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Energetic Assessment of Syngas Fuel for 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. As observed, at low ambient temperatures, equivalence ratio growth at low levels has significant reducing effect on the specific fuel consumption (SFC) of the regenerative gas turbine (RGT) power plant. The specific fuel consumption of the RGT power plant remains low at higher gasification pressures. As observed, the higher the wood chips of Acacia syngas rate, the more air is required to complete the gasification reactions, depending on the moisture content of the feed biomass rates. In addition, results observed that, at optimum air equivalence ratio (ER), the higher the biomass moisture content, the lower the gasifier's air low rate. Results revealed that, the combustor heat rate remains low at higher gasification pressure. At low ambient temperature and growth level of the ER, results observed gradual decreases of the RGT combustor heat rates. Results verified that, for RGT pant at low ambient temperatures, heat rates remain low at lower gasification temperature, and higher heating value of the syngas. The RGT thermal efficiency remains low at higher gasification temperatures. The CO, H_2, CH_4 mole fractions at the syngas final product show decreases amid increasing of the syngas rates and remain high at lower gasifier's ER. Moreover, results observed that, increasing of the Acacia wood chips syngas rate has led to decrease sharply the RGT thermal efficiency due irreversibilities. Results show that ER growth at low level increases the RGT power plant to an optimum limit. Results concluded that at lower level of ER and for constant syngas rate, temperature, pressure, and low compressor inlet temperature the RGT power is higher at lower gasifier efficiency due to the excess amount of wood chips, whereas at moderate and higher rates of the gasifier's air ER, the RGT power is higher at higher gasifier efficiency.

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. 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), 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

Fig.1: Wood Biomass in Sudan.

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.

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) alongwith methanation and water shift reactions provide for the enthalpy equations applied as (McKendry, 2002):

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

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.

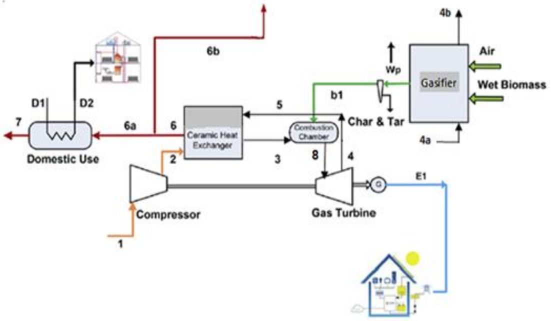
Parameter	Value	Unit
Rated Biomass Consumption	4-13	kg/s
Gasification Temperature	1000-1600	ºC
Temperature of Gas at Gasifier Outlet	250-400	ºC
Biomass Feeding	Machinery	-
Desired Gasifier Operation	Continuous (minimum 300)	days/yr
Gas Turbine Inlet Temperature	1200	ºC
Compressor Pressure Ratio	15	-
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.

3. **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.



4.

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):

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

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):

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

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 (Basu, 2010):

$$M_a = m_{th}.ER \tag{5}$$

For a fuel feed rate of M_f, the air requirement of the gasifier, M_{fa}, is (Basu, 2010):

$$M_{fa} = m_{th}.ER.M_f \tag{6}$$

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):

$$ER(< 1.0)_{gasification} = \frac{Actual\ Air}{Stoichiometric\ Air} = EA(> 1.0)_{combustion} \tag{7}$$

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):

$$\eta_{cg} = \frac{Q_g M_g}{LHV_{bm} M_f} \tag{8}$$

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

$$\eta_{hg} = \frac{Q_g M_g + M_g C_p (T_f - T_0)}{LHV_{bm} M_f} \tag{9}$$

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):

$$P_1 = P_{atm} - \Delta P_{intake} \tag{10}$$

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):

$$r_P = \frac{P_2}{P_1} \tag{11}$$

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):

$$\frac{T_1}{T_{2s}} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma_a-1}{\gamma_a}} \tag{12}$$

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):

$$\eta_c = \frac{T_{2s} - T_1}{T_2 - T_1} \tag{13}$$

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):

$$\dot{W}_c = \dot{m}_a C_{P_a}(T_2 - T_1) = \dot{m}_a C_{P_a} T_1 \left[\frac{r_p^{\frac{\gamma_a-1}{\gamma_a}} - 1}{\eta_c}\right] \tag{14}$$

With the specific heat of air taken as $C_{P_{air}} = 1.005\ \frac{kJ}{kgK}$, which can be substituted into Equations (6) and (7) for the range of (Rahman, Ibrahim, & Abdalla, Thermodynamic Performance Analysis of Gas Turbine Power Plant, 2011):

If $(T_1 \leq 800K)$

$$C_{P_{air}} = 1018.9 - 0.1378 \times T_1 + 1.9843 \times 10^{-4} \times T_1^2 + 4.2399 \times 10^{-7} \times T_1^3 - 3.7632 \times 10^{-10} \times T_1^4 \tag{15}$$

If $(T_1 > 800K)$

$$C_{P_{air}} = 7.9865 \times 10^2 - 0.5339 \times T_1 - 2.2882 \times 10^{-4} \times T_1^2 + 3.7421 \times 10^{-8} \times T_1^3 \tag{16}$$

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):

$$C_{P_g} = 1.8083 - 2.3127 \times 10^{-3} \times T + 4.045 \times 10^{-6} \times T^2 - 1.7363 \times 10^{-9} \times T^3 \tag{17}$$

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

$$\dot{m}_a C_{P_a} T_x + \dot{m}_f LHV + \dot{m}_a C_{P_f} T_f = (\dot{m}_a + \dot{m}_f) C_{P_g} T_{it} \tag{18}$$

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):

$$\eta_{C,C} = \frac{\dot{m}_g C_{P_g} T_{it} - \dot{m}_a C_{P_a} T_x}{\dot{m}_f * LHV_{gas}} \tag{19}$$

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

$$AFR = \frac{A}{F} = \frac{\dot{m}_a}{\dot{m}_f} \tag{20}$$

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

$$\dot{m}_g = \dot{m}_a + \dot{m}_f \tag{21}$$

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

$$\frac{T_3}{T_{4s}} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma_g-1}{\gamma_g}} \tag{22}$$

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

$$\eta_t = \frac{T_3 - T_4}{T_3 - T_{4s}} \tag{23}$$

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

$$\varepsilon = \frac{T_x - T_2}{T_4 - T_2} \tag{24}$$

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

$$\dot{W}_{GT} = \dot{m}_g C_{P_g}(T_4 - T_{it}) = \dot{m}_g C_{P_g}\eta_t T_{it}\left[1 - \frac{1}{r_p^{\frac{\gamma_a - 1}{\gamma_a}}}\right] \tag{25}$$

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

$$\dot{W}_{GT,Net} = \dot{W}_{GT,Net} - \dot{W}_C = \dot{m}_g C_{P_g}\eta_t T_{it}\left[1 - \frac{1}{r_p^{\frac{\gamma_g - 1}{\gamma_g}}}\right] - \dot{m}_a C_{P_a} T_1\left[\frac{r_p^{\frac{\gamma_a - 1}{\gamma_a}} - 1}{\eta_c}\right] \tag{26}$$

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

$$P_{GT} = [\dot{W}_{GT} - \dot{W}_C] \times \eta_{Mech}\eta_{Gen} \tag{27}$$

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):

$$\dot{Q}_{add} = \dot{m}_g C_{P_g} T_{it} - \dot{m}_a C_{P_a} T_x \tag{28}$$

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

$$Q_{add} = \frac{\dot{m}_f \times \eta_{C,C} \times LHV_{gas}}{\dot{m}_{air}} = \frac{\eta_{C,C} \times LHV_{gas}}{AFR} \tag{29}$$

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

$$\eta_{over,GT} = \frac{\dot{W}_{GT,Net}}{\dot{Q}_{add}} \tag{30}$$

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):

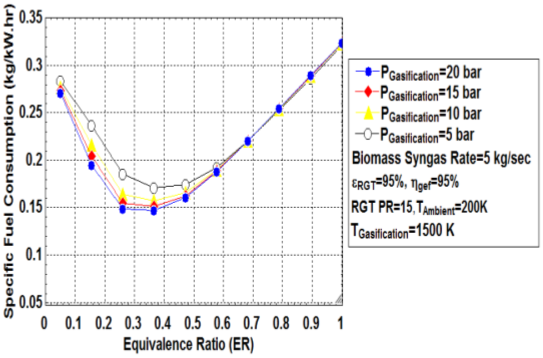
$$HR = \frac{3600 * \dot{m}_f * LHV}{\dot{W}_{GT,Net}} \tag{31}$$

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

$$SFC = \frac{3600 * \dot{m}_f}{\dot{W}_{GT,Net}} \tag{32}$$

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). Fig. 3, shows the effect of the ER on the specific fuel consumption (SFC) of the regenerative gas turbine at different gasification pressures (5-20 bar). As observed, at low ambient temperatures, equivalence ratio growth at low levels has significant reducing effect on the specific fuel consumption (SFC) of the RGT power plant. The SFC of the RGT power plant remains high at low levels of the ER, till an optimum ER is reached. An optimum ER for each gasification pressure is observed, in which the further increase of the ER has led to activate the oxidative combustion reactions, generating less effective syngas constituents, and minimizing the energy content of the syngas, which influenced the regenerative gas turbine power plant (RGT) to increase the specific fuel consumption and demanding more fuels. The increase in the regeneration effectiveness will normally decrease the specific fuel consumption for a lower and moderate compression ratio. Important to note, the specific fuel consumption of the regenerative gas turbine power plant (RGT) remains low at higher gasification pressures. Despite a constant syngas rate of 5kg/s the produced syngas contains different constituents at different levels of energy content, which are strongly dependent on the ER of the gasifier at the gasification reactions.



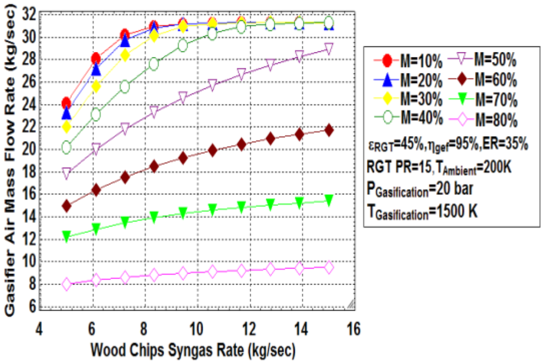
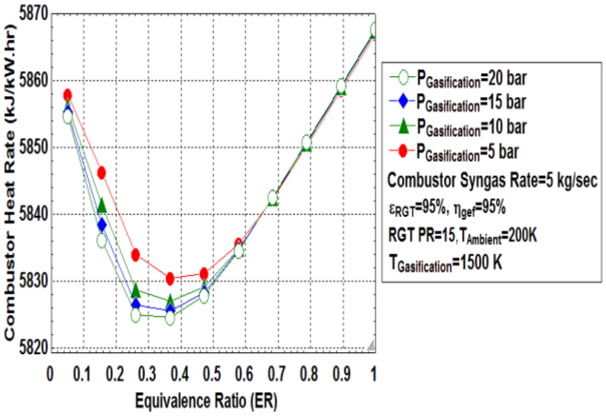


Fig.3: *Variation of Equivalence Ratio with Gasifier Biomass Mass Flow Rate at different Wood Chips syngas rates.*

***Fig.4**: Variation of Biomass moisture content with RGT thermal efficiency at different gasification pressures.*

As observed, the SFC of the RGT power plant decreases sharply from the maximum value of 0.28 kg/kWh at ER of 5%, to the minimum value of 0.15 kg/kWh at ER of 35%, for the highest gasification pressure of 20 bar. Fig. 4, depicted the variation of the wood chips (Acacia) syngas rate and the gasifier's air mass flow rates at different moisture content. As observed, more wood chips of Acacia syngas rates use more air to complete the gasification reactions, depending on the moisture content of the feed biomass rates. In addition, results observed that, the higher the biomass moisture content, the lower the gasifier's air flow rate. At constant air equivalence ratio of 35%, gasification pressure of 20 bar, temperature of 1500K, the lowest gasifier's air attained at 8 kg/s for the syngas rate of 5 kg/s, moisture content of 80%, whereas the highest gasifier's air rate observed at 31 kg/s for the syngas rate of 15 kg/s, and moisture content of 10%. At the optimum ER, higher moisture contents demand less amount of biomass feed rates for a complete gasification reaction.



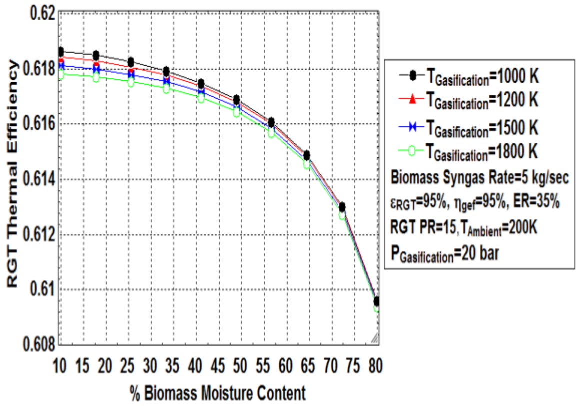


Fig.5: *Equivalence Ratio versus Syngas lower heating value at different Wood Chips syngas rates.*

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

Fig. 5, displays the effect of the equivalence ratio (ER) on the combustor heat rate at varying gasification pressures. Heat rate is the significant parameter to measure the efficiency of the electrical RGT power plant, that convert the fuel into heat and electricity. As observed in Fig.5, the combustor heat rate remains low at higher gasification pressure. At low ambient temperature and growth level of the ER, results observed gradual decreases of the RGT combustor heat rates. Since low levels of the ER promote higher energy content of the syngas and low demand of the fuel by the combustor as well as improvement of the thermal efficiency, heat rate of the RGT declines sharply. Beyond the optimum ER, results display gradual increase of the heat rate. The heat rate is strongly dependent on the lower heating value of the syngas, the plant's design, its operating conditions, and its level of electric power output. The fuel used in the RGT can indirectly affect the thermal efficiency and the heat rate. At low levels of ER, thermal efficiency of the RGT power plant exhibited gradual increase due high energy content of the fuel, and the heat rate remains low.

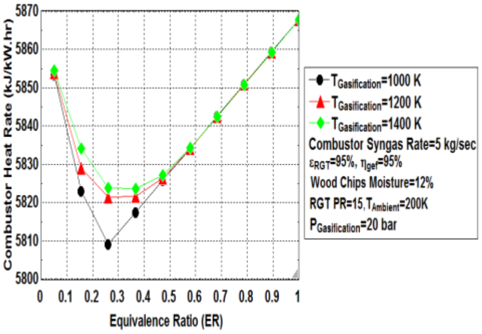


***Fig.7:** Influence of Equivalence Ratio on RGT Power at different gasification temperatures.*

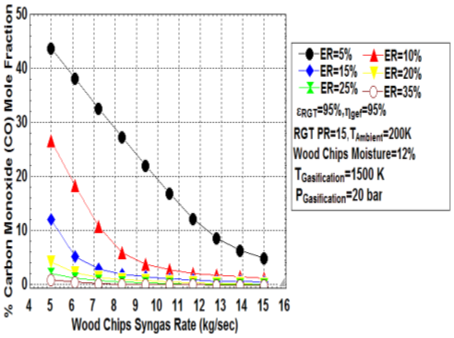


***Fig.8:** Effect of Equivalence Ratio and gasification pressure on the RGT thermal efficiency.*

Thus, for a RGT power plant, lower the heat rate, better the plant's efficiency, and lower the fuel demand of the combustor. Results verified that, for RGT pant at low ambient temperatures, heat rates remain low at lower gasification temperature (see Fig.7), and higher heating value of the syngas. Heat rate of the RGT plant can increase the emission of the pollutant gases, affecting the turbine's blades, regenerator heat, reducing the combustor's efficiency, and increasing the irreversibilities. For RGT at low temperature and constant regenerator effectiveness, results observed that the increase of the lower heating value has led to slow down the heat rate, however at higher ambient temperatures, the increase of the LHV led to increase the heat rate of the RGT combustor. At syngas rate of 5 kg/s, gasification temperature of 1500K, and biomass moisture content of 12%, the heat rate revealed minimum value of 5825 kJ/kWh at the optimum ER of 35% for gasification pressure of 20 bar and reached 5810 kJ/kWh at gasification temperature of 1000 K. Fig.6, displays the relationship between the biomass moisture content and the RGT thermal efficiency at different gasification temperatures (1000-1800K). As observed, the increase of the biomass moisture content decreased the RGT thermal efficiency.

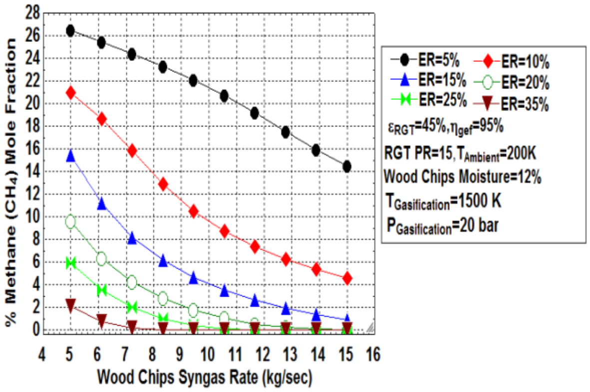


***Fig.9:** Variation of Biomass moisture content with the Syngas Lower Heating Value at different gasification temperatures.*

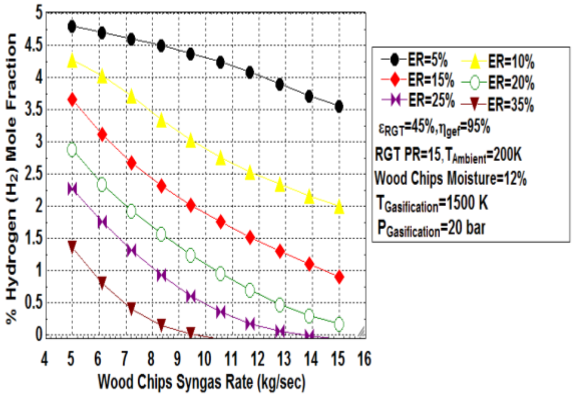


***Fig.10:** Variation of Equivalence Ratio with RGT thermal efficiency at different gasification temperatures.*

At 200 K and gasification pressure of 20 bar, the RGT thermal efficiency delivered a higher value of 61.80% at the lowest Biomass moisture content and the lowest value achieved at 60.90% at higher rates of moisture of 80%. Results observed that RGT thermal efficiency remains low at higher gasification temperatures. Higher values of biomass moisture content led to low energy content, which yielded low values of RGT thermal efficiency. As the quantity of the moisture content decreases, higher amounts of water must be evaporated, and more energy will be released at the gasifier. Since the heat required to vaporize this amount of water is transferred from the syngas constituents, the temperature of the products decreases, thus declining the energy content as well as the physical and chemical exergy of the syngas. The decrease of the gasification temperatures has positively influenced the RGT thermal efficiency, due enhancement of the water-gas shift and Boudouard reactions.

Fig. 8,9,10, depict the variation of the Acacia wood chips syngas rate and the CO, H_2, CH_4 percentage mole fraction for different gasifier's equivalence ratios. The CO, H_2, CH_4 mole fractions at the syngas final product show decreases amid increasing of the syngas rates and remain high at lower gasifier's air equivalence ratio (ER). At syngas rate of 5 kg/s, moisture of 12%, gasification temperature of 1500K, pressure of 20 bar, CO, CH_4, H_2 mole fraction reached the highest value of 45%, 26%, 4.80% for ER of 5% respectively, whereas reached 1.80%, 2%, 1.50% at the ER of 35%

respectively. Fig. 11, observed the relationship between the Acacia wood chips syngas rate and the RGT thermal efficiency for different Biomass moisture contents. As evident, increasing of the Acacia wood chips syngas rate leads to a sharp decrease in the RGT thermal efficiency. The production of more syngas uses more Acacia wood chips biomass and air inlet, causing a decline of the gasifier efficiency and the energy content of the final syngas product. Gasification of the biomass fuels results in gas mixture mainly consist of CO, H_2, N_2, CO_2 and some hydrocarbons. The main constituents of the syngas product that carry energy content is the CO_2, H_2 and CH_4 (see Fig.8,9,10). The unwanted materials such as Tar, Char and Ash have negative effects on the quality of the syngas rates, which influences the syngas fuel that will reveal less energy density, lower heating value, H_2/CO ratio, and fraction up to 50% of non-combustible products such as carbon monoxide and nitrogen. To achieve high performance of gasification's products, the gasification efficiency should be maximized with possible lower irreversibilities.

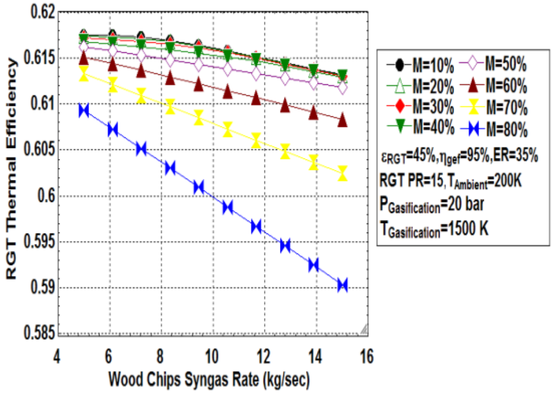


Fig.11: *Variation of Biomass moisture content with the Syngas Lower Heating Value at different gasification pressures.*

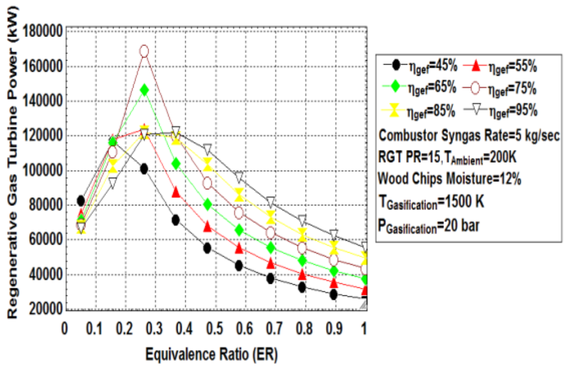


Fig.12: *Effect of Biomass moisture content on the Wood Chip Syngas composition.*

power produced at the RGT unit depend mainly on the quality of the produced syngas. The air equivalence ratio as the main parameter of the syngas quality and gasification efficiency affects the RGT power. The produced syngas composition depends mainly on the amount of the supplied air to the gasifier. The energetic and exergetic efficiency decreases with ER in all temperature and pressure ranges. The simulation results at Fig.12, carried out to predict the RGT power output at varied equivalence ratio of ER ranged between 5-100%, at constant syngas rate of 5 kg/s, gasification temperature of 1500K, pressure of 20 bar, regenerator effectiveness of 95%, compressor ambient temperature of 200K and moisture content of 12%, which are investigated at different gasifier efficiencies. Results show that ER growth at low level increases the RGT power plant to an optimum limit. Beyond the optimum point, the increase of the ER led to decline sharply the RGT power, due to shifting of the process more towards oxidative combustion reactions, and the change of the energy content of the constituent gas. Practically with the increase of the gasifier's ER, the temperature of the product gases increases. Moreover, results concluded that at lower level of ER and for constant syngas rate, temperature, pressure, and low compressor inlet temperature the RGT power is higher at lower gasifier efficiency due excess amount of wood chips biomass, whereas at moderate and higher rates of the gasifier's air ER, the RGT power is higher at higher gasifier efficiency. Higher rates of the ER mean high irreversibilities, less energy content of the syngas, and more fuel demand by the combustor.

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, the results show that locally available wood chips can achieve a high thermal efficiency and be a valuable energy saving process for Regenerative Gas Turbine Unit.

NOMENCLATURE

Symbols

T	Temperature	(K)	T_X	Combustor Inlet Temperature	(K)
S	Entropy	(kJ/kg.K)	$\Delta P_{C,C}$	Combustor Pressure Drop	(bar)
P	Pressure	(kPa)	$\eta_{C,C}$	Combustor Efficiency	-
r_P	Compression Ratio	-	ε	Regenerator Effectiveness	-
γ	Specific Heat Ratio	-	$\dot{W}_{GT}$	Turbine Shaft Work	(MW)
η_C	Isentropic Compressor Efficiency	-	η_T	Turbine Efficiency	-
η_{aef}	Gasifier Efficiency	-	y_i	Syngas Mole Fraction	-
T_S	Compressor Isentropic Temperature	(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)
$\dot{m}_a$	Gas Mass	(kg.gas)	C_{Pa}	Heat Capacity of Flue Gas	(kJ/kg.K)
M_{da}	Gasifier Stoichiometric Air Flow Rate	(kg air/kg dry	M_a	Gasifier Actual Air Flow Rate	(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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