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THERMODYNAMIC ANALYSIS OF AN INTEGRATED GASIFICATION COMBINED CYCLE POWER PLANT

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Abstract: Integrated gasification combined cycle (IGCC) power plants have become more attractive after the emission regulations of the thermal power plants. IGCC power plants enable to control emissions which cause global warming. Low grade lignites, biomass and wastes can be utilized by this technology. This study deals with the thermodynamic analysis of an IGCC power plant. Energy and exergy analysis are carried out for a Texaco type gasifier, one stage, oxygen blown and slurry fed. Cold gas cleaning (fuel gas treatment) system is considered for the simulations, performed in THERMOFLEX software. A parametric study is also carried out to show the effects of the O_2 purity, fuel supply temperature, gasifier temperature and H_2O content of the slurry to the IGCC performance. Net power and net electric efficiency are calculated to be 389.669 MW and 43.53% respectively. Exergy efficiency of the simulated IGCC is found to be 40.36% and the highest exergy destruction is observed in gasifier and the combustion chamber of the gas turbine.
Keywords: Integrated Gasification Combined Cycle, energy analysis, exergy analysis

BİR GAZLAŞTIRICILI KOMBİNE ÇEVRİM SANTRALİNİN TERMODİNAMİK ANALİZİ

Özet: Termik santrallerde emisyon salınımı düzenlemelerinden sonra gazlaştırıcılı kombine çevrim santrallerinin (GKÇS) daha popüler olmuşlardır. GKÇS'leri küresel ısınmaya neden olan emisyonların kontrolüne imkan vermektedir. Düşük kaliteli linyitler, biyokütle ve atıklardan bu teknoloji ile faydalanılabilir. Bu çalışmada bir GKÇS'nin termodinamik analizi yapılmıştır. Texaco tipi tek kademeli, oksijen ortamında ve kömürün bulamaç halinde beslendiği gazlaştırıcıda enerji ve ekserji analizleri gerçekleştirilmiştir. THERMOFLEX'te gerçekleştirilen simülasyonlarda soğuk gaz temizleme (gaz yakıt işleme) sistemi düşünülmüştür. Bununla birlikte, O_2 saflığının, yakıt besleme sıcaklığının, gazlaştırıcı sıcaklığının ve bulamaç su miktarının GKÇS performansına olan etkileri bir parametrik çalışma ile incelenmiştir. Net güç ve net verim sırasıyla 389.669 MW ve % 43.53 olarak hesaplanmıştır. Simülasyonu yapılan GKÇS'nde ekserji verimi % 40.36 olarak bulunmuş ve en fazla ekserji kaybı gazlaştırıcı ve gaz türbini yanma odasında bulunmuştur.
Anahtar kelimeler: Gazlaştırıcılı Kombine Çevrim Santrali, enerji analizi, ekserji analizi

NOMENCLATURE

e	Specific exergy	[kJ/kg]
E	Time rate of exergy	[MW]
ε	Exergy efficiency	[%]
h	Specific enthalpy	[kJ/kg]
m	Time rate of mass	[kg/s]
P	Pressure	[kPa]
Q	Time rate of heat loss	[MW]
s	Specific entropy	[kJ/kg]
T	Temperature	[°C]
W	Time rate of work	[MW]

Subscripts

CV	Control volume
D	Destruction
i	Inlet
o	Outlet
CH	Chemical
F	Fuel
KN	Kinetic
P	Product
PH	Physical
PT	Potential
ST	Steam turbine
GT	Gas turbine
com	Compressor
0	Dead state condition

INTRODUCTION

Coal is the most abundant and vital energy source for energy conversion systems. Primary energy needs, electricity generation, steel production and other industrial sectors widely use coal as an energy source due to its lower price and higher abundance. As a result of coal combustion CO_2, SO_2, NO_x, flyash, dust and other emissions are released to the atmosphere. According to the 2007 CO_2 emissions database, Turkey generates 27% of total electricity production from coal and it shows a growing trend due to increasing natural gas prices. In 2007, 115.4 million tonnes of CO_2 were released to the atmosphere due to coal combustion in Turkey. In Turkey, CO_2 emission during electricity and heat generation process from coal is given to be 1037 grCO_2/kWh. CO_2 emissions in the atmosphere, which causes greenhouse gas effect, contribute to global warming.

Clean coal technologies have an increasing trend and have become important in utilizing coal without harmful effects and efficiently. After combustion, electrostatic precipitators and fabric filters can remove over 99% of the fly ash from the flue gases. Flue gas desulphurization reduces the sulphur dioxide content of the flue gas. Fluidized bed technology allows reducing the SO_2 and NO_x emissions due to its combustion characteristics. Low NO_x burners and selective catalytic reduction techniques reduces NO_x emissions up to 90% in flue gas. The most promising technology for effective and harmless utilization of coal is the gasification. Integrated Gasification Combined Cycle (IGCC) uses coal to produce hydrogen and CO in gasifier and combustion takes place in the combustion chamber of the gas turbine. The integrated gasification combined cycles have both advantages and disadvantages when compared to the other alternatives. The net efficiency of an IGCC is more than that of a conventional thermal power plant and less than that of a natural gas fired combined cycle. It depends on the gasification and the gas cleaning technology. Gasifier and oxidant type, coal feeding system and gas cleaning system selections are directly affects the performance of overall power plant. Jiang et al. [1] performed an optimization study on the steam side of an IGCC and the effects of optimization on the net efficiency are given. According to the results of the study, increasing gas turbine outlet temperature increases the net efficiency. In the case of 10ºC pinch point temperature for the evaporator of heat recovery steam generator (HRSG) the efficiency is the highest. The results also demonstrate the effects of GT outlet temperature to the bottoming cycle efficiency and at 600ºC outlet temperature the efficiency of the bottoming cycle with a single and dual pressure HRSG are 38 and 40% respectively. At this temperature the ratio of steam turbine output to the gas turbine output is 63% for a dual pressure HRSG. Fortes et al. [2] compared eight different type of feedstock in an IGCC power plant in ASPEN software with real plant data sets. In the study, co-gasification of coal with petcoke and olive pornace was performed. According to results of simulation coal shows the best efficiency when compared to other alternatives and the efficiency of the overall power plant was found to be 52%. Huang et al. [3] simulated two alternatives of an IGCC with six cases on ECLIPSE software. The efficiency penalty for CO_2 capture is approximately 8 to 10% of total efficiency. The cost of CO_2 capture was found to be 22US$/ton$CO_2$ and economic analysis of CO_2 transportation was done. Zheng and Furinsky [4] compared gasifier types for three different fuel stocks by using ASPEN PLUS software. According to the results, heating values of clean syngas, compositions of syngas and power plant parameters are compared and indicated that lignite is the best fuel feedstock when compared to subbituminous and bituminous coals. The variation of thermal efficiency is found to be less than 0.5% with respect to coal type and KRW type of gasifiers affected from type of fuel more than others. Garcia et al. [5] performed a case study by using ASPEN PLUS software and compared CO_2 capture costs of simulated cases. According to the results CO_2 capture cost varies 28 to 30 US$/tonne$CO_2$ depending on the CO_2 capture efficiency. Duan et al. [6] suggested a novel cycle with semi closed Brayton cycle and steam injected H_2/O_2 cycle to capture CO_2 effectively. Rezenbrink et al. [7] reported a 450 MW IGCC/CCS project and made an economic analysis for CO_2 avoidance and storage costs. The expected efficiency and specific CO_2 emissions of the IGCC are 34% (LHV) and 107 g/kWh$_{net}$. Jimenez et al. [8] performed a simulation by using ASPEN PLUS software. Texaco gasifier is selected as base case and the efficiency of the cycle is found to be 45% (LHV). The results show that CO_2 and SO_x emissions are reduced to 698 kg/MWh and 0.15 kg/MWh respectively. Chen and Rubin [9] analyzed CO_2 capture costs for different type of coals in an IGCC. ASPEN PLUS is used for the simulations and GE type Quench gasifier is selected. CO_2 capture (CCS) is obtained by Selexol process. According to results of their simulations CCS reduces the power plant efficiency by 10-16% and first investment cost of the power plant increases by 23-27%. The minimum cost of electricity, generated in an IGCC, is found to be 80.4 $/MWh with 2008 prices which ion transport membrane and H type gas turbine are used in the simulations. Decamps et al. [10], showed the effects of CO_2 capture on IGCC performance and the results show that IGCC efficiency decreases with CCS by 8-12% when compared to non-CCS IGCC power plant. Mondol et al. [11], simulated a novel IGCC-CCS power plant in ECLIPSE and they compared the results with IGCC power plants with and without CCS. Absorption Enhanced Reforming process is used for CO_2 capturing and hot gas cleaning system is offered. The results show that the proposed CO_2 capture plants efficiencies were 18.5–21% higher than the conventional IGCC CO_2 capture plant. The specific investment cost of proposed power plants were between 1207 and 1493 €/kW$_e$.

This study focuses on the energy and exergy analysis of IGCC power plant and THERMOFLEX simulation software is used for the parametric simulations. A Texaco type gasifier, one stage, slurry fed, oxygen blown and cold gas cleaning system are planned for the simulations. The effects of the O_2 purity, fuel supply temperature, gasifier temperature and H_2O content of the slurry to the IGCC performance are investigated. GE 9FA type of gas turbine is selected for the simulations and the waste heat is utilized in a dual pressure HRSG.

DESCRIPTION OF THE POWER PLANT

The simulated power plant consists of a gasifier, an air separation unit (ASU), a gas cleaning system (GCS), a gas turbine (GT), a dual pressure heat recovery steam generator (HRSG), steam turbines and other relevant components. Air is compressed and cooled before being delivered to the cryogenic separation unit. Carbon dioxide, argon, water and any unused nitrogen are all discharged to the atmosphere. Simulated gasifier is a one stage, slurry fed, oxygen blown type (Texaco) and steam production is obtained by convective or radiant syngas coolers of gasifier. Cold gas cleaning system is considered for eliminating the impurities in raw syngas. Syngas scrubbers are used to remove particles and chlorine from the syngas at the outlet of the gasifier and syngas coolers reduces the temperature of the syngas to the cleaning process temperature. Incoming syngas enters the scrubber where it comes into direct contact with water. The water traps the particles and collects in the pool at the bottom of the vessel. Particle-free syngas, which has been moisturized in the process, leaves the scrubbers through demisters that collect water droplets to prevent carry-over. After scrubber syngas enters COS hydrolysis, which generates H_2S and CO_2. H_2S can be removed from the syngas in a downstream acid gas removal plant. COS hydrolysis and acid gas removal are used together to reduce plant sulfur emissions, and to reduce potential for fouling and corrosion in the HRSG. In the COS hydrolysis plant the syngas passes through a catalyst where COS reacts with water vapor in the syngas to produce H_2S and CO_2 which the reaction is given in Eq.1.

$$COS + H_2O \rightarrow H_2S + CO_2 \quad (1)$$

Clean syngas is fed to the GT to generate the electricity and combustion gases leaves the GT at a temperature of 450-500ºC. A supplementary firing system is used to obtain the same temperature at the inlet of HRSG. A dual pressure HRSG with reheat is considered. Steam expands in a steam turbine and generates electricity. Expanded steam enters the condenser and becomes liquid. A condensate pump is used to pump the condensate to the deaerator and then a circulation pump is used to pump the water to the high pressure super-heater. Connection and flow diagram of the power plant is given in Figure 1. In Table 1 ultimate and proximate analysis of coal is given.

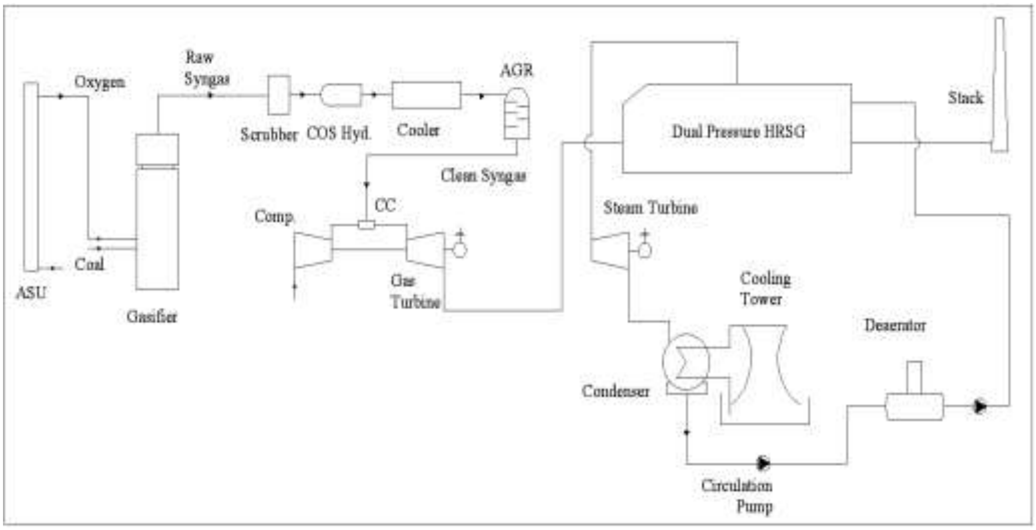

Figure 1. Flow diagram of an IGCC

Table 1. Ultimate and proximate analysis of the coal

Coal Ultimate Analysis (weight %)		Coal Proximate Analysis (weight %)	
Moisture	6	**Moisture**	6
Ash	9.94	**Ash**	9.94
C	69.36	**Volatile**	35.91
H	5.18	**Fixed Carbon**	48.15
N	1.22	**LHV (M&A inc.)**	27680 [kJ/kg]
S	2.85		
O	5.41		

In the simulations, O_2 purity at the exit of the ASU is taken 95% and the type of the ASU is multistage intercooled. Polytrophic and mechanical efficiencies are supposed to be 90 and 95% respectively. Gasifier pressure and temperature are supposed to be 32.52 bar and 1371.1ºC. Weight percentage of H_2O in the slurry is taken 35% and the minimum water fuel ratio in the feeding system is 0.2. The temperature at the exit of syngas cooler is 357ºC. The temperature at the exit of the scrubber and AGR unit and the conversion efficiency of the COS hydrolysis unit are taken 121ºC, 37.8ºC and 98% respectively. The pressure ratio of gas turbine is selected 15.8 and at ISO conditions turbine exit temperature is given 599ºC. A water cooled condenser is selected and the pressure of the condenser is supposed to be 0.0483 bar. Cooling water temperature rise is expected

10ºC. Deaerator pressure and the exit temperature of the water is taken 3.792 bar and 141.7ºC respectively.

Exergy Analysis

Exergy is the highest available work, which in a certain circumstance could be acquired from a certain thermal system, as it proceeds to a specified final state in equilibrium with its surroundings. Exergy is not conserved as energy and destructed in the system due to the internal or external irreversibilities. For a real process, the exergy input always exceeds the exergy outputs; this unbalance is due to irreversibilities, which known as exergy destruction [12]. The higher the value of exergy means more work obtainable from a system.

Exergy destruction

General form of exergy equation for an open system control volume is given in Eq.2 [13-16]. The exergy equation for the system at steady state conditions is given in Eq. 3, where time rate variations, given in Eq. 2, are neglected.

$$\frac{dE_{cv}}{dt} = \sum_j \left(1 - \frac{T_0}{T_i}\right)\dot{Q}_j - \left(\dot{W}_{cv} - p_0 \frac{dV_{cv}}{dt}\right) + \sum_i \dot{m}_i e_i - \sum_e \dot{m}_e e_e - \dot{E}_D \quad (2)$$

$$0 = \sum_j \left(1 - \frac{T_0}{T_i}\right)\dot{Q}_j - \left(\dot{W}_{cv}\right) + \sum_i \dot{m}_i e_i - \sum_e \dot{m}_e e_e - \dot{E}_D \quad (3)$$

Rearranging Eq.3 gives the exergy destruction of a steady state open system for a control volume.

$$\dot{E}_D = \sum_j \dot{E}_{qj}\dot{Q}_j - \left(\dot{W}_{cv}\right) + \sum_i \dot{E}_i - \sum_e \dot{E}_e \quad (4)$$

In the absence of nuclear, magnetic, electrical, and surface tension effects, the total exergy of a system $\dot{E}$ can be divided into four components. By neglecting potential and kinetic energy Eq. 5 can be rewritten as indicated in Eq. 6.

$$\dot{E} = \dot{E}_{PH} + \dot{E}_{CH} + \dot{E}_{PT} + \dot{E}_{KN} \quad (5)$$

$$\dot{E} = \dot{E}_{PH} + \dot{E}_{CH} \quad (6)$$

The specific physical exergy can be expressed as following where subscript "0" indicates reference conditions and the total exergy rate can be written as indicated in Eq. 8.

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$$e_{PH} = h - h_0 - T_0\left(s - s_0\right) \quad (7)$$

$$\dot{E} = \dot{m}\left[h - h_0 - T_0\left(s - s_0\right) + \bar{e}_{CH}\right] \quad (8)$$

The chemical exergy of a substance can be obtained from standard chemical exergy tables [13- 15] regarding to the specification of the environment. For mixtures containing gases other than those present in the reference tables, chemical exergy can be evaluated with the following equation.

$$\bar{e}_{CH} = \sum x_n (\bar{e}_{CH})_n + \bar{R} T_0 \sum x_n \ln x_n \quad (9)$$

In Eq. 9, x_n is the mol fraction of the k_{th} gas in the mixture and $\bar{R}$ is the universal gas constant. In the exergy analyses, another significant matter which must be noticed is the reference conditions. In this study, the atmospheric temperature and pressure are taken as reference conditions, 25ºC and 101.32 kPa respectively.

Exergy efficiency shows the rate of the fuel exergy provided to a system that is found in the product exergy. Moreover, the difference between 100% and the actual value of the exergy efficiency, expressed as a percent, is the ratio of the fuel exergy wasted in this system as exergy destruction and exergy loss [13].

$$\varepsilon = \frac{\dot{E}_P}{\dot{E}_F} \quad (10)$$

Generally, the exergy of the product shows the desired outcome of the system, whilst the exergy of the fuel represents the total given resources to the system. For this reason in different component of the power plant, the definition of the desired outcome and the given resource could be different. For the evaluation of the exergy destruction of the overall power plant, shown in Fig. 1, the exergy destruction in the individual components must be calculated. By taking each component as a control volume, the exergy equations for each one can be derived from the general exergy equation given in Eq. 4. It must be noted that, in this study, the exergy destructions caused by the heat losses from the components are neglected, since it has been assumed that the boundary temperature of the each component (T_j) is equal to the dead state temperature (T_0).

RESULTS

Radiant and convective syngas coolers are employed to cool down the syngas for cold cleaning process. Raw syngas first enters the radiant cooler with a pressure of 32.52 bar and a temperature of 1371ºC. The syngas velocity is found to be 0.64 m/s. The pressure drop at radiant syngas cooler section is calculated to be 1.626 bar. The exit temperature and pressure of syngas are 732ºC and 30.89 bar, respectively. Total heat transfer to the water wall is calculated to be 90.613 MW. The syngas secondly enters the convective cooler section. The pressure drop is calculated to be 1.545 bar and the exit pressure and temperature from convective syngas cooler are to be found 29.35 bar and 357ºC, respectively. The total heat transfer from syngas to the water wall is calculated to be 47.513 MW. For engineering design the estimated inner and outer diameters of gasifier are calculated to be 2.5 m and 4.3 m, respectively. The height of the gasifier is found to be

13.2 m. Table 2 shows the raw and clean syngas composition. The lower heating value of raw syngas is calculated to be 8943kJ/kg. After the cleaning process the volume percentage of CO and H_2 increases and the calculated lower heating value of clean syngas is 11009kJ/kg. At the exit of the cleaning process the temperature and the pressure of clean syngas were169.8ºC and 26.42 bar. The pressure of clean syngas should be higher than the pressure of the combustion chamber. In the atmospheric gasification process the syngas should be compressed. However, in a pressurized gasification process the pressure of syngas is greater than the combustion chamber pressure. In the ASU total power consumption is found to be 29.997 MW and ambient air compressor consumes 21.018 MW of total power requirement. The rest of total power consumption is consumed by oxygen compressor. At the exit of oxygen compressor the pressure of oxygen is found to be 32.52 bar and the temperature of oxygen is 108.4ºC. The mass flow rate of oxygen, with 95% purity, is 32.13 kg/s. The total shaft power of syngas combusted gas turbine is 233.53 MW and the exit temperature of combustion gas is 628ºC. The temperature and the mass flow rate of the combustion gas affect the design of HRSG.

.Table 2. Raw and clean syngas composition by volume

	CO	CO_2	CH_4	H_2	H_2S	O_2	H_2O	COS	N_2	Ar
Raw Synas	41	9.574	0.0037	26.62	0.7586	0	20.24	0.0395	1.767	0
Clean Syngas	52.4	11.28	0.0047	34.02	0.0102	0	0.0249	0.001	2.258	0

An additional burner is employed to supply the same gas turbine exit temperature. In this study a dual pressure HRSG is considered and the combustion gases pass through superheater, evaporator and economizer packages respectively. Steam is generated at two different pressure levels, 124.1 and 27.6 bar. The temperature of superheated steam is 557ºC for both pressure levels. The condenser pressure is taken as 0.075 bar and the saturation temperature at this point is 40ºC. At cooling tower side the temperature difference is taken as 10ºC. The rejected heat from the condenser is found to be 312.495 MW. The stack temperature and the mass flow rate of flue gas is 152ºC and 638.7 kg/s with a velocity of 21.4 m/s. The flue gas consists of 13.5% O_2, 8.4% CO_2, 5.4% H_2O and 73.68 N_2 by mole. The total CO_2 mass flow rate of simulated IGCC is calculated to be 80.37 kg/s. Some important output values are given in Table 3.

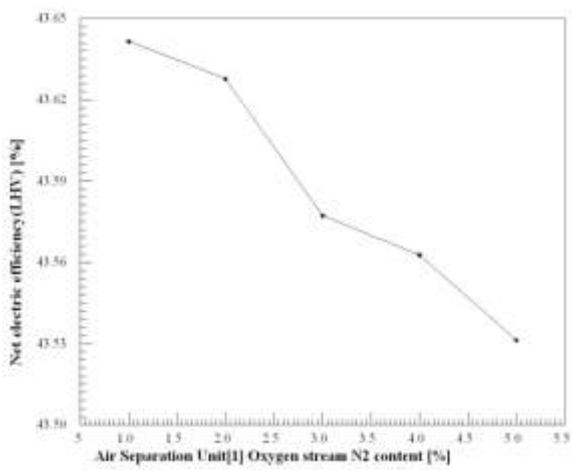

Figure 2. Net electric efficiency variation vs. O_2 purity

Table 3. Performance indicators of simulated IGCC

Ambient Temperature	25ºC	Net Heat Rate	8270 kJ/kWh
Net Power	389669 kW	Net Fuel Input	895133 kW
Net Electric Efficiency (LHV)	43.53 %	Plant Auxiliary	48976 kW

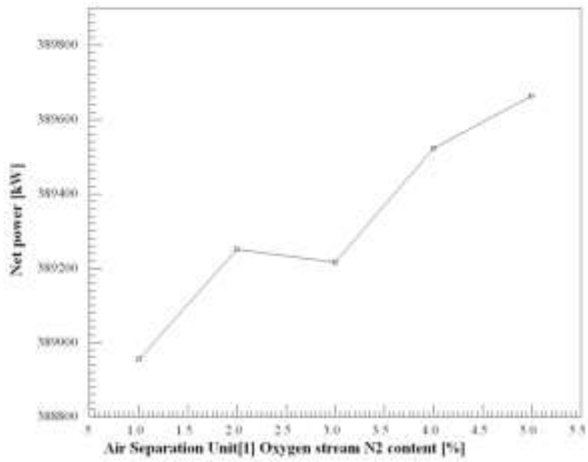

Figure 3. Net power variation vs. O_2 purity

The O_2 purity of the inlet stream to the gasifier is a key factor for increasing the net electric efficiency of an IGCC. In the simulations the O_2 purity is changed between 95-99% and the net electric efficiency is increased by 0.1% when the O_2 purity is increased. However, increasing the O_2 purity decreases net power due to the energy consumption of ASU. Net electric efficiency and net power curves are illustrated in Fig. 2 and 3.

Fuel can be supplied to the gasifier after a preheating system and it was shown that [17], preheating of slurry up to 320ºC increases the IGCC net efficiency by 5% while the gasifier conditions are 64 bar and 1500ºC. Fig. 4 and 5 illustrates the variation of net efficiency and net power with respect to the fuel supply temperature. In the simulations fuel supply temperature changed between 25ºC and 225ºC and the net electric efficiency increased approximately 0.6%. The net power generation also increased by 0.3 MW and the highest increment observed at 125ºC. The waste heat of radiant and convective syngas coolers can be used to preheat the slurry.

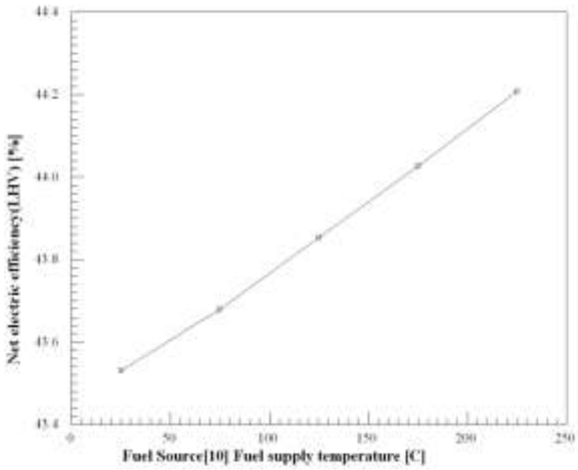

Figure 4. Net electric efficiency vs. fuel supply temperature

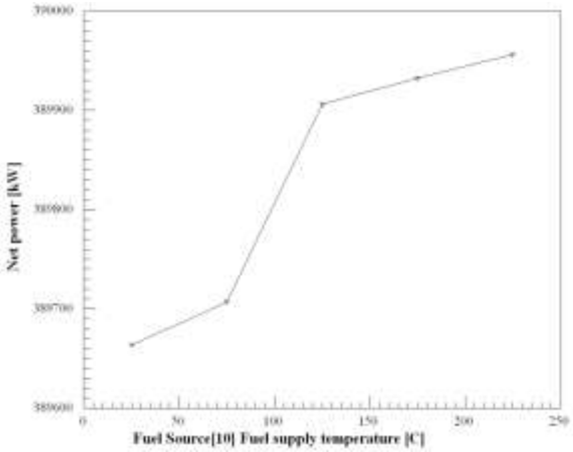

Figure 5. Net power vs. fuel supply temperature

The selection of gasifier type affects the gasifier temperature. In a fluidized bed gasifier, gasifier temperature is limited to 850-900ºC or in an entrained flow gasifier, gasifier temperature should be higher than the melting point of ash. The effects of gasifier temperature to the net power and net electric efficiency of the simulated IGCC is given in Fig. 6 and 7. The highest efficiency is found at 1350ºC gasifier temperature. The net electric efficiency starts to decrease however, net power generation increases after 1350ºC. The main reason of this result is the increased fuel flow rate. The power generation of the gas turbine is constant and same turbine exit temperature is obtained by more fuel consumption after 1350ºC.

Coal is fed to the gasifier as a slurry or dry where water is used to transport to coal into the gasifier. In dry feed CO_2, syngas or N_2 can be used to transport the coal. Cold gas efficiency, IGCC net electric efficiency and syngas gas composition change with the selection of transport medium. In a slurry feed gasifier cold gas efficiency (CGE) and IGCC net electric efficiency is found to be 65 and 38% for 70 bar 1500ºC gasifier conditions and 99% O_2 purity. At the same gasifier conditions in a dry feed gasifier CGE and IGCC efficiency is found to be 82 and 50%, respectively. H_2/CO molar ratio and CO_2/H_2S molar ratio is found to be approximately 0.41 and 34 for slurry feed gasifier. Same molar ratios are found to be 0.51 and 3.3 respectively in a dry feed gasifier [17]. In this study H_2O content of the slurry is changed between 20-40% and the effects of this variation to the net power and net electric efficiency is illustrated in Fig. 8 and 9.

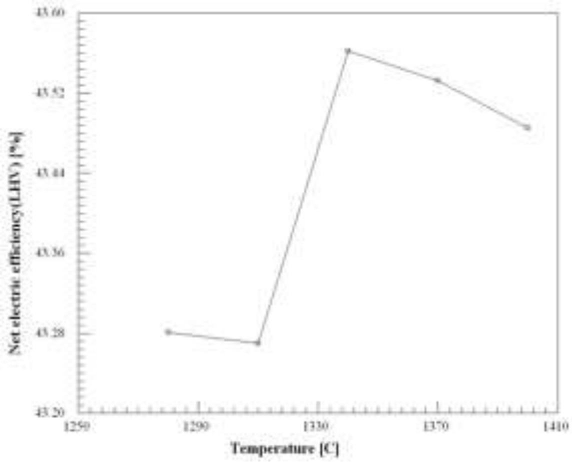

Figure 6. Net electric efficiency vs. gasifier temperature

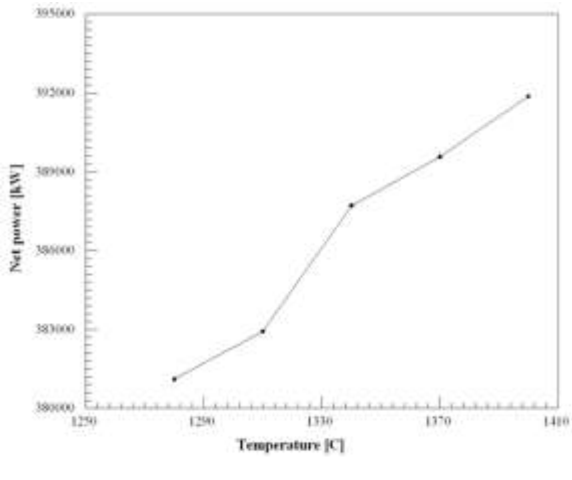

Figure 7. Net power vs. gasifier temperature

Increasing H_2O content of slurry increases net power however, net electric efficiency sharply decreases. The syngas composition and LHV of syngas decreases by increasing H_2O content of the slurry and as a result more coal is fed to the gasifier to obtain the same power from the gas turbine. The effects of syngas composition and LHV of clean syngas with respect to the H_2O content of slurry is given in Fig. 10 and 11.

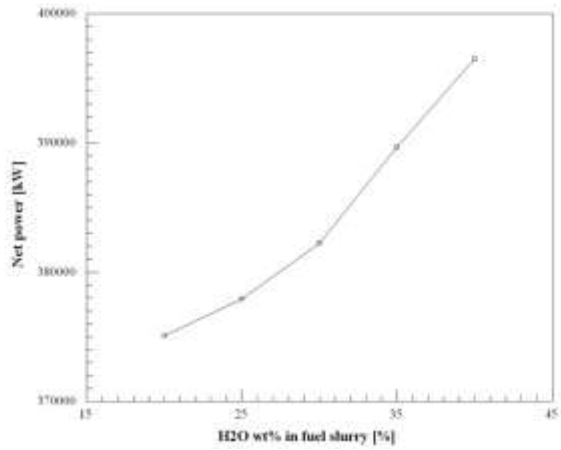

Figure 8. Net power vs. H_2O content of slurry

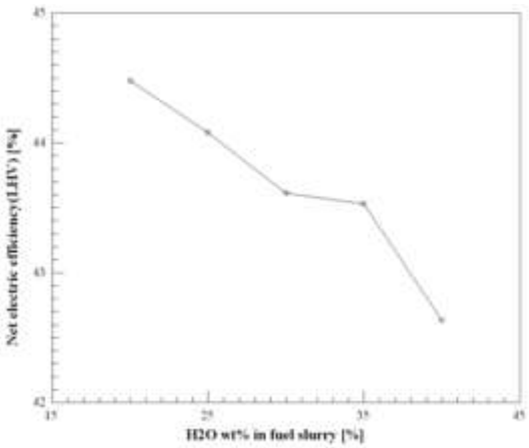

Figure 9. Net electric efficiency vs. H_2O content of slurry

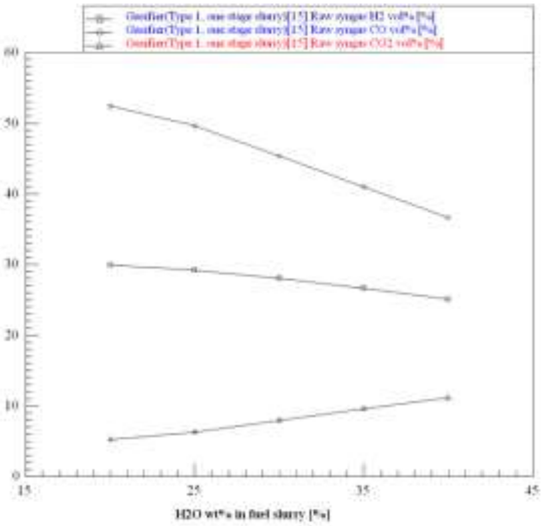

Figure 10. The variation of raw syngas composition

CO and H_2 content of the raw syngas decreases by increasing the H_2O content of the slurry. This reduction directly affects the LHV of syngas. Therefore, more coal is fed to the gasifier and the net power increases and the net electric efficiency decreases. Water consumption of a power plant is a critical factor in water scarce regions. Also, CO_2 mass flow rate is related to global warming. In Fig. 12 and 13 CO_2 mass flow rate and water consumption of the IGCC is given with respect to H_2O content of the slurry.

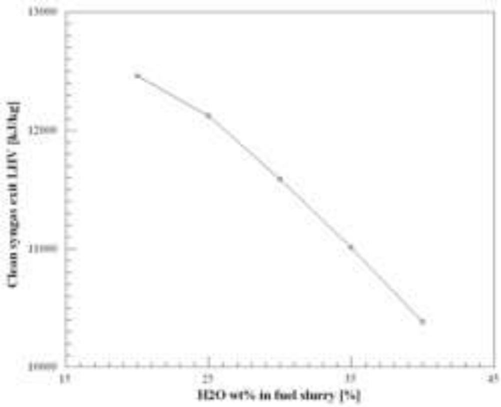

Figure 11. The LHV of clean syngas

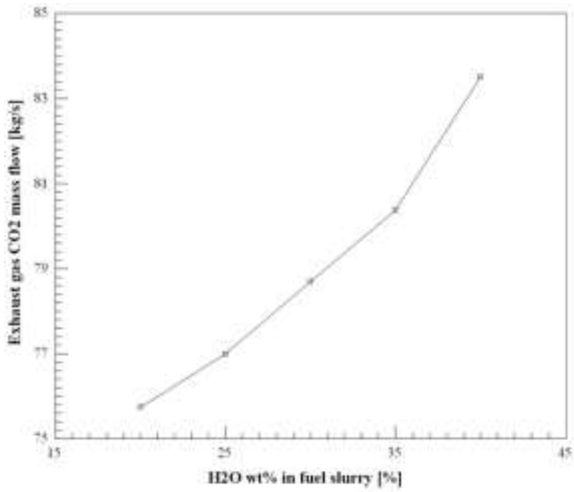

Figure 12. CO_2 mass flow rate

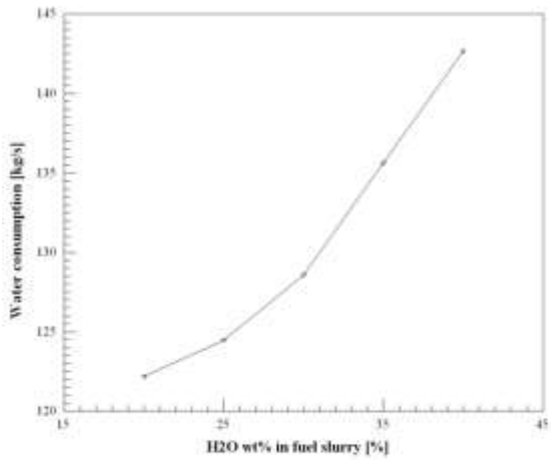

Figure 13. Water consumption of the IGCC power plant

Table 4 shows physical, chemical and total exergy values of each stream in the simulated IGCC. Stream number 4 indicates the raw syngas and after cold gas cleaning process, indicated number 11, the total exergy decreases. At the inlet of HRSG the total exergy of combustion gas is the highest. Stream number 25' and 25'' indicates air to combustion chamber and air to turbine coolant, respectively.

Table 5 provides the exergy destruction, the percentage of exergy destruction and the percentage of the exergy efficiency values for each component. The highest exergy destruction occurs in the gasifier and combustion chamber. The exergy destruction of the gasifier and combustion chamber are calculated to be 38,09 and 37,42 % of the total exergy destruction respectively. The lowest exergy efficiency is calculated in ASU. It is obvious from the Table 5 that the exergy destruction of the gasifier and the combustion chamber should be decreased to increase the exergy efficiency of the IGCC. The total exergy destruction of the power plant is calculated to be 451,84 MW and the exergy efficiency of the overall power plant is found to be 40,36%. The net electric efficiency of the simulated cycle, given in Table 3, is higher than exergy efficiency of the power plant. The percentage of the exergy efficiency and the exergy destruction of each component is also illustrated in Fig. 14.

CONCLUSIONS

In this study energy and exergy analysis of an integrated gasification combined cycle is presented. The gasifier island consists of a Texaco type gasifier, one stage, slurry fed, oxygen blown and cold gas cleaning system is applied. The effects of the O_2 purity, fuel supply temperature, gasifier temperature and H_2O content of the slurry to the IGCC performance is investigated. GE 9FA type of gas turbine is selected for the simulations and the waste heat is utilized in a dual pressure HRSG. According to the results of the study the net electric efficiency and the net power of the IGCC are found to be 43.53% and 389.669 MW respectively for the base case in which the ambient temperature and the H_2O content of the slurry are taken as 25ºC and 35%. Some of the important results of the study listed below.

- Increasing O_2 purity decreases the net power due to the increasing energy consumption of ASU.
- Increasing O_2 purity increases the net electric efficiency due to the decreasing fuel consumption.
- Increasing fuel supply temperature increases the net electric efficiency and net power generation.
- Increasing gasifier temperature increases the net power generation. The electric efficiency also increases; however, after the design temperature of the gasifier the electric efficiency tends to decrease. Therefore, operating the gasifier at the design temperature is crucial.
- Increasing the H_2O content of the slurry increases the net power. However, the fuel consumption also increases and the net electric efficiency decreases.
- Increasing the H_2O content of slurry decreases the LHV of syngas. CO and H_2 content of the syngas also decreases by increasing the H_2O content of slurry.
- Increasing the H_2O content of slurry increases the CO_2 mass flow rate and water consumption of the IGCC.
- The highest exergy destruction percentage is found in the gasifier and combustion chamber of gas turbine.
- Total exergy destruction of the IGCC is calculated to be 451.84 MW and energy and exergy efficiencies of the simulated IGCC are found to be 43.53 and 40.36 % respectively.
-

Table 5. Exergy destruction and exergy efficiency of each component

Component	Exergy Destruction [MW]	Exergy Destruction [%]	Exergy Efficiency [%]
ASU	21,97	4,86	48,24
Gasifier	172,09	38,09	82,12
Cooler	6,85	1,52	77,87
Gas cleanup System	10,53	2,33	98,55
Compressor	5,63	1,25	97,47
Combustion chamber	169,06	37,42	80,04
Gas turbine	23,98	5,31	95,02
HRSG	26,35	5,83	86,44
Steam turbine	20,84	4,61	91,03
Condenser	16,36	3,62	60,36
Deaerator	0,15	0,03	99,58
Pump1	1,78	0,39	50,81
Pump2	0,32	0,07	51,37
Overall plant	451,84	100,00	40,36

Table 4. Physical, chemical and total exergy values of each stream

Stream Number	**Fluid Type**	E_{phy} *[MW]*	E_{ch} *[MW]*	E_{total} *[MW]*	**Stream Number**	**Fluid Type**	E_{phy} *[MW]*	E_{ch} *[MW]*	E_{total} *[MW]*
1	Fuel	0,0000	951,7674	951,7674	23	Air	14,6351	0,0000	14,6351
2	Water	0,0144	2,4991	2,5135	24	Air	0,0000	0,0000	0,0000
3	Oxygen	2,4931	3,3497	5,8428	25	Air	204,8940	0,0000	204,8940
4	Syngas	74,6120	670,0528	744,6648	26	Comb. Gas	654,2917	23,6187	677,9103
5	Slag	0,0000	0,0000	0,0000	27	Comb. Gas	196,9196	26,8564	223,7761
6	Water	36,9077	13,6369	50,5446	28	Comb. Gas	14,3229	15,1845	29,5074
7	Steam	82,8430	13,6369	96,4799	29	Water	12,5829	24,0213	36,6042
8	Syngas	43,6774	670,0528	713,7302	30	Steam	210,3056	24,0040	234,3096
9	Water	19,3538	7,1510	26,5048	31	Water	0,3792	0,8478	1,2270
10	Steam	43,4416	7,1510	50,5925	32	Steam	3,2893	0,8394	4,1288
11	Syngas	25,4839	643,8613	669,3452	33	Steam	148,7334	23,3805	172,1139
12	Water	0,3277	1,5686	1,8962	34	Steam	186,0666	23,3805	209,4471
13	Water	0,7491	3,8517	4,6008	35	Steam/water	15,3898	23,9867	39,3765
14	Acid Gas	11,8822	23,6959	35,5781	36	Water	0,2074	23,9867	24,1941
15	Water	0,2743	23,9867	24,2610	37	Air	0,0000	0,0000	0,0000
16	Water	7,9951	23,9867	31,9817	38	Air	0,7200	0,0000	0,7200
17	Steam	7,3892	1,8531	9,2423	39	Water	10,7452	24,0213	34,7665
18	Water/steam	0,8678	1,8531	2,7209	40	Water	11,1248	24,8699	35,9947
19	Air	11,7730	0,0000	11,7730	41	Water	7,9798	24,0386	32,0184
20	Air	0,0000	0,0000	0,0000	25'	Air	177,6239	0,0000	177,6239
21	Water	1,0816	160,6501	161,7317	25"	Air	27,2560	0,0000	27,2560
22	Water	0,3989	160,6501	161,0490					

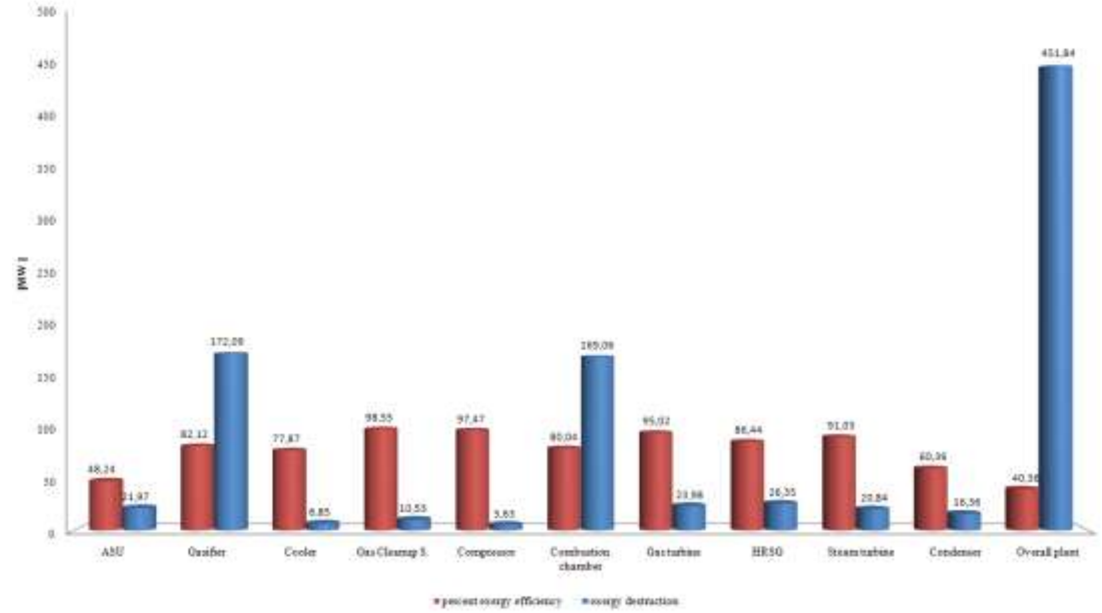

Figure 14. Percent exergy efficiency and exergy destruction of each component

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