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EXPERIMENTAL PERFORMANCE OF HUMID AIR TURBINE FUELED BY BIOMASS

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DECLARATION

I hereby declare that the work in this thesis is the result of my own investigation, except for quotations and summaries which have been duly acknowledged. The thesis also has not been accepted in substance for any degree and is not being concurrently submitted for the award of other degrees.

(Signature of student)

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Date:

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LIST OF ABBREVIATIONS

CHP	Combine Heat and Power
EFGT	Externally Fired Gas Turbine
DG	Distributed Generation
ORC	Organic Rankine cycle
TES	Thermal Energy Storage
HHV	Higher Heating Value
HAT	Humid Air Turbine
mGT	Micro Gas Turbine
STIG	Steam Injection Gas Turbine
WI	Water Injection
mHAT	Micro Humid Air Turbine
AHAT	Advanced Humid Air Turbine
REVAP	Regenerative EVAporation
HTHE	High Temperature Heat Exchanger
CSP	Concentrated Solar Power
EFCC	Externally Fired Combined Cycle
DFGT	Direct Fired Gas Turbine
HAT-EFGT	Humid Air Turbine-Externally Fired Gas Turbine
ANN	Artificial Neural Networks
LPG	Liquefied Propane Gas
LHV	Lower Heating Value
SFC	Specific Fuel Consumption
TIT	Turbine Inlet Temperature
TOT	Turbine outlet Temperature
COT	Compressor Outlet Temperature

ABSTRAK

Kebimbangan tentang masalah alam sekitar telah membawa kepada lebih banyak kajian dalam tenaga alternatif seperti tenaga boleh diperbaharui, biomas adalah salah satu daripadanya. Bagi penjanaan kuasa elektrik, minat generasi kecil-kecilan (DG) semakin meningkat disebabkan kelebihan ke atas penjanaan berpusat. Sistem turbin gas luar (EFGT) merupakan salah satu calon utama teknologi (DG). Dengan pengeluaran udara panas dalam haba gabungan dan kuasa (CHP) hasil daripada sistem (EFGT) ini boleh menjana penjanaan kuasa elektrik. Suntikan penindas bersuhu air/wap dalam sistem (EFGT) boleh meningkatkan kecekapan kitaran. Oleh itu, kitaran udara lembap turbin (HAT) digunakan ke dalam sistem (EFGT).

Tujuan kajian ini adalah untuk mencirikan prestasi udara lembap turbin (HAT) yang didorong oleh biomas dalam kaedah eksperimen. Dengan prestasi (HAT), boleh menganalisis kecekapan kitaran (HAT) dalam menjana (CHP). Pembakaran bahan setiap kelompok 15kg biomas didorong untuk mencirikan prestasi kitaran (HAT). Penemuan utama kajian menunjukkan bahawa suhu maksimum turbin inlet (TIT) 763°C pada 0.2 bar. Dari pemampat dan turbin kuasa pengiraan, kecekapan pengecas turbo adalah dalam lingkungan 8-12% dan penggunaan bahan api yang khusus (SFC) antara 4 hingga 11 kg/kWj pada tekanan yang berbeza.

Selain itu, suntikan wap telah digunakan untuk meningkatkan kitaran udara lembap turbin (HAT) oleh pembakaran biomass di dalam pendidih yang melekat pada sistem (EFGT). Oleh yang demikian, percubaan untuk mencirikan prestasi pendidih biomass dibuat bagi menentukan kadar aliran wap yang terbaik yang akan menyuntik ke dalam sistem (EFGT). Penemuan utama kajian untuk percubaan mencirikan pendidih biomass output dan input kuasa pendidih biomass, kecekapan dan (SFC) pada kadar aliran wap yang berbeza. Kecekapan pendidih adalah dalam lingkungan 63-73% dengan purata 0.21 kg/kWj.

ABSTRACT

The concern about environmental problems has led to more studies in alternative energy like renewable energy, biomass is one of them. As for electrical power generation, interest in small scale distributed generation (DG) has recently increased due to its advantages over centralized power generation. The externally fired gas turbine (EFGT) system is one of the main candidates for (DG) technology. With the hot air production in terms of combined heat and power (CHP) output of the (EFGT) system can generate electrical power generation. The injection of preheated water/steam in the (EFGT) system can increase the efficiency of the cycle. Therefore, the humid air turbine (HAT) cycle is used into the (EFGT) system.

The purpose of this study is to characterize the performance of humid air turbine (HAT) fueled by biomass in the experimental method. With the (HAT) performance, can analyze the efficiency of the (HAT) cycle in generating (CHP). The combustion of each batch of 15kg biomass was fueled to characterize the performance of (HAT) cycle. The main findings showed that the maximum turbine inlet temperature (TIT) was 763°C at 0.2 bar. From the compressor and turbine power calculations, turbocharger efficiency was in the range of 8-12% and specific fuel consumption (SFC) ranging from 4 to 11 kg/kWh at different pressures.

Besides, the steam injection was used to increase the humid air turbine (HAT) cycle by combustion of biomass in the boiler that attached to the (EFGT) system. Therefore, the experiment to characterize the performance of biomass boiler conducted to determine the best steam flow rate that will inject into the (EFGT) system. The main findings for experiment characterize biomass boiler are output and input power of biomass boiler, its efficiency and (SFC) at different steam flow rate. Boiler effeciency was in the range of 63-73% with average 0.21 kg/kWh.

CHAPTER 1

INTRODUCTION

1.0 Research background

Our Earth is right now confronting a lot of environmental concerns. The environmental issues like water pollution, air pollution, global warming, acid rain and natural disasters affect every human, animal and nation on this planet. Those issues can be clarified by the uncontrolled utilization of non-renewable energy like gas fuel for vehicles. Furthermore, also the uncontrolled abundant amount of agricultural residue which increasing from years to years.

Every year, at least 168 million tonnes of biomass waste was produced in Malaysia. As a rule, palm oil waste represents for 94% of biomass feedstock while the rest contributors are the agricultural and forestry by-products, such as wood residues (4%), paddy (1%) and sugarcane industry wastes (1%). Up to 4.5 million hectares of land was cultivated with oil palm, which translates to 13.6% of the country's total land area. The palm oil industry creates an abundant amount of by-products, especially through its processing. With more than 423 mills in Malaysia, the palm oil industry generated around 80 million dry tonnes of biomass.[1]

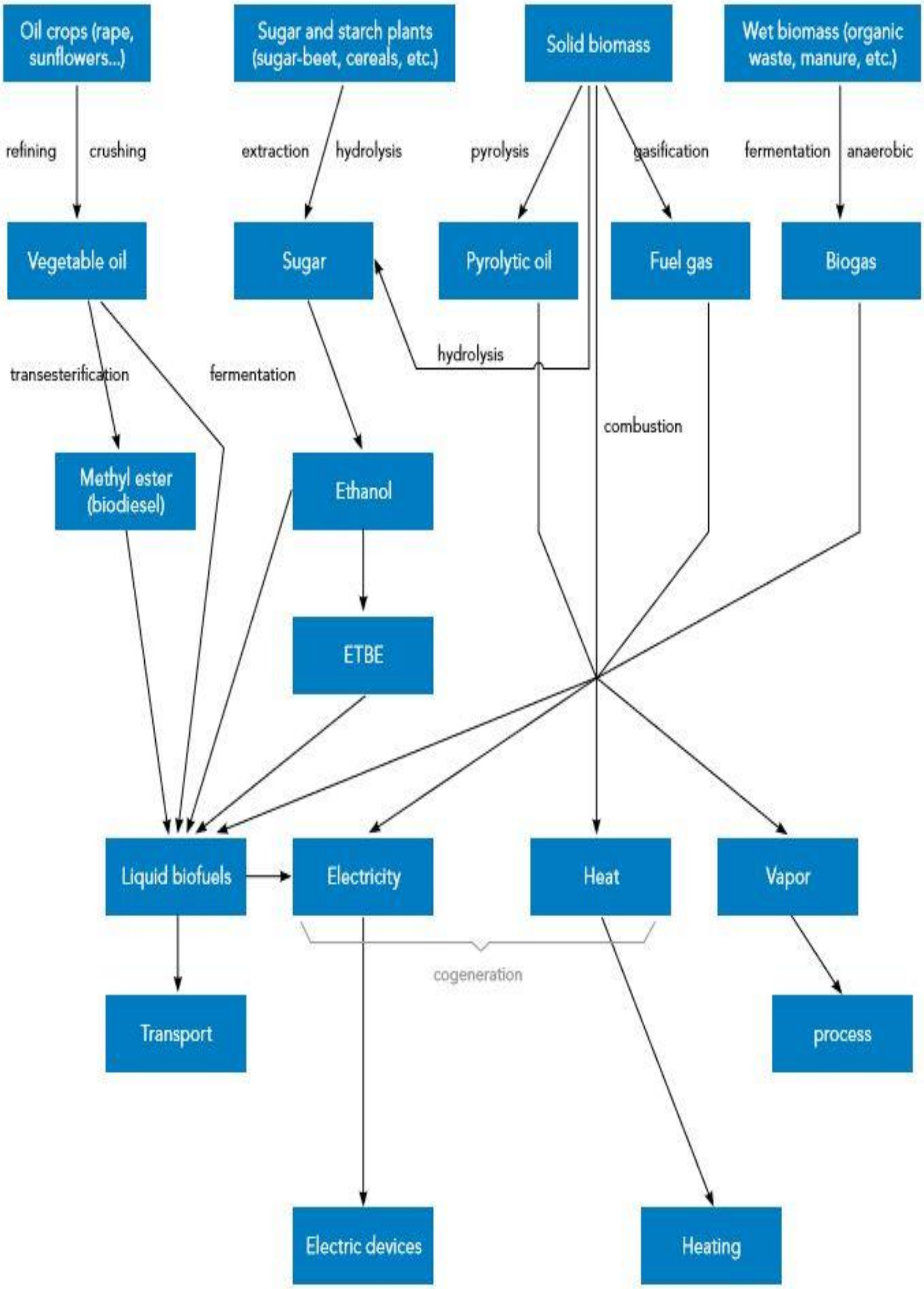
Furthermore, the abuse of our planet and the degradation of our environment have gone up at a disturbing rate. As our activities have been not in favor of protecting this planet, we have seen natural disasters striking us more regularly in the form of flash floods, tidal waves, hurricane and earthquake.

Over the last few decades, the concern about environmental problems has led to more studies in alternative energy like renewable and nuclear energy. Biomass is one of the renewable energy fuel sources that very important for combined heat and power (CHP) generating. Biomass fuel refers to any organic substance from plant materials or animal wastes used as fuels. Biomass includes, for example, agricultural residues, urban wastes even sewage sludge waste.

Next, biomass is a renewable energy source not only because the energy in it comes from the sun, but also because it can be regrown over a short period of time compared with the hundreds of millions of years that took for fossil fuels to be formed. Through the process of photosynthesis, chlorophyll in plants captures the sun's energy which is sunlight by converting carbon dioxide from the air and water from the ground into carbohydrates complex compounds composed of carbon, hydrogen, and oxygen. During these carbohydrates are burned, they turn back into carbon dioxide and water and release the energy they captured from the sun.

Biomass is a very promising source of renewable energy in Malaysia and at present. As one of the largest producers of palm oil, Malaysia is blessed with abundant biomass resources which can be converted into alternative energy. Therefore, the biomass commercialization needs further intervention to support the use of green technology in the industry and reduce the environmental problems in Malaysia.

In this project, the main concern is on the use of wood as an alternative to oil palm waste which acts as fuels to generate (CHP). The use of solid biomass as fuel can generate electricity and heat as shown in figure 1.1[2]. By producing this energy must use a combustion process that can get from biomass boiler with an externally fired gas turbine system for humid air that will use in this project.



Source: Renewable Energy World, 2006.

Figure 1.1: Biomass energy conversion overview

1.1 Biomass combine heat and power output

Biomass gasification is the thermochemical conversion of biomass fuels into combustible gaseous products. These products are used for thermal applications, electrical generation or (CHP) outputs (cogeneration). For thermal applications, the drying process is one of the biggest challenges for many industries to get a cheap and clean heat source, for example, timber drying and food processing. Mostly, the drying processes are using electrical heaters or steam based drying, the latter is more popular for drying because it is cheaper than the electrical heaters especially if the boilers are using biomass fuels. However, the steam based drying systems are complicated and require more maintenance.

For small scale electrical power applications in the range of 20-400kW, downdraft and fluidized bed gasifiers with diesel or gas reciprocating engines have shown a promising success, especially for rural areas where fossil fuels are not available. However, the main problem with these systems is the cost of maintenance. Since the reciprocating engines are sensitive to the amount of tar, temperature and humidity in the producer gas, additional cleaning, cooling and drying systems are required after the gasifiers. Further more, the engines working life becomes shorter, and for the rural places with the difficulties of giving the villagers a significant training to perform all the operation and maintenance duties in a correct way, so the system could fail due to poor maintenance.

Another option for power generation is to use gas turbine engines. However, for the direct firing of the turbine, an intensive cleaning of the producer gas is required before compressing and injecting the gas into the combustion chamber to reduce the turbine fouling problem. The main concerns in the recent studies are to reduce the cost of the producer gas cleaning process and to develop the technology of the low quality gas combustion.

1.2 Problem statement

Externally fired gas turbine (EFGT) system is one of the main distributed generation (DG) candidates and it has a large potential as combine heat and power (CHP) system. The importance of the (CHP) system are act as on site production of power, reduced energy costs and reduction in emissions compared to conventional electrical generators. However, the main concerns when using (EFGT) is the low turbine inlet temperature (TIT) due to the limitation in high temperature heat exchanger technology which has a negative effect on the cycle efficiency. In order to elevate (TIT) considerably, special alloys and ceramic materials for the heat exchanger have to be implemented. This will increase the cost of the system making it not suitable as a lowcost alternative (CHP) generation system for rural places. Therefore, this study proposes an alternative operating method that can operate the (EFGT) with lower (TIT) while maintaining acceptable power.

1.3 Objectives

a) To characterize the performance of biomass boiler fueled by biomass for externally fired gas turbine (EFGT) system.
b) To characterize the performance of humid air turbine (HAT) fueled by biomass from (EFGT) system for hot air producing.

1.4 Scope of the research & limitation

The scope of work and limitation for this study can be summarized as the following:

a) Run the biomass boiler and modified if needed.
b) The woods used as fuel during the combustion process for boiler and (EFGT) system are limited to off-cut furniture rubberwood from local furniture industries.
c) Run the (EFGT) system and troubleshoot if there is problem occur.
d) Characterize the biomass boiler and (EFGT) system are based on experimental work.
e) Tabulate the data from the performance of biomass boiler and performance of humid air turbine fueled by biomass by using excel software.

f) Calculate and discuss graphs of the efficiency of biomass boiler and humid air turbine based on thermodynamic formulae that have been studied.

1.5 Overview of the overall structure of the research

The concern about environmental problems has led to more studies in alternative energy like renewable energy. Biomass is one of the renewable energy fuel sources that very important for generating CHP. In chapter 2, some studies on the biomass boiler, humid air turbine cycle and EFGT system using biomass as fuel are presented. Then, the literature summary is also presented. Then, in chapter 3 will discuss the principles on the main HAT cycle including compressor, turbine and heat exchanger. After that, the performance parameters for the experimental work are presented.

Furthermore, in chapter 4, the study on characterize the performance of biomass boiler and humid air turbine fueled by biomass. In this chapter, the following topics will be discussed, EFGT system, biomass boiler, auxiliary equipment, experiment setup and methodology. Next, in chapter 5, presented the findings and results during the experiment of characterize the performance of biomass boiler and performance of humid air turbine fueled by biomass. Lastly, chapter 5 will conclude the results of the experimental work for the characterization of biomass boiler and HAT. Finally, recommendations for the future work are proposed to improve the performance of EFGT system.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

In this chapter, some studies on the biomass boiler, humid air turbine cycle and EFGT system using biomass as fuel are presented. Finally, literature summary is presented.

2.1 The different of biomass boiler use to produce steam in current industry

The boiler is a closed vessel which water was heated inside until the water converted into steam at required pressure. Fuel is burned in a furnace and hot gasses are produced. These hot gasses are contacted with water vessel where the heat of these hot gasses transfer to the water and consequently steam is producing in the boiler. There are wide range of sorts of boiler utilized for various purposes like running a production unit, sanitizing some area and to warm up the surrounding.

The biomass boiler is used to produce steam to be injected into the EFGT system. This is very important to generate CHP by using the method of combustion of biomass. With this method can reduce the use of fossil fuels as main fuel that tend to unsustainability for our earth. Biomass combustion is very interesting for smart grid and DG applications. The performance biomass boiler was studied in (Arianna Sorrentino, 2018)[3]. The flexible configuration of biomass-fired CHP system with ORC is proposed and applied to the case study of food retail buildings. The TES was proposed to improve the flexible operation of the plant and reduce the size of the biomass boiler. The results show the use of thermal storage can improve the boiler efficiency from 88% to 92% and reduce the biomass consumption in thermal-load following operating mode and increase investment profitability.

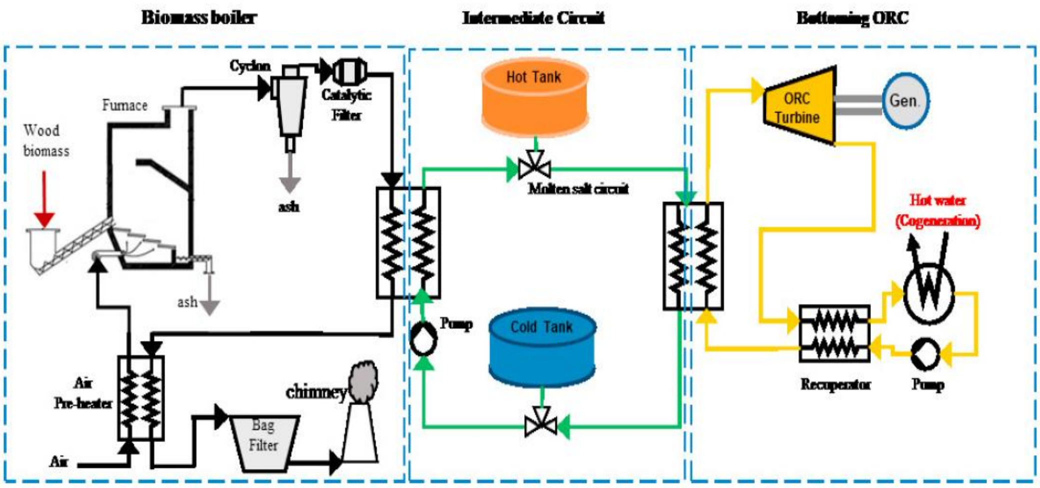


Figure 2.1: Layout of the system configuration

After that, these study (Gianluca Caposciutti F. B., 2017)[4], (Gianluca Caposciutti F. B., 2018)[5] aims to investigate the thermal behaviour of a 140kW fixed-bed boiler sited at the Biomass to Energy Research Centre of the University of Pisa and fed with the woodchips. This study had discussed the comparison between the simulated and experimental data that have been shown a good values agreement for the temperatures and the chemical species in the biomass bed volume. The temperatures are in the range of (1000-1500)K.

Then, there is also the study of the effect of air supply on the biomass combustion for the grate boiler (Anqi Zhou, 2019)[6]. The effect of air supply for biomass combustion characteristics in the grate bed is discussed based on the simulation results and then validated with experimental measurements. By the increase of air supply during combustion process shortens the burning time and raises the maximum combustion temperature. The suggested ratio of primary to secondary air is 43:57 for the industrial-scale grate boiler.

Besides, the study (Alan Carneiro, 2017)[7] of performance quantification of a cyclonic boiler aims to reduce harmful emissions to the environment that emit through the use of fossil fuels as sources to produce steam and heat. The experiment leads to the quantification of boiler thermal efficiency and gas species concentration. The experiment also uses Cedrella Fissilis biomass as sawdust. In the end, the experiment obtained thermal efficiency of 44%, biomass energy conversion through the combustion of 98% and carbon dioxide emissions in the eluded gases around 139 ppm.

Lastly, there is also study (Leonel J.R. Nunes, 2019)[8] to evaluate the implications of the use of maritime pine non-debarked wood chips as an alternative solid fuel in the industrial boilers in Portugal. In this study, several samples were used to determine the volatile matter content, fixed carbon content, ash content and HHV. In the end, it was concluded that the use of maritime pine non-debarked wood chips can significantly contribute to the formation of slagging and fouling phenomena in industrial boilers. Therefore, to avoid slagging on the furnace wall, the furnace must have sufficient wall surface to cool the furnace gas and ash particle before reached to any superheater surface (Cai Yongtie, 2017)[9]. Furthermore, the furnace also should be kept ash particles in suspension and away from the furnace surface and distribute heat evenly to avoid localized temperatures.

2.2 The various humid air turbine cycle

The use of steam or preheated water for the HAT cycle has been proven a very efficient way to introduce waste heat. Based on the study, (Ward De Paepe, 2017)[10] the aims to study the impact for more advanced of humidified gas turbine cycle concepts on the mGT performance by using the simulation method. The different cycles had been studied by referring the cycles on old journals which are STIG cycle, WI cycle, mHAT cycle (J. Parente, 2003)[11], AHAT cycle (Toru Takahashi, 2002)[12] and REVAP cycle (G. Allard, 1997)[13]. In the end, the REVAP cycle with feedwater preheat was identified as the optimal cycle layout. By using this cycle, the stack temperature could be brought down to 53°C and increase in electrical power output of 128.7 kW with the maximal absolute efficiency increase of 6.9% compared to the dry cycle layout which 100.1 kW electrical power output and 35.1% efficiency.

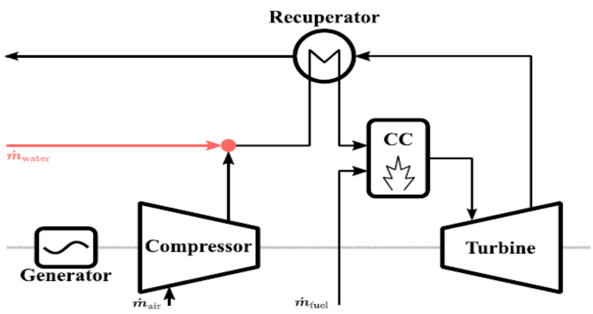


Figure 2.2: Layout use for WI cycle

Next, the paper (Marina Montero Carrero, 2017)[14] introduce and compare the Sankey (enthalpy flow) and Grassmann (exergy flow) diagrams of an mGT based on the Turbec T100 and the corresponding mHAT cycle. Results demonstrate that the electrical efficiency of the T100 rises by 2.5% absolute points with water injection, while the total exergy efficiency decreases by only 4.1%. In spite of the fact that there is an enthalpy gain in the saturation tower, exergy really diminishes in this component due to the increment in entropy identified with the dissipation of water. The air is saturated with high temperature water originating from the economiser, leading to an increase in electrical efficiency. The advantages of water injection, for the most part, depending on the heat capacity of the air-vapor mixture, the lower fuel consumption, the higher heat recovered in the recuperator, and the reduced power required by the compressor.

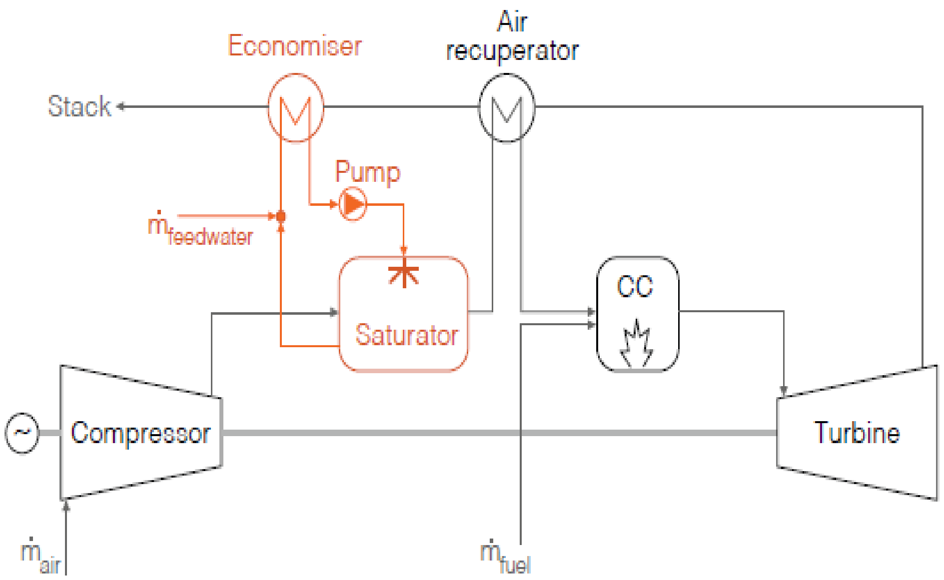


Figure 2.3: The main components of mHAT cycle

Besides, HAT also showed the potential to deliver high efficiency and power output combined with low emissions. This paper (Giovanni D. Brighenti, 2017)[15] investigates the part-load performance of a 40MW class AHAT for power generation applications across a range of operating conditions. Additionally, the effect of the ambient air and seawater temperature on the cycle's performance are also explored. The results of the research demonstrate that thermal efficiency if the system is less than 0.26% penalized when operating down to 50% of the design power output. Seawater temperature was found to have a more remarkable effect than the ambient air temperature on both power output and thermal efficiency.

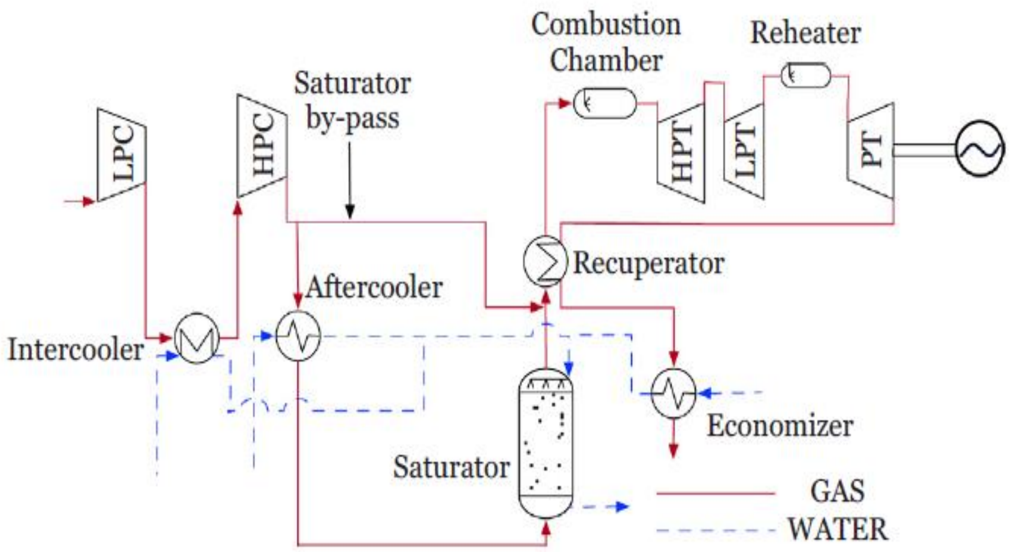


Figure 2.4: Reheated HAT system layout

Furthermore, there is also paper (Pau Lluis Orts-Gonzalez, 2018)[16] aims to identify the economic potential of a reheated HAT system for power generation applications. A parametric investigation is performed to associate the technology level of the framework with the required expense of the electricity for economic feasibility. The impact of fluctuations of the main cost drivers is assessed by means of uncertainty analysis. The performance of the studied reheated HAT is compared against recently studied humid configurations and well-established gas-steam combined cycles. The investigation uncovers the ability of the reheated HAT to be a financially feasible alternative for the power generation sector highlighting an estimated cost of electricity 2.2% lower than simpler humid cycles, and 28% lower than setting up combined cycles presented in service. The result of the work proves the capability of such systems for applications where high efficiency and economic performance are mutually required.

2.3 Externally fired gas turbine system with different cycle

The externally fired gas turbine is defined as the hot combustion gases are not in direct contact with the turbine blades. As it is not in direct contact, therefore the thermal power of the combustion gases should be transferred to the working fluid by HTHE. The special of EFGT from other alternative is it can be an open cycle or a closed cycled with air as the working fluid (K.A. Al-Attab, 2015)[17]. Thus, the additional gas cooler needs to be added to the closed cycle to reduce the gas temperature before reentering the compressor that makes the configuration ideal for the CHP generation.

In this paper (K.A. Al-Attab, 2015)[17], a wide range of thermal power sources utilizing EFGT such as CSP, fossil, nuclear and biomass fuels are reviewed. Gas turbine as the main component of EFGT is investigated from micro scale below 1MW to the large scale central power generation. Moreover, the different HTHE materials and designs are reviewed. Finally, the methods of improving cycle efficiency such as the EFCC, HAT, EFGT with fuel cells and other cycles are reviewed thoroughly.

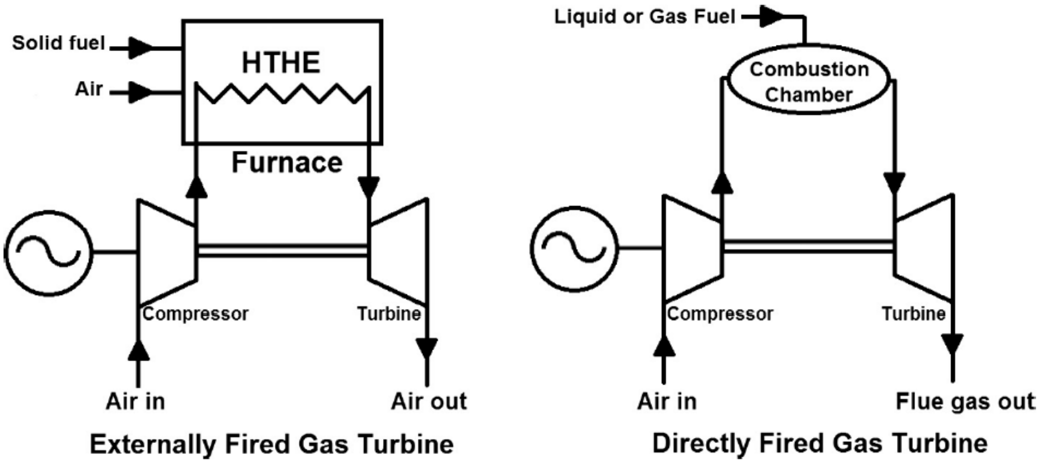


Figure 2.5: Different between EFGT and DFGT

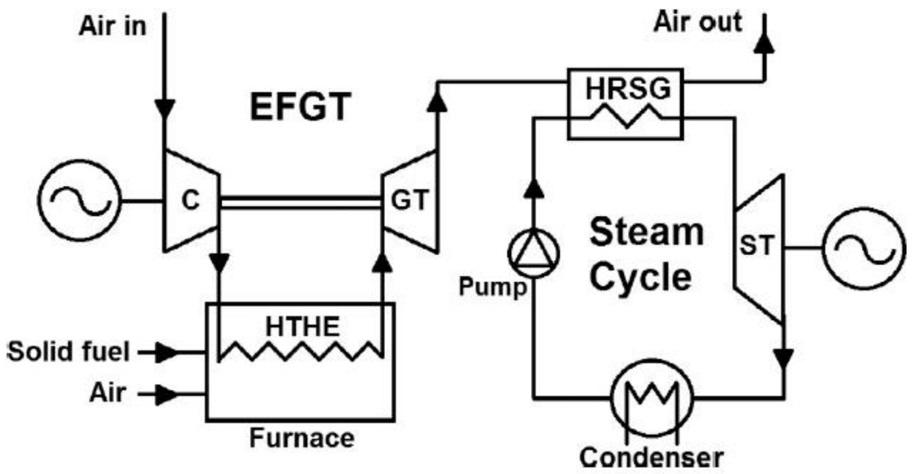


Figure 2.6: Simple EFCC

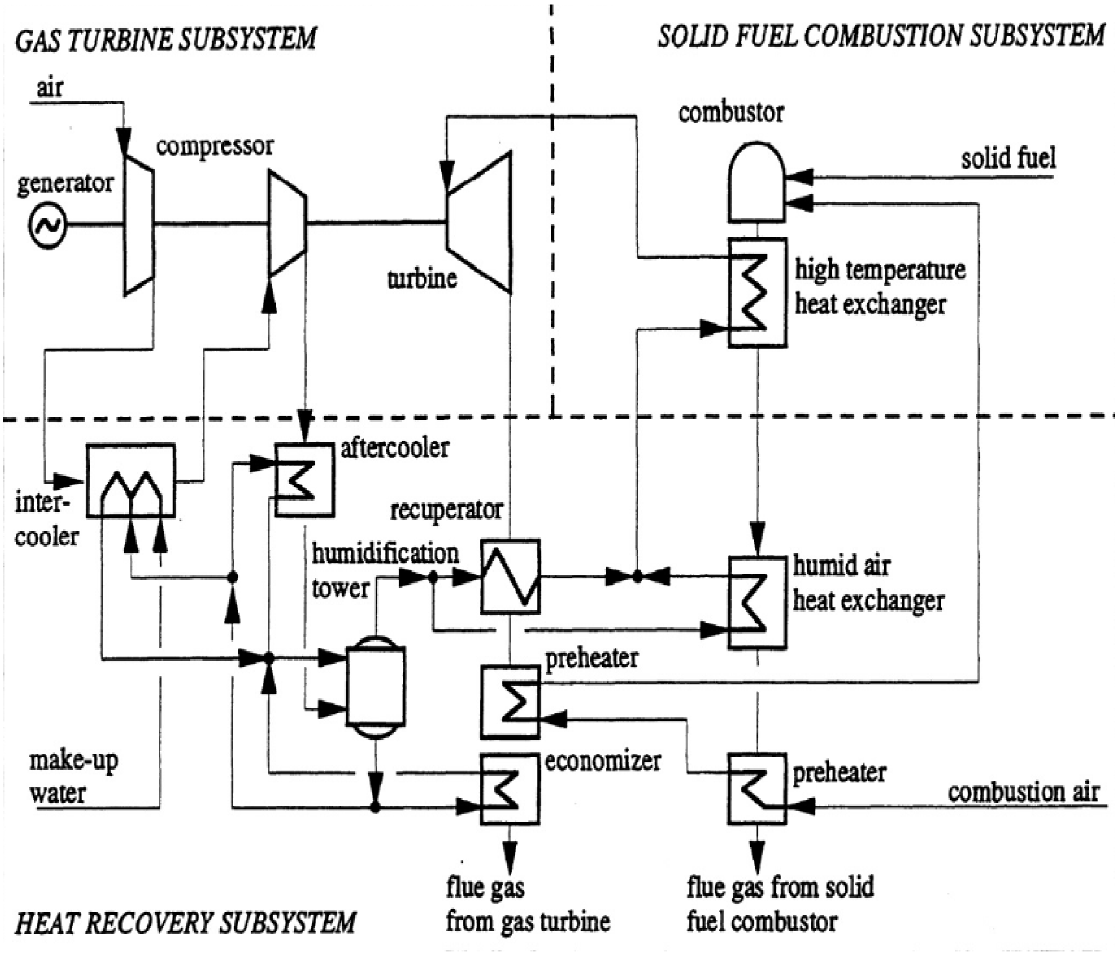


Figure 2.7: HAT-EFGT system with intercoolers, after-coolers and heat recovery unit

In this paper (Dimas Jose Rua Orozco, 2017)[19], a diagnostic system is proposed for EFGT, using the thermoeconomic strategy related to ANN to recognize malfunction components and their fuel effects. The ideas "Exergetic Operator" and "Transition Structure" are likewise exhibited. The EFGT was simulated using the software GateCycle™ 5.51, objective to achieve a power of 99.80 kW (design point) utilizing wood carbonization residual gas as fuel. An ANN was created with the commercial software MATLAB.

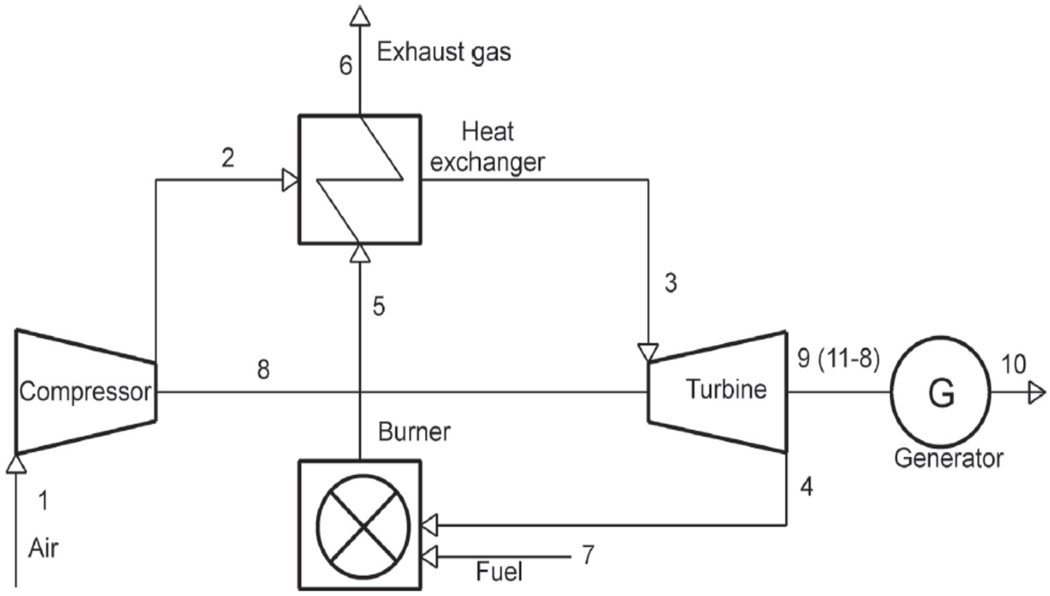


Figure 2.8: EFGT-Cycle layout use for MATLAB simulation

2.4 Literature summary

In the current industry, they usually use different boiler based on their situation. The situation can differentiate based on the purpose to provide steam. Usually, the stoker boiler needed more biomass because of its size. For biomass boiler in this project, needed less biomass and maximum steam flow rate of 3.00kg/min. Thus, the project not costly add woods are free to be provided.

Next, the experimental performance of HAT in the EFGT system still not available in the journals that have been reviewed. Usually, the projects only do in simulation because the experiment is very costly. It is very costly because of the system consist of turbine, compressor and needed to fabricate the heat exchanger and then cover all the system to avoid damages. The experiment also can be costly because of maintenance or troubleshooting if problems occur. By injection of steam into the HAT cycle can increase the performance compared to other cycles such as WI cycle. The thermal performance can be increased when using steam than water.

CHAPTER 3

THEORY

3.0 Introduction

This chapter discusses the principles on the main HAT cycle including:

a) Compressor
b) Turbine
c) Heat exchanger

Then, discuss the performance parameters for the experimental work.

3.1 Compressor

Compressor is a mechanical device that increases the pressure of steam or gas by reducing their volume. There are many types of compressor. One of it is a centrifugal compressor that used in this project. The centrifugal compressor uses a rotating disk or impeller in a shaped housing to force the gas to the rim of the impeller and increasing the velocity of the gas. A diffuser section changes over the velocity energy to pressure energy. It can achieve from 100 horsepower (75 kW) to thousands of horsepower. With multiple staging, they can achieve high output pressures greater than 1,000 psi (6.9 MPa)[20]. This type of compressor are extensively used in internal combustion engines as superchargers and turbochargers. Centrifugal compressors are also used in small gas turbine engines or as the final compression stage of medium-sized gas turbines.

3.2 Turbine

Turbine is a rotational mechanical device that extracts energy from a fluid flow and converts it into useful work[21]. Early turbine examples are windmills and waterwheels. The work produced by a turbine can be utilized for producing electrical power when joined with a generator. A turbine is a turbomachine with at least a moving part called a rotor assembly, which is a shaft or drum with blades attached. The moving fluids act on the blades thus impart the rotational energy to the rotor.

3.3 Heat exchanger

Heat exchanger is heat transfer of from one fluid to another through a series of tubes/plates from one side to the other side. Heat exchangers are broadly utilized in the industry both for cooling and heating large scale industrial processes. The type and size of heat exchanger used can be customized to suit a process depending on the type of fluid, its phase, temperature, density, viscosity, pressures, chemical composition and various other thermodynamic properties.

In many industrial processes, there is a waste of energy or a heat stream that is being exhausted, heat exchangers can be used to recover this heat and put it to use by heating a different stream in the process[22]. It can benefit and saves a lot of money in the industry, as the heat supplied to another stream from the heat exchangers may otherwise come from an external source that is more expensive and more harmful to the environment.

3.4 Performance parameters for the experimental work

In this section, some of the parameters that indicate the performance of biomass boiler and performance of humid air turbine fueled by biomass will be discussed.

3.4.1 Output power

Output power is steam flow rate multiplied by the differences of enthalpy of water at initial temperature and enthalpy of steam produced.

$$Output\ power, W = m_{steam} \times h_{fg}$$

3.4.2 Input power

Input power is biomass feedrate multiplied by the lower heating value (LHV) of wood which is 17000kJ/kg.

$$Input\ power, W = m_{fuel} \times LHV$$

3.4.3 Compressor work

Compressor work is mass flow rate of air multiply by its specific heat and different between compressor outlet and inlet temperature.

$$Compressor\ work, w_c = m_{air} \times cp_1 \times (COT - 30°\text{C})$$

3.4.4 Turbine work

Turbine work is total mass flow rate between air and steam multiply by its specific heat and different between turbine inlet and outlet temperature.

$$Turbine\ work, w_t = m_{total} \times cp_2 \times (TIT - TOT)$$

3.4.5 Specific fuel consumption

Specific fuel consumption is biomass feedrate in hour divided by input power.

$$Specific\ fuel\ consumption, SFC = \frac{m_{fuel} \times 3600}{W}$$

3.4.6 Efficiency

Efficiency is output power divided by input power multiplied by 100%. Then, the turbine efficiency is compressor work divided by turbine work multiplied by 100%.

$$Efficiency, \eta = \frac{W_{output}}{W_{input}} \times 100\%$$

$$\eta_{turbine} = \frac{w_c}{w_t} \times 100\%$$

CHAPTER 4

RESEARCH METHODOLOGY

4.0 Introduction

This research depended mainly on the experimental work, to study and characterize the performance biomass boiler and the performance of humid air turbine fueled by biomass as shown in the flow diagram of the study methodology in figure 4.1. In this chapter, the following topics will be discussed:

a) Externally fired gas turbine system
b) Biomass boiler
c) Auxiliary equipment
d) Experiment setup
e) Methodology

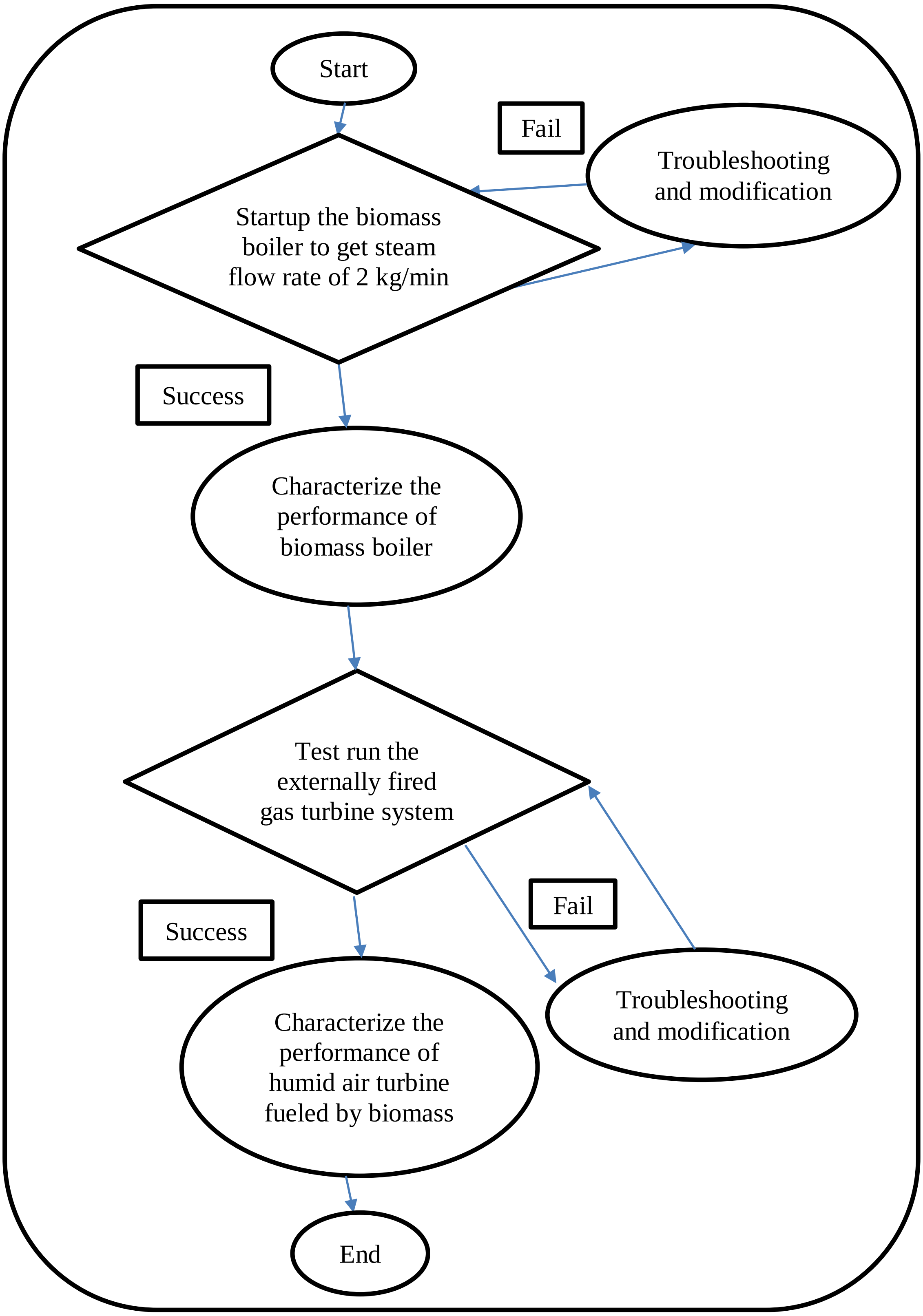


Figure 4.1: Flow chart of the activities

4.1 Externally fired gas turbine

The water stored from the tank was used in the experiment. The main valves connected between the tank and the water pump were opened. The electric current was provided to the motor and make the pump function and pumping the water to the biomass boiler through the copper coil. With the combustion of woods at the biomass boiler, the water changed to steam and will injected to the EFGT system. The steam injected to the EFGT system through the heat exchanger exit duct and pass through the high temperature heat exchanger (HTHE), the compressor and the turbine and lastly producing hot air. With the hot air, at the rural places, it can be used for drying process as it is one of the biggest challenges for many industries to get a cheap and clean heat source, for example, timber drying and food processing.

The EFGT consists of a centrifugal air compressor that is the compressor side of a diesel engine turbocharger while the turbocharger is still mounted on the engine and driven by the engine exhaust flue gases. The compressor provides lower air flow rate compared to the air blowers and that decreases the air heating rate and delays the startup process. In any case, the compressor provides much higher air pressure that is a critical factor for the turbine startup.

The Garrett GT-25 vehicular turbocharger engine is mounted on a single shaft along with the electric generator. The maximum air flow rate of about 2.5 kg/s was used as can reduces the system cost significantly and proposes the system as a good economical power alternative for the off-grid applications.

The gasifier-combustor consists of two chambers, namely the gasifier and the combustion chambers. It is a batch fuelled unit with a thermal power output of about 100 kW. It is a single flame gasifier-combustor where the flame extends from the combustion zone in the gasifier chamber to the combustion chamber through a horizontal throat. This provides a good chance for tar cracking before the flue gases reach the heat exchanger.

Next, the high temperature heat exchanger (HTHE) is made using material stainless steel (SS-304) counter-flow single-pass 6 m height shell and tube heat exchanger created to transfer thermal power from the combustor to the air as the working fluid of the turbine. It is a gas-to-gas heat exchanger where the cold fluid is air in the tube side and combustion flue gas is in the shell side.

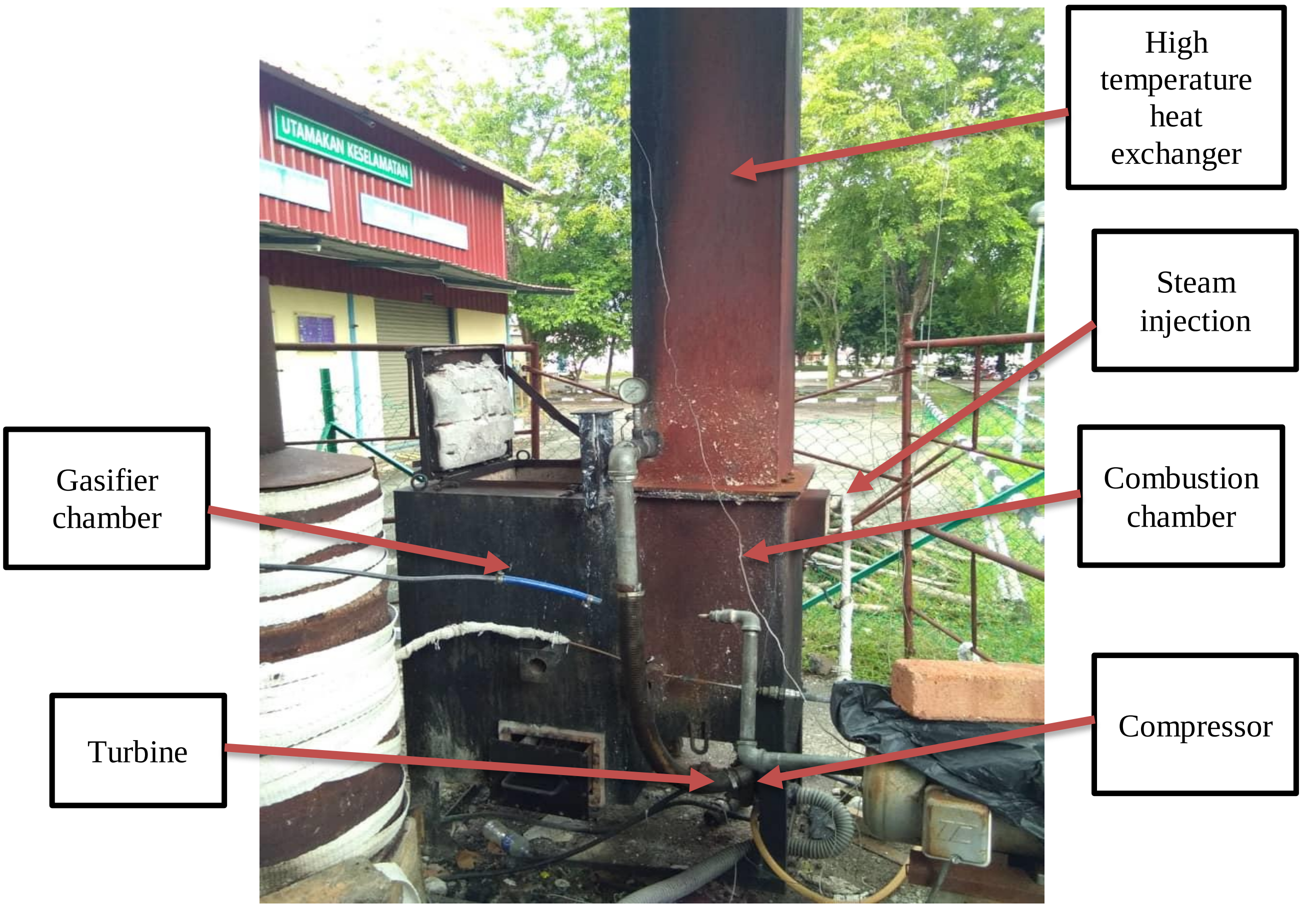


Figure 4.2: EFGT in Bioenergy Lab

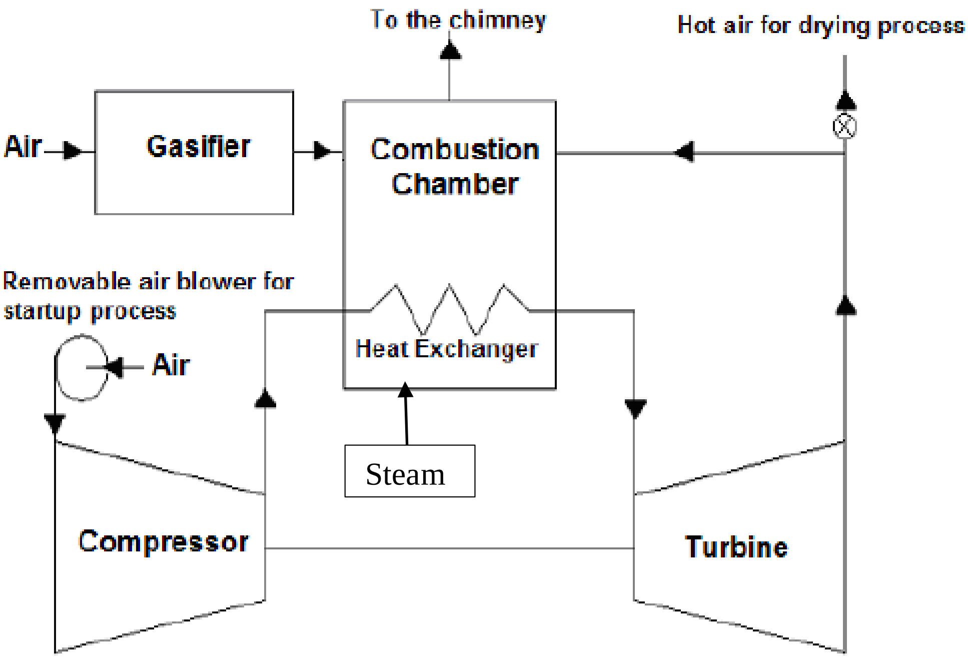


Figure 4.3: Schematic drawing of EFGT

4.2 Biomass boiler

The biomass boiler consists of copper coil with approximately 120 m long hung inside the insulation body. The copper coil was chosen because it is good in thermal conductivity during combustion. It also allow fluid and heat to pass through it quickly. Furthermore, they are safe in fires because they don't burn or support the combustion. Besides, the copper is corrosion resistance and low in the reactivity series. This means that it doesn't tend to corrode.

Then, the biomass boiler also consists of chimney to provide ventilation for hot flue gases or smoke from the boiler to the outside atmosphere. The chimney have been fabricated in vertical to ensure that the gases flow smoothly, drawing air into the combustion in what is known as the stack or chimney effect.

After that, at the lower part of the boiler, the arrangement of bricks or easy to call as combustion chamber differentiate between the boiler and the combustion part. Besides, the combustion grid was attached to the boiler near the combustion chamber. The purpose is to place the woods during combustion above the combustion grid and separate the ash from woods to make easier in cleaning the produced ash.

Figure 4.4: Biomass boiler

4.3 Auxiliary equipment

Auxiliary equipment refers to any electronic device that is capable of functioning independently without any direct communication with the main processing module. For example in this project, water pump system with tank, blower, voltage divider and lubricant oil system.

4.3.1 Water pump system with tank

The water pump system was used to provide the fluid which is water to flow into the copper coil. With the combustion and heating of the copper coil, the water would change to the saturated steam when exceeding 100°C as it is the boiling point of water.

Figure 4.5: Water pump system with tank

4.3.2 Blower

The blower was used in order to control the air flow rate and flame intensity. The LPG was provided first to produce fire and then the blower was used to generate fire for combustion. Specification of blower as below:

a) Manufacturer: Apex
b) Model: ES-729
c) Power: 5.5 kW
d) Voltage: 415V
e) Frequency: 50Hz
f) Rotation of speed: 2935 rpm

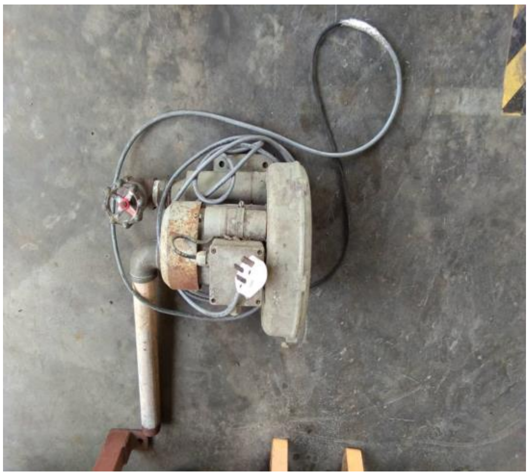


Figure 4.6: Blower

4.3.3 Voltage divider

The voltage divider used to control the motor that connected to water pump in this experiment. Usually 50V was used for low water flow rate and more than 50V for high flow rate.

Figure 4.7: Voltage divider

4.3.4 Lubricant oil system

The lubricant system with engine oil SAE 20W-50 was used to reduce friction between surfaces when the surfaces move. It may also have the function of transmitting forces and cooling the surfaces.