Modeling of Syngas Integrated Regenerative Gas Turbine Power Plants

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ABSTRACT

Wood chips available in Sudan can be successfully used in gasification process on the same basis as bio-renewable energy resources. Simulation models were used to characterize the gasification process integrated with a regenerative gas turbine unit. The results showed that, increasing the gasification temperature leads to a slow down the amount of the actual air required for Wood Chips gasification. Using air as a gasification medium, results revealed that the equivalence ratio growths at low values has significant effect of the gasifier's actual air and led to increase the required amount of the actual air for Wood Chips gasification process. Higher values of the gasification pressure revealed higher value of the RGT power. It was observed that, higher gasifier's pressure was responsible for the higher RGT power. Low equivalence ratio rates (ER) revealed higher RGT power at the lower temperature and higher pressure of the gasifier respectively. The increase of the gasification pressure revealed an increase of the actual air required for Wood Chips gasification. Results concluded that, increasing of moisture content released massive decrease on lower heating value (LHV) of the syngas, thus influencing the increase of the RGT combustor fuel rate. Moreover, results concluded that, lower heat syngas value (LHV), will demand more fuel by the RGT combustor to derive the plant. Whereas, at the optimum equivalence ratio (ER), the syngas heat value reached its maximum energy content, which revealed a higher RGT power. In-addition results observed that, the combustor fuel's rate revealed higher values amid increasing of the Biomass moisture content. The higher the gasification temperature is the higher the combustor fuel rate, due slowdown of the syngas energy content. the RGT thermal efficiency is higher at the optimum equivalence ratio ER (18%), which attained a value of 61.80%, for RGT compressor inlet temperature of 200K, and compression ratio of 15. At ER of 20%, gasification temperature of 1500 K, and a pressure of 30 bar, the results revealed slowdown in the concentration of the constituent's CO, N_2, amid increasing of the moisture content, whereas a gradual increase of the concentration of CO_2, CH_4,H_2 and H_2O, have been observed.

1. INTRODUCTION

Majority of the Sudanese population is dependent on agriculture as their main occupation (Mahgoub, 2014). Main agricultural exports out of Sudan fall into the following three categories: (i) field crops (ii) livestock and (iii) gum Arabic (Mahgoub, 2014). As Sudan transitions towards higher levels of industrialization, biomass will be essential as a renewable energy source to drive the nation. This is true of biomass worldwide and it is expected to play a key role in future energy scenarios. Retrofitting existing gas turbines in Sudan with the ability to combust syngas will help the Sudanese economy accelerate rapidly towards a clean energy economy whilst providing its population with stable power supply.

Gasification of biomass occurs after the initial drying step, followed by pyrolysis (Garcia-Perez, et al., 2008) (French & Czernik, 2010) which leads to devolatilization and shrinking of the original particle (Elliot, Neuenschwander, & Hart, 2013). The last step in the process is char gasification, the pyrolysis step starts out at the surface making its way to the center of a biomass particle. In a biomass gasifier, biomass is burned in a limited amount of air. This converts the biomass (which consists of carbon, hydrogen, oxygen, etc.) into an inflammable mixture of gases known as producer gas/syngas/wood gas (Kollmann & Cote, 1968). The producer gas consists of carbon monoxide (CO),

Fig.1: Wood Biomass in Sudan.

hydrogen (H_2), and methane (CH_4), along with carbon dioxide (CO_2) and nitrogen (N_2). This work aims to reinforce the understanding of a regenerative RGT as a thermal process utilizing the integration of the biomass gasification unit at the combustor, as well as applying similar design parameters of Khartoum North Station (GT,187 MW) (Johnke & Mast, 2002) in Sudan. This work studies the chemical process and the necessary data of the optimum design conditions including the integration of biomass gasification unit in a regenerative RGT cycle as a power generator unit. The aim of the work is to investigate the syngas fuel and its effect on the Integrated Biomass Gasification for Regenerative Gas Turbine Unit "IBGRGT", including the thermal efficiency, power generated, lower heating value and amount of raw biomass of the gasifier. The work implements similar design parameters of Khartoum North Station (GT,187 MW) (Mast M et al.,2002), in Sudan. The results of the

2. MODELING OF COMPONENTS

A schematic of a regenerative gas turbine and Biomass Integrated Unit (BIGT) with the syngas producer is shown in Fig.2. The system consists of a hot air driven gas turbine, compressor, combustor, and regenerator beside gasifier unit. The gasifier in the system produces syngas using gasification of dry biomass. The biomass material will be fed to the gasifier at ambient conditions as described briefly on the Fig.2. Since air is the gasification medium, gasification occurs in the presence of compressed air and produces the syngas, which enters the combustion chamber. A thermodynamic equilibrium method based on a stoichiometric approach according to the method of Jarungthammachote and Dutta will be used for modeling the gasifier. This model is used to predict the syngas composition at the gasifier working temperature and pressure. The gasification global reaction equations combined with (Khanmohammadi, Kouhikamali, & Atashkari, 2016) (Littlewood, 1977) equilibrium constant equations (Perry & Green, 1997) (Rajput, 1995) along with methanation and water shift reactions provide for the enthalpy equations applied as (McKendry, 2002):

$$\begin{aligned}\overline{h^{\circ}_{f,biomass}} + w\overline{h^{\circ}_{f,H_2O}} &= x_1\left(\overline{h^{\circ}_{f,H_2}} + \Delta\overline{h}\right) + x_2\left(\overline{h^{\circ}_{f,CO}} + \Delta\overline{h}\right) + x_3\left(\overline{h^{\circ}_{f,CO_2}} + \Delta\overline{h}\right) + x_4\left(\overline{h^{\circ}_{f,H_2O}} + \Delta\overline{h}\right) \\ &+ x_5\left(\overline{h^{\circ}_{f,CH_4}} + \Delta\overline{h}\right) + x_6\left(\overline{h^{\circ}_{f,N_2}} + \Delta\overline{h}\right)\end{aligned} \quad (1)$$

where, $\overline{h^{\circ}_{f,i}}$ is the formation enthalpy in terms of kJ/kmol, and its value for all the chemical compositions is zero in the reference state and $\Delta\overline{h}^{\circ}$ is the enthalpy difference value for the given state with reference state. The GT power plants consist of four components including the compressor, combustion chamber (CC), turbine, and generator. The integrated biomass regenerative combined cycle arrangement considered in Fig.2 is a clear presentation on how to utilize the hot turbine exhaust gas. Fresh atmospheric air is filtered and drawn continuously into the circuit, where energy is added by combustion of fuel. The products of combustion are expanded through the turbine (Rajput, 1995) and consequently produce electrical work while rest of the exhaust gases are discharged into the biomass gasifier and regenerator units.

Table 1: Initial design parameter of the integrated biomass gas turbine system.

Parameter	Value	Unit
Rated Biomass Consumption	4-13	kg/s
Gasification Temperature	1000-1600	ºC
Temperature of Gas at Gasifier Outlet	250-400	ºC
Biomass Feeding	Machinery	-
Desired Gasifier Operation	Continuous (minimum 300)	days/yr
Gas Turbine Inlet Temperature	1200	ºC
Compressor Pressure Ratio	15	-
Biomass Moisture Content	25-80	%
Gasifier Working Pressure	10-80	bar
Air Gasification Mass Flow Rate	15-35	kg/s

Mixed untreated Wood Chips available in Sudan with an average size of 1*2*3 cm were used as a feedstock and experimentally characterized according to the standard literature data (Shi, Si, & Li, 2016) (Alauddin, 1996) (Erlich & Fransson, 2011) (Olgun, Ozdogan, & Yinesor, 2011). The corresponding analysis results are shown in Table 1.

Table 2: Proximate and ultimate analysis of wood chips.

Proximate Analysis (wt %)				Ultimate Analysis (wt %)					Lower Heat Value (kJ/kg)
Water	**Ash**	**Volatile**	**Fixed Carbon**	**C**	**H**	**O**	**N**	**S**	
12.40	11.30	59.40	16.97	53.20	6.40	40.14	0.12	0.14	20123

The gasifier's required power output, Q (MWth), is an important input parameter specified by the client. Based on this, the designer makes a preliminary estimation of the amount of fuel to be fed into the gasifier and the amount of gasifying medium.

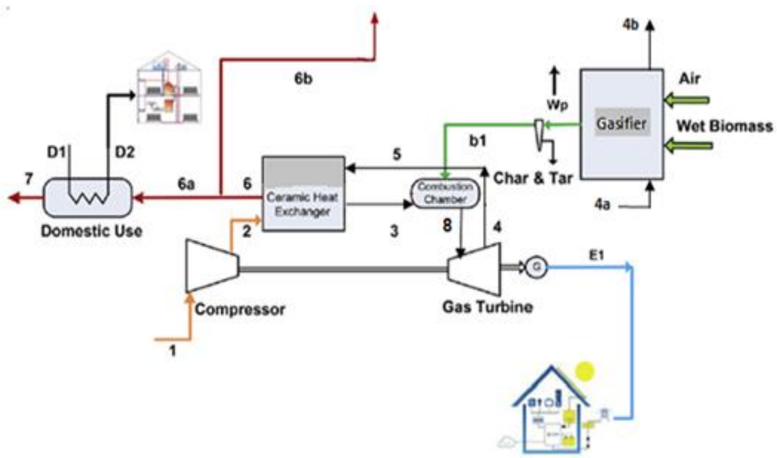

Fig.2: The regenerative gas turbine cycle integrated with Biomass Gasifier Unit.

The volume flow rate of the *product gas*, V_g (Nm^3/s), from its desired lower heating value, LHV_g (MJ/Nm^3) combined with the lower heating value (LHV) and higher heating value (HHV) provide the biomass feed rate taking the gasifier efficiency, $\eta_{gef,}$ into account (Basu, 2010):

$$M_f = \frac{Q}{LHV_{bm}\eta_{gef}} \tag{2}$$

Channiwala and Parikh developed the following unified correlation for HHV of the based on 15 existing correlations and 50 fuels, including biomass, liquid, gas, and coal (Basu, 2010):

$$HHV = 349.10C + 1178.3H + 100.5S - 103.4O - 15.1N - 21.1ASH \quad (\frac{kJ}{kg}) \tag{3}$$

Where *C*, *H*, *S*, *O*, *N*, and *ASH* are percentages of carbon, hydrogen, sulfur, oxygen, nitrogen, and ash as determined by ultimate analysis on a dry basis. The theoretical air requirement for complete combustion of a unit mass of a fuel, m_{th}, is an important parameter. Its calculation is shown in Eq. (4) (Basu, 2010):

$$M_{da} = [0.1153C + 0.3434\left(H - \frac{O}{8}\right) + 0.0434S] \qquad (\frac{kg}{kg\ dry\ fuel}) \tag{4}$$

For an air-blown gasifier operating, the amount of air required, M_a, for gasification of unit mass of biomass is found by multiplying it by another parameter ER which is similar to the feed rate of M_f, the air requirement of the gasifier, M_{fa}, is (Basu, 2010):

$$M_{fa} = m_{th}.ER.M_f \tag{5}$$

The equivalence ratio (ER) is an important gasifier design parameter. It is the ratio of the actual air-fuel ratio to the stoichiometric air-fuel ratio. This term is generally used for air-deficient situations, such as those found in a gasifier (Basu, 2010):

$$ER(< 1.0)_{gasification} = \frac{Actual\ Air}{Stoichiometric\ Air} = EA(> 1.0)_{combustion} \tag{6}$$

Where *EA* is the excess air coefficient. The quality of gas obtained from a gasifier strongly depends on the *ER* value, which must be significantly below 1.0 to ensure that the fuel is gasified rather than combusted. The oxygen requirement of a gasifier can be met by either air supply or an air-separation unit that extracts oxygen from air. The efficiency of gasification is expressed as cold-gas efficiency or hot-gas efficiency. Cold-gas efficiency is the energy input over the potential energy output. If M_f kg of solid fuel is gasified to produce M_g kg of product gas with an LHV of Q_g, the efficiency is expressed as (Basu, 2010):

$$\eta_{cg} = \frac{Q_g M_g}{LHV_{bm} M_f} \quad (7)$$

Where LHV_f is the lower heating value of the solid fuel. The hot-gas efficiency, η_{hg} can be defined as (Basu, 2010):

$$\eta_{hg} = \frac{Q_g M_g + M_g C_p (T_f - T_0)}{LHV_{bm} M_f} \quad (8)$$

Where T_f is the gas temperature at the gasifier exit or at the burner's entrance, and T_0 is the temperature of the fuel entering the gasifier. Accordingly, the intake pressure at the compressor inlet was modeled with the following equation (Omar, Kamel, & Alsanousi, 2017) (AF, 2008):

$$P_1 = P_{atm} - \Delta P_{intake} \quad (9)$$

Where the intake pressure drop (ΔP_{intake}) was taken to be 0.005 bar, and the intake temperature was modeled as the ambient temperature. The process on the temperature-entropy diagram is represented in Fig.2.The compressor compression ratio (r_P) can be defined as (AF, 2008) (Nag, 2008):

$$r_P = \frac{P_2}{P_1} \quad (10)$$

Where $P_1$and P_2 are compressor inlet and outlet air pressure, respectively. Accordingly, the isentropic outlet temperature leaving the compressor is modeled by the equation (Nag, 2008) (Volkov, 2012) (Mohapatra & Prasad, 2012):

$$\frac{T_1}{T_{2s}} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma_a - 1}{\gamma_a}} \quad (11)$$

The specific heat ratio for air $\gamma_a$was taken as 1.4 and was predicted at $\gamma_g = 1.3$ for the gas. The isentropic efficiency of the compressor and turbine was taken to be in the range of 85% to 90%. The isentropic compressor efficiency is expressed by the equation (Moran & Shapiro, 2008) (Rahman, Ibrahim, & Abdalla, Thermodynamic Performance Analysis of Gas Turbine Power Plant, 2011):

$$\eta_c = \frac{T_{2s} - T_1}{T_2 - T_1} \quad (12)$$

Where, T_1 and T_2 are the compressor inlet and outlet air temperatures respectively and T_{2s} is the compressor isentropic outlet temperature. The specific work required to run the compressor work (W_C) is modeled with the following equation (Rahman, Ibrahim, & Abdalla, Thermodynamic Performance Analysis of Gas Turbine Power Plant, 2011):

$$\dot{W}_c = \dot{m}_a C_{P_a} (T_2 - T_1) = \dot{m}_a C_{P_a} T_1 \left[\frac{r_p^{\frac{\gamma_a - 1}{\gamma_a}} - 1}{\eta_c}\right] \quad (13)$$

The specific heat of flue gas (C_{pg}) is given by Naradasuetal. (2007) (Rahman, Ibrahim, & Abdalla, Thermodynamic Performance Analysis of Gas Turbine Power Plant, 2011):

$$C_{P_g} = 1.8083 - 2.3127 \times 10^{-3} \times T + 4.045 \times 10^{-6} \times T^2 - 1.7363 \times 10^{-9} \times T^3 \quad (14)$$

From the energy balance in the combustion chamber (Nag, 2008):

$$\dot{m}_a C_{P_a} T_x + \dot{m}_f LHV + \dot{m}_a C_{P_f} T_f = (\dot{m}_a + \dot{m}_f) C_{P_g} T_{it} \quad (15)$$

Where $\dot{m}_f$is the fuel mass flow rate in (kg/s), $\dot{m}_a$is the air mass flow rate (kg/s), LHV is the fuel's low heat value, T_{it} is the turbine inlet temperature, C_{P_f} is the specific heat of fuel, and T_f is the temperature of the fuel. The specific heat of the flue gas was modeled with $C_{P_g} = 1.07\ kJ/kg.K$; efficiency was set at 95%, and a pressure drop of $\Delta P_{C,C} = 0.4785\ bar$ in the combustor. Accordingly, the efficiency of the combustor was modeled as (Nag, 2008):

$$\eta_{C,C} = \frac{\dot{m}_g C_{P_g} T_{it} - \dot{m}_a C_{P_a} T_x}{\dot{m}_f * LHV_{gas}} \quad (16)$$

The air fuel ratio at the combustor was modeled according to the following equation (Nag, 2008):

$$AFR = \frac{A}{F} = \frac{\dot{m}_a}{\dot{m}_f} \quad (17)$$

Where the total mass flow rate is given by (Nag, 2008):

$$\dot{m}_g = \dot{m}_a + \dot{m}_f \quad (18)$$

The discharge gas of the turbine was predicted according to the equation (Nag, 2008):

$$\frac{T_3}{T_{4s}} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma_g - 1}{\gamma_g}} \quad (19)$$

Where the actual outlet temperature leaving the turbine at the isentropic conditions was modeled according to (Nag, 2008):

$$\eta_t = \frac{T_3 - T_4}{T_3 - T_{4s}} \tag{20}$$

The regenerator effectiveness ε was modeled according to the equation (Shi, Si, & Li, 2016):

$$\varepsilon = \frac{T_x - T_2}{T_4 - T_2} \tag{21}$$

where T_x is the combustor inlet temperature. The shaft work produced from the turbine is determined by the equation (Mahmood & Mohammad, 2014):

$$\dot{W}_{GT} = \dot{m}_g C_{P_g}(T_4 - T_{it}) = \dot{m}_g C_{P_g} \eta_t T_{it} \left[1 - \frac{1}{r_p^{\frac{\gamma_a - 1}{\gamma_a}}}\right] \tag{22}$$

The work from the GT unit was expressed by the equation (McKendry, 2002):

$$\dot{W}_{GT,Net} = \dot{W}_{GT,Net} - \dot{W}_C = \dot{m}_g C_{P_g} \eta_t T_{it} \left[1 - \frac{1}{r_p^{\frac{\gamma_g - 1}{\gamma_g}}}\right] - \dot{m}_a C_{P_a} T_1 \left[\frac{r_p^{\frac{\gamma_a - 1}{\gamma_a}} - 1}{\eta_c}\right] \tag{23}$$

The output power from the GT is expressed with the equation (Nag, 2008) (Mahmood & Mohammad, 2014):

$$P_{GT} = [\dot{W}_{GT} - \dot{W}_C] \times \eta_{Mech} \eta_{Gen} \tag{24}$$

The mechanical (η_{Mech}) and generator (η_{Gen}) efficiencies were taken to be 92% and 95% respectively. The heat supplied was expressed with the equation (Nag, 2008):

$$\dot{Q}_{add} = \dot{m}_g C_{P_g} T_{it} - \dot{m}_a C_{P_a} T_x \tag{25}$$

The heat supplied (per kg. air) to the combustor was modeled according to the equation (Nag, 2008):

$$Q_{add} = \frac{\dot{m}_f \times \eta_{C,C} \times LHV_{gas}}{\dot{m}_{air}} = \frac{\eta_{C,C} \times LHV_{gas}}{AFR} \tag{26}$$

The GT efficiency was determined by the equation (Nag, 2008):

$$\eta_{over,GT} = \frac{\dot{W}_{GT,Net}}{\dot{Q}_{add}} \tag{27}$$

Accordingly, the heat rate (HR) which is defined as the consumed heat to generate unit energy of electricity was determined by the equation (Nag, 2008) (Sarvanamuttoo, Rogers, Cohen, & Strazinsky, 2009):

$$HR = \frac{3600 * \dot{m}_f * LHV}{\dot{W}_{GT,Net}} \tag{28}$$

The specific fuel consumption (SFC) is determined by the equation (Nag, 2008):

$$SFC = \frac{3600 * \dot{m}_f}{\dot{W}_{GT,Net}} \tag{29}$$

This section does not enunciate every step of the equations that for the modelling of the regenerative gas turbines. The set of complete equations has been detailed in the 'Modeling of Components' section of the 'Energy Analysis of Biomass' paper presented at the Refrigeration and Air Conditioning Conference of 2022 at Herrick Laboratories.

3. RESULTS AND DISCUSSIONS

The equations were executed using Thermodynamics Engineering Equation Solver (EES) codes and explore air as a gasification medium to produce syngas fuel for wood chips (Acacia Nilotica). As can be observed in Fig.3, using air as a gasification medium, increase of the equivalence ratio of the gasifier in the range of ER=5-60%, leads to increase in the required amount of the actual air for wood chips gasification. The equivalence ratio growths at low values have significant effect of the gasifier's actual air. As observed, at a produced syngas rate of 10kg/sec, and gasification pressure of 30 bar, the flowrate of air increases till reaching around 30 kg/sec, thereafter the air starts to stabilize due to the end of the biomass gasification. After ER of 22%, the calorific value of the syngas starts to slow down, changes of syngas composition occur, and the biomass started to deplete because of strengthened oxidative reactions of combustible product gases. The result showed that, increasing of gasification temperature from 1000-1600K, led to slow down the amount of the actual air required for wood chips gasification. In addition, the point of the ER inflection at 22% can be regarded as the point of the optimal design of the system to derive the amount of the required actual air for the assigned biomass quantity, and the gasifier efficiency.

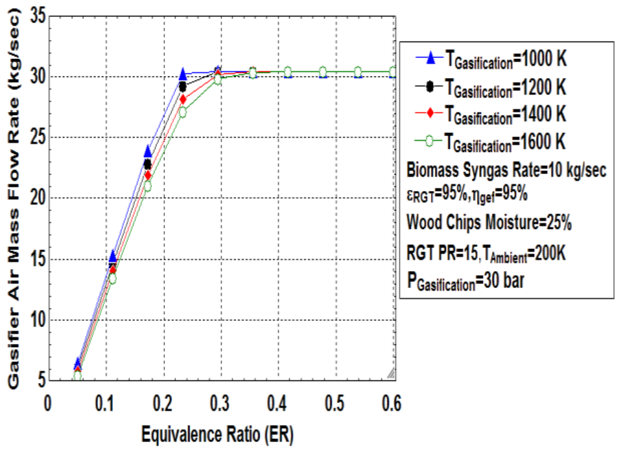

Fig.3: *Equivalence Ratio versus Gasifier air mass flowrate at different gasification temperatures.*

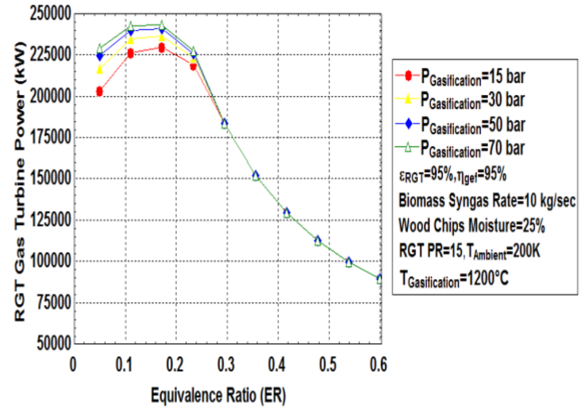

Fig.4: *Variation of Equivalence Ratio with RGT thermal efficiency at different gasification pressures.*

Fig.4 depicts the variation of ER and RGT power at different gasification pressures. As observed, the increase of the ER in a gradual range of 5-60% leads to an increase of the RGT power. However, the results show that there is an optimum (ER), although after the further increases of the ER will slow down the RGT power, due increasing of combustion products, changes of syngas constituents amid CO2, water vapor increases, and a massive decrease of the LHV of the syngas. In this way, with the lower heat value (LHV) of the syngas, the RGT combustor will consume more fuel to derive the plant's energy. Whereas at the optimum equivalence ratio (ER), the syngas heat value reached its maximum energy content revealing a higher RGT power. Higher values of the gasification pressure revealed higher value of the RGT power. The gasification pressure promoted an enhancement of the reaction rate of the primary, secondary water gas shift reactions, and methanation reactions, which revealed an increase in the concentration of the main constituents of the syngas products of H_2, CH_4, and CO. In addition, the increase of the gasification pressure showed an increase of the actual air required for wood chips gasification (see Fig.5).

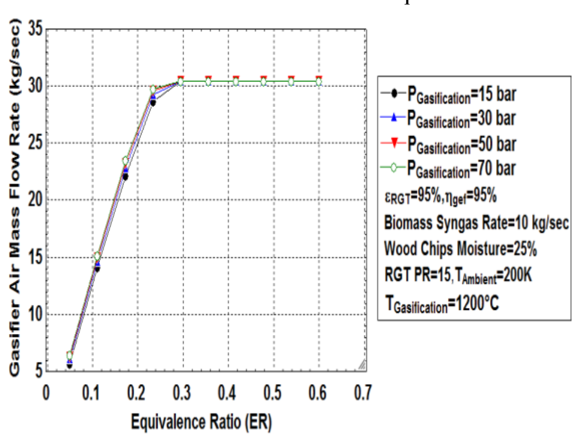

Fig.5: *Equivalence Ratio versus Gasifier air mass flowrate at different gasification pressures.*

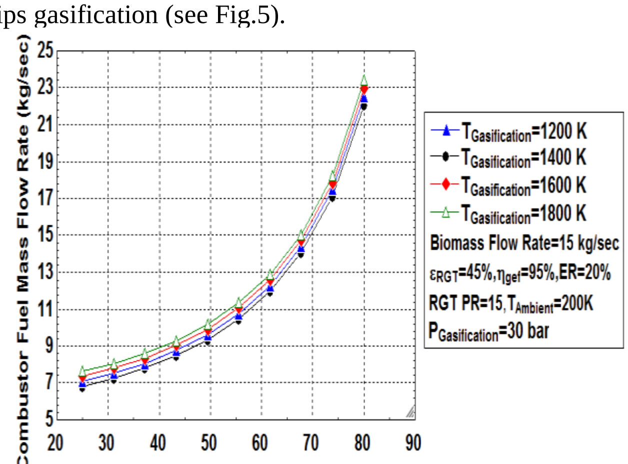

Fig.6: *Effect of the Biomass moisture content on the Combustor fuel mass flowrate for different gasification temperatures.*

The effect of the biomass moisture content (10-80%), on the combustor fuel mass flow rate at different gasification temperatures are displayed in Fig.6. The Biomass moisture content plays significant role on the syngas heat value. As observed, increase in the moisture content released shows a massive decrease on lower heating value (LHV) of syngas, thus increasing the combustor fuel rate. At a gasification pressure of 30 bar, biomass rate of 15kg/sec, gasifier efficiency of 95%, regenerator effectiveness of 45%, and a gasifier equivalence ratio (ER) of 20%, the combustor fuel rate delivered a value of 7 kg/sec at 25% moisture, and a value of 23kg/sec with biomass moisture at 80%. The result showed that higher the gasification temperature, higher the combustor fuel rate, due to slow down of the syngas energy content. Moreover, the fraction of syngas products of CO, H_2 and CH_4 decreases with increasing of the biomass moisture content, while the formation of the H_2O vapor was more favorable in the gasifier as the moisture content increases

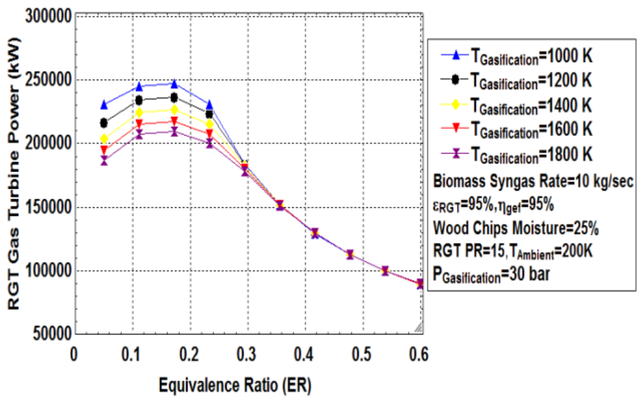

Fig.7: *Influence of Equivalence Ratio on RGT Power at different gasification temperatures.*

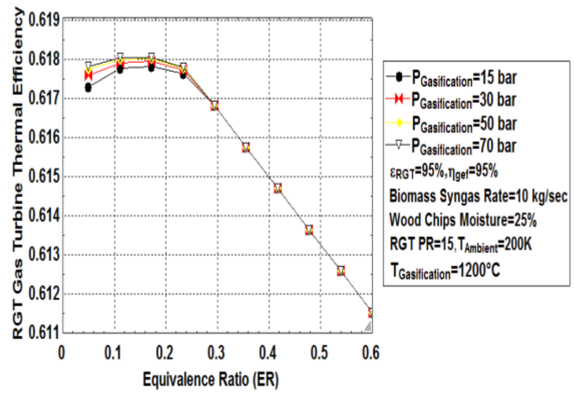

Fig.8: *Effect of Equivalence Ratio and gasification pressure on the RGT thermal efficiency.*

Fig.7 depicts the variation of the ER ranged between 5-60%, and the RGT power at different gasification temperatures (1000-1800K). At a syngas rate of 10kg/sec, wood moisture of 25%, and a gasification pressure of 30 bar. The result displayed an increase in ER, till an optimum amount of the equivalence ratio (18%), through after the further increase of the ER has led to a decrease in the RGT gas turbine power. This is attributed to the massive decrease of the syngas energy content, and the growth of the oxidative combustion reactions. Fig.8 displays the relationship between the ER in the range of 5-60%, and the RGT thermal efficiency. The results depicted that, the RGT thermal efficiency is higher at the optimum equivalence ratio at 18% attaining a value of 61.80% for RGT compressor inlet temperature of 200K, and compression ratio of 15. The higher RGT thermal efficiency at the optimum ER, is attributed to the increase in the energy content of the syngas heat value, which has the lowest irreversibilities as the combustor maximizes the power of the RGT turbine.

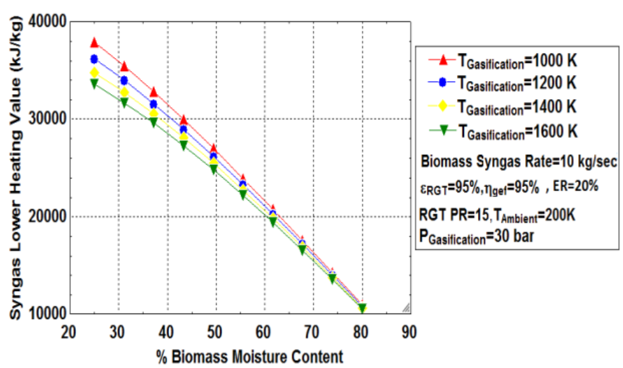

Fig.9: *Variation of Biomass moisture content with the Syngas Lower Heating Value at different gasification temperatures.*

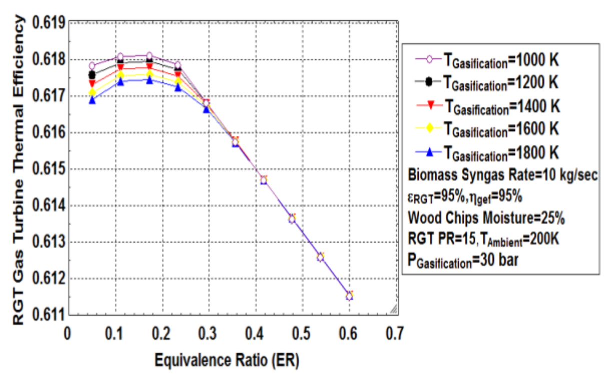

Fig.10: *Variation of Equivalence Ratio with RGT thermal efficiency at different gasification temperatures.*

As plotted in Fig.9, the model verified that increasing the biomass moisture content from 25-80%, has resulted in a massive slowdown of syngas lower heating value for different gasification temperatures. The moisture contents normally identify the quality of the Biomass fuel [39][40]. High quantity of the Biomass moisture content effects the cellular part of the biomass resulting in a decrease of the main syngas constituents of H_2, CO, and CH_4. In addition, the results verified that higher the gasification temperature, lower the RGT thermal efficiency (see Fig.10). Fig.11 observed that increasing of gasification pressure has influence on the syngas LHV, due the enhancement of the gasification reactions and the growth of the major constituents of the syngas product.

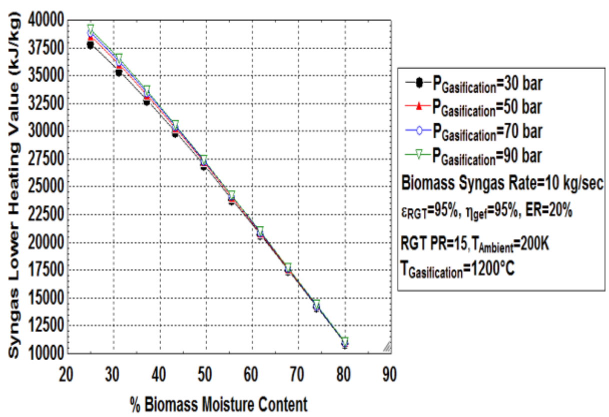

Fig.11: Variation of Biomass moisture content with the Syngas Lower Heating Value at different gasification pressures.

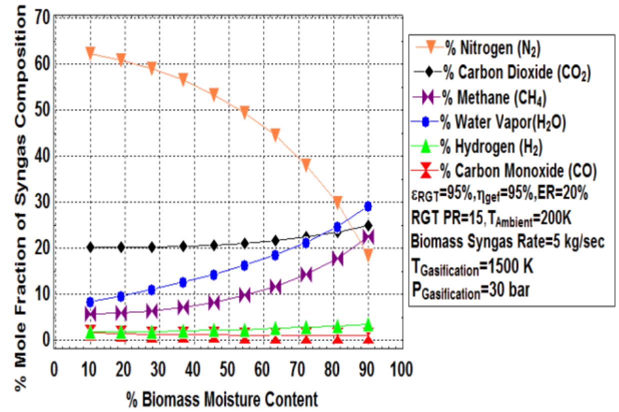

Fig.12: Effect of Biomass moisture content on the Wood Chip Syngas composition.

At the ER of 20%, biomass syngas rate of 5 kg/sec, gasification temperature of 1500 K and pressure of 30 bar, Fig.12, depicted the variation of the biomass moisture content and the final syngas composition. The prediction results show a gradual growth for the concentration of the constituent CO_2, CH_4, H_2, and H_2O, a reduction in the concentration for the CO and the N_2, amid increasing moisture content. The nitrogen content in the final syngas product, was significantly reduced by the increase of the biomass moisture content.

CONCLUSIONS

This work discussed and investigated the integration of the Biomass Gasifier unit with a Regenerative Gas Turbine power plant, including the effect of various parameters. Simulation models were used to characterize the gasification process of wood chips in Sudan. A parametric analysis of the released syngas composition, actual gasifier air, temperature, pressure, LHV, Moisture content, Equivalence Ratio, gasifier efficiency, the thermal efficiency, Power, Heat Rate, and Specific fuel consumption of the Regenerative gas turbine power plant were investigated carefully to identify the optimal design points of the gasifier system and the working conditions of the RGT power unit using such type of Biomass. With an average syngas LHV of 30000 MJ/kg, locally available wood chips can be used to produce syngas that is significantly cleaner than

NOMENCLATURE

Symbols

T	Temperature	(K)	T_X	Combustor Inlet	(K)
S	Entropy	(kJ/kg.K)	$\Delta P_{C.C}$	Combustor Pressure	(bar)
P	Pressure	(kPa)	$\eta_{C.C}$	Combustor Efficiency	-
r_P	Compression Ratio	-	ε	Regenerator	-
γ	Specific Heat Ratio	-	$\dot{W}_{GT}$	Turbine Shaft Work	(MW)
η_C	Isentropic Compressor	-	η_T	Turbine Efficiency	-
η_{gef}	Gasifier Efficiency	-	y_i	Syngas Mole Fraction	-
T_S	Compressor Isentropic	(K)	P_{GT}	GT Power	(MW)
$\dot{W}_C$	Specific Compressor Work	(MW)	$\dot{Q}_{add}$	Heat Supplied	(kW)
$\dot{m}_a$	Air Mass	(kg air)	C_{Pa}	Heat Capacity of Air	(kJ/kg.K)
$\dot{m}_f$	Fuel Mass	(kg.fuel)	C_{Pf}	Heat Capacity of Fuel	(kJ/kg.K)
$\dot{m}_g$	Gas Mass	(kg.gas)	C_{Pg}	Heat Capacity of Flue	(kJ/kg.K)
M_{da}	Gasifier Stoichiometric Air	(kg air/kg dry	M_a	Gasifier Actual Air	(kg air)

Subscripts

PR	Pressure ratio	ATM	Atmospheric
ER	Equivalence Ratio	HHV	Higher Heating Value
RGT	Regenerative Gas Turbine	LHV	Lower Heating Value

Mech	Mechanical	TIT	Turbine Inlet Temperature
Gen	Generator	ASH	Ash Content
AFR	Air Fuel Ratio	HR	Heat Rate
EES	Engineering Equation Solver	SFC	Specific Fuel Consumption
CC	Combustion Chamber		

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