained. It was found that the friction factor sharply increases as β increases from zero, then decreases after taking a maximum, and finally slowly approaches that of a straight pipe when β tends to infinity. It is interesting that a peak of the friction factor exists in the region $0.2 \leq \beta \leq 0.3$ for all the Reynolds numbers and curvatures studied in the present study, which manifests the importance of the torsion parameter in helical pipe flow.

Next, laminar forced convective heat transfer in a helical pipe with circular cross section subjected to wall heating was investigated comparing with the experimental data. In 3D steady calculations, we found the appearance of fully-developed axially invariant flow regions, where the averaged Nusselt number (averaged over the peripheral of the pipe cross section) were calculated, being in good agreement with the experimental data. Because of the effect of torsion on the heat transfer characteristics, the averaged Nusselt number exhibits repetition of decrease and increases as torsion increases from zero for all Reynolds numbers. It was found that there exists two maximums and two minimums of the averaged Nusselt number. It is interesting that the global minimum of the Nusselt number occurs at $\beta \cong 0.1$ and the global maximum at $\beta \cong 0.55$.

Name	Anup Kumer DATTA

Finally, turbulent flow through helical pipes with circular cross section was numerically investigated by use of three different turbulence models comparing with the experimental data. We numerically obtained the secondary flow, the axial flow and the intensity of the turbulent kinetic energy by use of three turbulence models. We found that the change to fully developed turbulence is identified by comparing experimental data with the results of numerical simulations using turbulence models. We found that RNG $k - \varepsilon$ turbulence model can predict excellently the fully developed turbulent flow with comparison to the experimental data. It was found that the momentum transfer due to turbulence dominates the secondary flow pattern of the turbulent helical pipe flow. It is interesting that torsion effect is more remarkable for turbulent flows than laminar flows.