UNIVERSITI PUTRA MALAYSIA

PARAMETRIC STUDY OF PORTABLE SOLAR-POWERED HEAT EXCHANGER USING COMPUTATIONAL FLUID DYNAMICS

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BERILMU BERBAKTI

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

December 2016

DEDICATION

TO MY BELOVED PARENTS AND
MY WIFE NORFARAHAIN WHOSE SUPPORT AND
UNDERSTANDING HELPED MAKE THIS POSSIBLE

SINCERELY
TENGKU MUHAMMAD FAHMI

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in Fulfillment of the requirements for the degree of Master of Science

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Chairman : Nor Mariah Adam, PhD, PEng
Faculty : Engineering

Water is important for human. Its importance is highlighted by the United Nation as decade for clean water in the world populations suffer lack of portable water in stressed area such as Africa and South East Asia. Therefore, solar powered water distillation system is important, especially for portable devices seems necessary. This study is concerned with parametric of heat exchanger for a portable telescopic solar powered water distiller. The water supply for the distiller is untreated water from rain water, tube well or flood water. The solar powered water distiller was a Master thesis project completed in 2014 but the heat exchanger requires further improvement on design and fabrication. Presently, the water distiller can produce 10L per day in good sunny weather. The shell and tube heat exchanger with parabolic trough collector (PTC) have potential to increase performance using computational fluid dynamics to produce clean water. Design geometry of heat exchanger was based on the conditions of high-pressure difference between the fluids. The setting of cooling temperature of water inlet is 31°C and water outlet is 29.8°C. However, the tube for fluid inlet is water vapour at 82°C and the temperature outlet is at 38°C. Water vapour comes into tube heat exchanger from the parabolic thermal collector (PTC). The methodology involves using computational fluid dynamics RNG k-epsilon turbulence flow model. The model was applied using CFD (computational fluid dynamics) package conjunction with conjugated heat transfer to predict the flow behavior inside the heat exchanger for both vapour and liquid water flow. Both heat conduction and heat convection are taken into account for this 3D computational method to determine fluid flow and temperature distribution. Parameters considered for design (shell diameter, number of tubes, baffles, temperature difference, velocity of fluid and heat transfer coefficient involved) can be used to develop optimum design of heat exchanger and also through selection of suitable materials. The material construction is a very important aspect in the design for heat exchanger to ensure operating conditions fabrication technique and safe drinking water is produced at a minimum cost and low maintenance. Selected materials have to view the shape design are able to withstand high temperatures and pressures for heat exchanger to perform efficiently. The analysis compares actual experimental result and defines the suitable material and the best thermal efficiency on the shell in tube heat exchanger. A multiple baffled shell-and-tube heat exchanger design performance is evaluated numerically using CFD (computational fluid dynamics) modeling approach. The field heat exchanger consists of two tubes inside a 0.535 m long and 0.140 m diameter shell. The simulated results are found to be in good agreement with the experiment data. Different materials for the heat exchanger used are stainless steel, copper and aluminum and their performances for a heat exchanger are compared. From the results, it is found that the temperature difference between the vapour outlet and water outlet is least in the case of copper and aluminum as a solid material. Thus, it can be concluded that the copper and aluminum material is giving highest heat transfer to the water. Using copper for heat exchanger can be very expensive and the produced water is not safe to be used for drinking compared to water produced with stainless steel. High heat transferred to the water will help in the sanitising process of the water. Sanitising is a process in which water is cleaned by the use of heat, to turn the water into a usable form.

Abstrak tesis yang dikemukakan kepada Senat, Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

KAJIAN BERPARAMETER PENUKARAN HABA BAGI SOLAR MUDAH ALIH BERKUASA MENGGUNAKAN PENGIRAAN DINAMIK BENDALIR

Oleh

TENGKU MUHAMMAD FAHMI BIN TENGKU IBRAHIM

Disember 2016

Pengerusi : Nor Mariah Adam, PhD, PEng
Fakulti : Kejuruteraan

Air adalah keperluan asas bagi manusia. Pertubuhan Bangsa-bangsa Bersatu menyatakan bahawa sebahagian besar populasi dunia mengalami kekurangan air bersih mudah alih seperti di Afrika dan Asia Tenggara. Oleh itu, penyulingan air berkuasa solar adalah penting terutamanya bagi alatan mudah alih. Kajian ini adalah mengenai parameter penukaran haba bagi penyuling air berkuasa solar mudah alih. Sumber air yang dibekalkan adalah air yang tidak dirawat yang didapati dari perigi, air hujan atau air banjir. Penyuling air berkuasa solar ini adalah dari projek tesis Master yang disiapkan pada 2014 tetapi penukar haba masih memerlukan peningkatan yang lebih lagi dari segi reka bentuk dan fabrikasi. Penyuling air boleh menghasilkan 10L air sehari ketika cuaca cerah. Kelompong dan tiub penukar haba dengan pengumpul palung parabola (PTC) mampu meningkatkan prestasi dengan menggunakan pengiraan dinamik bendalir untuk menghasilkan air bersih. Reka bentuk geometri penukar haba adalah berdasarkan perbezaan keadaan tekanan tinggi antara cecair. Tetapan suhu penyejukan pada aliran air masuk adalah 31°C dan aliran air keluar adalah 29.8°C. Walau bagaimanapun, wap air yang memasuki tiub masuk adalah pada suhu 82°C manakala suhu keluar adalah 38°C. Wap air memasuki tiub penukar haba dari pengumpul palung parabola (PTC). Metodologi yang terlibat adalah menggunakan pengiraan dinamik bendalir model aliran gelora RNG k-epsilon. Model aliran gelora diaplikasikan menggunakan pakej CFD (pengiraan dinamik bendalir) sealiran dengan penukar haba yang ditasrifkan untuk menjangka sifat aliran di dalam penukar haba bagi kedua-dua aliran wap air dan air. Kedua-dua pengaliran haba dan perolakan haba terlibat di dalam cara pengiraan 3D untuk menentukan aliran cecair dan penyebaran suhu. Parameter yang diambil kira untuk reka bentuk (iaitu, diameter kelompong, bilangan tiub, sesekat, perbezaan suhu, halaju cecair dan pekali penukaran haba yang terlibat) boleh digunakan untuk mereka bentuk penukar haba yang berprestasi maksimum disamping membuat pemilihan bahan-bahan yang sesuai. Pemilihan bahan adalah aspek yang sangat penting dalam reka bentuk penukar haba untuk memastikan teknik keadaan fabrikasi yang beroperasi dan air minuman yang selamat dihasilkan pada kos yang minimum dan penyelenggaraan yang rendah. Bahan yang dipilih mestilah sesuai dengan reka bentuk dan boleh menahan suhu dan tekanan yang tinggi dalam menjadikan penukar haba berfungsi dengan cekap. Analisis dilakukan untuk membandingkan keputusan eksperimen yang seterusnya menentukan bahan yang sesuai pada kelompong di tiub penukar haba. Beberapa hasil reka bentuk penukar haba dengan kelompong-dan-tiub bersesekat dinilai secara berangka menggunakan pendekatan model CFD (pengiraan dinamik bendalir). Ruang penukar haba terdiri daripada dua tiub kelompong yang berukuran 0.535 m panjang dan berdiameter 0.140 m. Dapatan kajian adalah menyokong data dari eksperimen. Bahan-bahan yang berbeza seperti besi tahan karat, tembaga dan aluminium digunakan pada penukar haba dan hasilnya diukur. Didapati bahawa penukar haba yang diperbuat dari tembaga dan aluminium memberikan perbezaan suhu paling sedikit di antara saluran keluar wap dan saluran keluar air. Oleh itu, ia dapat disimpulkan bahawa tembaga dan aluminium memberikan penukaran haba paling tinggi ke atas air. Pengunaan tembaga pada penukar haba memerlukan kos yang tinggi dan air yang dihasilkan tidak selamat untuk diminum berbanding dengan penggunaan besi tahan karat. Haba tinggi yang dipindahkan kepada air akan membantu pemprosesan air. Pembersihan adalah proses di mana air dibersihkan dari mikroorganisma dengan penggunaan haba untuk menjadikan air selamat digunakan.

ACKNOWLEDGEMENTS

In the name of Allah, The Most Gracious and Merciful who has given me strength and ability to complete my thesis for Master Degree. The author is taking this opportunity to express sincere gratitude to my supervisor, Assoc. Prof. Ir. Dr. Nor Mariah Adam for giving me an opportunity to do my Master Degree and her guidance, advices, criticism, systematic supervision, encouragements, and most of all her patience towards my attitude. Thanks are also expressed to Dr. Che Nor Aiza Binti Jaafar as the Co-supervisor for her kindness, information and suggestions during the project research.

I also appreciate those who have been supporting me in any respect during the completion of the project, especially Fluid Mechanics Laboratory Staff for their help and support during the working on this research work.

Last but not least, the author would like to express his heartfelt gratitude to his family members especially his beloved wife Norfarahain Bin Che Samsudin for their utmost support and motivation throughout this research work.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the supervisory committee were as follow:

Nor Mariah Adam, PhD
Associate Professor, Ir
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Che Noraiza Jaafar, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) were adhered to.

Signature: ______________________________

Name of Chairman of Supervisory Committee: Assoc Prof. Ir. Dr. Nor Mariah Adam, PhD, PEng

Signature: ______________________________

Name of Member of Supervisory Committee: Dr. Che Noraiza Jaafar, PhD

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A	Total surface area (m²)
A_c	Inner surface area of the tube under cleaned condition (m^2)
A_f	Inner surface area of the tube under fouling condition (m^2)
A_i	Inner tube surface (m²)
A_o	Outer tube surface (m²)
A_s	Fictitious cross sectional area (m²)
B	Baffle space (m)
C	Clearance between tubes (constant numbers)
c	Fluid specific heat (W/K)
C_p	Specific heat at constant pressure (J/kg.K)
D	Tube diameter (m)
D_e	Equivalent diameter (m) for square pitch layout
D_i	Inner tube diameter (m)
D_{ns}	Minimum inside shell nozzle diameter (m)
D_o	Outer tube diameter (m)
D_s	Shell diameter (m)
F	LMTD correction factor
f	Friction factor
g	Gravitational acceleration (m/s²)
G_s	Mass velocity in shell side (kg/m².s)
h	Heat transfer coefficient (W/m².K)
h_m	Modified heat transfer coefficient (W/m².K)
i_{fg}	Enthalpy (J/kg)
k	Thermal conductivity (W/m.K)
k_l	Liquid phase thermal conductivity (W/m.K)
L	Length of heat exchanger tube (m)
L_V	Vapour latent heat (kJ/kg)
m	Fluid mass (kg)
$\dot{m}$	Fluid mass flow rate (kg/sec)
N_t	Number of tube
N_u	Nusselt number
P_t	Tube pitch (m)
Q	Heat transfer (W)
q	Heat flow (kJ/sec)
R_{bs}	The ratio of baffle space to shell diameter($\frac{B}{D_s}$)
R_f	Fouling resistance factor (m²/K.W)
r	Tube radius (mm)
Re	Reynolds number
R_t	Total thermal resistance (m²/W.K)
R_w	Conduction resistance
T	Temperature (K)
T_A	Temperature of fluid A on wall side one (K)
T_∞	Free stream condition temperature (℃ or K)
T_B	Temperature of fluid B on wall side tow (K)
T_b	Base surface temperature (℃ or K)

t	Wall thickness (m)
U	Overall heat transfer coefficient (W/m² .K)
u_m	Fluid velocity in tube side (m/s)
u_c	Overall heat transfer coefficient for clean surface (W/m².K)
u_f	Overall heat transfer coefficient for fouling surface (W/m².K)
V_{ns}	Maximum fluid velocity in shell side
x	Vapor quality
ΔP	Pressure drop (Pa)
ΔT	Local temperature difference between two fluids (K)
ΔT_{lm}	logarithm-mean temperature difference (k)
ΔT_m	Suitable mean temperature difference across the heat exchanger (K)
$\Delta T_{overall}$	Temperature different between two sides wall (K)
Δx	Wall thickness (m)

Greek symbols

ε	Effectiveness of heat exchanger
η_o	Overall surface efficiency
μ	Dynamic viscosity (kg/m.s)
ρ	Fluid density (kg/m³)
Ω	Coefficient
α_g	Void fraction of the vapour

Subscripts

c	Cold fluid
f	Fouling
g	Gas phase
h	Hot fluid
i	Inner, Inside
l	Liquid phase
m	Mean
max	Maximum
min	Minimum
o	Outer, Outside, Overall
s	Shell side
t	Tube, Thermal, Total
v	Vapor phase
1	Inlet, Side 1
2	Outlet, Side 2

LIST OF ABBREVATIONS

ASS	Active Solar Still
CL	Tube Layout Constant
CPC	Compound Parabolic Collector
CFD	Computational Fluid Dynamics
CTC	Cylindrical Trough Collector
CSS	Conventional Solar Still
CSSP	Continuous Single Shell-Pass
CSP	Concentrated Solar Power
CH	Continuous Helical
DCMD	Direct Contact Membrane Distillation
DNS	Direct Numerical Simulation
EHT	Enhancing Heat Transfer
HBHE	Helical Baffle Heat Exchanger
HE	Heat Exchanger
HFC	Heliostat Filed Collector
HTC	Heat Transfer Coefficient
FPD	Fuzzy Proportional Derivative
FVM	Finite Volume Method
ID	Inside Diameter
ICS	Integrated Collector Storage
IEHX	Indirect Evaporative Heat Exchanger
LES	Large Eddy Simulation
LFR	Linear Fresnel reflector
LMTD	Log-Mean Temperature Difference
MCHX	Microchannel Heat Exchanger
NTU	Number of Transfer Unit
OD	Outside Diameter
OECD	Organization for Economic Cooperation And Development
PCM	Phase Change Material
PDE	Partial Differential Equations
PDR	Parabolic Dish Reflector
PR	Pitch Ratio

PTC	Parabolic Trough Collector
RANS	Reynolds-Averaged Navier Stoke
SSP	Shallow Solar Pond
SST	Shear Stress Transport
SRS	Suns River Still
STHX	Shell-and-Tube Heat Exchanger
SWH	Solar Water Heaters
TEAM	Tubular Exchanger Manufacturers Association
TOT	Twisted Oval Tube
TSS	Tubular Solar Still
UPM	Universiti Putra Malaysia
UDF	Under-Dynamic Factor
URF	Under-Relaxation Factor
URANS	Unsteady Reynolds-Averaged Navier Stoke
WHO	World Health Organization

CHAPTER 1

INTRODUCTION

1.1 Background

In the world today, humankind life depends on basic needs that include resources (oxygen, water, food and lodging). Many countries including both developed and under-developed countries are struggle with drinking water supply. This problem is rather more severe in the region where flood occurs frequently (seasonal and non-seasonal) and the rise of local poverty issue. In many years, it is believed that solar distiller can solve this problem with the technology advancement and for this purpose, a heat exchanger can be used to increase water distillation.

Solar distillation system based on Figure 1.1 is designed to transform undrinkable water into drinking water utilizing solar energy. To better engineer such design, heat exchanger inside solar distillation system is designed to take into account for its efficiency and productivity. This heat exchanger is based on shell-and-tube type as shown in Figure 1.2. The shell and tube design is greatly considered to have impact on the heat transfer performance, some key parameters are identified the number and size of baffles, number and size of internal tubes. In addition, material selection for the solid shell-and-tube heat exchanger will also have impact on the effectiveness and productivity performance. The construction for heat exchanger prototype for this kind is expensive in cost and time consuming. Therefore, a systematical approach using state-of-the-art computational fluid dynamics (CFD) method is proposed to study qualitatively and quantitatively the performance of the design.

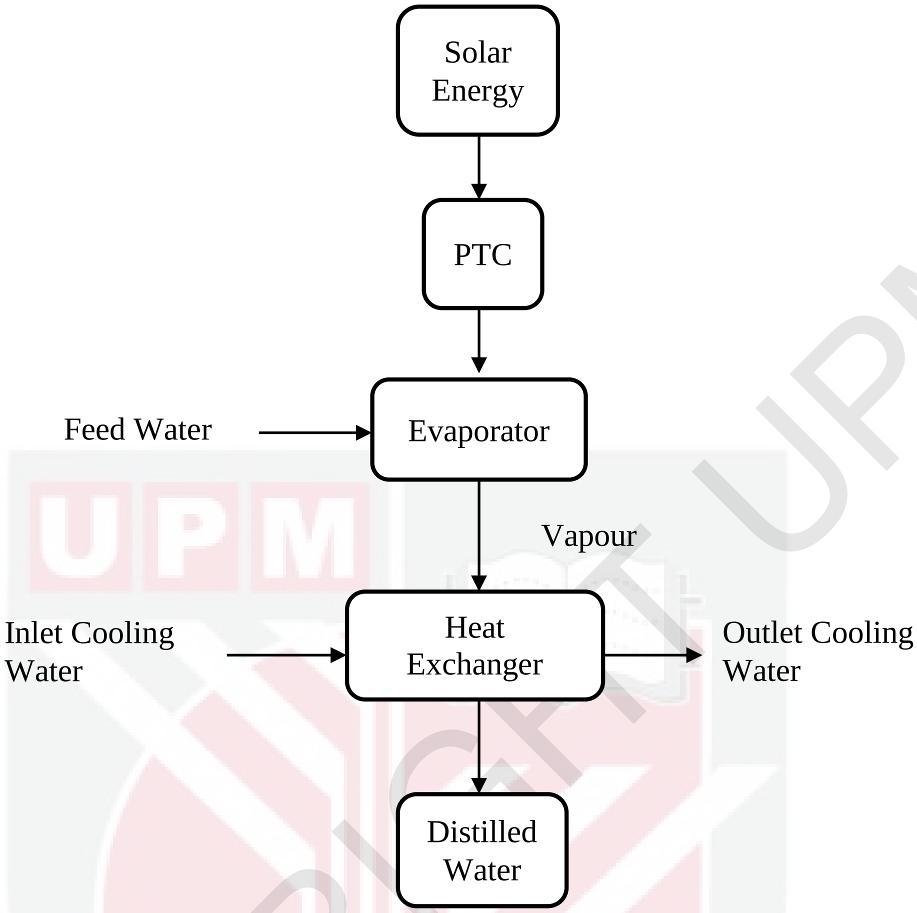

Figure 1.1: Solar powered water distiller system

The simulation results provide further insight into the significance of these design parameters to the overall efficiency of heat transfer performance. The numerical approach can also analyze in details of the fluid flow field, which is difficult to be measured or visualized from experimental work done to many parameters such as vapor mixture, heat transfer rate and water prediction. Using CFD analysis approach, many present problems encountered in experiments can be overcome without trial and error with expensive physical prototype and with much short turn-around time. Furthermore, the deployment of CFD process established from this current research on heat exchanger design can potentially maximize the productivity and quality of fresh drinking water that one can achieve based on an optimal design identification.

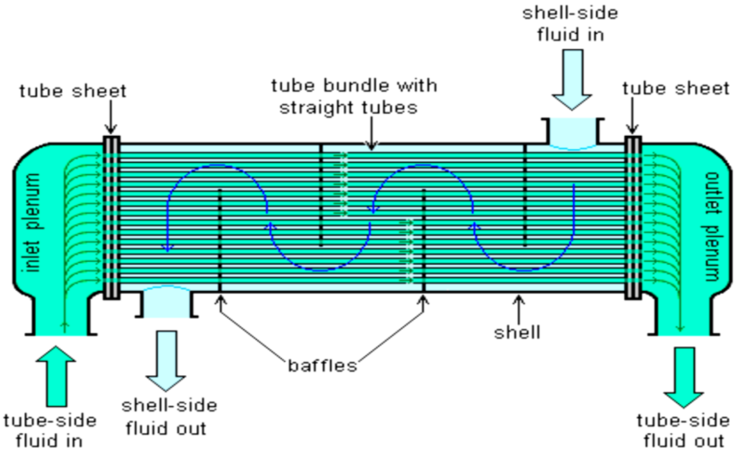

Figure 1.2: Shell-and-tube heat exchanger by Padleckas (2006)

Some literatures including report from Rajappan and Azhaguvelu (2013), stated that to increase the cooling efficiency of normal shell and tube heat exchanger such as parameters of surface temperature, temperature difference, velocity and pressure are crucial. Heat exchanger performance and efficiency are measured through the amount of heat transfer using least area of pressure drop and heat transfer. Overall heat transfer coefficient can be calculated to improve the efficiency of heat exchanger. Power requirement and capital cost of heat exchanger provide the actual area required for this work.

In addition, Stonebraker et al. (2014) have discussed a parabolic solar water distillation system concept performance based on their final assembly set-up. They have identified the key components needed in the design to produce clean drinkable water. Their design consists of 32 degree tilted acrylic film tape trough, absorber tube, sprayed nozzle, distiller with heat exchanger, integrated piping with insulation, Bachmann mini water pump, and distilled water reservoir. Their main objective of this design is to heat water to vaporization. Through their design, condensation rate of 0.5 gph is also measured with optical efficiency at 0.71 and heat radiation of 338.5 W/m^2.

1.2 Problem Statement

At Universiti Putra Malaysia (UPM), Khiabani (2011) has designed a point-focus solar collector for his system. His shell and tube heat exchanger designed to collect heat by absorbing sunlight using point-focus concentrators, (center receiver system). His shell and tube heat exchanger was designed and simulated using an implicit numerical scheme. Simulation result showed that accumulated mass water greatly depended on the inlet vapor temperature and volume, heat exchanger material, coolant water temperature and coolant volume. He reported that these inexpensive shell and tube heat exchanger could produce 10 L/day. If inlet pressure increase, vapor temperature will decline and thereupon, heat exchanger efficiency tangibility will increase. In general, solar powered water distiller is of fixed type.

Also at UPM, Ali Driver (2014) developed a solar powered water distiller using parabolic trough collector (PTC). He developed line focus concentrators PTC and linear fresnel collectors capable of producing 10L/day on a sunny day. Design factors include focus length, size of PTC, length of heat exchanger. Shell and tube heat exchanger is the most suitable type for solar powered distiller system. Design parameter investigated include shell diameter number of internal tube and temperature of water vapor develop as temperature input for heat exchanger. Recently, the project regarding to design heat exchanger solar powered water distiller using shell-and-tube heat exchanger with 10L/day output and in prediction in 15L/day capacity. The purpose of heat exchanger is to liquefy water vapor generated from the PTC and entering at 82°C into the heat exchanger. The inlet fluid temperature of water liquid is 25°C-28°C and outlet temperature is 35°C. However, water vapor entering the heat exchanger is at 80°C and the distillate water is produced at 30°C. The purpose of looking for potential suitable material is to ensure manufacture ability of that material but still produce high volume of clean water by ensuring a proper heat transfer. The water distiller work involves using CFD for design and analysis of shell and tube heat exchanger by changing the materials used for predicting the heat exchanger to find the temperature difference and heat transfer involved to develop an optimum design of heat exchanger by choosing suitable material and design. ANSYS FLUENT 14 is used to simulate and compare the results with different selected material for the temperature difference between inlet and outlet of heat exchanger.

1.3 Objectives

The main objectives of this research are of the following:

- To predict the performance of outlet temperature for vapor side a shell-and-tube heat exchanger for solar powered distiller application.
- To study material selection impact on heat transfer performance of the heat exchanger design.

1.4 Scope and Limitations

This work is based on numerical analysis. The major scope in this project is to find the best suitable material which can be used to manufacture the heat exchanger, the criteria for the best material is to get maximum heat transfer and ability to produce water and also easy to manufacture the heat exchanger using that material. The steps involved in CFD process includes geometry construction, meshing, flow boundary conditions setting, material selection, model simulation, and post-processing. Scope methodology following Haran (2013) as the parameter by experimental and numerical analysis using RNG k-Ɛ in steady state condition and boundary conditions materials is based on Ali Driver (2014) and Khaibani (2011). Limitation of selected materials are stainless steel, copper and aluminum as command fabrication. Discussions of the numerical results will also be included such as validation with experimental data, comparing the heat transfer performance of heat exchanger with different materials that are stainless steel, copper, and aluminum. To get an optimum design a comparative analysis of flow parameters such as fluid flow/solid temperature, pressure and velocity is done. Reynolds number for heat exchanger in laminar around 1866.80, which is the CFD analysis not using transient condition.

The project is limited to the change in the material used for the heat exchanger, no change in velocity, fluid and temperature is done. It is worthwhile to mention that the last activity of prototype built and testing are not required for the current study. This is outside the work scope of the current thesis but it is part of the entire research activity to be considered as complete process.

1.5 Thesis Layout

This thesis is laid out with total 5 chapters based on the following flow format:

It starts with the introduction chapter (Chapter 1) which presents the background of the thesis, and then followed by problem statement, research objectives, work scope and limitations, thesis contribution. Chapter 2 consists of literature review of relevant publications that were reported and studied in the past. These include different solar powered water distiller (background and mechanism), different heat exchanger types and flow arrangements, calculation of overall heat transfer coefficient, selected material properties for heat exchanger calculation using Log Mean Temperature Difference (LMTD) and the Effective-NTU method, satisfactory design, and heat exchanger design considerations.

Chapter 3 documents the methodologies conducted based on the current research. The methodology is broken down in the following different sections: Design methodology based on morphology chart and flow chart, CFD mathematical modeling approach, experiment and simulation validation results, CFD analysis discussion including FLUENT procedure, 3D geometry creation, computational mesh generation, and CFD solution and steps demonstration. Chapter 4 discusses in details of the numerical predictions from current research. This chapter reports the performance of 3 different CFD models comparison, baseline validation against experimental data, and then followed by CFD post-processing technique including contour plots, profile, mass and heat flux, pressure drop and heat transfer. Chapter 5 concludes the findings with remark and suggestion. This chapter also discuss some recommendations for future work.

REFERENCES

Abdelaziz, O., Radermacher, R., "Modeling heat exchangers under consideration of manufacturing tolerances and uncertain flow distribution", International Journal of Refrigeration, 33 (2010) 815-828.

Agra, O., Erdem, H. H., Demir, H., Atayilmaz, S. O., Teke, I., "Heat capability ratio and the best type of heat exchanger for geothermal water providing maximum heat transfer", Energy, 90 (2015) 1563-1568.

Agra, O., "Sizing and selection of heat exchanger at defined saving – investment ratio", Applied Thermal Engineering,31 (2011) 727-734.

Ahsan, A., Imteaz, M., Rahman, A., Yusuf, B., Fukuhara, T., "Design, fabrication and performance analysis of an improved solar still", Desalination 292 (2012) 105-112.

Alfan, N. H. B., "Analysis of characteristic heat pipes as an efficient cooling heat transfer device", Master thesis Universiti Tun Hussein Onn Malaysia, 2013.

Alkan, P. I., "Theoretical and experimental investigations on solar distillation of IYTE Guilbahce Campus area seawater", Master's thesis Izmir Institute of Technology, 2003.

Alkhakani, A. J., Adam, N. M., Hairuddin, A. A., Alsabahi, H. K., "Design and fabrication of a heat exchaner for portable solar water distiller system", The 7th International Conference on Sustainable Agriculter for Food, Energy and Industry in Regional and Global Context, ICSAFEI2015.

Antwi, E., Bensah, E. C., Ahiekpor, J. C., "Use of solar water distiller for treatment of fluoride-contaminated water: The case of Bongo district of Ghana", Desalination 278 (2011) 333-336.

Belytschko, T., Liu, W. K., Moran, B., Elkhodary, K. I., "*Nonlinear Finite Elements For Continua And Structures*", (2013).

Bhardwaj, R., ten Kortenaar, M. V., Mudde, R. F., "Influence of condensation surface on solar distillation", Desalination 326 (2013) 37-45.

Ben Bacha, H., Bouzguenda, M., Abid, M. S., Maalej, A. Y., "Modeling and simulation of a water desalination station with solar multiple condensation evaporation cycle technique", Renewable Energy, 18 (1999) 349-365.

Bouchekima, B., "A solar desalination plant for domestic water needs in arid areas of South Algeria", Desalination 153 (2002) 65-69.

Chen, F., Cai, J., Li, X., Huai, X., Wang, Y., "3D numerical simulation of fluid-solid coupled heat transfer with variable property in a LBE-helium heat exchanger", Nuclear Engineering and Design, 274 (2014) 66-76.

Chernysheva, M. A., Vershinin, S. V., Maydanik, Y. F., "Heat transfer during condensation of moving steam in a narrow channel", International Journal of Heat and Mass Transfer, 52 (2009) 2437-2443.

Clarke, D. D., Vasquez, V. R., Whiting, W. B., Greiner, M., "Sensitivity and uncertainty analysis of heat-exchanger designs to physical properties estimation", Applied Thermal Engineering, 21 (2001) 993-1017.

Corte, J. S., Rebello, J. M. A., Areiza, M. C. L., Tavares, S. S. M., Araujo, M. D., "Failure analysis of AISI 321 tubes of heat exchanger", Engineering Failure Analysis, 56 (2015) 170-176.

Coffrin, S., Frasch, E., Santorella, M., Yanagisawa, M., "Solar powered water distillation device", Second-quarter report, Northeastern University, 2007.

Cui, X., Chua, K. J., Islam, M. R., Yang, W. M., "Fundamental formulation of a modified LMTD method to evaporative heat exchangers", Energy Conversion and Management, 88 (2014) 372-381.

Delyannis, A., Delyannis, E., "Recent solar distillation developments", Desalination, 45 (1983) 361-369.

Disegi, J. A., Eschbach, I., "Stainless steel in bone surgery," Injury 31 (SUPPL. 4), 2000.

Dona, M. H. K., Jalalirad, M. R., "Software Evaluation via a study of deviations in results of manual and computer-based step-wise method calculations for shell and tube heat exchangers", International Journal of Applied Science and Engineering, 12:2 (2014) 117-126.

Elango, C., Gunasekaran, N., Sampathkumar, K., "Thermal models of solar still – A comprehensive review", Renewable and Sustainable Energy Reviews, 47 (2015) 856-911.

El-Sebaii, A., Enein, S. A., Ramadan, M. R. I., Khallaf, A. M., "Thermal performance of an active single basin solar still (ASBS) coupled to shallow solar pond (SSP)", Desalination 280 (2011) 183-190.

Gong, Z. X., Mujumdar, A. S., "Finite-element analysis of cyclic heat transfer in a shell-and-tube latent heat energy storage exchanger", Applied Thermal Engineering, 17:6 (1997) 583-591.

Goldstein, R. J., Eckert, E.R. G., Ibele, W. E., Patankar, S. V., Simon, T. W., Kuehn, T. H., Strykowski, P. J., Tamma, K. K., Heberlein, J. V. R., Davidson, J. H., Bischof, J., Kulacki, F. A., Kortshagen, U., Garrick, S., "Heat transfer – a review of 2001 literature", International Journal of Heat and Mass Transfer, 46 (2003) 1887-1992.

Garnier, C., "Performance measurement and mathematical modeling of integrated solar water heaters", PhD thesis Napier University, 2009.

Goosen, M. F. A., Sablani, S. S., Shayya, W. H., Paton, C., Al-Hinai, H., "Thermodynamics and economic considerations in solar desalination", Desalination, 129 (2000) 63-89.

Garcia-Rodriguez, L., Delgado-Torres, A. M., "Solar-powered Rankine cycles for fresh water production", Desalination, 212 (2007) 319-327.

Gao, B., Bi, Q., Nie, Z., Wu, J., "Experimental study of effects of baffle helix angle on shell-side performance of shell-and-tube heat exchangers with discontinuous helical baffles", Experimental Thermal and Fluid Science, 68 (2015) 48-57.

Hajabdollahi, H., Tahani, M., Shojaee Fard, M. H., "CFD modeling and multi-objective optimization of compact heat exchanger using CAN method", Applied Thermal Engineering, 31 (2001) 2597-2604.

Huang, L., Lee, M. S., Saleh, K., Aute, V., Radermacher, R., "A computational fluid dynamics and effectiveness-NTU based co-simulation approach for flow mal-distribution analysis in microchannel heat exchanger headers", Applied Thermal Engineering, 65 (2014) 447-457.

Hanafi, D., Than, M. N. M., Emhemed, A. A. A., Mulyana, T., Zaid, A. M., Johari, A. H., "Heat exchanger's shell and tube modeling for intelligent control design", International Conference on Communication Software and Networks IEEE, 3 (2011) 37-41.

Hrayshat, E. S., Al-Rawajfeh, A. E., "A solar multiple effect distiller for Jordan", Desalination 220 (2008) 558-565.

Haran, V. H., Reddy, G. R., and Sreehari, B., "Thermal analysis of shell and tube heat exchanger using C and Ansys", International Journal of Computer Trends and Technology, 4:7 (2013) 2340-2345.

Hung, T. C., Chen, H. C., Lee, D. S., Fu, H. H., Chen, Y. T., Yu, G. P., "Optimal design of a concentric heat exchanger for high temperature systems using CFD simulations", Journal of Applied Thermal Engineering 75 (2015) 700-708.

Juarez, R. A., Alvarez, G., Xaman, J., Lopez, I. H., "Numerical study of conjugate heat and mass transfer in a solar still device", Desalination 325 (2013) 84-94.

Jayachandriah, B., and Rajasekhar, K., "Thermal analysis of tubular heat exchanger using ANSYS", International Journal of Engineering Research 3:1 (2014) 21-25.

Kaushal, A., Varun, X., "Solar stills, A review", Renewable and Sustainable Energy Reviews, 14 (2010) 446-453.

K-Aliabadi, M., Tavasoli, M., Hormozi, F., "Comparative analysis on thermal-hydraulic performance of curved tubes: Different geometrical parameters and working fluids" Energy, 91 (2015) 588-600.

Khosravi, R., Khosravi, A., Nahavandi, S., Hajabdollahi, H., "Effectiveness of evolutionary algorithms for optimization of heat exchangers", Energy Conversion and Management 89 (2015) 281-288.

Kakac, S., et al., "*Heat Exchanger : Selection, Rating and Thermal Design*." 2012.

Krey, J., "Dampf-Flüssigkeits Gleichgewichte von Säuregemischen", VDI Verlag Nr.372. Dissertation RWTH Aachen 1994.

Klein, U., Zunkel, A., Eberle, A., "Breakdown of heat exchangers due to erosion corrosion and fretting caused by inappropriate operating conditions", Engineering Failure Analysis, 43 (2014) 271-280.

Kim, T., and Seo, T., "Numerical analysis of an ethanol-water distillation system using computational fluid dynamics (CFD)", International Journal of Mechanical & Mechatronics Engineering, 14:4 (2014) 1-6.

Kulkarni, S. Y., Jagadish, S. B., Manjunath, M. B., "Analysis comparing performance of a conventional shell and tube heat exchanger using Kern, Bell and Bell Delaware method", International Journal of Research, 3:3 (2014) 486-496.

Komilov, A., "A solar desalination plant containing separate chambers for evaporation and condensation with air heating after the condenser. Part 1: calculating distiller capacity", Journal of Applied Solar Energy, 50:1 (2014) 16-18.

Kalidasa Murugavel, K., Anburaj, P., Hanson, R. S., Elango, T., "Progress in inclined type solar stills", Renewable and Sustainable Energy Reviews, 20 (2013) 364-377.

Llopis, R., Cabello, R., Torrella, E., "A dynamic model of a shell-and-tube condenser operating in a vapour compression refrigeration plant", International Journal of Thermal Science, 47 (2008) 926-934.

Li, Q., Flamant, G., Yuan, X., Neveu, P., Luo, L., "Compact heat exchangers: A review and future applications for a new generation of high temperature solar receivers", Renewable and Sustainable Energy Reviews, 15 (2011) 4855-4875.

Lele, A. F., Ronnebeck, T., Rohde, C., Schmidt, T., Kuznik, F., Ruck, W. K. L., "Modeling of heat exchangers based on thermochemical material for solar heat storage systems", Energy Procedia, 61 (2014) 2809-2813.

Lopata, S., Oclon, P., "Modeling and optimizing operating conditions of heat exchanger with finned elliptical tubes", Fluid Dynamics, Computational Modeling and Applications, 2012. 327-356p.

Islam, K. M. S., and Fukuhara, T., "Production analysis of tubular solar still", Doboku Gakkai Ronbunshuu B, 63:2 (2007) 108-119.

Madhlopa, A., "Development of an advanced passive solar still with separate condenser", PhD thesis University of Strathclyde Glasgow 2009.

Mahkamov, K., and Akhatov, J. S., "Experimental study of the performance of multieffect solar thermal water desalination system", Journal of Applied Solar Energy, 44:1 (2008) 31-34.

Mroue, H., Ramos, J. B., Wrobel, L. C., Jouhara, H., "Experimental and numerical investigation of an air-to-water heat pipe-based heat exchanger", Journal of Applied Thermal Engineering, 78 (2015) 339-350.

Maalem, M. S., Benzaoui, A., Bouhenna, A., "Modeling of simultaneous transfers of heat and mass in a trapezoidal solar distiller", Desalination 344 (2014) 371-382.

Milman, O. O., Spalding, D. B., Fedorov, V. A., "Steam condensation in parallel channels with nonuniform heat removal in different zones of heat exchanger surface", International Journal of Heat and Mass Transfer 55 (2012) 6054-6059.

Medjaher, K., Samantaray, A. K., Bouamama, B. O., "Bond graph model of a vertical U-tube steam condenser coupled with a heat exchanger", Simulation Modeling Practice and Theory 17 (2009) 228-239.

Madhuri, Tiwari, G. N., "Performance of solar still with intermittent flow of waste hot water in the basin", Desalination, 52 (1985) 345-357.

Miller, J. E., 2003. "Review of Water Resources and Desalination Techniques. , pp.1 – 54. Available at http://prod.sandia.gov/techlib/access-control.cgi/2003/030800.pdf

Morcos, V. H., "Performance of shell-and-dimpled-tube heat exchangers for waste heat recovery", Heat Recovery Systems & CHP, 8:4 (1988) 299-308.

Ozden, E., Tari, I., "Shell side CFD analysis of a small shell-and-tube heat exchanger", Energy Conversion and Management 51 (2010) 1004-1014.

Padleckas, H., " *Wikipedia*," https://commons.wikimedia.org/wiki/File:Straight-tube_heat_exchanger_1-pass.PNG 2006, 21-04-2014.

Park, H., "A microchannel heat exchanger design for microelectronics cooling correlating the heat transfer rate in terms of Brinkman number", Microsyst Technol, 15 (2009) 1373-1378.

Ponce-Ortega, J. M., Serna-Gonzalez, M., Jimenez-Gutierrez, A., "Design and optimization of multipass heat exchangers", Chemical Engineering and Processing 47 (2008) 906-913.

Qunhui, L., Yangyan, Z., Biao, Y., "Numerical simulation study on the heat transfer characteristics of a double pipe heat exchanger", Power Engineering and Automation Conference IEEE, 1 (2011) 135-137.

Reif, J. H., Alhalabi, W., "Solar-thermal powered desalination: Its significant challenges and potential", Renewable and Sustainable Energy Reviews, 48 (2015) 152-165.

Roll, A. K. S., "Shell and tube heat exchanger design using CFD tools", B. Tech Thesis National Institute of Technology Rourkela, No-109CH0458, 2008.

Rahbar, N., Esfahani, J. A., Bafghi, E. F.,"Estimation of convective heat transfer coefficient and water-productivity in a tubular solar still – CFD simulation and theoretical analysis", Solar Energy 113 (2015) 313-323.

Rajappan, R., and Azhaguvelu, R., "Design and analysis of cross flow heat exchanger by using CFD", Proceedings of the National Conference on Emerging Trends in Mechanical Engineering 2013.

Rajaseenivasan, T., Kalidasa Murugavel, J., Elango, T., Hansen, R. S., "A review of different methods to enhance the productivity of the multi-effect solar still", Renewable and Sustainable Energy Reviews, 17 (2013) 248-259.

Ravagnani, M. A. S. S., Caballero, J. A., "A minlp model for the rigorous design of shell and tube heat exchangers using the TEMA standards", Chemical Engineering, 85 (2010) 1423-1435.

Saeedan, M., Bahiraei, M., "Effects of geometrical parameters on hydrothermal characteristics of shell-and-tube heat exchanger with helical baffles: numerical investigation, modeling and optimization", Chemical Engineering Research and Design, 96 (2015) 43-53.

Shah, R. K., Thonon, B., Benforado, D. M., "Opportunities for heat exchanger applications in environmental systems", Applied Thermal Engineering, 20 (2000) 631-650.

Sahin, H. M., Baysal, E., Dal, A. R., Sahin, N., "Investigation of heat transfer enhancement in a new type heat exchanger using solar parabolic trough systems", International Journal of Hydrogen Energy, 40 (2015) 15255-15266.

Skorupskaite, V., Tadjine, H. H., Harneit, S., Reuter, M., "Combined simulation of sun radiation and evaporation in solar seawater desalination", International Conference on Information & Communication Technologies IEEE, 2:1 (2006) 173-176.

Saettone, E., "Desalination using a parabolic-trough concentrator", Journal of Applied Solar Energy, 48:4 (2012) 254-259.

Schewarzer, K., Vieira da Silva, E., Hoffschmidt, B., Schwarzer, T., “A new solar desalination system with heat recovery for decentralized drinking water production”, Desalination 248 (2009) 204-211.

Santons, N. I., “Modeling passive solar distillation production in Las Vegas, Nevada”, Bachelor thesis University of Nevada Las Vegas, 2011.

Stonebraker, A., Newmeyer, J., Branner, M., “Parabolic solar water distillation”, Interim Report, San Diego State University, 2014.

Shabgard, H., Allen, M. J., Sharifi, N., Benn, S. P., Faghri, A., Bergman, T. L., “Heat pipe heat exchangers and heat sinks: Opportunities, challenges, applications, analysis, and state of the art”, International Journal of Heat and Mass Transfer, 89 (2015) 138-158.

Tan, F.L., Fok, S.C., “An Educational Computer-aided Tool for Heat Exchanger Design”, Computer Applications in Engineering Education, 14:2 (2006) 77-89.

Tiwari, G. N., Saxena, P., Thakur, K., “Thermal analysis of active solar distillation system”, Energy Conversion Management, 35:1 (1994) 51-59.

Tay, N. H. S., Belusko, M., Bruno, F., “An effectiveness-NTU technique for characterising tube-in-tank phase change thermal energy storage systems”, Applied Energy, 91 (2012) 309-319.

VDI-Wärmeatlas., “Berechnungsblätter für den Wärmeübergang”, 8 Auflage. Springer-Verlag Berlin 1997.

Vera-Garcia, F., Garcia-Cascales, J. R., Gonzalvez-Macia, J., Cabello, R., Llopis, R., Sanchez, D., Torrella, E., “A simplified model for shell-and-tubes heat exchangers: Practical application”, Applied Thermal Engineering, 30 (2010) 1231-1241.

Vengateson, U., “Design of multiple shell and tube heat exchangers in series: E shell and F shell”, Chemical Engineering Research and Design, 88 (2010) 725-736.

Wylen, V., Sonntag, “Fundamentals of classical thermodynamics”, 3rd edition, John Wiley and Sons, 1986.

Wee, L. S., “CFD simulation using Fluent to determine the heat transfer coefficient of a packed bed system”, Bachelor thesis University Malaysia Pahang, 2012.

Wang, S., Wang, Z., Shang, H., “Numerical simulation of ammonia phase change heat exchanger which used for composite air-cooling circulatory system”, Energy Procedia 17 (2012) 1086-1091.

Wenjing, D., Hongfu, W., and Lin, C., “Effects of shape and quantity of helical baffle on the shell-side heat transfer and flow performance of heat exchangers”, Chinese Journal of Chemical Engineering, 22:3 (2014) 243-251.

Yang, J. F., Zeng, M., Wang, Q.W., "Numerical investigation on combined single shell-pass shell-and-tube heat exchanger with two-layer continuous helical baffles", International Journal of Heat and Mass Transfer 84 (2015) 103-113.

Yang, J., Ma, L., Bock, J., Jacobi, A. M., Liu, W., "A comparison of four numerical modeling approaches for enhanced shell-and-tube heat exchangers with experimental validation", Journal of Applied Thermal Engineering, 65 (2014) 369-383.

Yang, R., Chiang, F. P., "An experimental study of heat transfer in curved pipe with periodically varying curvature for application in solar collectors and heat exchangers", American Institute of Aeronautics and Astronautics, 7 (2000) 154-162.

Yang, X., Yu, H., Wang, R., Fane, A. G., "Optimization of microstructured hollow fiber design for membrane distillation applications using CFD modeling", Journal of Membrane Science, 421:422 (2012) 258-270.

Yang, S. R., Wang, J. M., Zai, G. D., Kim, R. H., "Investigation of a heat transfer augmenter as a fouling cleaner and its optimum geometry in the tube side of a condenser", Experimental Thermal and Fluid Science, 5 (1992) 795-802.

Yang, J., Fan, A., Liu, W., Jacobi, A. M., "Optimization of shell-and-tube heat exchangers conforming to TEMA standards with designs motivated by constructal theory", Energy Conversion and Management, 78 (2014) 468-476.

Yilmazoglu, M. Z., "Effects of the selection of heat transfer fluid and condenser type on the performance of a solar thermal power plant with technoeconomic approach", Energy Conversion and Management 111 (2016) 271-278.

Yew, B. C. C., "Solar-still water production under Malaysian conditions", Bachelor Thesis Universiti Technologi PETRONAS, 2013.

Zerrouki, M., Settou, N., Marif, Y., Belhadj, M. M., "Simulation study of a capillary film solar still coupled with a conventional solar still in south Algeria", Energy Conversion and Management 85 (2014) 112-119.

Zargistalukder, M. D., Foisal, A., Siddique, A., Rafiqulalambeg, M., "Design and performance evaluation of solar water distillation plant", Global Journal of Research in Engineering General Engineering, 13:1 (2013) 7-12.

Zhang, X., Lu, K., Li, X., Xiong, X., "Research on the modeling and simulation of shell ad tube heat exchanger system based on MPCE", International Conference on Intelligent Human-Machine Systems and Cybernetics, 2012.

Zari, H., "Simulation of heat and mass transfer in suns river solar distillation", Master's thesis University of Texas El Paso, 2014.

Zilan, R., "Optimization of the geometry and material of solar water heaters", Master thesis The Middle East Technical University, 2001.

LIST OF PUBLICATIONS

T.M.F.T. Ibrahim, N.M. Adam and C.N. Jaafar, "Parametric Study of Portable Solar-Powered Heat Exchanger Using Computational Fluid Dynamics" Applied Thermal Engineering, EVISE, 03 February 2017 [Submitted]

Nor Mariah Adam, Mohd Zainal Abidin Abdul Kadir, Tengku Muhammad Fahmi Tengku Ibrahim “A Solar Powered Water Distiller” Intellectual Property Corporation of Malaysia, UI 2015704631, UPM, 13 April 2016

A.R. Zahari, S.Z.M. Daud, N.A. Zakaria, T.M.F.T. Ibrahim and C. Gomes “Potential of Wind Energy in Empowering Small Islands” Energy for Sustainable Development, Elsevier, 18 July 2016 [Submitted]

Mohd Tarmizi Mat Asim, Tengku Muhammad Fahmi Tengku Ibrahim, Nor Mariah Adam, Siti Ujila Masuri, “Strategic Energy Management Plan and MS ISO 50001:2011 Compliance” Mechanical Engineering & Science Postgraduate International Conference, UiTM, 10 July 2016 [Accepted]

T.M.F.T. Ibrahim, N.M. Adam and C.N. Jaafar, "Design of Heat Exchanger for Portable Solar Powered Water Distiller Using Computational Fluid Dynamics" Renewable Energy, Elsevier, 23 March 2016 [Submitted]

T.M.F.T. Ibrahim, N.M. Adam and C.N. Jaafar, "Determination of Maximum Temperature and Its Duration for Maximum Output Temperature of Solar Heat Exchanger" Postgraduate Research Colloquium in Mechanical and Manufacturing Engineering Semester 1 2015/2016, UPM, 29 December 2015

Ali Jaber, Tengku Muhammad Fahmi, Hanaa Kadhim, Nur Nasimah “Effect of Travel Distance between Farthest Point and Nearest Assembly Point on People Evacuation in Three Level Building” Proceeding Fire Safety Engineering and Regulations, UPM, 7 June 2015

Hanaa Kadhim, Ali Jaber, Tengku Muhammad Fahmi, “Current and Future Energy Storage Technologies” Proceeding Management Technology, UPM, 4 June 2015