Laminar Mixed Convective Nanofluids Flow Over a Triple Forward Facing Step having a circular cylinder

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ABSTRAK

Siasatan berangka yang dijalankan menggunakan kaedah isipadu terhingga kajian lamina perolakan pemindahan haba dan aliran nanofluids menegaskan langkah yang menghadap ke hadapan (FFS) dengan silinder bulat. Kesinambungan, momentum dan tenaga persamaan yang discretized dan skim algoritma MUDAH digunakan untuk menghubungkan tekanan dan halaju dalam bidang domain untuk empat jenis nanopartikel, Al_2O_3, CuO, SiO_2, dan ZnO dengan 1-4% jumlah kecil dalam cecair asas (air). The hiliran dinding langkah pertama dikekalkan pada fluks haba seragam, manakala dinding lurus yang membentuk bahagian lain saluran yang bersamaan dengan suhu cecair masuk. Dinding hulu langkah-langkah dan langkah-langkah yang dianggap sebagai permukaan adiabatik. Dalam projek ini, beberapa parameter seperti keadaan sempadan (nombor Reynolds yang berbeza), jenis cecair (cecair asas dengan yang berlainan jenis nanopartikel), jumlah pecahan yang berbeza dan diameter zarah yang berbeza disiasat untuk mengenalpasti kesannya terhadap pemindahan haba dan aliran cecair melalui Ffs geometri. Keputusan berangka menunjukkan bahawa Nanofluids dengan partikel padat rendah mempunyai kelajuan yang lebih tinggi daripada orang-orang dengan partikel padat tinggi. Empat jenis Nanofluid mencapai bilangan Nusselt lebih tinggi daripada air tulen. Nanofluid dengan SiO_2 zarah mencapai nombor Nusselt tertinggi diikuti oleh ZnO, $Al_2O_3$3 andCuO, masing-masing. Untuk semua nombor Nusselt kes meningkat dengan peningkatan nombor Reynolds dan nombor Nusselt akan meningkatkan mengelilingi silinder bulat yang terletak di hadapan menghadapi saluran langkah.

ABSTRACT

Numerical investigations are conducted using finite volume method of study the laminar convective heat transfer and nanofluids flows aver a forward facing step (FFS) with a circular cylinder. The continuity, momentum and energy equations are discretized and the SIMPLE algorithm scheme is applied to link the pressure and velocity fields inside the domain for four different types of nanoparticles, Al_2O_3, CuO, SiO_2, and ZnO with 1-4 % volume fraction in base fluid (water).The wall downstream of the first step was maintained at uniform heat flux, while the straight wall that forms the other side of the duct was equivalent to the inlet fluid temperature. The wall upstream of the steps and steps were considered as adiabatic surfaces. In this project, several parameters such as boundary condition (different Reynolds number), types of fluids (base fluid with different type of nanoparticles), different volume fraction and different particle diameter are investigated to identify their effect on the heat transfer and fluid flow over FFS geometries. The numerical results indicate that Nanofluids with low dense nanoparticles have higher velocity than those with high dense nanoparticles. The four types of Nanofluid achieved higher Nusselt number than pure water. Nanofluid with SiO_2 particle achieved the highest Nusselt number followed by ZnO, Al_2O_3 andCuO, respectively. For all the cases Nusselt number increased with the increase of Reynolds number and Nusselt number will increase around a circular cylinder located in forward facing step channel.

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CHAPTER 1

INTRODUCTION

1.1 Background

One of the important and interesting phenomena in convective heat transfer can be observe in separated-reattached flow fields. The existence of flow separation and subsequent reattachment due to a sudden expansion or compression in flow geometry, such as backward facing and forward-facing steps, respectively, play an important role in the design of wide variety of engineering application were heating or cooling is required . These heat transfer applications appear in cooling systems for electronic equipment, combustion chambers, cooling of nuclear reactors, chemical processes and energy systems equipment, high-performance heat exchangers, and cooling passages in turbine blades .The problem of laminar and turbulent flow over forward-facing and backward-facing step geometries in forced, natural, and mixed convection have been investigated rather extensively, both numerically and experimentally [1].

Besides the theoretical experimental approaches, numerical simulation has established itself as the most practical and viable alternative to study and to understand different engineering problems. However, numerical simulations would not be possible without the recent developments and improvements in computers in terms of memory size and computing speed[2].

As the power of supercomputers have increased in terms of computing speed and memory capacity, the accuracy of numerical simulations for physical problems has also increased by adding more complexity to the laws governing the phenomenon or by adding more any scientific and engineering problem can be achieved by using numerical simulation techniques and supercomputers.

The execution of numerical simulation avoids not only the annoying measurement in full-scale experimental setups, but also the prohibitively expensive and at times construction of such devices. On the other hand, the use of theoretical tools to solve such problems is limited and cumbersome thus precludes reaching the final solution. In contrast, numerical simulations are possible only after the complete mathematical description of the physical phenomenon is done and often experimental measurements are needed in order to verify the accuracy of the numerical results. In this sense, some followers define the numerical simulation as the modern approach, which joins the theoretical and experimental approaches for studying a physical phenomenon [3].

Currently, numerical simulation is employed in several scientific, engineering and industrial areas, e.g. analysis of stability in mechanical structures, optimization of chemical reactions and combustion process, bonding energy and atomic collision. Representations of DNA three-dimensional structures and microbiological reactions, meteorological and weather prediction, fluid flow in turbo machinery and aerodynamics in vehicles, design of engineering devices involving fluid flow and heat transfer phenomena, etc. [2].

Conventional fluids, such as water, engine oil and ethylene glycol are normally used as heat transfer fluids. Although various techniques are applied to enhance the heat transfer, the low heat transfer performance of these conventional fluids obstructs the performance enhancement and the compactness of heat exchangers. The use of solid particles as an additive suspended into the base fluid is technique for the heat transfer enhancement. Improving of the thermal conductivity is the key idea to improve the heat transfer characteristics of conventional fluids. Since a solid metal has a larger thermal conductivity than a base fluid, suspending metallic solid fine particles into the base fluid is expected to improve the thermal conductivity of that fluid. The enhancement of thermal conductivity of conventional fluids by the suspension of solid particles, such as millimeter- or micrometer-sized particles, has been well known for more than 100 years [4].

1.2 Scope of this study

The problem of laminar mixed convection flow over triple FFS will be study. The solutions will done using commercial code FLUENT which use finite volume method. Different type of nanofluids (Al_2O_3, CuO, ZnO, SiO_2) and nanoparticles' diameter (30-80nm) with different volume fraction (0%-4%). The wall downstream of the first step was maintained at uniform heat flux, while the straight wall that forms the other side of the duct was equivalent to the inlet fluid temperature. The wall upstream of the steps and steps were considered as adiabatic surfaces. Length of the bottom wall until the step is 1m, while length of the first, second and third step are respectively, 0.2 m, 0.4 m and 0.4 m. Height of the first, second and third step consider 0.02 m, 0.06 m and 0.08 m respectively as shown in Figure 1.1. No-Slip boundary conditions at walls and thermally and hydrodynamically fully developed fields will be considered.

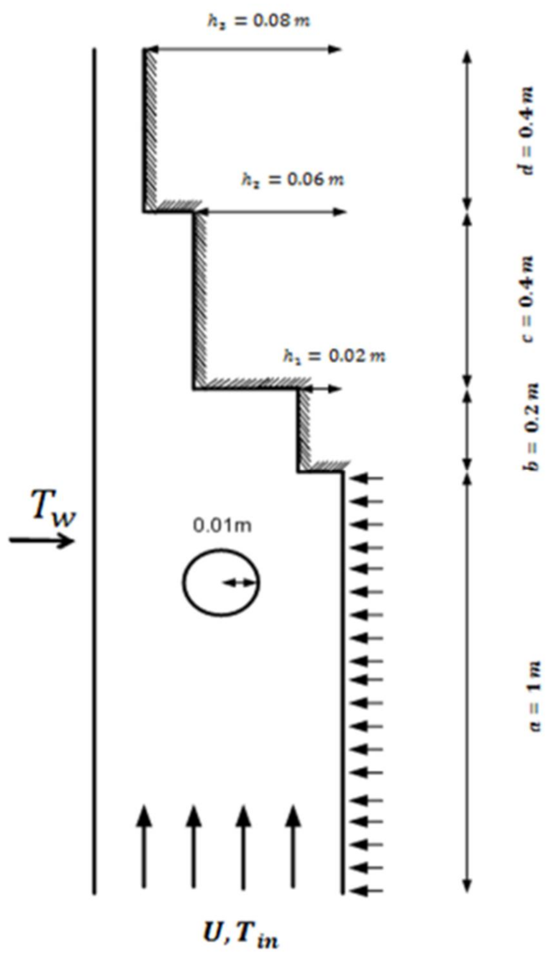

Figure 1. 1 Schematic diagrams of Triple Forward Facing Step having a circular cylinder

1.3 Motivation

To the best of the authors' knowledge, the mixed convection heat transfer in laminar regime for triple FFS flow and also using nanofluid as working fluid has not yet been investigated.

1.4 Project Objectives

This project aimed to investigate mixed convection laminar flow over triple forward facing step by using nanofluids as working fluid. The objectives of this study are:

1. To study the effect of Triple Forward Facing Step geometry on heat transfer enhancement

2. To analyze the effects of nanofluid types (Al_2O_3, CuO, ZnO, SiO_2), base fluid (water), nano particles' diameter(30-80nm) and volume fraction of nanofluid (0-4%) on thermal and flow fields.

3. To investigate the effects of varying Reynolds number in the range of 150 to 500 on thermal and flow fields

1.5 Dissertation Outline

This dissertation will expresses the ideas generate after numerically researching the mixed convection laminar flow over 2-D vertical FFS.

In Chapter 1 the basic concepts, importance, actual objective, and motivations for this research are stated. Chapter 2 indicates the existing literature related to the fluid flow and heat transfer problem in FFS and BFS geometry, including numerical and experimental studies for forced and convective flows in horizontal, inclined and vertical ducts.

REFERENCES

[1] Abu-Mulaweh HI. Turbulent mixed convection flow over a forward-facing step—the effect of step heights. International journal of thermal sciences. 2005;44:155-62.

[2] Kaufmann WJ, Smarr LL. Supercomputing and the Transformation of Science: WH Freeman & Co.; 1992.

[3] Griebel M, Dornsheifer T, Neunhoeffer T. Numerical simulation in fluid dynamics: a practical introduction: Society for Industrial Mathematics; 1997.

[4] Trisaksri V, Wongwises S. Critical review of heat transfer characteristics of nanofluids. Renewable and Sustainable Energy Reviews. 2007;11:512-23.

[5] Yılmaz I, Öztop HF. Turbulence forced convection heat transfer over double forward facing step flow. International communications in heat and mass transfer. 2006;33:508-17.

[6] Abu-Mulaweh HI. Investigations on the Effect of Backward-Facing and Forward-Facing Steps on Turbulent Mixed-Convection Flow Over a Flat Plate. Experimental Heat Transfer. 2009;22:117-27.

[7] Abu-Mulaweh H, Armaly B, Chen T. Measurements of laminar mixed convection flow over a horizontal forward-facing step. Journal of thermophysics and heat transfer. 1993;7:569-73.

[8] Abu-Mulaweh H, Armaly B, Chen T. Laminar natural convection flow over a vertical forward-facing step. Journal of Thermophysics and Heat Transfers. 1996;10:517-23.

[9] Barbosa-Saldaña JG, Sánchez-Silva F, Moreno-Pacheco LA, Carvajal-Mariscal I. NUMERICAL ANALYSIS FOR THE FLOW STRUCTURES

FOLLOWING A THREE-DIMENSIONAL HORIZONTAL FORWARD-FACING STEP CHANNEL. Mecánica Computacional. 2006;25:95-108.

[10] Hattori H, Nagano Y. Investigation of turbulent boundary layer over forward-facing step via direct numerical simulation. International Journal of Heat and Fluid Flow. 2010;31:284-94.

[11] Abu-Mulaweh H. A review of research on laminar mixed convection flow over backward-and forward-facing steps. International journal of thermal sciences. 2003;42:897-909.

[12] Gandjalikhan Nassab S, Moosavi R, Hosseini Sarvari S. Turbulent forced convection flow adjacent to inclined forward step in a duct. International journal of thermal sciences. 2009;48:1319-26.

[13] Abu-Mulaweh H, Chen T, Armaly B. Turbulent mixed convection flow over a backward-facing step—the effect of the step heights. International Journal of Heat and Fluid Flow. 2002;23:758-65.

[14] Saldana JGB, Anand N, Sarin V. Forced convection over a three-dimensional horizontal backward facing step. International Journal for Computational Methods in Engineering Science and Mechanics. 2005;6:225-34.

[15] Nie J, Armaly B. Reverse flow regions in three-dimensional backward-facing step flow. International journal of heat and mass transfer. 2004;47:4713-20.

[16] Armaly B, Li A, Nie J. Measurements in three-dimensional laminar separated flow. International journal of heat and mass transfer. 2003;46:3573-82.

[17] Abu-Mulaweh H, Armaly B, Chen T. Turbulent mixed convection flow over a backward-facing step. International journal of heat and mass transfer. 2001;44:2661-9.

[18] Khanafer K, Al-Azmi B, Al-Shammari A, Pop I. Mixed convection analysis of laminar pulsating flow and heat transfer over a backward-facing step. International journal of heat and mass transfer. 2008;51:5785-93.

[19] Chen Y, Nie J, Armaly B, Hsieh H. Turbulent separated convection flow adjacent to backward-facing step—effects of step height. International journal of heat and mass transfer. 2006;49:3670-80.

[20] Iwai H, Nakabe K, Suzuki K. Flow and heat transfer characteristics of backward-facing step laminar flow in a rectangular duct. International journal of heat and mass transfer. 2000;43:457-71.

[21] Nie J, Armaly B. Three-dimensional convective flow adjacent to backward-facing step-effects of step height. International journal of heat and mass transfer. 2002;45:2431-8.

[22] Sarin V. Numerical simulation of mixed convective flow over a three-dimensional horizontal backward facing step. Journal of heat transfer. 2005;127:1027.

[23] Iwai H, Nakabe K, Suzuki K, Matsubara K. The effects of duct inclination angle on laminar mixed convective flows over a backward-facing step. International journal of heat and mass transfer. 2000;43:473-85.

[24] Nie J, Chen Y, Hsieh H. Effects of a baffle on separated convection flow adjacent to backward-facing step. International journal of thermal sciences. 2009;48:618-25.

[25] Tsay YL, Chang T, Cheng J. Heat transfer enhancement of backward-facing step flow in a channel by using baffle installation on the channel wall. Acta mechanica. 2005;174:63-76.

[26] Cheng JC, Tsay YL. Effects of solid and slotted baffles on the convection characteristics of backward-facing step flow in a channel. Heat and mass transfer. 2006;42:843-52.

[27] Yang YT, Hwang CZ. Calculation of turbulent flow and heat transfer in a porous-baffled channel. International journal of heat and mass transfer. 2003;46:771-80.

[28] Ghadimi A, Saidur R, Metselaar H. A review of nanofluid stability properties and characterization in stationary conditions. International journal of heat and mass transfer. 2011;54:4051-68.

[29] Keblinski P, Phillpot S, Choi S, Eastman J. Mechanisms of heat flow in suspensions of nano-sized particles (nanofluids). International journal of heat and mass transfer. 2002;45:855-63.

[30] Das SK, Putra N, Thiesen P, Roetzel W. Temperature dependence of thermal conductivity enhancement for nanofluids. Journal of heat transfer. 2003;125:567.

[31] Xuan Y, Li Q. Heat transfer enhancement of nanofluids. International Journal of Heat and Fluid Flow. 2000;21:58-64.

[32] Li Y, Zhou J, Tung S, Schneider E, Xi S. A review on development of nanofluid preparation and characterization. Powder Technology. 2009;196:89-101.

[33] Godson L, Raja B, Mohan Lal D, Wongwises S. Enhancement of heat transfer using nanofluids—an overview. Renewable and Sustainable Energy Reviews. 2010;14:629-41.

[34] Zhang X, Gu H, Fujii M. Experimental study on the effective thermal conductivity and thermal diffusivity of nanofluids. International journal of thermophysics. 2006;27:569-80.

[35] Maxwell JC. A treatise on electricity and magnetism: Clarendon Press; 1881.

[36] Singh D, Timofeeva E, Yu W, Routbort J, France D, Smith D, et al. An investigation of silicon carbide-water nanofluid for heat transfer applications. Journal of Applied Physics. 2009;105:064306--6.

[37] Chopkar M, Das PK, Manna I. Synthesis and characterization of nanofluid for advanced heat transfer applications. Scripta Materialia. 2006;55:549-52.

[38] Das SK, Choi SUS, Patel HE. Heat transfer in nanofluids—a review. Heat Transfer Engineering. 2006;27:3-19.

[39] Yu W, France DM, Routbort JL, Choi SUS. Review and comparison of nanofluid thermal conductivity and heat transfer enhancements. Heat Transfer Engineering. 2008;29:432-60.

[40] Li C, Peterson G. Mixing effect on the enhancement of the effective thermal conductivity of nanoparticle suspensions (nanofluids). International journal of heat and mass transfer. 2007;50:4668-77.

[41] Nguyen C, Desgranges F, Roy G, Galanis N, Mare T, Boucher S, et al. Temperature and particle-size dependent viscosity data for water-based nanofluids–Hysteresis phenomenon. International Journal of Heat and Fluid Flow. 2007;28:1492-506.

[42] Wong KV, De Leon O. Applications of nanofluids: current and future. Advances in Mechanical Engineering. 2010;2010.

[43] Donzelli G, Cerbino R, Vailati A. Bistable heat transfer in a nanofluid. Physical review letters. 2009;102:104503.

[44] Kim S, Bang I, Buongiorno J, Hu L. Study of pool boiling and critical heat flux enhancement in nanofluids. TECHNICAL SCIENCES. 2007;55.

[45] Tester JW, Anderson B, Batchelor A, Blackwell D, DiPippo R, Drake E, et al. The future of geothermal energy. Massachusetts Institute of Technology, Cambridge, Massachusetts. 2006.

[46] Ma H, Wilson C, Borgmeyer B, Park K, Yu Q, Choi S, et al. Effect of nanofluid on the heat transport capability in an oscillating heat pipe. Applied Physics Letters. 2006;88:143116--3.

[47] Ma H, Wilson C, Yu Q, Park K, Choi U, Tirumala M. An experimental investigation of heat transport capability in a nanofluid oscillating heat pipe. Journal of heat transfer. 2006;128:1213.

[48] Armaly B, Durst F, Pereira J, Schonung B. Experimental and theoretical investigation of backward-facing step flow. J Fluid Mech. 1983;127:20.

[49] Hong B, Armaly B, Chen T. Laminar mixed convection in a duct with a backward-facing step: the effects of inclination angle and Prandtl number. International journal of heat and mass transfer. 1993;36:3059-67.

[50] He Y, Men Y, Zhao Y, Lu H, Ding Y. Numerical investigation into the convective heat transfer of TiO< sub> 2</sub> nanofluids flowing through a straight tube under the laminar flow conditions. Applied Thermal Engineering. 2009;29:1965-72.