STUDY ON FLOW STRUCTURE BEHIND MULTIPLE BLUFF BODIES IN A TANDEM ARRANGEMENT IN A CHANNEL UNDER THE EFFECT OF A MAGNETIC FIELD

BY

NUR MARISSA BINTI KAMARUL BAHARIN

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International Islamic University Malaysia

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ABSTRACT

Nuclear fusion is one of the future solutions towards sustainable energy. The concept of the magnetic field is introduced to contain high-temperatureture reaction of the nuclear fusion. However, the presence of the magnetic field influences the flow of fluid within the blanket module, which purpose is to harness the energy. This has the effect of reducing the efficiency of heat transfer through the channel of a heat exchanger. Thus, to counter this effect, this research investigates the flow structure behind multiple bluff bodies arranged in tandem in a channel under the influence of a magnetic field in the pursuit of increasing the heat transfer efficiency inside the channel. In this study, the effect of gap ratio, G/h = [1-2.4] and Hartmann parameters, H = [0-800] are analyzed for the critical Reynolds number, pressure drop and Nusselt number using a Computational Fluid Dynamics open-source software. It is found that the presence of the downstream cylinder with gap ratio, G/h = 1.2, 1.4 and 1.6 improves the flow in terms of critical Reynolds number and Nusselt number while having some pressure drop penalty. The multiple cylinders increased the Nusselt number compared with the flow past a single cylinder. In terms of the Hartman parameter, increasing the value of the parameter increases the critical Reynolds number and decreases the Nusselt number.

الخلاصة

الإندماج النووي هو أحد الحلول المستقبلية للطاقة المستدامة ممّا يشيد بأهمّية مفهوم المجال المغناطيسي من أجل إحتواء تفاعل درجة الحرارة العالية للانصهار النووي. ومع ذsلك، فإنّ المجال المغناطيسي يؤثر على تدفّق السّوائل داخل وحدة البطانية والذي يعتبر الغرض منه هو تسخير الطاقة، حيث يقلل المجال المغناطيسي من كفاءة نقل الحرارة في قناة المبادل الحراري. في سبيل مواجهة هذا التأثير، فإنّ هذا البحث يفحص هيكل التدفّق وراء مجموعة من الأجسام الغير إنسيابيه الشكل و مرتبة جنباً إلى جنب في داخل القناة تحت تأثير مجال مغناطيسي بهدف زيادة كفاءة نقل الحرارة داخل القناة. في هذه الدراسه تم تحليل تأثير نسبة الفراغ(١–٢.٤) و متغير هارتمان(٠–٨٠٠)، على رقم رينولدز الحرج وانخفاض الضغط بالإضافة إلى رقم نسلت بواسطة برنامج تحليل ديناميكية الموائع الحسابيه. ومن النتائج، وجد أن إسطوانة المصبّ بنسبة فراغ ١.٢ ، ١.٤ و ١.٦ يحسّن التدفق من حيث رقم رينولدز الحرج ورقم نسلت و أدّت الأسطوانات المتعددة إلى زيادة رقم نسلت مقارنةً بالتدفق الذي يتجاوز أسطوانة واحدة. فيما يتعلق بمتغيّر هارتمان ، تؤدّي زيادة قيمة المتغيّر إلى زيادة رقم رينولدز الحرج وتقليل رقم نسلت.

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Engineering

……………………………….
Mohd Azan Mohammed Sapardi
Supervisor

……………………………….
Syed Noh Syed Abu Bakar
Co-Supervisor

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science in Engineering

……………………………….

Amelda Dianne Binti Andan
Examiner

……………………………….

Azlin Binti Mohd Azmi
External Examiner

This thesis was submitted to the Department of Mechanical and Aerospace Engineering and is accepted as a fulfilment of the requirement for the degree of Master of Science in Engineering

………………………………….
Fadly Jashi Darsivan Bin Ridhuan Siradj
Head, Department of Mechanical and Aerospace Engineering

This thesis was submitted to the Kulliyyah of Engineering and is accepted as a fulfillment of the requirement for the degree of Master of Science in Engineering

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Sany Izan Ihsan
Dean of Kuliyyah of Engineering

DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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This thesis is dedicated to my parents for laying the foundation of what I turned out to be in life.

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Foremost, I would like to express my sincere gratitude to my supervisor Dr. Mohd Azan Bin Mohammed Sapardi for his patience, motivation, enthusiasm, immense knowledge, and for being the first to introduce to me the world of research. His guidance helped me in all the time of this research and the writing of this report. I could not have imagined having a better role model and mentor for this project. I am also grateful to my co-supervisor, Asst. Prof. Dr. Syed Noh Bin Syed Abu Bakar, whose support and cooperation contributed to the outcome of this work.

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TABLE OF CONTENTS

LIST OF ABBREVIATIONS

HD	Hydrodynamics
MHD	Magnetohydrodynamics
d	Diameter
G	Gap length between bluff bodies
G/h	Gap Ratio
H	Hartmann friction parameter
h	Height of channel
Ld	Downstream Length
Lu	Upstream Length
Pr	Prandtl number
Re	Reynolds number
Re_c	Critical Reynolds number
St	Strouhal number
t	time
U	Velocity
V	Kinematic viscosity
β	Blockage Ratio
U	Steady two-dimensional flow velocity
u	Velocity vector
u	x-direction velocity component
v	y-direction velocity component

w	z-direction velocity component
τ	stress
ρ	Fluid density
F_L	Lift force
C_L	Lift coefficient
T	Diffusivity
Nu	Nusselt number
Nu_w	Local Nusselt number along bottom heated wall
θ	Temperature field
θ_f	Bulk fluid temperature
θ_w	Local wall fluid temperature
P	Pressure
p	Kinematic pressure field

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

1.1.1 Magnetohydrodynamics

Electrically conducting fluids (magnetofluids), have their own behavior and magnetic properties. According to Singh (2017), the study of the magnetofluid, with respect to its behavior and magnetic properties, is known as magnetohydrodynamics or hydromagnetics.

The history of magnetohydrodynamics dates back to the 1940s when this branch of physics was first discovered by Swedish Physicist Hannes Alfvèn (Davidson, 2002). Hannes Alfvèn, won a Noble Prize in Physics as he was the pioneer in the field of magnetohydrodynamics (MHD).

Though it was not officially recorded under magnetohydrodynamics (MHD), the first experiment was, however, first conducted in 1832 by Michael Faraday (Malghan, 1996), where he called this effect "magneto-electric induction". Faraday attempted to determine the potential difference induced by the flow across the Thames River and the magnetic field of the Earth to determine the velocity of the flow. The experiment was not a success. But later, his invention of the electromagnetic flowmeter (Shercliff, 1962) made an impact today as it has contributed a lot and is vital in many industries.

1.2.1 Magnetohydrodynamics in Plasma Fusion Reactor

Studies pertaining to this matter were not as extensive before as it is now, but in order to create sustainable energy, more thesis and research studies are emerging to apply MHD to the existing problems. Some of the studies on MHD flow were done by Hussam et al. (2011, 2012a, 2012b, 2013), Hamid et al. (2015, 2016) and Sapardi et al. (2014, 2015).

International Thermonuclear Experimental Reactor (ITER) project introduces the first fusion facility to generate energy using the concept of MHD to create a plasma fusion reactor in 2005. The reactor confined a superheated plasma of hydrogen ions, namely Deuterium and Tritium, inside a magnetic field in a donut shape torus called a Tokamak. According to Mirnov (2018), the evolution of Tokamak started in late 1962, when it was first developed by Soviet Research under the leadership of academician L.A. Artsimovich. Later, as the more promising configuration of the magnetic fusion device, the Tokamak has been adopted worldwide. The largest Tokamak is under progress through the ITER project, where it will be twice as large as the biggest machine currently in service, and ten times the volume of the plasma chamber.

Though to Hussam and Sheard (2013), MHD flow in rectangular ducts has its own significance in metallurgical processing applications; however, the effect of MHD in the fusion blanket has to be avoided. However, the MHD effect in the fusion blanket must be avoided. The flow can conveniently be caused to laminarize by the steady strong magnetic field, (Moffatt 1967; Branover 1978; Mutschke et al. 1997) which may further decrease the effectiveness of the heat transfer from the fusion blanket. According to Zikanov et al. (2014), a magnetic field applied on the flow of an electrical conductive fluid can immensely alter the behaviour of the flow. This effect is seen in the laminar-turbulent transition situation in magnetohydrodynamics flow inside pipe, duct, and channel flows with the influence of magnetic field. All the studies (Moffatt 1967; Branover 1978;

Mutschke et al. 1997; Zikanov et al. 2014) show that MHD has an impact on flow behavior.

1.2 PURPOSE OF THE STUDY

The purpose of this study is to understand the flow past bluff bodies in a tandem arrangement in MHD complication in comparison to the flow past a single bluff body over the Reynolds number, pressure drop and Nusselt number. To further narrow down on a specific discussion, the behavior of conducting fluid is studied by placing two circular cylinder bluff bodies in a tandem arrangement so that the flow can transition from a steady to an unsteady state. Unsteady flow is essential in increasing the efficiency of heat transfer because it will improve the mixing of cold and hot fluids.

To support the study, it is keen to investigate the problem over a study parameter like the gap between bluff bodies.

1.3 PROBLEM STATEMENT

As a promising option to become the world's primary source of energy, the idea of plasma fusion is adapted to make up for toxic fossil fuels, nuclear waste and etc. The plasma fusion aligns well with Sustainable Development Goals number seven which is 'Affordable and Clean Energy'. Therefore, in order to support the vision, the problem that arises due to the effect of the magnetic field in the fusion blanket of the plasma fusion reactor must be overcome so that abundant energy can be harnessed from the fusion reactor.

According to Dobran (2012), the most technologically advanced machine built is the International Thermonuclear Experimental Reactor (ITER), where net energy from fusion is expected to be produced. However, the discussion is still open regarding the plasma confinement, heat removal, fuel supply and reactor materials. The efficiency of heat transfer in the fusion blanket with magnetic field effect is, therefore, of great technological pertinence, and in this paper, the behavior of the fluid flow and its ability to transfer heat under the effect of the magnetic field is addressed.

The MHD affects the fluid flow where the flow structure becomes steady and thus decreases the heat efficiency in the fusion blanket. Therefore, the problem that arises due to the presence of the magnetic field in the fusion blanket of the plasma fusion reactor must be overcome. This research is done by including bluff bodies in tandem arrangement inside the channel to create unsteady flow. Thus, the flow structure and heat transfer are then studied with the effect of the magnetic field.

1.4 RESEARCH OBJECTIVES

The aim of this study is to investigate the flow inside the channel of the heat exchanger behind bluff bodies in a tandem arrangement and under the effect of the magnetic field. A few objectives are built upon to support the aim of this study.

The specific objectives of the study are to determine the effect of gap length and the Hartmann parameter on the critical Reynolds number (The threshold Reynolds number where the flow transitioned from steady to unsteady flow), pressure drop, and the heat transfer efficiency. Over which all of the results will be compared with the results of the flow past singular cylinder.

1.5 SCOPE OF THE RESEARCH

This research will focus on including bluff bodies in a channel as a vortex promoter in a tandem manner and determining the optimal gap length, which will cause a steady flow to change its behavior to unsteady. Past studies have been made regarding cylindrical bluff bodies. The addition in this research is the gap length between the two cylindrical bluff bodies vortex promoters. The geometry meshes and simulations for this study will be carried out using Gmsh and OpenFOAM.

1.6 DELIMITATIONS AND ASSUMPTIONS

Several parameters are used as delimiting factors in this study to define the parameters, whereby the delimiting factors are referred from the thesis of Sapardi (2018) and are used as guidelines. The non-dimensional analysis is applied to this research problem. The blockage ratio, β, is in the range of [0.1, 0.3], Hartmann parameter, H = [0,800] and Re = [1,2500] depending on the aims of the studies. Since the condition of the quasi-two-dimensional condition that was established by Sommeria and Moreau (1982) and Poth'erat et al. (2002) is satisfied, the MHD flow in this research is assumed to be quasi-two-dimensional, and using the Prandtl number, Pr = 0.022. This Prandtl number is representative of Galinstan (GalnSn) liquid metals for heat transfer studies.

1.7 THESIS ORGANIZATION

The thesis is segregated into five distinct chapters. After the initial introduction, Chapter 2 enlightens a review of relevant literature of preceding works. Chapter 3 discuss the numerical methodologies applied in this research work. Results are then presented in Chapter 4. Breaking down chapter 4, subchapter 4.1 lays out the mesh and domain dependency study. Subchapter 4.2 validates the numerical methodologies. Subchapter 4.3 investigates the impact that the gap ratio and Hartmann parameter brings on the critical Reynolds number. Subchapter 4.4 studies the effect of the gap ratio and Hartmann parameter on pressure drop. Subchapter 4.5 presents the effect of the gap ratio and Hartmann parameter on the Nusselt number. Conclusions are presented in Chapter 5.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

A review of the relevant literature related to nuclear fusion, fusion cooling blanket, magnetohydrodynamics (MHD) and its effect on the cooling blankets, heat Transfer of magnetohydrodynamics flow, flow past bluff bodies, vortex promoter, and vortex promoter in a channel of two circular cylinders are presented in this chapter.

2.2 NUCLEAR FUSION

The research of nuclear fusion started back in 1950 when it was conducted by scientists at that time where they formulated the principles of magnetic containment of high temperature plasmas which would allow the development of a thermonuclear reactor (Smirnov, 2009). Conceptually, the sun shines because of nuclear fusion (Fiorentini, Ricci, Villante, 2004), which leads to the fact that fusion is a thermonuclear process of very high temperature. The primary source of solar energy, and also stars of similar sizes, is the fusion of hydrogen to form Helium. Reflecting on the sun has an abundance of energy, the concept is captured.

It has been said by Sapardi (2018) that the collision between deuterium and tritium nuclei of hydrogen ions causes the fusion reaction, which produces energy and helium 5. Helium 5 splits into Helium 4 and a free neutron, which both release additional energy. (See Figure 2.1)

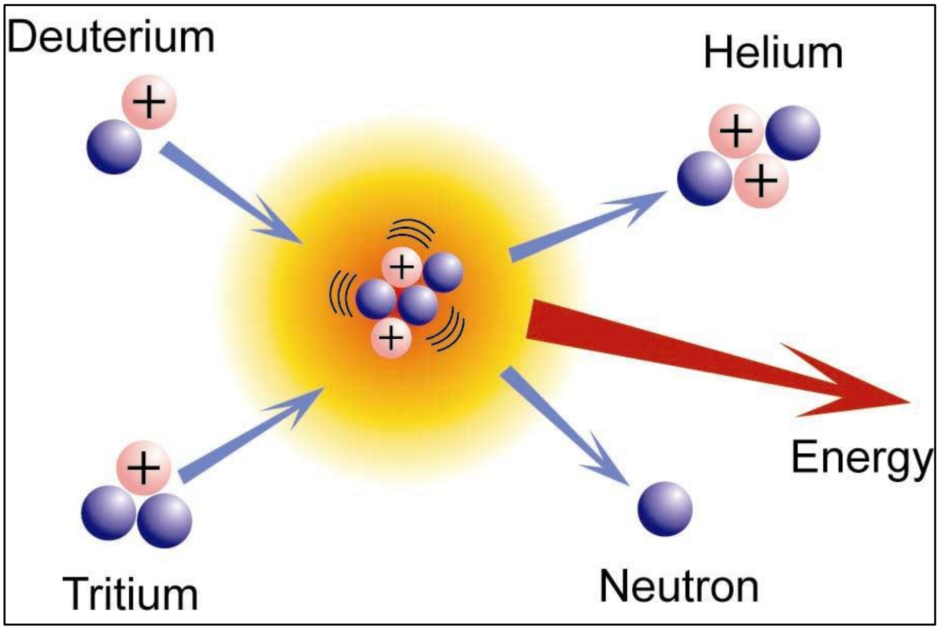

Figure 2.1 Energy, Helium and neutron is produced from the collision of Deuterium and Tritium of Hydrogen ions, also called the fusion reaction.

2.3 FUSION COOLING BLANKET

The fusion of the nuclei happens when the temperature of the fuel is extremely heated to circa 150 million degrees Celsius, forming hot plasma (Shivali, 2017). To keep the plasma away from the walls, a strong magnetic field is used as confinement so that it does not cool down and lose its energy potential. Magnetic fields generated by superconducting coils outside of a vacuum vessel keep the fusion reaction contained within the torus (Dobran 2012). This is shown in Figure 2.2 The Tokamak fusion reactor is designed where

Plasma has to be confined long enough for energy production and for fusion to occur. The intenal walls of the vacuum vessel is completely covered by the blanket modules that will Protect the structure of the steel and the superconducting toroidal field magnets from high temperature and high-energy neutrons resulting from the fusion reactions. When neutrons are slowed down in the blanket, the transformation from kinetic energy into heat energy occurs and will be collected by water coolant, where the energy that is harnessed will be used for power generation (Refer Figure 2.3).

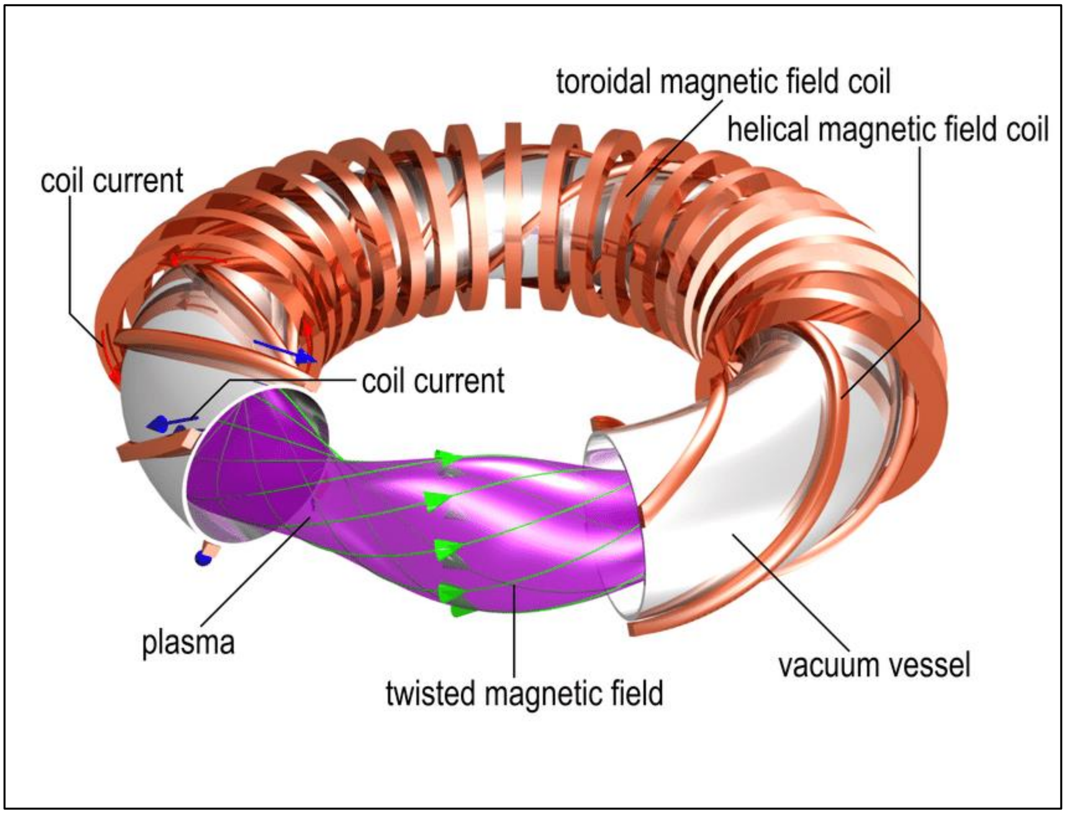

Figure 2.2 The Tokamak fusion reactor is designed where a metal blanket with self-cooling properties surrounds the plasma, which is contained in the shape of a torus.

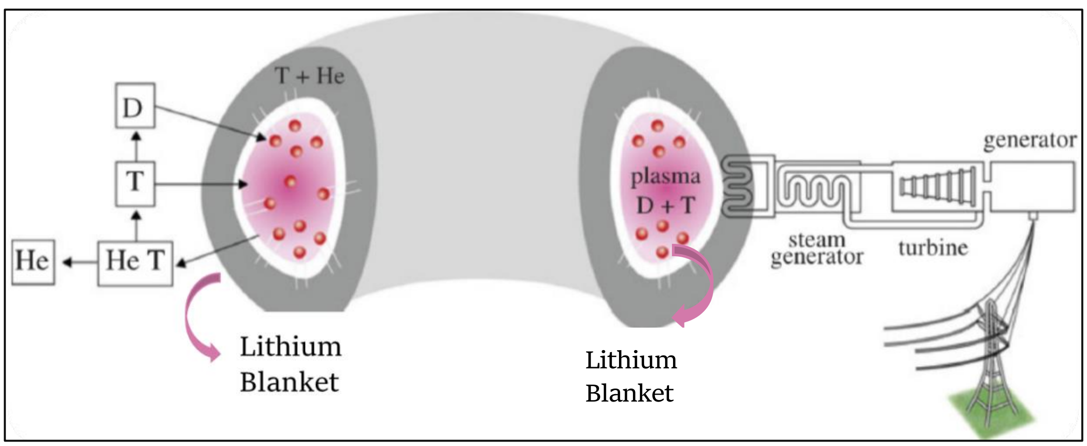

Figure 2.3 The blanket covering the fusion reaction that is connected to the generator.