INVESTIGATION INTO THE PERFORMANCE OF GAS TURBINE IN COGENERATION PLANT

By

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FINAL YEAR PROJECT REPORT

Submitted to the Department of Electrical & Electronic Engineering
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronic Engineering)

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CERTIFICATION OF APPROVAL

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Approved:

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

June 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, 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.

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GURUNATHAN MUNAIINI

ABSTRACT

Gas Turbine plays a major role in power plant especially in cogeneration system which consists of Combined Heat and Power Plant (CHP) and also Gas District Cooling plant (GDC). The main problem that a gas turbine engine encounter is that of efficiency, and one of the ways to overcome this is by increasing the performance of the engine itself before its waste (exhaust) being utilized through cogeneration system. Efficiency of a gas turbine is rated from 23 % to 33 %, and the rest are loses of the system and it being a waste through the exhaust. Cogeneration system has been introduced to improve the efficiency which actually can increase the whole system's efficiency from 75 % to 85 %. By knowing the factors that leads and affect the engines performance, the percentage of performance can be increased. In this paper the performance of the gas turbine in cogeneration system, will be discussed. This paper will also discuss on the methods to calculate the performance of a gas turbine's engine which consist of temperature in every stage, chemical reaction due to combustion reaction and fuel composition, engine exhaust flow (expandation) and also the output of the overall engine part.

Keywords-component; Gas turbine, Cogeneration, Efficiency, Performance, Exhaust

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CHAPTER 1: PROJECT BACKGROUND

1. Background of Study

In this project entitled *Investigation into the Performance of Gas Turbine in Cogeneration Plant* studies and researches has been done on the background of the system through many books, journals and also through internship experience as well. Theoretically gas turbine can be defined or also can be called as **combustion turbine** which is a type of internal combustion engine. It has an upstream rotating compressor coupled to a downstream turbine, and a combustion chamber in-between. Energy is added to the gas stream in the combustor, where fuel is mixed with air and ignited. In the high pressure environment of the combustor, combustion of the fuel increases the temperature. The products of the combustion are forced into the turbine section. There, the high velocity and volume of the gas flow is directed through a nozzle over the turbine's blades, spinning the turbine which powers the compressor and, for some turbines, drives their mechanical output. The energy given up to the turbine comes from the reduction in the temperature and pressure of the exhaust gas. To be explained in a easier and technically method, gas turbine is an engine which compress ambient air, combust the air and expands the air in order to create electricity as the main output else then other type of output with the aid of cogeneration system.

For further information, there are actually many types' gas turbines which stand from jet engines, turboprop engines, aero derivative gas turbine, radial gas turbine, micro gas turbine and also industrial gas turbine for power generation. This project will on be focused on the industrial gas turbine type because which is related to power generation side. Industrial gas turbines are different from aero derivative in that the frames, bearings, and blading are of heavier construction. Industrial gas turbines range in size from truck-mounted mobile plants to enormous, complex systems. They can be particularly efficient up to 60% when waste heat from the gas turbine is recovered by a heat recovery steam generator to power a conventional steam turbine in a combined cycle configuration. They can also be run in a cogeneration configuration whereby the exhaust is used for space or water heating, or drives an absorption chiller for cooling or refrigeration. Such engines require a dedicated enclosure, both to protect the engine from the elements and the operators from the noise.

The construction process for gas turbines can take as little as several weeks to a few months, compared to years for base load power plants. Their other main advantage is the ability to be turned on and off within minutes, supplying power during peak demand. Since single cycle (gas turbine only) power plants are less efficient than combined cycle plants, they are usually used as peaking power plants, which operate anywhere from several hours per day to a few dozen hours per year, depending on the electricity demand and the generating capacity of the region. In areas with a shortage of base load and load following power plant capacity or low fuel costs, a gas turbine power plant may regularly operate during most hours of the day. Base on this studies, many researchers and also engineers had encountered few types of problems from the gas turbine side especially form the efficiency side and one of the main cause that effects the efficiency of a gas turbine is because of excessive loss of heat and energy from the exhaust after the power turbine part. This exhaust air actually can be used back as input for few other systems such as to create combine cycle with steam turbine, HRSG and also district cooling system as we have one in our own university (UTP) here. Despite that, main features of a gas turbine engine, comparison on few types of gas turbines and also the efficiency increasing factors regarding cogeneration plant will be discussed as well.

2. Problem statement

Gases passing through an ideal gas turbine undergo three thermodynamic processes. These are isentropic[1] compression, isobaric[2] (constant pressure) combustion and isentropic expansion. Together these make up the **Brayton cycle**.

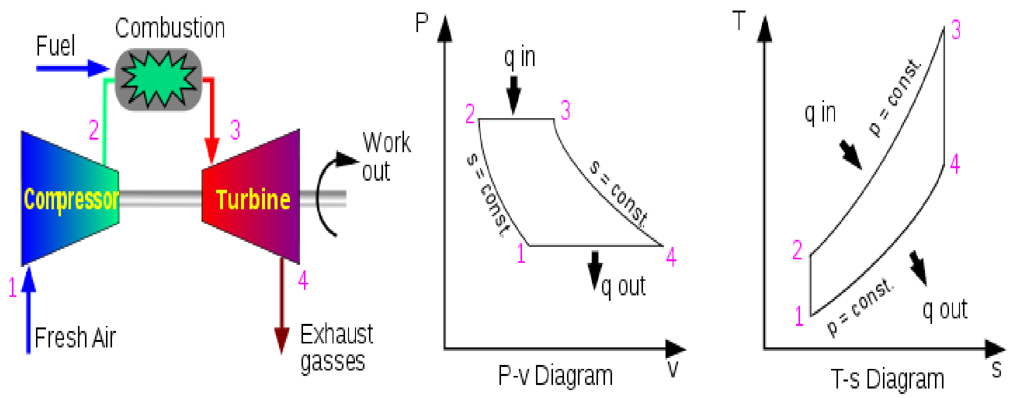


Figure 1: Brayton cycle

In a practical gas turbine, gases are first accelerated in either a centrifugal or axial compressor. These gases are then slowed using a diverging nozzle known as a diffuser, these processes increase the pressure and temperature of the flow. In an ideal system this is isentropic. However, in practice energy is lost to heat, due to friction and turbulence. Gases then pass from the diffuser to a combustion chamber, or similar device, where heat is added. In an ideal system this occurs at constant pressure (isobaric heat addition). As there is no change in pressure the specific volume of the gases increases. In practical situations this process is usually accompanied by a slight loss in pressure, due to friction. Finally, this larger volume of gases is expanded and accelerated by nozzle guide vanes before energy is extracted by a turbine. In an ideal system these are gases expanded

[1] (*thermodynamics*) Compression which occurs without any change in entropy

[2] (*thermodynamics*) Of equal or constant pressure, with respect to either space or time

isentropically and leave the turbine at their original pressure. In practice this process is not isentropic as energy is once again lost to friction and turbulence.

Relating to the above operation of a gas turbine engine, gas turbine plays a big role in power system industries as well as in power plant, but with only a gas turbine engine, the desired efficiency and also desired output cannot be achieved, because there are a lot of losses in this system as need to be recovered. This is the area that needs more research and studies in the formation of formulation and also the factors such as ambient air (normal atmosphere air), air density, fuel and also combustor as well.

A. Gas Turbine Systems

There are several types of gas turbine system available in industries and in this section some overview of the gas turbine system will be discussed briefly for further information.

a) Open Cycle

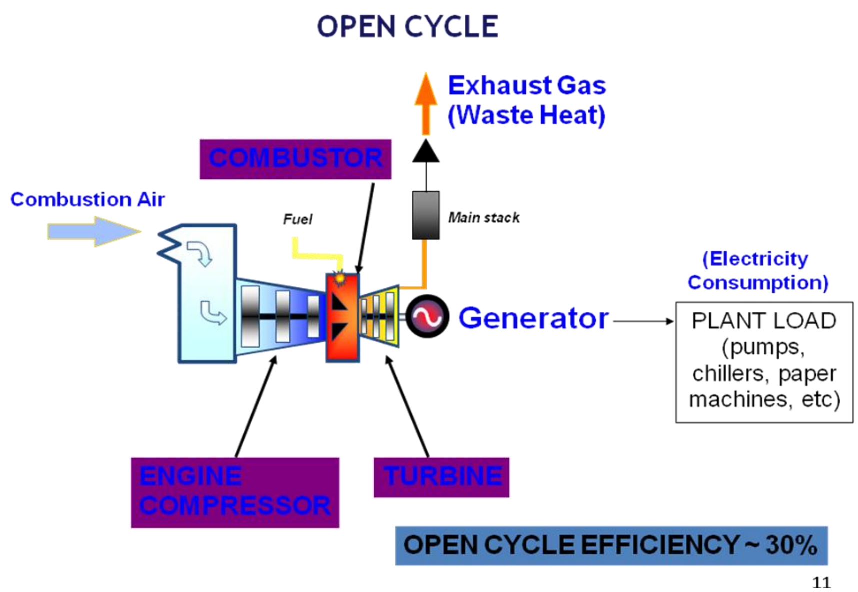


Figure 2: Open Cycle System

In a typical industrial Brayton cycle gas turbine application ambient air, approximately 300K enters into an axial compressor and is compressed (compression makes the density to be increased) by pressure ratio calculation. This compression of the air also increases the air's temperature to between 500K and 800K (the temperature and pressure of air are related via the isentropic relationship). The compressed air and slightly hotter air then enters into the axial combustion chamber or burner. In the combustion chamber, chemically stored fuel energy (LPG gas-Natural gas) is converted to thermal energy (heat) which is used to further increase the air temperature. In most gas turbine combustors, natural gas (which consists of methane, propane, butane, pentane, carbon dioxide and nitrogen) is burned with the presence and process of air. Once the air is burned through the combustion chamber, the very hot and compressed air now will exits the combustor and then expands (density decrease) to drive the axial turbine. Thus, the energy that was added to the air in the compressor and combustor is taken out in turbine.

b) Power & district cooling application (Cogeneration)

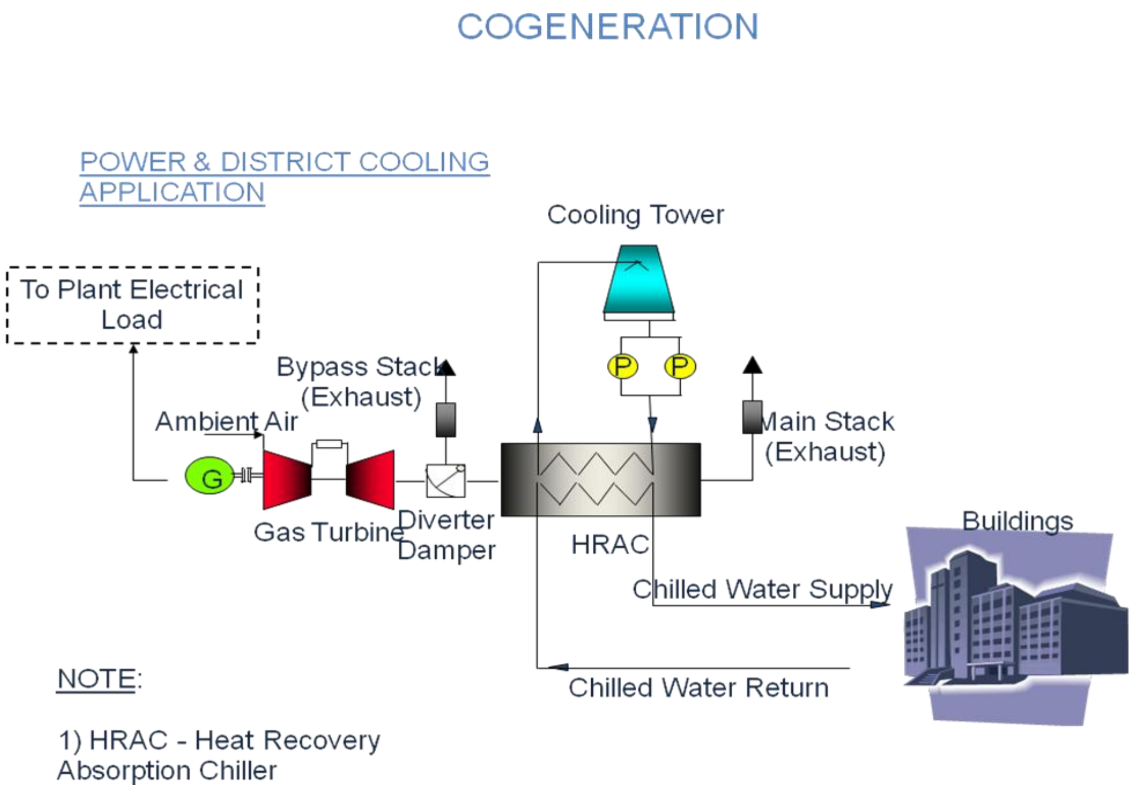


Figure 3: Gas District Cooling

As showed in figure 3 above, the cogeneration plant whereby a system is attached to the output of the gas turbine. In this system the exhaust flow will go through the Heat Recovery Absorption Chiller (HRAC) in order to cool down the temperature of the exhaust and here lithium bromide plays a major role in reducing the temperature and change the heat to water form (moist) through condensation process and then it will be transferred to the cooling tower in order to chill the water before it is sent to the building. For further information the chill water supply temperature is around 4-6 C and the returning chill water is around 12-14 C

c) Combined heat & power application (Cogeneration)

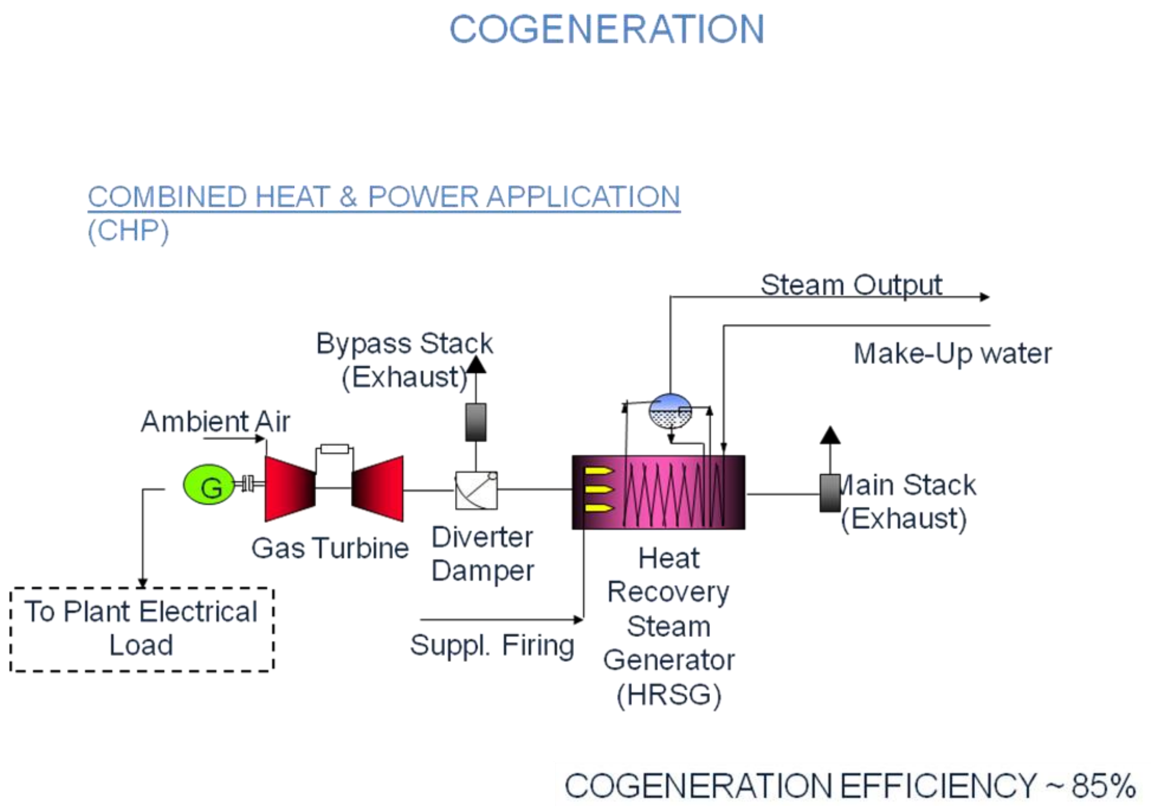


Figure 4: Heat Recovery Steam Generator

As in figure 4 above the combined heat and power generation system whereby the exhaust flow is now channeled to a HRSG which can be known as boiler as well. The heat from the exhaust will heat up and tend to boil the coil of water in the tubing and will change it to become steam and the steam will be used as the input for other combined system (steam turbine) or for industries usage such as paper products. This system is one of the ways to increase the efficiency of the gas turbine which it can gives 80-85% of efficiency because the waste energy(exhaust) has been utilized through the attached system.

I. Problem Identification

As showed in figure 1 earlier, the turbine and compressor are mounted on the same shaft and this makes some of the energy that the turbines extracts from the expanding process is being used to drive the compressor as well and the remaining energy the turbine can extract from the expanding air is effectively the gas turbine shaft output power. So in any system, achieving 100% output is impossible due to certain loses and same goes to gas turbine application which can only contribute efficiency from 25-30% and that depends on the type of the turbine that installed. This happens because of the heat losses from the exhaust, compressor shaft shares the power from turbine and this will drop the performance of the gas turbine which actually indirectly increasing the usage of fuel and its cost. As in figure 2 it clearly stated that the efficiency of a gas turbine engine is only around 30% and this is caused by the losses in exhaust flow.

II. Significant of Project

The main aim of this project is to do studies on the performance of the gas turbine (Cogeneration Plant) and to know what is actually practically happening in a gas turbine engine and the ways to overcome the efficiency problems and also to identify which factors affect the efficiency of the cogeneration plant and also to come out with a calculation data on gas turbine operating cycle for different variety of gas turbine families.

3. Objective

The main objective of this project is to investigate and study on all the factors that lead to efficiency drops in cogeneration plant (GTG) and also the ways to increase it and calculation steps in determining the rough efficiency as well. Besides that, through this project paper also, it can help students and engineers to be very familiar with the gas turbine fundamentals and also make them easier to calculate the performance of a gas turbine engine in a manual way without depending in special simulation.

There are also few other objectives which are:-

- To visit GDC plant in UTP to get information on the Cogeneration Plant
- To study the overall process of a gas turbine
- To study the cogeneration system
- To identify the relation between the efficiency of gas turbine and cogeneration system
- To identify the difference between various types of gas turbine families
- To meet the engineers from gas turbine companies and site.

I. Scope of Study

This project's scope is on determining and studying on gas turbine engine especially the compressor, combustor, RGB(reduction gear box) ,power turbines and also on how a gas turbine engine works and what actually needed to run a turbine engine. Besides that, this project is also will discover on cogeneration plant which is an extended system from gas turbine engine itself in order to increase the output of a gas turbine system rather than wasting the energy through the exhaust. Some studies will be involving in some calculation, and theory on pressure, compression ratio, temperature drop and also the performance of turbine due to all this factors.

II. The Relevancy of the Project

This project will focus on the efficiency side of different gas turbine as the core engine and combustor as well. In order to complete this project, thermodynamics laws are one of the main knowledge, are learned and also brayton cycle on gas turbine engine , and beside that some calculation on thermodynamics laws are fully required, and on the other hand basic of chemical calculation are needed as well, in order to be familiar with the combustion part in a gas turbine and to complete the studies and research of a gas turbine performance.

III. Feasibility of the project within the scope and time frame

This project is be held step by step whereby at first introduction on the related topics (gas turbines) gained by reading all the related books, journals and research papers and also through conversation with engineers and also people who is directly involved in this sector. Then more research has been done on the cogeneration plant side such as studies on compressors, turbine blades behavior and also chemical reaction behavior in order to complete the calculation task and also to complete my technical paper in order to be submitted for conference.

CHAPTER 2: LITERATURE REVIEW

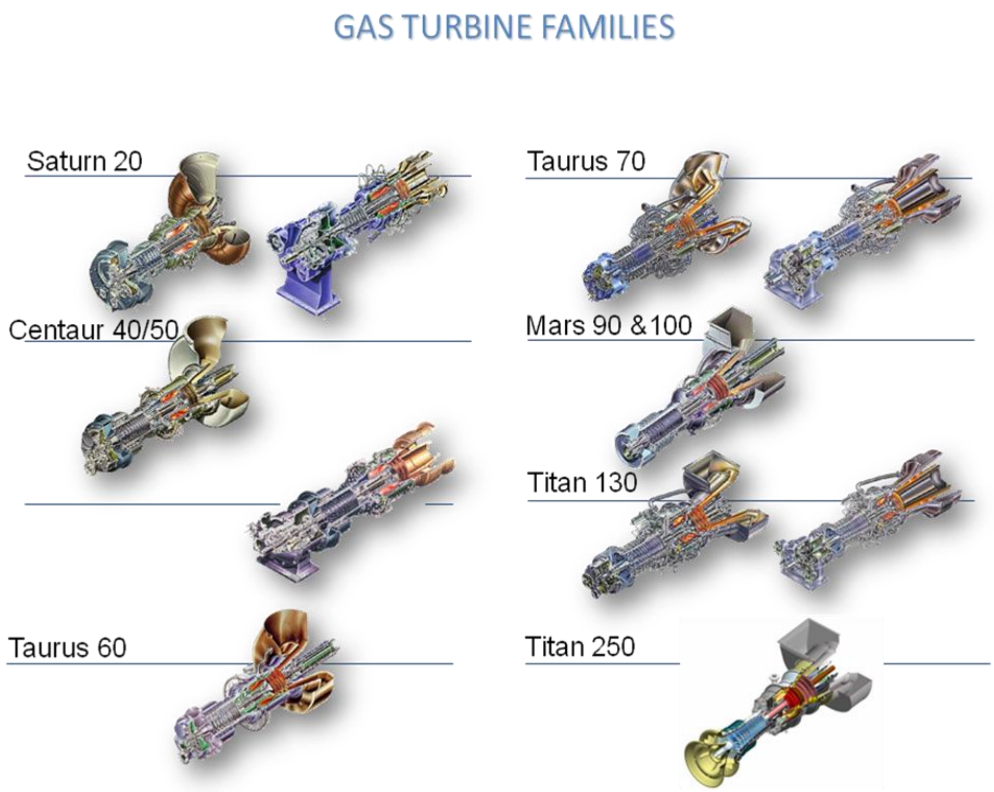


Figure 5: Gas Turbine Families

As in figure 5 above, it clearly shows that there are many types of gas turbine as the main engine for a cogeneration plant and it varies from different sizes as well as performance. Engineers face few efficiency problems regarding this gas turbine engine because for a cogeneration plant, gas turbine output which is the exhaust flow is the main input for a cogeneration plant either in District Cooling Plant (GDC) or Heat Recovery Steam Generator (HRSG) for heating and cooling industry purpose. In order to overcome all these types of affecting factor on gas turbine and cogeneration efficiency, few methods had been applied either in calculation way or technical way to improvise the output of the turbine. Regarding this issue few researches that had been done by other researchers and also engineers had been discussed briefly under literature review section.

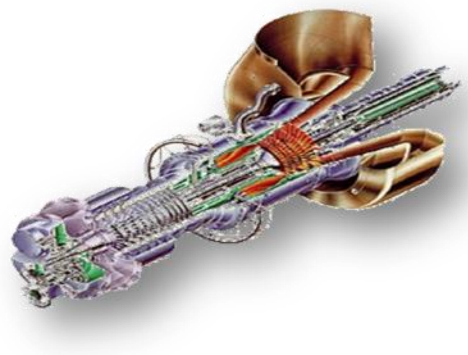
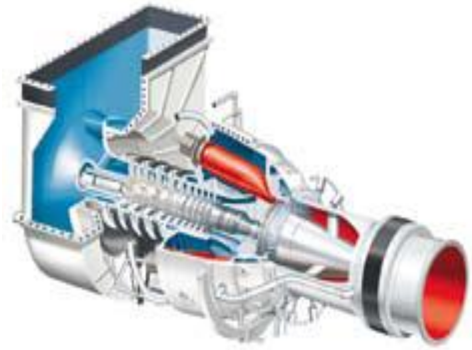
COMPANY	Solar Turbines	Siemens
ENGINE	 TAURUS 60	 SGT 100
POWER	5.6Mw	5.4Mw
EFFICIENCY	31.5%	31%
PRESSURE RATIO	12.2 : 1	15.6 : 1
EXHAUST TEMPERATURE	510 C	531 C
HEAT RATE	11 265 kJ/kW-hr	11,418 kJ/kW-hr

Table 1 : TAURUS 60 & SGT 100

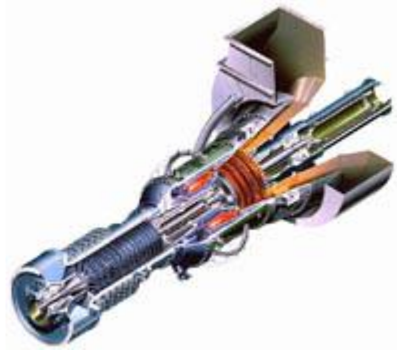
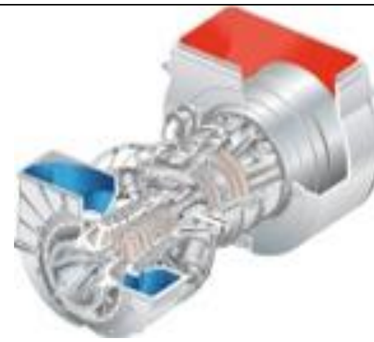
COMPANY	Solar Turbines	Siemens
ENGINE	 MARS 100	 SGT 400
POWER	11.86 Mw	12.90 Mw
EFFICIENCY	34.5%	34.8%
PRESSURE RATIO	17.1	16.8 : 1
EXHAUST TEMPERATURE	485 C	555 C
HEAT RATE	10,465 kJ/kW-hr	10,355 kJ/kW-hr

Table 2 : MARS 100 & SGT 400

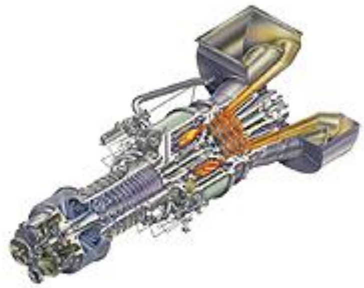
COMPANY	Solar Turbines	Siemens
ENGINE	 TITAN 130	 SGT 500
POWER	15.29 Mw	19.10 Mw
EFFICIENCY	36.2%	33.8%
PRESSURE RATIO	16 : 1	13 : 1
EXHAUST TEMPERATURE	505 C	369 C
HEAT RATE	9940 kJ/kW-hr	10,664 kJ/kW-hr

Table 3: TITAN 130 & SGT 500

Table 1,2 and 3 above are the comparison between few types of engines from two companies gas turbine manufacturing companies which has been conducted and from the table it is noticed that the performance of the engines are not the same even though the concept of the performance are just the same. This is because, different manufacturers have their own specification and also design to build their own turbines and the reason this project paper focused more on Solar Turbines engines are because most of the cogeneration plant in Malaysia are based on solar turbines engines and moreover the project scope is only around Malaysia.

I. *Operation of Evaporative Coolers*

Chilling the inlet air before it enter the compression part is one of the way to increase the efficiency of a gas turbine in an industrial and to prove this, a research paper on this matter has been discussed and viewed and this paper is by solar turbines principal R. S. JOHNSON, Sr., P.E**.** who is one of the member from *The American Society Of Mechanical Engineers***,** stated that Evaporative coolers are used with gas turbines to increase the density of the combustion air, thereby increasing power output. The air density increase is accomplished by evaporating water into the inlet air, which decreases its temperature and correspondingly increases its density. The water vapor passes through the turbine, causing a negligible increase in fuel consumption. Even though he stated this statement, but he still highlight that the raw water that is being used must be treated because it can cause corrosion on the blade and the level of water must be controlled to so that it won't be carried into the compressor blade.

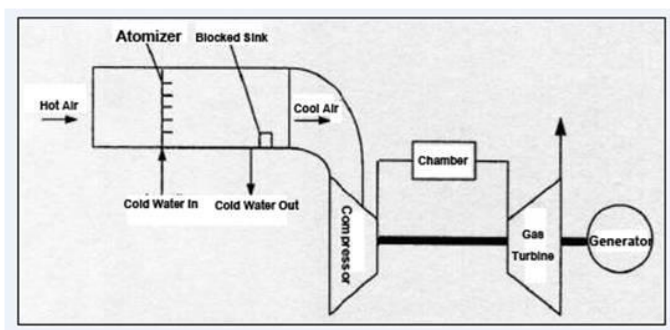


Figure 6: Evaporating Cooling System

Based on the figure above, one of the mechanical and electrical supplying company from China, Shenzhen Teweite Mechanical & Electronic Equipment Co.Ltd [7] have stated clearly that evaporating cooling method is one of the ways to improve the efficiency of the gas turbine output.

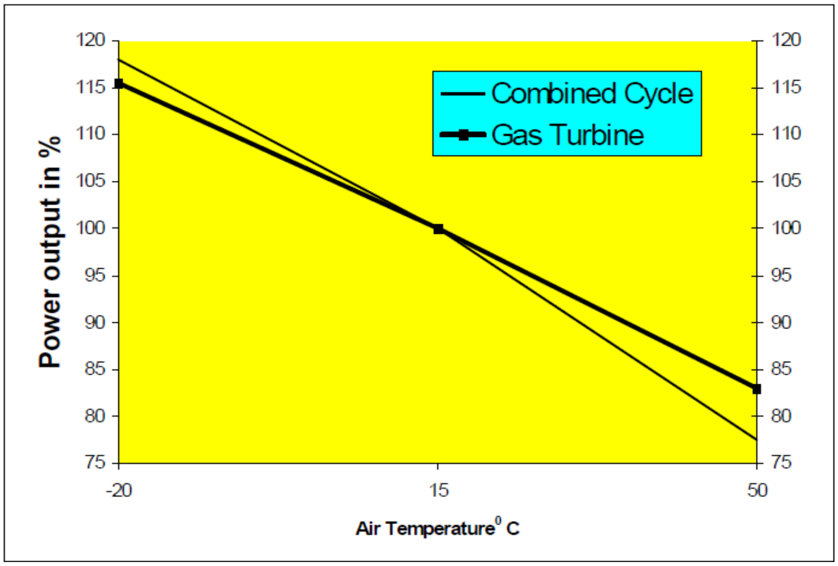


Figure 7: ISO rating for efficiency

Figure above shows the efficiency of a gas turbine under adiabatic condition which means without considering any loses. It shows that less input temperature (15’C) causes perfect efficiency according to ISO rating and this one of the reason evaporative cooling system is introduces in order to less the intakes temperature. Devki Energy Consultancy Pvt. Ltd. under their Cogeneration paper in the year of 2006 [5] stated too that higher ambient air temperature reduces the power output from the gas turbine. The mechanical work done by the gas turbine is proportional to the mass of flue gases entering the gas turbine, and mass depends on quantity of ambient air supplied to the combustion chamber through compressor

II. Exhaust Gas Recirculation in Gas Turbines for Reduction of CO2 Emissions

Petter E. Rokke from SINTEF Energy Research and his partner Johan E. Hustad from Norwegian University of Science and Technology from the Department of Energy and Process Engineering stated in his paper [4], when a fraction of the exhaust gas is injected in the entry of a gas turbine, the amount of CO_2 in the exhaust gas not being recirculated will be higher and less complicated to capture. However, with this change in combustion air composition, especially the reduced concentration of oxygen, the combustion process will be affected. The lower oxygen concentration decreases the stability and the increased amount of CO_2, H_2O and N_2 will decrease the combustion temperature and thus, the NO_x emissions. Testing has been performed on a 65 kW gas turbine combustor, to investigate the effect of adding N_2, CO_2 and O_2 in the combustion process, with focus on stability and emissions of NO_x. Results show that adding N_2 and CO_2 decreases the NO_x emissions, whereas O_2 addition increases the NO_x emissions. The tests have been performed both in a diffusion flame (pilot burner) and a premixed flame (main burner), and for additives being injected with the fuel or with the air stream. Addition into the fuel stream is proven to affect the NO_x emissions the most. The stability limits of the flames are indicated with respect to mass-based additive-to-fuel ratios in their research paper entitled Exhaust Gas Recirculation in Gas Turbines for Reduction of CO2 Emissions; Combustion Testing with Focus on Stability and Emissions.

III. Combustion Turbine Design

A driving factor in the design of all power generating units is efficiency and turbine blades plays a big role even. Higher efficiency translates to lower operating costs. In the case of combustion turbines, air leakage around the tips of turbine blades reduces efficiency. This paper examined the use of blade tip shrouds to minimize air loss by R. Seleski from Power Systems Mfg., LLC Jupiter, and FL [6]. It also looks at tip shrouds as a technique to reduce blade stress and fatigue. The paper also examines difficulties with tip shrouds, including creep, curling, and stress, and how these can be minimized. A gas turbine functions by allowing passage of expanding combustion gases through the turbine blades. To accommodate gas expansion and obtain maximum efficiency from the unit, the turbine chamber volume and blade length increase from inlet to outlet. Simple blades allow a significant amount of gas leakage around the blade tips. This reduces turbine efficiency. The most common method to correct these difficulties is to support the bucket at both the root and tip, using a tip shroud, instead of cantilevering the entire bucket from the root. Not only does the tip shroud change the natural frequency of the bucket as a system, but it provides additional friction damping. Tip shrouds also restrict gas leakage flow across the airfoil tip by using knife-edge seals designed to rub into a honeycomb seal material that is brazed onto the shroud blocks. While tip shrouding can be an excellent tool to improve combustion turbine operation, a number of factors must be taken into account when designing tip shrouds, as otherwise the shrouds may cause as many problems as they solved.

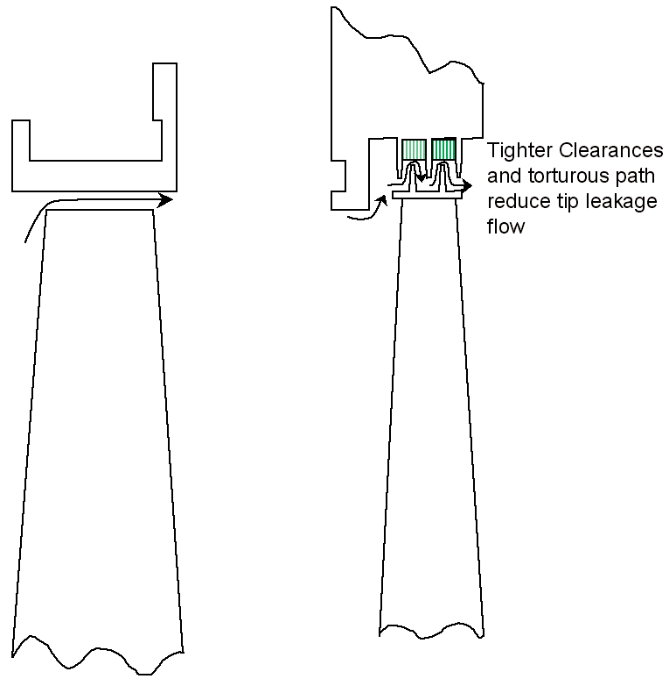


Figure 8: Shroud Combustion Turbine Design

From the figure above understood that efficiency of a gas turbine output is high whenever the temperature of the exhaust is less which means all the hot air was expand perfectly without loses but in case of using cogeneration system, a higher temperature exhaust flow is required in order to run the run the HRSG or District Cooling system.

IV. Compressor Washing

Routine compressor washing is essential to maintaining turbine output and efficiency. Significant performance degradation can be experienced due to dirty compressor blades, especially if the gas turbine is in, or near, an industrial environment. Compressor washes can take place with the unit in operation (online) as well as shut down (offline). Some turbines, especially those with low NOx combustors, do not allow detergent use during turbine operation. A typical regime for these turbines is to wash online once a day for a few minutes a day. When the unit can be taken offline, a more thorough wash is conducted, utilizing detergent, with wash and multiple rinse cycles. As an example, Gas Turbine Efficiency model 600i compressor wash systems were installed on two 9E gas turbines in Malaysia. Implementing a proper routine of online and offline washes, the plant realized a heat rate recovery of up to 1.5%. This resulted in an economic payback period of two months. Additionally, the gas turbine output was increased by 8% to 13% during the online wash cycles. Typical output recovery achieved after conducting an offline wash can exceed 2% when compared to pre-wash turbine operation. Other benefits include reduction in emissions. Results will vary based on turbine type, usage, and time since last washing.

CHAPTER 3: METHODOLOGY

This section is all about how this project started and the flow that it went through all over. Firstly project was started with information and research gathering related to gas turbine and also cogeneration plant as well as topics related to efficiency of the system. Books has been borrowed which is related and also downloaded a lot of journals and past research papers and journals. Regarding this topics too, few test run data need to be collected from the gas turbine site as well, in order to study the performance of the system at different site and it managed to be obtained from the internship company. Case studies shows many types of methods are found and are available in sense of overcoming the efficiency problems, and this paper is actually trying to figure out a simple and easier way to calculate the performance of a gas turbine in order to figure the main output of a gas turbine which is the exhaust flow and temperature before it enters HRSG or the district cooling system.

To run this method familiarization with few new additional subjects such as chemical reaction, chemical molar calculation and also thermodynamics laws are needed and has been learned and also it's relating calculation rather than only having knowledge on electrical side. Besides that, lecturers who are actually experts in this topic has been visited to gain their experience and saying about this

Through all this useful methods, FYP 1 is completely done and this directly heads this project for further step which is FYP 2 without much difficulties and as long as time is managed wisely and in FYP 2 the project was successfully completed with all the relevant information and also the calculation for the gas turbine performance was done and beside that a technical paper on this project with the title Investigation into the performance of gas turbine in cogeneration plant was completed and was submitted in few conference as well. During the FYP 2 period, some engineers from gas turbine companies was interviewed to gain some input regarding the projects and the technical paper.

I. Project Work Flow

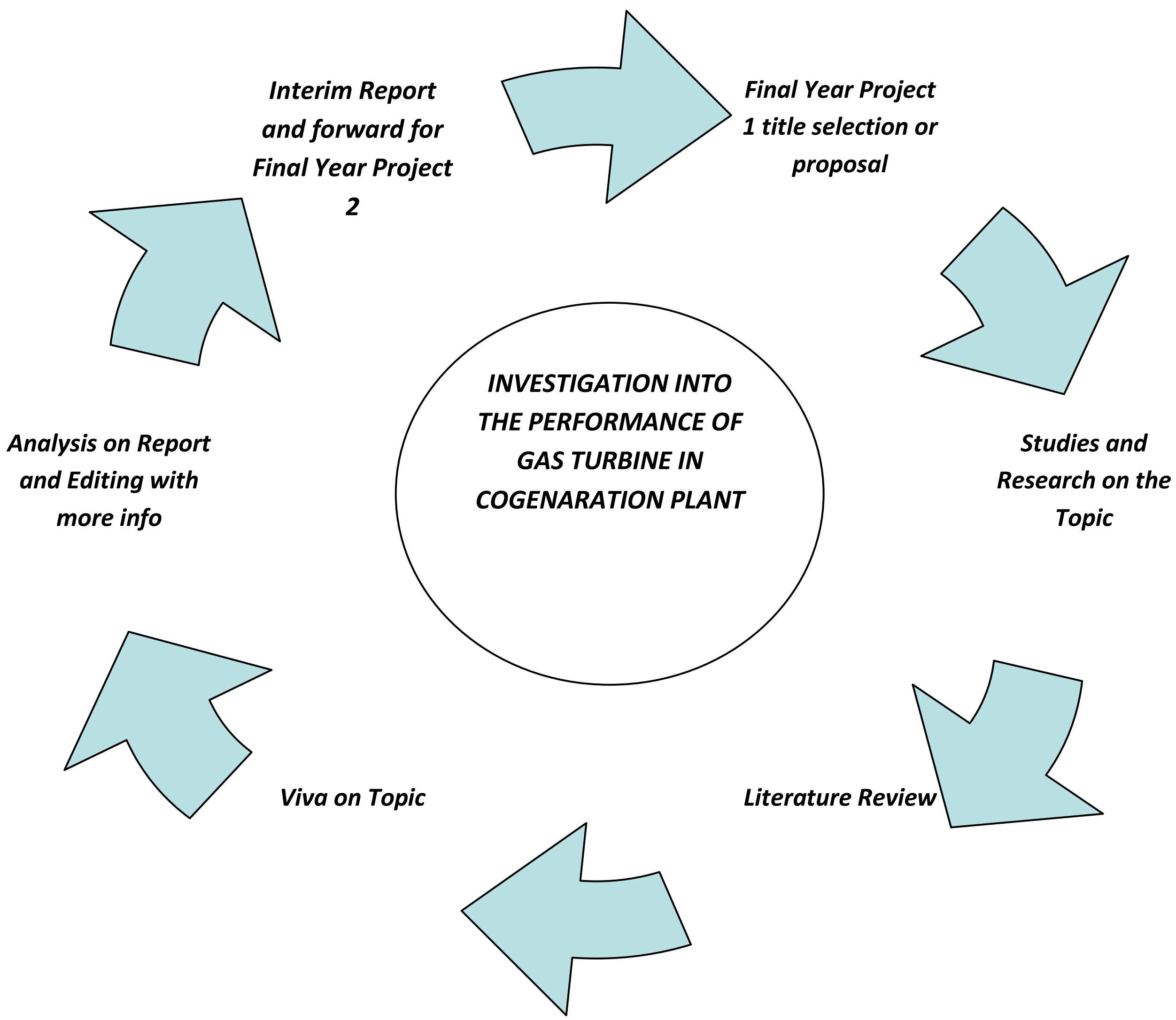


Figure 9: Project work flow FYP 1

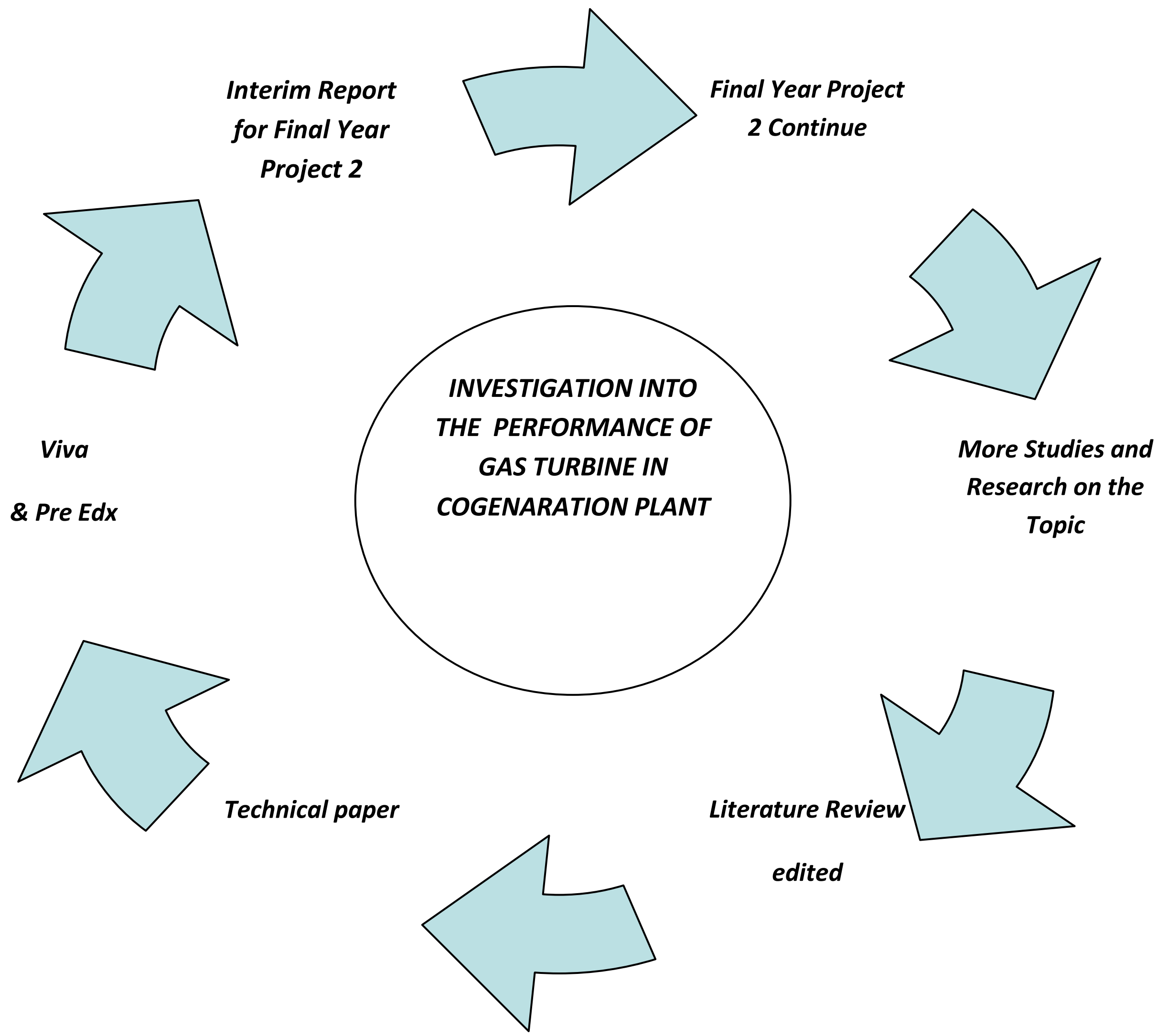


Figure 10 : Project Workflow FYP 2

No	Detail / Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic	■	■													
2	Preliminary research work		■	■	■	■										
3	Submission of Extended Proposal						★									
4	Proposal Defense									■	■					
5	Experimental works, familiarize with the equipments											■	■	■		
6	Experimental works regarding with materials (preliminary)											■	■	■		
7	Submission of Interim Draft Report														★	
8	Submission of Interim Report								Mid Semester Break							★

Figure 11: Gantt chart for the FYP 1 project implementation

■ Processes

★ Process Milestones

No	Detail / Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	FYP 2 (cont)															
2	More studies on calculation															
3	Performance calculating method															
4	Technical paper (conference purpose)															
5	Progress report															
6	Combining the formulas, documents and the paper															
7	Pre-EDX															
8	Submission of Interim Report and Viva								**Mid Semester Break**							

Figure 12 : Gantt chart for the FYP 2 project implementation

Processes

Process Milestones

CHAPTER 4: Results & Discussion

In order to get done with the results for this FYP 2 project, test run sheet are needed and below is the example of the test run sheet that required to compute some of the related results.

DATA FOR NOMINAL PERFORMANCE

Elevation	metres	10
Inlet Loss	mm H2O	75.0
Exhaust Loss	mm H2O	150.0

		1	2	3	4
Engine Inlet Temperature	deg C	28.0	30.0	32.0	34.0
Relative Humidity	%	80.0	80.0	80.0	80.0
Specified Load*	kW	FULL	FULL	FULL	FULL
Net Output Power*	kW	6534	6392	6251	6112
Fuel Flow	mmBtu/hr	69.70	68.82	67.97	67.14
Heat Rate*	kcal/kW-hr	2688	2713	2740	2768
Therm Eff*	%	31.987	31.691	31.380	31.062
Engine Exhaust Flow	kg/hr	90125	89122	88116	87107
Exhaust Temperature	deg C	501	503	506	508

Fuel Gas Composition (Volume Percent)

Methane (CH4)	90.57
Ethane (C2H6)	4.97
Propane (C3H8)	1.95
I-Butane (C4H10)	0.07
N-Butane (C4H10)	0.14
I-Pentane (C5H12)	0.04
N-Pentane (C5H12)	0.01
Hexane (C6H14)	0.0050
Carbon Dioxide (CO2)	1.86
Nitrogen (N2)	0.38
Sulfur Dioxide (SO2)	0.0001

Figure 13 : Test Run Sheet

As displayed in figure 13, few calculation methods regarding the method on how to calculate the performance of gas turbine in an easier ways and in order to know the behavior of different types of turbines in power industries had been carried out and below are the related results for this project

- ***Chemical reactions***

  In order to perform a full calculation of a gas turbines performance, every single input for the gas turbine need to be considered because it plays a role at the output. From what have been discovered, the info regarding the input in the performance sheet of gas turbine is very helpful besides thermodynamics and chemical equation . Gas turbine engines uses natural gas (LPG) as fuel to run the engine and the reason LPG is chooses is because it is cheap, save because it contains low carbon emission and the main content of LPG is mostly methane which is light gas. As in figure 13, it clearly shows that in LPG gas, methane is the main component and followed by ethane and propane and in the project calculation, only the three main components are considered as well which is methane, ethane and propane in order to calculate the air/fuel ratio weight because it will be used and helpful during the combustion part later.

- **Air / fuel ratio**
  - combustion happens with the presence of oxygen (76% of air is nitrogen and 23% is oxygen by weight)
- **Molar mass**
  - By weight
- **CnHm + (n+m/4)O2 -->nCO2 + (m/2)H2O**
  - Combustion chemistry

Above shows the chemical equation that is actually been used in this project's calculation and following is the example of the calculation on Taurus 70 :-

Methane (CH4)	46.9546 %
Ethane (C2H6)	7.4707 %
Propane (C3H8)	3.7604 %

Table 4 : Fuel Components

According to the fuel info from Table 4: methane =46.9546

ethane=7.4707

propane=3.7604

methane+ethane+propane=58.1857

- *methane % =$CH_4 + 2O_2 = CO_2 + 2H_2O$+Energy*

  = (46.9546/58.1857)*100

  =80.70@0.807

- ethane % =$2C_2H_6 + 7O_2 = 4CO_2 + 6H_2O$+Energy

  =(7.4707/58.1857) * 100

  =12.84@0.1284

- propane % =$C_3H_8 + 5O_2 = 3CO_2 + 4H_2O$+Energy

  =(3.7604/58.1857) * 100

  =6.463@0.06463

- (oxygen/methane) = (2*32)/(16)

  =4

- (oxygen/ethane)=(7*32)/(2*30)

  =3.73

- (oxygen/propane)=(5*32)/(42)

  =3.81

- (air/fuel)weight=[(0.807*4)+(0.1284*3.73)+(0.06463*3.81)]/ [0.23]

  =17.19

Figure above shows the detail calculation on how to calculate the molar weight of the fuel components in order to get the air/fuel ratio that is burned in the presence of Oxygen.

- ***Temperature Calculation***

- T1=Inlet Temperature
- T2/T1=(P2/P1)^[(k-1)/k]

  After compression

- T3= qr /[(air/fuel)*Cp*ratio) + T2]

  After combustion

- T4/T3=(P1/P2)^[(k-1)/k]

  Exhaust temperature

Above shows the another part of the calculation for the temperature part and also the combustion part. The calculation process for the gas turbine engine can be said as a chain relation because it values are related to the previous values such as in order to calculate the temperature of engine after the combustion, the temperature of the engine after the compression and also the air/fuel value must be determined 1st, and meaning to say that it only can be done step by step.

CH4 Specific Heat Ratio		CO2 Specifice Heat ratio	
T	Cp	T	Cp
600	3.256	600	1.075
650	3.432	650	1.102
700	3.602	700	1.126
750	3.766	750	1.148
800	3.923	800	1.168
850	4.072	850	1.187
900	4.214	900	1.204
950	4.348	950	1.220
1000	4.475	1000	1.234

Table 5 : Cp Values

In order to complete this temperature section calculation, Cp and Cv values of air, and methane are need to be provided and it can be obtained from the thermodynamics books.

- ***(T2/TI) = (P2/P1) ^ (k-1)/ (k)***

k=(1.005kj/kg.k)/(0.718kj/kg.k)=1.4 *(cp/cv of air)*

T2/(302.5)=(16.5/1)^[(1.4-1)/(1.4)]

T2=673.87K (400.87^{o} C)

via above calculation, the temperature of the air after compression can be obtained

- **T3={ qr/ [(air/fuel)*(cp)*ratio)]}+ (T2)**

T3={(48000kj/kg)/[(17.19)*(3.507)*(3)]}+673.87K

=939.27K (666.27^{o}C)

- 48000kj/kg is the maximum heating value of methane
- 17.19 is the air/fuel ratio as per calculation earlier
- 3.507 is the cp ratio that is obtained from table 5 when T=T2
- ratio is usually from the range of 3-6 and it depends on the type of turbine

- **{qr/ [(air/fuel)*(cp)]} + (T2)**

{48000kj/kg/[(17.19)*(3.6)]}+673.87K

=1449.5K (1176.5^{o}C)

above shows the method to calculate the maximum temperature in combustion and this calculation is important in this project is in order for the designer or engineer to know the maximum temperature that the combustor can goes and this will help them to design the turbine blades as well to withstand the heat

- now the cp ratio taken is 3.6 because in order to calculate the maximum temperature the ratio must be higher than the cp ratio in T3 calculation because it will be easier for the turbine designation.

❖ **T4/T3= (P1/P2) ^ (k-1)/k**

T4=(1/16.5)^[(1.111-1)/(1.111)] *[939.27]

=709.83K (436.83^{o}C)

Above shows the last step of the calculation on the exhaust side and this calculation is very helpful in determining the exhaust temperature which indirectly leads to the efficiency calculation and it is also helpful to determine the amount of loses in the engine because *more loses in exhaust creates less performance in the engine.*

➢ ***Performance calculation***

❖ **Thermal Efficiency= 1/ [Heat Rate (Kjkw/Hr) / 3600] * 100%**

=1/[(13677kjkw/hr)/3600]*100 %

= 26.32 %

- heat rate is taken from the performance sheet

❖ **Output Power of Engine (Kw) = [Fuel Flow (Kj/Hr) / (3600 * Thermal Efficiency)]**

=[62920000kj/hr/3600]*(0.279)

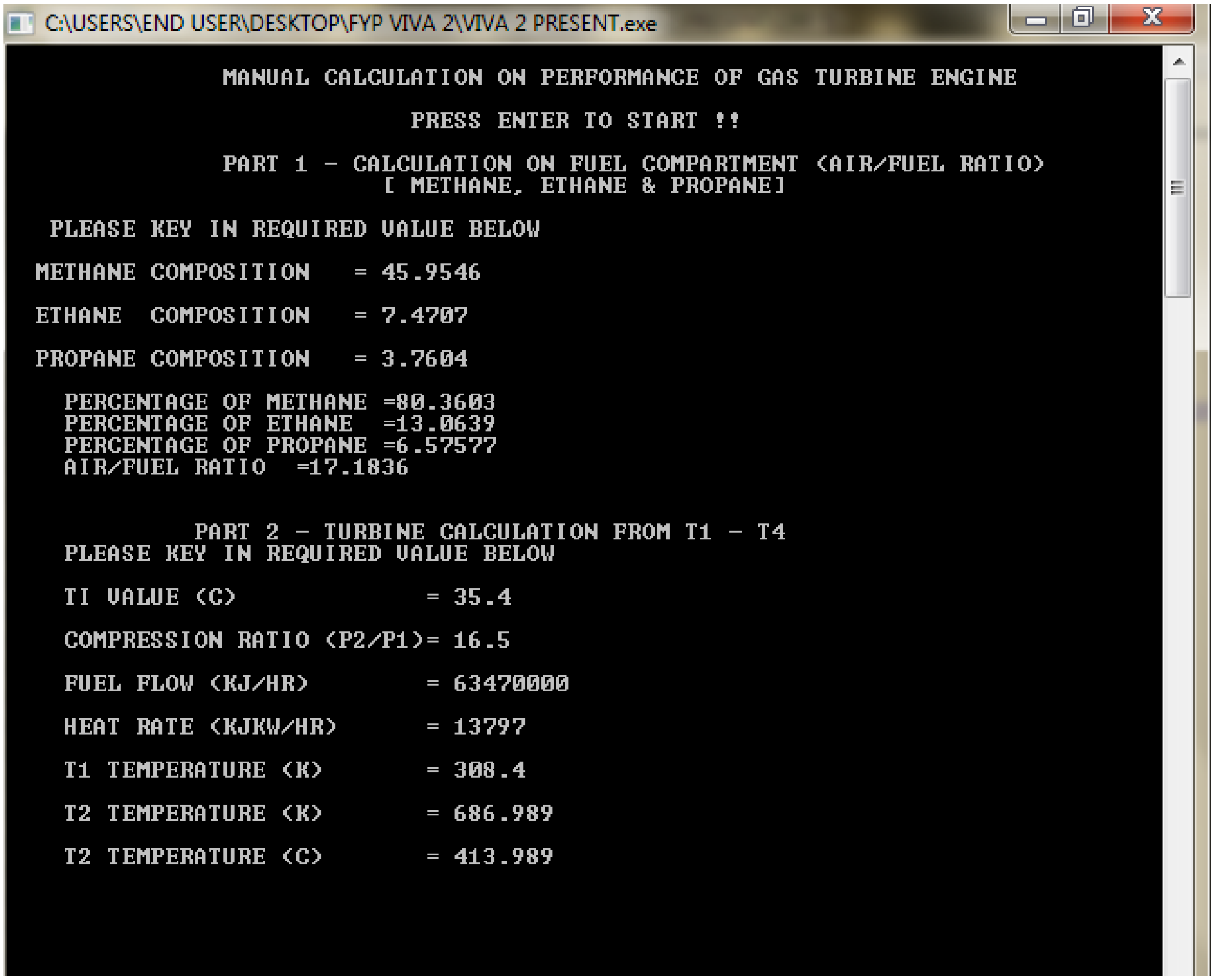
=4600.15Kw

- fuel flow is taken from the performance sheet

Stages	Performance Sheet	Via Calculation
Engine Inlet Temperature (^{o}C)	29.5	29.5
Specified Load(kw)	4600	4600.15
Net Output Load(kw)	4600	4600.15
Fuel Flow (Gj/hr)	62.92	62.92
Heat Rate(kj/kw-hr)	13677	13677
Thermal Efficiency (%)	26.317	26.32
Power Turbine Inlet Temparature (T3) (^{o}C)	672	666.27
Exhaust Temperature (T4) (^{o}C)	450	436.83

Table 6 : Performance sheet on Taurus 70

Table above shows the comparison between the manual calculation via this project and also the simulation calculation that was obtained from one of the gas turbine companies, Delcom. from the comparison, it can be said that the values that was obtained via the calculation method in this project is quite similarly hitting the real value from the company simulation test run itself.



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MANUAL CALCULATION ON PERFORMANCE OF GAS TURBINE ENGINE

PRESS ENTER TO START !!

PART 1 - CALCULATION ON FUEL COMPARTMENT (AIR/FUEL RATIO)
[METHANE, ETHANE & PROPANE]

PLEASE KEY IN REQUIRED VALUE BELOW

METHANE COMPOSITION = 45.9546

ETHANE COMPOSITION = 7.4707

PROPANE COMPOSITION = 3.7604

PERCENTAGE OF METHANE =80.3603
PERCENTAGE OF ETHANE =13.0639
PERCENTAGE OF PROPANE =6.57577
AIR/FUEL RATIO =17.1836

PART 2 - TURBINE CALCULATION FROM T1 - T4
PLEASE KEY IN REQUIRED VALUE BELOW

TI VALUE (C) = 35.4

COMPRESSION RATIO (P2/P1)= 16.5

FUEL FLOW (KJ/HR) = 63470000

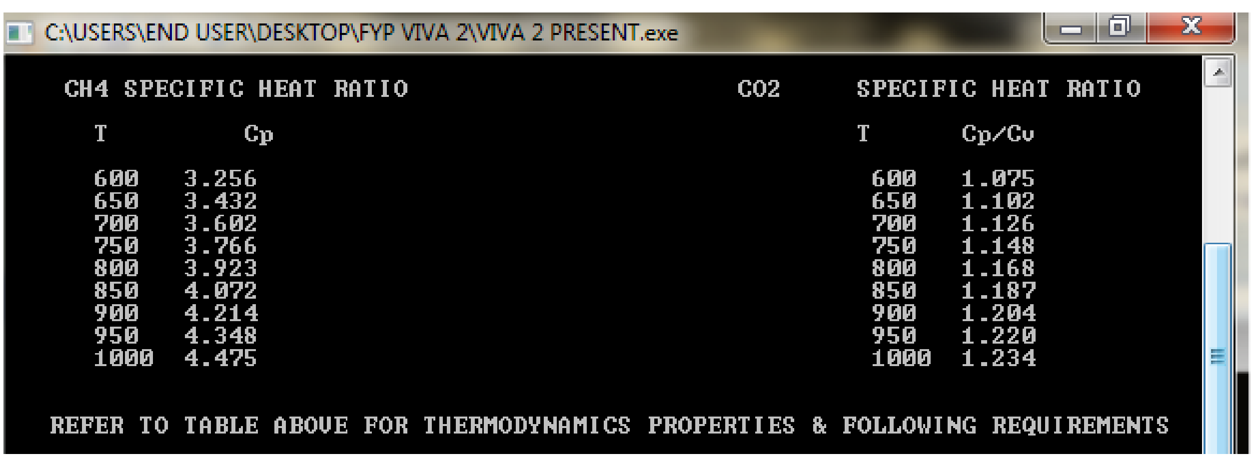
HEAT RATE (KJKW/HR) = 13797

T1 TEMPERATURE (K) = 308.4

T2 TEMPERATURE (K) = 686.989

T2 TEMPERATURE (C) = 413.989

Figure 14: Fuel Compartment Calculation



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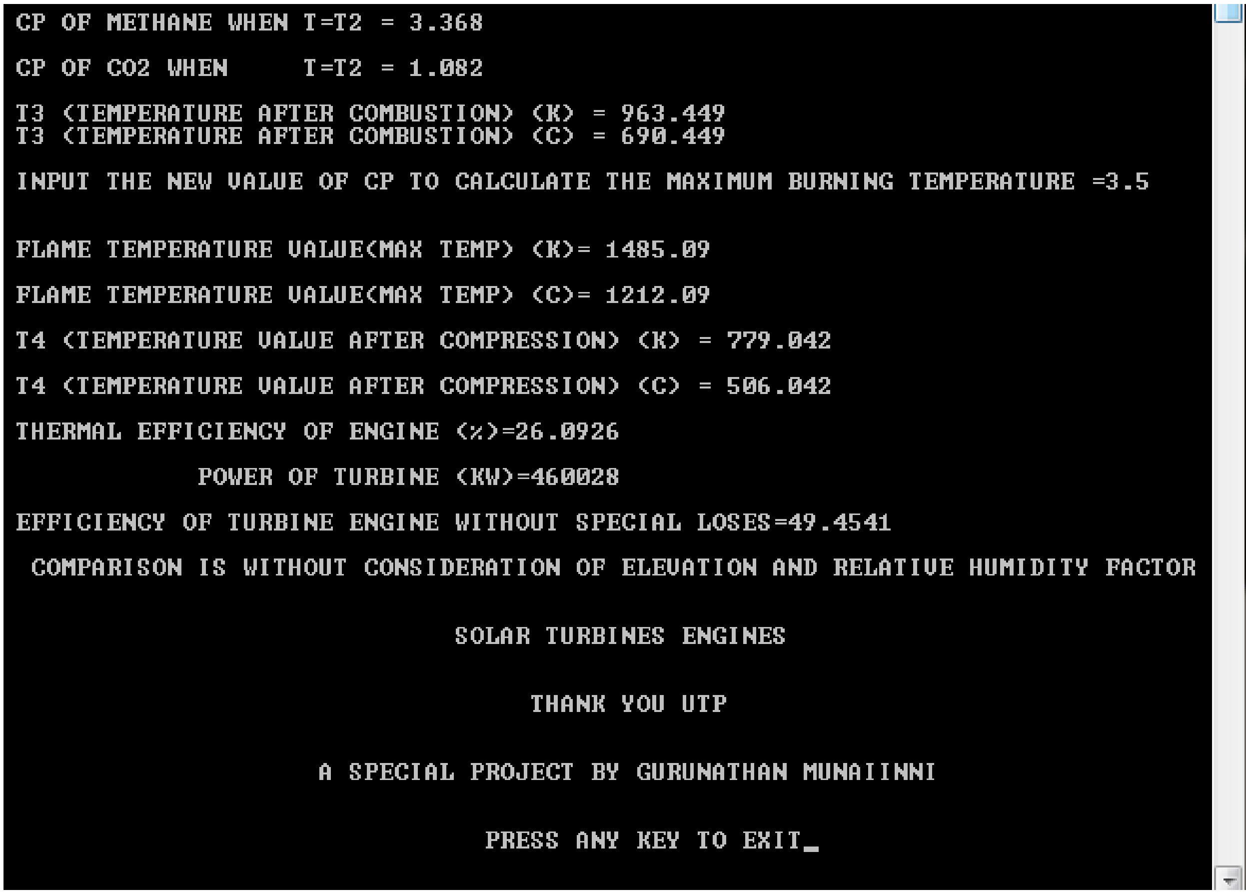
CH4 SPECIFIC HEAT RATIO		CO2 SPECIFIC HEAT RATIO	
T	Cp	T	Cp/Cv
600	3.256	600	1.075
650	3.432	650	1.102
700	3.602	700	1.126
750	3.766	750	1.148
800	3.923	800	1.168
850	4.072	850	1.187
900	4.214	900	1.204
950	4.348	950	1.220
1000	4.475	1000	1.234

REFER TO TABLE ABOVE FOR THERMODYNAMICS PROPERTIES & FOLLOWING REQUIREMENTS

Figure 15: Thermodynamics Table



```
CP OF METHANE WHEN T=T2 = 3.368

CP OF CO2 WHEN     T=T2 = 1.082

T3 (TEMPERATURE AFTER COMBUSTION) (K) = 963.449
T3 (TEMPERATURE AFTER COMBUSTION) (C) = 690.449

INPUT THE NEW VALUE OF CP TO CALCULATE THE MAXIMUM BURNING TEMPERATURE =3.5


FLAME TEMPERATURE VALUE(MAX TEMP) (K)= 1485.09

FLAME TEMPERATURE VALUE(MAX TEMP) (C)= 1212.09

T4 (TEMPERATURE VALUE AFTER COMPRESSION) (K) = 779.042

T4 (TEMPERATURE VALUE AFTER COMPRESSION) (C) = 506.042

THERMAL EFFICIENCY OF ENGINE (%)=26.0926

            POWER OF TURBINE (KW)=460028

EFFICIENCY OF TURBINE ENGINE WITHOUT SPECIAL LOSES=49.4541

 COMPARISON IS WITHOUT CONSIDERATION OF ELEVATION AND RELATIVE HUMIDITY FACTOR

                             SOLAR TURBINES ENGINES

                                  THANK YOU UTP

                    A SPECIAL PROJECT BY GURUNATHAN MUNAIINNI

                               PRESS ANY KEY TO EXIT_
```

Figure 16: T3,T4, and Turbine Output Calculation

Figure 14,15 and 16 above shows the manual calculation using Borland C++ 5.02 in order to simplify the calculation of the gas turbine engine part without depending on special simulation and this can helps engineers and consultants as well to choose and to be familiar with various type of turbine engine and throughout this programming on calculation too, we can actually identify what are the effect to the performance of turbine engine if changes applied to the input of turbine such as air and fuel.

CHAPTER 5:Conclusion & Recommendation

From the view of this project, studies and also the researches that has been carried out, it can be conclude that this topic is really a challenging topic because it needs a lot of effort to be put in order to know the whole system about gas turbine and also cogeneration plant using gas turbine because there are a lot of parameters involved and it has to been considered in order to research about the system's efficiencies. On the other side, the information that have been stated in this paper can still be explored more and more which is basically on a calculation sheet about gas turbine performance with the consideration of compression, combustion and also expand of the air in power turbine part for different families. Besides that, based on this project, conclusion can be made that the whole cogeneration plant is completely depends on the output of the gas turbine engine (exhaust) and improvement in gas turbine outlet directly increase the overall efficiency of the system because *more loses will give less performance* of the engine itself, so by attaching a cogeneration system the wasted exhaust heat can be used to run more sources and the engine is fully utilized.

Despite that few new recommendation need to be noted such as more research and studies need to be done for the engine performance base on their placement and installation because different places have its own behavior from its ambient air till its relative humidity and also studies need to be done one the differences between single shaft engine and dual shaft engine as well. on the other hand in future the calculation method that obtained in this project can be modified more because the current calculation is without considering the relative humidity and also the elevation factor because the play some roles when it comes to the performance of the gas turbine especially relative humidity because it stated that *more humidity less performance* because it of the density matters.

CHAPTER 6: References

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Authors: **Gurunathan Munainni**
Perumal Nallagownden
Norhisham Hamid

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