Woody Biomass Cogeneration with Hot Air Turbine: Application to a Wood Pellet Production Unit in Algeria

Amel Hamdi, Mohammed Amouri, Hocine Bennour, Toudert Ahmed Zaïd & Rabah Bouarab

Abstract− In this paper, the performance of a hot air turbine operating in an industrial combined heat and power (CHP) cogeneration is investigated, electrical and thermal energy supplied are intended for a pellet production unit. This unit is powered by Eucalyptus residue at 50% moisture content recovered from a forest located in El Taref, north-east of Algeria. The results show that when the air temperature at the boiler inlet Te exceeds 100 °C, an excess air ratio α above 90 % is required to maintain the flame temperature below 1200 K. Based on this, the parameters were set to α = 80 % and Te = 100 °C, resulting in a flame temperature of 1192 K. The turbine inlet temperature T3, which must remain below the flame temperature, was fixed at 1140 K. Once these conditions were established, the compression ratio maximizing the overall efficiency was determined to be around 8, yielding a cogeneration efficiency of 53 %, with an electrical efficiency of 20 % and a thermal efficiency of 33 %.

***Keywords*−Biomass, Cogeneration, Hot air turbine, Pellet.**

NOMENCLATURE

C_{ph}	specific oil (kJ/kg K)
C_{pb}	specific heat wood (kJ/kg K)
C_{pf}	specific heat of fume (kJ/kg K)
C_{P_a}, C_{P_g}	specific heats of air and products of combustion respectively (Btu/lb °F)
h	enthalpy (kJ/kg)
$\dot{m}_b$	wood mass flow rate (kg/s)
$\dot{m}_{cog}$	amount of wood for cogeneration system (kg/s)
$\dot{Q}$	Dryer heat requirement (kW)
$\dot{Q}_C$	Condenser heat rejection rate (kW)
$\dot{w}_{ORC}$	ORC power (kW)
$\dot{W}_{net}$	power required to supply the production unit (kW)
T	temperature (K)
τ	compression ratio
CHP	combined heating and power
ORC	Organic rankine cycle
LHV	lower heating value
HHV	higher heating value
α	total air ratio
α_0	excess air ratio
ε	gas / oil exchanger efficiency
η	efficiency

Manuscript received November 22, 2025; revised January 5, 2026.
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Digital Object Identifier (DOI): 10.53907/enpesj.v5i2.352

I. INTRODUCTION

The most common primary energy sources are fossil fuels like coal, natural gas, and petroleum, but their emissions seriously harm the environment by causing acid rain, global warming, ozone layer degradation, and ecosystem contamination. Supporting a sustainable energy transition and addressing environmental issues can be achieved through promoting and developing renewable energy [1]-[3].

As the best long-term solution to achieve environmental goals, the Algerian government is committed to promoting renewable energy through related policies and programs aimed at preserving dwindling fossil resources [4].

Initially the objectives of the National Plan for Renewable Energy (2011-2020) were to reach 11.000 MW of RE by 2030. However, in 2015, the Algerian government revised the initial program to target 22,000 MW of renewable energy by 2030 with the objective that 27% of all electricity produced come from renewable sources [5], [6].

Biomass has been recognized as a promising energy source. because it offers many social, economic, and environmental benefits [7]-[9], Currently, there is significant interest in utilizing agricultural waste as a replacement for fossil fuel. It can significantly contribute to decarbonizing energy production and achieving carbon neutrality targets [10], [11]. The pretreatment of biomass to improve its fuel quality or to meet specific performance standards across different energy system scales is a widely adopted practice. Biomass pelletization through the densification of raw materials significantly increases bulk density and reduces storage and transportation costs. In comparison to the direct combustion of untreated biomass, the use of biomass pellets in specially designed stoves can greatly enhance combustion efficiency and reduce pollutant emissions. It is widely recognized that, due to their higher density, biomass pellets exhibit slower devolatilization and prolonged combustion duration, which promotes more complete and efficient [12], [13].

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Wood pellets are characterized by a high bulk density of up to 750 kg/m³ and a lower heating value of approximately 16.5 GJ per ton. In contrast, woodchips have a lower bulk density of around 250 kg/m³ and an energy content of about 13 GJ per ton [14]. According to Monteiro et al. [15], combining biomass power generation with pellet production plants represents a highly effective strategy for optimizing pellet manufacturing processes. Combined heat and power (CHP) operations often represent the most efficient use of biomass, The energy conversion rate of biomass cogeneration can reach more than twice that of pure power generation [16], [17]. Various biomass cogeneration systems have been developed and implemented to optimize the production of heat and electricity. Wood combustion generates exhaust gases at high temperatures typically between 900 and 1000 °C [18], [19], which makes it especially well-suited for integration with high-temperature heat recovery technologies such as hot air turbines. Hot air turbines are a developing technology that enables the use of low-quality fuels by isolating the working fluid from combustion gases. Heat is transferred through a high-temperature exchanger operating above 900 °C to ensure reliable turbine operation [20], [21]. Indeed, Ibrahim et al. [22] highlighted in their study that the air temperature at the inlet of the turbine and the compressor's air compression ratio are critical parameters in this technology, with an optimal compression ratio existing that maximizes the system's efficiency.

This study analyzes a cogeneration system designed to supply 500 kW of electrical power for the production unit and to deliver thermal energy (via flue gases at 400–600 °C) for wood drying in a rotary drum dryer. A mathematical model was developed to evaluate system performance and optimize its operating parameters. The simulations are carried out in MATLAB using thermodynamic properties from the CoolProp database. An algorithm has been developed to determine the following parameters:

1. The variation of exhaust gas temperature at the chimney outlet,
2. the variation of flue gas temperature at the dryer outlet,
3. the variation of the electrical efficiency of the system,
4. The variation of the thermal efficiency of the system and
5. the variation of the overall cogeneration efficiency, as functions of the compression ratio, flame temperature, and turbine inlet air temperature.

This parametric study enabled the identification of the system's optimal parameters and the estimation of the required wood quantity for the project.

II. Materials and Methods

A. Production Unit

Wood pellets, made from wood industry byproducts, are 6–8 mm in diameter and up to 40 mm long. Production involves chipping, crushing, drying, pelletizing, and cooling, followed by packaging for transport [23]. A simplified representation of a typical unit available on the global market is shown in Fig. 1, along with the amount of electricity required for each stage of the process [24].

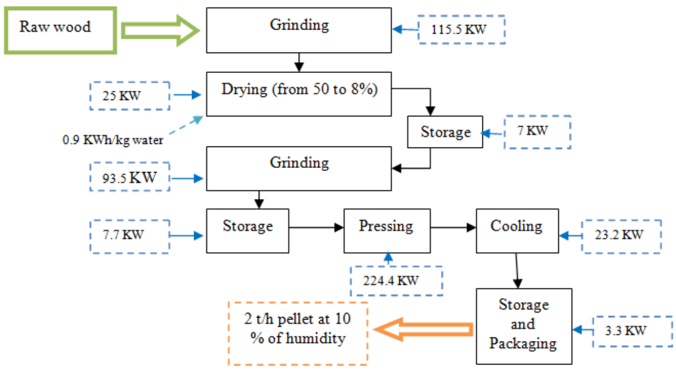

Fig. 1: A simplified representation of a common pellet production unit.

B. Biomass Resources

This study is based on the assumption of continuous wood availability, used as a working hypothesis to simplify the model and focus on the technical aspects of energy consumption. The assumption, validated by the General Directorate of Forests (DGF), presumes constant wood production throughout the year. The exploitable areas were determined according to a five-year program (see Table I).

Table. I
Exploited area from 2016 to 2020 and quantity of slash recovered from El Taref forests [31]

Year	2016	2017	2018	2019	2020
Exploited area (ha)	619	780	747	1000	782
Slash recovered (ton)	7738	9750	9338	12500	9775

In El Taref region, Eucalyptus plantations cover 10,822 hectares. Eucalyptus is well-suited for short-rotation systems due to its fast growth, environmental adaptability, and high lignin and cellulose content, making it ideal for biomass-based heat and electricity production. These plantations also support soil regeneration and reduce erosion [25], [26]. The DGF estimates that 20 to 30 m³/ha of woody biomass with a density of 500 kg/m³ can be recovered; this study assumes a recoverable volume of 25 m³/ha. The elemental composition of Eucalyptus is shown in Table II.

C. Combustion Assumptions

The study assumes complete combustion of wood, with all products gaseous except for ashes. Considering air contains 3.76 moles of nitrogen per mole of oxygen, the theoretical air needed for combustion is calculated. For raw wood at 50% moisture, 2.81 kg of air per kg of wood is required, with 25–100% excess air typically used to ensure full combustion [27].

Table. II
Elemental mass composition based on dry substance and at 50% moisture content [32]

	C	H	O	N	S	Ash
Dry	48.33	5.89	45.13	0.15	0.01	0.49
50 % moisture content	24.16	2.95	22.56	0.07	0.01	0.24

D. Composition of Flue Gases

Assuming complete combustion of Eucalyptus with ashes settling in the furnace, the resulting flue gases contain CO2, H2O, SO2, N2, and O2 (when excess air is present). The fuel's smoke power, measured as kilograms of smoke per kilogram of raw wood, is calculated as follows.

$$m_f = [CO_2] + [H_2O]_f + [SO_2] + [N_2] + [O_2] \quad (1)$$

where: [CO2], [H2O], [SO2], [N2] and [O2], represent masses formed from the combustion of 1 kg of raw fuel.

E. Calorific value of the fuel

The higher heating value (HHV) and lower heating value (LHV) of the fuel are determined using correlations based on the mass composition (dry basis). Using various calculations, the average values of HHV and LHV are 19220 kJ/kg and 7700 kJ/kg, respectively [28], [29].

F. Flame temperature T5

According to empirical formulas in the literature, furnace combustion is not totally adiabatic. One such formula is Eq. 2 (from [30]) as follows:

$$T_5 = \frac{LHV + A\alpha(HHV)C_{p_a}(T_a - 80)10^{-6}}{(1-0.01)(Ash) + A\alpha(HHV)C_{p_g}10^{-6}} \quad (2)$$

where: A is the theoretical air required per million (Btu fired,lb) (A = At * 106/HHV); Cpa and Cpf are the specific heats of air and products of combustion respectively (Btu/lb. °F); the LHV and HHV are given in British thermal units (Btu/lb); (Ash) is given as a percentage; α : total air ratio (theoretical air ratio + excess air ratio α0). Theoretical air ratio is the ratio of the actual air required to the stoichiometric air required. For perfect combustion, the theoretical air ratio is 1.

III. System Description

The proposed TAC system for the cogeneration unit is illustrated in Fig. 2.

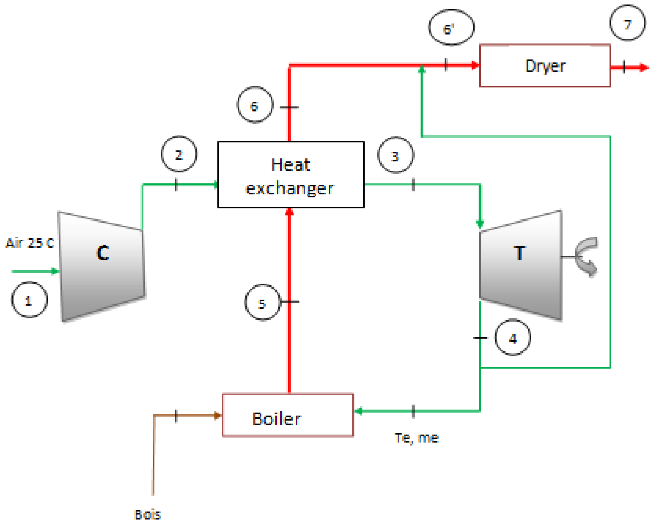

Fig 1: Hot air turbine system proposed for the cogeneration unit

It consists of a boiler, a compressor, a heat exchanger, and a turbine. Combustion gases from the wood-fired boiler can reach temperatures of up to 950 °C. These hot gases are directed into a heat exchanger, where they are used to heat air that has been previously compressed. After passing through the heat exchanger, the compressed air reaches high temperatures, typically between 700 and 950 °C. This hot air then drives a turbine connected to a generator, producing electricity. At the turbine outlet, the air remains hot. A portion of this air is mixed with the combustion gases exiting the heat exchanger and routed to a wood dryer, which is part of the pellet production unit. The remaining hot air is mixed with ambient air to improve combustion efficiency in the boiler.

A. Hypotheses

All operations (compressions, expansions, and heat exchanges) are assumed to be internally reversible; the air is assumed to behave as an ideal gas. The calculations were conducted with the following parameters: isentropic efficiency of the turbine (ηisT=0.90), Compressor efficiency (ηc =0.88) and T1: air temperature at compressor inlet (T1=25 C).

B. Balance Sheet on the Cogeneration Unit

The temperature rise across the compressor is determined using the following thermodynamic relationship

$$T_{2s} = T_1 * \tau^{\frac{\gamma-1}{\gamma}} \quad (3)$$

Noting that $\alpha = \frac{\gamma-1}{\gamma}$, it yields

$$T_{2s} = T_1 * \tau^{\alpha} \quad (4)$$

The efficiency of the compressor is defined as follows:

$$\eta_c = \frac{T_{2s}-T_1}{T_2-T_1} \quad (5)$$

$$T_2 = T_1 * (1 + \frac{\tau^{\alpha}-1}{\eta_c}) \quad (6)$$

However, T_{4s} can be expressed as follows

$$T_{4s} = T_3 * \tau^{-\alpha} \quad (7)$$

The turbine efficiency is defined as follows:

$$\eta_t = \frac{T_3-T_4}{T_3-T_{4s}} \quad (8)$$

which gives

$$T_4 = T_3(1 - \eta_t * (1-\tau^{-\alpha})) \quad (9)$$

Energy balance on the air-gas heat exchanger is given as follows

$$\dot{m}_a Cp_{a2}T_2 + \dot{m}_f Cp_{f5}T_5 = \dot{m}_a Cp_{a3}T_3 + \dot{m}_f Cp_{f6}T_6 \quad (10)$$

$$\frac{\dot{m}_a(Cp_{a2}T_2 - Cp_{a3}T_3) + \dot{m}_f Cp_{f5}T_5}{\dot{m}_f} = Cp_{f6}T_6 \quad (11)$$

where, Eq. 11 is solved by iterations using MATLAB to find T6, while Cp_{f6} is determined as a function of T6.

A portion of the air exiting the turbine is injected into the flue gases leaving the heat exchanger. To determine the mass flow rate of ambient air ($\dot{m}_e$) required to achieve the desired air temperature at the boiler inlet, an energy balance is performed at point e, where the hot air from the turbine mixes with ambient air.

$$\dot{m}_a Cp_{a4}T_4 + \dot{m}_e Cp_{a25}T_{atm} = \dot{m}_a Cp_{aTe}T_e + \dot{m}_e Cp_{a4}T_4 \quad (12)$$

$$\dot{m}_e = \frac{\dot{m}_a(Cp_{aTe}T_e - Cp_{a4}T_4)}{(Cp_{a25}T_{atm} - Cp_{a4}T_4)} \quad (13)$$

The energy balance at point 6′, representing the mixing of combustion gases with turbine outlet air, is expressed as:

$$\dot{m}_e Cp_e T_4 + \dot{m}_{f6} Cp_{f6} T_6 = (\dot{m}_{f6} + \dot{m}_e) Cp_{f6'} T_{6'} \quad (14)$$

$$\frac{\dot{m}_e Cp_e T_4 + \dot{m}_{f6} Cp_{f6} T_6}{(\dot{m}_{f6} + \dot{m}_e)} = Cp_{f6'} T_{6'} \quad (15)$$

It should be clarified that Eq. 15 is solved by iterations using MATLAB to find T6', where $Cp_{f6'}$ is determined as a function of T6'. As for the Dryer heat requirement, the mass balance through the dryer gives:

$$(\dot{m}_{f6'}+\dot{m}_e)Cp_{f6'}T_{6'} + \dot{m}_{b1}Cp_{b1}T_{b1} = (\dot{m}_{f6'}+\dot{m}_e)Cp_{f7}T_7 + \dot{m}_{b2}Cp_{b2}T_{b2} + \dot{m}_{ev}h_g \quad (16)$$

$$(\dot{m}_{f6'}+\dot{m}_e)Cp_{f6'}T_{6'} + \dot{m}_{b1}Cp_{b1}T_{b1} - \dot{m}_{b2}Cp_{b2}T_{b2} = (\dot{m}_{f6'}+\dot{m}_e)Cp_{f7}T_7 + \dot{m}_{ev}h_g \quad (17)$$

The equation is solved iteratively to determine T7. The iterations are performed using MATLAB, where Cpf6′ and hg are evaluated at each step based on T7 and the molar fraction of water in the flue gases, respectively.

Installation efficiency:

Turbine power

$$\dot{w}_T = \dot{m}_a\,(Cp_{a3}T_3 - Cp_{a4}T_4) \quad (18)$$

Compressor power

$$\dot{w}_c = \dot{m}_a\,(Cp_{a2}T_2 - Cp_{a1}T_1) \quad (19)$$

$$\dot{w}_{cycle} = \dot{w}_t - \dot{w}_c \quad (20)$$

Note that the power needed to operate the production unit ($\dot{w}_{unite}$) is 500 KW. In this case, the quantity of wood required to generate this energy is calculated as follows:

$$\dot{m}_{cog} = \frac{\dot{w}_{unite}}{\dot{w}_{cycle}} \quad (21)$$

$$\eta_{el} = \frac{\dot{w}_{unite}}{PCI*\dot{m}_{cog}} \quad (22)$$

in which, $\dot{Q}$ is the quantity of heat released by the fumes at the dryer. This can be written as follows

$$\dot{Q} = (\dot{m}_{f6'}+\dot{m}_e)\dot{m}_{cog}Cp_{f6'}T_{6'} - (\dot{m}_{f6'}+\dot{m}_e)\dot{m}_{cog}Cp_{f7}T_7 \quad (23)$$

$$\eta_{th} = \frac{\dot{Q}}{PCI*\dot{m}_{cog}} \quad (24)$$

$$\eta_{cog} = \eta_{el} + \eta_{th} \quad (25)$$

IV. Results and Discussion

In order to investigate how the flame temperature, air temperature at the turbine's inlet (T3), and compression ratio affect the cycle's performance, we have increased the amount of excess air from 35% to 85%, T3 from 1000 K to 1180 K, and the compression ratio from 2 to 10. To ensure stable and complete combustion without operational issues, it is essential to minimize bottom ash formation and limit unburned gaseous and solid emissions. Bottom ash forms when ash reaches its melting point, which, for wood, must remain below its softening temperature approximately 1200 °C. To prevent this, the flame temperature should be kept under 1000 °C by adjusting the excess air ratio (α_0). Unburned materials not only reduce system efficiency but also have harmful environmental effects. Additionally, the flue gas temperature at the boiler outlet should remain above the acid dew point to prevent condensation. While this point typically ranges from 125 to 135 °C for sulfur-rich fuels [33], [34], a lower limit of 100 °C is acceptable in this study due to the low sulfur content (0.01%) of the wood.

The temperature at the dryer inlet, T6', must remain above the dryer's operating temperature (>400 °C). The evolution of flame temperature as a function of the total air ratio (α) and the boiler inlet air temperature (Te) is shown in Fig. 3.

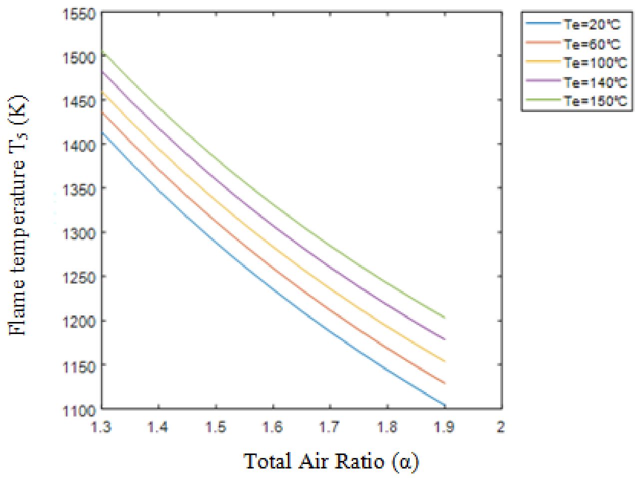

Fig.2: Evolution of flame temperature with total air ratio (α) and boiler inlet air temperature (Te)

This figure shows that the flame temperature varies inversely with the excess air ratio: as the excess air increases, the flame temperature decreases. This trend is expected, since higher excess air dilutes the combustion gases with a larger amount of nitrogen and unreacted oxygen, thereby lowering the flame temperature. Conversely, the flame temperature increases with higher boiler inlet air temperatures. Indeed, preheated combustion air enhances the combustion reaction and reduces thermal losses associated with heating the oxidant. It is also observed that for boiler inlet air temperatures above 100 °C, an excess air ratio higher than 90% is required to maintain the flame temperature below 1200 K. From these observations, optimal operating parameters can be set. By selecting: an excess air ratio α = 80% and a boiler inlet air temperature Te = 100 °C, the resulting flame temperature is 1192 K (≈ 919 °C), which represents a satisfactory compromise between energy performance and compliance with material constraints and pollutant emission limits.

The influence of turbine inlet air temperature and compression ratio has been studied. Variation of electrical, thermal, and cogeneration efficiencies all with compression ratio are presented in Fig. 4, Fig. 5 and Fig. 6, respectively.

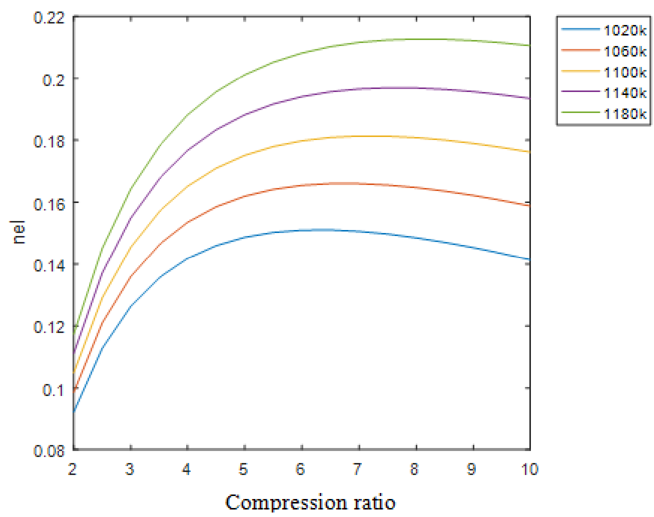

Fig.3: Variation of electrical efficiency with compression ratio

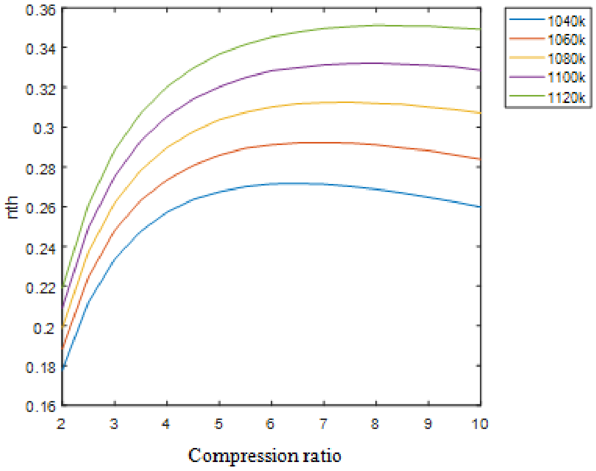

Fig.4: Variation of thermal efficiency with compression ratio

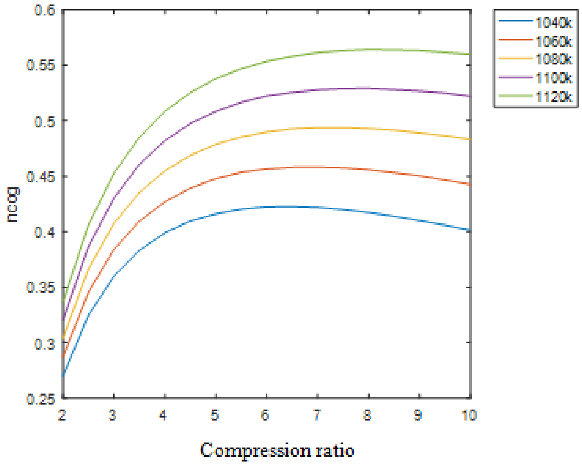

Fig.5: Variation of cogeneration efficiency with compression ratio

From the results shown in Fig.4, 5, and 6, it can be observed that, regardless of the value of T3, the curves display a similar trend, which can be divided into two distinct phases:

First phase: a rapid increase in performance up to a maximum point. This growth reflects the energy gain obtained from raising the turbine inlet air temperature.

Second phase: beyond this maximum, a stability zone appears, where performance remains nearly constant. The recorded values stay close to those at the optimal point, indicating that increasing T3 beyond a certain threshold brings little additional improvement.

Furthermore, for a fixed compression ratio, the different parameters studied (efficiency, gas temperature, etc.) generally increase with T3. However, this temperature must remain below the flame temperature, with a minimum safety margin of 50 °C. This constraint is essential to avoid overheating issues that could damage materials and increase NOx emissions. Taking these conditions into account, the turbine inlet air temperature can be set at T3 = 1140 K (867 °C). This choice represents an optimal compromise, ensuring both high energy performance and safe cycle operation.

Fig.7 and Fig. 8 illustrate the evolution of the inlet and outlet temperatures of the dryer, respectively.

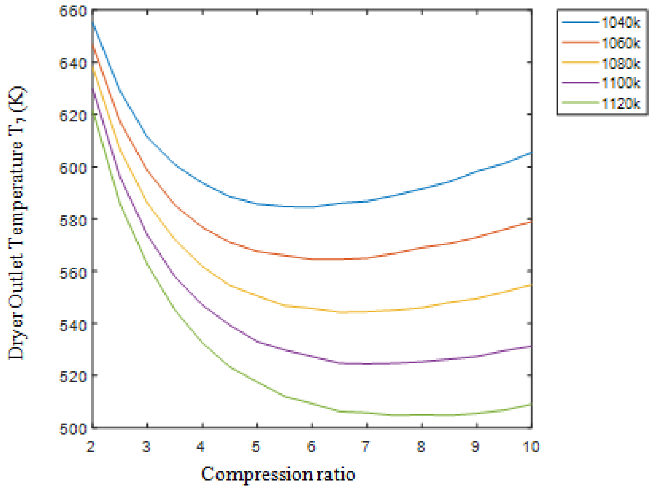

Fig.6: Curves of Dryer Outlet Temperature (T7) Evolution as a Function of Compression Ratio

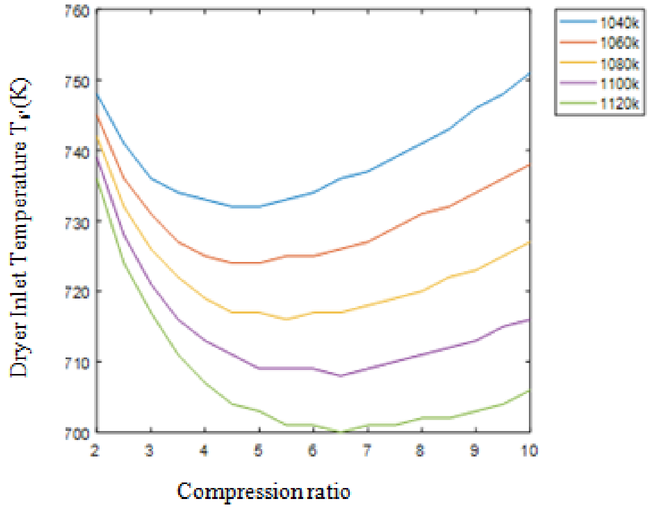

Fig.7: Curves of Dryer inlet Temperature (T6') Evolution as a Function of Compression Ratio

Initially, both curves decrease rapidly, reach a minimum, and then rise again. This trend reflects the nonlinear behavior of heat exchange between the exhaust gases and the moist wood. The passage through a minimum explains the reduction in overall efficiency observed from this point: the energy contained in the gases is recovered less effectively, which lowers drying performance. Critical flue gas temperatures are maintained regardless of compression ratio or turbine inlet temperature: T7 stays above the acid dew point to prevent corrosion, and T6′ remains above 400 °C to ensure efficient and continuous wood drying. These results demonstrate that, despite the efficiency drop observed near the minimum, the process remains thermodynamically viable and safe, while ensuring both drying quality and equipment protection.

Table III identifies the compression ratio that maximizes efficiency, $\tau = 8$, for which the overall efficiency of the plant is 52.91%.

To validate the developed model, the results of the present study were compared with several reference studies available in the literature [21], [35]-[37].

Table IV highlights the performance of different case studies involving biomass-fired hot air turbine cogeneration systems. The discrepancies observed among the results are mainly attributed to the installed capacity, the type of biomass used, the operating conditions (turbine inlet temperature, compression ratio), as well as the selected simulation model. The net power output calculated in the present work is 500kW, which is significantly higher than the reported values ranging from 30 to 100 kW. This difference is essentially related to the design conditions. However, the turbine outlet temperature remains comparable to that reported in previous studies, with a value of 867 °C in this work versus 830-900 °C in the literature. Regarding electrical efficiency, the developed model yields 19.68%, which is close to the values obtained by Vera et *al*. [35]-[37] and Pantaleo et *al*. [38] but slightly lower than those reported by Iora and Silva [35] and Durante et *al.* [21], which reach 23.5% and 27.6%, respectively. In contrast, the thermal efficiency and overall cogeneration efficiency obtained (33.23% and 52.91%) fell within the range of reference studies, although some values, such as the overall efficiency of 83.6% reported by Vera et al., are higher due to specific operating conditions. These results confirm the consistency of the proposed model with previous works, while also highlighting the differences arising from calculation assumptions, the types of biomass employed, and operating parameters (compression ratio, flame temperature, and turbine characteristics). This comparison therefore validates the developed model and situates its performance within the range of those found in the broader scientific literature on biomass-fueled hot air turbine cogeneration systems.

Table I: Program results for T3=1140 K, T5=1192K, and Te=373K

τ	$T_{6'}$ (K)	T_7 (K)	η_{th}	η_{el}	η_{cog}	m_{cog} (Kg/s)
2,0	739,00	630,00	0,2091	0,1111	0,3202	0,5845
2,5	728,00	596,00	0,2494	0,1371	0,3866	0,4735
3,0	721,00	573,75	0,2752	0,1550	0,4301	0,4191
3,5	716,00	557,75	0,2931	0,1676	0,4607	0,3875
4,0	713,00	547,00	0,3053	0,1767	0,4820	0,3675
4,5	711,00	539,25	0,3141	0,1834	0,4975	0,3541
5,0	709,00	533,00	0,3202	0,1882	0,5084	0,345
5,5	709,00	529,75	0,3249	0,1917	0,5166	0,3388
6,0	709,00	527,25	0,3283	0,1941	0,5224	0,3346
6,5	708,00	524,75	0,3299	0,1956	0,5255	0,3319
7,0	709,00	524,50	0,3314	0,1965	0,5279	0,3304
7,5	710,00	524,75	0,3320	0,1969	0,5289	0,3298
8,0	**711,00**	**525,25**	**0,3323**	**0,1968**	**0,5291**	**0,3299**
8,5	712,00	526,25	0,3317	0,1964	0,5281	0,3307
9,0	713,00	527,25	0,3311	0,1956	0,5268	0,3319
9,5	715,00	529,50	0,3304	0,1946	0,5250	0,3336
10,0	716,00	531,25	0,3286	0,1934	0,5220	0,3357

Table IV: Performance of Hot Air Turbines in Biomass Cogeneration Units Compared with Modeling and Simulation Results from the Literature

	Present study	Iora and Silva [35]	Durante et *al.* [21]	Vera, Jurado, and Carpio [36]	Vera, Jurado, de Mena, et *al.* [37]	Pantaleo et *al.* [38]
w_{net} **(kW)**	500	72.7	98.82	70	30	77.54
$T_{outlet\ turbine}$ **(C)**	867	850	-	850	830	900
η_{el}	19.68	23.5	27.6	19.6	20.1	19.19
η_{th}	33.23	43	-	64	40.1	-
τ	8	5.37	5.5	4	4	-
η_{cog}	52.91	66.5	-	83.6	60.2	-
Type of biomass	eucalyptus	-	eucalyptus	olive residues	olive residues	biomass

V. Conclusion

Our study was designed as an analysis to assess the feasibility conditions of an industry adapted to the wood-energy sector in Algeria. To address this issue, we designed a pellet production unit with a capacity of 2 t/h, coupled with a cogeneration system to ensure self-consumption. The latter cogenerates an electrical power of 500 kW and thermal energy in the form of combustion flue gases at temperatures between 400 and 600 °C. The supply chain is fed with biomass from eucalyptus residues with 50% moisture content, collected from forests located in the northeast of Algeria (El Tarf).

The simulation carried out in MATLAB enabled the determination of the optimal operating parameters for each studied system, taking into account both thermodynamic conditions and performance constraints. This approach facilitated the parametric analysis of the cycles.

The analysis showed that if the air temperature at the boiler inlet exceeds 100 °C, an excess air ratio above 90% is required to keep the flame temperature below 1 200 K. Based on this, the parameters were set to $\alpha = 80\%$ and $T_e = 100$ °C, resulting in a flame temperature of 1 192 K (919 °C). The turbine inlet temperature T3 must remain below the flame temperature and was fixed at 1 140 K (867 °C). Once these parameters were defined, the compression ratio maximizing efficiency was determined to be about 8, yielding a cogeneration efficiency of 53% (electrical efficiency = 20%, thermal efficiency = 33%). Therefore, to produce 2 t/h of pellets at 10% moisture content, the unit requires 4.78 t/h of wood at 50% moisture content, of which 1.18 t/h is consumed by cogeneration, which achieves an overall efficiency of 53% (20% electrical and 33% thermal). The potential of the studied region would allow meeting the heating needs of up to 2 700–2 750 households, i.e., about 15 000 inhabitants (approximately 3.2% of the total population of the region).

This study highlights the potential of forestry residues as a renewable energy source to develop Algeria's wood-energy sector, particularly for pellet production, offering an eco-friendly alternative to fossil fuels. However, challenges such as sustainable biomass availability, forest fires, high moisture content, technical constraints, and economic costs must be addressed. Success depends on sound resource management, supportive policies, skilled workforce, and public acceptance. Careful planning is essential to ensure the long-term viability of biomass cogeneration and support Algeria's energy transition.

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