



**SUDAN UNIVERSITY
OF SCIENCE AND TECHNOLOGY
COLLEGE OF GRADUATE STUDIES**

**DESIGN OF PRE COOLER FOR GAS TURBINE AT
GARRI(1 and 2) POWER STATION BY USING
VAPOUR COMPRESSION REFRIGERATION SYSTEM**

**تصميم مبرد قبلي للتوربين الغازي في محطة كهرباء قري
الحرارية (2،1) باستخدام نظام التبريد الإنضغاطي**

**A Thesis Submitted in Partial Fulfillment of the Degree of
M.Sc. in Mechanical Engineering (POWER)**

**By:
JASSIM SALAH MOHAMMED HAMAD**

**Supervisor:
Dr. Ali Mohammed Hamdan Adam**

Feb 2016

الإفتتاحية
بسم الله الرحمن الرحيم

قال تعالى :

لَا يُكَلِّفُ اللَّهُ نَفْسًا إِلَّا وُسْعَهَا لَهَا مَا كَسَبَتْ وَعَلَيْهَا
مَا اكْتَسَبَتْ رَبَّنَا لَا تُؤَاخِذْنَا إِنْ نَسِينَا أَوْ أَخْطَأْنَا رَبَّنَا
وَلَا تَحْمِلْ عَلَيْنَا إَصْرًا كَمَا حَمَلْتَهُ عَلَى الَّذِينَ مِنْ قَبْلِنَا
رَبَّنَا وَلَا تَحْمِلْنَا مَا لَا طَاقَةَ لَنَا بِهِ ۖ وَاعْفُ عَنَّا وَارْحَمْنَا
أَنْتَ مَوْلَانَا فَانصُرْنَا عَلَى الْقَوْمِ الْكَافِرِينَ ﴿٢٨٦﴾

سورة البقرة - الآية 286

Dedication

To my father who gives me direction to the sky

To my mother who gives me lovely life

To my brothers and sisters who give me support

Acknowledgement

First of all I would like to submit my best greeting to my supervisor Dr. Ali Mohammed Hamdan for his acceptance to supervise my research and for his directions during preparing this research. Also my full respect and appreciation to my all friends, colleagues and co-worker enhanced me in this research and helped me in data collection stage. Finally, a lot of thanks to Garri Power Station Directorate which gave me permeations to apply this research and analysis in the station and has been supplying me by all data I needed throughout the research.

Abstract

Gas-turbine inlet air cooling has been considered for boosting the power output during hot seasons, the gas turbine being a constant volume-flow machine, the power of the gas turbine is directly proportional to the mass flow rate of air passing through it, which is directly proportional to sucked air density. A high ambient temperature reduces the air density. Gas turbines designed to operate at standard conditions of 15°C therefore gas turbine lose a significant portion of their generating capacity when installed in hot climates. Reduce the temperature of inlet air by using chilled water to the design condition increase output power by 8 MW for each turbine in Garri power plant these amount of power equals 25% of the rated power of turbine. This research is the trial to calculate the increase in output power from gas turbine by designing pre cooler system to increase the efficiency and output power of the turbine.

تجريدة

يبرد الهواء عند مدخل التوربينة الغازية لزيادة القدرة الكهربائية المولدة فى المناطق الحارة وذلك لان التوربين الغازي يتأثر كثيراً بدرجة حرارة الهواء المسحوب لتغيير كثافته تبعاً لدرجة الحرارة مما يؤثر على كتلة الهواء المسحوب للتوربينة الغازية وعادة يتم تصميم التوربينة عند درجة حرارة 15 درجة سليزيوس لتعطى قدرتها القصوى التشغيلية فى البلدان الحارة تقل هذه القدرة بمقدار 25 % من القدرة التصميمية، كما هو فى السودان خلال شهور الصيف. هذا البحث محاولة لتصميم مبرد يعمل بدورة انضغاطية لتبريد وسيط التبريد (الماء) الذى يبرد الهواء عند المدخل للتوربينة لتعمل التوربينة الغازية على الظروف القياسية لها مما يرفع الكفاءة و يوفر الطاقة.

Contents

Title	No
الإفتتاحية	II
Dedication	III
Acknowledgement	IV
Abstract	V
تجريدة	VI
Contents	VII
Abbreviations	IX
Symbols	X
List of Tables	XII
List of Figures	XIII
Chapter: one Introduction	
1-1 Introduction.	2
1-2 Problem Statement	3
1-3 Objectives.	3
1-3-1 Overall objectives	3
1-3-2 Specific objective	3
1-4 Methodology.	3
1-5 Expected results.	3
Chapter two: Literature review	
2-1 Basic Gas Turbine Operation	5
2-2 Joule-Brayton cycle: The Ideal Cycle For Gas-Turbine Engines	6
2-3 Deviation of Actual Gas-Turbine Cycles from Idealized Ones	10
2-4 The Joule-Brayton Cycle with Regeneration	11
2-5 The Joule-Brayton Cycle with Intercooling, Reheating, and Regeneration	12
2-6 Preview studies.	14
2-7 Gas Turbine Inlet Air Cooling Available Technologies	20
2-7-1 Evaporative cooler	20
2-7-2 Fogging system	21
2-7-3 Mechanical refrigeration system	23
2-7- 4 Lithium Bromide Absorption chiller	24
Chapter three: Design model for pre cooler	
3-1 Introduction	27
3-1-1 Environment description	27

3-1-2	Water Availability at Garri	29
3-1-3	Chilling system	29
3-2	Design Suggested procedures for pre cooling model	30
3-2-1	Chiller system	30
3-2-1-1	The Compressor	31
3-2-1-2	The condenser	32
3-2-1-3	The Expansion Valve	32
3-2-1-4	The Evaporator	33
3-2-2	Cooling tower	34
3-2-3	Heat exchange	34
Chapter four: Calculation and Discussion		
4-1	Calculation	36
4-1-1	Quantity of heat must remove from air.	36
4-1-2	Quantity of chilled water.	38
4-1-3	Number of tubs needs to install in side intake air filter house	38
4-1-3-1	Volume flow rate of chilled water through the large pipe	39
4-1-3-2	Number of rows	39
4-1-3-3	Volume flow rate of chilled water through the small pipe	39
4-1-3-4	Overall heat transfer coefficient	40
4-1-3-5	The Number of cooling stages	42
4-1-4	Heat Exchanger Area	42
4-1-5	The Chiller System Selection	43
4-2	Simulation	43
4-2-1	Introduction	43
4-2 -2	Geometry	44
4-2-3	Mesh	45
4-2-4	Setup	46
4-2-5	Solution	48
4-2-6	Result	49
4-3	Discussion	53
4-4	Payback period	57
Chapter five: Conclusion and Recommendations		
5-1	Conclusion	59
5-2	Recommendations	60
	Reference	61

Abriviations

CTIAC	combustion turbine inlet air cooling
CWT	chilled water temperature
GCPS	Garri Complex Power Station
GE	General Electric
LCWT	Leaving Chiller Water Temperature
PI	Power Input (Compressor Only)
P – v	Pressure - volume Diagram.
RH	Relative Humidity
T. CAP	Total Capacity
T. CAPs	Total Capacity for selected chiller system
T – s	Temperature – Entropy Diagram.
WFR	Water Flow Rate
WPD	Water Pressure Drop

Symbols		Units
A_o	Total Area of Heat Exchanger	m ²
a_i	inlet Area of the small pipe	m ²
a_o	Outlet Area of the small pipe	m ²
a_s	Surface Area of the small pipe	m ²
Cp_a	Specific Heat of air at constant pressure.	kJ/kg K
Cp_{cw}	Specific Heat of chilled water at constant pressure.	kJ/kg K
D_i	Inner Diameter of large the pipe	mm
D_o	Outer Diameter of the large pipe	mm
d_i	Inner Diameter of the small pipe	mm
d_o	Outer Diameter of the small pipe	mm
F	Correction Factor	%
L	Length of the small pipe	m
LMTD	Log Mean Temperature Difference	°C
m_a	Air flow rate.	kg/sec
m_{ch}	Chilled water flow rate.	kg/sec
N_{row}	Number of rows in Heat Exchanger	rows
N_{st}	Number of cooling stages	Stages
N_{tubes}	Total Number of Tubes	Tubes
Q_a	Rate of Heat loss.	kw
Q_{ch}	Rate of Heat gained	kw
q_{supply}	Volume flow rate of chilled water through the large pipe	m ³ /sec
q_{tube}	Volume flow rate of chilled water through the small pipe	m ³ /sec

R_T	Total Heat Resistance	K/W
S_L	Longitudinal pitch	mm
S_T	Transverse pitch	mm
T_{ai}	Inlet air temperature	°C
T_{ao}	outlet air temperature	°C
T_{chi}	Inlet chilled water temperature	°C
T_{cho}	outlet chilled water temperature	°C
U	Overall Heat Transfer Coefficient	w/m ² K
V_{ch}	Volume flow rate of chilled water	m ³ /sec
v_{tube}	Velocity of chilled water through the small pipe	m/sec

List of Tables

Table 3.1	Specifications of Garri service water	29
Table4.1	The Thermodynamics specifications of fluids	37
Table4.2	Heat Exchanger parameters	39
Table4.3	chiller system Model PSC 460	43
Table 4.4	Dimensions of single tube of heat exchange	44
Table 4.5	Power generated Efficiency and Heat Rate at gas turbine Before and After Installing of Evaporator Unit.	53
Table 4.6	Power generated Efficiency and Heat Rate at gas turbine Before and After Installing of Chilling Unit.	53

List of Figures

Figure No	Title	No
Figure 2-1	Schematic layout of a single-shaft gas turbine.	5
Figure 2-2	An open-cycle gas-turbine engine.	7
Figure 2-3	A closed-cycle gas-turbine engine.	7
Figure 2-4a	T-s diagram of an ideal Joule-Brayton cycle.	8
Figure 2-4b	P-v diagram of an ideal Joule-Brayton cycle.	8
Figure 2-5	Thermal efficiency of the ideal Joule-Brayton cycle as a function of the pressure ratio, r_p .	9
Figure 2-6	The fraction of the turbine work used to drive the compressor.	9
Figure 2-7	The irreversibility in the Joule-Brayton cycle	10
Figure 2-8	A gas-turbine engine with regeneration.	11
Figure 2-9	T-s diagram of a Joule-Brayton cycle with regeneration.	11
Figure 2-10	Comparison of work inputs to single-stage compressor and two-stage compressor with inter cooling.	12
Figure 2-11	A gas-turbine engine with two-stage compression with inters cooling, two-stage expansion with reheating, and regeneration.	13
Figure 2-12	T-s diagram of an ideal gas-turbine cycle with inter cooling, reheating, and regeneration.	14
Figure 2-13	Schematic shows the evaporative cooler	20
Figure 2-14	Schematic shows the Fogging system	21
Figure 2-15	Fogging system	22
Figure 2-16	Schematic System Using a Mechanical Chiller	23
Figure 2-17	Absorption Chiller Inlet Air Cooling System Schematic	24
Figure 2-18	Absorption Chiller Flow Diagram from York international.	25
Figure 3-1	Layout of Garri (1&2) power plant	27
Figure 3-2	Climatical data of Garri	28
Figure 3-3	Main components of the pre cooler system	30
Figure 3-4	Main components of chiller system.	31
Figure 3-5	Screw compressor.	31
Figure 3-6	Water cooled condenser	32
Figure 3-7	Thermostatic expansion device	33
Figure 3-8	Water-Cooling Evaporator (Chilled Water).	33
Figure 3-9	Cross-flow of cooling water	34
Figure 3-10	Cross flow heat exchange	34
Figure 4-1	Cross flow heat exchanger (Chilled water & Air).	36
Figure 4-2	Air density distributions in heat exchanger	49

Figure 4-3	Distribution of air Temperature in heat exchanger.	50
Figure 4-4	Air pressure distributions in heat exchanger	51
Figure 4-5	Distribution of air velocity in heat exchanger.	52
Figure 4-6	The effect of Evaporator cooler and chilling cooler of the gas turbine in power generated	55
Figure 4-7	The effect of Evaporator cooler and chilling cooler of the Efficiency gas turbine	55
Figure 4-8	8The effect of using evaporator cooler and chilling cooler in heat rate of the gas turbine	56
Figure 4-9	Fuel consumption of the gas turbine with Evaporator cooler and chilling cooler.	56