EXPERIMENTAL INVESTIGATION ON THE CHIMNEY DIVERGENCE AND WIRE MESH INFLUENCES ON THE PERFORMANCE OF SOLAR CHIMNEY

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ABSTRACT

Solar chimney power generation system is a renewable alternative option to fossil fuels to generate electric energy, but its construction and maintenance are expensive. A lot of innovative prototypes of solar chimneys were developed by researchers to reduce costs related to its size, yet no significant solution has been established. This study aims to investigate the performance of divergent solar chimney compared to cylindrical-solar chimney at different inlet heights and electric heat loads. The electric heating load is gained from the electrical coil located below the chimney to simulate the solar energy in the collector. Scaled down divergent and cylindrical solar chimney models were designed and fabricated in the lab. The working parameter of the scaled down solar chimney was measured at different electric heat loads to observe the performance variants. A wire mesh addition at the chimney exit was also tested and analysed to study the effect of cold inflow to divergent solar chimney performance. Experimental results of the divergent chimney showed improved stack effect and increases in velocity at the throat caused by the reduced area. The power potential of the chimney is also increased from 6 to 15 times compared to a cylindrical chimney. Wire mesh addition at the exit of the chimney prevents cold inflow by the formation of eddies due to flow separation and an increase in turbulence flow. As such, it causes improved flow behaviour and an increase in air velocity by 30%. This study concludes that divergent chimney has a better performance compared to a cylindrical chimney. The addition of wire mesh further increases the power potential of the divergent solar chimney. These findings show that the divergent solar chimney is a highly probable alternative design to reduce capital cost by reducing the height while having better power potential.

ABSTRAK

SIASATAN EKSPERIMENTAL KESAN CEROBONG CAPAH DAN JARINGAN DAWAI TERHADAP PRESTASI CEROBONG SOLAR

Penjana sistem cerobong kuasa suria adalah satu alternatif bagi menjana tenaga elektrik, namun pembinaan dan penyelenggaraannya melibatkan kos yang agak tinggi. Terdapat banyak prototaip inovasi cerobong suria telah dibangunkan oleh para penyelidik untuk mengurangkan kos awal pembinaannya termasuklah dari segi saiz, tetapi inovasi yang telah dibangunkan masih berada dalam peringkat kajian. Kajian ini dijalankan bertujuan untuk menyelidik kecekapan cerobong suria berbentuk tirus berbanding cerobong suria berbentuk silinder pada ketinggian dan beban kepanasan elektrik yang berbeza. Beban kepanasan elektrik didapati daripada pemanas elektrik yang terletak di bawah cerobong sebagai simulasi pengumpul tenaga solar. Model cerobong suria tirus dan berbentuk silinder telah direka dan dibangunkan dalam makmal. Model cerobong suria tirus diukur pada ketinggian dan beban kepanasan elektrik yang berbeza untuk diperhatikan perbezaan prestasi. Analisis dan ujian juga turut dijalankan bagi mendapatkan kesan aliran balik udara sejuk pada cerobong suria tirus apabila net besi dipasang pada bahagian hujung keluar cerobong. Keputusan eksperimen cerobong suria berbentuk tirus menunjukkan kesan stack dan peningkatan halaju angin pada tengkorok atas pengurangan diameter cerobong. Potensi kuasa cerobong juga meningkat dari 6 ke 15 kali berbanding dengan cerobong berbentuk silinder. Pemasangan net besi pada hujung cerobong dapat menghalang aliran balik udara sejuk dengan pembentukan perolakan disebabkan oleh pemisahan aliran dan peningkatan aliran udara bergolak. Dengan itu, bentuk aliran udara dapat diperbaiki dengan 30% peningkatan halaju udara. Kajian ini menyimpulkan bahawa cerobong berbentuk tirus mempunyai prestasi yang lebih baik berbanding cerobong berbentuk silinder tepat. Potensi kuasa cerobong suria berbentuk tirus turut meningkat dengan pemasangan net besi. Dapatan kajian ini juga menunjukkan bahawa cerobong suria berbentuk tirus adalah alternatif reka bentuk yang boleh di guna pakai untuk mengurangkan kos awalan pembinaan cerobong suria dengan pengurangan ketinggian cerobong di samping mempunyai potensi kuasa yang lebih baik.

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LIST OF ABBREVIATION

CFD	-	Computational Fluid Dynamics

LIST OF SYMBOLS

A_{ch}	-	Chimney Cross-sectional area (m^2)
BM_h	-	Bellmouth height (m)
BM_r	-	Bellmouth radius (m)
D	-	Diameter (m)
D_m	-	Diameter of model (m)
D_p	-	Diameter of Prototype (m)
fr	-	Frouder number (dimensionless)
g	-	Gravitational acceleration (ms^{-2})
h	-	Height of chimney (m)
$\dot{m}$	-	Mass flowrate (kgs^{-1})
$P_{electric}$	-	Electric Power Generation (W)
P_{wind}	-	Wind Power Potential (W)
T	-	Temperature (K)
$T_{chimney}$	-	Temperature inside chimney (K)
T_{∞}	-	Ambient Temperature (K)
V	-	Velocity (ms^{-1})
V_m	-	Velocity in model (ms^{-1})
V_p	-	Velocity in Prototype (ms^{-1})

LIST OF GREEK LETTERS

η_g	-	Generator efficiency (dimensionless)
η_t	-	Turbine efficiency (dimensionless)
ρ	-	Fluid Density ($\mathrm{kgm^{-3}}$)
ΔT	-	Temperature difference between exit and ambient (K)

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Population growth, modernization, technological development and dependencies on electric power have led to global power crises. So, the feasibility of the cheap, sustainable and environment-friendly power generation through fossil fuel and renewable energies is now a hot debate. Power generation is mostly done using the fossil fuel which leads to hazardous emissions and other forms of pollution namely water pollution and thermal pollution (Bozkurt, 2010; Hausfather, 2014). It has a very high impact on the environment, which in-turn cause's disturbances in the ecosystem. While renewable energies like solar and wind energy are infinite, abundant and environment-friendly. It is estimated that the world will be generating about 30% of global electricity through renewable energy sources; this encourages the expansion of renewable energy technologies and reduce the dependencies on fossil fuel (Saygin *et al.*, 2015).

Solar PV system and wind turbine are used to harvest electrical energy from sun and wind. These two technologies are well established and adequate yet other efficient ways need to be considered also; one of them being the solar chimney which lacks attention due to bigger size and capital cost, though this technology was established a long time ago. The first working prototype of the solar chimney, in Manzanares, Spain had a gigantic chimney and less power generating capability, making its implementation harder (BRIGITTE, 2007). The solar chimney does not produce any emissions or cause any pollution, unlike electricity generation through fossil fuels (Chen, 2014). The solar chimney can be a promising solution to future electricity-generation problems since it is environment-friendly and can be installed in rough areas and weathers. Also, its maintenance cost is very low. Study suggest that a solar chimney infrastructure is reliable for more than 80 years that makes it a unique and promising technique to generate the electricity (Grose, 2014).

The working principle of the solar chimney is very simple; it has solar collectors that receive energy from solar radiations and heat the air. The hot air from the solar collector rises upwards in the chimney due to the buoyancy. The chimney is equipped with a turbine that uses kinetic energy of hot air molecules and converts it into mechanical energy. This mechanical energy is used to generate electrical energy by the generator. The hot and less dense air is ejected into the surroundings through the chimney; this phenomenon is also known as the Stack Effect.

Outcomes obtained from a vast number of simulations, mathematical models and small scale laboratory experiments, performed by different researchers, encourage the use of solar chimney for power generation. The construction of a solar chimney power plant consists of 3 major parts: solar collectors, chimney or draft, and turbines. The application of a solar chimney is not limited to electricity generation, it can also be used for other purposes such as paddy and vegetable dryer, and the passive cooling for buildings (Chungloo & Limmeechokchai, 2007). Also, the distillation of waste water and seawater can be done efficiently by using a solar chimney (Zuo *et al.*, 2011a).

Solar chimney's efficiency depends upon the diameter, pattern and material quality of the solar collector. A sufficient number of researches have been carried out on solar collector's quality, design and heat storage as well as on how to enhance the efficiency of the plant during night time and in the winter (Kayiem, 2006; Bernardes, 2013; Choi *et al.*, 2016;). Gigantic height of the chimney is a major drawback of a solar chimney. Also, a tall solar chimney is less efficient due to lower temperature at higher altitude. The cold air from the surrounding also enters at the chimney exist, resulting in a decrease in the power generation. There is little or no research on the divergent design and effects of cold inflow on the performance of a solar chimney power plant. Therefore, this study focuses mainly on experimental results obtained from the model draft to enhance efficiency. A wire