



Ain Shams University
Faculty of Engineering
Mechanical Power Department

Effect of an Impinging Jet on Horizontal Cylinder Cooling

A thesis submitted in fulfillment of the requirements for the degree of

MASTER OF SCIENCE
In
MECHANICAL ENGINEERING

By

Eng. Ahmed Sayed Saber Sayed Mohamed

B.Sc. Mechanical Engineering
Ain Shams University, 2010

Supervised by:

Prof. Dr. Mahmoud Mohamed Abo El-Nasr

Professor in the Mechanical Power Eng. Dept.
Faculty of Engineering - Ain Shams University

Dr. Mahmoud Mohamed Kamal

Associate Professor in the Mechanical Power Eng. Dept.
Faculty of Engineering - Ain Shams University

Dr. Hamdy Ahmed Abotaleb

Doctor in the Mechanical Power Eng. Dept.
Faculty of Engineering - Ain Shams University

Cairo, 2014



AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING

Effect of an Impinging Jet on Horizontal Cylinder Cooling

By

Ahmed Sayed Saber Sayed Mohamed

B.Sc. Mechanical Engineering
Ain Shams University, 2010

EXAMINERS COMMITTEE

Name

Signature

Prof. Dr. Mahmoud Abdel Fattah Elkady

.....

Prof. Dr. Adel Abdelmalek Alahwany

.....

Prof. Dr. Mahmoud Mohamed Abo El-Nasr

.....

Dr. Mahmoud Mohamed Kamal

.....

Date: /...../.....

STATEMENT

This thesis is submitted in the partial fulfillment of masters degree in Mechanical Engineering, Mechanical Power Engineering Major, Faculty of Engineering, Ain-Shams University.

The author carried out the work included in this thesis, and no part of this thesis has been submitted for a degree or qualification at any other university or institution.

Signature

Ahmed Sayed Saber Sayed Mohamed

Researcher Data

Name of Researcher	Ahmed Sayed Saber Sayed Mohamed
Date of Birth	January, 9 th , 1989
Place of Birth	Cairo, Egypt
First University Degree	B.Sc in Mechanical Engineering
Department	Mechanical Power Department
University	Ain Shams University
Date of Degree	June 2010
Current Job	Teaching Assistant at the Mechanical Power Department

Acknowledgement

First of all, I am so grateful to Allah for giving me the guidance, strength, patience, and hope to finish my research. It is the mercy of God, and my trust in him that have made such a dream to become a reality.

I give many thanks for my advisor, **Prof. Mahmoud Mohamed Abo El-Nasr** for his advices along the research period, and for facilitating the work in our faculty.

I would like to thank my advisor, **Dr. Mahmoud Mohamed Kamal** for his valuable comments and advices throughout the research.

I wish to express my deep gratitude to my advisor, **Dr. Hamdy Ahmed Abotaleb**, for his inspiring guidance, valuable advice, and encouragement throughout the progress of this research. His suggestions, criticism, and patience have been great assets.

I express sincere thanks for **my family** for providing insightful opinions and recommendations as well as for their positive attitude, coaching, and encouragements that tremendously facilitate the progress of this work.

I would like to express my gratitude to **AVL Company** for supporting and providing me with the license and the technical support of the AVL-Fire package for the research purposes.

Finally, I would like to express my thanks to **my faculty** for their financial support and for the facilities that I used in my lab.

Abstract

Investigating the quenching phenomena has an important impact on many applications such as steel hardening and cooling in nuclear power plants. Few studies investigated the usage of liquid slot jets. Experimental and numerical investigations have been conducted on the effect of quenching of hot horizontal stainless-steel cylinders by sub-cooled liquid slot jets. The temperatures, the cooling rates, heat flux, and the behavior of the maximum heat flux point have been experimentally investigated for changing different parameters, such as the cylinder initial temperature (between 400 and 600°C), the coolant temperature (with degrees of sub-cooling between 20 and 60°C), the coolant velocity (between 1.0 and 1.5 m/s), and the coolant type (including fresh water, and saline water 1%). The coolant was impinged from a slot of 1.3 mm width that covered the whole length of the cylinder. The slot was 5 cm above the cylinder in the vertical direction, so as to be parallel to the cylinder axis. A previous numerical model for circular jets using AVL-FIRE software was modified and validated for the slot jets as well.

The results of the present investigation indicate, for both the fresh water and saline water 1%, that increasing the initial temperature of the specimen caused the temperature at which the film boiling ended, the maximum rate of temperature decrease, and consequently the point of maximum heat flux to lag and increase in value. However, increasing the degree of sub-cooling led them to come earlier and with higher values, and increased the cooling rates. The jet velocity within the range under study had slight effect on the cooling curves. Using saline water 1% enhanced the cooling rates for the selected ranges. Up on going deep from the surface, more homogeneity in temperatures and slower cooling rates were achieved. The numerical model showed good agreement with the experimental values in most of the trials.

Key Words: Slot impinging Jet; cylinder quenching; liquid coolants; Steel heat treatment; quenchant type.

TABLE OF CONTENTS

Acknowledgement	i
Abstract	ii
Table of Contents	iii
List of Figures	vii
List of Tables	xiii
Nomenclature	xiv
Chapter 1: Introduction	1
1.1. General	1
1.2. Applications	1
1.3. Types of Quenching	2
1.4. Quenching Effect	3
1.5. Regions of The Cooling Curves	4
1.6. Existence of The Coolant on The Specimen During Quenching....	6
1.7. Challenges of The Quenching Process	7
1.8. Thesis Outlines	7
Chapter 2: Literature Review	9
2.1. General	9
2.2. Review of Some Previous Experimental Work	9
2.2.1. Using fresh water coolant	9
2.2.2. Using different coolants	16
2.3. Review of Some Previous Numerical Work	18
2.4. Concluding Remarks	22
2.5. Objectives of The Present Study	22
Chapter 3: Experimental Work	24
3.1. Introduction	24
3.2. Test Rig	24
3.3. Specimen	26
3.4. Specimen Heater	27
3.5. Data Acquisition Unit	27
3.6. Thermocouples	28
3.7. Water Flow Meter	29

3.8. Uncertainty of Measurements	29
3.9. Experimental Program	29
3.10. Experimental Procedures	30
Chapter 4: Numerical Model	32
4.1. Introduction	32
4.2. Mathematical Modeling	32
4.2.1. Film boiling model	34
4.2.2. Transition boiling model	35
4.2.3. Nucleate boiling model	36
4.3. Simulation Procedure	36
4.3.1. Model and boundary conditions	37
4.3.1.1. Solid domain	37
4.3.1.2. Coolant domain	38
4.3.2. Model running procedures and initial conditions	40
Chapter 5: Results and Discussion	41
5.1. Introduction	41
5.2. Experimental Results	41
5.2.1. The Cooling Curves	41
5.2.2. The Rate of Temperature Decrease	44
5.2.3. The Change in The Cooling Curves with The Angle from The Stagnation Point	47
5.2.4. The Change in The Rate of Temperature Decrease with The Angle from the Stagnation Point	48
5.2.5. The Change in The Maximum Rate of Temperature Decrease and Maximum Heat Flux with the Angle from the Stagnation Point	50
5.2.6. The Relation Between The Rate of Temperature Decrease and The Degree of Solid Surface Superheating	51
5.2.7. The Relation Between The Rate of Temperature Decrease and The Degree of Solid Surface Superheating at Different Angles θ Temperature Distribution at Different Angles at Time t	53
5.2.8. The outer temperatures at Different Angles at Time t	54
5.2.9. Effect of Specimen Initial Temperature	56
5.2.9.1. The cooling curves	56
5.2.9.2. The rate of temperature decrease	61
5.2.9.3. The change in the rate of temperature decrease with the angle from the stagnation point at different specimen initial temperatures	62

5.2.9.4. The change in the maximum rate of temperature decrease and maximum heat flux with the angle from the stagnation point at different specimen initial temperatures.....	64
5.2.9.5. The relation between the rate of temperature decrease and the degree of solid surface superheating at different angles θ	65
5.2.9.6. The outer temperatures at different angles at time t at different specimen initial temperatures	65
5.2.10. Effect of Coolant Sub-cooling	68
5.2.10.1. The cooling curves	68
5.2.10.2. The rate of temperature decrease	71
5.2.10.3. The change in the rate of temperature decrease with angle from the stagnation point at different degrees of coolant sub-cooling	73
5.2.10.4. The change in the maximum rate of temperature decrease and maximum heat flux with the angle from the stagnation point at different degrees of coolant sub-cooling	73
5.2.10.5. The relation between the rate of temperature decrease and the degree of solid surface superheating at different angles θ	75
5.2.10.6. The outer temperatures at different angles at time t at different degrees of coolant sub-cooling	77
5.2.11. Effect of Jet Velocity	79
5.2.11.1. The cooling curves	79
5.2.11.2. The rate of temperature decrease	82
5.2.11.3. The change in the rate of temperature decrease with the angle from the stagnation point at different jet velocities	83
5.2.11.4. The change in the maximum rate of temperature decrease and maximum heat flux with the angle from the stagnation point at different jet velocities	85
5.2.11.5. The relation between the rate of temperature decrease and the degree of solid surface superheating at different angles θ	86
5.2.11.6. The outer temperatures at different angles at time t at different jet velocities	87
5.2.12. Effect of Coolant Type	88
5.2.12.1. The cooling curves	88
5.2.12.2. The rate of temperature decrease	91