論文の要旨

題目　STUDY ON HEAT TRANSFER OF STEADY AND PULSATING TURBULENT FLOWS IN STRAIGHT AND 90° CURVED PIPES
（直管と 90°曲り管内の定常および脈動乱流場における熱伝達に関する研究）

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The fluid flow and heat transfer in the intake/exhaust system, which is the subject of this study, is also an important phenomenon that affects engine performance such as thermal efficiency, fuel consumption, emissions, etc.... Straight and curved pipes are essential components of the intake and exhaust manifold, and the flow and heat transfer characteristics of the straight and curved pipes directly affect the performance of the downstream catalyst. Therefore, both the fluid flow and heat transfer in the pipes is important for maintaining the high performance of the close-coupled catalytic converter (CCC) in automotive engines.

The heat transfer of the steady turbulent flow and the pulsating turbulent flow in straight and 90° curved square pipes were investigated in this study. An inner length of the pipes and their wall thickness are 32 mm and 4 mm, respectively. Both experimental temperature field measurements at the corresponding cross-sections of the pipes and conjugate heat transfer (CHT) simulation were performed. The steady turbulent flow was investigated and compared to the pulsating flow under the same time-averaged Reynolds number.

The novelty and originalities of this research can be summarized as the following aspects:

(1). The measurements of temperature fields inside pipes were investigated which have rarely been reported in other studies owing to the difficulty of measuring the internal temperature of pipes in turbulent flow.

(2). The heat transfer of turbulent flow and pulsating flow in straight and curved pipes based on the third type of wall thermal boundary condition (the heat transfer coefficient of the wall and ambient temperature are defined).

(3). Conjugate heat transfer (CHT) simulation was applied to obtain the instantaneous information of both fluid domain and solid domain and reveal the heat transfer mechanism of the pulsating flow.

The main points and results obtained in this study are summarized as the follows:

In the Chapter 2, both experimental and numerical investigations of turbulent forced convection in the straight and the 90° curved square SUS pipes were performed. In both the streamwise and circumferential directions, the experimental and numerical temperature field results agreed well. Based on the analysis of the numerical time-averaged velocity fields, it was discovered that the deviation and impingement of the high-velocity air core and the formation of secondary flow strengthened heat transfer. Conversely, the separation effect suppressed heat transfer. The overall heat transfer performances of these two pipes were investigated in the last section using the local averaged Nu number. It was demonstrated that the heat transfer performance of the 90° curved pipe was 20% higher than that of the straight pipe.

In the Chapter 3, both experimental and numerical investigations of turbulent forced convection in the straight and the 90° curved square Aluminum pipes were reported. The temperature distribution in the straight and the curved aluminum pipes is similar to that of the SUS pipes, no matter it is in the direction of the streamwise or the circumferential direction of the cross section. Based on both fluid domain and solid domain of the comparison in the numerical simulation, it was discovered that the material of the pipe has little effect on the flow and heat transfer of the air in the pipe. However, in the solid domain, the temperature field is directly related to the pipe material.

In the Chapter 4, experiment of the pulsating flows was performed for straight and 90° curved square aluminum pipes. The velocity measurement at the "Outlet" verified the existence of reverse flow under a pulsating flow with a large velocity amplitude. In both the streamwise and circumferential directions, the results of temperature fields in the experiment reported the difference between the steady and pulsating flows in the straight and curved pipes. The local heat flux of different cross-sections in the experiment provided quantitative results of the heat transfer. The local heat flux of the pulsating flow in a straight pipe exhibits a large variation in different cross-sections. The closer to the pulsation generator, the larger the temperature oscillation and the higher the heat transfer performance are. It has an extremely large local heat flux near the outlet of the curved part of the curved pipe. In the test section, for both the steady and pulsating flows, the total heat flux of the curved pipe was higher than that of the straight pipe. For both straight and curved pipes, the total heat flux of the steady flow was higher than that of the pulsating flow.

In the Chapter 5, the fluid flow and heat transfer of pulsating flow in straight and 90° curved pipes were studied by numerical simulation. Through the analysis of several typical instantaneous velocity and temperature fields of acceleration phase, maximum velocity, deceleration phase, minimum velocity and inflection point at acceleration phase, the mechanism of pulsating flow heat transfer was revealed, and the accuracy of the experimental results was verified. In the straight pipe, the spatial-averaged temperature variation of the different cross-sections shown that the closer to the pulsation generator, the greater the amplitude of the temperature oscillation and the better the heat transfer performance. The instantaneous velocity and temperature fields of pulsating flow are more complicated in the curved pipe. The behaviors, such as the obvious separation between the air and pipe wall, the low-temperature core impingement, and the reverse flow suppressed the heat transfer.

As for the future prospect, changing the inlet boundary conditions such as the time-averaged Reynolds number of the inlet, the frequency of the pulsation generator and the inlet air temperature is necessary to further reveal the heat transfer mechanism of pulsating flow. In addition, it is necessary to study the pulsating flow and heat transfer of pipes with complex geometries.