PERFORMANCE CHARACTERIZATION OF MICRO POROUS MEDIA BURNER FOR HEAT OR POWER GENERATION

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by

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LIST OF ABBREVIATIONS

ER	Equivalence ratio
VO	Vegetable oil
CAD	Computer Aided Design
CFD	Computational fluid dynamics
CO	Carbon monoxide
LPG	Liquid petroleum gas
LPM	Litre per minute
NO	Nitrogen oxide
PMC	Porous media combustion
PMB	Porous media burners
PM	Porous media
SEM	Scanning electron microscopy
TE	Thermoelectric
TPV	Thermophotovoltaic
UDF	User-defined functions
UHC	Unburned hydrocarbons
USM	Universiti Sains Malaysia
XRD	X-ray diffraction
USB	Universal Serial Bus
DAQ	Data acquisition
AF_S	Stoichiometric air fuel ratio
AF_a	Actual air–fuel ratio

LIST OF SYMBOLS

C_w , C_p	specific heat of water and the container (J/kg-K)
t	Thickness if preheat layer (mm)
h	Height of the reaction layer (mm)
Pe	Peclet number
F	Laminar flame speed (m/s)
D	Equivalent diameter (m)
ρ	Density of the gas mixture (kg/m3)
k	Thermal conductivity (w/mk)
r	Radius (m)
T	Temperature (˚C)
t	Time (s)
Q_{in}	Energy supplied from butane (kW)
Q_{out}	Energy generated from combustion (kW)
V_f	Volumetric flowrate (kg/m^3)
M_f	Mass flow rate (kg/s)
n_{th}	Thermal efficiency
M_w	Mass of water (kg)
T_i	Initial temperature (^{o}C)
t'	Time (s)
$\overline{x}$	Mean value
σ_x	Standard deviation
$\sigma_{\bar{x}}$	Standard error

CIRI PRESTASI PEMBAKAR MIKRO MEDIA BERLIANG UNTUK PENGHASILAN HABA ATAU KUASA

ABSTRAK

Ancaman kehabisan bahan api mempengaruhi ekonomi negara. Oleh itu, beberapa usaha dibuat untuk menambah baik penggunaan bahan api dengan mencipta pembakar yang lebih efisien. Oleh yang demikian, kajian ini berfokus untuk membina pembakar mikro media berliang berasaskan butana. Pembakar ini direka bentuk untuk menjalani pembakaran permukaan dan tenggelam dengan nisbah setara. Dua jenis lapisan reaksi diuji; media berliang jenis buih dan bola, manakala busa tembikar di zon pra pemanas. Ketebalan tindak balas dan lapisan pra pemanas diubah untuk mendapatkan prestasi pembakaran yang optimum. Oleh itu, kecekapan haba 90% telah dicatatkan dengan menggunakan busa alumina 15 mm bersama-sama dengan busa tembikar 10 mm. Nilai NOx dan CO pada nisbah setara yang optimum adalah kurang daripada 15 dan 60 ppm. Tambahan pula, peningkatan 4% dalam kecekapan haba dicapai dengan menambahkan titisan minyak sayur-sayuran sebanyak 80μL ke atas lapisan reaksi. Di samping itu, kuasa elektrik 2.018 W dihasilkan dari pembakaran permukaan menggunakan sel TE. Sel-sel TE ini disepadukan dengan konfigurasi hibrid, termasuk kipas litar yang dikuasakan oleh panel solar. Selain itu, ketinggian antara lapisan reaksi dan sel TE dioptimumkan (69 mm) menggunakan reka bentuk eksperimen untuk meningkatkan lagi kuasa elektrik sebanyak 8%. Akhir sekali, kajian berangka tiga dimensi dilakukan untuk membandingkan data eksperimen untuk kedua-dua suhu dan pelepasan (NOx dan CO) pada nisbah setara kritikal (ER = 0.7).

PERFORMANCE CHARACTERIZATION OF MICRO POROUS MEDIA BURNER FOR HEAT OR POWER GENERATION

ABSTRACT

The threat of fossil fuel depletion affects the nation's economy. Consequently, attempts are made to improve the use of fuels by developing highly efficient burners. With this intention, present work was focused to develop premixed butane based micro porous media burner. The burner was designed to undergo surface and submerged flames by varying equivalence ratio. Two types of reaction layer were tested; foam and ball type porous media (PM), while porcelain foam in preheat zone. Thickness of reaction and preheat layer was varied suitably to get optimum burner performance. Thus 90% thermal efficiency was noted by using 15 mm alumina foam along with 10 mm porcelain foam. Values of NOx and CO at optimum equivalence ratio was less than 15 and 60 ppm respectively. Further, 4% improvement in the thermal efficiency was achieved by adding 80 μL of vegetable oil droplets over reaction layer. In addition, electric power of 2.018 W was generated from the surface flame using TE cells. These TE cells are integrated to a hybrid configuration, it includes circuit fan powered from solar panels. Moreover, height between reaction layer and TE cells was optimized (69 mm) using design of experiments to further increase electric power by 8%. Finally, three dimensional numerical study was performed to compare experimental data for both temperature and emissions (NOx and CO) at a critical equivalence ratio (ER=0.7).

CHAPTER ONE

INTRODUCTION

1.1 General Introduction

The major direct impact to any nation across the world is due to the fast depletion of fossil fuel. Every possible attempts are made to save even a small bit of fossil fuels in some way or the other. One of the most popular device which consumes large amount of fossil fuels are burners, which are extensively used in domestic and industrial sectors. Nowadays, major international organizations such as WHO (World Health Organization) and IUAPPA (International Union of Air Pollution Prevention and Environmental Protection Associations) have made direct mandatory rules for both domestic and industrial sectors in controlling air pollution caused by fossil fuels. Thus, porous media burner (PMB) have gained popularity because of their outstanding performance in terms of technical and economic aspects, especially the burners with premixing and a two-layered structure (Mujeebu et al., 2009a).

A porous material can be defined as "a material with a specific size and number of pores, which are well connected to each other to form a solid shape". Porous media (PM) have become popular choice because of their ability to generate better heat transfer between combustible and solid media, as well as the dispersion of the reactant in the reaction zone. Generally, once combustion in PMB gains better thermal efficiency, the by-products of emissions such as NOx, shows less than 10 ppm (parts per million) (Mujeebu et al., 2011a). A literature survey from the past three decades indicates good quality and quantity of work has reported on various aspects and applications of porous media combustion (PMC). However, various aspects of dual layer PMB have yet to be confirmed, especially when it comes to presence of preheat layer. Exhaustive reviews on PMB indicate a the good scenario on the development of innovative and efficient burners (Mujeebu et al., 2009a; Mujeebu et al., 2009b). Ismail et al. (2013) made a successful breakthrough experimental study with butane as a source fuel to revolutionize the conventional use of LPG for cogeneration applications with foam type of porous media (PM). Exclusive research reported from (Ismail et al., 2013; Ismail et al., 2016) on butane PM burners highlighted the importance of butane for reduction of emissions and stable surface temperatures at various ER, thereby performs better over LPG.

Literature on PMB identifies the popular methods used to increase thermal efficiency includes usage of a unique fuel mixtures, changing the thickness of the reaction/preheat layer, and replacing PM with new materials (Mujeebu et al., 2010).

Another possible method to improve burner characteristics is by using external additives/fuels over the reaction zone. Lapirattanakun and Charoensuk (2017) developed a novel PMB that works with vegetable oil (VO) along with steam injection. Their PMB achieved significant improvement in thermal efficiency. Thus, VO can be regarded as a stand-alone or a biofuel input to develop a cooking stove, a semi-industrial boiler, and a liquid PMB cogeneration applications (Mustafa, 2015). VO can also be an interesting alternative to consider as external additives/fuels for boosting conventional combustion systems. Another important concern by researchers was that the heat generated from the burner should not just be limited to domestic/industrial heat supply but also support cogeneration system. Therefore, many studies focused on cogeneration system with porous media burners utilize the heat from the exhaust/walls to convert it into other forms of energy. One of the popular ways to generate electric power from heat energy is by considering Thermoelectric (TE) cells. It operates on the phenomenon of Seebeck effect which produces electric voltage when subjected to temperature gradient across two dissimilar metals (which are fused together). Consequently, power output from TE cell can be further increased provided the temperature difference across two surfaces of the cell are kept higher.

1.2 Problem Statement

The combustion of fossil fuels is an important aspect for both domestic and industrial sector to act as power source. Even though tremendous amount of experimental work has been carried out to improve combustion in burner, but still there is a need to improve burner thermal efficiency to much greater level since fuels are getting expensive day by day. Especially in a burner which can generate submerged flame, since submerged flame gives pure radiation and finds good number of applications in domestic and industrial sectors such as in bakery, cosmetic companies and textile industries. Apart from aiming to improve thermal efficiency, major concern is to focus on reduction of emission parameters like NOx and CO. The emission generated during combustion mainly depend on physical and chemical mechanisms involved during combustion (Mohamad, 2005). Hence there is almost need for new burner with better thermal efficiency and low emissions.

Porous media burner (PMB) are able to generate two types of flame, namely surface and submerged flame. The flame that can be easily seen by the naked eye is called a surface flame, were in the actual movement of flame can be easily noticed. While, the flame that runs under the surface of reaction zone is known as a submerged flame. Submerged flame can directly heat the objects in a common environment, not the air in between. Hence, heat transfer study with surface/submerged flame in a burner can be an interesting aspect of the study. Selection of PM inside burner is a challenging task. Three main factor play important role in building novel PMB includes type of PM to installed in reaction and preheat layer, porosity and ppcm (pores per centimetres). In addition, mechanism of stable combustion phenomenon depends on burner size, and type of incoming fuel mixture. Size of the PMB are decided based on the actual application of the burner, cost of the system, required flame type and available PM. Next, importance of fuel identification is a critical aspect, since commercially available fuels are obtained from fossil fuels. Gaseous fuels like methane, propane, butane and LPG finds their own advantages and limitations based on application of the burner.

Thermal efficiency can also be enhanced by the using suitable combustion enhancing liquids like vegetable oil, spraying nano particles and biofuel spray. These liquids release additional energy during combustion, thereby increases thermal efficiency. Involvement of external liquids can be utilized in different ways either over surface of the reaction zone or it can be injected between porous media. Considering vegetable oil to enhance efficiency is an interesting option, due to its availability. Since the triglycerides present in vegetable oil contains significant amount of oxygen, which enhances combustion (Mustafa, 2015).

Heat energy from the burner can also be utilized to convert in to electric power by using energy conversion cells. Since electric power is very much essential for electronic gadgets like; mobile phone and portable LED lamps. Generally, thermoelectric (TE) or thermophotovoltaic (TPV) are the potential candidate in conversion of heat energy in to electrical energy with respect to burners. Therefore, the need to generate both heat and electrical power generation by micro burner can be considered as better approach of study. Hence, by focusing on low fuel consuming burner, emission perspectives, external additives to boost thermal efficiency and electric power generation all together shall give rise to new research and development in the area of burners.

1.3 Objectives of the study

The objectives of the study are listed below,

I. To develop a dual layered micro porous media burner to undergo both surface and submerged flames at low fuel mixture.

II. To obtain the performance of porous media burner experimentally by using foam and ball type of porous media with various thickness of reaction and preheat layers.

III. To investigate the effect of vegetable oil droplets during porous media combustion at various equivalence ratios.

IV. To measure the electric power using thermoelectric cells with the help of hybrid configuration.

1.4 Scope of the Study

The scope and limitation of the study are given below,

I. The fabricated burner was designed only to undergo surface and submerged flame at low fuel rate, in order to save the fuel.

II. Porous media used in the study was limited to the alumina foam and ball type; alumina and zirconia sphere with 10 mm size.

III. Only butane as a gaseous fuel was used throughout the experimental trials with equivalence ratio from 1 to 0.4.

IV. Vegetable oil was varied from of 20 to 80 μL in steps of 20 μL.

V. Only thermoelectric cells where used to generate electric power.

VI. Optimum height at which thermoelectric cells need to be located was determined using RSM optimization technique.

VII. Three dimensional numerical analysis using ANSYS FLUENT with standard governing equation and global reaction mechanism was conducted in the study at only critical equivalence ratio only.

1.5 Thesis overview

This thesis consists of five chapters, with this first chapter highlights on general introduction about the work done. Chapter two highlights on research work carried out by previous researchers. It basically summarizes the research trends and findings with respect to the study of porous media combustion especially involving various types of burner used by other researchers for domestic and industrial applications. For better understanding a detailed discussion on types of flames i.e., surface and submerged flame was added. Importance of adding external liquids to enhance porous media combustion (PMC) was also focused. It is worth to be noted that the impact of external liquids shall enhance performance of burner, thereby generating high thermal efficiency.

Next, chapter three highlights main aspects of methodology adopted. It includes detailed explanation on how presented work was performed with justified