DEVELOPMENT AND CHARACTERIZATION OF BIOMASS STEAM BOILER FOR EXTERNALLY FIRED MICRO GAS TURBINE (EFMGT) SYSTEM

By:

AMIRUL AZIM BIN AZMAN

(Matrix no.: 125002)

Supervisor:

Dr. Khaled Ali Mohammad Al-Attab

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DECLARATION

This thesis is the result of my own investigation, except where otherwise stated and has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any other degree.

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(Signature of Student)

Date:

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LIST OF ABBREVIATION

CHP	Combined of Heat and Power
ASTM	American Society for Testing and Materials
HAT	Humid Air Turbine
EFMGT	Externally Fired Micro Gas Turbine
LPG	Liquefied Propane Gas
DG	Distributed Generation
AF	Air-Fuel
FA	Fuel-Air
PG	Producer Gas
MGT	Micro Gas Turbine
RPM	Revolution per minute
EvGT-BAT	Evaporated Biomass Air Turbine Cycle
IGCC	Integrated Gasification Combined Cycle
PCC	Pressurized Cyclone Combustor
LHV	Low Heating Value
SFC	Specific fuel consumption
HTHE	High Temperature Warm Exchanger
EFCC	Externally Fired Consolidated

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PEMBANGUNAN DAN KARAKTERISASI PRESTASI DANDANG HABA MENGGUNAKAN BAHAN API BIOJISIM UNTUK SISTEM TURBIN GAS MIKRO YANG DIBAKAR SECARA LUARAN (EFMGT)

ABSTRAK

Bahan api alternatif adalah keutamaan dalam bidang penyelidikan tenaga, berikutan isu kekurangan bahan api fosil dan kemusnahan alam sekitar. Biojisim adalah sumber bahan api yang boleh diperbaharui dan penting untuk aplikasi haba dan kuasa, terutamanya di negara-negara seperti Malaysia di mana terdapat sisa biojisim yang melimpah ruah. Bagi penjanaan kuasa elektrik, tumpuan ini meningkat dalam generasi kecil yang diedarkan (DG) kerana kelebihannya terhadap penjanaan kuasa berpusat. Enjin pembakaran dalaman (IC), turbin gas mikro yang dibakar secara luaran (EFMGT) dan turbin angin merupakan calon utama bagi teknologi DG. Dandang yang didorong oleh biojisim untuk EFMGT telah menunjukkan kejayaan untuk penjanaan kuasa.

Penyelidikan ini membangunkan dan mencirikan dandang stim biojisim untuk sistem EFMGT. EFMGT menyatukan dua kelebihan. Antaranya, penggunaan haba buangan dari turbin dalam proses pemulihan dan, di sisi lain, kemungkinan untuk membakar bahan api "kotor". Khususnya, EFMGT membuka pilihan baru untuk menggunakan biojisim untuk gabungan haba dan kuasa dan menyumbang untuk mengurangkan pelepasan gas rumah hijau. Dandang adalah tiub tunggal dengan konfigurasi aliran kaunter. Bahan tiub yang dipilih adalah tembaga dengan diameter dan panjang 10 mm dan 120 m masing-masing. Ruang pembakaran ini dibina dengan bata dan simen tahan api. Dimensinya adalah diameter dalaman 0.57 m dan ketinggian 0.2 m. Peralatan tambahan yang terlibat adalah, pam, motor, dan penghembus dengan pengawal inverter. Reka bentuk dandang diuji sepanjang eksperimen.

Sasaran utama adalah mensasarkan hasil 2 kg/min stim dan untungnya ia mencapai lebih tinggi dari yang diharapkan. Dandang ini boleh menghasilkan sehingga 2.8 kg/min dengan keadaan stim tetap dan minimum 1 kg/min dengan keadaan stim yang tetap. Julat kecekapan adalah 93% hingga 98% bergantung pada kadar aliran air atau kuasa masukan.

DEVELOPMENT AND CHARACTERIZATION OF BIOMASS STEAM BOILER FOR EXTERNALLY FIRED MICRO GAS TURBINE (EFMGT) SYSTEM

ABSTRACT

Alternative fuels are a priority in energy research field, due to issues of fossil fuel depletion and environmental degradation. Biomass is an important renewable energy fuel source for thermal and power applications, especially in countries like Malaysia where abundant biomass waste available. As for electrical power generation, interest has recently increased in small scale distributed generation (DG) due to its advantages over centralized power generation. Internal combustion (IC) engines, externally fired micro gas turbines (EFMGT) and wind turbines are the main candidates for DG technology. Boiler fueled biomass for EFMGT have shown success for power generation.

This research developed and characterized a biomass steam boiler for EFMGT system. The EFMGT unites two advantages. On the one hand, the utilisation of the waste heat from the turbine in a recuperative process and, on the other, the possibility to burn “dirty” fuel. In particular, the EFMGT opens a new option to utilise biomass for combined-heat-and-power and contributes to reduce greenhouse gas emissions. The boiler is a monotube with counter flow configuration. The chosen tube material is copper with diameter and length of 10 mm and 120 m respectively. The combustion chamber is built up of bricks and refractory cement. The dimensions are 0.57 m internal diameter and 0.2 m height. The auxiliary equipments involved are, pump, motor, and blower with inverter controller.

The design of boiler is tested throughout the experiment. The main target is targetting the produced of 2 kg/min steam and fortunately it achieve higher than expected. This boiler can produced up to 2.8 kg/min with steady state of steam and minimum of 1 kg/min with steady state of steam. The efficiency range is 93% to 98% depends on the water flow rate or input power.

CHAPTER 1

INTRODUCTION

1.0 BACKGROUND

Excessive fossil fuel utilization has led to fuel depletion, global warming and pollution. Thus, the last decade has witnessed significant increment in renewable fuels research and development for new techniques to utilize them. Renewable energy sources such as hydropower, wind, biomass, geothermal and solar are the preferable and most promising fossil fuel alternatives.

Low-cost and ease drying advances reasonable for rural farming regions are displayed. A portion of the critical contemplations as to their appropriateness incorporate low introductory capital and simple to-work with no entangled electronic/mechanical convention, and successful in advancing better drying energy. The drying advancements that were chosen incorporate fluidized bed, gushed bed, infrared, sunlight based, straightforward convective and desiccant drying. A concise presentation on each drying innovation has been introduced trailed by some specialized points of interest on their working operations. Cases of cultivating crops reasonable for the work of individual drying innovation are given to represent their potential application in agricultural product drying [1].

Biomass is an important type of renewable energy fuel source in Malaysia. It provides more reliable electrical and thermal power source throughout the year with wider distribution compared to solar and wind power sources. Biomass fuel refers to any organic substance from plant materials or animal wastes used as fuels. Biomass includes for example, food crops, grassy and woody plants, agricultural or forestry residues and urban wastes.

Biomass fuels occur in multitude of physical forms. This physical disparity accounts in part for the large number of boiler designs available today. Hence, the fuel properties are very important in determining satisfactory operating conditions. Therefore, these boilers will be able to use only a limited range of biomass with controlled specifications.

There are two types of analyses, which are proximate and ultimate analysis. They are useful for defining the physical, chemical and fuel properties of biomass feedstock. The proximate analysis determines the moisture, volatile matter, ash, and fixed carbon content of a fuel, using standard ASTM tests. While ultimate analysis gives the chemical composition and the higher heating value of the fuels. The chemical analysis usually lists the carbon, hydrogen, oxygen, nitrogen, sulfur, and ash content on weight percentage basis.

An example of the biomass source is the palm leave produced by the tree as waste and Malaysia is the country with large scale of palm tree plantation. Approximately 90 million tons of lignocellulosic biomass are produced per year and hence it can be considered as the main source of biomass for the project.

Biomass fuel combustion does not increase the net carbon dioxide emissions in the atmosphere through the biomass growth cycle where carbon dioxide is removed through photosynthesis process. Biomass can be used for liquid or gaseous fuel production, direct power production and bioproducts. Main methods of converting biomass into a useful form of energy are summarized in Table 1.1.

Table 1.1 Biomass main conversion technologies

Technology	Conversion Process Type	Major Biomass Feedstock	Energy or Fuel Produced
Direct Combustion	Thermochemical	Wood, agricultural waste, municipal solid waste, residential fuels	Heat, steam, electricity
Gasification	Thermochemical	Wood, agricultural waste, municipal solid waste	low or medium-Btu producer gas
Pyrolysis	Thermochemical	Wood, agricultural waste, municipal solid waste	synthetic fuel, oil (biocrude), charcoal
Anaerobic Digestion	Biochemical (anaerobic)	animal manure, agricultural waste, landfills wastewater	medium Btu gas (methane)
Ethanol Production	Biochemical (aerobic)	sugar or starch crops, wood waste, pulp, sludge, grass straw	ethanol
Biodiesel Production	Chemical	Rapeseed, soy beans, waste vegetable oil, animal fats	biodiesel
Methanol Production	Thermochemical	Wood, agricultural waste, municipal solid waste	methanol

Source: [2]

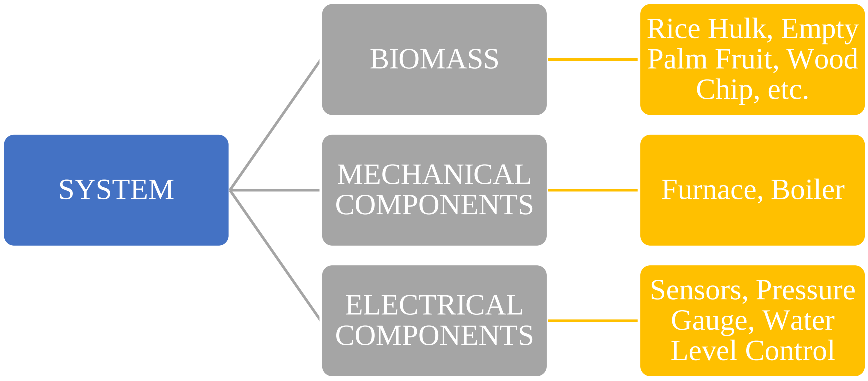

Figure 1.1 Make-up of the system

A complete system would consist of several elements that work together so the system can function according to what it is designed for. Those elements are input, output, processor, control feedback loop, boundary and environment.

The steam boiling system is studied in this project would be planned to be installed in the Biomass Laboratory beside the workshop of the School of Mechanical Engineering. The boiler would be fed with biomass as the input of system and to be able to generate 2 kg/min of steam as the main output in this project. The core components or processors in this system are furnace and boiler which includes the evaporator and superheater to convert the biomass energy into thermal energy in order to vaporise the water into steam as a steam supply unit for the available Humid Air Turbine (HAT) cycle or the Externally Fired Micro Gas Turbine (EFMGT)

While there are necessary in installing the control system to monitor the parameter of operation to detect any abnormal situation of the power plant. Hence, sensors for water inlet and thermal sensor in the boiler are needed for sending signal of those parameters so that the necessary control could be made through the control of rate of biomass fuel transported into the furnace, pressure of water input and amount of steam produced at the outlet. While the performance would be drastically affected by the quality of the biomass input due to the inconsistent of its moisture content and chemical content.

1.1 BIOMASS FOR THERMAL AND POWER OUTPUT

In Malaysia, with million of hectares of oil palm plantation and biotechnology development was emphasized in the Malaysian 9th economical plan. However, besides bioproducts and biofuel production, significant amounts of oil palm industry wastes are abundant and not fully utilized.

This waste can be convert into thermal applications, electrical generation or combined thermal and electrical power outputs. For thermal applications, one of the most important applications in the industry sector is the drying process, such as timber drying and food processing. However, the big challenge is to get a cheap and clean heat source, knowing that the most used methods are electrical heaters or steam-based dryers. Drying is usually highly energy-intensive process and most of industrial sectors require this process to some extent. For some applications such as food processing, drying process requires special quality for the drying medium with minimal undesirable contaminations. Thus, hot filtered air is used for such process. Therefore, biomass fueled hot air production unit can reduce drying process cost significantly.

1.2 GAS TURBINE FIRING METHODS

There are two main methods for gas turbine firing, the directly fired turbine (DFGT) and the externally fired turbine (EFGT). The direct firing of gas turbine refers to the conventional gas turbine firing where combustion products expand directly in the turbine. Whereas the externally or indirectly fired gas turbine means that the combustion chamber is not directly connected to the gas turbine. Therefore, the combustion product gases are not in direct contact with the turbine’s impeller. The combustion process heats up a compressed fluid (commonly air) using high temperature heat exchanger. The hot compressed fluid then expands in the turbine producing high speed shaft power.

The indirectly and directly fired gas turbine, are both similar in concept and explained thermodynamically by the Brayton cycle. The ideal Brayton cycle temperature-entropy (T-S) diagram is shown in Figure 1.2 for the two methods. For DFGT (on the right), air is drawn by the compressor (1) and compressed (2). The pressurized combustion process (2-3) is assumed to be under a constant pressure. Hot pressurized combustion products (3) are then expanded through the turbine (4) and released to the environment.

For EFGT (on the left), combustion process (a-b) is done externally and is usually atmospheric. The working fluid is drawn by the compressor (1), compressed (2) and then passed through a heat exchanger for heating up (3). Combustion thermal power (Q) is subjected on the high temperature heat exchanger resulting in lower thermal power (q) gained by the working fluid at (3). The compressed hot fluid then expands through the turbine (4), and either discharged directly to the environment or returned back to the compressor after cooling process. As can be noticed from the figure, gas turbine inlet temperature (TIT) at (3) for DFGT is higher than TIT for EFGT, resulting in lower cycle surface area for the latter and lower efficiency.

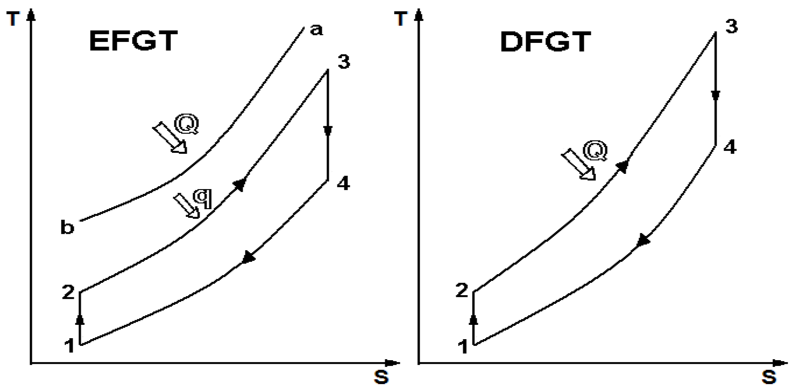

Figure 1.2 Ideal Brayton cycle T-S diagram for EFGT and DFGT

1.3 BOILER WORKING PRINCIPLE

A boiler is a closed vessel in which water or other fluid is heated. The fluid does not necessarily boil. (In North America the term "furnace" is normally used if the purpose is not actually to boil the fluid.) The heated or vaporized fluid exits the boiler for use in various processes or heating applications, including central heating, boiler-based power generation, cooking, and sanitation.

The basic working principle of boiler is very simple and easy to understand. The boiler is essentially a closed vessel inside which water is stored. Fuel (generally coal) is burnt in a furnace and hot gasses are produced. These hot gasses come in contact with water vessel where the heat of these hot gases transfer to the water and consequently steam is produced in the boiler. Then this steam is piped to the turbine of thermal power plant. There are many different types of boiler utilized for different purposes like running a production unit, sanitizing some area, sterilizing equipment, to warm up the surroundings and others.

1.4 PROBLEM STATEMENT

EFMGT is one of the main DG candidates and it has a large potential as CHP system especially with biomass fuel since the system can be located near the biomass sources. CHP system is introduced to enhance the production of paddy without cause the global warming which can affect the surrounding. The biomass is the potential alternative power sources for the generation of thermal energy for any heating purpose generally and drying paddy specifically, due to the abundance of biomass resources from plantation in this country. However, there are many difficulties in utilizing the biomass derived LPG for EFMGT firing. These difficulties can be summarized as following:

1) The current generation system in rural areas are based on diesel engine gen set. It has high CO emissions due to incomplete combustion.
2) Diesel gen set has low CHP capacity, so it cannot be used for agriculture paddy or crop drying.
3) Diesel transport difficulties and high price whereas biomass is available but not utilized.
4) To produce higher power of EFMGT, it requires very high air temperature for running the turbocharger which requires either expensive heat exchanger or by injecting steam from boiler.

1.5 OBJECTIVES OF THE STUDY

The main objectives for this study can be summarized as following:

1) To design monotube boiler steam with a flow rate of 2 kg/min .
2) To characterize with wood blocks biomass fuels.

1.6 SCOPE AND LIMITATIONS OF THE STUDY

The scope of this research work and the equipment limitations are summarized as following:

- Design of the steam boiler is based on design calculation using Excel software.
- Fabricating the boiler.
- Characterizing the steam boiler system based on experimental work.
- Flow rate and moisture content of the boiler flue gases were not available for mass balance calculations.
- Flow rate of the steam produced determined based on the volum flow rate of water inlet at water pump.
- The boiler used in this study can preferably use large wood blocks as fuel. Biomass fuel is limited to off-cut furniture wood available from local furniture industries.

1.7 OVERVIEW OF THE STUDY

Introducing biomass into the boiler was getting more attention lately. Some of the studies on the different system configurations of boiler, small scale biomass fueled micro gas turbine systems and gas turbines running on solid fuels or low HV gas fuels are presented in Chapter 2. The chapter also presents a variety of technologies and methods on the biomass combustion and different system configuration with parallel and counter flow boiler. Chapter 3 presents the theoretical frame work of the study including the following technologies: boiler, combustion, micro gas turbine, and biomass. In Chapter 4, methods those were implemented during the research are discussed elaborately, including: boiler system design and development, and also the experimental during the different stages of the study.

In Chapter 5, the findings during the boiler development phase are discussed followed by the performance of the different parts of the system. Different flow rate of water with temperature of steam produced are compared. The final part of the chapter includes the system performance comparison for the three main manipulated variables with the flow rater of water inlet. The performance of the different flow rate are concluded in Chapter 6. This chapter also includes different recommendations for further development of the system.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

In this chapter, some of the studies using biomass fuel are presented under 4 main categories: boiler, the different system configurations of boiler, small scale biomass fueled micro gas turbine systems and gas turbines running on solid fuels or low HV gas fuels. Finally, literature summary and the study contributions are presented.

2.1 BOILER

A boiler is an enclosed vessel that provides a means for combustion heat to be transferred into water until it becomes heated water or steam. The hot water or steam under pressure is then usable for transferring the heat to a process. Water is a useful and cheap medium for transferring heat to a process. When water is boiled into steam its volume increases about 1,600 times, producing a force that is almost as explosive as gunpowder. This causes the boiler to be extremely dangerous equipment that must be treated with utmost care.

The process of heating a liquid until it reaches its gaseous state is called evaporation. Heat is transferred from one body to another by means of radiation, which is the transfer of heat from a hot body to a cold body without a conveying medium, convection, the transfer of heat by a conveying medium, such as air or water and conduction, transfer of heat by actual physical contact, molecule to molecule.

2.1.1 BASIC SYSTEM OF BOILER

The boiler system comprises of: feed water system, steam system and fuel system. The feed water system provides water to the boiler and regulates it automatically to meet the steam demand. Various valves provide access for maintenance and repair. The steam system collects and controls the steam produced in the boiler. Steam is directed through a piping system to the point of use. Throughout the system, steam pressure is regulated using valves and checked with steam pressure gauges. The fuel system includes all equipment used to provide fuel to generate the necessary heat. The equipment required in the fuel system depends on the type of fuel used in the system [3].

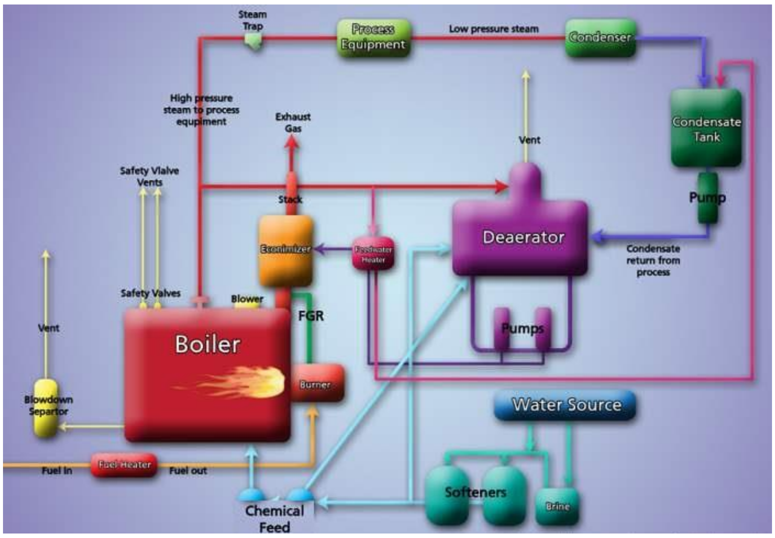

Figure 2.1 Basic system

2.2 METHODS AND TOOLS: DIFFERENT SYSTEM CONFIGURATION OF BOILER

There are virtually infinite numbers of boiler designs. Under this section, the type of boiler will be discussed, generally they fit into one of two categories: fire tube and water tube boiler.

2.2.1 FIRE TUBE BOILER

Fire tube or "fire in tube" boilers; contain long steel tubes through which the hot gasses from a furnace pass and around which the water to be converted to steam circulates. Fire tube boilers, typically have a lower initial cost, are more fuel efficient and easier to operate, but they are limited generally to capacities of 25 tons/hr and pressures of 17.5 kg/cm^2 [4].

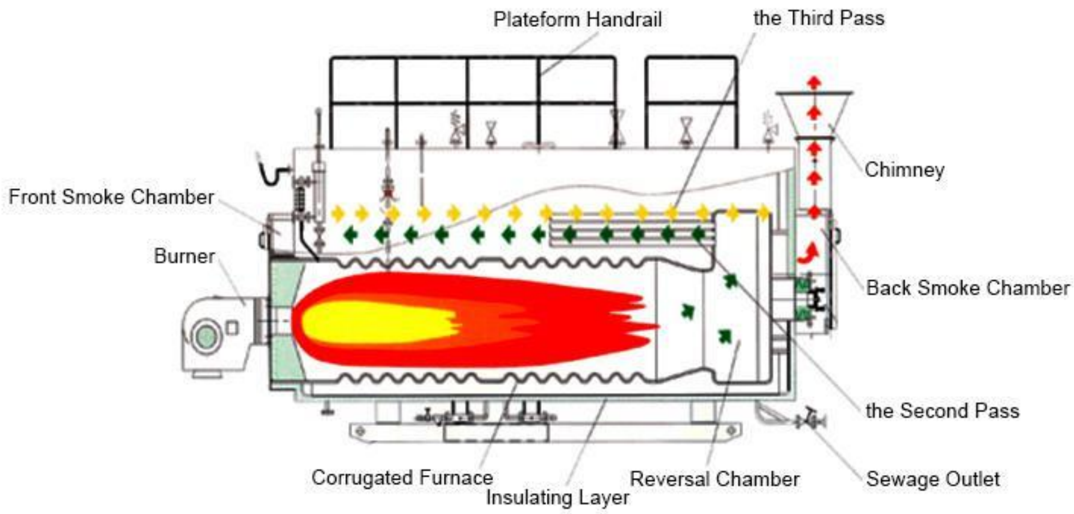

Figure 2.2 Firetube boiler

2.2.2 **WATER TUBE BOILER**

Water tube or "water in tube" boilers in which the conditions are reversed with the water passing through the tubes and the hot gasses passing outside the tubes. These boilers can be of single- or multiple-drum type. These boilers can be built to any steam capacities and pressures, and have higher efficiencies than fire tube boilers [5].

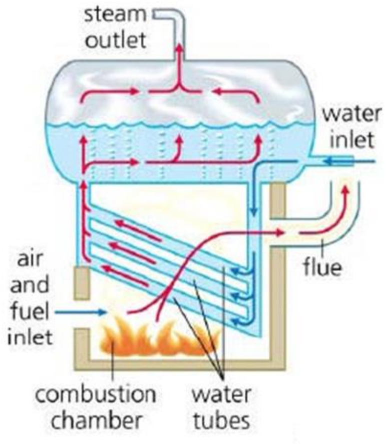

Figure 2.3 Water tube

This simulation focus about researches both distinctive heater determinations and different sorts of evaporator incorporation in sun powered warm combi frameworks with the assistance of another created non-renewable energy source kettle display [6]. For every variation, the simulation results to be talked about are the yearly kettle productivity, the cycling rate and, as the principle marker, the essential vitality reserve funds of the total framework. The outcomes demonstrate that the impacts of a sun oriented warm framework on the yearly kettle proficiency are little. Other than the framework design the yearly measures of boiling water and space warming interest and their temperature levels influence the effect of the sun oriented warm framework. Each extra stockpiling tank, which is warmed by regular vitality, ought to be broke down fundamentally because of their extra warmth misfortunes, which decrease the framework proficiency. The last is especially valid for an evaporator cushion stockpiling. This investigation brings up that the reserve funds of essential and last vitality are the most imperative pointers for the evaluation of sun powered warm combi frameworks [6]. Subsystem pointers like the yearly estimations of gatherer yield and evaporator proficiency give extra data, however they are not adequate for a full assessment of a total framework.

Boiler and solar buffer are connected in parallel in variant 4. A four-way valve directs the return mass flow to both components, where the distribution is depending on return, storage and set temperature. The motivation for this scheme is that the boiler may be operated in its optimum condition, because it receives the lowest possible return temperature and not a pre-heated mass flow. This seems to be advantageous, as the inlet temperature mainly affects the boiler efficiency, but the outlet temperature has only a marginal effect.

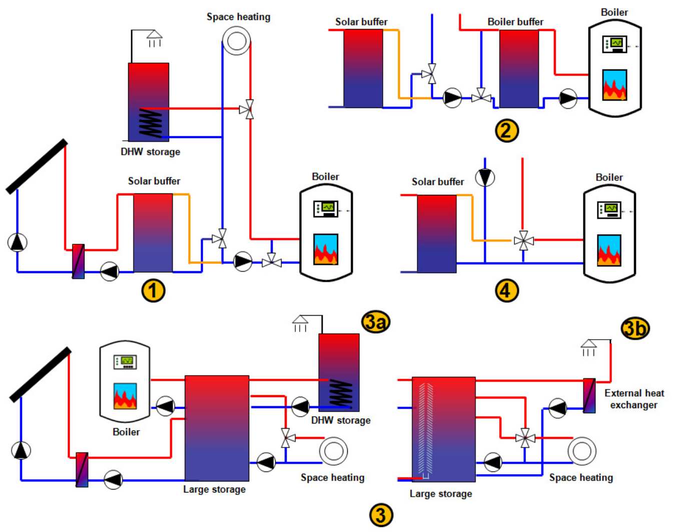

Figure 2.4 Simulation variants of solar thermal combi systems

The paper displays the impact of fumes gas and channel air temperature on warm proficiency for evaporator framework [7]. In view of the numerical model, the execution files of heater framework are computed at various conditions utilizing EES (Engineering Equation Software). The outcomes demonstrate that when the depleted gas or delta air temperature builds 10-15°C, the warmth loss of fumes gas diminishes 0.8%-1% and warm proficiency of kettle framework increments 0.8%-1%; The urgent variables that can influence warm effectiveness are fumes gas temperature and fuel unstable proportion; seven streamlined plans are intended for an instance of heater framework. Another philosophy is accommodated assessing the productivity of heater framework.

Evaporator framework is primarily made out of wind, smoke and steam-water framework. Feed pump, warm exchangers, drum, air blower, heater, stack are the fundamental parts of the framework. Tap water is provided to kettle through the sustain pumps, and afterward warmed by flame. Chilly air is drawn into the burner through a blower, icy air and fuel are blended in the burner and after that ignition. Fuel gas is released into the stack [8].

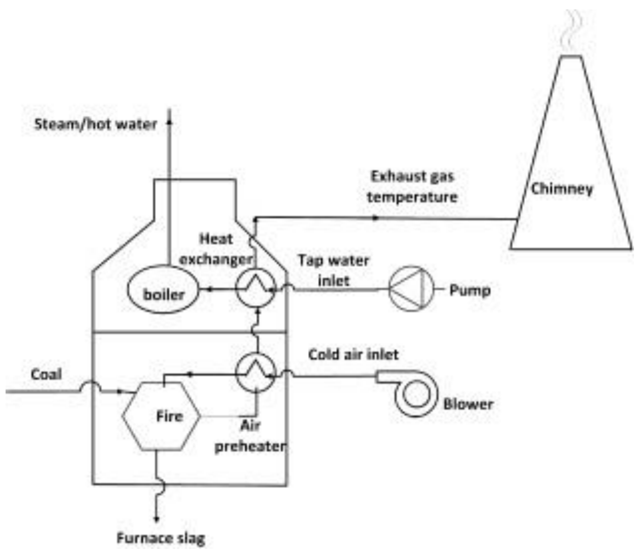

Figure 2.5 Physical model of boiler system

2.2.3 **PACKAGED BOILER**

The packaged boiler is so called because it comes as a complete package. Once delivered to site, it requires only the steam, water pipe work, fuel supply and electrical connections to be made for it to become operational. Package boilers are generally of shell type with fire tube design so as to achieve high heat transfer rates by both radiation and convection [9].

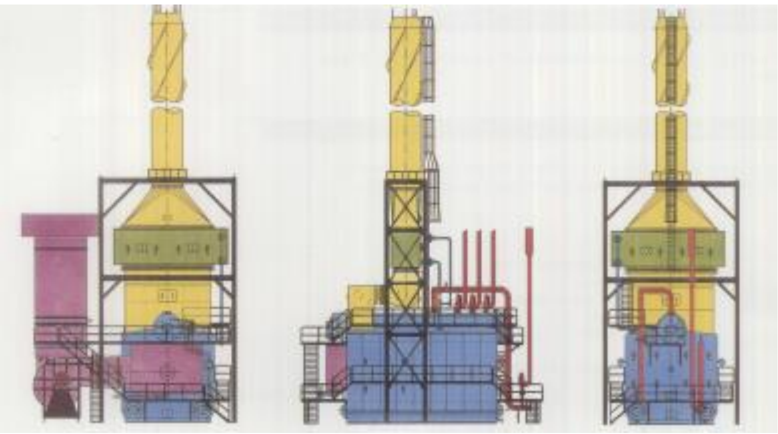

Figure 2.6 Packaged boiler

The features of packaged boilers are small combustion space and high heat release rate resulting in faster evaporation. It has large number of small diameter tubes leading to good convective heat transfer. Have forced or induced draft systems resulting in good combustion efficiency. It also has number of passes resulting in better overall heat transfer and higher thermal efficiency levels compared with other boilers.

2.2.4 **STOKER FIRED BOILER**

Stokers are classified according to the method of feeding fuel to the furnace and by the type of grate. The main classifications are: Chain-grate or traveling-grate stoker and spreader stoker.

2.2.4.1 **CHAIN-GRATE OR TRAVELING-GRATE STOKER BOILER**

Coal is fed onto one end of a moving steel chain grate. As grate moves along the length of the furnace, the coal burns before dropping off at the end as ash. Some degree of skill is required, particularly when setting up the grate, air dampers and baffles, to ensure clean combustion leaving minimum of unburnt carbon in the ash [10].

The coal-feed hopper runs along the entire coal-feed end of the furnace. Acoal grate is used to control the rate at which coal is fed into the furnace, and to control the thickness of the coal bed and speed of the grate. Coal must be uniform in size, as large lumps will not burn out completely by the time they reach the end of the grate. As the bed thickness decreases from coalfeed end to rear end, different amounts of air are required- more quantity at coal-feed end and less at rear end.

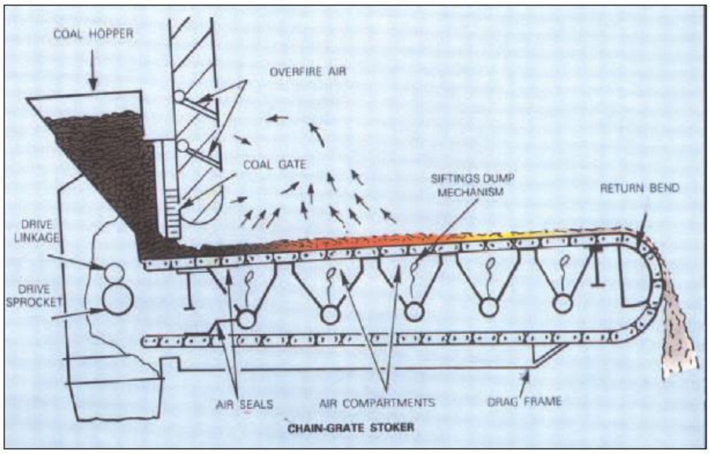

Figure 2.7 Chain-grate or traveling-grate stoker

2.2.4.2 **SPREADER STOKER**

Spreader stokers utilize a combination of suspension burning and grate burning. The coal is continually fed into the furnace above a burning bed of coal. The coal fines are burned in suspension; the larger particles fall to the grate, where they are burned in a thin, fastburning coal bed. This method of firing provides good flexibility to meet load fluctuations, since ignition is almost instantaneous when firing rate is increased. Hence, the spreader stoker is favored over other types of stokers in many industrial applications [11].

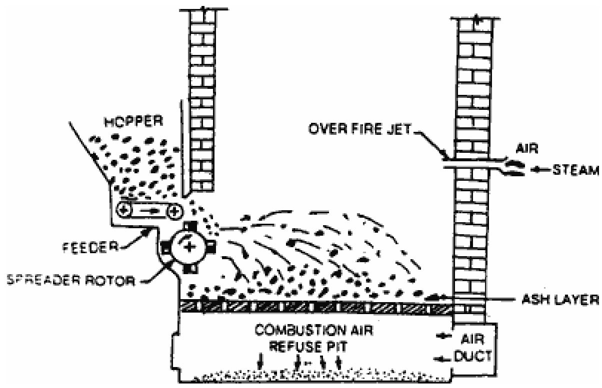

Figure 2.8 Spreader Stoker

2.3 **SMALL SCALE BIOMASS FUELED MICRO GAS TURBINE SYSTEMS**

Small scale MGT systems suffers from lower efficiency due to the scale down effect and the operation at lower pressure levels since most of the modern MGT engines use single-stage compressor. The studies on biomass fueled MGT systems focus on its efficiency and how to increase it by the combination between different technologies such as MGT with fuel cells. Mostly used simulation approach with very few experimental studies due to the high MGT cost.

The EFMGT cycle was studied [12]. The study has discussed the EFMGT principle and reviewed the different possible option of biomass combustors and high temperature heat exchangers. A $100kW_e$ Turbec T100 MGT was simulated in EFMGT cycle using ASPEN-PLUS program. Net electrical efficiency was found to be 27.8% for pressure ratio and TIT of 4.3 and 900ºC, respectively,

A renewable energy proposal to the joint solicitation offered by the USDA & DOE was presented [13]. The system layout is shown in Figure 2.9. The parts of the system were proposed to be manufactured by different manufacturers. A wood gasifier of $586kW_e$ was used with direct PG combustion into a high temperature heat exchanger. For the gasifier-combustor, inducing draft fan, primary and secondary fans with different control systems were used. The wood size was about 2½" with wide range of moisture content (8%-55%). The heat exchanger was expected to achieve effectiveness of about 84%. A $30kW_e$ micro gas turbine with high speed generator was proposed for this project.

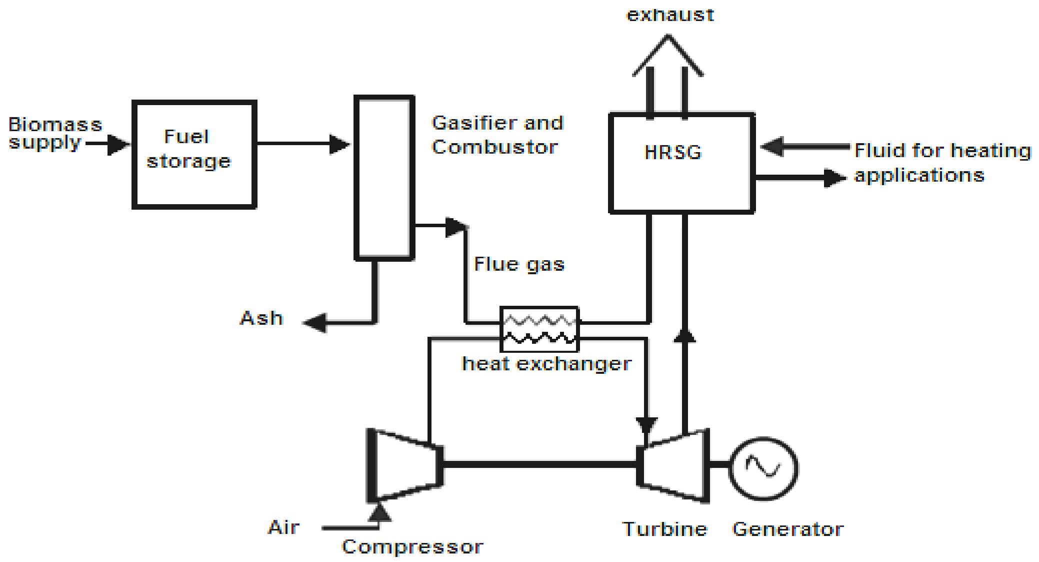

Figure 2.9 Biomass fueled EFMGT cogeneration

2.3.1. EVAPORATIVE GAS TURBINES

The evaporative gas turbine (EvGT), also known as humid air turbine (HAT) has a humidification tower that is the key component in the cycle. Heat and mass transfer occurs between the pressurized air that passes through the tower and a circulated hot water resulting in a saturated heated humid air out of the tower. The cycle has been studied widely with variety of fuels. A pilot EvGT plant was developed in the Lund Institute of Technology, Sweden [14]. The plant was a small scale natural gas fueled 600kW$_e$ EvGT with Volvo VT600 gas turbine, humidification tower, recuperator and aftercooler.

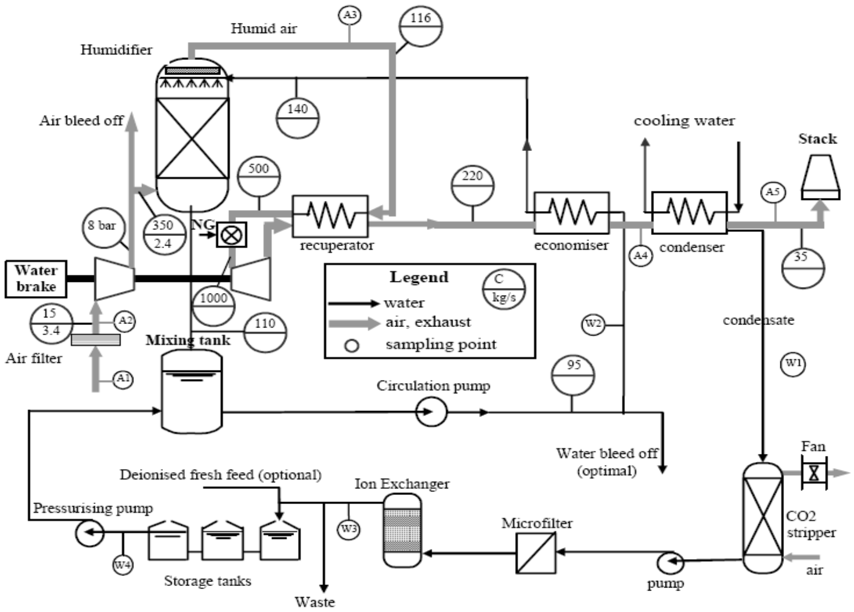

Figure 2.10 A diagram of the natural gas fueled EvGT pilot plant, Sweden

Another study on biomass fueled EvGT was also studied [15]. The study simulated an evaporated biomass air turbine cycle (EvGT-BAT). Different gasifiers were studied and compared with the EFGT method. Biomass pre-drying was also studied and the cycle was compared to the integrated gasification combined cycle (IGCC). Cycle efficiency with and without biomass pre-drying was found to be 44.5% & 41%, respectively.

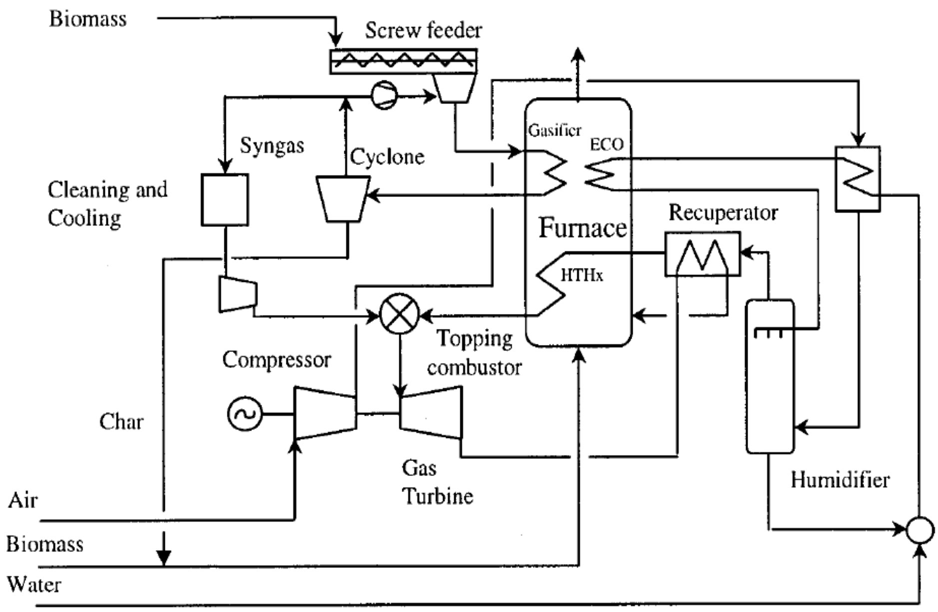

Figure 2.31 Biomass fueled EvGT-BAT

2.4 EXISTING SOLUTIONS: GAS TURBINES RUNNING ON SOLID FUELS OR LOW HV GAS FUELS

A two-stage small scale gas turbine (MGT) with low speed generator was created to work completely on maker gas (PG) from a pressurized downdraft gasifier with no helper petroleum product. It is an effective and condition well-disposed system for hot air creation for any modern drying process. For the Low Heating Value(LHV) PG burning, a pressurized cyclone combustor (PCC) was composed and upgraded utilizing computational liquid progression re-enactment. The system was portrayed tentatively with liquefied petroleum gas (LPG) and PG fills in double fuel mode and after that with pressurized PG in single-fuel mode. The system as a combined-heat-and-power (CHP) has accomplished a general effectiveness of around 58% with 35 kW_{th} hot air generation as thermal output of the system [16].

Next, externally fired heat engines were utilized generally since helium the mechanical insurgency utilizing messy strong energizes for instance coal, because of the absence of refined powers. Be that as it may, with the accessibility of clean fills, outside terminating mode was deserted, aside from steam power plants. Recently, with the worldwide pattern moving towards green power creation, the possibility of the outside fired system has caught the consideration again particularly externally fired gas turbine (EFGT) because of its more extensive scope of power age and the capability of utilizing condition neighbourly sustainable power sources like biomass. In this paper, an extensive variety of thermal power sources using EFGT, for example, concentrated solar power (CSP), fossil, atomic and biomass fills are assessed. Gas turbine as the principle part of EFGT is examined from miniaturized scale beneath 1MWe to the huge scale focal power age.[17] Also, the distinctive high temperature warm exchanger (HTHE) materials and plans are assessed. At long last, the techniques for enhancing cycle effectiveness, for example, the externally fired consolidated cycle (EFCC), humidified air turbine (HAT), EFGT with energy units and different cycles are checked on completely.

In addition, the idea of external fired micro gas turbine (EFMGT) utilizing biomass powers is getting more consideration over the most recent two decades. Be that as it may, the greater part of the examinations was directed utilizing computer simulation to assess the EFMGT systems with an absence of exploratory investigations.

A small scale EFMGT was produced utilizing a vehicular turbocharger as a micro gas turbine. Distinctive micro turbine begins up strategies were tentatively explored with most extreme turbine bay temperature and weight of around 694 C and 2.1 bar, individually. The challenges experienced amid the turbocharger motor start up process are accounted for in this paper. Driving the turbocharger shaft from the compressor side utilizing the wind current pressure driven power was not an adequate technique for the EFMGT dissimilar to the specifically fired turbine.[18] The main demonstrated turbine begins up technique for the EFMGT is the mechanically determined turbine shaft.

Last but not list, the syngas generation utilizing double throat downdraft gasifier was described through full gas creation scope of 25– 250 m3/h. The gasifier could create ignitable syngas in an extensive variety of air fuel (AF) comparability proportion (k) of 0.3– 0.4. Syngas ignition steadiness was described in a violent wind combustor.[19] Stable burning was accomplished from lean fuel air (FA) equality proportion condition (u = 0.49) to the rich ignition constrain (u = 1.25). Thermal power from the combustor was recouped by an annular tube thermal exchanger to exhibit a basic and effective method for hot air creation from biomass energizes. The hot air creation setup was portrayed and the ideal operation condition was observed to be at (u = 0.68) lean ignition. This design can create 36 kW_{th} of hot air with overall effectiveness of 46% and NOx and CO emissions beneath 140 ppm.

2.4.1 CO-FIRING BIOMASS WITH OTHER FUELS FOR GAS TURBINE SYSTEMS

A study on coal/biomass co-firing was based on a commercially available P800 module developed by ABB Carbon as shown in Figure 2.12 [20].

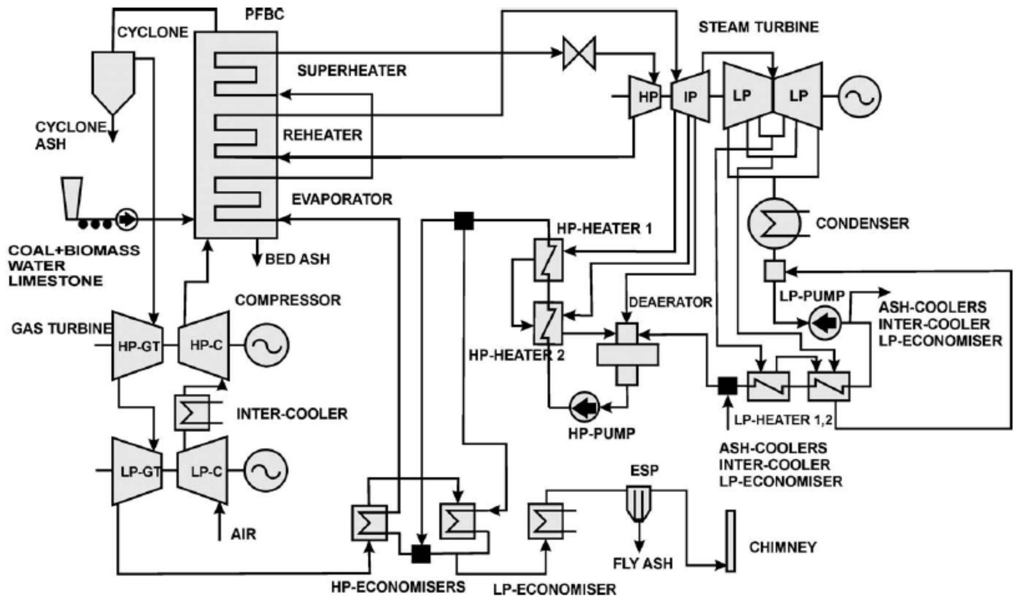

Figure 2.12 Schematic drawing of the PFBC combined cycle power plant

In this study, computational simulation was carried out for various fuel feedstock mixtures of up to 40% biomass maximum to avoid major modifications in this coal fired system. The bed temperature inside the combustor was low of about 855°C to prevent melting of the ash and to reduce NOx emissions. In this system, only one converting step was used to convert the solid fuels into combustion products that can be expanded directly in the gas turbine. This can be acceptable in the fluidized bed systems due to the long combustion residence time. Hot flue gases out of the PFBC were passed through parallel sets of two-stage cyclones before expanding in a two-stage gas turbine that is coupled with a two-stage compressor with intercooler.

The compressor provides about 16bar pressurized air at 300°C for the combustor. The combustor also provided thermal power for electrical generation using steam turbine power plant. The overall electric power output of the PFBC combined cycle was expected to be about 360MW_e. The selected types of biomass and biomass were: straw, willow chips, switch grass, miscanthus and olive pits. The moisture contents varied from 7.17% to 33.51%. The results showed that the steam cycle output reacts more sensitive to the fuel configurations comparing with the gas turbine cycle.

Also, the increased fraction of biomass reduces net CO_2 and SOx significantly. However, NOx emissions tended to rise for all biomass types, except the high moisture content willow chips. Although the increment of biomass co-firing ratio has caused a reduction in steam cycle thermal power, flue gas flow has increased, resulting in a larger fraction of gas turbine output. For example, willow chips co-firing ratio of 40% has increased the gas turbine output by $17.93MW_e$ and decreased the steam turbine output by $37.51MW_e$ compared to 100% coal. Thus, although the turbine inlet temperature decreases with biomass, higher flue gas flow through the turbine provides more output power. This is encouraging for the future development of biomass fueled gas turbine systems.

2.5 LITERATURE SUMMARY

The externally fired micro gas turbine (EFMGT) has two advantages which are the utilisation of the waste heat from the turbine in a recuperative process and the possibility to burn “dirty” fuel. Practically, the EFMGT provides us a new option to fully utilise biomass for combined-heat-and-power (CHP) and contributes to reduce greenhouse gas emissions. It leads an example to study the effects of temperature difference and pressure loss in the gas-to-air heat exchanger on cycle efficiency and power.

Biomass co-firing with other high HV fuels like natural gas or diesel can be an economical option for large scale power plants to avoid any modifications on the heavy-duty industrial gas turbines. However, in the rural places in Malaysia, small scale systems can be developed to utilize the available biomass fuels. A 100% biomass fueled system is an economically attractive alternative since it eliminates the fuel transportation difficulties to remote places.

For small scale radial flow EFMGT, there is a lack of experimental studies on the biomass fueled monotube boiler. The experimental test for the following technologies presents the key novelty elements in this study:

- The ultra-low pressure EFMGT operation.
- The use of biomass fueled EFMGT for hot air production.

CHAPTER 3

THEORY

3.0 INTRODUCTION

This chapter includes a discussion on the main HAT system theories including:

- Boiler
- Combustion.
- Micro gas turbine technology.
- Water level circuit.

3.1 BOILER

The biomass fuel is burned in a boiler to produce high-pressure steam that is used to power a steam turbine driven power generator. In many applications, steam is extracted from the turbine at medium pressures and temperatures and is used for process heat, space heating, or space cooling. electric output. It is actually the biomass fueled boiler for thermal and electrical power outputs. The 7 elements of mechanical system:

- Input - Biomass fuel.
- Output – 2 kg/min of steam flowrate.
- Processor - Furnace and boiler.
- Control - Rate of biomass fuel transported into the furnace, air flow rate and water flow rate
- Feedback - Monitoring water level.
- Boundary and Interface - Size of the furnace and boiler.
- Environment - Combustion of biomass fuel and disposal of ash.