Introducing Novel Convergent Geometries to Enhance Pipe Flow Convective Heat Transfer

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INTRODUCTION: A wide variety of engineering applications, such as electronics, solar collectors, and internal combustion engines produce heat. This heat can be a positive or negative aspect for a particular application [1]. Enhancing heat transfer has encouraged many researchers to investigate various techniques. In conventional pipe flows, for instance, the straight pipe profile has not satisfied the rise in cooling/heating performance requirements. As a result, an effective configuration improvement technique, such as manipulating the pipe shape, is required [2]. This technique is quite attractive for thermal management of pipe flow especially in applications with limited space. Moreover, the double pipe heat exchanger has been one of the most common heat transfer equipment in many industrial and engineering applications for decades. This configuration has been addressed for many years to maximize heat transfer despite the rise in pressure drop which is a conjugate constraint [3]. The present work aims at utilizing the convergence concept and the wall profile manipulation to introduce and analyze the flow and heat transfer, employing conventional and nano fluids, in innovative convergent pipes and double pipe heat exchangers, as seen in Figs. (1-3).

Figure 1: Schematic of the convergent pipe considered for the first investigation [1].

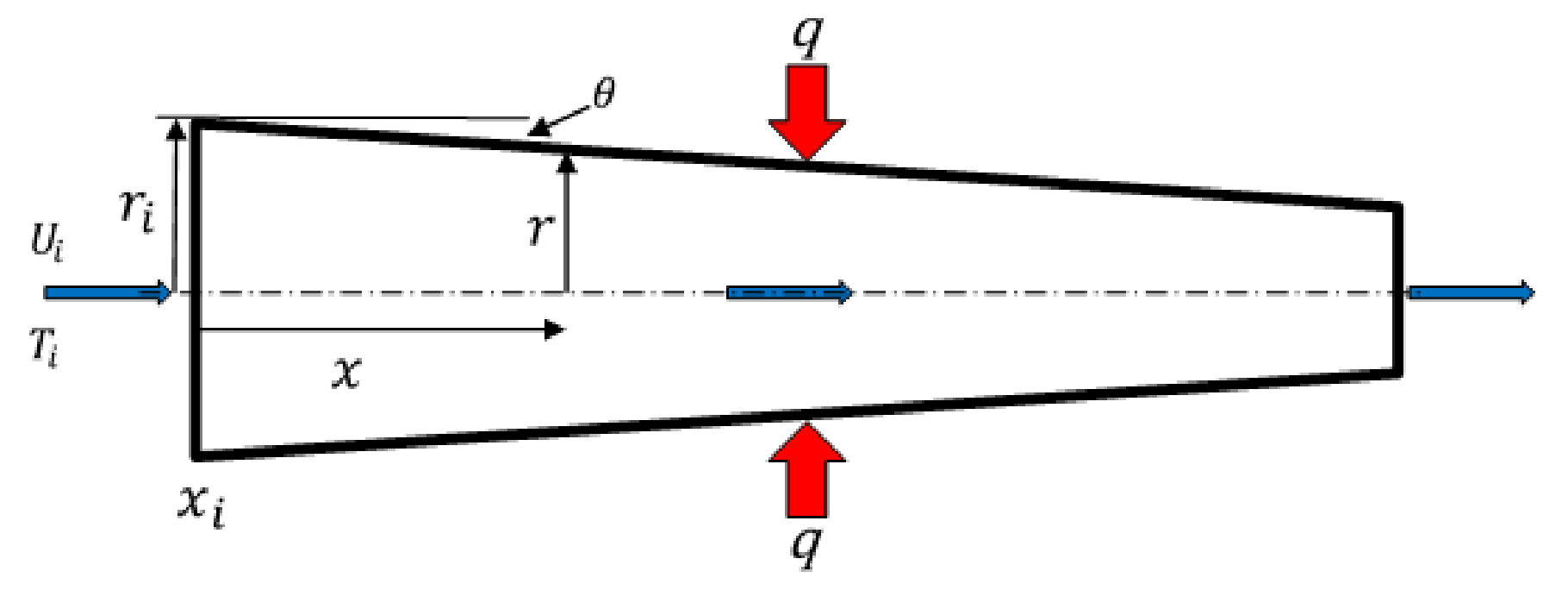


Figure 2: Schematic of the concave/convex convergent pipe considered for the second investigation [2].

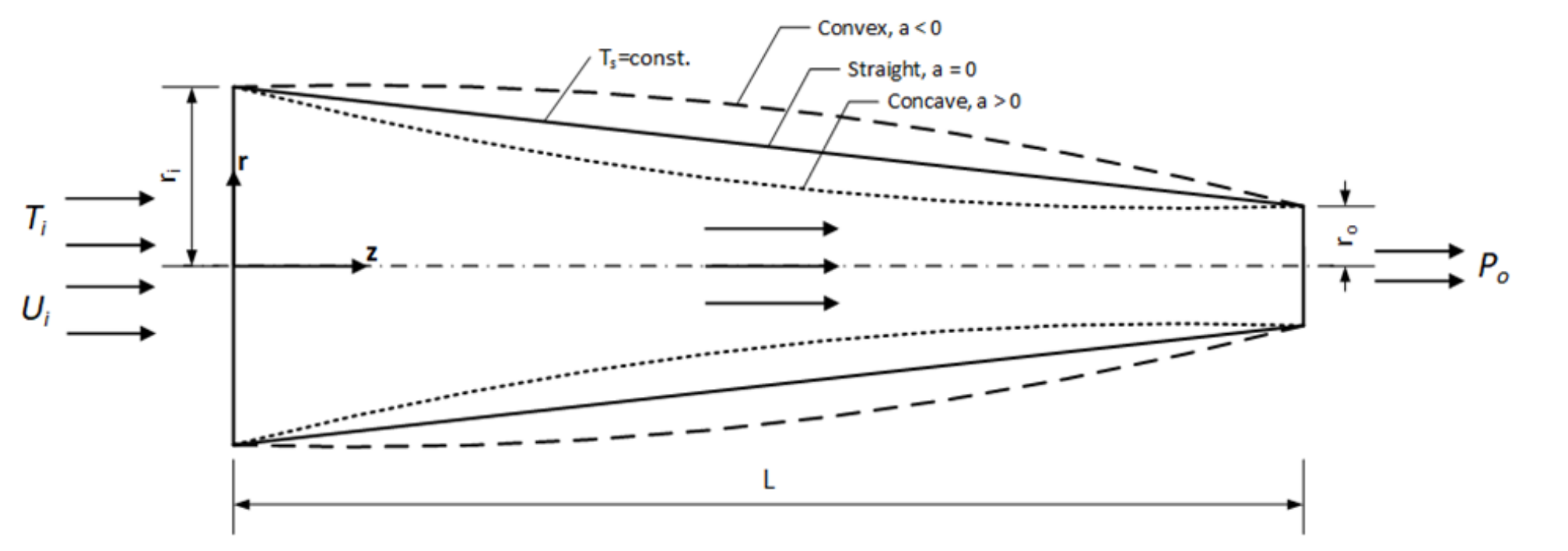
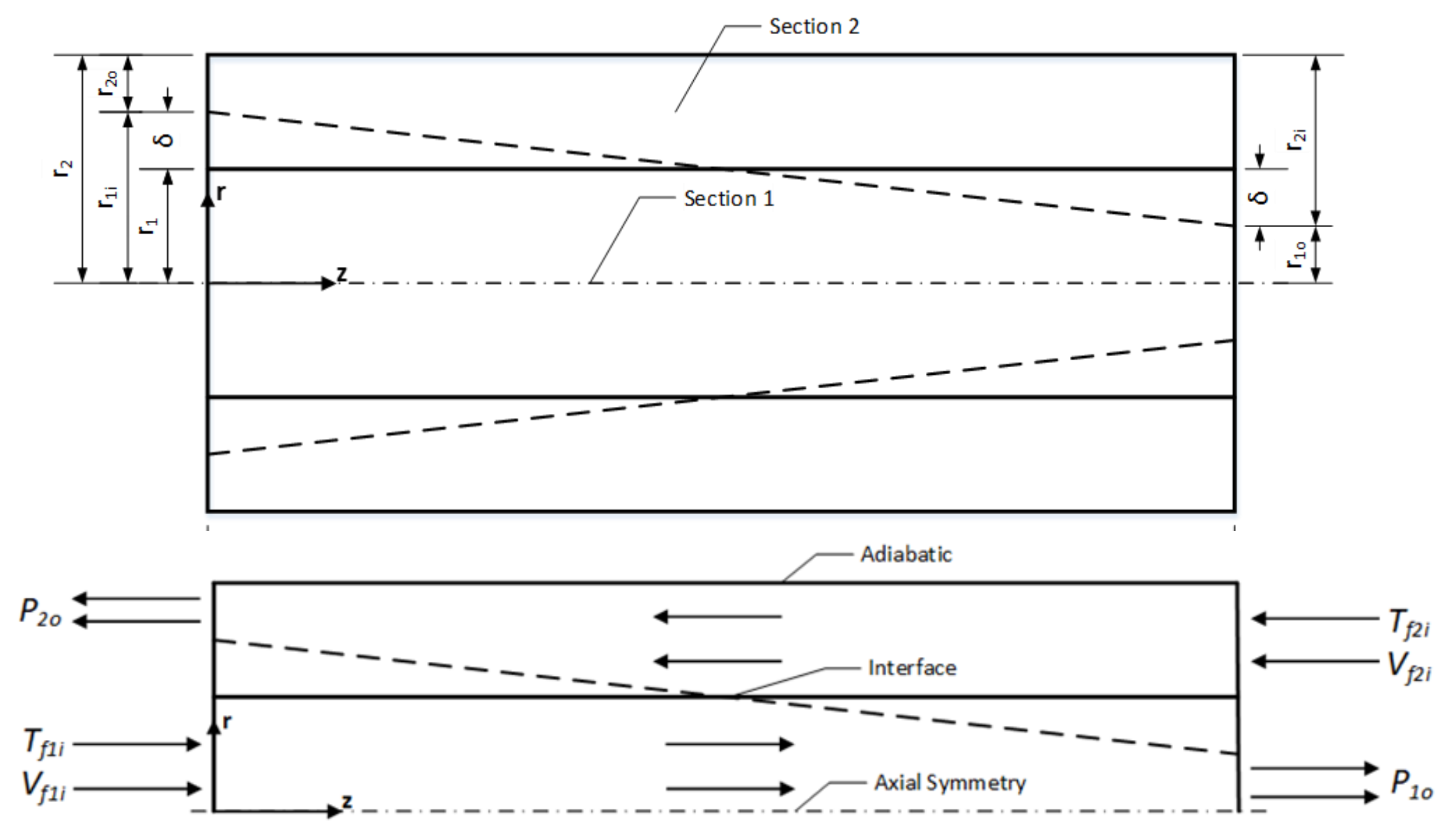


Figure 3: Schematic of the convergent double-pipe heat exchanger considered for the third investigation; (a) geometrical considerations, and (b) the two-dimensional (2D) axisymmetric model with boundary conditions [3].



COMPUTATIONAL METHODS: In this research, the configurations are symmetric around the z-axis, as such two-dimensional axisymmetric models have been adopted. Continuity, momentum, and energy equations have been employed, and the finite element approach is implemented using COMSOL Multiphysics® software to simulate flow and heat transfer numerically. The governing partial differential equations are fully coupled, discretized, and are described by boundary conditions across the computational domain. The convergence in solution takes place when the accuracy of the velocity–pressure and temperature coupling equations reaches 10^{-4} and 10^{-5}, respectively. To ensure the accuracy of the numerical solution with less computational cost, a grid independence survey was performed by means of increasing the grid density until the variance in local heat transfer coefficient was being less than 0.5% [2], as displayed in Fig. 4. Accordingly, proper grid distributions have been adopted for the remainder of our investigation.

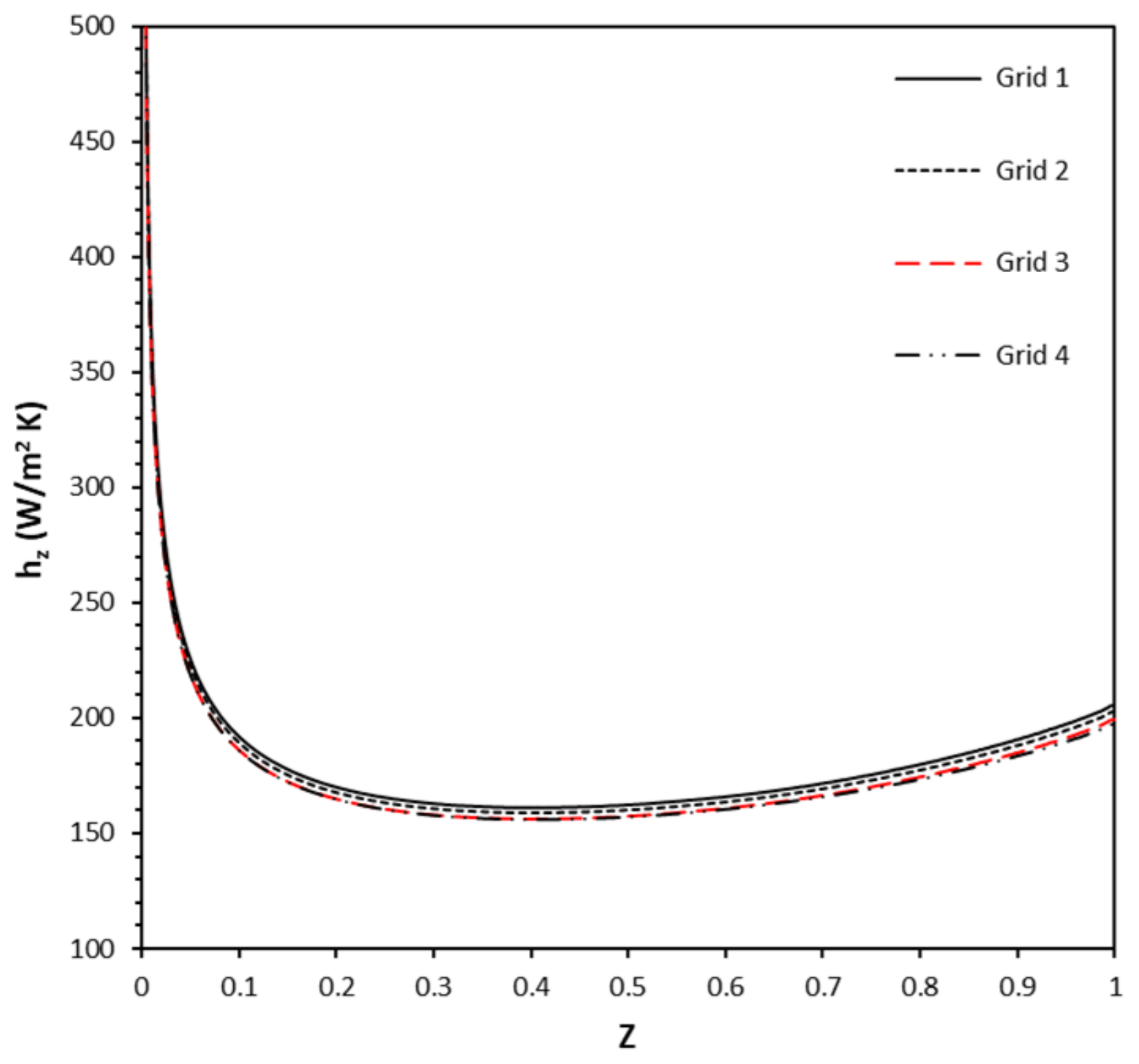


Figure 4: The grid independence study results [2].

VERIFICATION: Extensive validations have been carried out to evaluate the accuracy of our results over the range of Reynolds and Prandtl numbers studied in the current work. Figures 5 and 6 exhibit the local pressure (P) along the axial direction of a circular pipe, as well as, the local Nusselt number (Nu) results along the thermally developing flow in the pipe section of a double-pipe heat exchanger, respectively, compared to the correlations available in the literature [1,3]. As shown from the foregoing figures, an excellent agreement is observed between our results and those existing in the literature.

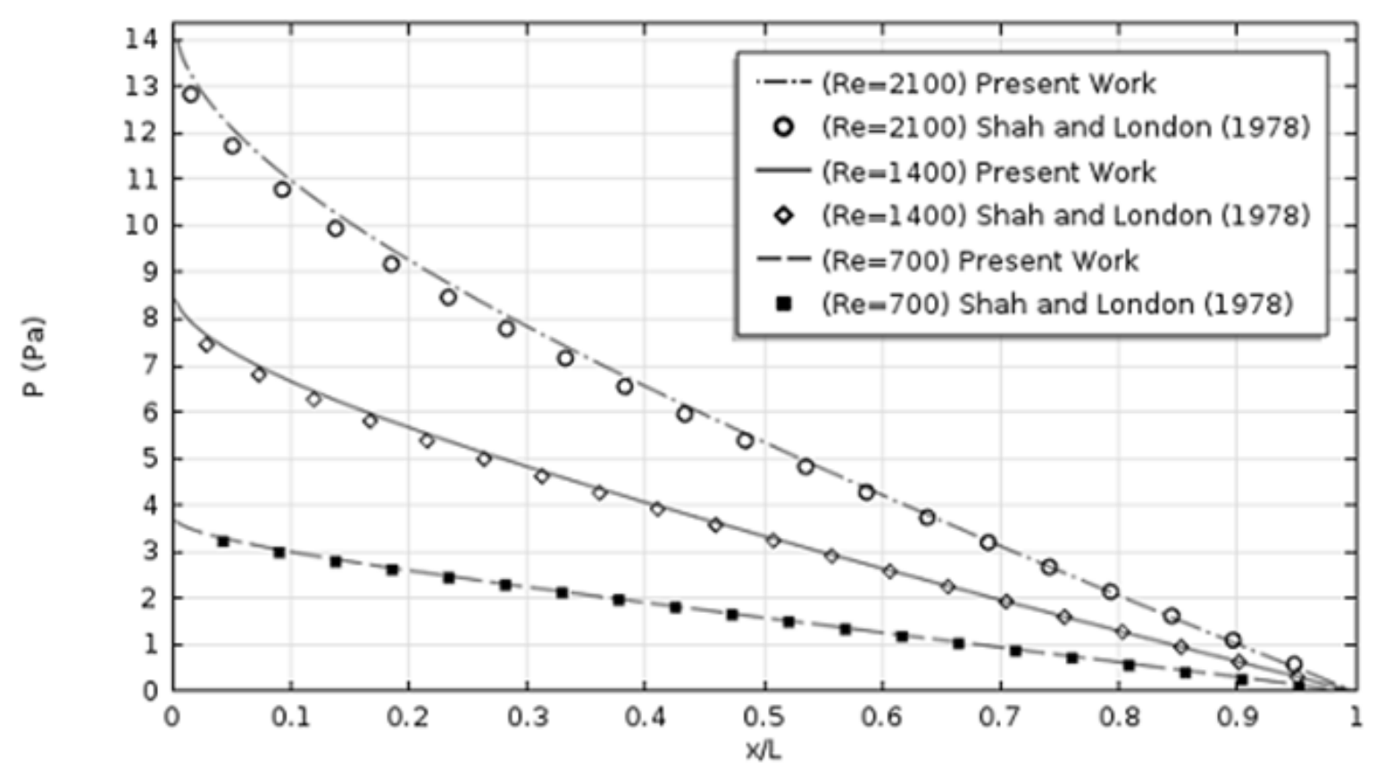


Figure 5: Local pressure vs. dimensionless axial direction in a plain circular pipe at different Reynolds numbers, air case [1].

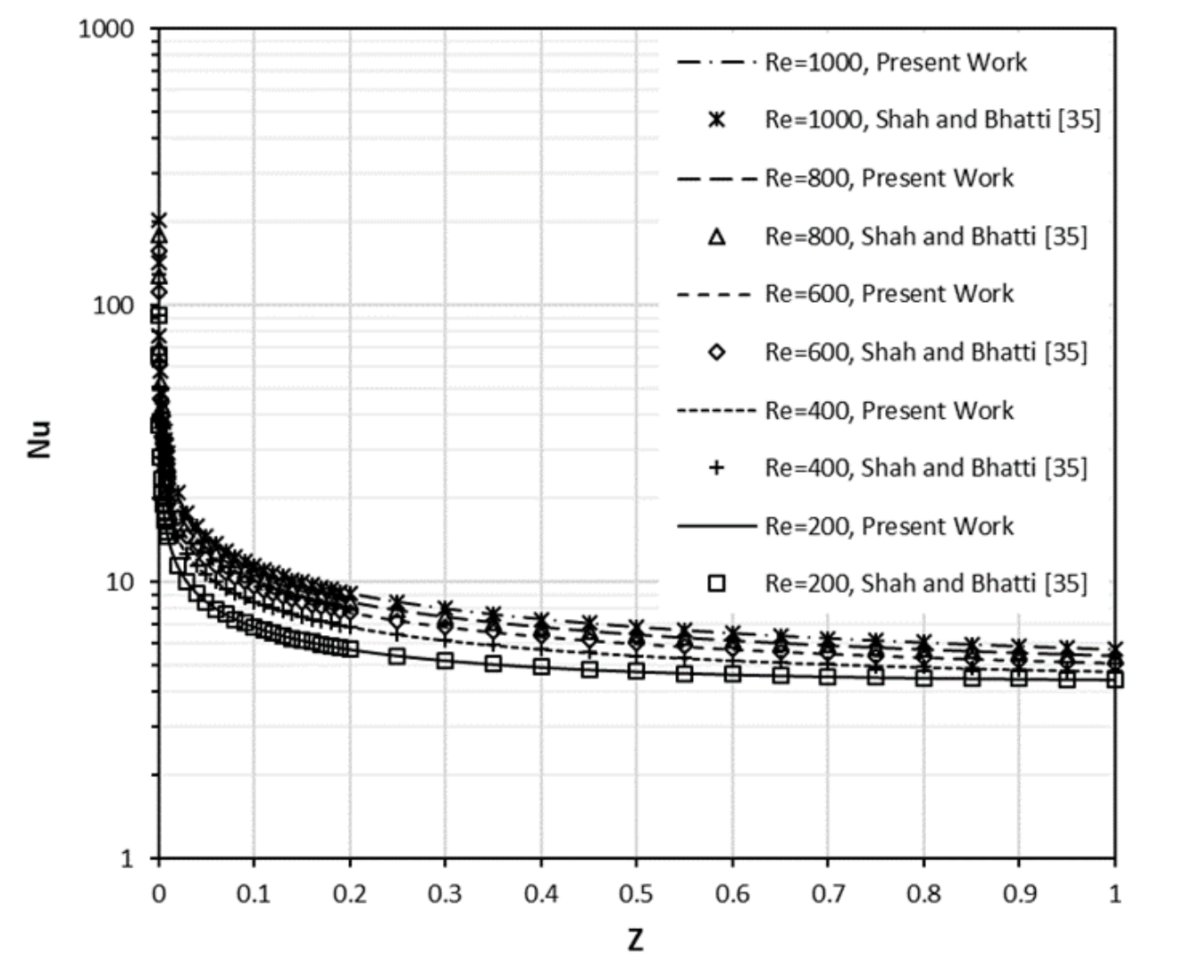


Figure 6: Comparison of the local Nusselt number results along the pipe section of double-pipe heat exchanger with available data from the literature, water case [3].

RESULTS AND CONCLUSIONS: In the current work, the thermal and hydraulic performance of convergent pipe, concave/convex isothermal convergent pipe, and novel convergent double-pipe heat exchanger (C-DPHE) have been investigated and evaluated. The effects of convergence angle, pipe wall profile, volume fraction of nanoparticles, contraction ratio, as well as Reynolds and Prandtl numbers on the flow field and heat transfer throughout these configurations were examined [1-3]. The following can be inferred:

- Increasing convergence angle, Reynolds number, concavity of the convergent pipe wall, volume fraction of nanoparticles, and contraction ratio augments heat transfer [1-3].
- The concave wall profile of the convergent pipe shows a prominent enhancement in heat transfer up to 41%; while, the convex wall profile provides a sustainable and superior performance factor up to 1.223 compared to the straight one, respectively [2].
- A modest rise in heat transfer and pressure drop has been observed when the nanoparticles volume fraction increases; thus, the addressed configuration improvements play a crucial role in augmenting heat transfer more than employing nanofluids [2].
- The convergent double pipe heat exchanger (C-DPHE) has a prominent and sustainable performance, compared to the conventional double pipe heat exchanger (DPHE), with an enhancement in heat transfer rate up to 32% and performance factor (PF) higher than one [3].
- The C-DPHE is quite effective and functional at low Reynolds and high Prandtl numbers, respectively, since no high operating pumping power is required [3].
- The optimal operating conditions of the C-DPHE can be established utilizing the comprehensive information provided in this work [3].

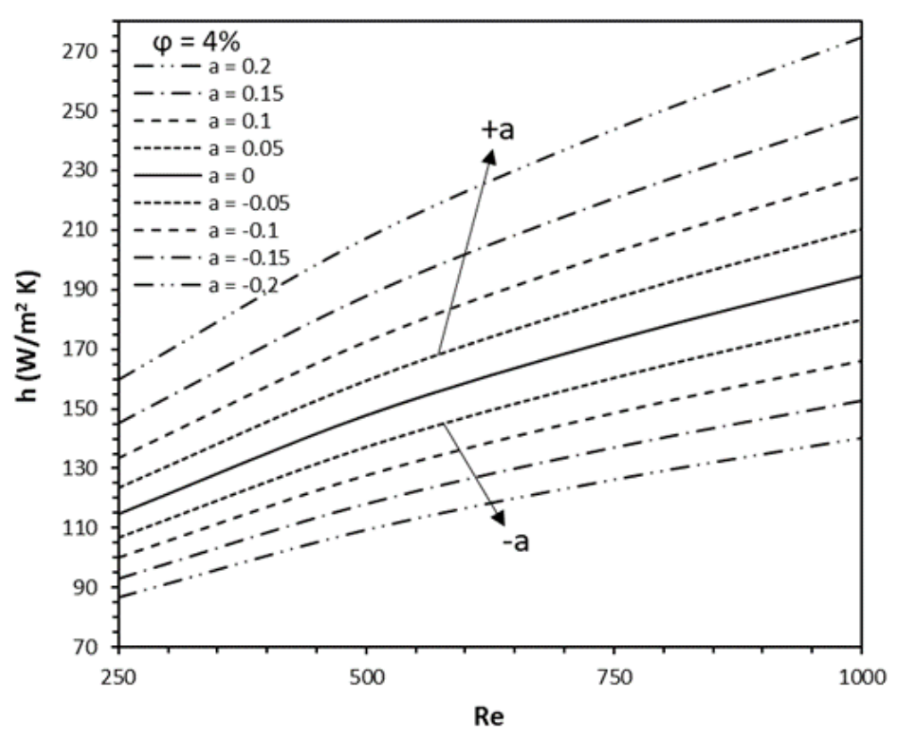


Figure 7: Average heat transfer coefficient for concave (+a) and convex (-a) wall profiles at ϕ=4% [2].

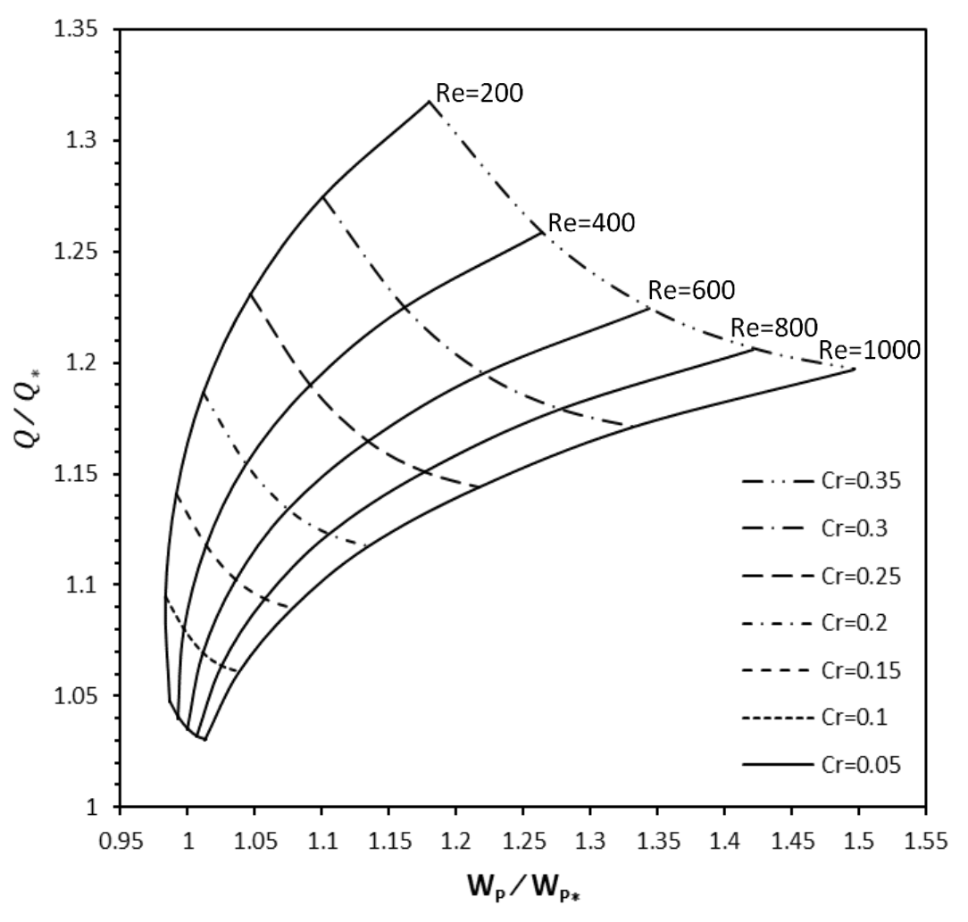


Figure 8: Heat transfer enhancement vs. pumping power increase for various contraction ratios, air case [3].

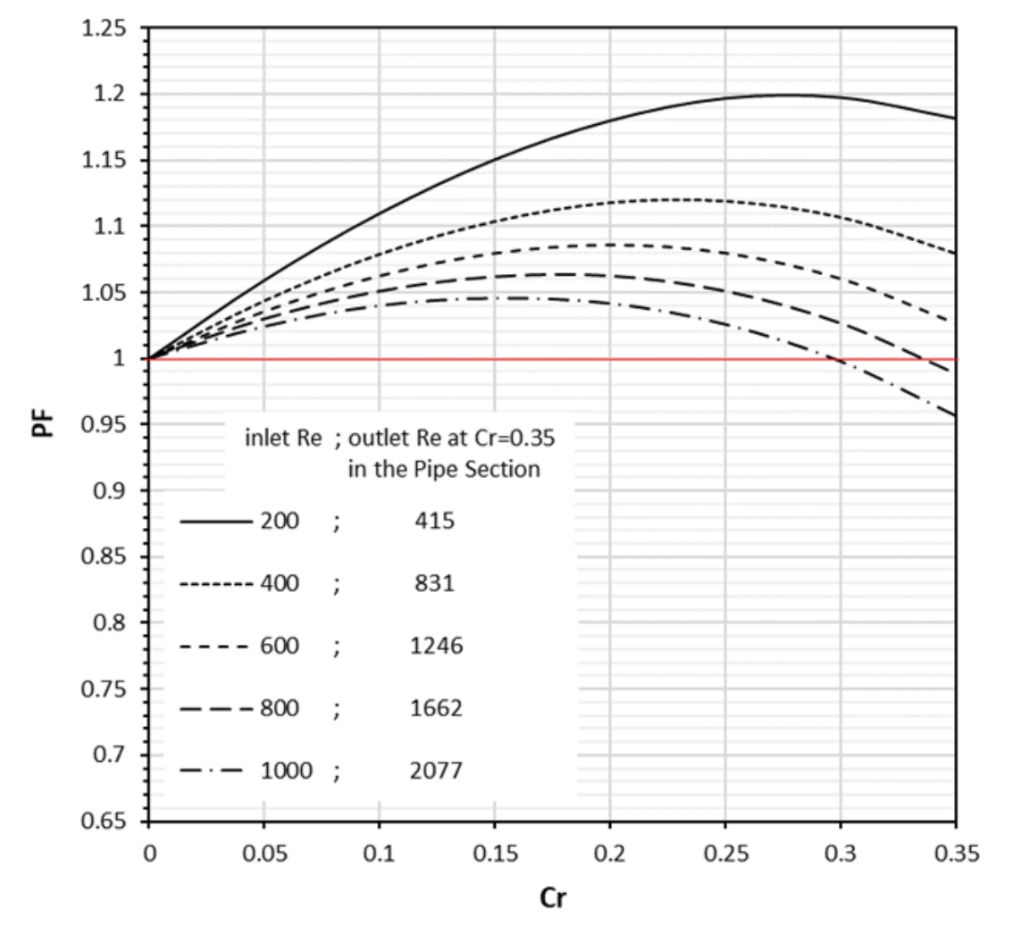


Figure 9: Performance factor vs. contraction ratio, water case [3].

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