Artificial Neural Network-Aided Heat Transfer Analysis for Actual Engine Cooling Systems

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Model-based development and control of engine thermal management require appropriately identified zero-dimensional models. In addressing this need, two key questions arise: 1) Can zero-dimensional models be effectively applied to actual engines with inherently three-dimensional structures? and 2) How can the parameters of such models be identified using only limited measured data? To address these questions, we are investigating the application of zero-dimensional heat-balance models to actual engine cooling systems, with a particular focus on identifying model parameters using artificial neural networks.

In this study, a heat-balance model for the SI engine system has been proposed, accounting for three-dimensional physical properties and the influence of temperature distribution on zero-dimensional modeling. The effects of such unknown three-dimensional distributions on zero-dimensional models are incorporated into the model parameters of the zero-dimensional models. Each model parameter is regarded as a function of control or condition parameters to represent some three-dimensional distribution caused by influences.

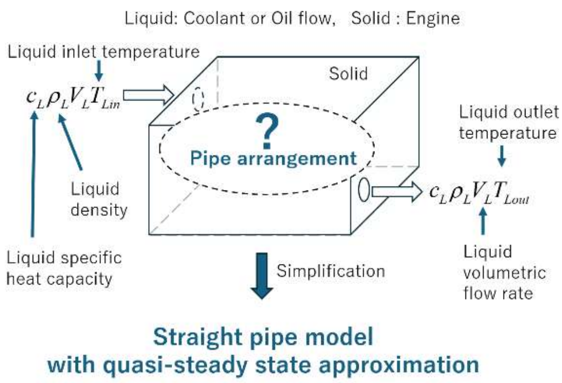

Fig.1 Black-box representation of an actual engine cooling system

Furthermore, allowing a black-box structure for in-engine liquid (coolant or oil) flow channels (Fig. 1), the present straight-pipe model provides a physical model of the apparent thermal conductance between the engine body and the liquid (coolant or oil) channel in-engine flows. Eq. (1) shows a physical model expression of KL, the thermal conductance in terms of in-engine liquid flows. c, V are density, specific heat capacity, and flow rate, respectively. The subscript L denotes liquid involving coolant and oil.

$$K_L = \rho_L c_L V_L \left\{1 - \exp\left(-\frac{B}{{V_L}^n}\right)\right\} \qquad (1)$$

To identify the model parameters of the engine heat balance model and a cooling system model, we used measured data obtained by an actual 1.6 L SI engine experiment on an actual engine test bench with WLTC driving mode. The model parameter identification was conducted using artificial neural networks. The thermal conductance K_L has also been identified by numerical experiments using trained artificial neural networks with changing only the liquid flow rate V_L. Analyzing the resulting data of V_L and K_L, the model parameters n and B in Eq. (1) are determined. n and B are characterization parameters for thermal flow and channel structure, respectively. The results show n = 0.238 and B = 0.0236 for coolant flow, and n = 0.217 and B = 0.00129. According to Colburn analogy, when n' (= 1-n) is 0.75 ~ 0.8, the heat exchange is turbulent heat transfer; therefore, the present analysis shows that both the coolant and oil thermal flows are characterized by turbulent heat transfer. How to apply the results of B should be studied further.

According to our previous report, application of Eq. (1) with the determined parameters n and B enables the zero-dimensional heat balance model to predict the representative temperature of an actual engine accurately. Consequently, the present study demonstrates that Eq. (1) for zero-dimensional heat balance models effectively captures the typical heat transfer characteristics of real in-engine liquid flows.

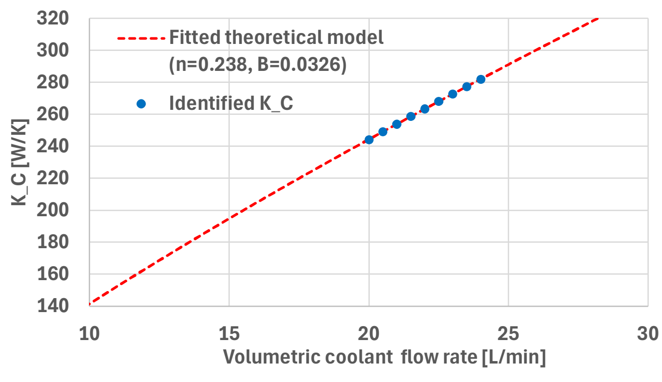

Fig. 2 Identified K_C and fitted theoretical model given by Eq. (1) with the parameters n and B.

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