Environmental Impact of Gas District Cooling:

A Case Study of a Small Cogeneration Plant

by

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Dissertation submitted in partial fulfilment of

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

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(Dr. Syed Ihtsham Ul Haq Gilani)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
May 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this report, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

VOON CHOON LIN

ABSTRACT

Cogeneration is a better efficiency power generation technology compared to other traditional fossil fuel power plant. It uses heat engine or a power station to simultaneously generate both electricity and useful heat. Cogeneration consists of many types of technology and one of them is Gas District Cooling (GDC). In Malaysia, cogeneration technology has yet to catch up with only 5 GDC built but so far environmental impact of GDC has yet to be assessed. The objective of this project is to fill in that vacuum by assessing the environmental impact cause by GDC. The scope of this project will be observing and analysing the amount of CO_2, CO, NO_X and SO_X released by GDC and determine if it exceeds emission limit. Apart from the impact on surrounding temperature is also monitored to see if there is any rise in temperature due to the release of hot exhaust gas. The project mainly involves gas samples being collected within GDC and analysed to see the composition of the gas. Then the temperature at the various distance from GDC are taken. The content of NO_X and SO_X in the exhaust gas is compared to European Union and United States emission standards and GDC if found to release both emission gases well below the limit. The data is also used to compare with readings from oil-fired and coal-fired power plants to show the reduction of NO_X and SO_X emission and it is found to release far less SO_X than both types of power plants. The emissions of GDC working on full load and partial load are also compared where full load released more SO_X and NO_X however partial load is less efficient and released higher temperature exhaust gas since its heat energy is not extracted. For the surrounding the temperature, a graph of temperature and humidity in relation with distance from GDC is plotted and it is found to have minimal impact. All the results indicate that GDC is a clean and safe method to produce electricity.

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ABBREVIATIONS AND NOMENCLATURES

CO	Carbon Monoxide
CO_2	Carbon Dioxide
GDC	Gas District Cooling
GT 1	Gas Turbine 1
GT 2	Gas Turbine 2
HRSG	Heat Recovery Steam Generator
MW	Megawatt
NO_X	Nitrogen Oxides, can be NO (Nitric Oxide) or NO_2 (Nitrogen Dioxide)
PETRONAS	Petroliam Nasional Berhad, Malaysian oil and gas company, wholly owned by the Government of Malaysia
RT	Refrigeration Tonne
SO_X	Sulphur Oxide

CHAPTER 1
INTRODUCTION

1.1 Background Study

1.1.1 Abundance of Energy

Humans have been dependant on energy ever since the dawn on mankind. Before the invention of electric motor or gas turbine, human extracts the energy from the nature by using ingenious techniques such as windmill which is used to convert wind energy into rotational motion for grinding grains and obtaining fresh water from underground or for drainage.

Figure 1.1: Windmill in Amsterdam [1]

Soon, human could not depend on traditional energy harnessing techniques anymore because like windmill, it is very unreliable because it depends on the presence of wind and wind speed while for horse-powered mechanism is not sufficient because more powerful energy is needed for more intense application.

Hence, human began to search and finally invent generator and turbines. The new inventions can extract energy from a variety of sources like the abundant oil, gas, water, wind, tidal wave, and so on. Then, with the advancement of electronics, solar panels were invented. Due to the economic feasibility of oil and coal, a lot of power plants around the world are powered by these sources. But as mankind become more environmental conscious, development of renewable energy that is self-sustainable started, less impact on air and water pollution and does not affect mitigation of climate change.

According to Wikipedia [2], wind, hydroelectric, solar, biomass, geothermal and tidal powers are renewable sources while fossil fuels like oil, natural gas and coal along with fission and fusion nuclear are non-renewable energy.

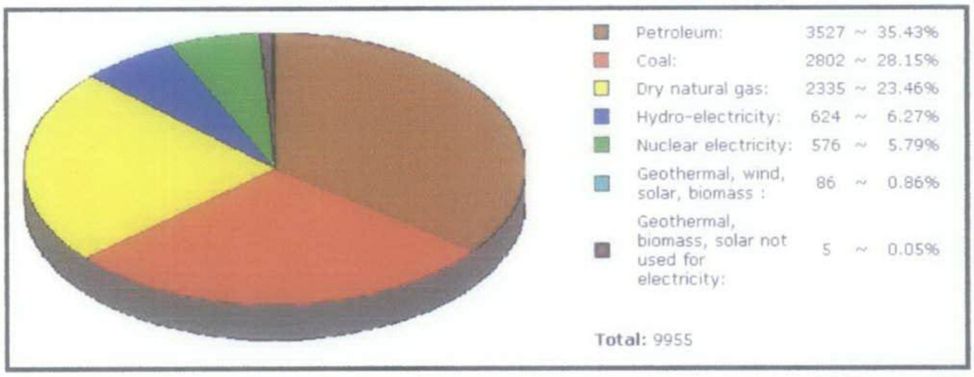

Figure 1.2: World Energy Consumption by Type in 2006 **[3]**

1.1.2 Environmental Deterioration

As good as renewable energy sounds, each of them has their own set of problems but most of them involves high setup and maintenance cost due to the immaturity of the technology. While on the other side, nuclear is deemed dangerous in case of melt down. For fossil fuels, it generates too much carbon dioxide and other harmful materials from their exhaust, causing the now hotly-debated global warming.

Over the past few years, environmental research found that global warming and global climate change are closely linked to carbon dioxide emissions from the combustion of fossil fuels. This forces the energy industry to look for alternative fuel or better efficiency technology to produce electricity to reduce the industry's impact on the environment.

Among all the fossil fuels, natural gas is the best for further development. This is because it is cheap, abundant and it produces the least pollutant in their exhaust. With all these benefits, everywhere in the world are starting to push the use of natural gas to power their power plant.

1.1.3 Intermediate Technology

For researchers and parties concern with the environment, they are now using natural gas power plant as the intermediate technology between traditional power plant and future renewable energy power plant. Intermediate technology is the technology that is used for transition from old to new technology. It slowly phases out the old technology while waiting for new technology to mature and becomes more economic feasible to implement. A good example would be hybrid cars. Petrol-powered cars are very harmful to the environment however the new generation electric car is too expensive and problematic. This is where hybrid cars come into play, it will function as the intermediate technology just like natural gas power plant.

To further enhance natural gas power plant, researches design the plants to be cogenerative. This will add more benefits to the already very attractive natural gas power plant technology. By making cogeneration natural gas power plant, it will increase the efficiency of the plant, sometimes double as much as non-cogeneration natural gas power plant.

1.1.4 Cogeneration

Cogeneration, which is a better efficiency power generation technology, is one of the answers. It uses heat engine or a power station to simultaneously generate electricity and useful heat **[4]**. In other words, cogeneration is the simultaneous production of electricity and thermal energy, with a single fuel input.

The first modern use of cogeneration was in 1882 Pearl Street Station by Thomas Edison. It produces both electricity and thermal energy while using waste heat to warm neighbouring buildings. However due to regulations and discouragement of decentralized power generation, such as cogeneration, the technology was not used widely.

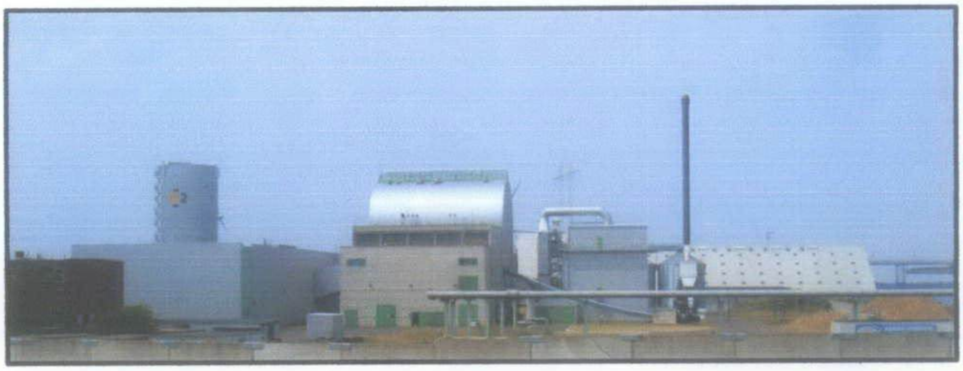

Figure 1.3: Masnedø Cogeneration Power Station in Denmark **[5]**

Recently, due to the emergence of environmental-conscious society, the depleting fossil fuels and the fight against global warming, many technologies now revolves around efficiency rather than capacity. That is why only these past few decades, cogeneration technology is heavily promoted again. Cogeneration plant has an efficiency of 60% – 85% while traditional power plant has an efficiency of 35% maximum. The double in efficiency means that less fuel is needed and less carbon and carbon dioxide are emitted, hence good for the environment **[6]**.

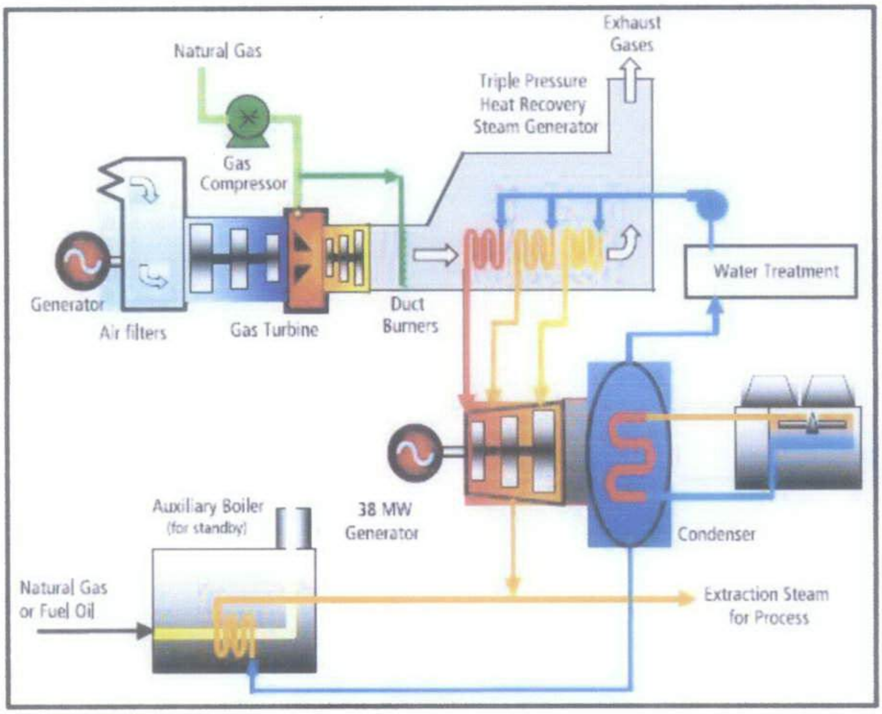

Figure 1.4: An Example of Cogeneration Process **[7]**

1.1.5 Cogeneration in Malaysia

However in Malaysia, cogeneration technology has yet to catch up. This is due to the subsidized fuel provided for the utility companies. They rather build a traditional power plant and make a handsome profit out of it. In Malaysia, there are only 5 Gas District Cooling (GDC) plants and all of them are owned and operated by the Malaysian national oil company, PETRONAS.

Although all the plants are relatively new, but their environmental impacts have yet to be studied. This study aims at the collection of environmental data within and across the GDC plants and also collection of plant's operational data, to ensure that cogeneration power plant is not only green and efficient but also safe for mankind and the environment.

1.1.6 Environmental Impact of Power Plant

NO_X and SO_x

GDC, like other fossil fuel power plant, generates by-products like NO_X and SO_x in their exhaust gas. NO_X and SO_x are considered primary pollutants and they can lead to harmful respiratory effects.

Second pollutants like acid rain, fine particles, and ozone are formed in the atmosphere from direct NO_X and SO_x emissions and other substances. These secondary pollutants have more substantial environmental and health impacts than direct NO_X and SO_x emissions alone and, hence, are the focus in this project **[8]**.

Acid deposition or acid rain occurs when NO_X and SO_x emissions react with water, oxygen, and oxidants in the atmosphere. Once formed, these acidic compounds can be transported thousands of kilometres where they impair air quality and ultimately fall from the atmosphere in rain form.

Acid deposition can change surface water chemistry, making lakes and streams more acidic and releasing toxic substances into the water. Acidification of surface water and the surrounding soil can be a harmful combination for sensitive fish population, causing species loss. Acidification can also lead to release of aluminium from soils into lakes and streams. Aluminium is highly toxic to many aquatic organisms and can result further loss of fish and other species. Acid deposition can also destroy agriculture and forests, as well as, outdoor structures and automobile paints.

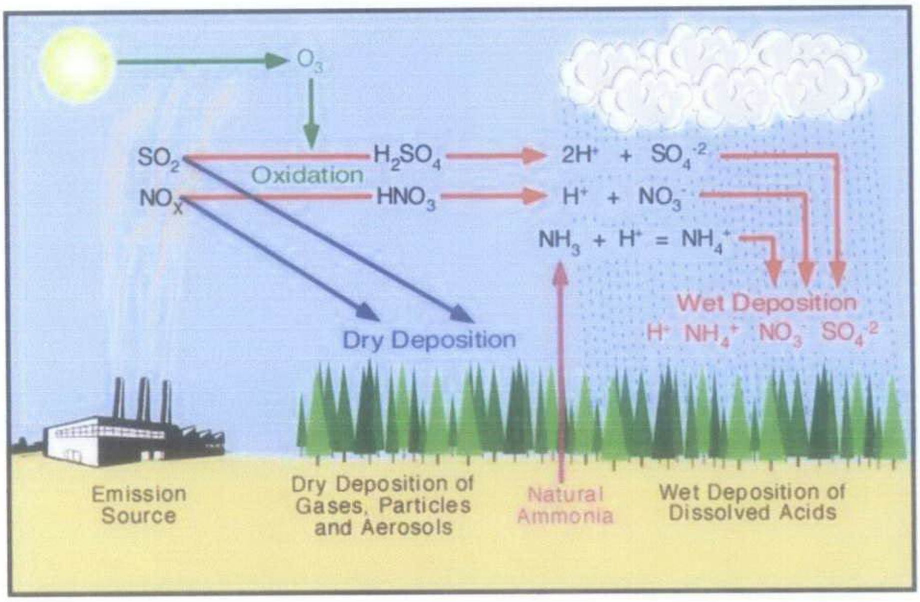

Figure 1.5: Formation of Acid Rain **[9]**

Greenhouse Gas and Hot Exhaust Gas

Apart from NO_X and SO_2, GDC also produces CO_2 and hot exhaust gas which will cause climate change. Climate change can be further categorised into global climate change and local climate change. In global climate change, the CO_2 which is a greenhouse gas, release from power plant will trap more heat on the earth surface, causing temperature to rise. During pre-industrial time, concentration of carbon dioxide is about 280 ppm but right now the concentration of carbon dioxide is 382 ppm, where power plants produce majority of them.

With global warming, world precipitation will change and hence are more difficult to predict. Whether or not rainfall will increase or decrease remains difficult to project for specific regions. Then sea level will rise and the change in temperature will affect forests, crop yields, and water supplies. Climate change could also affect human health, animals, and many types of ecosystems.

On the other hand, local climate change has the same effect like global climate change however it is more likely to be caused by the hot exhaust gas released from power station than carbon dioxide. A classic case of local climate change would be Cameron Highland where it experiences rapid rise in temperature over the decades due to rapid development in the area. It is not used to be as cool as before anymore. Same goes with the surroundings of power plant like GDC, the surrounding temperature will definitely rise and if the rise in temperature is high, it will cause problems to surrounding plants and animals due to sudden change of climate.

1.2 Problem Statement

While Gas District Cooling (GDC) has a lot of benefits, but its actual environmental impact has yet to be assessed. The exhaust gas from GDC is suspected to contain enough SO_X and NO_X to cause acid rain when they are in contact with clouds. Acid rain destroys the surrounding ecosystem, nearby buildings and harmful to human being. Besides that, the exhaust gas is also very hot, so it is also speculated that it will cause rise in temperature at the surroundings. The change in temperature will affect the flora and fauna's habitat, making it unsuitable for them to stay there.

1.3 Objectives

The objective of this project is to assess the environmental impact of cogeneration power plant onto the surrounding environment.

1.4 Scope of Work

The study will be done at the GDC plant at UTP and the parameters that will be studied are CO_2, CO, NO_X, and SO_X temperature, and humidity. This study will be done within 1 year which is from July 2010 till August 2011.

The scope of work to be accomplished in FYP 1 is:

1. Research related data and information on the project
2. Collect surrounding temperature and humidity data

The scope of work to be accomplished in FYP 2 is:

3. Collect gas samples from GDC to be analysed using fixed gas analyser
4. Present all the data collected in graphics form
5. Conduct benchmarking by comparing the data with other power stations and standards available to determine if GDC fulfil the requirements. Comparison between full load and partial load is also conducted.

1.5 Significance of the Project

Although there is a lot of hype about GDC or cogeneration power plant due to its ability to produce clean energy and highly efficient but until now no one has actually assessed their environmental impact. This project will fill that vacuum by monitoring the emissions and surrounding temperature, proving once and for all that GDC is indeed safe and environmental-friendly. It will give assurance for countries and companies wishing to pursue GDC to produce electricity that GDC is definitely environmentally friendly. It will also prove that GDC will allow countries to save carbon credit by cutting down CO_2 emissions and use those credits for carbon trading.

CHAPTER 2

LITERATURE REVIEW

Many researches, studies, experiments and modelling had been done about cogeneration plants. However, most of them are related to increasing its efficiency, very little studies have been done on the environmental damages caused by cogeneration plant. Thankfully, recently a lot of them have realised the gap between cogeneration plant and its environmental impact and lots of observations have been done.

These studies are very important because through them, cause and effect of the environment damages can be identified and solved before the whole world starts to adopt this technology. Weidner and Mez (2008) **[10]** said that the ever since the Federal Government of Germany introduced the Thermal Act and the Act for Promotion of Cogeneration, many original power plants has been modified for cogeneration and many cogeneration plants have been constructed however due to the lack of understanding of cogeneration process, local climate has been affected by them.

Then, Lucon and Goldemberg (2010) **[11]** proved that sugarcane bagasse, which is a by-product in the sugar and ethanol production, can be used for electricity cogeneration and the exhaust fumes produced are safe for the environment and locals. Rabl et al. (1988) **[12]** have showed that cogeneration plant significantly decrease the pollutant produced compared to traditional power plant however the level of pollutant released by cogeneration plant is still very high.

Most published works praises that cogeneration plant can be considered as renewable energy and it has a lot of benefit towards the environment however many of them do not conduct any studies to prove that. For example, Stipanuk and Denlea (1986) **[13]** mentioned that cogeneration is the way to cut energy costs and protect the environment however how cogeneration protects the environment is never mentioned. Same goes with Mosekilde and Meyer (1981) **[14]** where they said that cogeneration of steam and electricity is a reduction to fuel use and hence protect the environment. Lastly a study by Norman (1981) **[15]** says that despite cogeneration's high efficiency, it needs to be built in a massive number due to its lack of capacity; this in turns will actually make the environmental damages worse than traditional power plant. A lot of studies similar like those mentioned but none of them actually take a reading at the exhaust gas and observe the local temperature rise. This might because they only compare the environmental damages done with conventional power plant, hence if there is an improvement, no further studies should be done. It is like choosing the best from the worst.

Apart from that, according to Charles (2009) **[16]**, it focuses on the use of excess heat using cogeneration technology rather than improvement in design for new cogeneration plant. Works like Marinova et al. (2008) **[17]** and Ross (1989) **[18]** also emphasize on harnessing thermal energy from their paper mills or manufacturing plants to either heat up the nearby district or produce additional power. These mean that, more people are actually looking ways to extract heat waste from existing plant for further usage, so they do not really care to improve exhaust fumes released by their plant.

However, not all hopes are lost. There are increasing number of researches studying the actual environmental impact by cogeneration plant and ways to reduce the. For example, in the latest study by Aklilu and Gilani (2010) **[19]**, they found that the exhaust gas flow of a cogeneration plant working at 50% load is almost the same as a cogeneration plant working at 100% load. Other than that, they also noticed that the efficiency increases while the specific fuel consumption decreases as the cogeneration plant's load increases.

There is still lack a lot of studies on the environmental impact by cogeneration plants and also insufficient data to prove their benefits to the environment. Most statements about how good cogeneration plants on the environment are just based on comparison with traditional power plant. That is why this project is in important, that is to really show the true impact of a cogeneration on the environment and device solutions to solve them.

After further research, it is found that people around the world, although small in number, has already started studying on this topic and the following is the summary of their published journals and overall conclusion.

Katsigiannis and Papadopoulos (2005) **[20]** proposed a general and systematic procedure with computer codes along to assess small-scale CHP system installations. They will be able to assess it technically, economically and environmentally. The proposal is based on a case study in a local textile industry which uses as CHP units and based on the economic incentives provided by Greece's policy. The proposal is able to be economically feasible and environmentally friendly.

On the other hand, Chicco and Mancarella (2008) **[21]** are trying to introduce a unified model to assess energy and environmental performance of poly-generation systems fuelled by a unique source of primary energy which in this case is natural gas. They use PPES (Poly-generation Primary Energy Saving) and PCO2ER (Poly-generation CO_2 Emission Reduction) indicators have respectively been used to assess the primary energy saving and the CO_2 emission reduction brought by taking advantage of the combined generation by the power producing system. In this paper, quad-generation systems which combine electricity, hot water, steam and cooling have proven the effectiveness of the indicators. The indicators proposed should be taken into consideration in policy development in the energy industry. The authors hope to extend the models to cover other thermal energy input such as gas from biomasses and hydrogen.

Chicco and Mancarella (2007) **[22]** again had another paper. The paper has presented a novel approach to assess the GHG (Greenhouse Gases) emission performance from cogeneration and trigeneration systems. The TCO_2ER (Trigeneration CO_2 Emission Reduction) indicator is used to assess the emission reduction brought by the combined energy systems with respect to conventional references. The characteristics of all the equipment involved in the analysis have been modelled through black-box models. The approach has been formulated by zooming on the CO_2 emissions as the most relevant GHG alongside with methane contained in the thermal equipment exhaust gases or leakages of GHG substances used as refrigerants in the chillers.

On the following year, Chicco and Mancarella (2007) **[23]** did a global and local emission impact assessment of distributed cogeneration. The paper presents a general methodology to assess the emission impact due to adoption of DG CHP (Distributed Generation Combined Heat and Power) systems in the urban areas under general operating conditions including partial-load operation. Then, Chicco and Mancarella (2009) **[24]** make simplified models based upon the difference between local and global emissions have been presented and their suitability has been discussed for different air pollutant. Different levels and durations of partial-load operation are represented in a synthetic way through the equivalent load model introduced in the paper to get a fuller picture of the actual emission pressure from CHP system under real operating conditions. At low equivalent load, the NOX emissions are critically high and the CO emissions are also alarming high at basically any load condition but it is found that CO emissions increase tremendously at partial load compared to full-load.

In another paper, energy equilibrium approach was used to assist in decision making by modelling and optimizing cogeneration-based DE (District Energy) systems by Wu and Rosen (1999) **[25]** The energy equilibrium model is used to study conventional systems and cogeneration-based DE systems for providing heating, cooling and electrical services. It also helps develop optimal configurations while considering economic and environmental factors. The energy equilibrium model is formulated and solved using the software called WATEMS which uses sequential non-linear programming to calculate the intertemporal equilibrium of energy supplies and demand. The method can be used to look into the potential opportunities for new cogeneration based DE systems and to maximize the benefits realizable from existing plans for such system.

Costa et al. (2007) **[26]** had produced a paper investigating the economics of trigeneration in a kraft pulp mill for enhanced energy efficiency and reduced GHG emissions. The paper aims to enhance process efficiency in the pulp and paper industry by comparing 3 cases. They are Power production from liberated steam capacity using a cogeneration unit, Maximised energy savings using an AHP (Absorption Heat Pump) and power production combined with heat upgrading and cold production using a trigeneration unit. The SPB (Simple Payback) and NPV (Net Present Value) of the options have been calculated and the results suggest the economic viability for all options should be investigated. All three cases produce positive NPV which means that they are all viable.

A paper about environmental and health benefits of district cooling using utility-based cogeneration in Ontario, Canada was conducted by Hart and Rosen (1996) [27]. There are two district-cooling scenarios assessed, the first assumes implementation of utility based cogeneration/absorption chilling to satisfy a minor portion of the cooling demands of the residential-commercial-institutional sector. The other scenario is assumes a larger portion of the sector cooling demands are satisfied using utility-based cogeneration/absorption chilling. The paper look into the reductions in emissions, effects and environmental and health costs with the introduction of utility-based cogeneration. The effects considered are mortality, morbidity, lost work days, lost crop yield, lost fish yield, building damage, global warming and aquatic thermal effect. This study found out that the implementation of utility-based district cooling, along with utility-based heating, is very beneficial to the citizens around the area and the environment.

	1989 Emissions per annum	
Fuel use and type of emission	Utilities	Other sectors
Fuel use (PJ):		
gas	0	824
oil	14	782
coal	286	21
uranium	640	0
Atmospheric emissions:		
SO_2 (kt)	321	1,060
NO_x (kt)	92	526
CO_2 (kt)	32,000	132,000
CO (kt)	4	3,500
particulate (kt)	11	837
VOC (kt)	0.5	775
radiation (Bq)	8.2E15	...
Aquatic emissions:		
thermal (PJ)	591	—
radiation (Bq)	2.7E15	—
Solid waste (kt):		
FGD waste	126	—
coal ash	880	—
spent uranium	1.04	0
uranium tailings	107	0
Mine effluent (kt):		
coal mine	12.8	...
uranium mine	24.8	0

Table 2.1: Environmental Emissions Associated with the Existing Energy System

Based on all the papers above, it is found that a lot of research focuses on small sized turbines or microturbines which are same like the turbines at GDC UTP. Among all, most of the studies only observe CO2 emissions while only a handful of others look at other emissions such as NOX and CO.

This final year project will fill the research study gap by conducting observation on the release of CO, CO2, NOX and SOX along with the rise of surrounding temperature due to cogeneration power plant. The outcome of this project will show if cogeneration technology is as clean as it is thought to be all along.

CHAPTER 3
METHODOLOGY

3.1 Project Plan

1. Research on subjects and topics related to this project.
2. Plan the execution of the project using flowchart.
3. Collect the data for the targeted parameters (CO_2, CO, NO_X and SO_X), temperature and humidity from the environment.
4. Analysis will be done by comparing the data acquired, compare them with other power plants and international standards and look for trends.

3.2 Analysis Technique

3.2.1 Chemical Equations

Before any observation is done, the fundamental chemical equation for gas turbine combustion process must be known. This is to understand the reason for the formation of nitrogen oxide and sulphur oxide.

When combustion process is occurs in gas turbine, it will experience complete and incomplete combustion.

In complete combustion, it will produce carbon dioxide.

$$CH_4 + 2\ O_2 \rightarrow CO_2 + 2\ H_2O$$

On the other hand, for incomplete combustion, it will produce carbon monoxide which is very poisonous to human.

$$2\ CH_4 + 3\ O_2 \rightarrow 2\ CO + 4\ H_2O$$

Although nitrogen does not take part in combustion process however at high temperatures, some nitrogen will be converted to NOX, usually between 1% and 0.002% (2 ppm).

$$N_2 + O_2 \rightarrow 2\,NO$$

$$N_2 + 2\,O_2 \rightarrow 2\,NO_2$$

Apart from that, due to the presence of sulphur inside natural gas, it will also react with oxygen in high temperature.

$$S8 + 8\,O_2 \rightarrow 8\,SO_2$$

3.2.2 Data Collection

1. The exhaust gas of the power plant would be taken via the sample gas outlet situated at the bottom of the stack. The exhaust gas is pumped from the top of the chimney stack and then cooled before flowing into the gas sample bags. Then, the gas is taken in the morning with the gas turbine is running at full load and another time at night when the gas turbine is running at half load. A few measurements are taken to get the average reading.

2. The gas sample bags will be brought to the fixed gas analyser for composition analysis with emphasis given to CO_2, CO, NO_X and SO_X.

3. The atmospheric air is tested directly from the fixed gas analyser since the air composition for air intake at GDC and air composition at the lab will be the same.

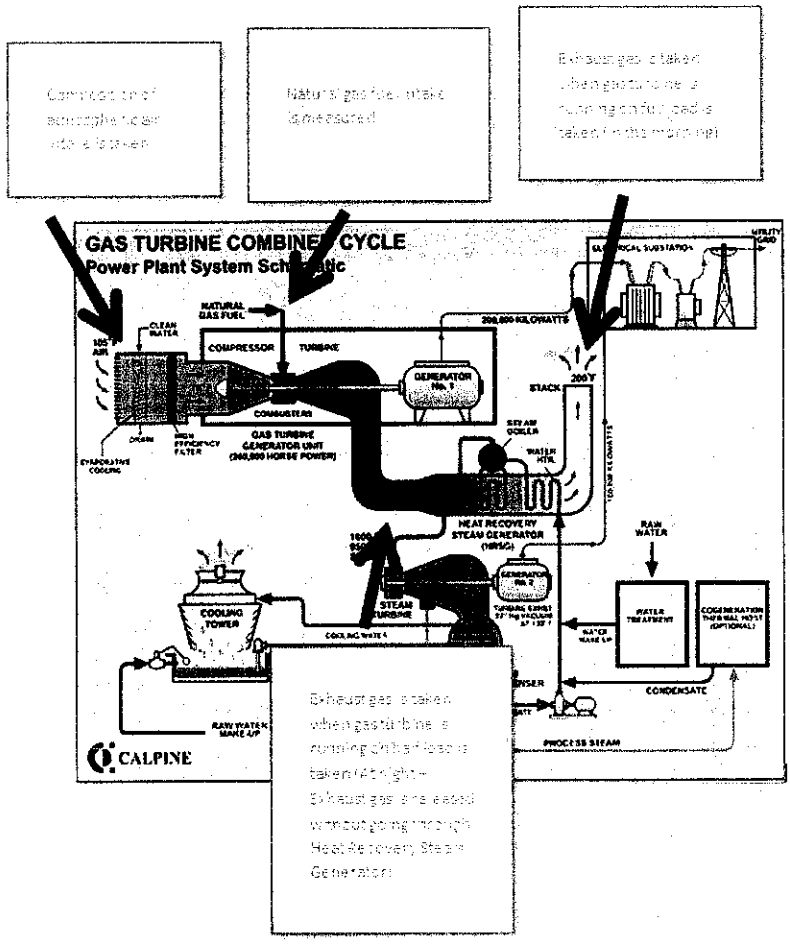

Figure 3.1: Measurement Points in GDC **[28]**

4. No samples can be taken for the natural gas because there is no sample gas outlet like exhaust gas, hence the gas supplier is called to provide the composition of the natural gas.

5. The temperature of the natural gas and exhaust gas cannot be taken manually, hence the reading would be taken from the temperature sensors installed at the natural gas inlet and chimney stack. For temperature of air intake, it will be measured manually using thermometer.

6. Temperature and humidity surrounding GDC are taken at a distance of 50m, 100m, 150m, 200m and 500m at various locations. Readings are taken in the morning and at night. 500m will be assumed as ambient condition.

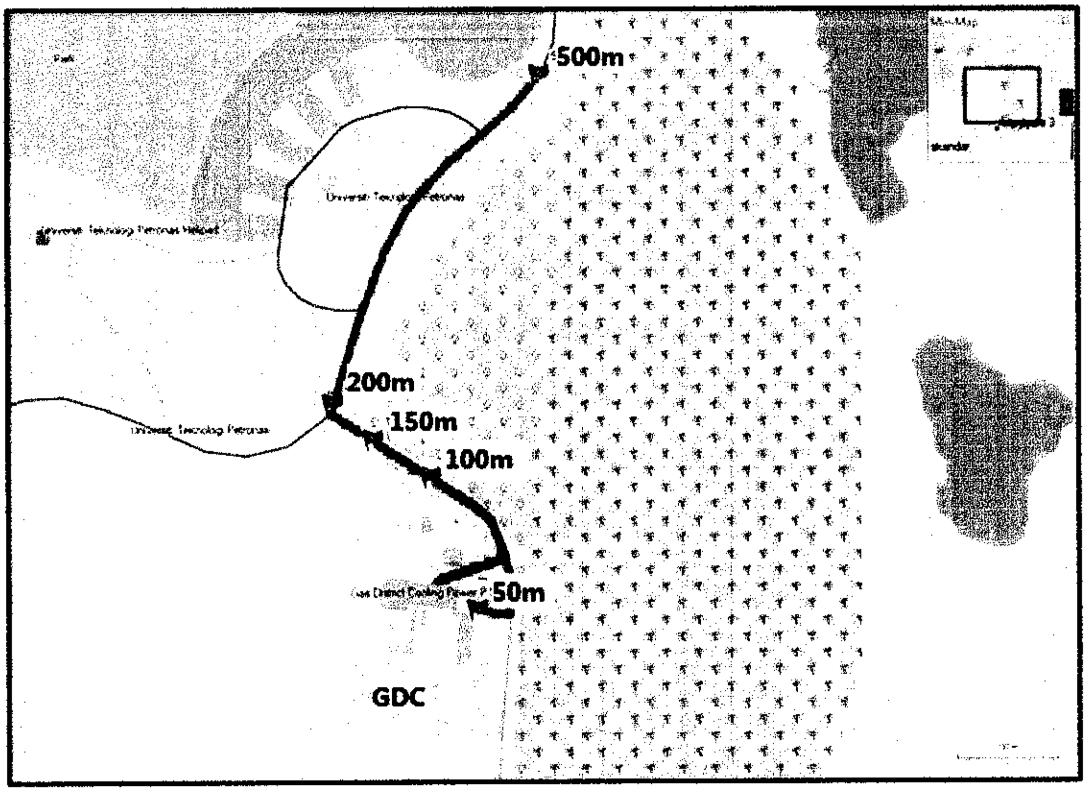

Figure 3.2: 50m, 100m, 150m, 200m, and 500m from GDC Positioned in GPS (Map Courtesy of Garmin)

3.2.3 Data Analysis

1. Benchmarking is conducted between the exhaust gases of GDC with other fossil power plant to determine if GDC is more environmental friendly.
2. Evaluation is conducted on exhaust gases of GDC to determine if GDC comply to European Union and United Stated standards for power plant gas emissions. European Union and United States standards are used since there is no standard set by the Malaysian government. Besides that European Union and United States are famous for their strict standards.
3. Comparison is done between the surrounding temperature of GDC and normal ambient temperature to spot for rise in temperature due to the release of hot gases from GDC.

3.3 Project Execution Flow Chart

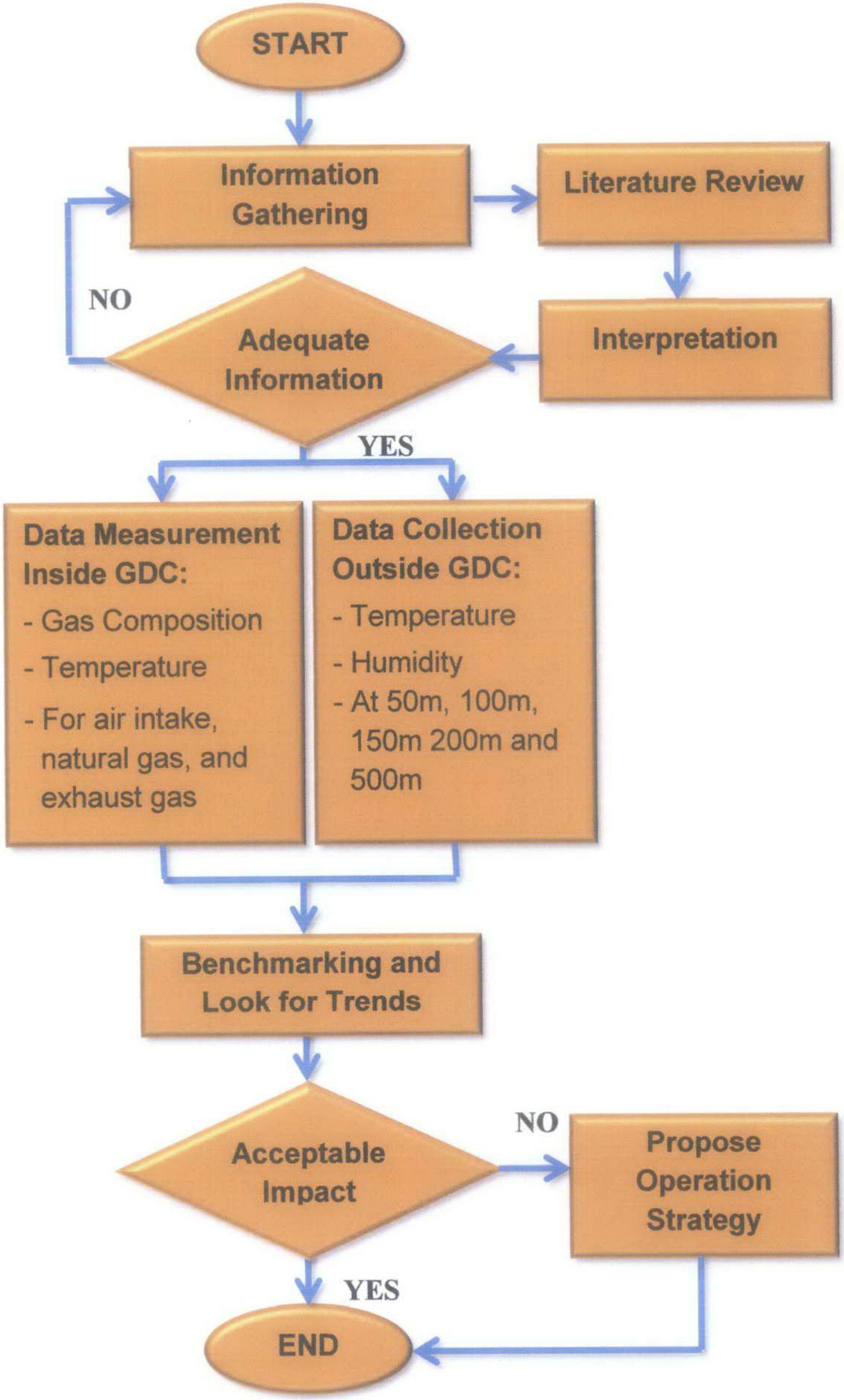

Figure 3.3: Project Execution Flow Chart

3.4 Key Milestone

No	Item	Due (Week)	Status
FYP 1			
1	Obtaining Equipment	9	Completed
2	Data Collection I	14	Completed
FYP 2			
7	Data Collection II	9	Completed
8	Data Analysis	11	Completed

Figure 3.1: Key Milestone

Final Year Project 1

No	Detail / Week	1	2	3	4	5	6		7	8	9	10	11	12	13	14
1	Selection of Project Topic							Mid Semester Break								
2	Preliminary Research Work															
3	Literature Survey & Information Gathering															
3	Submission of Preliminary Report															
4	Obtaining Equipment															
	Plant Visit															
6	Data Collection															
7	Submission of Progress Report															
8	Seminar															
11	Submission of Interim Report Final Draft															
12	Oral Presentation	During Study Week														

Table 3.2: Gantt Chart for FYP 1

Final Year Project 2

No	Detail / Week	1	2	3	4	5	6		7	8	9	10	11	12	13	14
1	Data Collection							Mid Semester Break								
2	Submission of Progress Report															
3	Analysis															
4	Pre-EDX															
5	Submission of Draft Report															
6	Submission of Dissertation (Soft Bound)															
7	Submission of Technical Paper															
8	Oral Presentation															
9	Submission of Dissertation (Hard Bound)								During Study Week							

Table 3.3: Gantt Chart for FYP 2

Legend

Week allocated

3.5 Tools and Equipment Required

3.5.1 Gas Sample Bags

Gas sample bags are made from durable plastic with strong adhesive at the plastic borders to ensure no gas leakage. The gas samples can be stored for up to 2 days however the best result can be obtained by analysing the gas on the day of collection itself. Its only downside it that it is very expensive and can only be used once.

Specification: Able to keep 1L of gas samples for 2 days.

Figure 3.4: Gas Sample Bags

3.5.2 Fixed Gas Analyser

Portable gas analyser is not used in this project due to their inability to detect SO_X which is the main thing this project is about. Hence, a fixed gas analyser is opted instead. It has the ability to measure more than 50 types of gases in a given air sample however due to its bulkiness, it is very immobile. That is why gas sample bags are needed to transfer the gas from GDC exhaust to the fixed gas analyser

Specification: Able to detect targeted gases which are CO_2, CO, NO_X and SO_X.

Figure 3.5: Fixed Gas Analyser

3.5.3 Digital Thermometer

Digital thermometer is very accurate in their reading however their detection range is very small. It is very suitable for the project since only ambient temperature will be measured which is around 25°C - 40°C. Temperature of places that is not physically reachable will be taken using temperature sensors installed.

Specification: Has detection range of -10°C until 120°C

Figure 3.6: Digital Thermometer

3.5.4 Hygrometer

Hygrometer is used to measure relative humidity. Relative humidity is a measure of how much water the air is holding, relative to the maximum amount of water the air could possibly hold at a given temperature. Because of the delicate design of hygrometers, it is easy for them to become inaccurate.

Specification: Able to detect relative humidity at ambient temperature.

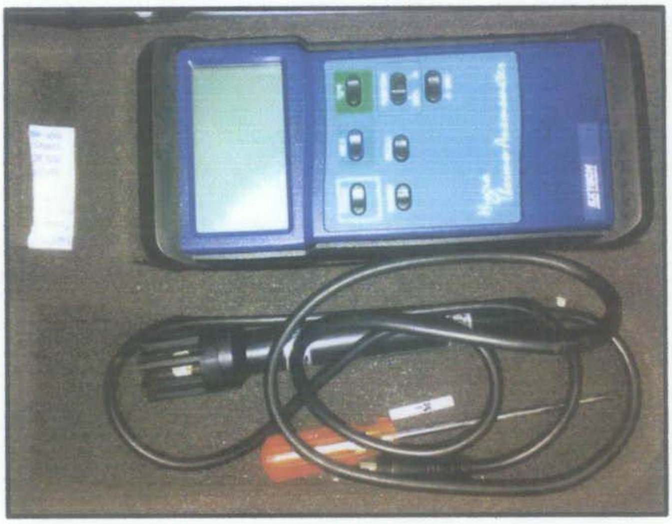

Figure 3.7: Hygrometer

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Inlet Configuration

4.1.1 Interview with GDC Operators

An early interview was conducted with operators inside GDC. They said that the plant does have problems with SO_X release into the atmosphere. The Malaysian government environment agency, Jabatan Alam Sekitar (JAS), which does annual check on GDC has detected high amount of SO_X. This information is very crucial because this project needs to ensure GDC is safe for human and the environment. Hence, operating data such as chilled water provided, electricity produced and fuel consumption are taken so that the operating pattern can be determined.

Apart from that, he has provided specifications of GDC as below:

Equipment	Capacity	Quantity	Total
Gas Turbine Generator	4.2 MW	2	8.4 MW
Heat Recovery Steam Generator	12 T/h	2	24 T/h
Steam Absorption Chiller	1250 RT	2	2500 RT
Electric Cooled Chiller	325 RT	4	1300 RT

Table 4.1: Specifications of GDC

4.1.2 Chilled Water Supplied versus Time

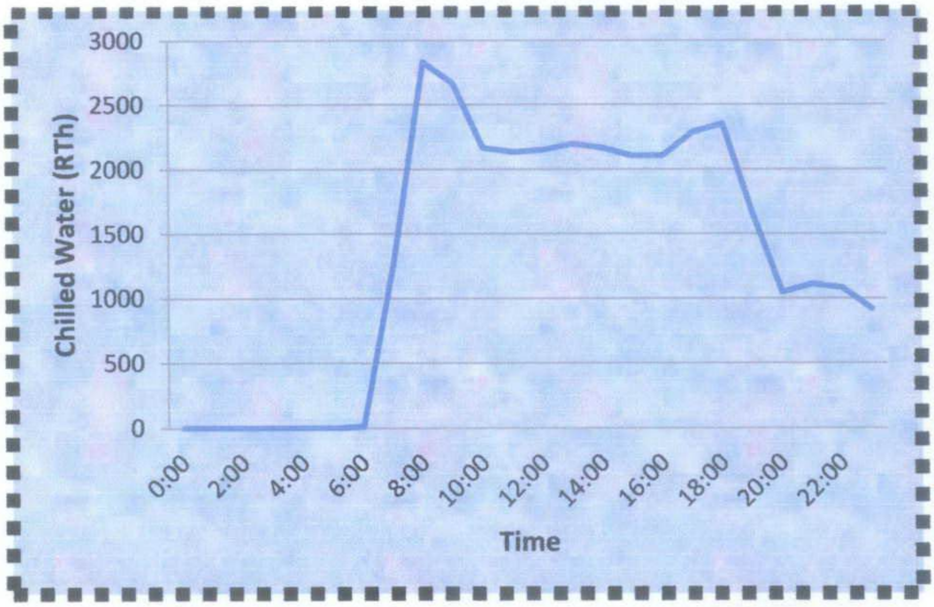

Figure 4.1: Chilled Water vs. Time Graph

Analysis

Based on the raw data in **APPENDIX C**, **Figure 4.1** is obtained. The chilled water is only supplied starting from 7 in the morning. This is because the staffs only enter the academic complex around that time. From midnight until 6 in the morning, no chilled water is used. Then after 6 in the evening when most of the classes have finished, the chilled water supplies dropped significantly. Hence, two observations have to be made, one in the morning to check on the condition when the plant run while providing chilled water and another at night to see the condition when the plant provides power only.

4.1.3 Electricity Produced versus Time

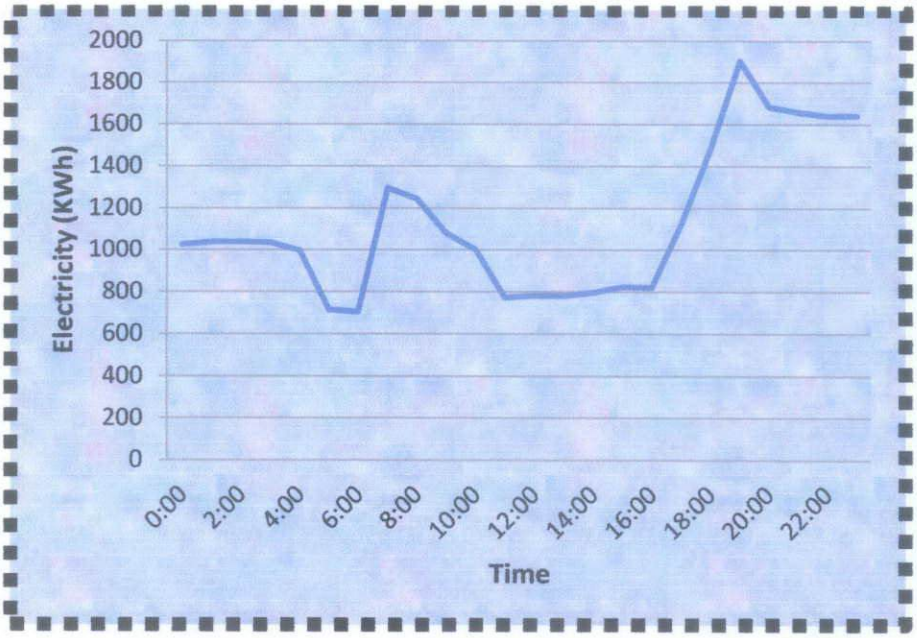

Figure 4.2: Electricity Produced vs. Time Graph

Analysis

From the graph in **Figure 4.2** which is also based on the raw data in **APPENDIX C**, it can be observed that there is fluctuation in electricity supplied to the university. One of the peaks is at 7 in the morning is due to activating the pump to transfer chilled water into the academic complex. The peak period is when classes are on while off-peak period is when classes are off. The electricity usage at night is high because electricity is used for lighting street lamps and hostel usage.

4.1.4 Fuel Consumption versus Time

HOUR	FUEL (m^3)
0:00	1114
1:00	1114
2:00	1114
3:00	1114
4:00	1114
5:00	1114
6:00	1114
7:00	1114
8:00	1114
9:00	1114
10:00	1114
11:00	1114
12:00	1114
13:00	1114
14:00	1114
15:00	1114
16:00	1114
17:00	1114
18:00	1114
19:00	1114
20:00	1114
21:00	1114
22:00	1114
23:00	1114
Total	**26738**

Table 4.2: Fuel consumed according to time

Analysis

From **Table 4.1**, the amount of fuel consumed is the same all the time. Since the data is same for all, no graph is needed to look for trends. This shows that the fuel consumed by the plant is the same whether it is running on full load or partial load.

4.1.5 Chilled Water Supplied versus Day

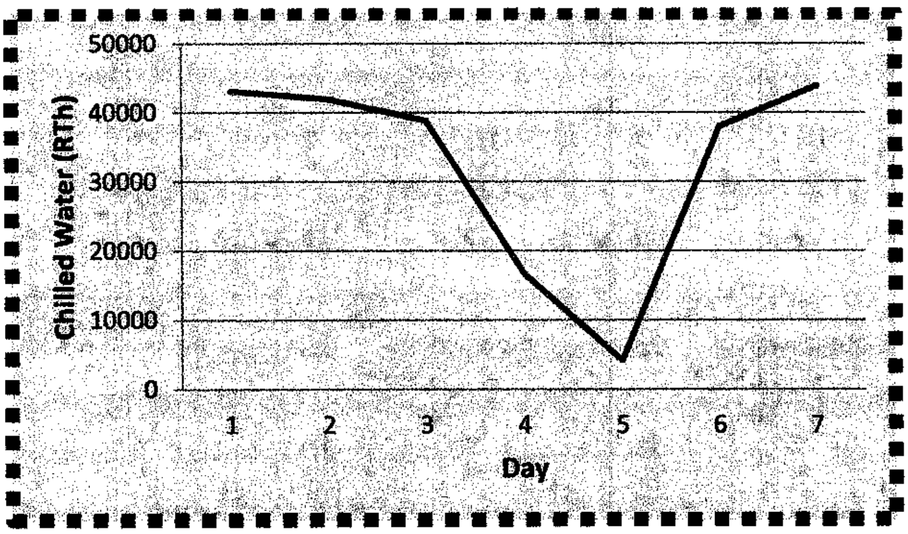

Figure 4.3: Chilled Water Supplied vs. Day Graph

Analysis

From the graph in **Figure 4.3** where the raw data is in **APPENDIX C**, the daily average chilled water supplied is almost the same except Day 4 and Day 5. This is because Day 4 is a Saturday where the staffs work half day and Day 5 is Sunday where no staffs come to work except a small number of them. That explains the sharp decrease in use in those 2 days.

4.1.6 Electricity Produced versus Day

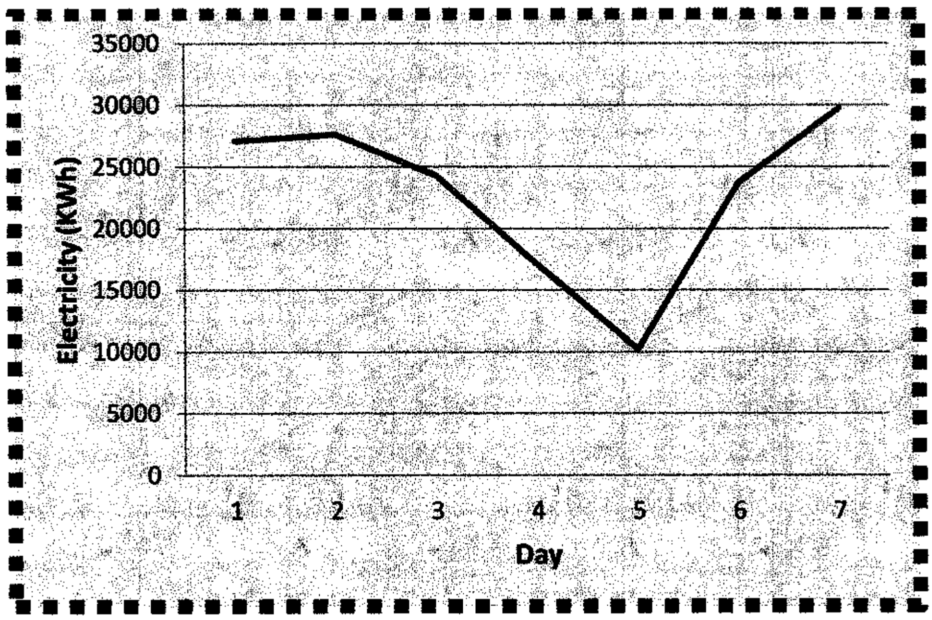

Figure 4.4: Electricity Produced vs. Day Graph

Analysis

The pattern of the graph in **Figure 4.4** is almost the same like the one in **Figure 4.3**. The reason for the sharp decrease in electricity produced is the same, where Day 4 and Day 5 used less electricity because both days are in weekend. Again, the raw data is available in **APPENDIX C**.

4.1.7 Fuel Consumed versus Day

The fuel consumed every week is as below:

DAY	FUEL (m^3)
1	26738
2	26738
3	26738
4	26738
5	26738
6	26738
7	26738

Table 4.3: Fuel consumed according to day

Analysis

From **Table 4.2**, it can be seen that the total fuel consumed remains the same. Since all the values are constant hence no point using graphs to represent them. The table shows that the gas turbines operate at the same load condition throughout the whole week, even during weekends, it still consumes the same amount of fuel.

From all the data collected, some conclusions can be drawn about the operating pattern of GDC.

(a) GDC operates full load in the day and half load at night hence gas samples have to be taken twice, once in the morning and another time at night.

(b) The gas turbine operates at the same condition during weekdays and weekends, so the collection of data during any day of the week will be consistent.

(c) GDC will utilise Heat Recovery Steam Generator (HRSG) in the morning only hence the temperature of the exhaust gas is predicted to differ in between morning and night, hence both day and night surrounding temperature has to be taken.

4.1.8 Inlet Parameters

Air Intake

	Full Load (Day)	Half Load (Night)
N2	78.08%	78.11%
O2	29.14%	29.10%
CO2	0.03%	0.01%
Temperature	31.2°C	29.0°C
Humidity	72.1% RH	83.5% RH

Table 4.4: Average composition, temperature and humidity of air intake

Natural Gas

	Whole Day	
Methane (CH_4)	82.0% - 94.0%	
Ethane (C_2H_6)	3.0% - 6.0%	
Propane (C_3H_8)	0.1% - 2.0%	
Butane (C_4H_{10})	0.1% - 0.7%	
Sulphur	10 ppm	
Temperature	Day	Night
	43°C	45°C

Table 4.5: Average composition and temperature of air intake

4.2 Data Collection

4.2.1 Exhaust Gas

	Full Load (Day)		Half Load (Night)	
	Gas Turbine 1	**Gas Turbine 2**	**Gas Turbine 1**	**Gas Turbine 2**
O_2	19.85%	19.83%	19.81%	19.82%
CO_2	0.81%	0.83%	0.80%	0.82%
CO	49.7 mg/Nm^3	47.4 mg/Nm^3	41.8 mg/Nm^3	43.6 mg/Nm^3
NO_X	97.2 mg/Nm^3	79.0 mg/Nm^3	82.2 mg/Nm^3	80.5 mg/Nm^3
SO_X	3.9 mg/Nm^3	3.9 mg/Nm^3	1.1 mg/Nm^3	0.7 mg/Nm^3
Temperature	430.0°C	461.8°C	456.1°C	478.1°C

Table 4.6: Average composition and temperature of exhaust gas

The data obtained in Table 4.5 will be used for comparison. The data is compared to European Union and United States emission limit and emissions from coal-fired and oil-fired power plant are also compared to see the reduction of emissions by GDC. The data between full load and half load is compared to see the effect of running at both conditions.

Comparison with EU and US Standards

Table 4.6 shows the comparison between emission limits for facilities burning fossil fuels set by European Union, United States and GDC's Gas Turbine 1 and Gas Turbine 2.

	EU Standards Limit	US Standards Limit	Full Load Emission		Half Load Emission	
			GT 1	**GT 2**	**GT 1**	**GT 2**
CO (mg/Nm^3)	100	N/A	49.7	47.4	41.8	43.6
NO_X (mg/Nm^3)	200	310	97.2	79.0	82.2	80.5
SO_X (mg/Nm^3)	35	310	3.9	3.9	1.1	0.7

Table 4.7: Comparison of EU and US Standards Limit with GT 1 and GT 2 of GDC

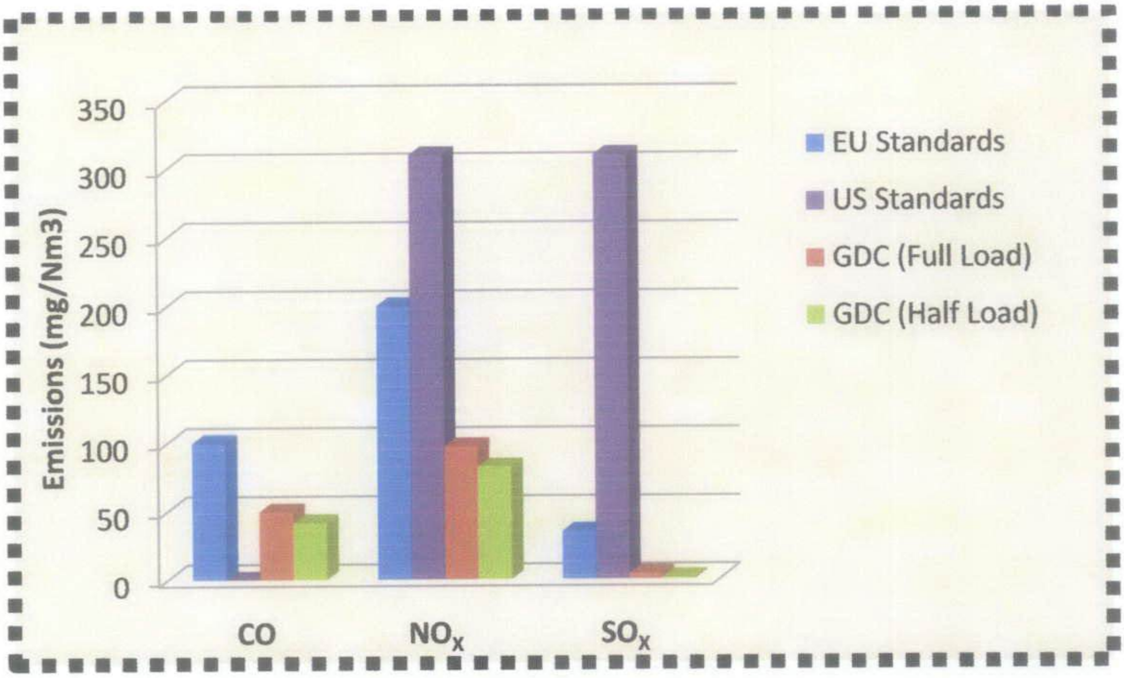

Figure 4.5: Comparisons of CO, NO_X, and SO_X of GDC with EU and US Standards

Note: There is no US standard for CO emission limit

From the comparison chart in **Figure 4.5**, GDC has perform exceptionally well in complying with the EU and US standards for emission limits. All the emissions from GDC are less than half the allowable limit. This proves that GDC is indeed a very environmental friendly power plant.

Comparison with Other Fossil Fuel Power Plant

Coal-fired Power Plant: E.ON Maasvlakte, Netherlands

Figure 4.6: E.ON Maasvlakte Coal-fired Power Plant **[29]**

	GDC	E.ON Maasvlakte	Percent Difference
CO (mg/Nm^3)	48.6	N/A	-
NO_X (mg/Nm^3)	88.1	65.0	+35.5%
SO_X (mg/Nm^3)	3.9	40.0	-90.3%

Table 4.8: Comparison of emissions from GDC and Maasvlakte Coal-fired Power Plant

From the comparison in **Table 4.7**, GDC produced more NO_X than the coal power plant however it manage to significantly reduce SO_X, hence cutting the risk of acid rain.

Oil-fired Power Plant: E.ON Grain Power Station, United Kingdom

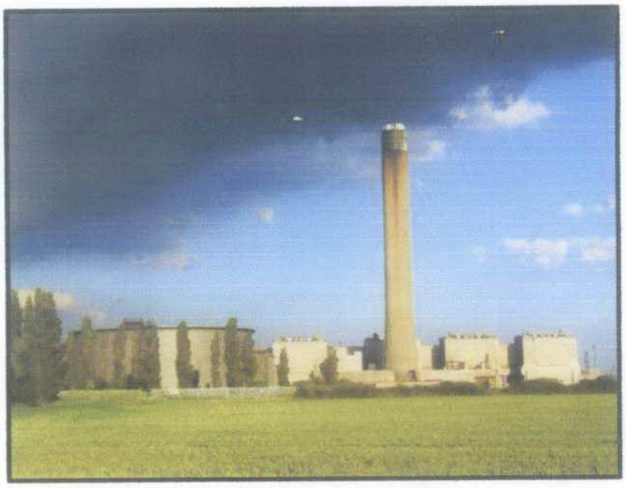

Figure 4.7: E.ON Grain Oil-fired Power Plant **[30]**

	GDC	E.ON Grain	Percent Difference
CO (mg/Nm^3)	48.6	98.0	-50.4%
NO_X (mg/Nm^3)	88.1	361.0	-75.6%
SO_X (mg/Nm^3)	3.9	1330.0	-99.7%

Table 4.9: Comparison of emissions from GDC and Grain Oil-fired Power Plant

From the comparison chart in **Table 4.8**, GDC outperformed oil-fired power plant by producing less than half of CO, NO_X and SO_X than the latter. The reduction in NO_X and SO_X also mean less risk of acid rain. In fact I was told by officer in E. ON that they will close down this plant by 2015 due to failure to meet emissions requirements but they will replace it with the newly constructed gas power plant.

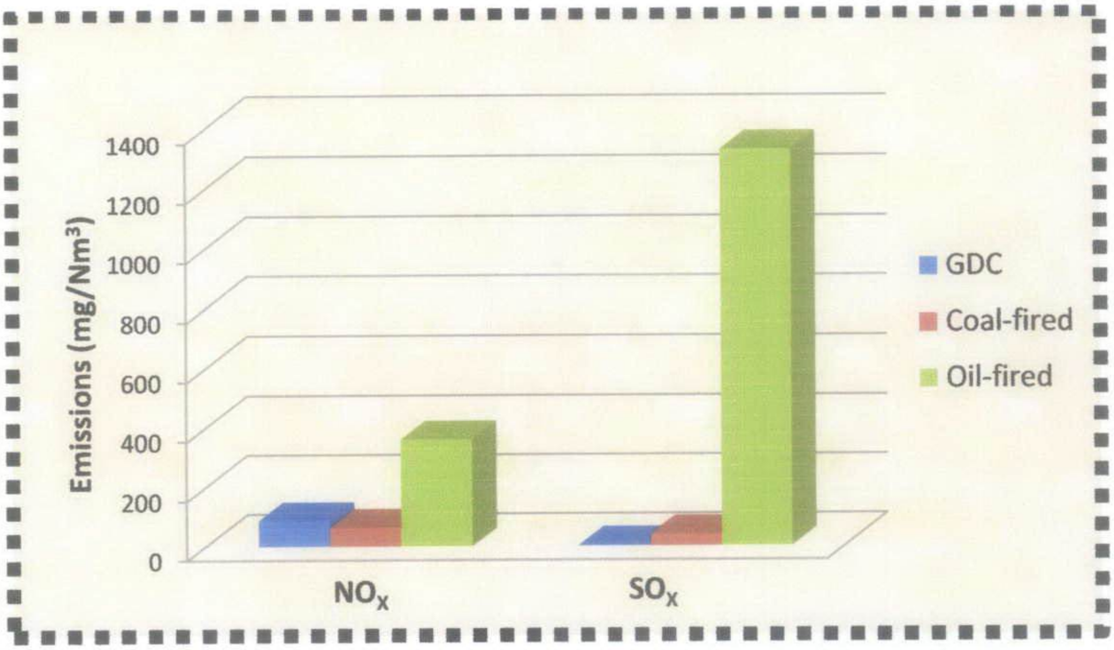

Figure 4.8: Comparisons of NO_X and SO_X of GDC with Coal-fired and Oil-fired Power Plant

From both comparisons, we can see that GDC is somewhat better than coal-fired and oil-fired power plant especially in reducing the emission of SO_X. Hence, it is very definite that cogeneration gas turbine power plant is the current most economical green and safe technology. Power producers should consider making the great leap forward by moving to upgrade their facilities to cogeneration gas-fired power plant.

Comparison between Full Load and Half Load

	Full Load	Partial Load	Percent Difference
O_2 (%)	19.8	19.8	0%
CO_2 (%)	0.82	0.81	+1.2%
CO (mg/Nm^3)	48.6	42.7	+13.8%
NO_X (mg/Nm^3)	88.1	81.5	+8.1%
SO_X (mg/Nm^3)	3.9	0.9	+3.3%
Temperature (°C)	445.9	467.1	-21.2°C

Table 4.10: Comparison of emissions and temperature between full load and partial load

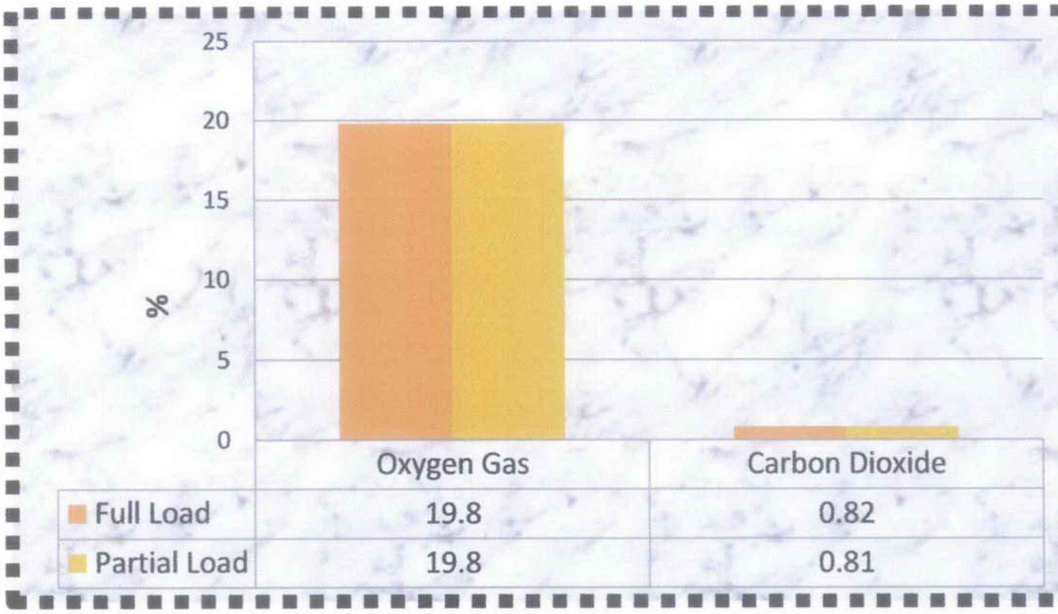

Figure 4.9: Comparisons of O_2 and CO_2 between Full Load and Partial Load

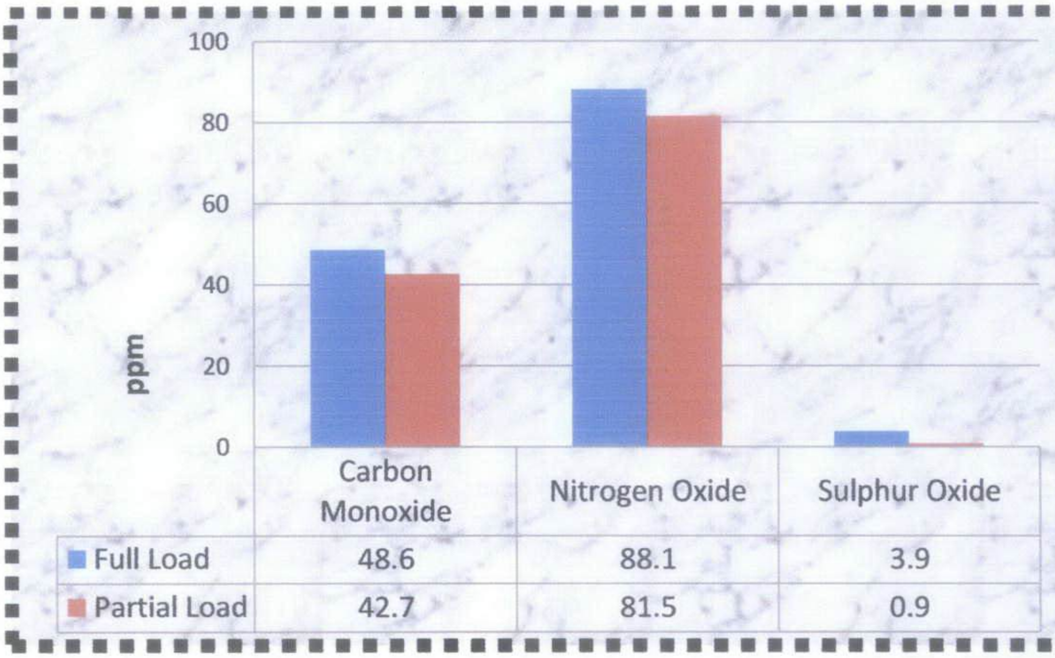

Figure 4.10: Comparisons of CO, NO_X, and SO_X between Full Load and Partial Load

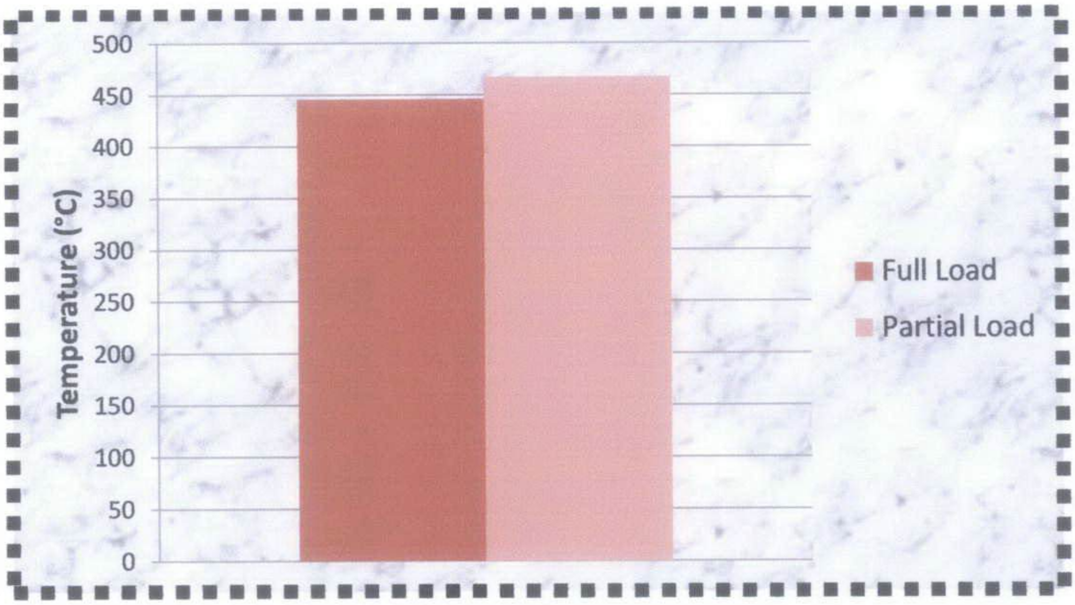

Figure 4.11: Comparison of Exhaust Gas Temperature between Full Load and Partial Load

From the series of comparison charts in **Figure 4.09**, **4.10** and **4.11**, between full load and partial load, it is noticeable that during partial load, gas turbine generates less CO, NO_X and SO_X than running during full load. This is due to the fact that less fuel is consumed during partial load than full load, hence less emission gases will be released too.

There is another important parameter which is the temperature. Notice that the temperature released by GDC when running at partial load is higher than full load. This is because when the GDC is running at full load in the day, both the gas turbines need not run on full capacity. However at night, when GDC runs at partial load, the lone gas turbine has to run at full capacity to meet the electricity demand, hence higher temperature of exhaust gas is released. The effect of those high temperature exhaust gas released into the surrounding will be analyse in the next section.

It can be concluded that GDC running at full load is better than running at partial load because although when GDC running at full load will release a bit more CO_2, NO_X, and SO_X however it has higher efficiency and heat energy in the exhaust gas is extracted which outweigh all the cons.

4.2.2 Surrounding Temperature and Humidity

	50m		100m		150m		200m		500m	
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
Day 1	34.0	29.8	33.3	29.5	33.3	29.4	33.0	29.5	33.1	29.0
Day 2	34.6	29.9	33.8	30.0	33.4	29.7	33.5	29.9	33.1	29.0
Day 3	33.9	29.7	33.1	29.3	33.7	29.0	33.0	29.2	33.0	29.3
Day 4	33.9	29.8	33.8	29.7	33.5	29.4	33.0	29.1	33.2	29.1
Day 5	34.0	30.2	33.9	30.0	33.4	29.8	33.1	28.9	32.8	28.7
Day 6	33.6	29.7	34.0	29.6	33.2	29.4	33.3	29.1	32.7	28.9
Day 7	33.8	29.5	33.8	29.5	33.5	29.5	33.4	29.4	32.9	29.2
Day 8	33.9	30.1	33.5	29.9	33.5	29.8	34.0	29.2	33.0	28.9
Day 9	34.4	29.6	33.9	29.3	33.9	29.2	33.9	28.5	33.2	28.4
Day 10	34.3	29.7	34.5	29.5	33.8	29.4	33.0	29.4	33.0	29.3
Average	34.0	29.8	33.8	29.6	33.5	29.5	33.3	29.2	33.0	29.0

Table 4.11: Temperature (in °C) at 50m, 100m, 150m, 200m, and 500m from GDC

	50m		100m		150m		200m		500m	
	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
Day 1	72.9	89.2	77.9	85.2	70.1	87.0	74.2	91.4	74.5	84.2
Day 2	70.0	87.5	71.4	80.5	72.1	86.3	69.8	85.3	72.3	85.4
Day 3	71.3	82.3	73.2	88.3	73.3	82.4	73.9	85.9	74.6	82.9
Day 4	77.5	79.2	74.4	83.4	78.9	80.3	72.6	84.3	75.1	86.4
Day 5	73.4	83.2	73.7	80.2	74.5	81.4	74.0	81.0	73.3	85.1
Day 6	80.1	85.6	78.1	79.9	80.4	82.9	73.6	80.4	79.3	84.5
Day 7	78.2	84.2	73.4	84.0	75.3	86.3	79.9	88.0	79.1	82.3
Day 8	74.3	88.9	73.1	85.4	76.7	84.4	74.7	87.1	74.3	89.0
Day 9	75.4	82.3	75.4	85.3	73.0	82.3	76.0	79.9	75.2	82.0
Day 10	76.0	85.7	72.6	82.5	71.2	85.0	73.5	89.6	74.8	86.1
Average	74.9	84.8	74.3	83.5	74.6	83.8	74.2	85.3	75.3	84.8

Table 4.12: Humidity (in % RH) at 50m, 100m, 150m, 200m and 500m from GDC

Temperature

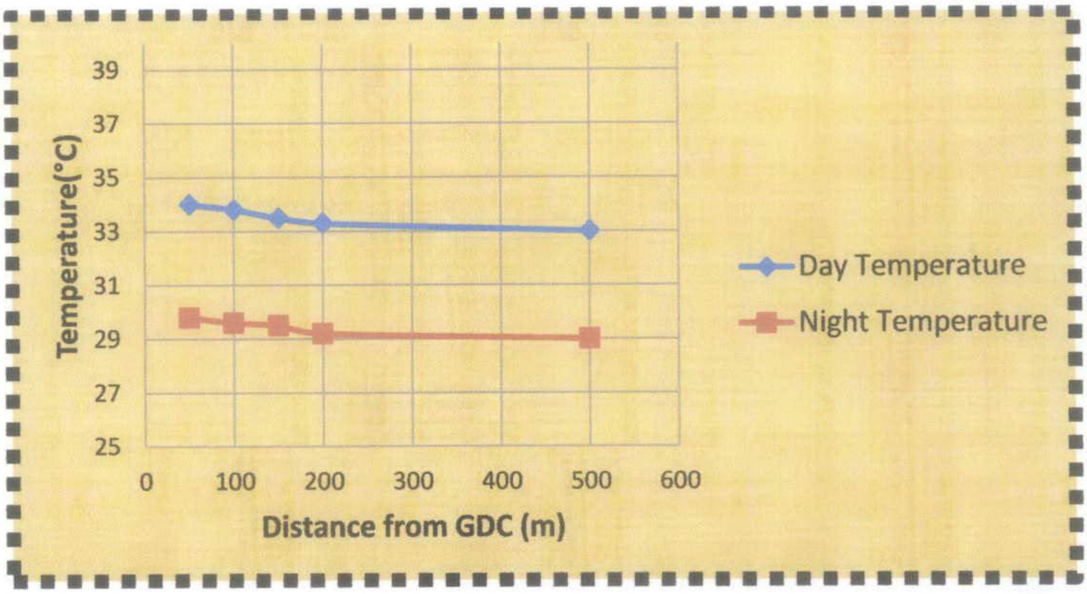

Figure 4.12: Temperature (°C) vs Distance (m) from GDC

From **Figure 4.12**, it can be seen that there is a rise of almost 1°C around the GDC. This is consistent for our observation in the day and at night. This observation confirms our suspicion which is GDC does raise the surrounding temperature. However the rise in temperature is minimum hence no harm is done on the environment.

Humidity

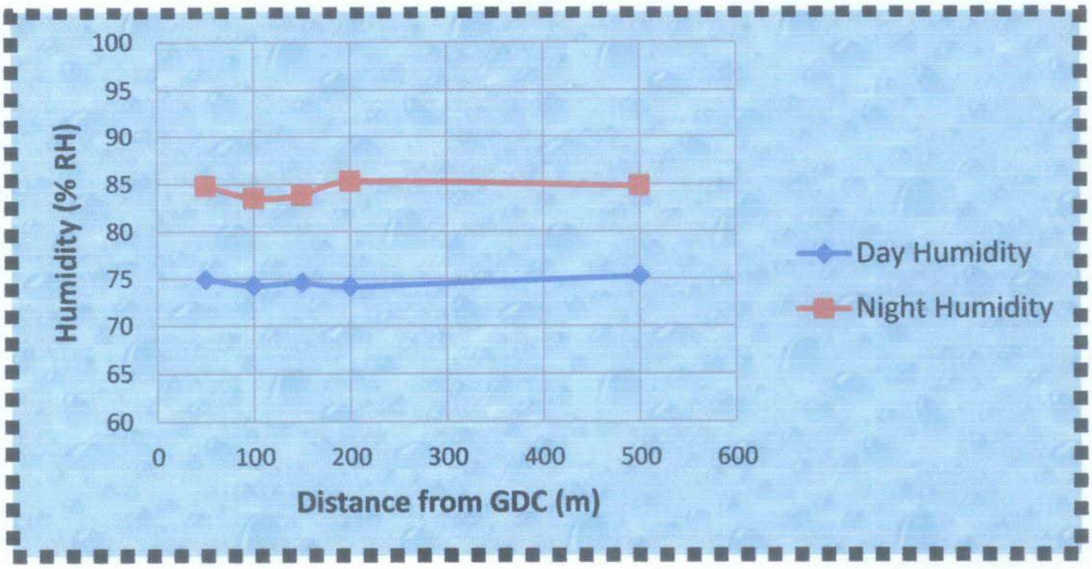

Figure 4.13: Humidity (% RH) vs Distance (m) from GDC

From **Figure 4.13**, it can clearly be seen that the release of exhaust gas into the air by GDC does not affect the humidity of the surrounding area. However the level of humidity is considered high compare to the humidity reading provided by Malaysian Meteorological Department. This is because the result is affected by the palm oil plantations and jungle around GDC. The moisture released by the plants will increase the humidity of the surroundings.

4.3 Discussion

All in all, GDC's NO_X and SO_X emissions fulfil the requirements of strict international standards. It is also much cleaner than coal-fired and oil-fired power plant. The hot exhaust gas released has minimum impact on the surrounding temperature and humidity. GDC is indeed proven to be a clean power generation technology.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

GDC's environmental impact has been assessed and is proven to be clean and environmental friendly. It complies with both European Union and United States emissions limit. It releases less than half of the CO and NO_X permitted by EU standard. Then GDC only releases 30% NO_X of the permitted amount by US standard. For SO_X, GDC releases only 10% of the limit set by EU and 1% of the allowable emission by US. It also releases far less emission gases than traditional fossil fuel power plants. There is reduction of 90% of SO_X emission when GDC is compared to coal-fired while there is a 50%, 75% and 99% of reduction for CO, NO_X and SO_X respectively when it is compared with oil-fired power station. It is also noticed that full load emits more emission gases than partial load by 1% for CO_2, 14% for CO, 8% for NO_X and 3% for SO_X. However, the heat of exhaust gas from partial load is higher than full load's by 21°C, this is because partial load bypassed HRSG and it is also less efficient. It can conclude that GDC is certainly a green and safe power generation technology. Malaysia should encourage this technology being implemented in future power plants. Hopefully, the findings for this project will be of great assistance and reference to those who requires it for reference.

5.2 Recommendation

The next stage of this project would be to observe more parameters for GDC.

1. **Particulate Matters (PM)**

   Particulate matters can be further split into PM_{10} particulates and $PM_{2.5}$ particulates. PM_{10} particulates are the most visible form of pollution: smoke, dust and their health and other impacts are obvious and well known. On the other hand, $PM_{2.5}$ particulates can penetrate more deeply into the lungs and can be highly acid, perhaps carcinogenic. They are a prime cause of haze and photochemical smog.

2. **Mercury**

Mercury is highly toxic even in extreme small quantities. Mercury exists when the gas turbine runs on diesel fuel. Mercury is emitted into the atmosphere in three forms: elemental mercury (Hg^0), reactive gaseous mercury (RGM) and fine particulate mercury (Hg(p)). Most of the mercury in the atmosphere (98%) is found in the elemental form. Mercury deposits to the Earth in wet and dry forms and can be a significant threat to aquatic and terrestrial ecosystems.

3. **Ground-level Ozone**

Ozone usually exists in the Earth's upper atmosphere (stratosphere) and shields the planet from the sun's harmful ultraviolet rays however at ground level (troposphere) ozone can be harmful to human health and ecosystems. Ozone pollutions form when emissions of NO_X and Volatile Organic Compound (VOC) react in the presence of sunlight. Ozone itself is rarely emitted directly into the air.

Figure 5.1: UTP GDC

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APPENDIX A

EUROPEAN UNION STANDARDS FOR EMISSION LIMITS FOR FACILITIES BURNING FOSSIL FUELS

APPENDIX A: European Union Standards for Emission Limits for Facilities Burning Fossil Fuels

Emission Limits for Facilities Burning Fossil Fuels				
	SO_2 (mg/Nm^3)	**NO_2 (mg/Nm^3)**	**CO (mg/Nm^3)**	**Ash (mg/Nm^3)**
Over 300 MWt				
Solid Fuel	500	650	250	100
Liquid Fuel	500	450	175	50
Gas	35	200	100	10
Less than 300 MWt				
Solid Fuel	1,700	650	250	100
Liquid Fuel	1,700	450	175	50
Gas	35	200	100	10

Note: There are currently no standards for CO_2 emissions but European Parliament has suggested introducing mandatory CO_2 emission standards to replace current voluntary commitments.

APPENDIX B

US NEW SOURCE PERFORMANCE STANDARDS – EMISSION LIMITS FOR FOSSIL-FUEL FIRED ELECTRIC POWER PLANTS

APPENDIX B: US New Source Performance Standards – Emission Limits for Fossil-Fuel Fired Electric Power Plants

Stationary source type	Unit Size Threshold	SO_2 Limit value	NO_x Limit Value
Fossil-fuel electric power plants (constructed after 1971 August 17)	Heat input capacity > 250 million Btu per hour	*Coal*: 544 grams per million Btu *Oil and gas*: 363 grams per million Btu	*Coal*: 318 grams per million Btu *Oil*: 136 grams per million Btu *Gas*: 91 grams per million Btu
Fossil-fuel electric power plants (constructed after 1978 September 18)	Heat input capacity > 250 million Btu per hour	Coal: 544 grams per million Btu and controlled to 90% below potential concentration or 272 grams per million Btu and controlled to 70% below potential concentration Oil and gas: 363 grams per million Btu and controlled to 90% below potential concentration or 91 grams per million Btu	*Coal*: 227 grams per million Btu *Oil*: 136 grams per million Btu *Gas*: 91 grams per million Btu

APPENDIX C: Raw Data

Hourly Chilled Water Supplied

HOUR	CHILLED WATER (RTh)
0:00	0
1:00	0
2:00	0
3:00	0
4:00	0
5:00	0
6:00	14
7:00	1273
8:00	2832
9:00	2666
10:00	2168
11:00	2135
12:00	2153
13:00	2199
14:00	2168
15:00	2106
16:00	2109
17:00	2290
18:00	2355
19:00	1669
20:00	1048
21:00	1111
22:00	1084
23:00	921
Total	**32299**

Hourly Electricity Produced

HOUR	ELECTRICITY (KWh)
0:00	1027
1:00	1039
2:00	1041
3:00	1036
4:00	998
5:00	714
6:00	705
7:00	1298
8:00	1245
9:00	1082
10:00	1002
11:00	772
12:00	782
13:00	781
14:00	796
15:00	824
16:00	820
17:00	1122
18:00	1481
19:00	1903
20:00	1683
21:00	1657
22:00	1639
23:00	1640
Total	**27088**

Daily Chilled Water Supplied

DAY	CHILLED WATER (RTh)
1	43115
2	41973
3	38842
4	16699
5	4158
6	38005
7	43924

Daily Electricity Produced

DAY	ELECTRICITY (KWh)
1	27084
2	27613
3	24324
4	17124
5	10211
6	23739
7	29745