THE EFFECT OF OUTER SURFACE ROUGHNESS FOR EVAPORATOR TUBE IN THE DESALINATION PLANT

LIM CHIH HOO

UNIVERSITI TEKNOLOGI MALAYSIA

THE EFFECT OF OUTER SURFACE ROUGHNESS FOR EVAPORATOR TUBE IN THE DESALINATION PLANT

LIM CHIH HOO

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master Engineering (Mechanical)

Faculty of Mechanical Engineering
Universiti Teknologi Malaysia

JANUARY 2015

To my precious Lord Jesus, family and friends.

ACKNOWLEDGEMENTS

Above all, I thank God for His grace and strength given me so that this research could be made possible. Without His compassion and grace, it was not possible would I be able to complete my master project.

Secondly, I must extend my thankfulness to my research supervisor, Dato' Prof. Ir. Dr. Alias Mohd Noor, for his great understanding, encouragement and trust in me throughout the entire research. I am grateful for his constructive comments and careful review of all the reports.

I also wish to thank the following technicians, Mr. Hanafi and Mr. Rosli from Thermodynamic Lab who had given their time and help in performing the tests. To my parents, thank you very much for your continuous support, supplication and loving thoughts.

Finally, to all my brothers and sisters from Hope Church Johor Bahru, thank you for your love, acceptance and forgiveness. These are the important elements which sustain me along the process. Thank you.

ABSTRACT

The purpose of this study is to investigate the evaporator tube performance with different outer surface roughness and under different feeder water load. A test rig with horizontal aluminum evaporator tube had been designed and fabricated to collect the steam from boiler and converted it into condensate. The study was carried out on two aluminum evaporator tubes with different outer surface roughness and under five different feeder water loads. The performance of each evaporator tube was based on the collected amount of condensate. A theoretical relationship was modified from previous study which derived based on the film wise condensation Nusselt's equation, heat transfer equation and falling film equation. Theoretical calculation was conducted with Maple software and the outcomes were compared with the experimental results. Results showed that the mass flow rate of the condensate increases as the feeder water load increases for both the tube. The evaporator tube with higher outer surface roughness showed better performance compared with the one with lower outer surface roughness. Also, the modified theoretical relationship showed higher accuracy compared to the previous study. Based on the results, the evaporator tube outer surface roughness plays an important role in the evaporator tube performance.

ABSTRAK

Tujuan penyelidikan ini adalah untuk mengkaji prestasi tiub penyejat dengan kekasaran permukaan luar yang berbeza di bawah beban penyejuk yang berbeza. Ikatan ujian dengan tiub aluminium penyejat telah direka dan dibentuk untuk mengumpul wap dari dandang dan ditukar kepada kondensat. Kajian ini telah dijalankan ke atas dua tiub aluminium penyejat yang mempunyai kekasaran permukaan luar yang berbeza dan dengan lima beban penyejuk yang berbeza. Prestasi setiap tiub penyejat adalah berdasarkan kepada jumlah kondensat yang dikumpul. Dalam kajian ini, satu hubungan teori daripada kajian sebelumnya yang diperolehi berdasarkan persamaan filem pemeluwapan Nusselt, persamaan pemindahan haba dan persamaan filem jatuhtelah diubahsuai. Persamaan ini diselesaikan dengan menggunakan perisian Maple. Selepas itu, keputusan teori telah dibandingkan dengan keputusan ujikaji. Daripada keputusan ujikaji, kadar aliran kondensat bagi kedua-dua jenis tiub meningkat apabila beban penyejuk dinaikkan. Tiub penyejat dengan kekasaran permukaan luar yang lebih tinggi menunjukkan prestasi yang lebih baik berbanding dengan permukaan luar tiub yang mempunyai kekasaran yang lebih rendah. Selain itu, persamaan telah berjaya diubahsuaikan dan memberikan keputusan dengan ketepatan yang lebih baik berbanding dengan persamaan yang sebelumnya. Berdasarkan kepada keputusan yang didapati, kekasaran permukaan luar bagi tiub penyejat memainkan peranan yang penting dalam prestasi tiub penyejat.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

Symbols

C_p	-	Specific heat at constant pressure
d	-	Diameter
g	-	Gravity
h	-	Heat transfer coefficient
H	-	Latent heat capacity
k	-	Thermal conductivity
L	-	Heat transfer surface length on evaporator tube
Q	-	Rate of heat transfer
r	-	Radius
T	-	Temperature
v	-	Velocity
Ra	-	Surface Roughness
Re	-	Reynolds number
$\dot{m}$	-	Mass flow rate
LPM	-	Litre per minute
R.H.S	-	Right hand side equation

Greek Symbols

β	-	The fraction of summation of inlet and outlet water temperature
Γ	-	Mass flow rate per unit length
δ	-	Thickness
μ	-	Dynamic viscosity
ρ	-	Density

Subscript

ave	-	Average
cond	-	Condensate
f	-	Falling film
fg	-	Vaporization
g	-	Saturated vapour
i	-	Inlet
if	-	Inlet Feeder water
l	-	Liquid
m	-	Overall
o	-	Outer
of	-	Outlet Feeder water
s	-	Steam (using liquid state properties.)
si	-	Steam in
so	-	Steam out
w	-	Wall

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

In marine transportation, a large amount of fresh water is consumed for a single trip. Each crew consumes on average about 70 litres per day and in one of the passenger ships, consumption hasbeen reported to reach up to 225 litres per day for each capital. The fresh water is not only for drinking but also for daily use such asshowering and cleaning. (Smith 1983)

According to Smith (1983), the ship did not take all the amount of fresh water which was needed along the trip as a large water tank will surely occupy a big portion of space in the ship. Therefore, it is common practice for the ship to take only a minimal supply of fresh water while the rest is supplied by the desalination plant on the ship.

In a desalination plant, evaporators are the most important part in the whole plant due to condensation that is taking place there. Condensation will occur when the vapour temperature is reduced below its saturation temperature as mentioned byCengel(2006). According to the paper regarding condensation inside the tube by Noor (1980),the same process occurred inside the evaporators when the vapourscome into contacted with the surface of the evaporators where the temperature was lower than the vapour saturation temperature. During this process, the heat energy from the vapours inside the evaporator is transferred through the evaporator wall to the seawater feedas shown in Figure 1.1.

Theoretically, the higher the thermal conductivity of the evaporator, the better the heat transfer for the vapours inside the evaporator which will improve condensation. Hence, an experimental study of the thermal conductivity effect on the desalination plant performance will be done by determining the relationship between the thermal conductivity of the evaporator to the vapour condensation rate. This information will provide a good reference in choosing the most cost effective material for the evaporators.

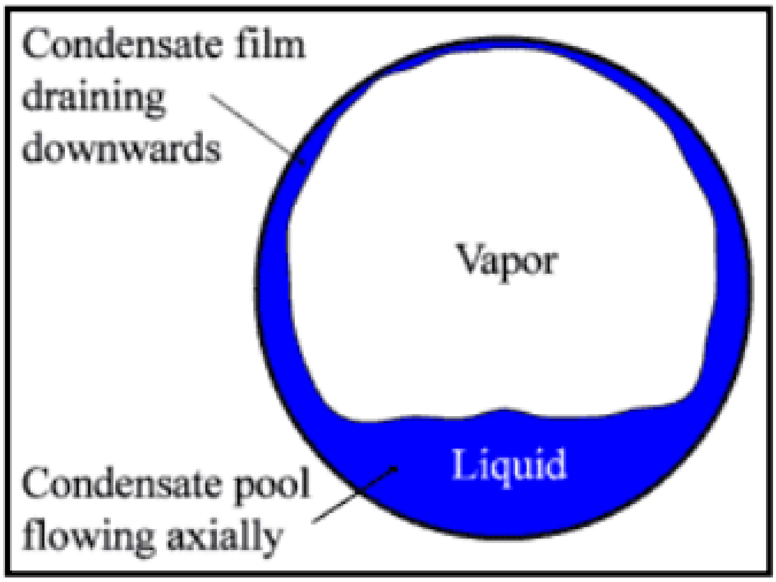

Figure 1.1 Condensation inside evaporatortube. (Wolverine Tube Inc, 2006)

1.2 Background of the Problem

A study had been done by Noor (1980) to investigate the performance of brass-aluminium evaporator with various feeder loads and feeder temperature. In the study, a theoretical equation had been derived to predict the condensate flow rate under different feeder loads. The fraction of summation of inlet and outlet water temperature β was found to play an importance role in theoretical results calculation and the results were more accurate when β was within the range of 0.5 and 0.7.

However, a very important factor namely outer surface roughness of the evaporator tube was not taken consideration in previous work. Therefore, this project was carried out in order to improve the outcomes from the previous work by taking tis factor as a parameter. Also, an aluminium evaporator tube is selected for this projectinstead of brass-aluminium evaporator tube which has better conductivity.

As the result, a more accurate equation was derived from the previous work and the effect of outer surface roughness to the evaporator performance had been investigated.

1.3 Objective of the Study

This study embarks on the following objectives:

1) To study the effect of feeder load and outer surface roughness on the performance of an aluminium evaporator.

2) To improve previous equation to obtain more accurate theoretical results.

1.4 Scope of Study

A study will be carried out to find out the evaporator tube's outer surface roughness effect on the performance of the desalination process only. The selected material for this study is aluminium. The performance of the system willbe evaluated based on the volume of condensate produced per minute.

1.5 Significance of Study

The study on the effect of outer surface roughness on evaporator performance enables the engineers to design more cost effective evaporator system. Besides that, the modified equation will also help to predict the amount of condensate produced more accurately.

REFERENCES

Cengel, YA (2006). *Heat and Mass Transfer*.(3th ed.) New York.:McGraw-Hill.

Clayton (2009).*Instruction Manual Steam Generator*.In Clayton (Ed.). *Maintenance and Operation Instructions Clayton Steam Generator EO-20-3* (pp. 1-62). Bornem: Clayton.

Gala,T, Kalendar,A, Al-Saftawi,A &Zedan, M (2010). Heat Transfer Performance of Condenser Tube in an MSF Desalination System.*Journal of Mechanical Science and Technology*. 24, 2347-2355.

Garimella, SV, John, P & Hale(2010). Bubble Nucleation Characteristics in Pool Boiling of a Wetting Liquid on Smooth and Rough Surfaces.*International Journal of Multiphase Flow*. 36, 249-260.

Hoboken & Wiley,NJJ (2004)*Water Desalting Planning Guide for Water Utilities*. American Water Works Association: Water Desalting Committee.

Hoyt, CH, James, JM, Adel, FS, Geoffrey, DS, Phillip, CW & Kent, SK (2008).*Heat and Mess Transfer*. In Perry, RH& Green, DW (Ed.).*Perry's Chemical Engineers' Handbook*(8thed) (pp. 5-11 – 5-13). New York: McGraw-Hill.

Kim,HY & Kang,BH(2003). Effect of Hydrophilic Surface Treatment on Evaporation Heat Transfer at the Outside Wall of Horizontal Tubes.*Applied ThermalEngineering*. 23, 449-458.

Leroy, SF &Sernas, V (1974). Evaporation from Thin Water Film on Horizontal Tubes. *Ing. Eng. Chem., Process Des. Develop*. 13: No 3.

Liu, ZH &Yi, J (2002).Falling Film Evaporation Heat Transfer of Water/Salt Mixture from Roll-worked Enhances Tubes and Tube Bundle.*Applied Thermal Engineering*. 22, 83-95.

Ming, J, Wu, X, Shen, L&Gao, F (2011).Hydrophilic Treatment and Performance Evaluation ofCopper Finned Tube Evaporators.*Applied Thermal Engineering*. 31, 2936-2942.

Mohamed, AMI(2010). Experimental Study of Heat Transfer and Flow Characteristics of Liquid Falling Film on a Horizontal Fluted Tube. *Heat Mess Transfer*. 46, 841-849.

Noor,AM (1980). *Condensation Inside Tube.*Degree thesis, University of Glasgow, Glasgow.

Prasanta(2004). *Performance of MED Evaporators with Different Tube Profiles and Material.* Master thesis, National University of Singapore, Singapore.

Putilin, JV,Podberezny, VL&Rifert, VG (1996). Evaporation Heat Transfer in Liquid Films Flowing down Horizontal Smooth and Longitudinally Profiled Tubes.*Desalination*. 105, 165-170.

Ribatski, G & Jacobi, AM (2005). Falling Film Evaporation on Horizontal Tubes---a Critical Review. *International Journal of Refrigeration*. 28, 635-653.

Rifert, VG, Podberezny, VI, Putilin, JV, Nikitin, JG&Barabash, PA (1989). Heat Transfer in Thin Film-typeEvaporator with Profiled Tubes.*Desalination*. 74, 363-372.

Roques,JF, Dupont, V&Thome, JR (2002). Falling Film Transition on Plain and Enhanced Tubes.*Journal of Heat Transfer*. 124, 491-499.

Smith (1983).*Marine Auxiliary Machinery*.London: Butterworth.

Wang,J& Catton,I (2001). Enhanced Evaporation Heat Transfer in Triangular Grooves Covered with a Thin Fine Porous Layer.*Applied Thermal Engineering*. 21, 1721-1737.

Wolverine Tube Inc(2006).*Chapter 8: Condensation inside Tube*.In Wolverine Tube Inc (Ed.).*Engineering Data Book III*(pp. 8-2).Decatur: W.T.I.

Xu, L, Ge, M,Wang, S &Wang, Y(2004a).Heat Transfer Film Coefficients of Falling Film Horizontal Tube Evaporation.*Desalination*. 166,223-230.

Xu, L, Wang, SY,Wang, S& Wang, Y(2004b). Study on Heat Transfer Film Coefficient inside a Horizontal Tube in Falling Film Evaporators.*Desalination*. 166, 215-222.

Yang,L & Shen, S(2008). Experimental Study of Falling Film Evaporation Heat Transfer outside Horizontal Tubes. *Desalination*. 220,654-660.