ENERGY BALANCE STUDY ON GASIFICATION AND SYN GAS UTILIZATION IN ASPEN PLUS

By

Saravana Bharathy R

Roll no: R660211019

College of Engineering

University of Petroleum and Energy Studies

Dehradun

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A thesis submitted in partial fulfilment of the requirements for the Degree of Master of Technology (Energy System).

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Saravana Bharathy R

Roll no: R660211019

Under the Guidance of

G Sanjay Kumar,

Assistant Professor,

College of Engineering Studies,

University of Petroleum and Energy Studies,

Dehradun

Approved By,

DEAN
University of Petroleum & Energy Studies
College of Engineering Village
& P.O., Bidholi Via-Premnagar,
Dehradun (U.K)-248007

Dean

College of Engineering Studies,

University of Petroleum and Energy Studies,

Dehradun

ABSTRACT

The project deals with an energy balance on the utilization of the syn gas coming from a gasification process. Various downstream utilization system are been studied with different modes of application to get electrical power and thermal power needed by an industry. Electrical power has been generated by different options like CCGT(Closed Cycle Gas Turbine), Gas Engine, Solid Oxide Fuel cell. These utilisation option has been compared with the combustion which has been used in various biomass industries for the energy conversion. The flow models created in the Aspen Plus for the simulation has been run for the efficiency of utilization systems for heat and power. Operational parameter of process steam at conditions of 5 bar @350° C also included in the model for verifying the heat and energy balance. Process models were i Aspen plus with assuming that the gas inlet into the utilization models doesn't contain any tar in it. The energy balance sheet has been made for the process with the stream flow data form Aspen plus simulation engine. Since the flow rate of the air to the solid oxide fuel cell and gas engine is lesser than the other systems, hence the efficiency of the system is higher than the other models. Comparatively the output energy from SOFC is higher than gas turbine with and without dryer.

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First of all, I gratefully thank The Lord Almighty for providing me the moral support needed to carry out the project.

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Chapter 1

Introduction

Energy is the primitive basis of the modern world's growth and also for meeting life's daily needs. Energy plays a pivotal role in the progress of developing nations and in bring sustainability to the developed nations. Hence naturally the demand for this source is increased and it plays an major role in deciding the economy of various nations.

Conventional energy resources are rapidly depleting with large demand of gap between usage and requirement. Conversion of the biomass resources to energy plays important role in reducing this gap. Biomass energy conversion system constitute with generation of various by - products for different usage systems. The energy conversion from the biomass to electricity with thermal power thermal energy generated by the process can be used in different process in industries.

1.1 Biomass

Biomass is one of the main sources for energy generation on renewable energy sector because of it's enormous supply in regard with fuel that can be used for generation of energy. Various technologies are employed for the process of conversion from wastes to useful energy by combustion to continuously progressing gasification, digestion and others. These techniques are actively take part in converting the biomass feedstock(collectively wastes and feed from various plant derivatives) to useful energy needed by industries and manhood.
Biomass feedstocks are ranges from the agricultural wastes, agricultural residues, wastes from various process industries, energy crops and algae. Cultivation of energy crops is at very larger scale in various developing countries. At Germany, one of the key nation regarding the renewable energy generation plants more energy crops than any nation in the world.

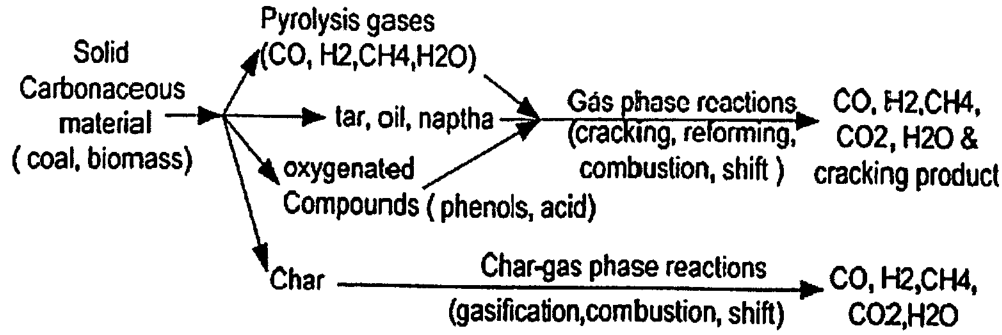

Figure 1.1: Gasification Path[9]

The chemical energy of the biomass feedstock was converted into electricity or heat by the process of combustion or gasification. Bio fuels was compared as best replacement for the conventional fossil fuel for energy generation and also as a transportation fuel. This will also reduce the GHG emissions to the atmosphere by using various fossiil fuels.

1.2 Gasification of Biomass

Energy conversion from biomass feedstock to gasification comprises of different phases. They are,

- Pyrolysis
- Combustion
- Gas phase reactions

In pyrolysis thermochemical conversion of the biomass feed stock taken place with absence of oxygen. The resultant products from pyrolysis are charcoal or oxygenated compounds and gases including Methane, Carbon mono - oxide, Carbon di - oxide and Hydrogen. The stream is then processed by gasification agent to convert the products of pyrolysis to the syn gas. Syn gas then can be utilised in different systems to generate the heat and power.

Syn gas has char and other constituents, which will be removed by using scrubber. Char also removed from the syngas before the process of energy generation. Syn gas produced through

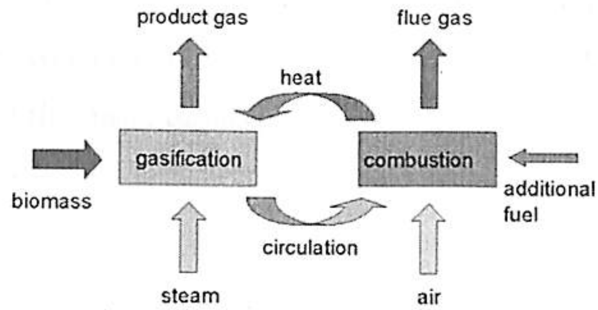

Figure 1.2: Gasification flow drawing[9]

gasification process has successively used in various utility system for energy generation.

Fluidized bed gasification was classified according to superficial velocity of gases through fluidised bed. Flow velocity of Bubbling bed will be lesser than the superficial velocity of the column. But in fluidised bed gasification, velocity of gasification agent will be higher than the superficial velocity. Fluidised bed gasifiers has low residence time reactivity of char is low. Circulating bed has higher gas velocity due to the in the entrainment of bed material on gasification medium. This will be circulated back to the reactor which for high carbon conversion.

1.3 Utilisation System

Utilisation of syn gas generated by gasification in industries is done through continuous heat and power technique. Small scale use utilizes the gas engines for useful energy conversion. Continuous heat and power systems utilises the heat of gases to expand in gas turbine or by using steam turbine with conversion of heat value through heat transfer equipments. Heat in the form of steam is also generated in this system.

Various system has been utilised in the process of energy conversion from syn gas. Some of the systems process of energy conversion are Closed cycle gas turbine, Gas Engine and Solid oxide fuel cell system. Waste heat from gas turbine will pass through waste heat recovery systems to generate energy through gas turbine.

By using the back pressure turbine we can generate steam at required pressures for process heat. Steam turbines with the extraction at different pressures can also used in this process. This also increases the efficiency of the steam turbine.

Various utilisation system

- Continuous heat and power
- Direct Electric conversion system

1.3.1 Continuous heat and power

Various process industries uses continuous heat and power system for fulfilling their energy needs for process and their utilities. This system will fulfill the industries need of both thermal and electrical energy. It has been classified according to the usage,

- Power generation through gas turbine and process heating application
- Combined cycle power generation through gas turbines and steam turbines with process heating applications

Industries majorly uses later system than former as the losses through the former system is more. Because of exhaust gases carrying away larger amount of heat from system. The former also affect environment in larger scale due to passing the exhaust gases at much higher temperatures.

Whereas in later system the efficiency has been boosted up with increased energy usage in gas turbine additionally generation of energy by steam turbine.

The temperature of the exhaust gases must maintained at minimum to reduce the emissions to environment and also to utilise the heat from flue gas to maximum extent for increase the efficiency.

1.3.2 Direct Electric Conversion System

Direct electric conversion system is majorly un - familiar Magneto Hydro Dynamic systems(MHD) which utilises uses the gases from the process will the expand in MHD turbine. Electricity is directly produced in the systems by magnetic action.

1.4 Drying of Biomass

Major problem concern with biomass energy conversion system are losses due to the moisture in fuel. This reduces efficiency of combustion and also the efficiency of boiler. Emissions from combustion of wet biomass increases the temperature of the gases on the stack. This can be reduced by utilising the energy from flue gas to dry the fuel. This increase the efficiency of combustion, boiler and also reduces the net air emissions to environment. Dryer consumes energy for the purpose of heating and evaporation of the fuel's moisture content which will reduce the residual moisture of the feed.

1.5 Objectives

The objectives of the project are,

- Energy balance of syngas utilisation on down stream.
- Analysis of the thermodynamic efficiency of utilisation system on downstream for the different models.
- Comparing of the utilisation system with the direct biomass combustion system.

Chapter 2

Literature Review

2.1 Biomass resources

A report made by [8] says, total biomass resources in the world is 1800 billion tonnes and Energy from various feed stocks on earth will accounts to 33000 EJ which is 80 times more than the total annual energy consumption by world. Biomass resources are diverse which include resources from forests and oceans. Energy available from different systems get varied according to types of resources. Biomass resources has been classified according to,

- Biomass from agricultural residues
- Biomass from waste

As per the sugar technologist association of India[2], Variety of by products has been available from various industries that can be utilized in the energy conversion. The total energy from the biomass resource is approximately amounts to 128 EJ, in that the agricultural biomass amounts to 48 EJ with livestock biomass of 43 EJ followed by forestry biomass amounts to about 37 EJ.
* t/t - waste generated with respect to tonnes of useful crop Biomass feedstock constitute

Table 2.1: Biomass feedstock energy co-efficient[2]

Biomass Species	Waste Production rate (t/t)	Energy conversion co-efficient (GJ/t)
Wheat	1.3	17.5
Sugarcane residue	0.28	17.33
Rice	1.4	16.3
Maize (corn)	1	17.7
Roots & tubers	0.4	6

of waste and residues from various agricultural and other process. The energy availability for different biomass resources are,

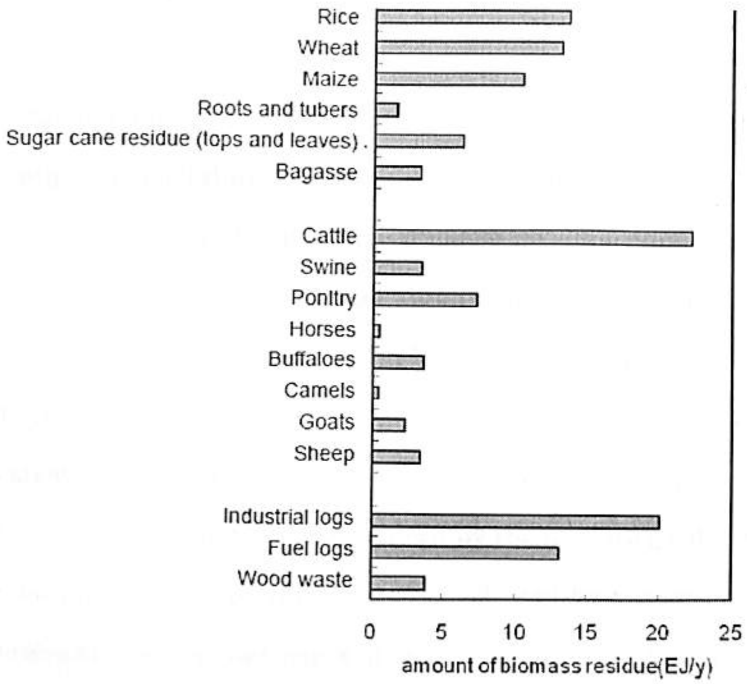

Figure 2.1: Biomass Resources[2]

2.2 Global Sugar cane Processing Industry

As per the Sugar technologist association of India[2], World production of sugar has been controlled by Brazil, India and China. It needs an water requirement of 1.2 - 1.6 m/yr and the maturing period is about 9 - 14 months. Food and Market exchange states that an sugar mill produce with an crushing capacity of 3000 TCD(Tonnes of Cane per day) will produce varied products of sugar, molasses and energy. It produces an sugar at a rate of 345 tonnes of sugar with by products of 3 tonnes of yeast, alcohol from molasses from at an rate of 6000 litres with potash fertiliser at an range of 15 tonnes, press mud fertiliser ranges about 150 tonnes, pulp of about 25 tonnes which can be used for production of paper and electricity of about 240 MWh. As per[8], Bagasse is the final residue of the sugar cane which is an fibrous stalk. There will be an better bagasse yield over the period of maturity of cane and also by efficient of crushing. Remains of sugar onto the cane affects the efficiency of power generation on the power generation system.

2.3 Potential of Bagasse

According to[2], the remains from sugar was used in the process of energy generation. Paper was produced from pulp remained during the processing of cane. India is processing about 40 MMT of bagasse around the year. With the minimal use of pulp for paper production the remaining is available for energy conversion. There are about 500 sugar cane industries in India on which majority of industries are been located around Uttar Pradesh, Bihar and Punjab in North India, Gujarat and Maharashtra in Western part of India. In southern part of India the sugar cane processing industries are been located at Tamilnadu, Andhra Pradesh and Karnataka. As per the report made by[9], volume of the gas produced by the bagasse gasification is much lesser than the direct combustion. The gas production is not affected by any means of feed characteristics as the feed is uniform bagasse and hence it doesn't affect the design of gasifier due to non - uniform feed. CFB gasifier is best suited for the gas production as there is an higher volumetric capacity of the gasifier. This increases the efficiency of carbon conversion. Since the flexibility of the gasifier is higher if CFB is incorporated onto the system, thereby the efficiency of the gas conversion system is higher. As the Circulating fluidized bed has been used the volumetric capacity of the gasifier can be easily controlled.

2.4 Bagasse Gasification

Report made by Mohit Mohan Sahu[16], cites industries incorporate direct combustion for the energy conversion from bagasse, which has very lesser thermodynamic efficiency than gasification. As most of the sugar cane industry currently has back pressure turbine for the energy production process, the thermodynamic efficiency of the system was reduced much lesser.
Saroj Mishra[?] reported the use of gasification will increase the efficiency of energy conversion. Net thermal efficiency of the gasification system is around 40 - 45 %. Gasification process also has an increased opportunity because the sugar industry produce about 150 tonnes of press mud/ day on the plant during the process of sugar production. This is can be utilised apart

from the energy conversion of bagasse gasification separately. As the bagasse gasification has needs lesser volumetric capacities, this can be utilised in small and large mills irrespectively. This will be the major advantage of gasification compared to combustion technique which has an higher losses in case at smaller one.

2.5 Energy Utilisation from Syngas

Energy from the syn gas has been utilised by various systems using the principles of Brayton cycle and Rankine cycle. While the Brayton cycle utilises the gas utilisation in the gas turbine, whereas the Rankine cycle utilises the waste heat to energy in the Heat recovery steam generation systems for energy conversion. Continuous heat and power systems has been the major principle for converting the gas to the useful energy in the form of heat and electricity. Various Continuous heat and power utilisation systems are,[10]

- Gas Turbine
- Gas Engine
- Solid oxide fuel cell

2.5.1 Rankine Cycle

In the rankine cycle the heat on from the flue gas has been transferred to the water thereby the conversion of water to steam taken place at an higher pressure.

- 1-2 Isentropic pump work
- 2-3 Constant pressure heat addition
- 3-4 Isentropic Turbine work
- 4-1 Constant pressure heat rejection

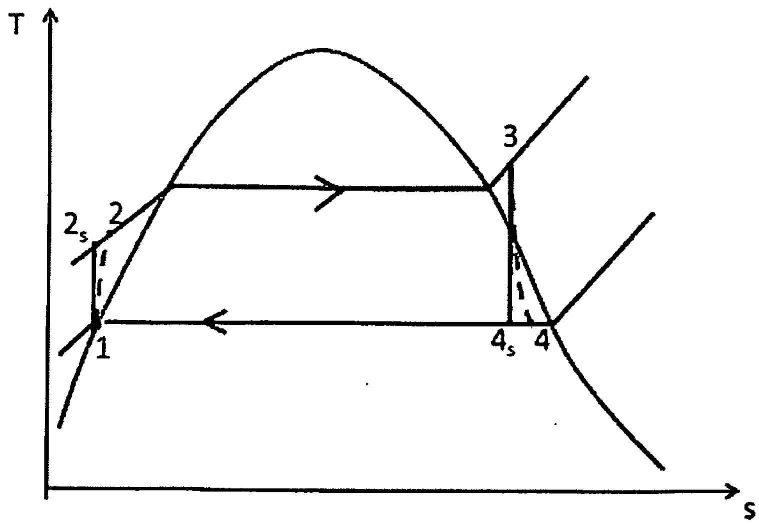

Figure 2.2: Rankine cycle[14]

On explaining Rankine cycle R S Khurmi states that[14],In 1-2 feed pump pumps water from condenser to boiler which is operating at an higher pressures fluid needs to be in liquid state for this operation. At 2-3 heat was transferred from to water at an constant pressure for the conversion of water onto steam. And on 3-4 steam has been expanded in the turbine to generate work. By rejecting the heat on the condenser steam has been condensed onto the water.

2.5.2 Brayton Cycle

Instead of water in rankine cycle air has been used as a working fluid in the system.

- 1-2 Isentropic compression
- 2-3 Constant pressure heat addition
- 3-4 Isentropic expansion in Gas turbine'
- 4-1 Constant pressure heat rejection

On explaining Rankine cycle R S Khurmi states that[14],in 1-2 working fluid has been compressed to the highest pressures and then it has been heated at the constant temperatures to

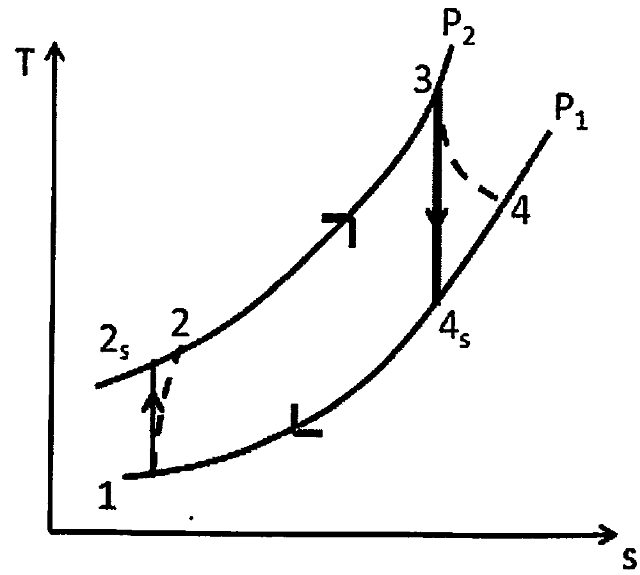

Figure 2.3: Brayton Cycle[14]

the higher temperatures. Then by expanding in the gas turbine heat has been rejected to the atmosphere as flue gas. The downstream of syn gas utilisation through the brayton cycle can be coupled with the heat recovery system.

2.6 Combined Cycle Gas Turbine

According to Richard Toonsen[18], Combined cycle utilises the both Rankine cycle and Brayton cycles on the system. This has been done by the syngas combustion according to the brayton cycle. The studies based on Jayakumar[11], says the gas from petcoke gasification has higher efficiency higher than expansion of steam in the steam turbine by combustion process. Efficiency is also relates with the increase in the cost of the gasification system. But this can be recovered faster than the combustion system models because of higher efficiency. The efficiency of the gasification process is 10% more than the combustion model of expansion.

According to the R Bachman[3], the combined cycle systems has been majorly employed in the gas turbine cycle systems. In this models heat carried away by the gases plays an major role

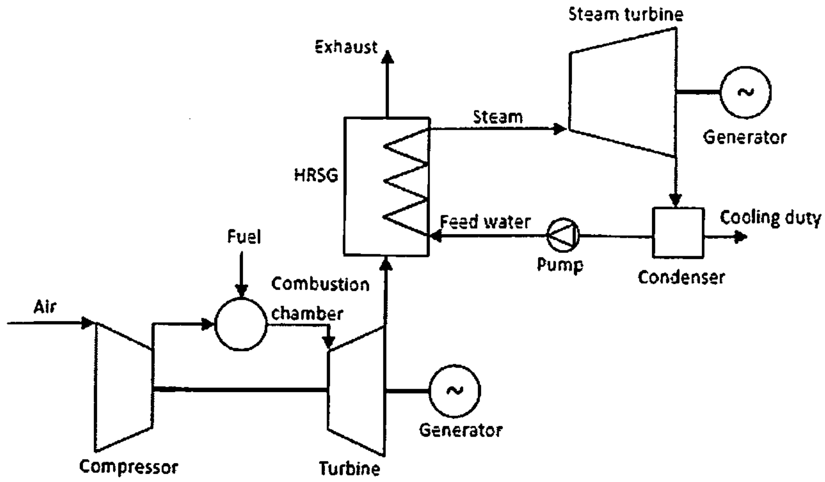

Figure 2.4: Combined cycle

because of the cooling gases quantity get increased if the heat produced on the combustion is more.

Jayakumar reported[11], auxiliary power consumption on combined cycle is more than the steam turbine utilisation due to the increase in the work required by the compressor for compressing the inlet air for combustion in combustion chamber. When the inlet temperature of the gas get reduced work required by the compressor is considerably reduced.

R S Khurmi states that [14], inter - cooling and reheating can be preferred in gas turbine systems. This will increase the efficiency of the system. The required for the combustion of syngas will get reduced. Brayton cycle produces an higher efficiency than the Rankine cycle, since the cycle is majorly depends upon heating the working fluids to higher temperatures. Adiabatic compressor efficiency plays an major role in the system. Because of increase in adiabatic compressor efficiency, overall cycle efficiency of the system will get increased due to the reduced compressor losses. This will increase the temperature of air towards the combustion chamber stream.

According to Roelf Bachman[3], the importance in of the air passed for the compressor is based on the complete combustion at combustion chamber. Gases from combustion chamber was allowed to expand in the gas turbine. The maximum temperature of the gas turbine operation should be less than 1550° C, hence the cooling air has been allowed to reduce the maintain operational temperature of the gas turbine. To maintain this more amount of cooling air allowed

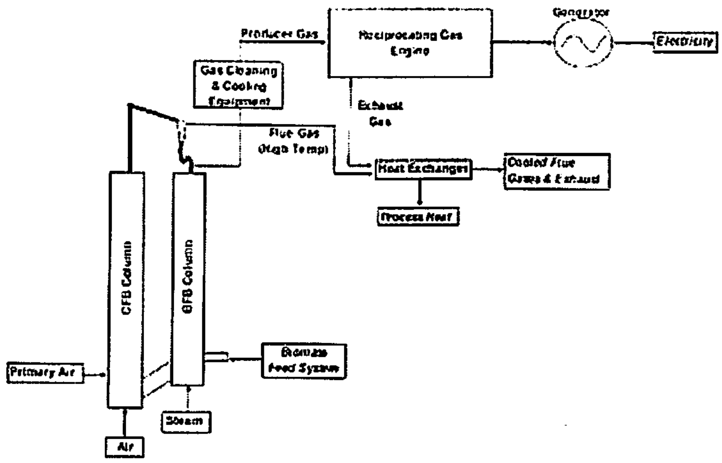

Figure 2.5: Gas Engine[9]

into the turbine. The maximum temperature for the operation in gas turbine depends upon the mass of fuel inlet to the system. The efficiency of the system was depends upon the operating temperature of the gas turbine.

Wayne Doherty reported[4], At low temperatures of operation more amount of fuel is inlet into the system to maintain the higher power generation by the gas turbine. The efficiency of the system has been about 40 - 45%. By introducing an fuel dryer on to the system will reduce the efficiency of the cycle.

2.7 Utilisation system through Gas Engine

Gregorio reported[1], syn gas utilisation system through th e gas engine of reciprocating type which depends on the quality of the fuel input to the gas engine. The exit of the gas engine has been used in the process heating of the fuel and water for gasification.

As per C Zygarlicke[19], gas engine system needs clean gas without any impurities like acids, tars and dust from the gasification process. Gas with these particles will cause wear and tear on engine surface. Combustion parameters of syn gas engine is different from other fuels combusted in gas engine. Compression ignition(CI) mode of combustion is preferred over the Spark ignition(SI) engine for syn gas utilisation system. SI engines won't operate with higher efficiency at changing pressure ratios due to improper mixing of the gases.

Sridhar reports[6], the emissions on the combustion of syn gas is more than the other utilisation system. Since combustion due to the release of un burnt carbon on th exhaust of system. Efficiency of the syn gas combustion produce comparatively lesser efficiency than the gasoline fuel burning in the system. Process heat systems has been extended to process air heating and also for process steam generation for the gasification.

2.8 Solid Oxide Fuel Cell

Wayne Doherty[4], explains that thermo - chemical action was taken place in fuel cell to generate heat and electricity from syngas. Un - burnt in the syngas combustion get reduced in fuel cell which increases the efficiency of combustion.

Raido Huberg explains[7] that, SOFC is made up of Yttria - Stabilised Zirconia is a non - porous metal oxide with solid electrolyte acts as a a conductor of oxygen. O^{2-} will be act as the carrier of charge between anode and cathode. The reactions in the anode and cathode are as follows,

Anode: $H_2 + O_{2-} \longrightarrow H_2O + 2e^-$

Cathode: $(1/2)O^{2-} + 2e^- \longrightarrow O^{2-}$

Vincenzo Liso states[12] that, working of the SOFC is similar to inter - cooling in the gas turbine wherein the gas flowing out will increase the temperature of compressed air. In SOFC instead of increasing the temperature of air, syngas is passed through the fuel cell to produce an additional power on the systems. Outlet from SOFC is allowed to expand in gas turbine to produce additional power.

Richard Toonsen reports[18], irrespective of their nature of fuel energy can generated through fuel cell. Some of the fuels used in fuel cell are methanol, syn gas through biomass gasification,

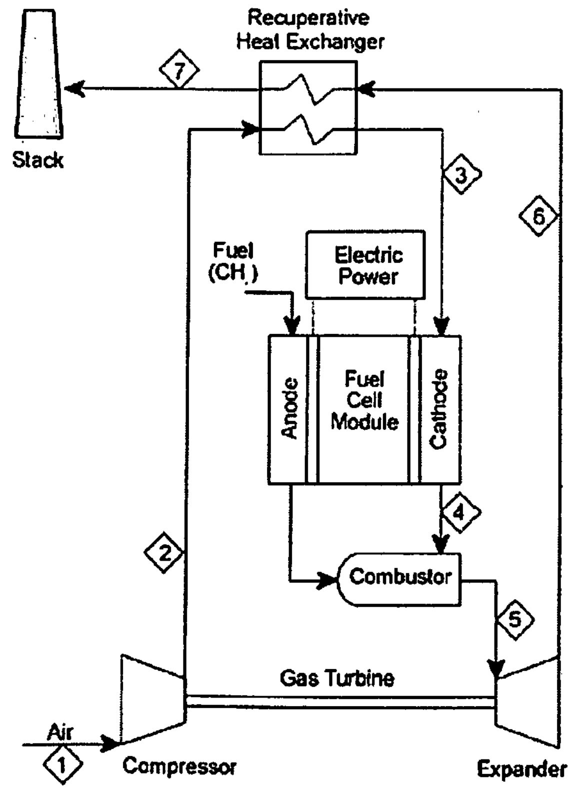

Figure 2.6: SOFC flow drawing[15]

natural gas, kerosene and coal because of its higher operating temperatures.

Wayne Doherty states that[4], Solid oxide fuel cell has been integrated with the gas turbines is currently manufactured by Siemen's Electric. Pre - heating of air increases the operational temperature of fuel cell. Reduction in fuel cell. Air and steam has been produced by using various heat transfer equipments. Reaction in the fuel cell starts when it approach walls of fuel cell.

According to Vincenzo Liso[12], various factor affecting the property of the fuel cell model is,

- Utilisation factor
- Current density
- Steam to Carbon ratio

Utilisation factor defines the amount of syngas been utilised in the system for conversion in fuel cell. Oxygen is used as conductor in fuel cell. With decrease in utilisation factor, voltage produced in fuel cell is also get reduced. Reactions take place in pre - former has been respon-

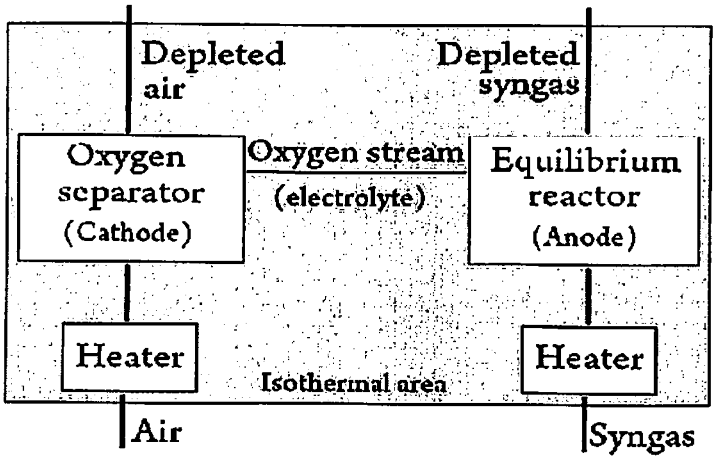

Figure 2.7: Fuel cell model[12]

sible for conversion of syn gas components to hydrogen rich stream.

Steam reforming C_xH_y + xH_2O $\longrightarrow (y/2+x)H_2$ + xCO

Water Gas Shift reaction CO + H_2O $\longrightarrow CO_2$ + H_2

Reduced current density in fuel cell increase voltage losses on cell. This results in reduction of power produced through the fuel cell. Parasitic losses and energy input to fuel cell(by compressors and fuel) get with increased air consumption on fuel cell.

The need of the pre - forming in fuel cell reported by Vincenzo Liso as[12],

- To heat the mixture of depleted and fuel towards on to the fuel cell
- For partial conversion of methane on the to hydrogen
- Water gas shift reaction on the system

Increasing of STCR (Steam to Carbon Ratio) decrease in mole fraction of H_2 and CO with increase of CO_2 and H_2O ratio on the fuel cell, thus improves the combustion efficiency and stack performance of the solid oxide fuel cell and gas turbine. Combusted gas is then allowed to pass through This process has been come under the continuous heat and power system wherein the syn gas has been allowed to pass through gas turbine. Campanari states[15] that, working temperature of the fuel cell is around 600 - 1000 ^{o} C due to material constraints.

Fryda et al., reported that, high temperatures are maintained in the fuel cell to increase the conductivity of fuel cell. When operating under lower temperatures the solid electrolyte can't able to conduct the oxygen through the fuel cell. Fuel cell produces energy in Direct current(DC), by using inverter it converts into AC.

Different Operational parameters discussed by[5]are,

- Operating at part loads
- Full load Operations

Operating at part loads

Vincenso liso[12], shows that fuel cell operates at higher efficiency during part loads with increase in voltage. Increase in voltage is due to the maintaining stack temperatures at outlet of fuel cell. Because of the reduction in the load on the system, voltage along the cell decreases with an increase in the voltage of the cell and thereby increase of electrical efficiency.

Full load operation

Vincenso liso[12], at full load operation system voltage get increased to higher extent because of increase in temperature of gases. This directly increases the voltage on full operation.

Wayne Doherty[4], shows that the Power to the heat ratio has been comparatively increased by about 12 % with inclusion of Solid Oxide fuel cell on system.

2.9 Drying of Biomass

R Bachman [3] states that, biomass feed stocks of all kind has more moisture content. Combustion efficienvy in boiler decreased considerably. Whereas in gasification efficiency doesn't affect considerably. Drying of feed stock depend on type of gasifier used for gasification and the

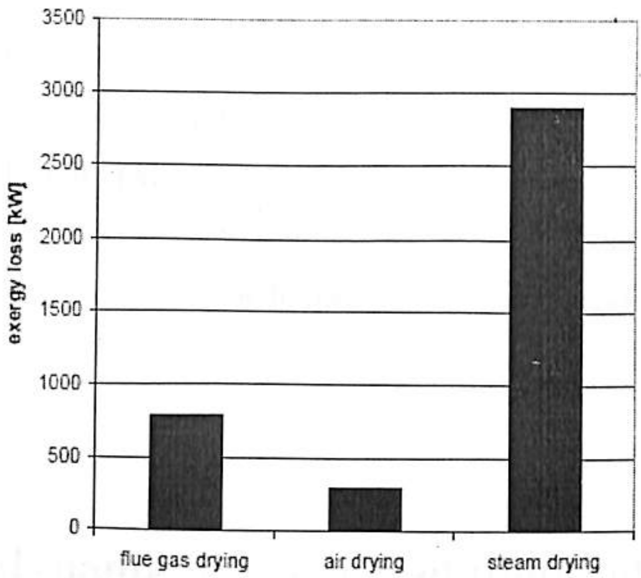

Figure 2.8: Comparison between different drying process[9]

amount of tars generated during gasification. In Fluidized bed and Updraft gasifiier moisture content about 65 % and 50% can be accommodated.

Drying of biomass increases the LHV of the feed stock and also the efficiency of the gasification. The chemical exergy of the biomass feedstock has been increased with the chemical exergies on H_2 and CO.

Jayakumar reports[11] that, increase in moisture content will decrease the efficiency of gasification. So the fuel sent to the drying system and then to gasification system. Drying of feedstock has can include on the system if the gasification temperature beyond the carbon - boundary temperature of biomass feedstock. Efficiency of the drying is majorly depends on the dryer temperature with hence the drying becomes essential for the system. Hence the heat from the flue gas will be utilised for the process of drying.

Anne jayanthi reports[9], moisture content in bagasse was about 35 - 55% after crushing of the sugar cane in the industry. Total generation of bagasse is around 25 - 30% of cane crushed in the industry. Heating value of the bagasse has been around 9000 KJ/kg. By drying heating value of bagasse is also increased the energy generation from the system.

Campanari S states[15] taht, emissions and air required air furnace for combustion of feedstock reduced by the process of drying. Air drying is the best option for the drying of feedstock as it has the best exergy efficiency compared to the other drying process. Bagasse feedstock get burnt when the fuel is dried beyond carbon - boundary temperature. Bagasse is a light weight particle has a tendency to from conveyor belt during transportation of fuel. By using flue gas drying temperature at the exit of system get reduced.

Various sources are been used for the drying of biomass feedstock in the industries. Steam has the higher exergetic losses in the process of drying. But the flue gas and air drying system will produce an higher efficiency than the steam drying systems.

2.10 Thermodynamic Efficiency of different systems

Roelf Bachman states[3] that, different systems has been employed on for the utilisation of syn gas depends which depends on the end gas application needed by the users.

2.10.1 Gas Turbine system

Valencio lizo states [12] that, the gas turbine energy conversion system is the highest efficient one and also it is suitable for both the large and small scales.

Jaykumar reports[11] that, Gas need to be cleaner without any tar content when it has expands in the gas turbine. Because the tar content will affect the operation of turbine. Pressure and temperature losses in cleaning gases will reduce the temperature of gases inlet to the utilisation system. This will reduce the combustion efficiency of the CC. Gas cleaning operations will increase the auxiliary work needed by the system. R S Khurmi suggests[14] that, inter - cooling will increase the temperature of air inlet to the combustion chamber which utilise heat from hot gas from outlet of gas turbine. This will maintain an higher temperature at the burner as far as considering the condensation of gases.

2.10.2 Gas Engine system

Mukunda Sridhar stated that[6], gas engine needs similar to the gas turbine as in the tar content is allowed in a minimal level. Cleaning of syn gas from in the outlet of gasifier is essential to run the prime mover of gas engine. Selection of gas engine for syn gas fuel is mainly depends on tar content in syn gas. Gas engine is much higher efficient and most economical at smaller sizes and scale. M Santonastasi et al., reports that[1], With increase in capacities, size of the engine get increased. But this system has very easy start-up compared to the gas turbine systems. But majorly gas engine systems has been restricted to the small scale electricity production.

2.10.3 Solid Oxide Fuel Cell system

Raido Huberg reports that[7], solid oxide fuel cell uses bottoming cycle for power generation. This cycle produces an higher efficiency corresponds to the higher work with addition of work done through the Gas turbine combined cycle. Fuel cell needs high cost material for its manufacturing hence the cost of the solid oxide fuel cell model will cost more than the actual combined cycle system of gas engine, gas turbine and other continuous heat and power application systems. The plant operating with SOFC is producing higher efficiency than the gas engine system, since it has a continuous heat and power application with the SOFC model of power generation.

2.10.4 Combustion System

Jayakumar explains that[11], combustion system has been majorly depends on the maximum temperature of the boiler tubes used for the combustion systems. Since it has an minimum cost of build-up and lesser period for the finishing, it seems more favourable. But the scale formation is higher in the line of the water and steam along the combustion surface which reduce the system efficiency on long run. The limiting size of the boiler plays an major role in these system which needs an bigger if an higher power generation system is needed. Combustion and electricity

Energy Conversion Device	Net Electrical Efficiency
Steam turbine	10-20%
Gas turbine	15-25%
Externally fired gas turbine	10-20%
Gas engine	13-28%

Figure 2.9: Comparison between different systems[9]

conversion efficiency is lower compared to gasification.[11]

Chapter 3

Theoretical Development

3.1 Process Description

Syn gas generated from the gasification is allowed to pass through utilisation system for energy conversion. Various utilisation systems used for the energy conversion analysed in this project is Closed cycle gas turbine, Gas Engine and Solid oxide fuel cell. The utilisation system is modelled to extract the maximum heat from input fed onto the system.

3.2 Product Gas Utilisation by Closed cycle Gas Turbine

Syn gas is fed into utilisation system at a temperature of 400°. Gas fed into utilisation system doesn't have any tar content onto it. After combustion with air, mixture is allowed to expand in gas turbine. Inlet temperature of the gas turbine is maintained on or below 1500° C. Air is compressed from ambient conditions on compressor, pressure ratio of 9 is maintained in compressor. Combusted gas is expanded in Gas turbine to lower pressure to extract maximum amount of work from it. By waste heat recovery system, steam is generated to expand in steam turbine.

Energy in Producer Gas

Energy in the producer gas is calculated by calculating heat available on fuel and by the sensible heat in fuel. The heat on the fuel is the low heating value of the gas an the sensible heat is the heat taken away by the gas on the cooling of the gas on the system.

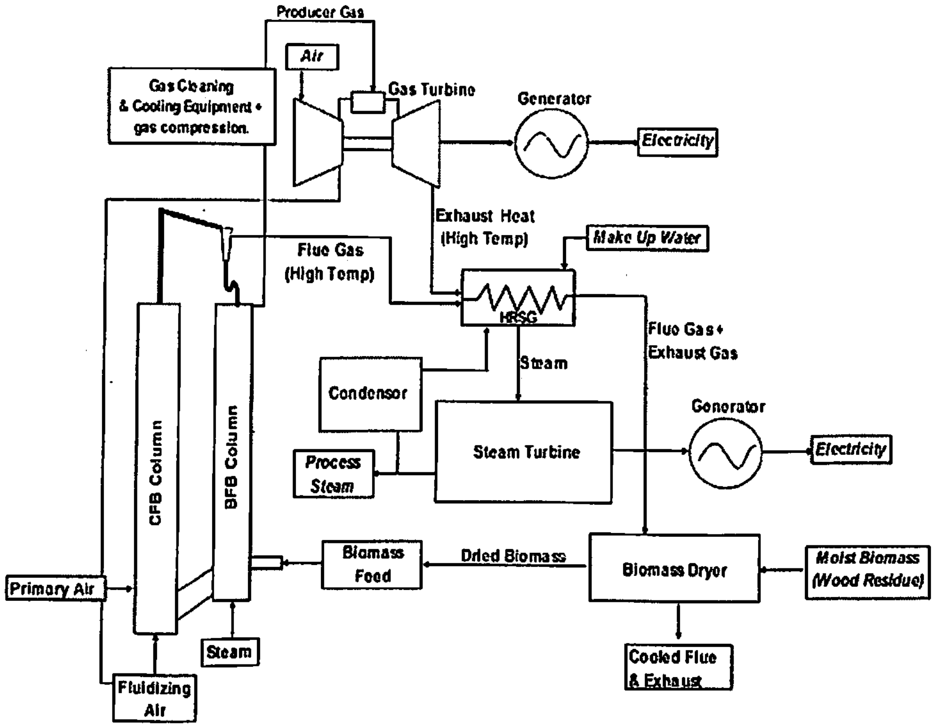

Figure 3.1: CCGT Flow model

$$E_{syn} = m_{syn} \times LHV_{syn} + C_{pi} \times dT \tag{3.1}$$

E_{syn} - Energy in syn gas in KW

m_{syn} - mass of syn gas flow into system

LHV_{syn} - Low heating value of syn gas

Energy in Air

Air has been send in to the system to combust the syngas on the combustion chamber to produce energy. The gas need to send inside the compressor at a very low temperature which makes the compressor to need lesser power.

$$E_{air} = m_{air} \times C_{pair} \times (T_{air} - T_{ref}) \tag{3.2}$$

E_{air} - Energy in air KW

C_{pair} - Specific heat capacity of air at constant pressure in KJ/kg

T_{air} - Temperature of air inlet to the system in K

T_{ref} - Reference temperature taken for consideration in K

Energy Output

Energy produced in the Gas Turbine

The combusted gas has been expanded the gas turbine to produce energy. The expanded gases are then been utilised in for the process heat generation.

$$Workproduced = EnthalpyofGasatinlet - Enthalpyofgasatoutlet \tag{3.3}$$

Energy utilised for HRSG

The total heat utilised by the Hear recovery steam generation system is,
Heat utilised by the HRSG system = $H_1 + H_2 + H_3 + H_4$

$$Totalheatavailableintheflueegassystemis = m_{flue} \times C_{pi} \times (T_{flue} - 378) \tag{3.4}$$

m_{flue} - mass of fluid in kg/hr

C_{pair} - Specific heat capacity of air at constant pressure in KJ/kg

T_{flue} - Flue gas temperature in K

Heat load in Economiser

The economiser operating temperature will be 150° C.

$$Total heat available or used by the economiser H_1 = (m_f \times (h_{fo} - h_{fi}))/3600 \tag{3.5}$$

H_1 - Heat load in economiser

m_f - mass of fluid in kg/hr

h_{fo} - Enthalpy of water at outlet of economiser

h_{fi} - Enthalpy of hot water at inlet of economiser

Heat load in Boiler

The economiser operating temperature will be 400° C which is heating the water from 150° C.

$$Total heat available in the boiler H_2 = (m_f \times (h_{fg} - h_f)/3600) \tag{3.6}$$

H_2 - Heat load in boiler

m_f - mass of fluid in kg/hr

h_{fg} - enthalpy of water steam mixture before the entry of boiler h_f - enthalpy of water before the entry of boiler

Heat load in Super heater

The super heater has been operating at 40 bar @400° C.

$$Total heat available in the super heater = (m_f \times (h_s - h_g)/3600 \quad (3.7)$$

m_f - mass of fluid in kg/hr

h_s - Enthalpy of super heated steam in KJ/kg

h_g - Enthalpy of dry steam in KJ/kg

Heat lost in condensate

The condenser is operate on a pressure 0.8 bar at 55° C. Factor is considered because of condenser pressure is lesser than atmospheric pressures whereas condenser temperature will be higher than inlet temperature of water to the system.

$$Heat in condensate h_c = h_{fg} - h_f KJ/kg \quad (3.8)$$

h_c - Enthalpy of condensate in KJ/kg

h_f - Enthalpy of water entering the condensate in KJ/kg

h_{fg} - Enthalpy of water steam mixture entering the condensate in KJ/kg

Work produced by the Steam Turbine

$$Workproducedbythesteamturbine = (m_f \times (h_s - h_c))/3600 \tag{3.9}$$

m_f - mass of fluid in kg/hr

h_s - Enthalpy of super heated steam in KJ/kg

h_c - Enthalpy of condensate in KJ/kg

3.3 Bagasse Combustion system

Like conventional fuels bagasse can be burnt to extract the heat from the fuel. The calorific value determine the amount if heat extraction from the system which is predominantly reduced by the moisture in the fuel. The air requirement of the bagasse combustion will changed according to the stoichiometry of the combustion process. The air passes for the combustion plays an major role in this process. Flue gas generation is based upon the bagasse fuel's proximate and ultimate analysis. The moisture and oxygen content will increase the amount of flue gas, also the oxygen with the extra air will increase the amount of oxygen in the exhaust gas. Steam generation has been carried out under 40 bar @ 500° C.

Heat load in Economiser

The economiser operating temperature will be 150° C.

$$HeatavailableoneconomiserH_1 = (m_f \times (h_{fo} - h_{fi}))/3600) \tag{3.10}$$

H_1 - Heat load in Economiser

m_f - Mass of fluid in kg/hr

h_{fo} - Enthalpy of fluid (water) at outlet of economiser in KJ/kg

h_{fi} - Enthalpy of fluid (water) at inlet of economiser in KJ/kg

Heat load in Boiler

The economiser operating temperature will be 400° C which is heating the water from 150° C.

$$Heat available on boiler H_2 = (m_f \times (h_{fg} - h_f)/3600) \tag{3.11}$$

H_2 - Heat load in boiler

m_f - Mass of fluid in kg/hr

h_{fg} - Enthalpy of fluid (water - steam) at outlet of economiser in KJ/kg

h_f - Enthalpy of fluid (water) at inlet of economiser in KJ/kg

Heat load in Super heater

The super heater has been operating at 40 bar @400° C.

$$Heat available in superheater H_3 = (m_f \times (h_s - h_g)/3600) \tag{3.12}$$

H_3 - Heat load in super heater

m_f - Mass of fluid in kg/hr

h_s - Enthalpy of super heated steam at outlet of economiser in KJ/kg

h_g - Enthalpy of dry steam at inlet of economiser in KJ/kg

Heat lost in condensate

The condenser has been operated under 0.8 bar @ 55° C.

$$Heatincondensateh_c = h_f + h_{fg}KJ/kg \tag{3.13}$$

h_c - Enthalpy of condensate in KJ/kg

h_f - Enthalpy of water entering the condensate in KJ/kg

h_{fg} - Enthalpy of water steam mixture entering the condensate in KJ/kg

Work produced by the Steam Turbine

$$Workproducedbythesteamturbine = (m_f \times (h_s - h_c))/3600 \tag{3.14}$$

m_f - mass of fluid in kg/hr

h_s - Enthalpy of super heated steam in KJ/kg

h_c - Enthalpy of condensate in KJ/kg

3.4 Solid oxide fuel cell model

Solid oxide fuel cell model calculations are depends on the partial pressure, operational temperature and consumption of hydrogen on the solid oxide fuel cell. Solid oxide fuel cell model is mainly depend on hydrogen consumption in the reaction. Operational temperature of the fuel cell is around 900° C which is main constraint of operation of fuel cell. Conversion calculations of syn gas components from combusted product are listed below.

3.4.1 Hydrogen consumption in the system

$$Totalhydrogeninsyngas = n_{H2syngas} + 1(n_{COsyngas}) + 4 \times (n_{CH4syngas}) \tag{3.15}$$

$n_{H2syngas}$ - no. of hydrogen molecules in syngas

$n_{COsyngas}$ - no . of carbon mono - oxide molecule in syngas

$n_{CH4syngas}$ - no. of methane molecule in syngas

Utilisation factor of the solid oxide is,

$$Utilisation factor U_f = n_{H2consumed}/n_{Hin} \tag{3.16}$$

$$Oxygenconsumed n_{O2consumed} = 0.5 n_{H2consumed} \tag{3.17}$$

$n_{H2consumed}$ - Total hydrogen consumed by solid oxide fuel cell

n_{Hin} - Hydrogen consumed by fuel cell

$n_{O2consumed}$ - Oxygen consumed by fuel cell

Split ratio for the cathode on to the cell,

$$Splitratio O_{2split} = n_{O2} consumed/n_{O2} in \tag{3.18}$$

Oxygen is diverted on to cathode for a required level needed for combustion in anode. The air sent inside the system is maintained below temperature of the combustion. Hence the heat added and the temperature maintained in the system will plays a major role in the system.

3.4.2 Voltage Calculation

Voltage calculation of the system has been done by calculating the Nernst equation with accommodating the losses of ohmic, concentration and activation losses. Formula for calculating the Nernst voltage on system is,

$$V_N = (\Delta G_f/2F) + (R_g \times T_{avg}/2F) \times ln((P_{H2}P_{O2}^{0.5})/P_{H2O} \qquad (3.19)$$

V_N - Nernst Voltage

ΔG_f - Gibbs free energy formation

R_g - molar gas constant, J/mol K

T_{avg} - Average temperature of fuel cell

F - Faraday constant C/mol

P_{H2} - Partial pressure of H_2O

P_{O2} - Partial pressure of H_2O

The ohmic loss in the system is because of the loss of resistance in the electron flow in both cathode and anode. The inter connection losses in the fuel cell due to the ion flow along the electrolytes of the SOFC. The activation losses is corresponds to the starting charge in the system which is used to start the reaction.

Ohmic losses in Fuel cell

Ohmic losses in the anode is corresponds to the Activation energy, resistivity and toturosity of the fuel cell,

$$Ohmiclossinanode = (\rho_{an} \times \tau_{an})/A_{act} \tag{3.20}$$

$$OhmiclossinCathode = (\rho_{cat} \times \tau_{cat})/A_{act} \tag{3.21}$$

$$Ohmiclossinelectrode = (\rho_{ele} \times \tau_{ele})/A_{act} \tag{3.22}$$

$$Ohmiclossininterconnection = (\rho_{int} \times \tau\tau_{int})/A_{act} \tag{3.23}$$

$\rho - resistivityohm.m$

$\tau - electrodetortuosity$

$int - interconnection$

A_{act} - constant for activation ele - Electrode

cat - Cathode

an - Anode

This give the total ohmic losses happen in anode, cathode, electrode and interconnection of the solid oxide fuel cell.

Concentration losses in fuel cell

Concentration losses in the fuel cell is due to the factor of electrode and other constituents retarding the flow of electrons when the syngas is passed through it. Since the concentration losses is happening only in the anode and cathode because the flow of electrons is not happening in the electrolyte and interconnection, hence those are not considered.

$$Lossincathode = (RT/2F) \times ln(1 - (U_f \times U_a)) \tag{3.24}$$

$$Lossinanode = (RT/4F) \times ln(1 - (Uf \times Ua)) \tag{3.25}$$

R - molar gas constant J/mol K

F - Faraday constant C/mol

U_f - Fuel utilisation factor

U_f - Air utilisation factor

T - Operational temperature

This losses is majorly concerned with the utilisation factor air and fuel.

Activation losses

Activation of the fuel cell in the cell is due to flow of current along the fuel cell when the power is generated. This loss is majorly concern with the smaller cells compared to the larger ones. At cathode

$$(1/R_{cat} - a) = (2F/R_gT_{op} \times K_a \times (P_{H2}/P$$

$$o)^{\times} e^{-(} E_a/R_g T_{op})(3.26)$$

$$Activationlossatcathode = R_{cat} - a \times CurrentDensity \quad (3.27)$$

At anode

$$(1/R_{an} - a) = (4F/R_g T_{op} \times K_a \times (P_{O2}/P_O)^{\text{'}} \times e^{-(} E_a/R_g T_{op}) \quad (3.28)$$

$$Activationlossatcathode = R_{an} - a \times CurrentDensity \quad (3.29)$$

$$Activationlossatcathode = R_{an} - a \times CurrentDensity \quad (3.30)$$

$$Totalvoltageinthesystemwillbe = V_N - Voltagelossesdueto(Ohmic + Concentration + Activation) \quad (3.31)$$

R - molar gas constant J/mol K

F - Faraday constant C/mol

U_f - Fuel utilisation factor

U_f - Air utilisation factor

T_{op} - Operational temperature

E - activation energy in J/mol

Current density j - mA/cm^2

3.4.3 Current calculation

Fuel cell in Solid oxide fuel cell is assumed as pile of cells clustered together to form a . The current density of the cell has been assumed as 178 mA/cm^2 and of the active area of the fuel cell used for the utilisation is 70 m^2.

Chapter 4

Computational Development

Aspen plus was selected for the simulation of the syn gas utilisation system on downstream because of it's flexibility and incorporating excel and FORTRAN codes. Aspen plus has various utility devices like gas turbine, compressors, heat exchangers, reactor models, splitters and mixers for simulating different utilisation system as flow models. of utilisation different streams and also of utilising the different components for calculation of the utilisation.

With use of Aspen plus , feasibility of utilisation system can be anayzed on different operational parameters of system. The outcome of the process can be checked for different input parameters which affect the utilisation system. Operational parameters can be checked for different operational conditions for optimization and for comparison.

In this utilisation system of design model, for the values and properties of syn gas data's for Ms. Anne Jayanthi[9] was used.

Table 4.1: Composition of syn gas stream

Syngas Composition				
Component	kmol/hr	Mole % wet basis	Molecular Wt	mass flow rate (kg/h)
H2	1.13	18.22	2	2.27
CO	1.01	16.26	28	28.358
CO2	1.18	19.02	44	52.131
CH4	1.09	17.59	16	17.537
H2O	1.32	21.31	18	23.898
Char	0.47	7.58	16.06	7.587
	6.22			131.782

4.1 Utilisation system Design

Syn gas utilisation system is done by incorporating various aspen models on flow sheet. Different reactor and other utilisation components are assigned for different models. Modelling of combustion and heat exchanging devices on the aspen flow sheet gives a different results by varying the inputs to the process. Since the overall system depends on model of combustion of syn gas which generate energy for system.

4.1.1 Equipment for Combustion

For process of combustion in combustion chamber RSTOIC reactor of Aspen plus was used. In this system minimum operating pressure is the pressure attained after compression. Combustion takes place in the closed chamber of gas turbine in which the adiabatic temperature has been calculated by the RSTOIC model for complete combustion. In RSTOIC model heat duty of reactor is assumed as 0 to calculate the temperature of complete combustion. RSTOIC model majorly cares of the stoichiometric modes of the reaction takes place in the reactor.

For boiler kind of systems RGIBBS rector model is used, which works according to minimum Gibbs energy formation to find out final conditions and composition of the reaction in the model. This gives the system's operating condition for different operational temperatures, pressures and heat duty of the system.

RYIELD reactor models is used in the system to get defined output of components at exit of reactor for specified input of feedstock or components fed into system. RYIELD will calculate values according to operating conditions set on it. Factors affecting the reactions will calculated internally and final results are produced.

4.1.2 Turbine and Compressors

Process of compression and expansion for compressor and turbine is done in the COMPR and MCOMPR model of Aspen plus which is used for gas and liquid(steam) streams respectively. Both the streams calculate the change in enthalpy for system power generation. Pressure at inlet and outlet is considered to calculate energy generated from turbine. Back pressure turbine conditions are considered in the process of extracting steam. In compressor model power is required, whereas in the turbine work is getting out form the system.

4.1.3 Heat exchangers

HEATX model of Aspen plus is used for heat exchanging between two streams. For heat exchanging the main factor to be considered is, outlet temperature of the cold stream is lesser than the inlet temperatures or else the equipment will be bypassed by the simulator engine.

4.1.4 Mixers, Splitters and Separators

For mixing two different streams in system, MIXER model is used. For this both the streams is to be in same state andd temperature is not a constraint. By using the SPLITTER model, defined percentage of component from the input stream can be separated into two streams. Whereas in SSPLIT model of separation which uses the separation of solid - liquid or solid - gas state streams which is considered as centrifugal action of separation.

In solid oxide fuel cell model SEP model is used as anode to separate the gases. Seperated gases send to combustion chamber and also to anode for thermo - chemical reaction.

4.2 ASPEN declarations

In the process of simulation other than fixing the model on the flow sheet, operational parameters and other user defined values need to enter in the system for simulating the reaction. This has different conditions and the values need to enter on three different places namely,

- Properties
- Stream values
- Blocks
- Calculator blocks

And also in this model flue gas from the gasification column is mixed with the gases at exit of the gas turbine which is used to tap more heat from these gases.

Properties

In properties block components which takes place in all models entered which will be appeared as the overall data of components utilised in the stream. Then next, component entered in components block will appear in component blocks. Components need to refer as conventional, non - conventional and solid in component block. For non - conventional heat capacities need to inserted. Declarations will depend on the type of system that we utilise in the model.

Pure component block was been utilised in the system which will be used to enter the heating values for the non - conventional components take part in the system. These values are not been in ASPEN data banks. Hence we need to enter to set of values for these non - conventional component. Stream class need to be mention in the system for an overall definition of streams in the models.

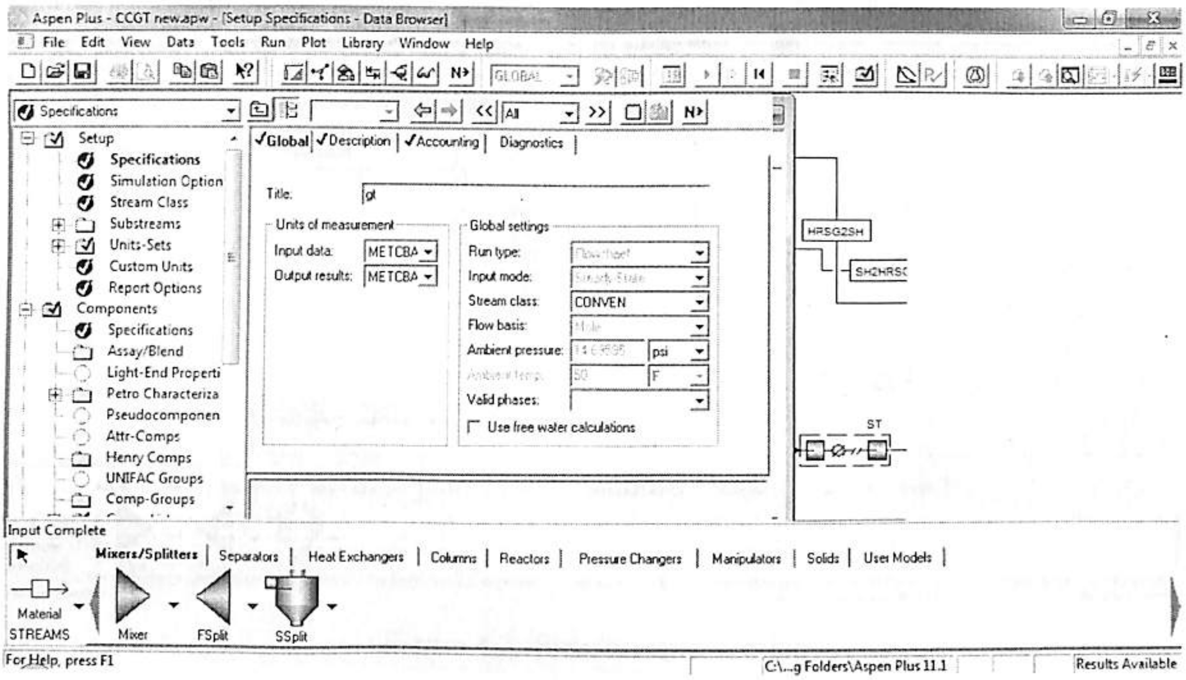

Figure 4.1: Specification of the system in ASPEN

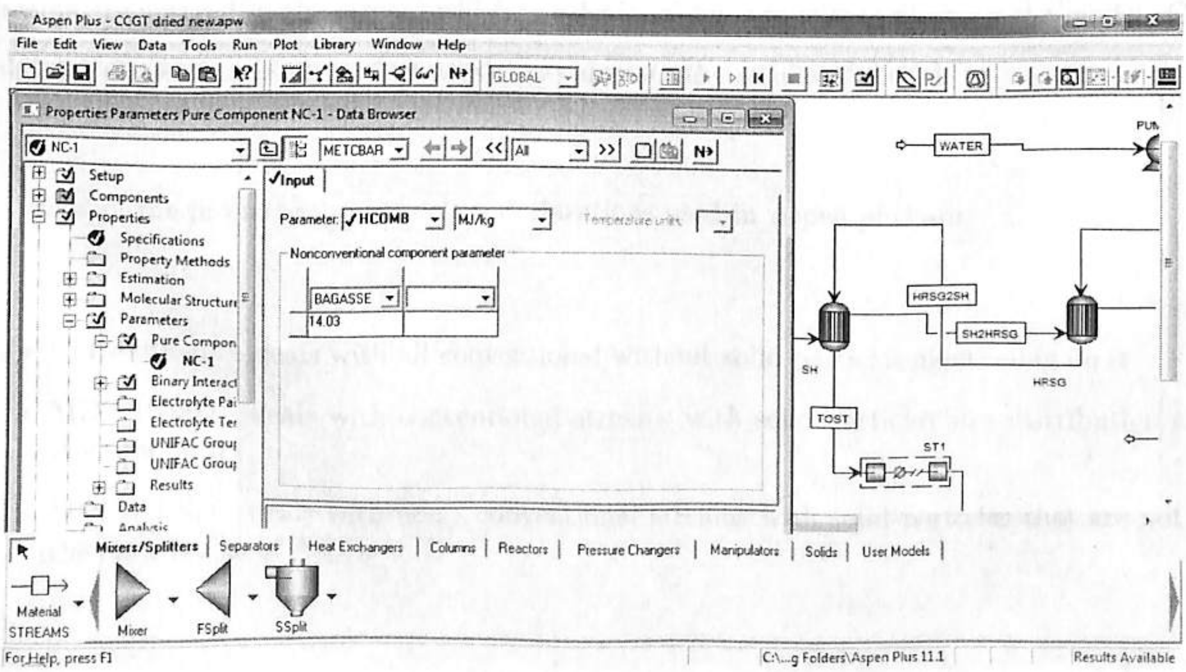

Figure 4.2: Pure components specification

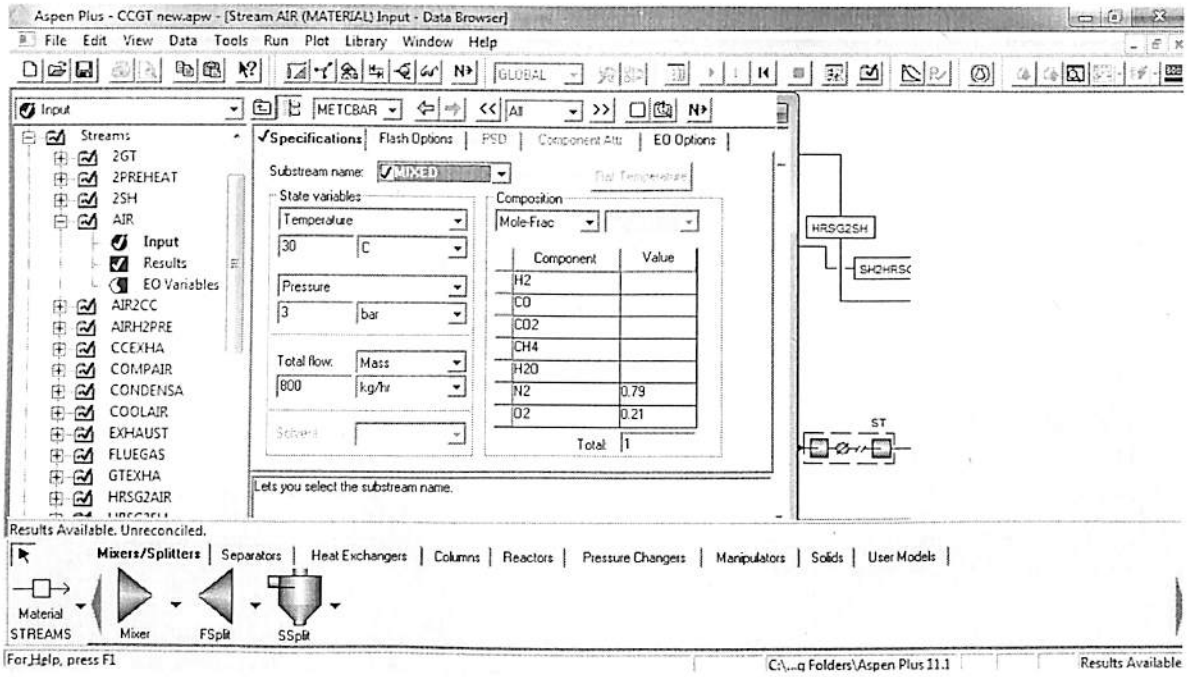

Figure 4.3: Streams specification

Streams

Streams are used to connect two different components on the flow model. Characteristics of streams are entered in the stream which is calculated by equipments place on the model. Calculations done accordingly in flow model to calculate the results of model.

Some of the properties stream class declarations used in Aspen plus are,

- Conventional - deals with all conventional without solid particles mentioning on it
- MIXCPDSD - deals with conventional streams with solid particles size distribution and reaction on it
- MIXNCPSD - deals with non - conventional streams with solid particles that are not in the data banks of Aspen

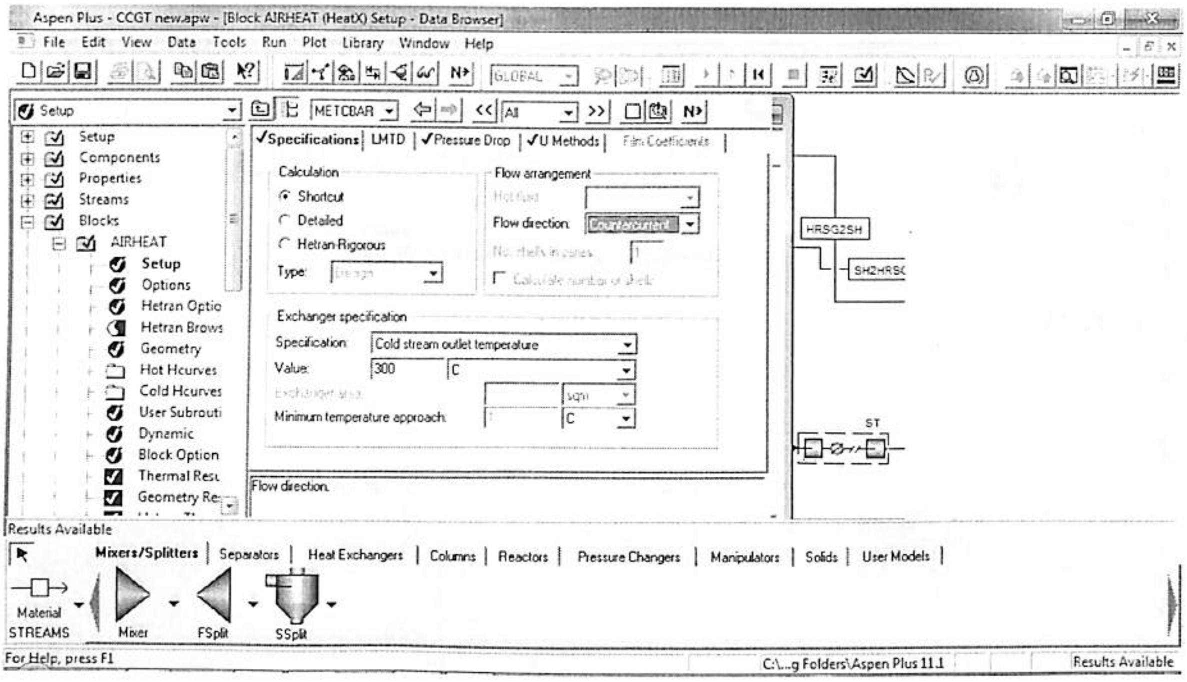

Figure 4.4: Blocks specification

Blocks

The blocks are characterized by the individual equipments like reactors, heat exchangers and others. Every equipment is accounted as an block in Aspen plus in which the values entered will calculate results according to consideration entered onto the blocks.

Calculator blocks

In calculator blocks, calculations or formulas different from Aspen plus will enter in the systems in the form of excel flow sheet or executable FORTRAN declarations which will be assessed by ASPEN plus simulation engine during simulation.

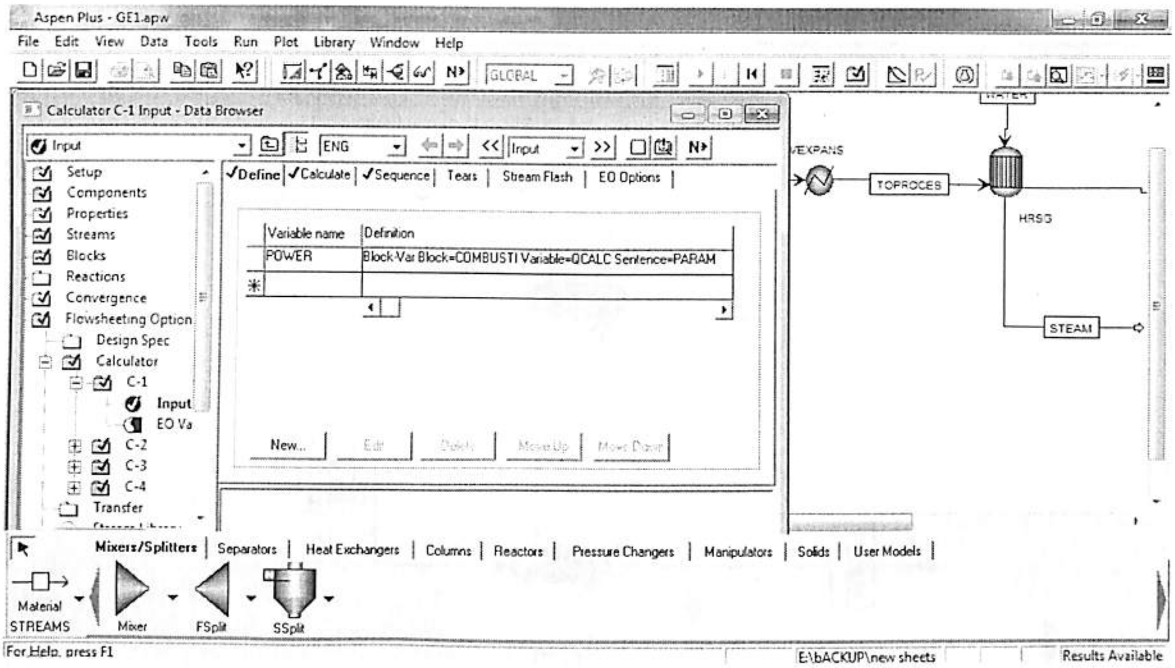

Figure 4.5: Calculator block

4.3 Continuous heat and power model

In continuous heat and power flow model gas turbine is modelled using COMPR from ASPEN plus as the model of the compressor. For combustion chamber RSTOIC from ASPEN plus is used, which is used for the combustion of syngas with the compressed air from compressor. Combustion model in the RSTOIC will give the adiabatic flame temperature of combustion in gases. To maintain the temperature inlet to gas turbine as 1500° additional compressed air is sent into the gas turbine. A pressure ratio of 9 is maintained in the compressor and the turbine has been expanded to its lower operational pressure for the extraction of heat from flue gas.

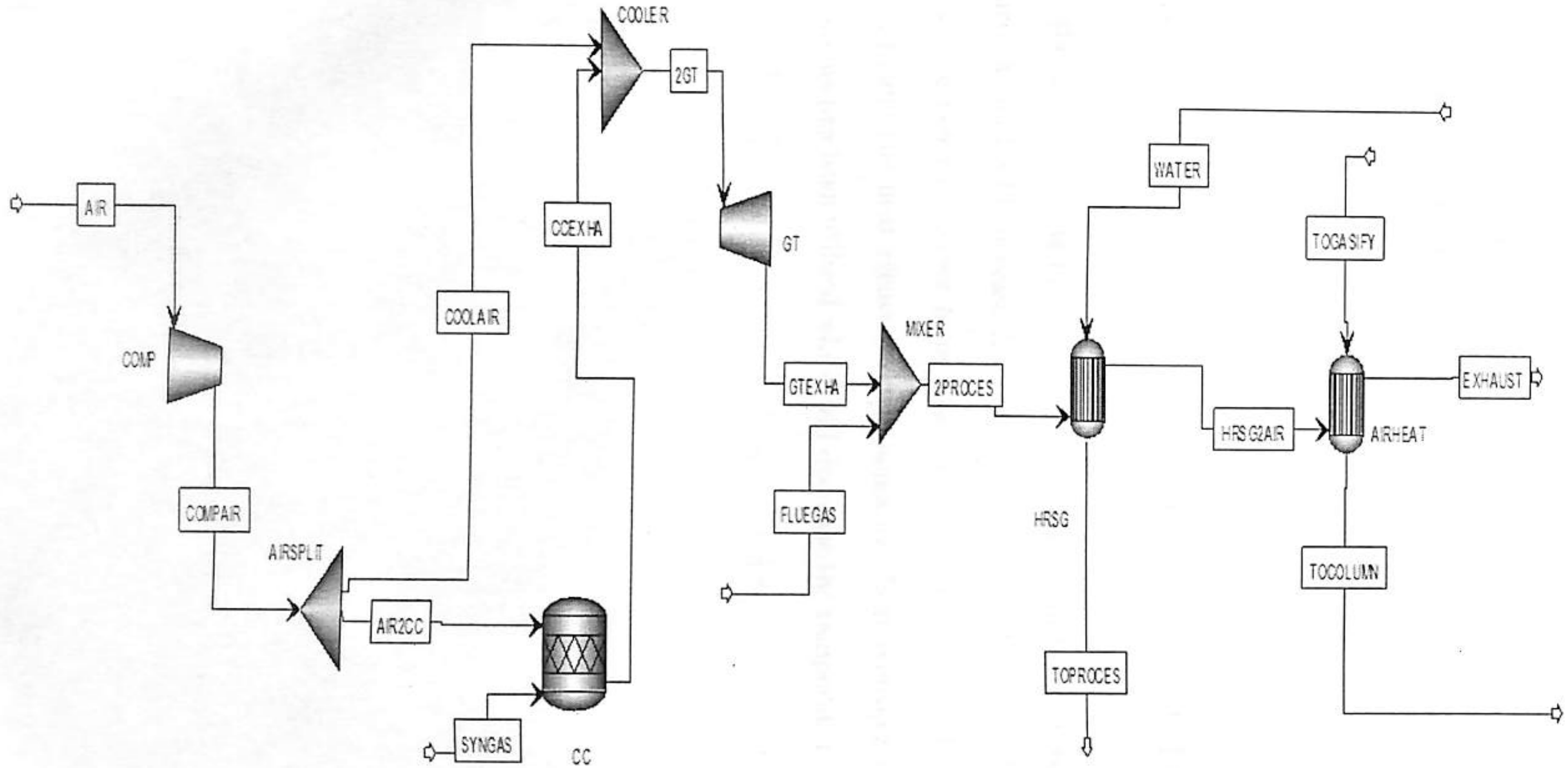

Figure 4.6: Continuous heat and power

Heat exchangers are used in exchanging heat from flue gas for waste heat recovery. Heat is exchanged from flue gas by using waste heat recovery steam generator and air heater for utilisation system. Heat is tapped by both of the equipments for gasification process heating. The heat values of the different streams has been calculated in excel by calculating the molar heat value of different components.

4.4 Combined Cycle Gas Turbine without Dryer

In this process the gas turbine is modelled similar to the continuous heat and power model. But the pressures at exit will increase from previous model. Because of the need to utilise heat from flue gas to generate power from steam turbine with process heat generation. Similar to the above model the heat recovery equipments like heat recovery steam generator and the air heater systems has been utilised which will decrease the temperature of flue gases at exit.

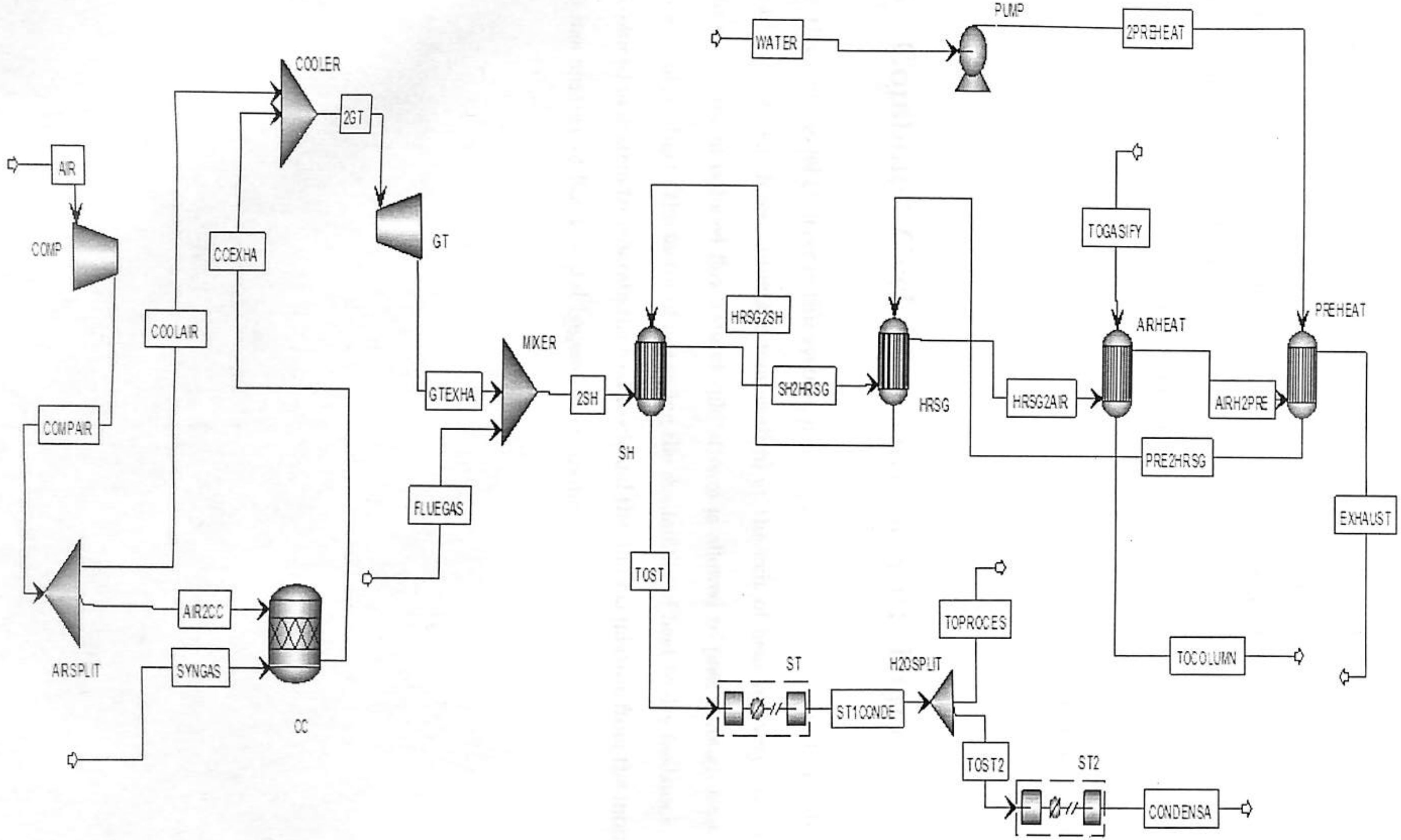

Figure 4.7: Combined cycle gas turbine without dryer

The exit gases from the utilisation system has been maintained above 105° C to prevent the condensation of gases and also to provide the energy to the gases for exhaust from the system. The temperature at the exit of the pre - heater system is around 100° C and at the heat recovery steam generator is around 400° C with an increase of 150° C super heat at super heater. The steam is then expanded in the steam turbine to generate process steam of 5 bar, 350° C at the exit of the Steam turbine 1 and then the remaining is expanded in the second steam turbine to generate maximum power. Pressure at 40 bar is selected for operational pressure of turbine.

4.5 Combined Cycle Gas Turbine with Dryer

Other than the model of dryer in this system, it is similar to the system with the combined cycle gas turbine without dryer. Flue gas temperature at the exit of heat recovery systems is less due to the factor of reduced flow rate of cold stream is allowed to pass through heat recovery sections. This is due to the factor of increasing the availability of heat to dry feedstock. SSPLIT is introduced in system to separate the feed stock and the flue gas mixture from the input stream which has mixture of flue gas and bagasse after drying.

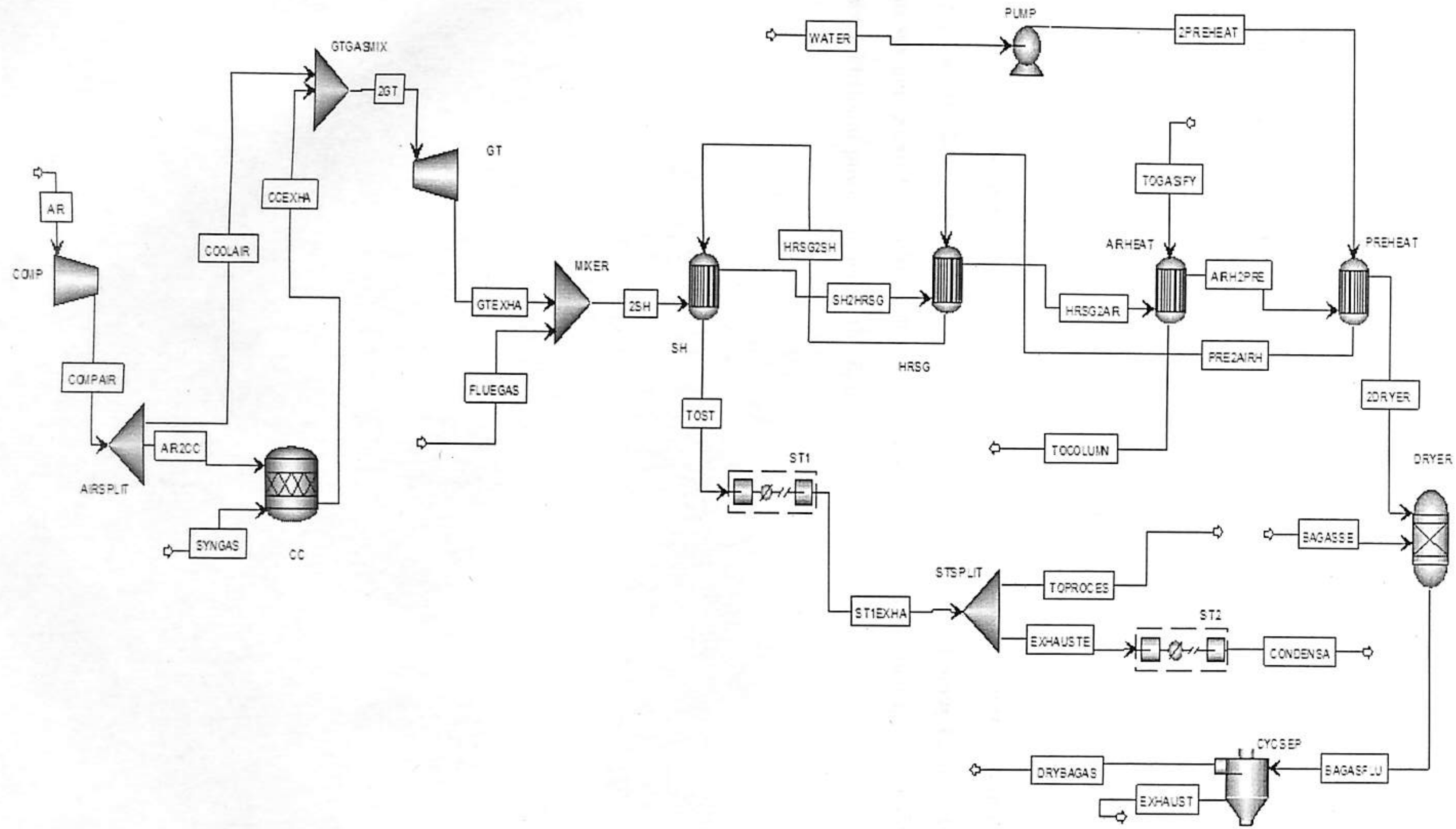

Figure 4.8: CCGT with dryer

Drying operation is done through RYIELD reactor which yield the product specified by user for the conditions required by the user at an operating conditions and also gives the output of heat or the process needed by the system at exit.

4.6 Solid Oxide Fuel Cell model

Solid oxide fuel cell model of power generation system is done through incorporating Microsoft excel for its calculation of power through fuel cell. Since its a bottoming cycle of power generation system exhaust from fuel cell can be allowed to expand through gas turbine which will produce additional power. Refer to the figure below,

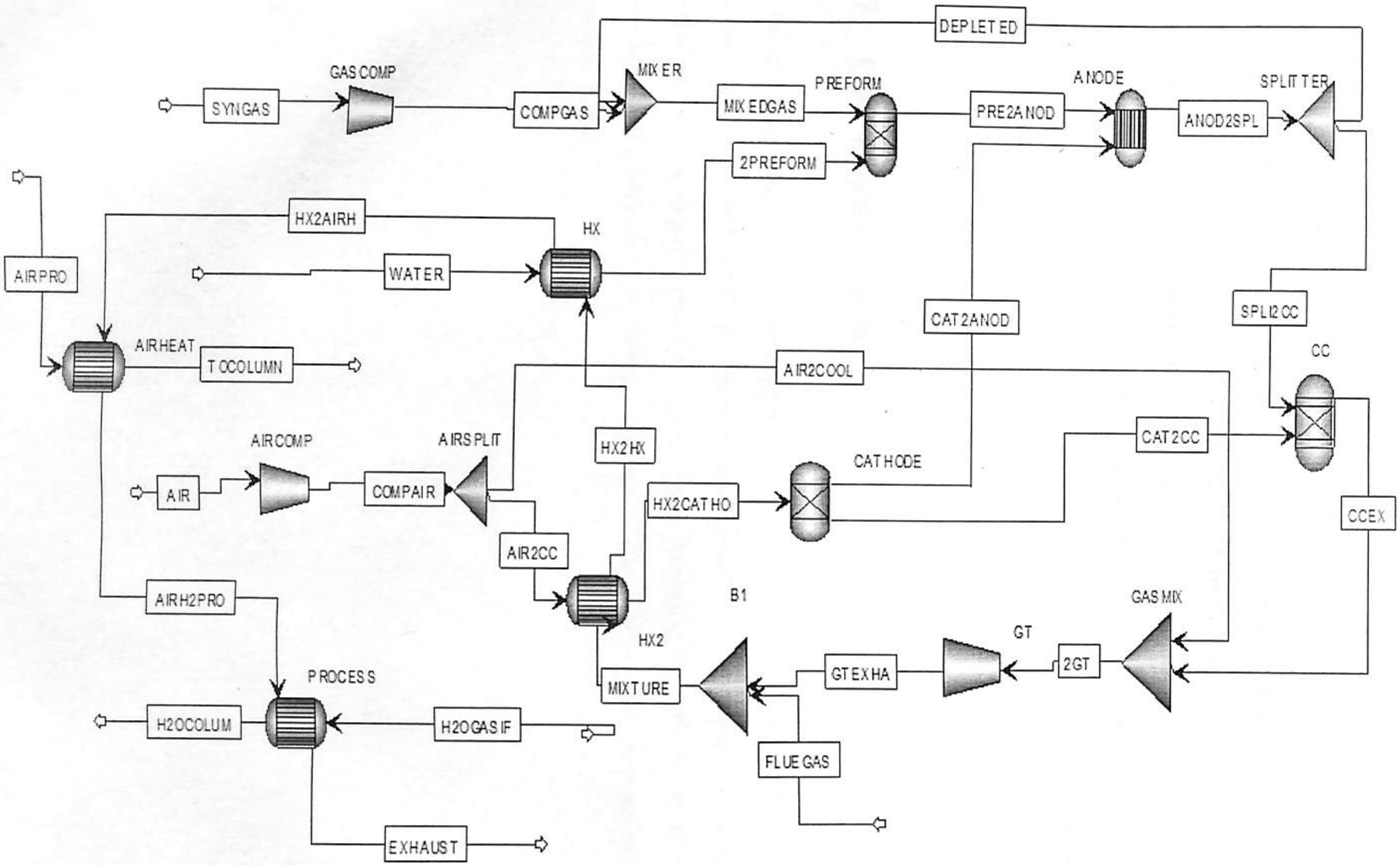

Figure 4.9: Solid oxide fuel cell model

Compressors are used for compressing both syn gas and air to increase the temperature of both streams which bring temperature of streams nearer to point of combustion in system. RGIBBS model of reactor is used in the process of pre - forming and on the reaction in anode. This reactor utilises the minimum Gibbs energy formation of components at an particular temperature. In Pre - former and anode blocks certain components are assumed as inert. Because of the reaction happen by these components will affect the system temperature and also the operation of fuel cell.

4.7 Gas Engine model

For the gas engine model certain assumptions has made to model in the Aspen plus. In Aspen plus, gas engine cycle of Compression ignition was assumed. For process of cooling and heat rejection on coolers are been introduced into flow model through excel. With the introduction of coolers and other models on to the system by using calculator blocks, the system will be similar to the gas engine.

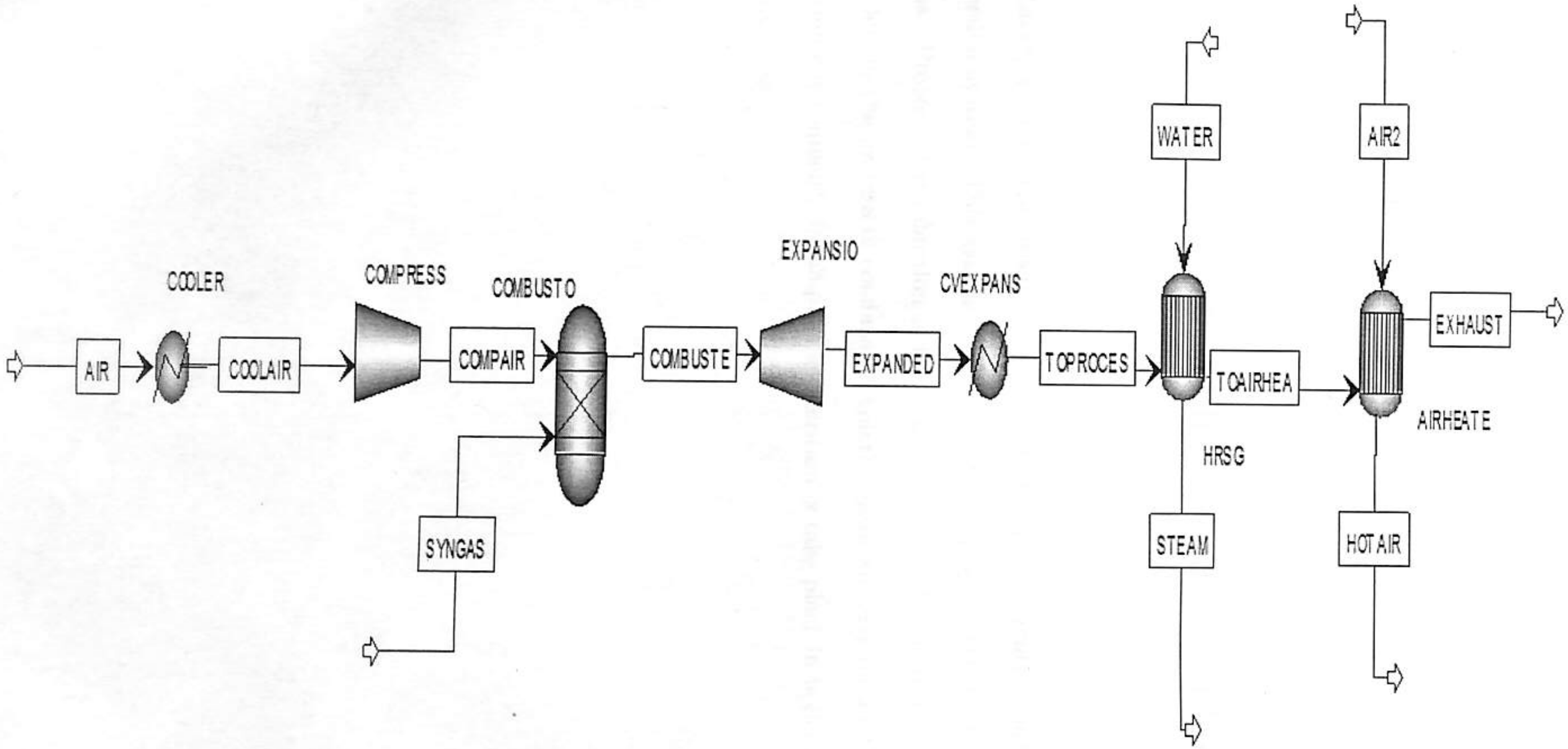

Figure 4.10: Gas engine model

The heat recovery systems is then modelled to recover heat from system for the process of gasification. Air heating system and steam generation systems are used to tap heat from flue gas. Hot air and steam is then used in gasifier for gasification process.

4.8 Direct Combustion model of burning biomass feedstock

Biomass feedstock is combusted directly in furnace which is used currently in majority of biomass energy conversion system. This system is modelled for comparing energy generation through other systems. Process of combustion is take place in two different reactors in the ASPEN plus flow model. In the process of combustion volatile gases are first released when it exposed onto combustion environment. Incomplete combustion is take place in boiler due to increased moisture contet in it.

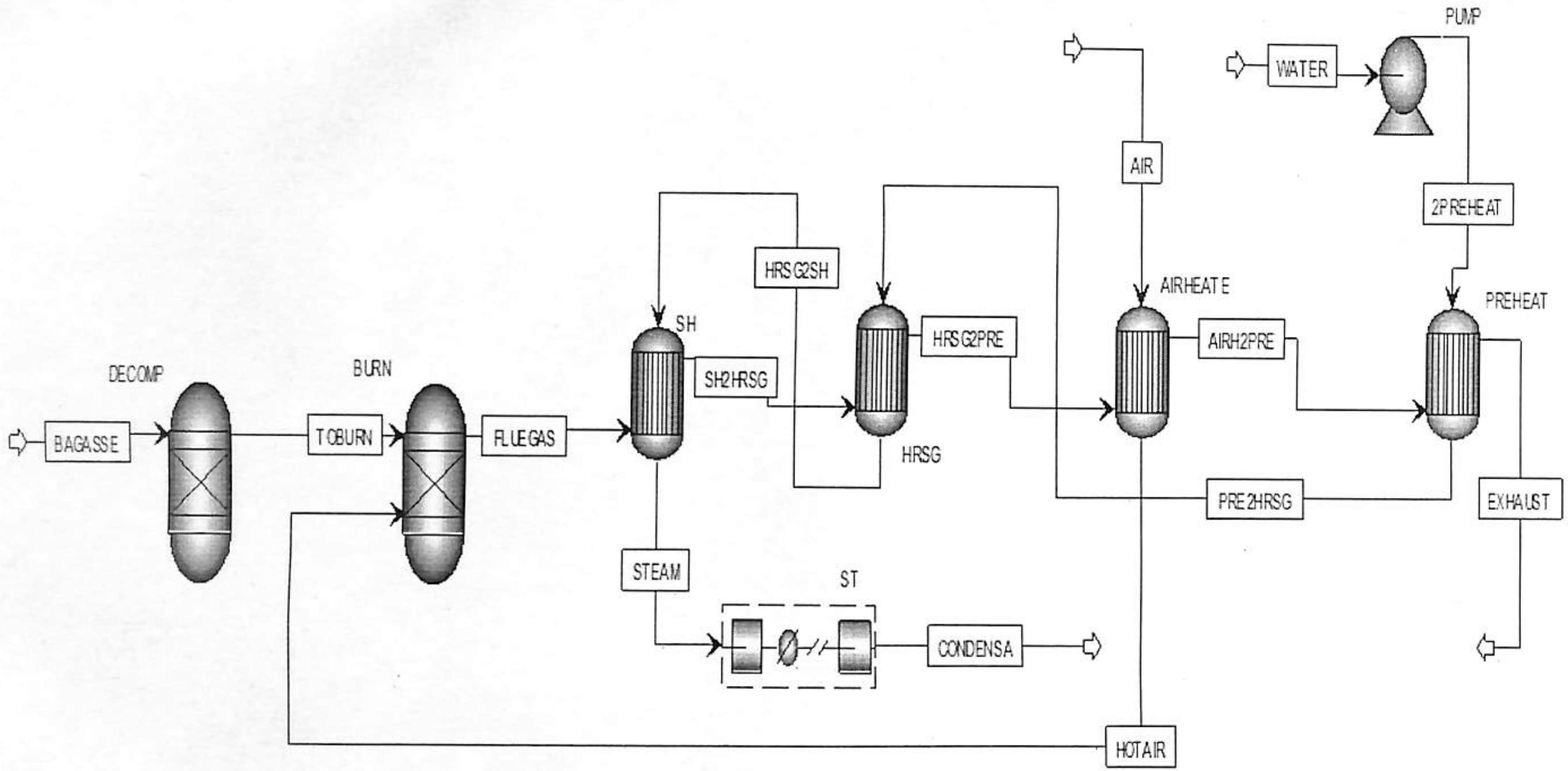

Figure 4.11: Combustion model

For the combustion in ASPEN Plus RGIBBS reactor is used, which calculate the minimum Gibbs energy formation of components for combustion. Combustion temperature of the furnace is limited because of the material constraints.

Chapter 5

Result and Discussion

5.1 Utilisation system

Syn gas utilisation system comprises of Gas turbine, Gas engine and solid oxide fuel cell model. Gas has been combusted in the combustion chamber of gas turbine. The gases then expands in gas turbine. In gas engine syn gas is combusted at the end of compression stroke. Adiabatic flame temperature of about 1900° C is reached in the combustion chamber . Hence more air is required for cooling. Additional air supplied for the maintaining temperature of inlet at gas turbine. This will increase the auxiliary energy required by utilisation system for compressing additional air. This factor is not considered in gas engine systems.

Inter - cooling is not provided in current systems due to increased flow rate air to cool the gas on inlet to the gas turbine. Gas expanded in the turbine is mixed with the flue gas form gasifier to utilise the waste heat from gasifier. Exhaust of the flue gases has maintained below 105° C for taking into the factor of condensation of flue gases. Power produced by the gas turbine is uniform and non variable. But using secondary heat recovery system will change the efficiency of system. Overall analysis of the gasification utilization proves that this system can provide the energy with process heat recovery without use of any energy aid. This doesnt affect the energy utilization efficiency to a larger extent.

Process heat recovery system generates heat for heat required by gasification reaction. Steam at a rate of 61 kg/hr with a pressure of 5 bar at 350° C was generated to fulfil the needs of gasification reaction in the BFB column. Hot air at a rate of 109 kg/hr with a pressure of 5 bar 300° C has been generated for the combustion column of gasifier.

5.1.1 Electrical conversion efficiency

Electrical conversion efficiency of syn gas utilization system is around 30 40%. Depending on the process heat application needed by the system efficiency will vary. Whereas SOFC model of power generation produce higher power due to additional energy generation by fuel cell.

5.2 Continuous Heat and Power system

Hot gas from combustion chamber is expanded in gas turbine which produce an electrical energy directly. Thermal energy conversion is takes place by passing flue gas through air heater and process hot steam generator. In this model of utilisation energy produced is higher than other systems. Due to reducing the gas pressure beyond 2 bar produce higher energy in flue gas. Heat loss in CHP system was analysed for using heat recovery systems for tapping it. This gives an idea about the energy that can be generated by passing the flue gas on through the waste heat recovery equipments for higher energy tapping.

Stream name	AIR	COMPAIR	AIR2CC	SYNGAS	CCEXHA	2GT	GTEXHA	FLUEGAS	2PROCES	TOPROCES	HRSG2AIR	TOCOLUMN	EXHAUST
To	COMP	AIRSPLIT	CC	CC	COOLER	GT	MIXER	MIXER	HRSG		AIRHEAT		
From		COMP	AIRSPLIT		CC	COOLER	GT		MIXER	HRSG	HRSG	AIRHEAT	AIRHEAT
Phase	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR
Substream: MIXED													
Mole Flow kmol/hr													
H2	0.00	0.00	0.00	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO	0.00	0.00	0.00	1.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	0.00	1.20	3.29	3.29	3.29	0.24	3.54	0.00	3.54	0.00	3.54
CH4	0.00	0.00	0.00	1.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H2O	0.00	0.00	0.00	1.34	4.64	4.64	4.64	0.00	4.64	6.66	4.64	0.00	4.64
N2	20.54	20.54	13.69	0.00	13.69	20.54	20.54	1.31	21.84	0.00	21.84	4.11	21.84
O2	5.46	5.46	3.64	0.00	0.40	2.22	2.22	0.08	2.30	0.00	2.30	1.09	2.30
Total Flow kmol/hr	26.00	26.00	17.33	5.78	22.03	30.70	30.70	1.63	32.33	6.66	32.33	5.20	32.33
Total Flow kg/hr	750.00	750.00	500.00	125.00	625.00	875.00	875.00	50.00	925.00	120.00	925.00	150.00	925.00
Total Flow cum/hr	218.41	81.83	54.56	64.73	151.21	104.16	1376.57	166.11	2919.20	74.56	2042.06	49.55	1941.12
Temperature C	30.00	294.77	294.77	400.00	1955.88	1563.36	805.61	950.00	812.89	400.00	486.57	300.00	449.02
Pressure bar	3	15	15	5	27	45	2	1	1	5	1	5	1
Energy balance													
Energy in H2	0.00	0.00	0.00	15464.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Energy in CO	0.00	0.00	0.00	14922.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Energy in CO2	0.00	0.00	0.00	28417.03	339181.64	247675.50	132504.70	10001.77	123861.60	0.00	62186.18	0.00	55490.73
Energy in CH4	0.00	0.00	0.00	32597.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Energy in H2O	0.00	0.00	0.00	0.00	373174.97	271696.34	142542.27	0.00	124033.42	345958.80	63420.32	0.00	56845.55
Energy in N2	3187.52	170988.43	106867.78	0.00	844338.10	944126.13	549298.26	33349.64	509834.85	0.00	266871.67	32705.63	239847.71
Energy in O2	854.00	47232.78	29520.49	0.00	26242.46	108002.97	69096.79	2205.95	62470.53	0.00	32537.85	9038.18	29200.20
Total Energy in KJ/hr	4041.52	218221.21	136388.27	91401.11	1582937.17	1571500.94	893442.02	45557.35	820200.40	345958.80	425016.02	41743.81	381384.20
Total Energy in KW	1.12	60.62	37.89	25.39	439.70	436.53	248.18	12.65	227.83	96.10	118.06	11.60	105.94

Figure 5.1: Continuous Heat and power Stream data

The energy generated by the gas turbine is 215 KW as there very little need for end heat utilization such as other than steam generation and process air heating. Heat duty of the waste heat recovery systems are less as it is handling little amount of cold fluid in the system. Utility systems like process heat generation system and air heating system has been utilized to recover the maximum heat. Since only minimal about of heat is tapped in this system, heat carried away by the flue gas is more.

Table 5.1: Energy balance of Continuous heat and Power

Input Energy

Component	**KW**	**%**
Heat input through fuel	439.04	81.48
Sensible heat in the fuel	25.39	4.71
Heat input through air	1.12	0.21
Sensible heat through air	60.62	11.25
Heat input through flue gas	12.65	2.35
Heat input to gasification air	0.21	0.04
Total Input Energy	538.82	100

Output Energy

Component	**KW**	**%**
Work done by the gas turbine	200.52	37.21
Work needed by the compressor	45.34	8.41
Heat taken away by exhaust flue gases	105.94	19.66
Heat taken away by exhaust steam	96.10	17.84
Heat duty of the HRSG	55.22	10.25
Heat duty of the air heater	10.56	1.96
Heat carried away by the gasification air	11.60	2.15
Losses	13.55	2.51
Total output energy	538.82	100.00

5.2.1 Influence of Compression ratio on the system

Compression ratio increases the energy availability and also the auxiliary energy usage by compressor which may become one third of the systems. At compression ratio of 5 the power need by the compressor is around 25 30 KW with losses. But with the increase of the compression ratio to 9 the energy needed by the compressor becomes 65 KW with losses. This also increase the operational pressures of combustion chamber. This will increase the energy produced by the system.

5.3 Combined cycle gas turbine without drying

Combined cycle gas turbine utilizes the combusted gas from the combustion chamber to produce electrical energy from the gas turbine. Air is compressed in air compressors which is then fed to combustion chamber. To maintain the gas inlet temperature to a minimum temperature of 1500°C, additional air is compressed and sent to gas turbine to maintain the temperature below 1500° C. Compressed air has been inlet into the system to reduce the pressure losses on the gas turbine. Reduction in inlet temperature of air produces higher efficiencies.

Stream name	AIR	COMPAIR	SYNGAS	CCEXHA	2GT	GTEXHA	FLUEGAS	2SH	HRSG2SH	AIRH2PRE	WATER	2PREHEAT	EXHAUST	TOST	CONDENSA
TO	COMP	AIRSPLIT	CC	COOLER	GT	MIXER	MIXER	SH	SH	PREHEAT	B13	PREHEAT		ST	
From		COMP		CC	COOLER	GT		MIXER	HRSG	AIRHEAT		B13	PREHEAT	SH	ST2
Phase	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	LIQUID	LIQUID	VAPOR	VAPOR	LIQUID
Substream: MIXED															
Mole Flow kmol/hr															
H2	0.00	0.00	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO	0.00	0.00	1.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	1.20	3.29	3.29	3.29	0.24	3.54	0.00	3.54	0.00	0.00	3.54	0.00	0.00
CH4	0.00	0.00	1.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H2O	0.00	0.00	1.34	4.64	4.64	4.64	0.00	4.64	11.10	4.64	11.10	11.10	4.64	11.10	7.72
N2	21.91	21.91	0.00	13.69	21.91	21.91	1.31	23.21	0.00	23.21	0.00	0.00	23.21	0.00	0.00
O2	5.82	5.82	0.00	0.40	2.58	2.58	0.08	2.67	0.00	2.67	0.00	0.00	2.67	0.00	0.00
Total Flow kmol/hr	27.73	27.73	5.78	22.03	32.43	32.43	1.63	34.06	11.10	34.06	11.10	11.10	34.06	11.10	7.72
Total Flow kg/hr	800.00	800.00	125.00	625.00	925.00	925.00	50.00	975.00	200.00	975.00	200.00	200.00	975.00	200.00	139.00
Temperature C	30.00	294.77	400.00	1955.88	1506.45	906.30	950.00	908.38	400.00	444.85	30.00	34.29	396.97	283.60	55.00
Pressure bar	3.00	15.00	5.00	27.00	45.00	5.00	1.00	1.00	5.00	1.00	1.00	50.00	1.00	3.00	0.80
Vapor Frac	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00
Energy balance															
Energy in H2	0.00	0.00	15464.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Energy in CO	0.00	0.00	14922.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Energy in CO2	0.00	0.00	28417.03	339181.64	247675.50	132504.70	10001.77	142769.41	0.00	27537.37	0.00	0.00	18341.68	0.00	0.00
Energy in CH4	0.00	0.00	32597.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Energy in H2O	0.00	0.00	0.00	3.73E+05	2.72E+05	1.43E+05	0.00E+00	1.43E+05	5.83E+05	2.90E+04	2.51E+04	2.51E+04	1.96E+04	6.20E+05	23702.28
Energy in N2	3.19E+03	1.71E+05	0.00E+00	8.44E+05	6.29E+05	5.49E+05	3.33E+04	5.84E+05	0.00E+00	1.24E+05	0.00E+00	0.00E+00	8.38E+04	0.00E+00	0.00E+00
Energy in O2	8.54E+02	4.72E+04	0.00E+00	2.62E+04	1.95E+04	6.91E+04	2.21E+03	7.15E+04	0.00E+00	1.49E+04	0.00E+00	0.00E+00	1.01E+04	0.00E+00	0.00E+00
Total Energy in KJ/hr	4.04E+03	2.18E+05	9.14E+04	1.58E+06	1.17E+06	8.93E+05	4.56E+04	9.41E+05	5.83E+05	1.95E+05	2.51E+04	2.51E+04	1.32E+05	6.20E+05	2.37E+04
Total Energy in KW	1.12	60.62	25.39	439.70	324.51	248.18	12.65	261.36	162.04	54.23	6.99	6.96	36.62	172.23	6.58

Figure 5.2: CCGT without dryer stream data

Increase of compression ratio increase the combustion temperature to certain extent. Energy is greatly increased by th additional cooling air enter into the system. Maximum power produced by the gas turbine system without the drying setup is about 189 KW. Most of the energy is still been available on flue gas stream for extraction in the form of waste heat recovery. Waste heat recovery system consist of the Super heater, Heat recovery steam generator and for preheating. Additionally heat is supplied for heating fluidizing air in combustion column and for steam generation in gasification column for the gasification reaction by extraction from steam turbine. The heat recovery system produce s the energy from steam turbine to about 22 KW with the steam needed for the gasification system.

But the energy in the flue gas is still available which can be utilized in the energy conversion for

Table 5.2: Combined Cycle gas Turbine without dryer

Input Energy

Component	**KW**	**%**
Heat input through fuel	439.04	81.48
Sensible heat in the fuel	25.39	4.71
Heat input through air	1.12	0.21
Sensible heat through air	60.62	11.25
Heat input through flue gas	12.65	2.35
Heat input to gasification air	0.21	0.04
Total Input Energy	538.82	100

Output Energy

Component	**KW**	**%**
Work done by the gas turbine	183.93	34.14
Work done by the steam turbine	25.32	4.70
Work needed by the compressor	43.67	8.10
Heat taken away by exhaust flue gases	36.62	6.80
Heat taken away by exhaust steam	41.87	7.77
Heat taken away by steam condensate	6.58	1.22
Heat duty of the superheater	11.65	2.16
Heat duty of the HRSG	148.67	27.59
Heat duty of the air heater	10.56	1.96
Heat duty of water pre - heater	8.27	1.53
Heat carried away by the gasification air	11.60	2.15
Work done by pump	0.93	0.17
Losses	9.16	1.70
Total output energy	538.82	100.00

low temperature system like district heating system and for the fuel utilization system, which require less heat for energy conversion.

5.3.1 Influence of compression ratio

Compression ratio plays an important role in the process of combustion. An increase in compression ratio will directly increases the combustion temperature. This is due to the pressure increase in the system increase the heat available by the gases. More air (Cooling stream) will need to be passed through the system. Auxiliary energy usage and cost of equipment get increased.

Compression ratio increase the total energy produced by the gas turbine but it doesn't have any effect in steam turbine. This is due to the temperature at exit of the gas turbine is able to transfer the required heat needed by the heat recovery equipments.

Table 5.3: Effect of Compression ratio

Compression ratio	6	8	9
Power produced in gas turbine KW	175.2	176.32	183.93
Power produced in steam turbine KW	25.32	25.32	25.32
Exhaust flue gas temperatures °C	172.34	202.97	227.32

5.3.2 Effect of inlet Temperatures

With the increase in inlet temperature of syngas to combustion chamber, temperature at the exit of combustion chamber get increased. To reduce the temperature at inlet to the gas turbine more air is required. This directly increase the energy consumed by compressor.

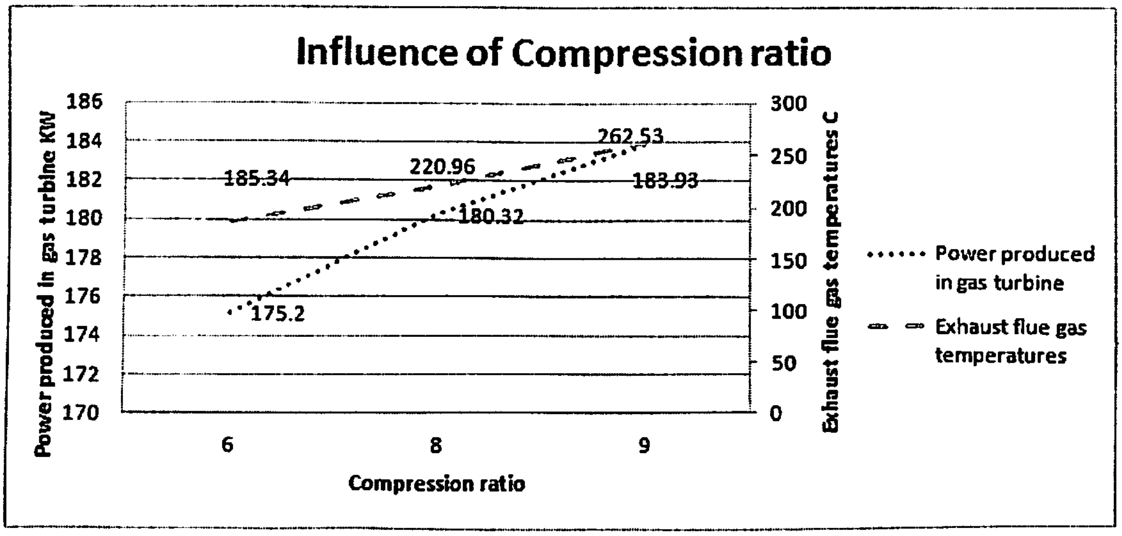

Figure 5.3: Effect of compression ratio

Table 5.4: Effect of fuel inlet temperature

Effect of inlet temperatures C	350	400	450
Temperature at exit of CC C	1899.62	1911.76	1924.18

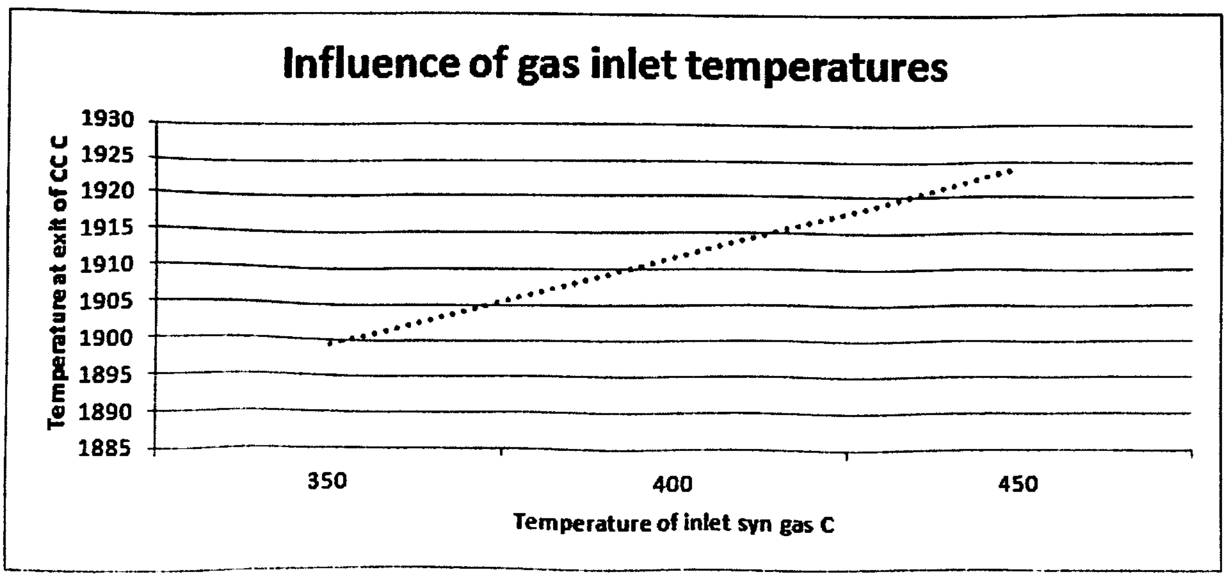

Figure 5.4: Effect of inlet temperature of fuel

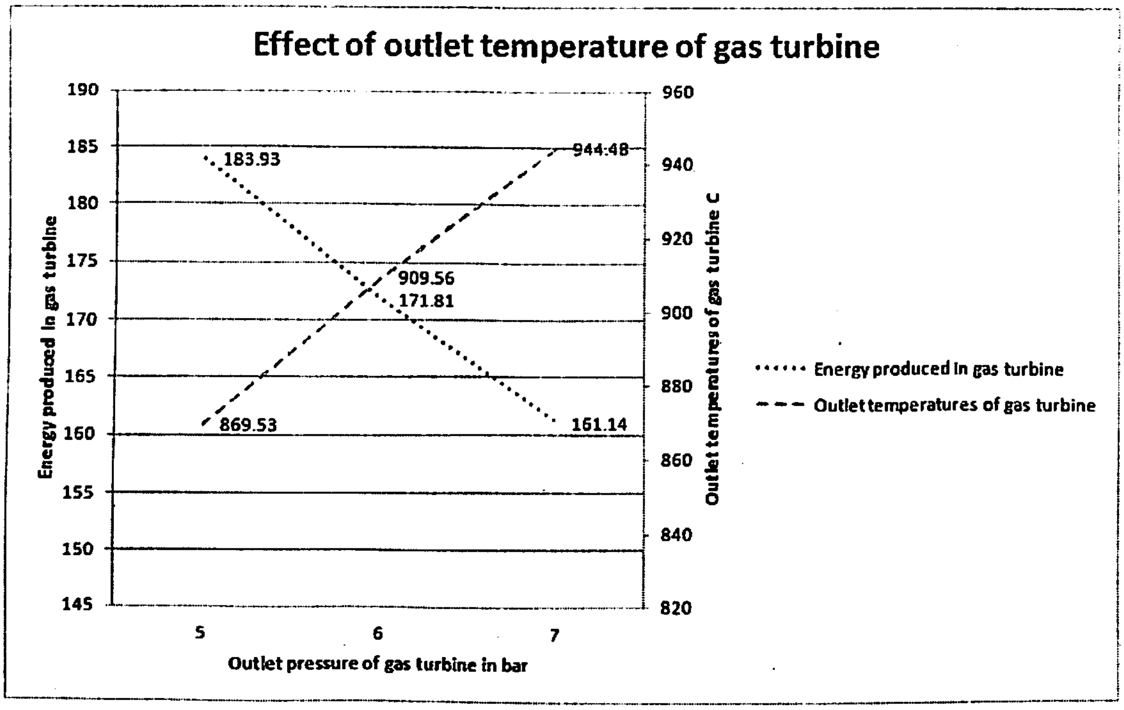

Figure 5.5: Effect of outlet temperature of gas turbine

5.3.3 Effect of outlet pressure of Gas turbine

With the increase in pressure at the exit of the gas turbine power produced in the gas turbine will get decreased. Whereas outlet temperatures of gas turbine will get increased. These type of system will be utilised in higher capacity heat recovery systems.

Table 5.5: Effect of outlet pressures

Effect of outlet pressures of gas turbine	5	6	7
Energy produced In gas turbine	183.93	171.81	161.14
Outlet temperatures of gas turbine	869.53	909.56	944.48

5.4 Combined Cycle gas turbine with Dryer

Exhaust from the gas turbine is allowed to recover heat by various heat transfer equipments. By reducing the moisture content in the fuel, gasification preocess will get more efficient. Dryer in this system is utilising heat from exhaust flue gases from pre - heater. Moisture content of the feedstock is converted onto water vapour with utilising heat from flue gas. The feed stock and flue gas is separated by cyclone separator as individual streams.

Stream name	AIR	COMPAIR	SYNGAS	CCEXHA	2GT	GTEXHA	FLUEGAS	2SH	HRSG2SH	AIRH2PRE	WATER	2PREHEAT	EXHAUST	TOST	CONDENSA
TO	COMP	AIRSPLIT	CC	COOLER	GT	MIXER	MIXER	SH	SH	PREHEAT	B13	PREHEAT		ST	
From		COMP		CC	COOLER	GT		MIXER	HRSG	AIRHEAT		B13	PREHEAT	SH	ST2
Phase	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	LIQUID	LIQUID	VAPOR	VAPOR	LIQUID
Substream: MIXED															
Mole Flow kmol/hr															
H2	0.00	0.00	1.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO	0.00	0.00	1.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	0.00	0.00	1.20	3.29	3.29	3.29	0.24	3.54	0.00	3.54	0.00	0.00	3.54	0.00	0.00
CH4	0.00	0.00	1.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H2O	0.00	0.00	1.34	4.64	4.64	4.64	0.00	4.64	11.10	4.64	11.10	11.10	4.64	11.10	7.72
N2	21.91	21.91	0.00	13.69	21.91	21.91	1.31	23.21	0.00	23.21	0.00	0.00	23.21	0.00	0.00
O2	5.82	5.82	0.00	0.40	2.58	2.58	0.08	2.67	0.00	2.67	0.00	0.00	2.67	0.00	0.00
Total Flow kmol/hr	27.73	27.73	5.78	22.03	32.43	32.43	1.63	34.06	11.10	34.06	11.10	11.10	34.06	11.10	7.72
Total Flow kg/hr	800.00	800.00	125.00	625.00	925.00	925.00	50.00	975.00	200.00	975.00	200.00	200.00	975.00	200.00	139.00
Temperature C	30.00	294.77	400.00	1955.88	1506.45	906.30	950.00	908.38	400.00	444.85	30.00	34.29	396.97	283.60	55.00
Pressure bar	3.00	15.00	5.00	27.00	45.00	5.00	1.00	1.00	5.00	1.00	1.00	50.00	1.00	3.00	0.80
Vapor Frac	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	1.00	1.00	0.00
Energy balance															
Energy in H2	0.00	0.00	15464.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Energy in CO	0.00	0.00	14922.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Energy in CO2	0.00	0.00	28417.03	339181.64	247675.50	132504.70	10001.77	142769.41	0.00	27537.37	0.00	0.00	18341.68	0.00	0.00
Energy in CH4	0.00	0.00	32597.18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Energy in H2O	0.00	0.00	0.00	3.73E+05	2.72E+05	1.43E+05	0.00E+00	1.43E+05	5.83E+05	2.90E+04	2.51E+04	2.51E+04	1.96E+04	6.20E+05	23702.28
Energy in N2	3.19E+03	1.71E+05	0.00E+00	8.44E+05	6.29E+05	5.49E+05	3.33E+04	5.84E+05	0.00E+00	1.24E+05	0.00E+00	0.00E+00	8.38E+04	0.00E+00	0.00E+00
Energy in O2	8.54E+02	4.72E+04	0.00E+00	2.62E+04	1.95E+04	6.91E+04	2.21E+03	7.15E+04	0.00E+00	1.49E+04	0.00E+00	0.00E+00	1.01E+04	0.00E+00	0.00E+00
Total Energy in KJ/hr	4.04E+03	2.18E+05	9.14E+04	1.58E+06	1.17E+06	8.93E+05	4.56E+04	9.41E+05	5.83E+05	1.95E+05	2.51E+04	2.51E+04	1.32E+05	6.20E+05	2.37E+04
Total Energy in KW	1.12	60.62	25.39	439.70	324.51	248.18	12.65	261.36	162.04	54.23	6.99	6.96	36.62	172.23	6.58

Figure 5.6: CCGT with dryer stream data

Energy of 44 KW is needed by dryer for drying of biomass feedstock. The flue gas and the fuel mixture is then mixed in the reactor to exchange the heat between two streams. The outlet temperature of the flue gas is been around 150° C. The flue gases and the dried fuel has been separated by the cyclone separator which works according to the centrifugal force of separation. Due to the process of drying, the energy generation through the steam turbine is reduced. This is due to the factor of maintaining energy in flue gases to maximum for drying. Waste heat energy utilization system's flow rate is reduced to maintain the temperature of flue gases for drying.

Energy produced through gas turbine is same as that of energy generated by CCGT without

Table 5.6: Combined cycle gas turbine with Dryer

Input Energy		
Component	**KW**	**%**
Heat input through fuel	439.04	81.48
Sensible heat in the fuel	25.39	4.71
Heat input through air	1.12	0.21
Sensible heat through air	60.62	11.25
Heat input through flue gas	12.65	2.35
Heat input to gasification air	0.22	0.04
Total Input Energy	538.82	100
Output Energy		
Component	**KW**	**%**
Work done by the gas turbine	182.96	33.96
Work done by the steam turbine	25.32	4.70
Work needed by the compressor	42.53	7.89
Heat taken away by exhaust flue gases	13.34	2.48
Heat taken away by exhaust steam	42.56	7.90
Heat taken away by steam condensate	5.64	1.05
Heat duty of the superheater	10.23	1.90
Heat duty of the HRSG	135.26	25.10
Heat duty of the air heater	10.56	1.96
Heat duty of water preheater	8.27	1.53
Heat carried away by the gasification air	11.60	2.15
Work done by pump	0.93	0.17
Heat duty of dryer	44.71	8.30
Losses	4.92	0.91
Total output energy	538.82	100.00

drying system. The energy generated is around 183 KW whereas the total energy generated by the gas and steam turbine is around 205 KW. Energy utilized by the compressor is around 43 KW.

The heat duty by various equipments has been reduced by about 10% due to the reduced flow rate in the waste heat energy utilisation systems. Heat duty of sry to reduce moisture content is about 44 KW.

5.4.1 Influence of Flue gas temperature on the system

Final gas temperature plays an important role for the energy available and utilization of the gases in the drying system. The main problem in the process of drying is burning of fuel during the exchange of heat between flue gas and the fuel feed stock to be dried. When the gas temperature is low the fuel system need extra heat to run the process. As for as the present system is concerned the final temperature is huge and thus the more amount of heat can be utilized. Hence less amount of external heat is needed.

5.4.2 Influence of drying

With the decrease in the moisture content needed at exit of dryer heat duty of dryer get increased. More heat from flue gas has been trapped by feed stock for the reduction of moisture content. Hence the energy losses through exhaust flue gas is also reduced.

Table 5.7: Effect of moisture content in the feed stock

Moisture content in final	15	20	25
Heat duty of dryer	44.71	30.41	16.12

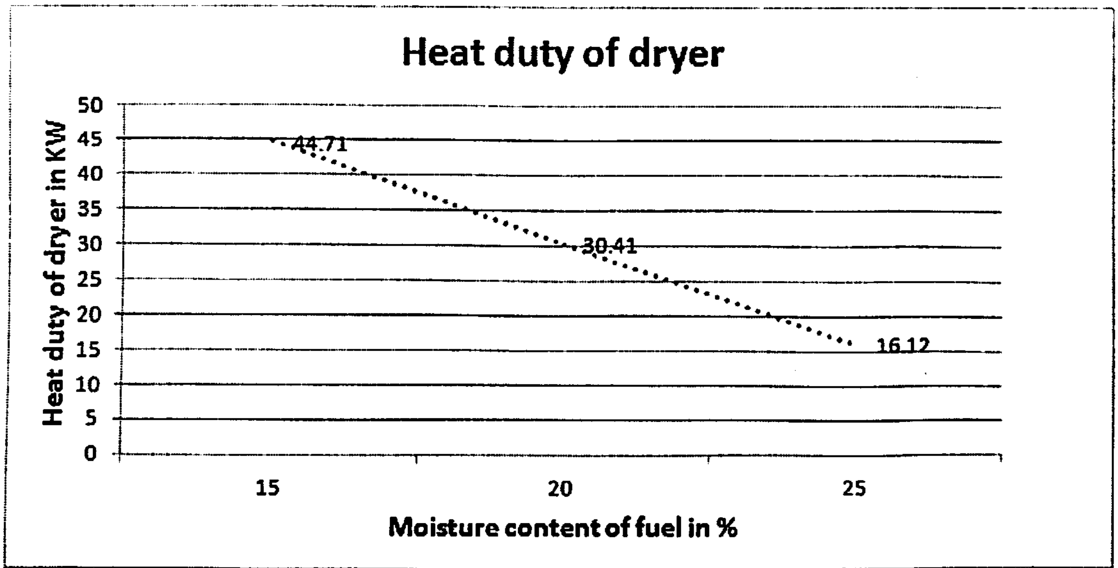

Figure 5.7: Influence of heat duty in dryer

5.5 Solid Oxide fuel cell system

In solid oxide fuel cell, energy is generated by solid oxide fuel cell. Then the combusted gas in the solid oxide fuel is expanded in gas turbine. Gas turbine with fuel cell Fuel cell produces higher efficiency than the steam turbine which produces energy of about 125 KW. But Solid oxide fuel cell produces an power of around 83 KW with expansion in gas turbine makes the best option for other models of syn gas utilisation. Cooling air requirement is reduced in this system.

Stream name	SYNGAS	COMPGAS	MIXEDGAS	2PREFORM	PRE2ANOD	ANOD2SPL	CAT2CC	CCEX	AIR	CAT2ANOD	CCEX	2GT	HX2HX	HX2AIRH	2PREFORM	AIRH2PRO	H2OGASIF	EXHAUST
To	GASCOMP	MIXER	PREFORM	PREFORM	ANODE	SPLITTER	CC	GASMIX	AIRCOMP	ANODE	GASMIX	GT	HX	AIRHEAT	PREFORM	PROCESS	PROCESS	
From		GASCOMP	MIXER	HX	PREFORM	ANODE	CATHODE	CC		CATHODE	CC	GASMIX	HX2	HX	HX	AIRHEAT		PROCESS
Phase	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	LIQUID	VAPOR
Substream: MIXED																		
Mole Flow kmol/hr																		
H2	1.15	1.15	1.15	0.00	3.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO	1.02	1.02	1.62	0.00	2.38	2.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2	1.20	1.20	1.59	0.00	1.59	1.59	0.00	3.29	0.00	0.00	3.29	3.29	3.29	3.29	0.00	3.29	0.00	3.29
CH4	1.08	1.08	1.18	0.00	0.42	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
H2O	1.34	1.34	3.42	2.22	4.88	8.31	0.00	6.86	0.00	0.00	6.86	6.86	6.86	6.86	2.22	6.86	4.44	6.86
N2	0.00	0.00	2.17	0.00	2.17	8.67	6.50	13.01	15.06	6.50	13.01	15.06	15.06	15.06	0.00	15.06	0.00	15.06
O2	0.00	0.00	0.00	0.00	0.00	0.01	1.73	0.22	4.00	1.73	0.22	0.77	0.77	0.77	0.00	0.77	0.00	0.77
Total Flow kmol/hr	5.78	5.78	11.13	2.22	14.88	21.39	8.23	23.39	19.06	8.23	23.39	25.99	25.99	25.99	2.22	25.99	4.44	25.99
Total Flow kg/hr	125.00	125.00	259.17	40.00	299.17	536.67	237.50	640.00	550.00	237.50	640.00	715.00	715.00	715.00	40.00	715.00	80.00	715.00
Total Flow cum/hr	64.73	10.11	204.44	28.55	184.05	417.32	24.28	145.05	96.10	24.28	145.05	151.75	982.09	828.20	28.55	781.64	0.08	482.36
Temperature C	400.00	778.07	831.36	500.00	470.76	900.00	613.83	1591.78	30.00	613.83	1591.78	1482.78	635.98	493.52	500.00	450.42	30.00	173.38
Pressure bar	5.00	50.00	5.00	5.00	5.00	5.00	25.00	25.00	5.00	25.00	25.00	25.00	2.00	2.00	5.00	2.00	5.00	2.00
Energy balance																		
Energy in H2	15464.56	12948.30	14810.73	0.00	36813.25	0.02	0.00	63.12	0.00	0.00	63.12	57.98	29.85	21.26	0.00	13.75	0.00	2.70
Energy in CO	14922.35	12447.68	14278.33	0.00	26399.69	59965.10	0.00	130.55	0.00	0.00	130.55	120.67	61.75	43.40	0.00	27.70	0.00	5.35
Energy in CO2	28417.03	23661.10	27179.20	0.00	26788.98	63518.19	0.00	265097.18	0.00	0.00	265097.18	243078.28	129979.31	89792.94	0.00	55827.28	0.00	10049.03
Energy in CH4	32597.18	26742.52	31060.25	0.00	7689.55	20264.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Energy in H2O	0.00	0.00	58395.24	120129.60	63692.61	252934.18	0.00	430050.26	0.00	0.00	430050.26	393625.36	192458.35	133574.34	120129.60	84367.08	270564.00	16050.05
Energy in N2	0.00	0.00	29872.76	0.00	23812.09	215774.74	115893.38	633278.60	2191.42	115893.38	633278.60	677453.80	346725.01	243917.51	0.00	155948.58	0.00	30240.50
Energy in O2	0.00	0.00	50.51	0.00	39.80	362.69	32521.94	11338.04	587.13	32521.94	11338.04	36464.86	18752.55	13173.74	0.00	8377.62	0.00	1593.92
Total Energy in KJ/hr	91401.11	75799.61	175647.01	120129.60	185235.97	612819.74	148415.32	1339957.74	2778.55	148415.32	1339957.74	1350800.94	688006.83	480523.19	120129.60	304562.01	270564.00	57941.54
Total Energy in KW	25.39	21.06	48.79	33.37	51.45	170.23	41.23	372.21	0.77	41.23	372.21	375.22	191.11	133.48	33.37	84.60	75.16	16.09

Figure 5.8: Stream data of SOFC

The energy conversion from DC to AC plays has a efficiency is around 98%, hence more power is available from the system.

The energy generated by the gas turbine is around 168 KW and the energy produced through the solid oxide fuel cell is around 83 KW. Majority of the flue gas heat is utilized in the process of pre forming water and in process of heating air for anode. The increase in the temperature of about 300° C producing the power in the gas turbine of about 150 KW and in the solid oxide fuel cell of about 50 KW. Hence more amount of heat is added in the system for producing a better conversion in anode.

Table 5.8: Solid oxide fuel cell model

Input Energy		
Component	**KW**	**%**
Heat input through fuel	439.04	86.44
Sensible heat in the fuel	25.39	5.00
Heat input through air	1.12	0.22
Sensible heat through air	29.51	5.81
Heat input through flue gas	12.65	2.49
Heat input to gasification air	0.22	0.042
Total Input Energy	507.93	100
Output Energy		
Component	**KW**	**%**
Work done by the gas turbine	168.76	33.23
Work done by the SOFC	83.00	16.34
Work needed by the compressors	43.67	8.60
Heat taken away by exhaust flue gases	16.09	3.17
Heat taken away by process steam	41.87	8.24
Heat duty of the heat exchangers	78.26	15.41
Heat duty of the air heater	11.09	2.18
Heat duty of the water heater	57.67	11.35
Losses	7.52	1.48
Total output energy	507.93	100.00

5.6 Power from Fuel cell

Power produced in fuel cell is depends on the operating temperatures of fuel cell. In this system the operational voltage depends on various factors. Fuel cell molar concentration is actively take part in the cell reaction with the increase in pressures and temperatures of the cell. Fuel cell voltage has been stated as the Nernst voltage which has been accounted with different losses like ohmic losses, Activation losses and Concentration losses of the fuel cell.

Voltage generated in fuel cell will change considerably with a change in utilisation factor of the fuel cell. The fuel cell systems shows an decrease in the voltage of the systems when the utilisation factor of the system get decreased. This shows the characteristics of fuel cell according to the .

Table 5.9: Values of voltage calculation

Parameters	Values	units
Nernst Voltage	0.9117401	V
Total ohmic losses	0.037999	V
Total concentration losses	-0.039951	V
Total activation losses	0.182	V
Net voltage in the system	0.7316921	V
Current density	178	mA/sq.cm
Power in the system	83.34	KW

5.6.1 Influence of Temperature increase in Pre - forming and Air heating

With the increase in pre - forming temperatures conversion at the pre - former get increased. Energy produced through gas turbine get increased with an reduction of exhaust flue gas temperatures.

Increase of air heating temperatures doesn't affect energy produced through gas turbine to

Table 5.10: Add caption

Temperature C	400	450	500
Power in gas turbine	162.35	165.32	168.77
Pressure at Anode in bar	5	5	5
Composition of gases at Anode			
H2	4.76E-07	6.11E-07	1.05E-06
CO	2.35	2.36	2.38
CO2	1.59	1.59	1.59
CH4	0.45	0.44	0.42
H2O	8.25	8.28	8.31
N2	8.67	8.67	8.67
O2	0.07	0.04	0.01
Total Flow kmol/hr	21.38	21.38	21.39
Total Flow kg/hr	536.67	536.67	536.67
Exhaust flue gas temperatures	225.34	200.35	181.72

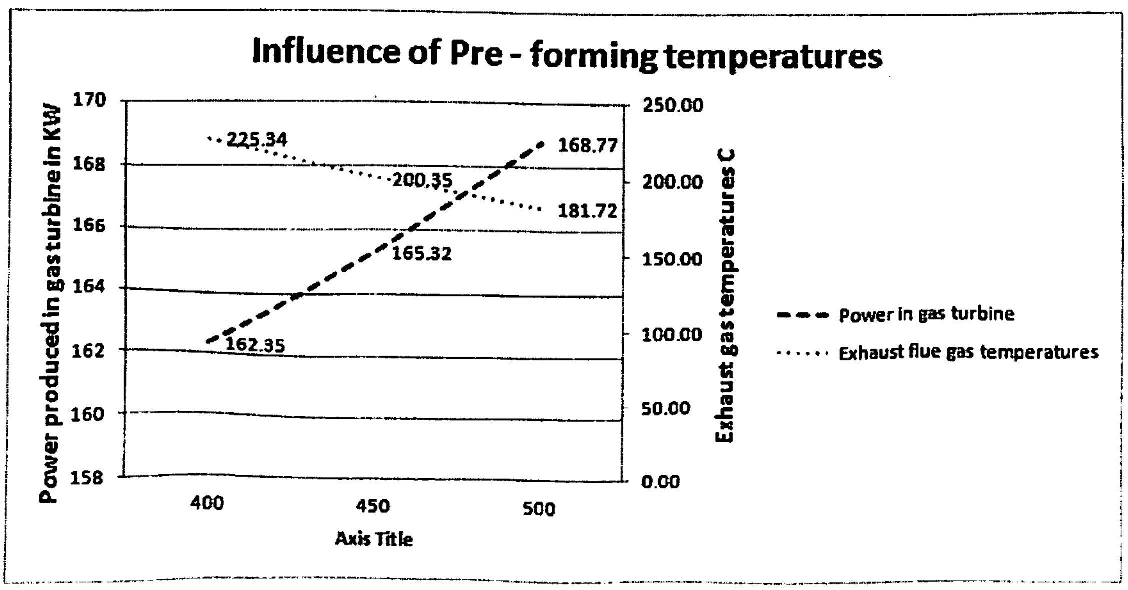

Figure 5.9: Influence of preforming

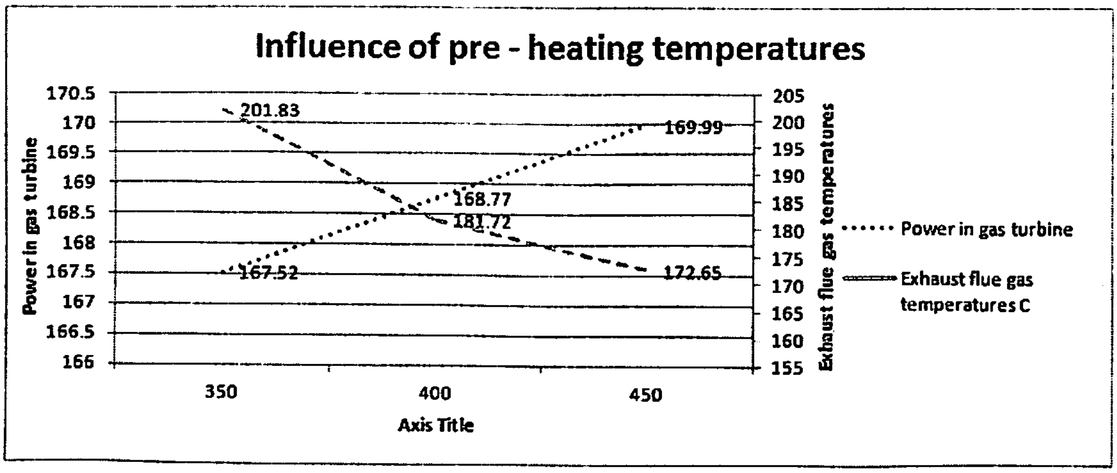

Figure 5.10: Influence of air preheating

a larger extent. Exhaust flue gas temperatures also get decreased. At the exit of anode the composition of CO get increased at little fraction.

Table 5.11: Effect of air heating temperatures

Temperatures C	350	400	450
Power in gas turbine	167.52	168.77	169.99
Composition of gas in the after anode			
H2	1.02E-06	1.05E-06	1.02E-06
CO	2.37	2.38	2.38
CO2	1.59	1.59	1.59
CH4	0.41	0.42	0.42
H2O	8.31	8.31	8.31
N2	8.67	8.67	8.67
O2	0.014519	0.01	0.01
Total Flow kmol/hr	21.39	21.39	21.39
Total Flow kg/hr	536.66	536.67	536.67
Exhaust flue gas temperatures C	201.83	181.72	172.65

5.6.2 Influence of Anode Temperatures

Energy produced through fuel cell will increase with the increase of temperature. This is due to increase in the voltage generated on the system. Power produced by gas turbine get increased because of products to the combustion chamber inlet to the system at higher temperatures.

Table 5.12: Influence of Anode temperatures

Temperatures	800	850	900
Power in gas turbine	164.86	166.19	168.77
Power produce in SOFC	76	79	83
Composition of gas after anode			
H2	2.94E-08	1.39E-07	1.05E-06
CO	2.29	2.33	2.38
CO2	1.59	1.59	1.59
CH4	0.50	0.46	0.42
H2O	8.14	8.22	8.31
N2	8.67	8.67	8.67
O2	0.14	0.078	0.01
Total Flow kmol/hr	21.34	21.37	21.39
Total Flow kg/hr	536.66	536.66	536.66

5.6.3 Influence of heat recovery

Since more heat is trapped by the pre - forming steam and with the air heating, heat available for the gasification column and for combustion column get reduced. This pushes the factor of not utilising steam turbine for energy generation.

5.7 Gas Engine system

Gas engine system is operating with respect to the pressure ratios maintained on gas engine. Energy is released from gas engine at the end of compression stroke. Energy is supplied to the other strokes with the energy generated at the end of compression stroke. Useful energy produced by gas engine is around 161.77 KW which is relatively nearer to energy generated by gas turbine. Compartatively heat loss by the exhaust flue gas is comparatively less than other utilisation models.

A maximum pressure ratio of 22 is allowed in gas engine, because of the constraint in area of

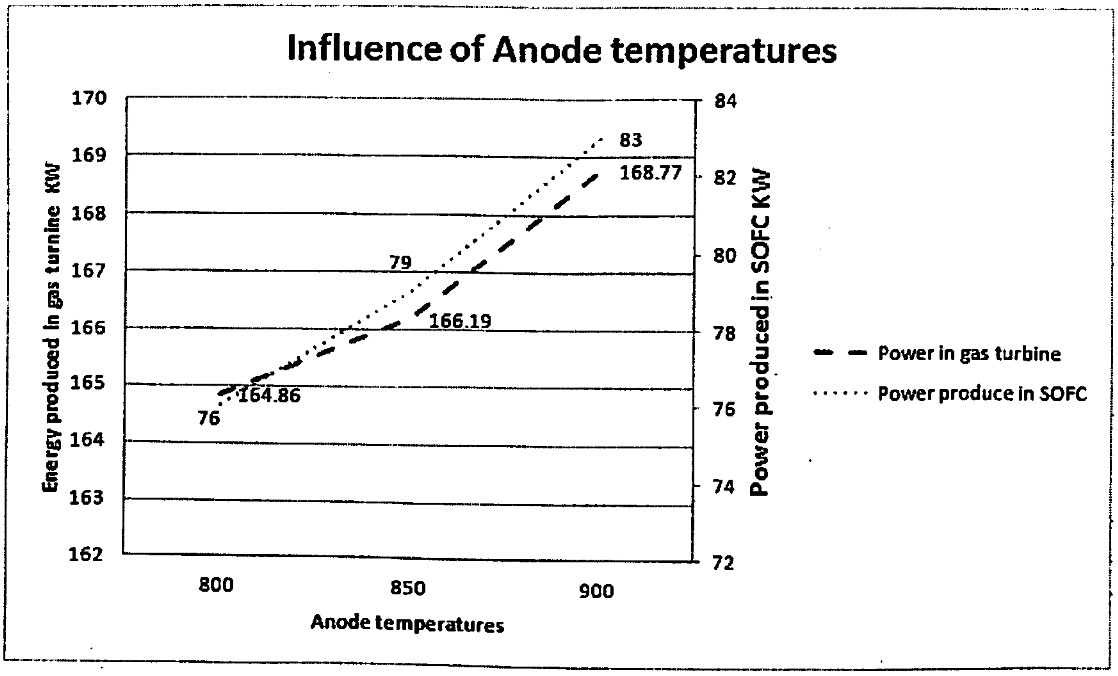

Figure 5.11: Influence of anode temperatures

Table 5.13: Energy balance of Gas Engine

Input Energy

Component	KW	%
Heat input through fuel	373.31	79.14
Sensible heat in the fuel	25.39	5.38
Heat input through air	0.69	0.15
Sensible heat through air	72.30	15.33
Total Input Energy	471.68	100.00

Output Energy

Component	KW	%
Work done by the gas engine	161.77	34.30
Work on expansion and coolers	32.14	6.81
Work needed by the compression	71.43	15.14
Heat taken away by exhaust flue gases	16.09	3.41
Heat taken away by process steam	46.72	9.91
Heat duty of the heat exchangers	61.53	13.04
Losses	82.00	17.38
Total output energy	471.68	100.00

gas engine chambers. This makes the gas engine to produce higher energy like gas turbine with efficiency nearer to gas turbine.

At elevated temperatures gas engine produces uniform combustion. Hence at a operating temperatures of 700 - 1000° produce a incomplete combustion in gas engine.

Stream name	TOBURN	HOTAIR	FLUEGAS	HRSG2SH	STEAM	SH2HRSG	HRSG2PRE	AIR	HOTAIR	AIRH2PRE	2PREHEAT	PRE2HRSG	EXHAUST
To	BURN	BURN	SH	SH	ST	HRSG	AIRHEATE	AIRHEATE	BURN	PREHEAT	PREHEAT	HRSG	
From	DECOMP	AIRHEATE	BURN	HRSG	SH	SH	HRSG		AIRHEATE	AIRHEATE	PUMP	PREHEAT	PREHEAT
Phase	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	LIQUID	LIQUID	MIXED
Substream: MIXED													
Mole Flow kmol/hr													
H2O	1.11	0.00	5.05	19.43	19.43	5.05	5.05	0.00	0.00	5.05	19.43	19.43	5.05
N2	0.36	18.48	18.84	0.00	0.00	18.84	18.84	18.48	18.48	18.84	0.00	0.00	18.84
O2	0.31	4.91	0.00	0.00	0.00	0.00	0.00	4.91	4.91	0.00	0.00	0.00	0.00
H2	4.96	0.00	1.03	0.00	0.00	1.03	1.03	0.00	0.00	1.03	0.00	0.00	1.03
C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO	0.00	0.00	1.48	0.00	0.00	1.48	1.48	0.00	0.00	1.48	0.00	0.00	1.48
CO2	0.00	0.00	2.52	0.00	0.00	2.52	2.52	0.00	0.00	2.52	0.00	0.00	2.52
Total Flow kmol/hr	6.74	23.40	28.91	19.43	19.43	28.91	28.91	23.40	23.40	28.91	19.43	19.43	28.91
Total Flow kg/hr	50.00	675.00	773.00	350.00	350.00	773.00	773.00	675.00	675.00	773.00	350.00	350.00	773.00
Temperature K	673.15	513.15	1573.15	673.15	773.15	1325.63	550.23	303.15	513.15	392.34	304.44	373.15	348.63
Pressure atm	3	3	3	49	49	3	3	3	3	3	49	49	3

Energy Balance

Energy in H2	42608.2	0.0	33945.2	0.0	0.0	31404.5	9946.5	0.0	0.0	5388.6	0.0	0.0	2628.1
Energy in CO	0.0	0.0	50117.1	0.0	0.0	46576.1	14785.2	0.0	0.0	7958.5	0.0	0.0	3863.1
Energy in CO2	0.0	0.0	143821.5	0.0	0.0	132502.2	38124.4	0.0	0.0	19767.7	0.0	0.0	9329.9
Energy in H2O	11571.4	0.0	221448.0	836670.0	956826.0	203448.9	59665.2	0.0	0.0	31743.9	37584.9	87570.0	15317.9
Energy in N2	3151.9	116796.7	662239.6	0.0	0.0	611527.4	188226.8	2689.5	116796.7	101213.1	0.0	0.0	49146.2
Energy in O2	2918.9	32092.0	0.0	0.0	0.0	0.0	0.0	720.6	32092.0	0.0	0.0	0.0	0.0
Total Energy in KJ/hr	60250.4	148888.6	1111571.4	836670.0	956826.0	1025459.1	310748.1	3410.0	148888.6	166071.9	37584.9	87570.0	80285.2
Total Energy in KW	16.7	41.4	308.8	232.4	265.8	284.8	86.3	0.9	41.4	46.1	10.4	24.3	22.3

Figure 5.12: Gas Engine stream data

5.8 Combustion Model

Combustion of biomass feedstock on furnace is used in the process of energy conversion at Industries. The results of combustion is compared with other utilisation systems.

Biomass feedstock has higher moisture content in it. On combusting the feedstock in furnace moisture is first released from fuel. This retards the process of combustion and results in incomplete combustion. Power of about 125 KW is generated from the system which is much lesser than other utilisation system. Efficiency of combustion is about 70 % which is majorly reduced by moisture content on fuel. Temperatures of combustion is restricted by material properties of furnace. Hence the incomplete combustion results in furnace which results in reduction of this model.

Stream name	TOBURN	HOTAIR	FLUEGAS	HRSG2SH	STEAM	SH2HRSG	HRSG2PRE	AIR	HOTAIR	AIRH2PRE	2PREHEAT	PRE2HRSG	EXHAUST
To	BURN	BURN	SH	SH	ST	HRSG	AIRHEATE	AIRHEATE	BURN	PREHEAT	PREHEAT	HRSG	
From	DECOMP	AIRHEATE	BURN	HRSG	SH	SH	HRSG		AIRHEATE	AIRHEATE	PUMP	PREHEAT	PREHEAT
Phase	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	VAPOR	LIQUID	LIQUID	MIXED
Substream: MIXED													
Mole Flow kmol/hr													
H2O	1.11	0.00	5.05	19.43	19.43	5.05	5.05	0.00	0.00	5.05	19.43	19.43	5.05
N2	0.36	18.48	18.84	0.00	0.00	18.84	18.84	18.48	18.48	18.84	0.00	0.00	18.84
O2	0.31	4.91	0.00	0.00	0.00	0.00	0.00	4.91	4.91	0.00	0.00	0.00	0.00
H2	4.96	0.00	1.03	0.00	0.00	1.03	1.03	0.00	0.00	1.03	0.00	0.00	1.03
C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO	0.00	0.00	1.48	0.00	0.00	1.48	1.48	0.00	0.00	1.48	0.00	0.00	1.48
CO2	0.00	0.00	2.52	0.00	0.00	2.52	2.52	0.00	0.00	2.52	0.00	0.00	2.52
Total Flow kmol/hr	6.74	23.40	28.91	19.43	19.43	28.91	28.91	23.40	23.40	28.91	19.43	19.43	28.91
Total Flow kg/hr	50.00	675.00	773.00	350.00	350.00	773.00	773.00	675.00	675.00	773.00	350.00	350.00	773.00
Temperature K	673.15	513.15	1573.15	673.15	773.15	1325.63	550.23	303.15	513.15	392.34	304.44	373.15	348.63
Pressure atm	3	3	3	49	49	3	3	3	3	3	49	49	3

Energy Balance

Energy in H2	42608.2	0.0	33945.2	0.0	0.0	31404.5	9946.5	0.0	0.0	5388.6	0.0	0.0	2628.1
Energy in CO	0.0	0.0	50117.1	0.0	0.0	46576.1	14785.2	0.0	0.0	7958.5	0.0	0.0	3863.1
Energy in CO2	0.0	0.0	143821.5	0.0	0.0	132502.2	38124.4	0.0	0.0	19767.7	0.0	0.0	9329.9
Energy in H2O	11571.4	0.0	221448.0	836670.0	956826.0	203448.9	59665.2	0.0	0.0	31743.9	37584.9	87570.0	15317.9
Energy in N2	3151.9	116796.7	662239.6	0.0	0.0	611527.4	188226.8	2689.5	116796.7	101213.1	0.0	0.0	49146.2
Energy in O2	2918.9	32092.0	0.0	0.0	0.0	0.0	0.0	720.6	32092.0	0.0	0.0	0.0	0.0
Total Energy in KJ/hr	60250.4	148888.6	1111571.4	836670.0	956826.0	1025459.1	310748.1	3410.0	148888.6	166071.9	37584.9	87570.0	80285.2
Total Energy in KW	16.7	41.4	308.8	232.4	265.8	284.8	86.3	0.9	41.4	46.1	10.4	24.3	22.3

Figure 5.13: Stream data for combustion

5.8.1 Influence of Air temperature in the system

Inlet temperature of the air produces an higher efficient combustion with higher conversion rate of feedstock. Increase in temperature of combustion produce complete combustion and thus emissions to atmosphere get reduced.

With increase in the temperature of air complete combustion and increase in the power has been noticed in the model. But this will increase the heat duty of the air heating system.

Table 5.14: Combustion model

Energy Input		
Components	KW	%
Energy through fuel	409.16	93.76
Energy through water	10.48	2.40
S ensible heat through air	16.74	3.835298
Total energy input to the system	436.37	100
Energy output		
Components	KW	%
Energy obtained through turbine	135.52	28.76
Heat duty in Preheater	23.89	5.47
Heat duty in HRSG	190.01	43.54
Heat duty in SH	11.25	2.58
Heat carried away by flue gas	22.30	5.11
Heat duty of Air heater	40.26	9.23
Work given to pump	0.43	0.10
Heat carried away by exhaust condensate	10.47833	2.40
Un accounted losses	12.24	2.80
Total output	436.37	100

5.9 Comparison

Various systems has been compared and assessed here. At present gas engine models are been widely used now in various cycles as the systems with practical due to its feasibility and easy operation, easy starting and easy adaptable to different conditions. Whereas the gas turbine

Parameters	CHP	CCGT	CCGT with dryer	SOFC	Gas Engine	Combustion
Total input	538.82	538.82	538.82	507.93	471.68	436.37
Output on GT	200.52	183.93	182.96	168.76	-	
Output on ST	-	25.32	20.32	-	-	135.52
Fuel cell energy	-	-	-	83	-	-
Electrical Efficiency	37.21	38.83	37.69	49.57	34.30	28.76
Compressor work	45.34	43.67	42.53	43.67	-	-
Flue gas heat	105.94	36.62	13.34	16.52	16.09	22.30

Table 5.15: Comparison of different utlisation system

models has been costly and it comparatively higher time for startup with very clean gases is needed for the operation over its life cycle.

As far as the solid oxide fuel models are concerned the operational parameters are very similar to the gas turbine models, whereas the cost has been higher than other models due to fact that the fuel cell electrolytes of higher cost.

Combustion need to be replaced by the gasification system of models to produce an higher efficiency of utilisation biomass feedstock and also creating lesser harm to environment.

5.9.1 Between Previous works

The comparison between the previous works and to this is essential, which makes this simulations as an benchmark with previously evaluated data's and also the systems operational parameters can be characterized. As far as the previous calculations made on the gas turbine is concerned whole system is made on theoretical manner, hence the comparison of calculation relates between theoretical and simulated calculations through Aspen plus.

Because of the higher inlet temperature on to the gas turbine of gas turbine with lesser pressure at exit, gas turbine extracts more energy than the previous system. This makes the system more efficient than the previous system. But the gas turbine exhaust temperature is more hence more energy can be extracted by the waste heat recovery system. Since this system utilise waste heat

Table 5.16: Comparison between present Vs previous system

Factors	CCGT with dryer	GE	Combustion
Present Work	182.96	161.47	135.52
Past Work	180.05	190.53	142.43
Relative difference	-2.91	-29.06	-17.11

for the feed stock drying which makes the system more efficient than other systems.

5.9.2 Solid Oxide Fuel Cell Comparison

Solid oxide fuel cell has been compared with one of the literature for justification of calculation. In the system we are comparing, they use natural gas for power generation through fuel cell. Due to this higher flow rate of methane, more amount of current is generated in the fuel cell makes the energy generation more suitable in the system. Comparatively higher losses has been considered in the system for DC to AC conversion. As in literature [4], the DC to AC conversion efficiency is 92 %, but in present, DC to AC conversion efficiency is 98%.
Because of the higher current density in the literature model[4], it produces more energy through

Table 5.17: SOFC model compariosn

Factors	Literature[4]	Model
Voltage	0.661	0.74
Current density mA/cm$\hat{2}$	200.62	178
Power on fuel cell	87	83
Overall efficiency of the system	49.8	49.57

fuel cell which increase energy generation through fuel cell. Since the current density is more than present model, energy generation through fuel cell is reduced in aspen plus simulated model.

Chapter 6

Conclusion

By considering various models for syn gas utilisation system with its application of recovering heat from flue gas, each system has its own advantage. Currently most of the biomass energy conversion systems employ combustion model of energy conversion, which is operating under a very low efficiency . Losses in combustion is higher than the other process due to the higher moisture content in the biomass feedstock.

Steam and condensate exit from utilisation system accounts for higher losses in all systems. Hence waste heat recovery system need to optimize for higher efficiency.

Solid oxide produces higher efficiency than other systems. It produces higher efficiency because of higher energy produced by fuel cell and gas turbine by using bottoming cycle. But in gas turbine and gas engine models the energy produced in the system is majorly relates with the compression ratio. In gas turbine model compression ratio increases temperature of combustion chamber. Hence amount of air inlet onto the system get increased. Whereas in gas engine system the change in compression ratio decrease the incomplete combustion in system.

6.1 Utilisation through gas engine

Gas engine model of syn gas utilisation has a formidable advantage of less cost of equipment with easy build up cost and also has the advantage of compactness. System efficiency is mainly based on the process of combustion. Uniform and full combustion in the system is limited because of the operational temperature inside the engine. With the increase in capacity of gas engine, a bigger gas engine is needed. Also the factor of unit multiplier for the size to capacity is much higher than other systems. Hence the gas engine models has been majorly used in the small scale utilisation systems on which make this utilisation systems much costlier than others at large scale.

6.2 Utilisation through gas turbine system

Efficiency of gas turbine system is much higher than gas engine and combustion modes of energy generation models. Main factors affecting the gas turbine utilisation systems are usage factors and cost of gas turbine. As far as the gas turbine system is considered major cost covers up for the cost of the combustion and utilisation module. Similarly for gas turbine system, more clean gas is needed for combustion in gas turbine. This makes the cost higher for incorporating gas cleaning systems on the utilisation side. With the use of fuel cell more clean gas is produced and also the cost of system get higher.
These factor makes the system much complicated and also costlier at smaller scale. But at larger cycle factor of size to capacity is lesser and hence it can be utilised in larger scale easily.

But as far as the combustion mode is compared both gas engine model of utilisation and gas turbine model of utilisation can be used for operations which will have higher efficiency than combustion.

6.3 Scope of Future work

Heat loss optimization study can studied for reducing the losses in the system. With the change in the operational parameters for different kind of feedstock can be analysed. This extends to find out a best operational model of gasification for the energy generation process.
The drying concept can be utilised in the system which will produce an optimization of efficiency and also an higher thermodynamics efficiency of the utilisation.

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