Republic of Iraq
Ministry of Higher Education
& scientific research
University of Technology
Mechanical Engineering Department

Investigation of Heat Transfer by Condensation on Three Dimensional Pinned Tubes

A thesis
Submitted to the Department of Mechanical Engineering of the University of Technology in a partial fulfillment of the requirements for the Degree of Master of Science in Mechanical Engineering

By

Bashar Ali Afan

B.SC. (Mechanical Engineering)

Supervised by:

Dr. Abdulhassan A. Karamallah

(Professor)

October 2013

1434 A.H. 2013 A.D.

بسم الله الرحمن الرحيم

شَهِدَ اللّهُ أنَهُ لآ اَلهَ الاَّ هُو و الملائكةُ وأولوا العِلمِ قائما بالقسطِ لآ الهَ إلا هُو العزيزُ الحكيمُ

صدق الله العظيم

سورة ال عمران (الاية ١٨)

Supervisor's Certification

I hereby certify that this thesis entitled ***"Investigation of Heat Transfer by Condensation on Three Dimensional Pinned Tubes"*** was prepared by engineer **[Bashar Ali Afan]** under my supervision at the University of Technology, Mechanical Engineering Department, in partial fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering.

Signature:

Prof. Dr. Abdulhassan A. Karamallah

Mechanical Eng. Dept.

University of Technology

/ 10/ 2013

Dedication

To the prophet Mohammed (peace upon him)

To my dear Parents,

The widest heart which never asks but always gives.

To my Dear Brothers and sisters

With love and respect.

To every one I had learned from him in my life.

I dedicate this modest effort.

Bashar

2013

Acknowledgements

Praise be to Allah for the mercy, blessing and assistance during the preparation of this work.

I would like to express my deep thanks to my supervisor; **Prof. Dr. Abdulhassan A. Karamallah** for his support throughout the research period and assistance in conducting this work.

I would like also to submit my thanks to all staff members of the Mechanical Engineering Department and Central Library at the University of Technology for their cooperation.

Last but not least, I submit my thanks to my family and every one helped me in one way or another in the preparation of this thesis.

Bashar

2013

Linguistic Certification

I certify that this thesis entitled **(*Investigation of Heat Transfer by Condensation on Three Dimensional Pinned Tubes*)** was prepared by **(Bashar Ali Afan)** under my linguistic supervision. It was amended to meet the style of English language.

Signature:
Name: Dr. Arkan kh. Husain AL –Taie
Title: Professor
Date: / 10 / 2013

Examination Committee Certification

We, the examining committee, certify that we have read this thesis entitled **"Investigation of Heat Transfer by Condensation on Three Dimensional Pinned Tubes"** and examined the student **" Bashar Ali Afan "** in its contents and in what is related to it. In our opinion, it meets the standard of a thesis for the degree of Master of Science in Mechanical Engineering.

Signature:
Prof. Dr. Abdul-Hassan A. Karamallah
(Supervisor)
Date: / 3 /2014

Signature:
Asst. Prof. Dr. Ahmed Q. Mohammed
(Member)
Date: / 3 /2014

Signature:
Asst. Prof. Dr. Abdul-Satar J. Mohammed
(Member)
Date: / 3 /2014

Signature:
Asst. Prof. Dr. Waheed S. Mohammed
(Chairman)
Date: / 3 /2014

Approved by mechanical Engineering Department

Signature:
Prof. Dr. Jaafar M. Hassan
Head of Department
Date: / 3 /2014

Abstract

This work presents an experimental and a theoretical treatment of heat transfer by condensation of pin tubes. Four test tubes are manufactured from aluminum and copper materials with different pins spacing and pin heights. The fifth test tube is fin tube while the sixth test tube is smooth tube, the fifth and sixth test tube are tested for comparison purposes. The inner and outer diameter of each tube are (12 and 15) mm respectively.

The test rig composed of test section with all required accessories for testing each tube, cylindrical boiler for generating steam to the test section, shell and tube condenser and water tank. All parts are manufactured from carbon steel material except the steam boiler and the shell and tubes of the condenser manufactured from stainless steel material and these parts provided with necessary measuring devices. The flow rate of the cooling water supply to test tubes are (1.4, 3.5 and 7) l/min and the inlet temperatures of the cooling water are (23, 25, 30, 35 and 40) ℃ with (2250 and 3000)W boiler power used for each test.

The experiments are carried out under atmospheric conditions and some cases under vacuum. The experimental results showed that the enhancement ratio for pinned tube are higher by (2 - 2.5) times the smooth tube and (1.5 - 1.8) times the smooth tube when using fin tube. The vacuum operating conditions gave enhancement in heat transfer rate by (30) % more than atmospheric operating conditions. The present study has been treated theoretically by solving the available theoretical equations in literature which included the main parameters of heat transfer in pinned tubes. The theoretical results are compared with experimental results and an acceptable agreement is obtained.

Contents

Supervisors Certification		I
Acknowledgements		III
Linguistic Certification		IV
Abstract		VI
Contents		VII
List of Figures		X
List of Tables		XVI
Nomenclature		XVIII
Chapter One Introduction		
1.1	Heat Transfer Enhancement	1
1.2	Classification of Enhancement Techniques	1
1.3	Condensation and Modes of Condensation	3
1.4	Heat Transfer Enhancement by Enhanced Tubes	6
1.5	Advantage of Enhancement Technique by pinned tubes	7
1.6	Objectives of the Present Work	8
Chapter Two Literature Survey		
2.1	Introduction	9
2.2	Experimental Studies into Condensation Heat-Transfer on Enhanced Tubes	10
2.2.1	Tubes with Two Dimensional Fins	10
2.2.2	Tubes with Three Dimensional Pin Fins	14
2.3	Summary	21
Chapter Three Experimental work and Procedure		
3.1	Introduction	28
3.2	The Components of Experimental Test Rig	29
3.3	Description of the Main Parts	31
3.3.1	The Boiler	31
3.3.2	Test Section	33
3.3.2.1	Fixation the Parts of the Test Section and Test Section Body	37
3.3.2.2	Mounting and Removing the Test Tubes	38
3.3.3	Test Tubes	40
3.3.4	Steam Condenser	48
3.3.5	Water Supply Tank	51

3.4	Secondary Parts of the Experimental Test Rig	52
3.5.1	Thermocouples	55
3.5.2	Pressure Gauges	59
3.5.3	Flow Meter	59
3.6	Calibration Procedure	60
3.7	Experimental Test Procedure	60
3.8	Experimental Calculations	63
	Chapter Four ***The Theoretical Work***	
4.1	Introduction	67
4.2	Assumptions for the Theoretical Procedure	67
4.3	Semi-Empirical Expression for Condensation Retention Angle on Pin-Fin Tubes	68
4.4	Expressions for Condensation Heat Transfer Rate on Pin-Fin Tubes	70
4.5	Vapour-Side Heat Transfer Enhancement Ratio	77
4.6	Determination of the Unknown Constants	78
4.7	Heat Transfer Coefficient with Three-Dimensional Pin Tubes	79
4.8	Theoretical Equations Solution Procedure	80
	Chapter Five ***Results and Discussion***	
5.1	Introduction	83
5.2	Experimental Results and Discussion	84
5.3	Comparison between Experimental and Theoretical Results	90
5.4	Comparison of Tubes Performance in Atmospheric and Vacuum Operation Conditions in Parted Curves	91
	Chapter Six ***Conclusions and Recommendations***	
6.1	Conclusions	109
6.2	Recommendations and Suggestions for Further Works	110
	References	111
	Appendices	
Appendix (A):	Error Analysis	116
Appendix (B):	Sample of Calculations	142
Appendix (C):	Tables of Experimental Data and Results	150

List of figures

Figure		***Page No.***
(1.1)	Dropwise condensation of steam: (a) on Plain surface (b) on corrugated wires with coated tube	3
(1.2)	Photo of Filmwise condensation on integral wired-fin tubes.	5
(1.3)	Photo of pinned tube	5
(1.4)	Idealized pinned-tube (rectangular pin)	7
(2.1)	Dependence of vapour-side heat transfer ratio on fin spacing rectangular-section integral-fin tubes	25
(2.2)	Dependence of active area enhancement ratio on fin spacing	25
(2.3)	Dependence of retention angle on circumferential pin spacing	26
(2.4)	Dependence of retention angle on circumferential pin thickness	26
(2.5)	Photo of the test tubes which used in investigation of Hafiz and Briggs	27
(3.1)	Schematic diagram of experimental test rig	30
(3.2)	Photo of the experimental test rig	31
(3.3)	Photo of the steam boiler	32
(3.4)	(a) Schematic of the test section body (b) Photo of the test section body	33-34
(3.5)	(a) Schematic of the test section cover (b) Photo of the test section cover	34-35
(3.6)	(a) Schematic of the steam distribution plate (b) Photo of the steam distribution plate	35-36
(3.7)	(a) Schematic of the flow delimiter plates (b) Photo of the flow delimiter plates	36-37
(3.8)	Photo of the test section with internal parts fixation and test tube	39
(3.9)	(a) Schematic of the first test tube (b) Photo of the first test tube	41
(3.10)	(a) Schematic of the second test tube (b) Photo of the second test tube	42
(3.11)	(a) Schematic of the third test tube (b) Photo of the third test tube	43

(3.12)	(a) Schematic of the fourth test tube (b) Photo of the fourth test tube	44
(3.13)	(a) Schematic of the fifth test tube (b) Photo of the fifth test tube	45
(3.14)	(a) Schematic of the sixth test tube (b) Photo of the sixth test tube	45-46
(3.15)	Photo of the family of the test tubes	48
(3.16)	(a) Photo of the tubes inside the shell (b) Photo of the complete steam condenser body with Inlet and outlet connection pipes for water and steam	50
(3.17)	(a) Water tank before insulation (b) Water tank after insulation	51
(3.18)	Photo of the water pump	52
(3.19)	Photo of the Vacuum pump	53
(3.20)	Photo of the electrical control panel	54
(3.21)	Photo of the thermocouples type k (TP-01)	57
(3.22)	Photo of the thermocouple fixation method in the connection pipes	57
(3.23)	Photo of the thermocouple fixation method in the water tank	58
(3.24)	(a) Photo of the thermocouple fixation method on the external surface of the test tube, step (1) (b) Photo of the thermocouple fixation method on the external surface of the test tube, step (2)	58
(4.1)	Relation of constant *C*	69
(4.2)	Schematic of pin-fin tube identifying five regions for Heat transfer	70
(4.3)	Physical model of pin-fin tube	71
(4.4)	Approximation for mean vertical pin height	71
(4.5)	Diagram explains solution steps for the theoretical equations	81-82
(5.1.a to c)	Variation of condensate heat transfer coefficient with steam-tube wall temperature difference at (1.4) l/min cooling water flow rate, full power of boiler heater and atmospheric opearation conditions for all test tubes	92

(5. 2.a to c)	Variation of condensate heat transfer coefficient with steam-tube wall temperature difference at (3.5) l/min cooling water flow rate, full power of boiler heater and atmospheric opearation conditions for all test tubes	93
(5. 3.a to c)	Variation of condensate heat transfer coefficient with steam-tube wall temperature difference at (7) l/min cooling water flow rate, full power of boiler heater and atmospheric opearation conditions for all test tubes	94
(5. 4.a to c)	Variation of condensate heat transfer coefficient with steam-tube wall temperature difference at (1.4) l/min cooling water flow rate, (75) % power of boiler heater and atmospheric opearation conditions for all test tubes	95
(5. 5.a to c)	Variation of condensate heat transfer coefficient with steam-tube wall temperature difference at (1.4) l/min cooling water flow rate, full power of boiler heater and vacuum opearation conditions for all test tubes	96
(5. 6.a to c)	Variation of condensate heat transfer coefficient with steam-tube wall temperature difference at (3.5) l/min cooling water flow rate, full power of boiler heater and vacuum opearation conditions for all test tubes	97
(5.7)	Variation of heat transfer rate with cooling water flow rate for first test tube at atmospheric operation conditions	98
(5.8)	Variation of heat transfer rate with cooling water flow rate for fifth test tube at atmospheric operation conditions	98
(5.9)	Variation of heat transfer rate with cooling water flow rate for sixth test tube at atmospheric operation conditions	98
(5.10.a to e)	Variation of cooling side Nusselt number with steam-tube wall temperature difference at (1.4 l/min) cooling water flow rate, full power of boiler heater and atmospheric operation conditions for all test tubes	99

(5.11.a to e) Variation of cooling side Nusselt number with steam-tube wall temperature difference at (3.5 l/min) cooling water flow rate, full power of boiler heater and atmospheric operation conditions for all test tubes	100
(5.12.a to e) Variation of cooling side Nusselt number with steam-tube wall temperature difference at (7 l/min) cooling water flow rate, full power of boiler heater and atmospheric operation conditions for all test tubes	101
(5.13.a to e) Variation of cooling side Nusselt number with Steam-tube wall temperature difference at (1.4 l/min) cooling water flow rate, (75%) power of boiler heater and atmospheric operation conditions for all test tubes	102
(5.14.a to e) Variation of cooling side Nusselt number with steam-tube wall temperature difference at (1.4 l/min) cooling water flow rate, full power of boiler heater and vacuum operation conditions for all test tubes	103
(5.15.a to e) Variation of cooling side Nusselt number with steam-tube wall temperature difference at (3.5 l/min) cooling water flow rate, full power of boiler heater and vacuum operation conditions for all test tubes	104
(5.16) Enhancement ratio for pinned tubes and finned tube at (1.4 l/min) cooling water flow rate with atmospheric operation conditions	105
(5.17) Enhancement ratio for pinned tubes and finned tube at (1.4 l/min) cooling water flow rate and (75%) power of heater boiler with atmospheric operation conditions.	105
(5.18) Enhancement ratio for pinned tubes and finned tube at (1.4 l/min) cooling water flow with vacuum operation conditions.	105
(5.19. a to c) Comparsion between experimental and theoretical results for the condensate heat transfer coefficient of the pinned tested tubes at (1.4 l/min) cooling water flow rate and atmospheric operation conditions	106
(5.20. a to c) Comparsion between experimental and theoretical results for the condensate heat transfer coefficient of the pinned tested tubes at (1.4 l/min) cooling water flow rate and vacuum operation conditions	107

(5.21. a to d)	Comparsion between atmospheric and vacuum results for heat transfer rate for pinned tubes at (3.5) l/min and full power of boiler heater	108
(A.1)	The calibration curve for thermocouple No.1	129
(A.2)	The calibration curve for thermocouple No.2	129
(A.3)	The calibration curve for thermocouple No.3	129
(A.4)	The calibration curve for thermocouple No.4	130
(A.5)	The calibration curve for thermocouple No.5	130
(A.6)	The calibration curve for thermocouple No.6	130
(A.7)	The calibration curve for thermocouple No.7	131
(A.8)	The calibration curve for thermocouple No.8	131
(A.9)	The calibration curve for thermocouple No.9	131
(A.10)	The calibration curve for thermocouple No.10	132
(A.11)	The calibration curve for digital thermometer	132
(A.12)	The calibration curve for glass thermometer	132
(A.13)	The calibration curve for pressure gauge (6 bar)	139
(A.14)	The calibration curve for pressure gauge (10 bar)	139
(A.15)	The calibration curve for pressure gauge (30 inHg)	139
(A.16)	The calibration curve of flow meter	141

List of tables

	Title	***Page No.***
(1.1)	Classifications of heat transfer enhancement techniques	2
(2.1)	Summery of experimental literature review	23-24
(3.1)	Show the dimensions and material type of the steam boiler	32
(3.2)	Construction details of all test tubes	46
(3.3)	Pins and fin constructions dimensions for test tubes	47
(3.4)	Dimensions and specification of the shell side and tubes side of the constructed steam condenser	49
(4.1)	Empirical constant	69
(4.2)	Empirical constants for pin regions	78
(A.1)	The uncertainties in each individual measurement	118
(A.2)	The results of calculations for error analysis for (1.4 l/min) cooling water flow rate	120

(A.3)	The results of calculations for error analysis for (3.5 l/min) cooling water flow rate	121
(A.4)	The results of calculations for error analysis for (7 l/min) cooling water flow rate	122
(C.1)	The experimental data and results of measurements for (1.4) l /min cooling water flow rate and full power of the boiler heater with atmospheric operation conditions.	150
(C.2)	The experimental data and results of measurements for (3.5) l /min cooling water flow rate and full power of the boiler heater with atmospheric operation conditions.	151
(C.3)	The experimental data and results of measurements for (7) l /min cooling water flow rate and full power of the boiler heater with atmospheric operation conditions.	152
(C.4)	The experimental data and results of measurements for (1.4) l /min cooling water (75%) rate and full power of the boiler heater with atmospheric operation conditions	153
(C.5)	The experimental data and results of measurements for (1.4) l /min cooling water flow rate and full power of the boiler heater with vacuum operation conditions	154
(C.6)	The experimental data and results of measurements for (3.5) l /min cooling water flow rate and full power of the boiler heater with vacuum operation conditions	155

Nomenclature

English Symbols

Symbol	***Title***	***Units***
A_L	Constant	-------
A_D	Constant	-------
A	Area.	m^2
B	Constant	-------
$\bar{B}$	Empirical constant	
C	Empirical constant	-------
C_{loss}	Constant	-------
c_p	Specific heat capacity	$J/kg.℃$
d_i	Inner diameter of test tube.	m
d_o	Outer diameter of test tube.	m
d_t	Tip diameter of pin or fin tube.	m
d_h	Hydraulic diameter.	m
f	Darcy friction factor	-------
g	Specific force of gravity.	m^2/s
h	Pin or fin height.	m
h_{con}	Condensation heat transfer coefficient.	$W/m^2.℃$
h_{fg}	Specific enthalpy of vaporization.	J/kg
h_v	Mean vertical pin or fin height.	m
i	Pin number	-------
j	Number of pins in unflooded region.	-------
k	Thermal conductivity	$W/m.℃$
l_t	Length of the tested part from test tube.	m
l_{ts}	Length of test section.	m
$\dot{m}$	Mass flow rate	kg/sec
Nu	Nusselt number.	-------
n	Total number of pins per circumference.	-------
p	Pin or fin pitch.	m
P_{ts}	Pressure of steam in test section.	bar
P_{gr}	Pressure gauge reading.	bar
$\bar{P}$	Perimeter of pin	-------
Q	Heat transfer rate.	W
Q_{smooth}	Heat transfer rate through a smooth tube.	W
Q_B	Total power input to the boiler.	W
$\bar{Q}$	Heat transfer rate to pin base	w

q	Heat flux	W/m^2
q_o	Heat flux on outside surface of test tube.	W/m^2
q_L	Heat flux on a plate.	W/m^2
q_d	Heat flux on outside surface of horizontal tube.	W/m^2
q_{smooth}	Heat flux through smooth or plain tube.	W/m^2
R	Boiler heater resistance	ohm
Re	Reynold number	-------
r_o	Outer radius of test tube.	m
s	Pin or fin longitudinal spacing at pin or fin root.	m
$s_{\bar{c}}$	Circumference pin spacing.	m
T	Temperature	℃
t	Pin or fin tip thickness in the longitudinal direction.	m
$\bar{t}$	Tube wall thickness.	
t_b	Pin or fin base thickness in the longitudinal direction.	m
$t_{\bar{c}}$	Circumference pin thickness.	m
u	Velocity	m/s
V	Voltage drop across boiler heater.	$Volt$
$\dot{V}$	Cooling water flow rate inside test tube.	l/min
We	Weber number.	-------
$We_{\bar{c}}$	Weber number for circumferential face of the pin.	-------
We_l	Weber number for longitudinal face of the pin.	-------
x_D	Linear dimension of tube diameter.	m
x_g	Characteristic length for gravity driven flow.	-------
x_L	Linear dimension of plate length.	m
x_σ	Characteristic length for surface tension driven flow.	-------
Y	Function of geometric parameters.	-------
Z	Height of the condensate film on the test tube	m

Greek Symbols

Symbol	***Title***	***Units***
β	Angle defined by equ. (4.19)	degree
ΔT	Saturation steam-tube wall temperature difference.	℃
ΔT_c	Cooling water temperature rise due to condensation.	℃
ε	Enhancement ratio.	-------
μ	Dynamic viscosity	$kg/m.s$
$\xi(\emptyset)$	Function.	-------
ρ	Density.	kg/m^3
$\tilde{\rho}$	$\rho_{con} - \rho_s$.	kg/m^3
σ	Surface tension.	N/m
θ	Pin or fin tip half angle.	degree
$\emptyset$	Angle measured from the top of a pin or fin tube.	degree
$\emptyset_f$	Condensate flooding or retention angle measured from the top of a pin or fin tube.	degree

Subscripts

Symbol	***Title***
a	Air.
b	Base.
c	Cooling.
ci	Cooling inlet.
cou	Cooling outlet.
con	Condensation.
f	Film.
$flank\ 1$	Pin flank 1.
$flank\ 2$	Pin flank 2.
h	Hydraulic.
i	Pin number.
ic	Inner cross section of test tube.
$i\ ts$	Inner cross section of the test section.
iwc	Inlet water to condenser.
owc	Outlet water to condenser.
os	Outer surface.
$root\ 1$	Pin root 1.
$root\ 2$	Pin root 2.

rw	Return water.
s	Steam.
sat	Saturation.
st	Steam in test section.
tip	Pin tip.
w	Wall.

Abbreviations

Symbol	***Title***
AOC	Atmospheric Operation Conditions.
Exp	Experimental.
NRV	Non Return Valve.
PVC	Polly Vinyl Chloride
$Theo$	Theoretical.
VOC	Vacuum Operation Conditions.
equ	Equation.
No.	Number

Chapter one

Introduction

Chapter Two

Literature Survey

Chapter Three

Experimental Work and Procedure

Chapter Four

The Theoretical Work

Chapter Five

Results and Discussion

Chapter Six

Conclusion and Recommendations

References

Appendices