Proceedings of the 4th World Congress on Mechanical, Chemical, and Material Engineering (MCM'18)
Madrid, Spain – August 16 – 18, 2018
Paper No. HTFF 144
DOI: 10.11159/htff18.144

Modelling Local Nusselt Numbers for Channels with Flow in Transition

Ivan Cornejo, Petr Nikrityuk, Robert Hayes
University of Alberta
116 st & 85 Ave, Edmonton, Canada
cornejog@ualberta.ca; nikrityu@ualberta.ca; hayes@ualberta.ca

Extended Abstract

This work reports a study of heat transfer in turbulent flow entering into small channels, which causes a transition to laminar flow. Heat transfer in channels has been extensively studied, especially the Nusselt-Graetz problem, most commonly constant wall temperature or constant wall heat flux. Early works reported Nusselt values for circular pipes with laminar developed flows, including analytical solutions validated with experiments. Later, developing laminar flows were also studied, presenting correlations for Nusselt-Greatz along the entry region. Most of the engineering flows are turbulent, in such flows, convection increases significantly and laminar flow assumptions are not valid. Although that there are Nusselt numbers reported for the developed turbulent flows, describing the entry region is still a challenge. In literature, flows in circular channels are classified into three main categories: Laminar for Re < 2 300, turbulent for Re > 10 000, and transitional for the Re in between [1]. However, some cases, such as monolith type substrates, fit into none of those categories. Monolith based reactors are extensively used in the automotive industry, since they produce lower pressure drop than fixed beds; they are implemented in several other industrial processes as well. It creates a growing interest in its modelling [2, 3]. Usually, the flow before a monolith is turbulent (Re ~ 10^4), however, its pass from an inlet pipe to channels that are one or two orders of magnitude smaller, decreases the Reynolds number dramatically. Although, there is a strong reduction of the Reynolds, to the order of 10^2 typically, turbulence is still strong in the entry region. In these cases, laminar flow does not apply, also, correlations for turbulent flow are not meant to work at such low Reynolds numbers, neither for decaying turbulence. Clearly the decaying turbulence will affect the mass and heat transfer coefficients in the entry region, which could have a significant impact on the performance of the entire reactor; hence, it must be described accurately.

The goal of this study is to identify and quantify the effect of the decaying turbulence on the Nusselt along the entry region of monolith channels. We used circular channels as a first approach, which are still not studied under the mentioned conditions. Given the difficulty to measure accurate profiles inside channels of about 1 mm of diameter [4], the study used Large Eddy Simulation, which is a highly precise and extensively validated numerical technique, suitable for flows in transition. The results agreed previously reported data [1, 5], also showed a significant effect of the entering turbulence on the Nusselt along the beginning of the channels. This work extends available models for laminar flow, to take into account the turbulence. The proposed model describes the heat transfer in the transitional region accurately; it also converges to the correct Nusselt in the fully developed laminar zone. RANS models were also tested, finding different levels of agreement, but, in general, resulting not suitable to describe the entire region accurately.

References

[1] T. L. Bergman, F. P Incropera, D. P. DeWitt and A. S. Lavine. *Fundamentals of heat and mass transfer*. John Wiley & Sons, 2011.

[2] A. Devatine, H. Chaumat, S. Guillaume, D. T. Tchibouanga, F. D. Martínez, C. Julcour and A. M. Billet. "Hydrodynamic study of a monolith-type reactor for intensification of gas-liquid applications," *Chemical Engineering and Processing: Process Intensification*, vol. 122, pp. 277-287, 2017.

[3] I. Cornejo, P. Nikrityuk and R. Hayes. "Multiscale RANS-based modeling of the turbulence decay inside of an automotive catalytic converter," *Chemical Engineering Science*, vol. 175, pp. 377-386, 2018.

[4] M. Hettel, C. Diehm, B. Torkashvand and O. Deutschmann, "Critical evaluation of in situ probe techniques for catalytic honeycomb monoliths," *Catalysis today*, vol. 216, pp. 2-10, 2013.

[5] R. Hayes, A. Donoso and J. Mmbaga, "Entry length effects for momentum, heat and mass transfer in circular ducts with laminar flow," *The Canadian Journal of Chemical Engineering*, vol. 93, no. 5, pp. 863-869, 2015.