UNIVERSITI TEKNIKAL MALAYSIA MELAKA

EFFECT OF POROUS STRUCTURE PARAMETER ON THE GAS FLOW IN THE THERMAL TRANSPIRATION PUMP

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A thesis submitted in fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering Technology with Honours

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DECLARATION

I declare that this project entitled "Effect of Porous Structure Parameter on the Gas Flow in the Thermal Transpiration Pump" is the result of my own research except as cited in the references. The chosen item has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature :

Name : Muhammad Zarif bin Ibrahim

Date : 11/01/2023

APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Mechanical and Manufacturing Engineering Technology with Honours.

Signature : ....

Supervisor Name : Sushella Edayu binti Mat Kamal

Date : 11/01/2023

DEDICATION

I would like to thank my family and all of my friends for their unwavering support throughout my academic career by devoting this final year project to them. I am grateful that you have provided me with the chance to better myself and demonstrate my worth throughout my life. Your affection, exemplary behaviour, and wise counsel have been the driving forces behind everything positive that has occurred in my life.

ABSTRACT

The Knudsen Pump (KP) is a form of micro-pump that operates without the use of any mechanical parts through the use of thermally generated flows in rarefied gas conditions. These flows are induced by temperature fields. It has several benefits, such as having no moving parts, having a basic design structure, being straightforward to create, being able to work with a diverse array of energy sources, and having such a low energy consumption rate. Many researchers and academics have devoted a significant amount of time and effort to the investigation of KP since the advent of Micro Electro Mechanical Systems (MEMS) during the course of the years, and the majority of KP applications have been put to use in a variety of contexts. Because of the rapid growth of new technologies in today's world, it is necessary to make adjustments in order to be able to compute more precisely by employing simulations and analyses. However, there have not been a comprehensive study on the effect of porous structure parameter on the gas flow in the thermal transpiration pump. In this project, the best porosity design that has been fabricated by using 3D printing will be selected to be analyze and compare to the current porous medium available that has been used in Knudsen pumps. As the hot chamber is heated, hot gas will be produced within the chamber. Thermocouples is used to measure the temperature and pressure sensor is used to observe the pressure difference. After the temperature rises to the required value, the gas flow is observed. Therefore, the temperature difference as well as pressure difference can be analyzed.

ABSTRAK

Pam Knudsen (KP) ialah sejenis pam mikro yang beroperasi tanpa bahagian mekanikal oleh aliran teraruh terma dengan teraruh oleh medan suhu dalam persekitaran gas jarang. Ia mempunyai banyak kelebihan seperti tiada bahagian yang bergerak, struktur reka bentuk yang ringkas, mudah untuk dibina, boleh digunakan dengan pelbagai sumber tenaga dan mempunyai penggunaan tenaga yang begitu rendah. Dengan pembangunan Sistem Mekanikal Elektro Mikro (MEMS) sepanjang tahun, ramai sarjana dan penyelidik telah memberikan banyak perhatian kepada kajian KP dan kebanyakan aplikasi KP telah digunakan dalam banyak kesempatan. Dengan perkembangan teknologi moden pada masa kini, ia diperlukan untuk menyesuaikan diri untuk mengira dengan lebih tepat dengan menggunakan simulasi dan analisis. Walau bagaimanapun, belum ada kajian menyeluruh mengenai kesan parameter struktur berliang ke atas aliran gas dalam pam transpirasi terma. Dalam projek ini, reka bentuk keliangan terbaik yang telah direka dengan menggunakan cetakan 3D akan dipilih untuk dianalisis dan dibandingkan dengan medium poros semasa yang ada yang telah digunakan dalam pam Knudsen. Apabila ruang panas dipanaskan, gas panas akan dihasilkan di dalam ruang. Termokopel digunakan untuk mengukur suhu dan penderia tekanan digunakan untuk memerhati perbezaan tekanan. Selepas suhu meningkat kepada nilai yang diperlukan, aliran gas dianalisis dan diperhatikan. Oleh itu, perbezaan suhu dan juga perbezaan tekanan dapat diperhatikan.

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LIST OF SYMBOLS AND ABBREVIATIONS

KPs	-	Knudsen pumps
AM	-	Additive Manufacturing
SLA	-	Stereolithography
SLS	-	Selective Laser Sintering
FDM	-	Fused Deposition Modeling
PLA	-	Polylactic Acid
ABS	-	Aclyonitril Butadine Styrene
TPU	-	Thermoplastic Polyurethane

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Natural convection in enclosures have been studied by researchers for decades by reason of the multipurpose and widespread uses of applications such as thermal insulation, cooling of electronic equipment, to design a nuclear reactor and as simple as to push fluid through pump, fan, etc without using mechanical force. Knudsen invented a non-mechanical micro-pump in which the gas flow is thermally generated by temperature gradients in a small channel (Knudsen, 1909; Knudsen 1910). Later then, the Knudsen Pumps (KPs) or Knudsen compressors were the names given to micro-pumps. Many academics have paid close attention to Knudsen Pumps because of the advantages it offers as there are no mechanical parts, moving parts, the structure is simple, easy to make mass production and also low energy consumption.

According to the concept of transpiration, two closed chambers with different temperatures are connected by a narrow channel, and the rate of gas flow from one chamber to the other is directly proportional to the pressure in that chamber and inversely proportional to the square root of its temperature.(Schabmuller, 2002). Thus, if the initial pressure in the two chambers are equal, there will be an effective movement of gas molecules from the cold chamber to the hot chamber. However, current material for the narrow channels uses porous ceramics, which are suitable for thermal insulation purposes.

The additive manufacturing (AM) of porous ceramics has been given a lot of attention because of their lightweight structure, very high surface area, customize-able geometry and also multi-functionalities. These unique properties are most suitable for thermal insulation which is used in the Knudsen Pump (Zhao, 2020; Bertino, 2018).

1.2 Problem Statement

Thermal transpiration pumps or Knudsen pumps in general operates through thermal transpiration-driven gas flow through a narrow channel connecting both two isolated chambers which is at different temperatures, cold chamber and hot chamber. The pump requires very small channel thus the narrow flow can be achieved by porous media. However, due to the current design of porous ceramics fabricated through porous ceramic processing which is used in the narrow channel, the required accurate size of porosity can't be achieved. Thus, by designing the porous media using additive manufacturing, needed variables and parameters can specifically be set in order to achieve the required results.

1.3 Research Objective

The main aim of this research is to design a 3D printed porous structure to be used in the Knudsen pump with suitable efficiency requirement. Specifically, the objectives are as follows :

a) To determine the existing material and method of 3D printed porous structure.
b) To design and develop 3D printed porous structure by for thermal transpiration pump.
c) To analyse the effect of porous structure properties on the gas flow in the thermal transpiration pump.

1.4 Scope of Research

The scope of this research are as follows:

- The research conducted is exclusively only for experimental studies.
- 3D printed porous structures will be manufactured with porosity percentage which is 10% calculated from the diameter of the current narrow channel used in the experiment rig.
- The type of gas used in the experiment is operated with air.
- Thermal transpiration pump/Knudsen pump will operate at atmosphere pressure.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discussed the previous research and sources related to the design and material of porous media used in the Knudsen pump. The sources include journals, reports, book, and websites. These sources serve as a guide for completing this research by providing pertinent information, ideas, and expertise. In this study, theories and analysis related to the material and design of porous media is discussed.

2.2 Micro-pump

In 1990s, Micro Electro Mechanical Systems (MEMS) were first introduced (Fluitman, 1996). Nowadays, they have been widely used in variety of fields as they can be manufactured in large quantity and easy extension. Multiple research has been conducted on various microfluidic devices such as micro fuel cells (Yang X et al., 2006; Lee et al., 2012), lab-on-a-chip systems (Hong. C et al., 2007), micro-gas chromatographs (Terry et al., 1979; Jean-Baptiste et al., 2010; Zareianjahromi et al., 2009; Dziuban et al., 2004; Astle et al., 2007), micro mass spectrometers (Ferran et al., 1996; Sanders et al., 2010; Orient et al., 1997), micro spectrometers (Blomberg et al., 1997; Schuler et al., 2009), reformers (San Ramon, 2000; Ogden, J. M, 2001; Calo et al., 2010) and micro air vehicles. The driven control engine for micro fluids is the micro-pump, which is the key to the development of microfluidic devices.

There are several actuation concepts and morphologies for micropumps. Mechanical micro-pumps are separated from non-mechanical micro-pumps by the presence or absence of moving components. Mechanical micro pumps use the mechanical energy of its moving components to propel fluid flow, and their primary working medium are liquids. Due to the presence of moving components, their durability, sensitivity, and stability are inadequate. In non-mechanical micro-pumps, fluid movement is generated by non-mechanical forms of energy such as electric energy, thermal energy, chemical energy, and magnetic energy. Their working fluids are not need to be liquids; they may be be gases or solids with nanometer-sized particles.

There are various types of classifications for mechanical micro-pumps such as piezoelectric pumps (Fang et al., 2010; Wang et al., 2017), electrostatic pumps (Zengerle et al., 1995; Ghazali et al., 2017), thermo pneumatic pumps (Wego, 2001), shape-memory alloy (SMA) pumps (Bernard et al., 1998), and electromagnetic pumps (Amrani, 2018). Non-mechanical micro-pumps, such magnetohydrodynamic pumps, may be classified separately from mechanical micro-pumps (Jang, 2000), electroosmotic pumps (Yoshida et al., 2017) and Knudsen pumps (KP) (An S. et al., 2014; Qin et al., 2015). Technically, micro-pumps and non-micro-pumps are very different in terms of mechanisms. In micro electrical mechanical systems, non-mechanical micro-pumps overall have better performance and is more convenient and preferable with regard to research and development in comparison to mechanical micro-pumps.

Knudsen was the first to design a non-mechanical micro-pump using temperature gradients along the walls to generate gas flow (Knudsen, 1909; Knudsen 1910). KPs, or Knudsen compressors, were the name given to the micro-pumps at the time. The KP's operation is based on the thermal creep phenomenon in rarefied gases. (Maxwell, 1878;

Reynolds 1879). Due to its advantages such as having no moving parts, simple structures and low energy consumption, many researchers and scholars give much attention to the Knudsen pump.

2.3 Additive Manufacturing Technology

The first known variations of 3D printing may have been discovered in Japan in the early 1980s. In 1981, Hideo Kodama was seeking for a method to build a rapid prototyping system. He developed a layer-by-layer manufacturing process based on a UV-polymerized photosensitive resin. Charles Hull submitted the first stereolithography (SLA) patent the same year. Hull, an American furniture manufacturer who was unhappy with the difficulty of making small bespoke pieces, invented a technology for creating 3D models by curing photosensitive resin layer by layer. In 1986, the first patent application for the technology was submitted by him, and in 1988, he established the 3D Systems Corporation. The SLA-1, the first commercial SLA 3D printer, was released by the company during that same year. Subsequently, SLA was not the only type of process in additive manufacturing being founded during at that time.

At the same year during 1988, Card Deckard from University of Texas have filed the patent application for Selective Laser Sintering (SLS) technology. In comparison to the SLA which used liquid, SLS system used fused powders, using a laser.

Fused Deposition Modeling (FDM) or also called Fused Filament Fabrication was also patented around the same time by Scott Crump. In comparison to SLA and SLS in which uses light, the filament is directly extruded from a heated nozzle. Nowadays, Fused Filament Fabrication technology are now the most common form of 3D printing that we used today.

2.3.1 Stereolithography (SLA)

Stereolithography is one of the method for additive manufacturing that came from vat photopolymerization. It is commonly referred to as resin 3D printing since it employs UV lasers as a light source to selectively melt and cure polymer resin.. Patented in 1986, stereolithography was known as the first 3D printing technology. Nowadays, it is still one of the most cost-effective whenever parts that requires very smooth surface and highly detailed finished are required. The finishing of the end products depends on the designer and operator as nest results are achieved when the advantages of the limitations and advantages of the manufacturing process are taken into account. In SLA 3D printing, several materials are used such as liquid resins in which can take form in various materials including standard resin, high detail resin, clear resin, castable resin, durable resin, high temperature resin, this also includes the properties on the end use of the part such as thermal resistance properties, abrasion resistant or also smooth surface finish. However, different properties or materials varied in prices. Standard material will cost less and specialty materials will cost higher. SLA materials (thermosets) however, are more brittle than FDM or SLS (thermoplastics) and for this reason alone the SLA generated parts are not meant to be used for prototypes as it will break easily.