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# The effect of gaseous slip on microscale heat transfer: An extended Graetz problem

R.S. Myong [a,b,*], D.A. Lockerby [c], J.M. Reese [a]

[a] Department of Mechanical Engineering, University of Strathclyde, Glasgow G1 1XJ, United Kingdom
[b] Department of Mechanical and Aerospace Engineering and Research Center for Aircraft Parts Technology, Gyeongsang National University, Chinju, Kyeongnam 660-701, South Korea
[c] School of Engineering and Design, Brunel University, Uxbridge UB8 3PH, United Kingdom

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**Abstract**

On the basis of Langmuir's theory of adsorption of gases on solids, the effect of temperature jump on microscale heat transfer is investigated. A mathematical model, extended from the classical Graetz problem, is developed to analyze convective heat transfer in a microtube in various slip-flow regimes. The surface slip corrections are made by employing the Langmuir model, as well as the conventional Maxwell model. The effects of axial heat conduction are also investigated by extending the finite integral transform technique to the slip-flow case. We show that the Langmuir model always predicts a reduction in heat transfer with increasing rarefaction, as does the Maxwell model, except when the energy accommodation coefficient is relatively much smaller than that for momentum accommodation. This implies that, for most physical applications, the Reynolds analogy between heat transfer and momentum transfer is preserved in slip-flow regimes with low Mach numbers.


*Keywords:* Extended Graetz problem; Temperature jump; Langmuir adsorption; Reynolds analogy; Microfluidics; Rarefied gas dynamics; Slip flow

## 1. Introduction

The study of non-linear transport in gas flows associated with micro and nanodevices [1,2] has emerged as an important topic in recent years. Understanding the fundamental physical phenomena [3–5] in such devices is essential in predicting their performance and searching for an optimal design. Several international theoretical and experimental research programmes are aiming to identify the main physical features of microscale gas flow and heat transfer [1,2,6]. The results of such fundamental work will be critical in answering questions about the usefulness of micro or nanodevices: can overall performance be improved by dividing a system into large numbers of microscale components? and can the traditional fluids knowledge base be applied in a scaled-down fashion to microfluidics?

In the field of microscale heat transfer, convective heat transfer in slip-flow regimes in simple geometries like channels and tubes is a key problem. Constant-wall-temperature convective heat transfer in microscale tubes and channels has been studied recently using analytical solutions to an extended Graetz problem [7–10] and DSMC simulations [10,11]. Using the fact that the characteristic speed in micro and nanodevices is usually very small (i.e. low Mach number), previous theoretical work has used the linear Navier–Stokes–Fourier equations (which rely on quasi local thermal equilibrium) to model flow and heat transfer phenomena. Accommodation coefficients of diffusive reflection were employed to describe the molecular interaction between the gas particles and solid surface atoms. The initial result in Ref. [7], based on the eigenvalues with velocity

* Corresponding author. Address: Department of Mechanical and Aerospace Engineering, Gyeongsang National University, Chinju, Kyeongnam 660-701, South Korea.
*E-mail address:* myong@nongae.gsnu.ac.kr (R.S. Myong).

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