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THERMODYNAMIC AND ECONOMICAL ANALYSIS OF INTERNAL COMBUSTION ENGINES FED BY WOOD GASIFIER

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Master Degree in Renewable Energy and Energy Efficiency

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Dedication

From the deepest part of my heart and with the greatest pleasure of this world,

I dedicate this work to my dear father, to my dear mother, for their sacrifices, their great loves that they bore me. For all they have endured to satisfy all of my concerns in hoping to witness this very distinguished day. May God preserve them in good health and long life and may they find in these modest words the testimony of my gratitude and sincere love.

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Abstract

This dissertation consists of a numerical and theoretical thermodynamic and economical study of a small scale wood biomass gasification of two systems using internal combustion of two engines; the RCX-210 engine of the MRX-50 motor pump for System 1 and the engine of a Honda CG-125 Titan motorcycle for System 2.

This analysing consisted on using the Aspen Plus software for modeling the prototype of the two system to study the thermoenergetic analysis numerically as well as the laws of thermodynamics, obtaining as a results the composition of syngas 20.68% CO_2, 13% CO, 60.07% N_2, 0.133% H_2, and 0.0339% CH_4 of mass fraction with 5500 KJ/Kg of LHV_{syngas} for 0.577*10^{-3} Kg/s of biomass for system 1 and respectively, 21.25, 10.92, 51.58, 0.933, 0.000198 for CO_2, CO, N_2, H_2, and CH_4 for 1.6*10^{-3} Kg/s of biomass for system 2. The power delivered to the shaft of the System 1 engine value is 2.561 kW and for the System 2 engine value is 6.40 kW.

Moreover, with the global energy analysis an efficiency of 22.8% was obtained for system 1 and 20.27% for system 2 , observing how efficiently the biomass was converted to the operation of the system. The Third Law of Thermodynamics was applied, identifying the exergetic performance analysis, with irreversibilities values for the System 1 engine value is 4.22 kW and for the System 2 engine value is 11.52 kW.

Finally, an overall exergetic efficiency of 24.4% for system 1 and 21.63% for system 2.

The economic analysis consisted on determining the annual saving expected (ASE) to study the payback period which is 4 years with a 12% of interest rate. The Net Present Value (NPV) ranges from 4 430.332 - 11 177.64€ for 2000-6000 h/year of operation period and the Internal Rate of Return IRR is 20.30%.

Keywords: Biomass, gasification, small scale, thermodynamic, economical analysis, modeling, energy, exergy, efficiency.

Resumo

Esta dissertação consiste num estudo termodinâmico numérico e teórico de uma gasificação de biomassa de madeira em pequena escala de dois sistemas usando combustão interna de dois motores; o motor RCX-210 da bomba motorizada MRX-50 para o Sistema 1 e o motor de uma motocicleta Honda CG-125 Titan para o Sistema 2.

Esta análise consistiu em utilizar o software Aspen Plus para modelar o protótipo dos dois sistemas para estudar numericamente a análise termoenergética, bem como as leis da termodinâmica, obtendo como resultado a composição do syngas 20,68% CO_2, 13% CO, 60,07% N_2, 0. 133% H_2, e 0,0339% CH_4 de fracção de massa com 5500 KJ/Kg de LHV_{syngas} para 0,577*10^{-3} Kg/s de biomassa para o sistema 1 e, respectivamente, 21. 25, 10,92, 51,58, 0,933, 0,000198 por CO_2, CO, N_2, H_2, e CH_4 por 1,6*10^{-3} Kg/s de biomassa para o sistema 2. A potência entregue ao eixo do motor do Sistema 1 é de 2,561 kW e para o motor do Sistema 2 o valor do motor é de 6,40 kW.

Além disso, com a análise energética global foi obtida uma eficiência de 22,8% para o sistema 1 e 20,27% para o sistema 2, observando a eficiência com que a biomassa foi convertida para o funcionamento do sistema. Foi aplicada a Terceira Lei da Termodinâmica, identificando a análise do desempenho exergético, com valores de irreversibilidade para o valor do motor do Sistema 1 de 4,22 kW e para o valor do motor do Sistema 2 de 11,52 kW.

Finalmente, uma eficiência exergética global de 24,4% para o sistema 1 e 21,63% para o sistema 2.

A análise económica consistiu em determinar a poupança anual esperada (ASE) para estudar o período de retorno que é de 4 anos com uma taxa de juro de 12 O Valor Actual Líquido (VAL) varia entre 4 430.332 - 11 177.64€ para 2000-6000 h/ano de período de operação e a Taxa Interna de Retorno TIR é de 20,30%.

Palavras-chave: Biomassa, gaseificação, pequena escala, termodinâmica, análise econômica, modelagem, energia, exergia, eficiência.

Résumé

Cette thèse consiste en une étude thermodynamique numérique et théorique d'une gazéification de biomasse de bois à petite échelle de deux systèmes utilisant la combustion interne de deux moteurs ; le moteur RCX-210 de la motopompe MRX-50 pour le système 1 et le moteur d'une moto Honda CG-125 Titan pour le système 2.

Cette analyse a consisté à utiliser le logiciel Aspen Plus pour modéliser le prototype des deux systèmes afin d'étudier numériquement l'analyse thermo-énergétique ainsi que les lois de la thermodynamique, en obtenant comme résultat la composition du gaz de synthèse 20. 68% CO_2, 13% CO, 60.07% N_2, 0.133% H_2, et 0.0339% CH_4 de fraction massique avec 5500 KJ/Kg de LHV_{syngas} pour 0.577*$10-3$ Kg/s de biomasse pour le système 1 et respectivement, 21. 25, 10.92, 51.58, 0.933, 0.000198 pour CO_2, CO, N_2, H_2, et CH_4 pour 1.6*10^{-3} Kg/s de biomasse pour le système 2. La puissance délivrée à l'arbre du moteur du système 1 est de 2,561 kW et celle du moteur du système 2 est de 6,40 kW.

En outre, l'analyse énergétique globale a permis d'obtenir un rendement de 22,8% pour le système 1 et de 20,27% pour le système 2, ce qui montre l'efficacité avec laquelle la biomasse a été convertie pour le fonctionnement du système. La troisième loi de la thermodynamique a été appliquée, identifiant l'analyse de la performance énergétique, avec des valeurs d'irréversibilités pour le moteur du système 1 de 4,22 kW et pour le moteur du système 2 de 11,52 kW.

Finalement, un rendement énergétique global de 24,4% pour le système 1 et 21,63% pour le système 2.

L'analyse économique a consisté à déterminer l'économie annuelle attendue (ASE) pour étudier la période de remboursement qui est de 4 ans avec un taux d'intérêt de 12%. La valeur actuelle nette (VAN) est comprise entre 4 430,332 et 11 177,64EUR pour une période de fonctionnement de 2000 à 6000 h/an et le taux de rendement interne (TRI) est de 20,30%.

Mots clés : Biomasse, gazéification, petite échelle, thermodynamique, analyse économique, modélisation, énergie, exergie, efficacité.

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List of abbreviations

$\dot{m}_{air,stoic}$	Mass flow rate of air stoichiometric combustion [kg/s]
$\dot{m}_{air}$	Mass flow rate of air [kg/s]
$C_{el.ICE}$	Electricity production cost [Euro/kWh]
C_{HW}	Hot water cost [Euro]
$C_{mainICE}$	ICE maintenance cost [Euro]
$C_{mainw.g.plant}$	Wood gasification maintenance cost [Euro/kWh]
C_{syngas}	Syngas production cost [Euro/kWh]
C_{synICE}	Cost of syngas in ICE [Euro]
$Cmain_{HW}$	Maintenance cost of hot water [Euro]
COP_{HW}	Operation cost of hot water [Euro/kWh]
COP_{ICE}	ICE operation cost [Euro/kWh]
$COP_{w.g.plant}$	Wood gasification plant operation cost [Euro/kWh]
E_{HW}	Energy generated by hot water [kW]
E_i	Energy in [kW]
E_O	Energy out [kW]
$E_{Pgasifier}$	Gasifier power generated [kWe]
E_{pICE}	Energy generated by ICE [kW]
$Ex_{in/out}$	Exergy in/out [kW]

Fp_E	Electricity production factor by consumed fuel
FP_{HW}	Hot water production factor by consumed fuel
G_{el}	Electricity gain [Euro/kWh]
G_{HW}	Hot water gain [Euro/kW]
h_i	Enthalpy in
I_{ch}	Chemical irreversibility [kW]
I_{ki}	Kinetic Irreversibility [kW]
I_{ph}	Physical Irreversibility [kW]
I_{po}	Potential Irreversibility [kW]
$Inv_{exchanger}$	Investement cost of exchanger [Euro]
Inv_{ICE}	Investment cost of ICE [Euro]
$Inv_{w.g.plant}$	Wood gasification plant investment [Euro]
LHV_{syn}	Lower heat value of syngas [kJ/m^3]
m_i	Mass in [kg]
S_{ch}	Chemical entropy [kJ/kg k]
S_{ki}	Kinetic entropy [kJ/kg k]
S_{ph}	Physical entropy [kJ/kg k]
S_{po}	Potential entropy [kJ/kg k]
V_A	Air mass flow [kg/s]
E_{syn}	Energy generated by syngas [kW]
ΔT	Interval of temperature [k]
η_g	Efficiency of gasifier [%]
η	Efficiency [%]

ε	Exergy [kW]
ASE	Annual saving expected [Euro]
A	Area [m^2]
COP	Operation cost of the plant [Euro/kWh]
ER	Equivalence ratio
f	Annuity factor
H	Equivalent period of utilisation [h/year]
ICE	Internal combustion engine
IRR	Internal rate of return [%]
I	Irreversibility [kW]
K	Payback period [year]
LHV	Lower heat value [kJ/kg]
L	Lenth [m]
MSW	Municipal solid waste
NPV	Net present value [Euro]
PBP	Pay back period [year]
Q	Heat [kW]
r	Annual interest rate [%]
S	Entropy [kJ/kg k]
W	Work [kW]

Chapter 1

Introduction

1.1 Objectives

The objective of this thesis is to evaluate the thermodynamic performance of a demonstrative functional prototype of a wood block gasification system using internal combustion of two different engines: RCX-210 from the Camperon MRX-50 motor pump, and a Honda CG 125 Titan motorcycle. The second objective is analysing the economic aspects of implementing this type of systems considering the annual interest rates and the amortisation periods in order to evaluate its feasibility.

1.2 Thesis framework

Renewable energy sources include solar, wind, tides, geothermal, and hydroelectric. Biomass is a substantial source of energy that is generated by our daily activities all over the world. Biomass is an important component in the generation of fuel and energy. Renewable energy's potential for urban and rural growth, liquid fuel replacement, and greenhouse gas reduction are all major topics right now around the world.

Biomass can be defined as (Stucley and al,2004) [1]: "recent organic matter originally derived from plants as a result of the photosynthetic conversion process, or from animals, and which is destined to be used as a store of chemical energy to provide heat, electricity, or transportation fuels," according to renewable energy perception and, small-scale heat and power generation using biomass downdraft reactors and reciprocating internal combustion engines is a feasible technology. [2].

Gasification is one of the biomass-to-energy conversion methods that plays an important role [3]. In contrast to combustion, which needs extra air, gasification uses partial oxidation. It creates a flammable gas that is a combination of carbon monoxide (CO), hydrogen (H_2), and methane (CH_4). Biomass gasification plants are still in the early stages of commercialization.

When utilized to generate power, the size of the plant has a significant impact. An updraft gasifier has a 10% to 20% efficiency at 1 MW electrical (MWe), a 10 MWe fluid bed gasifier has a 25 to 35% efficiency, and a 100 MWe entrained flow or pressurized circulating fluid bed gasifier has a 40 to 50% efficiency[4].

Generally, the utilisation of several organic wastes from agricultural and forestry are used as biomass of gasifier with a notable CO_2 emissions which is considerable as one of the main greenhouse effect agents [5]. Based on this, downdraft gasification provides higher conversion efficiencies while producing less tar and particulate matter. As the tar formed during the pyrolysis stage is thermally converted into gas during the combustion stage of the gasification process, and has an impact on the internal design of these systems [6].

Despite the fact that downdraft gasification technology is well-known and studied, further experimental studies are still needed due to biomass composition variability. Since experiments can be costly, numerical methods like the software ASPEN PLUS emerge as a strong and useful tool since it is capable of executing much of main calculations of mass, energy and exergy balance. Furthermore we can still measure the chemical balance of vapor-liquid, heat transfer, mass transfer, fractions, and pressure drop widely used in industry for dynamic and steady-state simulation, process design, performance and optimization.

Small-scale power generation using biomass downdraft reactors, coupled to internal combustion engines, is gaining popularity in this context as a way to provide energy to remote areas using local renewable fuels[5].

Various technologies can be used to recover energy from wood, such as:

- Combustion, which is a rapid chemical reaction between two or more substances, is generally referred to as burning. Because reaction rates increase exponentially with temperature in realistic combustion systems, the chemical reactions of the principal chemical species, carbon (C) and hydrogen (H_2) in the fuel and oxygen (O_2) in the air, are fast at the prevalent high temperatures (approximately greater than 900 °C)[6].

- Pyrolysis, which involves heating a fuel with little or no oxygen to produce "syngas," which can be used to generate energy or as a feedstock for creating methane (CH_4), chemicals, biofuels, or hydrogen (H_2) [6].

- Gasification is a thermochemical process that converts biomass into syngas at high temperatures by partial air oxidation, partial oxygen oxidation, or partial water steam oxidation.

The extraction of syngas takes place within the gasifier. The produced gas would be used to power an internal combustion engine. The gasification device is driven by wood as its primary source of energy. Since the syngas will be used to control two different types of motors, the study will be applied to two different systems. A gasifier, gas/water heat exchanger, wood sawdust filter, and RCX-210 engine from a Camperon MRX-50 motor pump are needed for the first system. A gasifier, gas/air heat exchanger, wood sawdust filter, and a Honda CG 125 Titan motorcycle engine make up the second device.

1.3 Structure of the thesis

The research discussed in this thesis is divided into five parts:

The first chapter (Introduction) provides a brief overview of the current project and its goals.

The second chapter (Literature review) consist of the state of the art within the perspective of the findings of biomass gasifier research and the theoretical fundamentals with the thermodynamic analysis of the gasification system, in addition of the gasification ; steps of gasification, types, temperature and equivalent ratio. As well as mentioning biomass characterisation and its resources also synthetic gas composition from wood resource. This chapter also aims the economic aspects of the system such as its investment, maintenance cost and the system annual interest rates.

The third chapter (Materials and Methods) introduces the materials and methods, as well as systems and their components. It includes the description of the ASPEN PLUS software as well as process tools and steps of the simulation.

The findings and discussion of the research carried out in the two studied structures are presented in **Chapter 4 (Results and Discussions)**.

Chapter 5 (Conclusions and Future Work) includes the thesis conclusions as well as the project's potential horizons as a proposal for future work.

Chapter 2

Literature Review

2.1 State of the Art

In the past, gasifiers were crucial in substituting oil-based fuels in internal combustion engines. During World War II, for example, gasifiers driven by coal, wood, or peat fueled over a million vehicles, buses, trucks, cars, ships, and trains according to [7].

The first commercial gasifier was installed in 1839, according to [8]. The gasifier was an updraft type that used air as an oxidizing agent in continuous solid fuel gasification. In 1881, the first engine to run on gas from a gasifier was built. The engine sucked the gas produced by the gasifier, which was referred to as ”suction gas” at the time.

The downdraft gasifier had a greater conversion efficiency while producing less tar and particulate matter [7]. Some characteristics, such as particle size, moisture content of the biomass feedstock, and the air/fuel equivalence ratio employed in the gasification process, however, might cause a loss of syngas quality if they are not well specified.

[24] represented a literature assessment on downdraft gasifier design changes and their impact on performance. They addressed a number of projects aimed at improving the basic model of small-scale downdraft gasifiers.The feeding system, air supply system, producing gas re-circulation system, and discharge system are all being improved. Screw, pneumatic, and belt conveyors are used to improve the feeding system. The use of a multi-stage and heated air supply system improves the use of single-stage and atmospheric air supply systems, respectively, such as a gasifier with a Eucalyptus feedstock biomass, composed of carbon steel and refractory wall, with an internal diameter of 300 mm and a height of 1060 mm (top to grate) gives an optimum equivalence ratio of 0.4, airflow rate of $20Nm^3$/h, and the injection of 2nd stage air, the pyrolysis zone temperature approaches that of the oxidation zone. CO, CH_4, and H_2 percentages are 19.04, 0.89, and 16.78%, respectively, at an air ratio of 80%, and Producer

gases has a lower heating value of 4539 kJ/Nm^3.

The effects of particle size, moisture content of biomass feedstock, and the air/fuel equivalency ratio used in the gasification process on the quality of the producer gas were evaluated by [7]. The results of several diesel and spark ignition RICEs supplied with syngas were reported. According to the literature, a downdraft type reactor's low heating value and process cold efficiency are around 4-6 MJ/Nm^3, 50-70%, and the average temperature in the combustion zone is around 1000°C. The equivalence ratio should be kept between 0.2 and 0.4, the biomass particle size should be less than 5 cm, and the moisture content should be less than 25%, according to the findings. The combustion parameters of syngas, such as its LHV, auto-ignition duration, and typical spark ignition time, are often lower than those of traditional fuels such as gasoline and natural gas, according [8], resulting in a drop in engine power efficiency. When an engine is operated with syngas, the drop in theoretical value is around 30%. However, thermodynamic analysis has revealed that using syngas in engines with a higher compression ratio can result in a lower power value of 15 to 20% power depreciation. These numbers, however, are sufficient for this gas to be employed as an internal combustion engine fuel.

Ruiz and al [30] reviewed gasification processes as well as the key criteria to consider during the plant design stage. Temperature, gasifying agent, equivalent ratio, residence time, and catalyst additives like dolomite and others (which significantly convert the tars, reducing their content in the gases generated) have all been shown to influence the progress of the gasification process as well as the quality of the synthesis gas produced.

In a small-scale gasifier (10 kWe), the processes of lignite gasification with mixed wood wastes were explored using air as the gasification agent. One of the goals of [9] was to see if adding wood residues to the syngas may improve the LHV value. The efficiency of the gasifier was determined using the fuel consumption rate and gas composition values. The mass and energy balances of the gasification of lignite with mixed waste wood mixture were calculated using the first and third laws of thermodynamics. Energy efficiency, exergetic efficiency, syngas LHV, and syngas yield all increased by 8.92, 11.66, 6.31, and 9.33%, respectively.

By comparing IC engines and combined cycle gas turbine (CCGT) based plants with a system where syngas is delivered to fuel cell devices, [10] examine the benefits of employing biomass-derived syngas in terms of energy and environmental balances. The syngas-fuel cell system provides greater results (electrical efficiency of about 45%). The IC engine plant structure appears to be suited for small CHP plants (100–1000 kW_{el}), as the thermal power produced can be utilised at the local scale, avoiding the installation of a long and expensive district heating network, according to the study. Because it primarily generates electricity, the CCGT plant might be built up to medium levels (10–20 MW_{el}). Due to issues with biomass sourcing and storage, larger plants are rarely employed.

According to [11], there are two methods for modeling the gasification process with the Aspen Plus simulator: thermodynamic equilibrium modeling and kinetic modeling. The thermodynamic equilibrium models are based on the Gibbs free energy and can be stoichiometric or non-stoichiometric. They can be implemented by first defining a set of reactions and then calculating the equilibrium composition (stoichiometric approach), or by first defining a set of chemical elements in the feeding and compounds in the output and then calculating the composition that minimises the system's Gibbs free energy (non-stoichiometric approach). Its application is based on the following assumptions: the gasifier is dimensionless and contains a perfect mixture, so the temperature is uniform, reaction rates are quick enough, and the residence time is long enough to achieve chemical equilibrium. The kinetic modeling approach, on the other hand, is more difficult to execute since it requires a thorough understanding of the gasification reactions and their kinetics, as well as the reactor architecture, but the findings are said to be closer to experimental data.

According to [12] the pyrolysis zone, combustion zone, and reduction zone were all segregated into three sections of the reactor. An external MS-Excel function was used to specify the yield and composition of the main components, namely char, gas, and tar, in the pyrolysis process simulation. A kinetic model was used to simulate the combustion and reduction processes. These models were calibrated and then validated using data from gasification of four different types of biomass in a pilot-scale bubbling fluidized bed reactor with varying equivalency ratios (from 0.17 to 0.35) and temperatures (from 709 °C to 859 °C). For a set of biomass types and operating parameters, the simulation results, specifically the concentrations of CO, CO_2, H_2, CH_4, C_2H_4 in the producer gas, were in good agreement with the experimental results. H_2 gas had the lowest accuracy of all the gases studied, always being overestimated; yet, the largest absolute error obtained for H_2 was just 4.4%. Finally, the projected tar concentration was between 20 and 42 g/Nm^3 and dropped as the equivalency ratio, temperature, and biomass particle size increased.

Aspen Plus can calculate mass and heat transfer, material and energy balance, plus phase and chemical equilibrium, among other things. It can be used to model pyrolysis [13]), transesterification, steam reforming, and gasification, among other processes.

[14] research provides a thermodynamic equilibrium model built by Aspen Plus for simulating biomass gasification in a downdraft gasifier. The char and tar generation model is based on the chemical processes of water-gas shift and methanation, as well as the application of the "temperature approach" to these processes. Model validation was accomplished by comparing experimental data from two biomass samples with variable moisture content and

gasification conditions, for a total of 16 cases studied. The experimental results and the predicted percentages of combustible gases (H_2, CH_4, CO) using the model were found to be in good agreement. The average error was 15% when it came to the combustible gases in the syngas and less than 7% when it came to the Lower heat value LHV forecasts.

The biomass employed in the experiment, according to [15], was eucalyptus wood pellets with an 8% moisture content. The simulation was performed for product gas compositions such as H_2, CO, CO_2 CH_4, and N_2 using experimental conditions for eucalyptus wood for a total air flow of 20 Nm^3/h. The producer gas for this operational condition had a composition of 19.2 CO, 1.3 CH_4, 17.14 H_2, 14.22 vol% CO_2, and an average LHV of 4.74 MJ/Nm3 and an average LHV of 4.74 MJ/Nm3.

[16] research was about the experimental and numerical analysis of a biomass downdraft gasifier, gas purification system, and gas piston engine in a combined heat and power (CHP) plant. Its economic research took into account the policies and regulations that govern the Polish energy market. The study found that using the generated power and heat for self-consumption rather than selling it on the market is more profitable. Even with the supporting policies in place, the payback time will be around 8 years, with a positive net present value (NPV) value for self consumption 81050 € using 100% pellet and an internal rate of return (IRR) exceeds 11%.

According to [17] the economic model of a downdraft gasifier system based on a combination of three financial indicators, NPV, IRR, and PBP, was constructed for the economic study. Electricity generation expenses, initial investment, operating and maintenance costs, and fuel costs were all taken into account. Electricity sales to the national grid were used to determine revenue. The economic model showed promising results, indicating that the project may be implemented under current market conditions. The results for the Portuguese scenario revealed an NPV of 29.32 k€ for acacia and 18.99 k€ for MSW, whereas the Brazilian scenario indicated an NPV of 28.45 k€ for eucalyptus and 31.65 k€ for MSW. The IRR rates were found to be 19.34% for acacia, 16.88% for municipal solid waste (MSW), 19.28% for eucalyptus, and 20.09% for MSW, respectively. In terms of PBP, the results predicted that acacia would take 9.20 years, MSW 12.61, eucalyptus 9.38, and MSW 8.67 years. In general, the investment projects planned for deployment in Brazil provided improved economic results, demonstrating increased feasibility, owing to the country's higher electricity sales prices.

2.2 Theoretical Fundamentals

2.2.1 Biomass

Biomass is a renewable organic material that comes from animals or plant matter generated throw photosynthesis that contains chemical energy from the sun. This chemical energy can be used directly or converted to a renewable liquid and gaseous fuels through various process.

The most common biomass material used for energy are residues, including in these both residues of forest and forest industry also residues of agriculture and waste of Agro-food industry and its tributaries. Excretions of animals from the livestock farms, the organic fraction of municipal solid waste, grown energy crops including short rotation forestry are called biomass feed stocks. The biofuels that come from the transformation of biomass can be classified into three main groups that are related to the origin of its material such as: biofuels from wood, biofuels from non-forest plantation and biofuels from urban waste [18]. In this present work, wood biomass was used to produce synthesis gas, more commonly called syn-gas.

2.2.2 Converting biomass to energy

The energy can be converted into usable energy through direct ways like the direct combustion (burning) to produce heat and indirect ways such as proceeding into biofuels. The thermochemical conversion to produce solid gaseous and liquid fuels includes gasification wish is thermal decomposition process entails feedstock heating to (800°C-900°C) with a controlled quantity of oxygen to produce carbon monoxide and hydrogen rich gas called syngas and slag. [19] The following figure 2.1 [20] shows different process to obtain energy from biomass

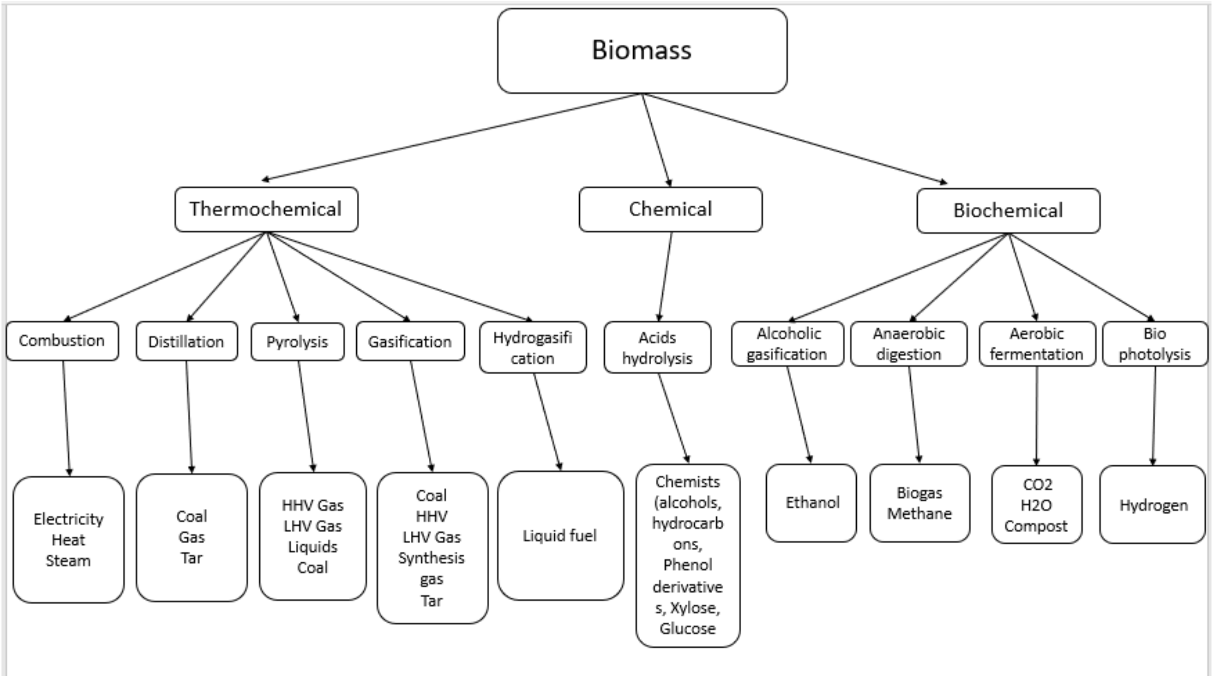

Figure 2.1: Ways to obtain energy and products from biomass

2.2.3 Characterization of biomass wood resources

The technical characteristics that should be studied for a biomass when used to produce fuels are:

- **Elementary chemical composition:** the percentage by mass of the main elements that make up biomass is listed, where generally referring to dry basis. This information is important because it serves as a basis for calculating combustion, air/gas volumes and enthalpy and for determining the calorific value of the fuel [21].

- **Immediate chemical composition:** relates to the percentage of Fixed Carbon (F), Volatile Materials (V), Ash (A) and Humidity (W) in relation to the fuel mass

- **Humidity:** it is the free water mass present in the biomass, and it is possible to present humidity values on a dry or humid basis, depending on the reference used. When biomass has a moisture content greater than 30%, there is a reduction in the calorific value of the gas due to the expenditure of energy in burning to evaporate the water present [18]. Therefore, humidity 11 is considered a very important factor in the transformation of biomass into fuels.

- **Calorific value:** is the amount of thermal energy that is released during the burning of a fuel per unit of mass or volume (kJ/kg or kJ/m^3). The higher heating value (HHV) is when it is considered that the water present in the fuel condenses and remains in a liquid state. The Lower heating value (LHV) is calculated when considering that the water present in the biomass stay in the form of steam. It must always be evidenced which type of calorific power will be used, since, in the efficiency calculations of the systems, the efficiency related to the LHV is higher than the value determined according to the HHV [18].

Table 2.1 present values of calorific value and immediate elementary composition for some biomass of energetic interest also considering the influence of humidity.

Table 2.1: Technical characteristics of different types of biomass on a dry basis

Type of biomass				Elementary composition (%)			immediate composition (%)			
	C	H	O	N	S	W	V	A	F	LHV
Pine	49,29	5,99	44,36	0,06	0,03	0,30	82,54	0,29	17,70	20,0
Eucalyptus	49,00	5,87	43,97	0,30	0,01	0,72	81,42	0,79	17,82	19,4

Biomass from wood have a greater calorific value and a complete influence of humidity. It is possible to analyse that biomass is composed mostly of carbon 49.00% and 49.29% with a small variation from one type to another in addition a low-ash content related to biomass from wood can be analysed less than 0.79%.

2.3 Gasification

Gasification is a reaction in which crushed biomass is oxidized by gasification agent in a gasifier which is an important factor that effect the gasification process, reaction and product in order to produce syngas along with bio-char and some tar. The mainly gasification products are CO_2, CO, H_2, CH_4 and very small amount of H_2S, NH_3 and tar also can be included it depends on the type origin of the biomass its characteristics, catalyst types gasification and operation conditions [22]. Biomass gasification is regarded as the most effective process by far to produce hydrogen.

2.3.1 Steps of gasification

Gasification contains four important steps: pyrolysis, drying, partial combustion and reduction, in each step there are specific equation describing the chemical reaction.

2.3.1.1 Drying

This process takes place in the heating zone in order to heat up the biomass approximately to 100-150°C [23]. In this part of the downdraft the moisture in biomass has to be reduced by 5% [23] before it enters pyrolysis and it can be expressed in term of mass balance [24] by the following equation 2.1

$$m(OH)_t = m(OH)_g \tag{2.1}$$

2.3.1.2 Pyrolysis

Pyrolysis is a process entails heating raw biomass in the absence of oxygen. During this process biomass atoms break into gases: CO, CO_2, Hydrogen, Tar and char [23] at temperature between 200 and 700 °C [25]

$$Biomass \xrightarrow{Q_B} \sum_{liq} C_xH_yO_z + C_aH_bO_c + H_2O + Char \tag{2.2}$$

2.3.1.3 Partial and complete oxidation

Complete and partial oxidation takes place at the combustion zone. Some quantity of heat is produced from the complete oxidation 394 kJ/mol and 111 kJ/mol from partial oxidation [25]. Combustion is a form of the exothermic reaction which is the main energy source of the system. The following equations presents the thermo-chemical oxidation equation 2.3 and 2.4

* Partial oxidation

$$C + \frac{1}{2}O_2 \longrightarrow CO \tag{2.3}$$

* complete oxidation

$$C + O_2 \longrightarrow CO_2 \tag{2.4}$$

2.3.1.4 Reduction

The reduction occurs at the bottom of the downdraft gasifier reactor and in this region the hot gases formed is converted in to producer gas by the endothermic reaction equations [26] from

2.5 to 2.8 using the energy of combustion [27]

* Bouduard reaction

$$C + CO_2 \longrightarrow 2CO \tag{2.5}$$

* Water gas reaction

$$C + H_2O \longrightarrow CO + H_2 \tag{2.6}$$

* Water gas shift reaction

$$CO + H_2O \longrightarrow CO_2 + H_2 \tag{2.7}$$

* Methane reaction

$$C + 2H_2 \longrightarrow CH_4 \tag{2.8}$$

2.3.2 Temperature of gasification

Temperature has an impact on the carbon transformation all through the oxidation and gasification reactions, gas yield, heating value, cold gas effectiveness and at long last char and tar yields in gasification processes as well [23]. The ideal temperature for the several types of reactor are diverses. In the downdraft gasifier the temperature is about 1300°C [28]. Temperature gasification is related to the equivalent ratio; when the temperature improves, the equivalent ratio declines due to upgrading combustion reaction in oxidation zone[23].

2.3.3 Equivalent ratio

ER is one of the foremost critical parameters, which have impact on the gasification process including syngas composition. Therefore, it is considered as an important parameter which influences the gasification efficiency [29]. ER is the ratio of the real air/fuel proportion to the stochiometric air/fuel proportion [25], it is also defined as the quotient of the actual air volume supplied per kg of biomass fuel and the volume of the gasification agent which is mostly air due to its availability and cost consideration [30]. High ER implies better oxygen content allowed to react with the volatile present in the combustion zone. As long as ER is increasing tar formation in the product gas is reduced [31]. Typically, ER is 1 for the perfect combustion and range between 0.2 and 0.4 in biomass gasification [28] to sustain auto thermal state [29]. The ER is defined as follows in equation 2.9 [30]

$$ER = \frac{\dot{m}_{air}}{\dot{m}_{air,stoic}} \qquad (2.9)$$

Where,

- $\dot{m}_{air}$ is the mass flow rate of air
- $\dot{m}_{air,stoic}$ is the mass flow rate of air required for stoichiometric combustion.

It is also presented as follows[30]:

$$ER = \frac{r_{(air-fuel)real}}{r_{(air-fuel)stoic}} \qquad (2.10)$$

2.3.4 Type of gasifier

Gasifier it is the main equipment (reactor vessel) witch is responsible of the gasification process. Gasifiers are regularly classified according to the flow rate of the fuel source and the gases produced[32].

2.3.4.1 Fixed bed

Fixed bed reactors are the oldest type technology used to produce gas. It is then classified as downtraft, updraft and cross-draft depending upon the course and passage of air flow [25].

- Updraft gasifier:

Biomass is fed from the top of gasifier whereas gasification agent witch is steam oxygen and/or air flows in contercurrent configuration is supplied at the bottom [25].

- Downdraft gasifier:

Biomass and the gas flow rate of the downtraft producer and the gas of the reactor outgoing producer under the gird. The gasification medium is suplied from the top or the upper part of the reactor [25].This type of gasifier is the most widely used gasification model, due to the low tar and particulate content produced, in order to preserve internal combustion engine (ICE) from damage [33].

- Cross-draft gasifier:

The cross-draft gasifier, with the inlet for the gasification medium and the outlet for the product gas located on opposite sides of the reactor [25].

2.3.4.2 Fluidized bed reactors

Fluidized bed gasification is generally utilized for coal gasification in which the solid particles resemble a fluid. Widely, the fluidized medium is hot air and water vapour. The gasification process is held when hot fluidized materials touch the raw material [25]. Tow basic types of fluidized bed gasifier are actualy used: the circulating fluidized bed and the bubbling bed [34]. Figure 2.2 [25] shows the different classifications of gasifier reactors.

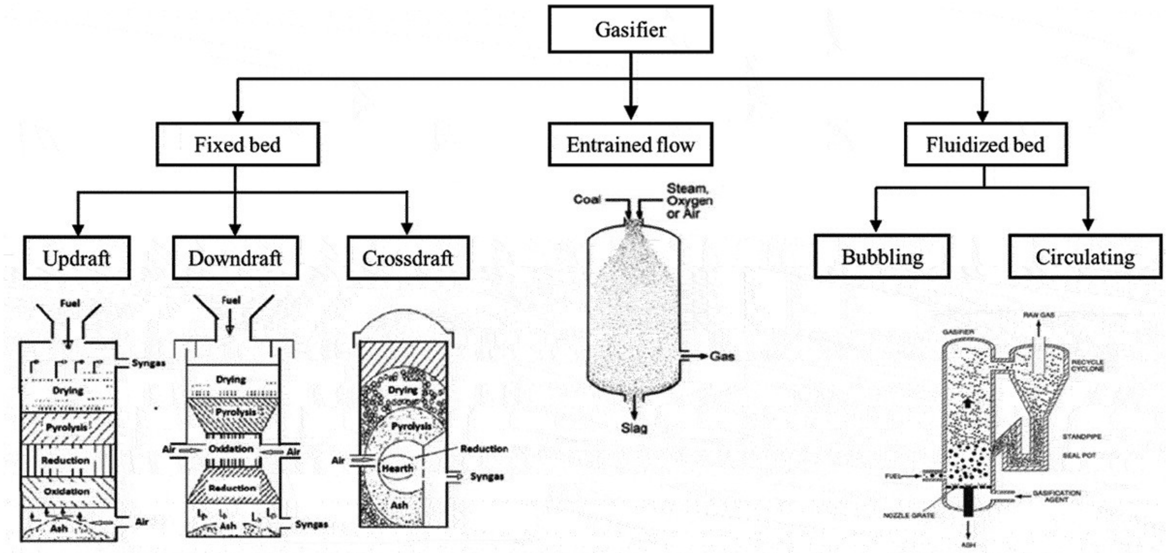

Figure 2.2: Types of Gasifier reactors [24]

There are several applications of gasifiers and their power is one of the parameters that measure the scale of application, The fixed bed reactor is best suited for a small-capacity plant, particularly the downdraft reactor [13]. the small gasifiers of 10 kW being used in small engines or large gasifiers of more than 100 MW to supply thermoelectric power stations [25]. The following figure 2.3 [25] shows the different thermal capacity input of gasifiers.

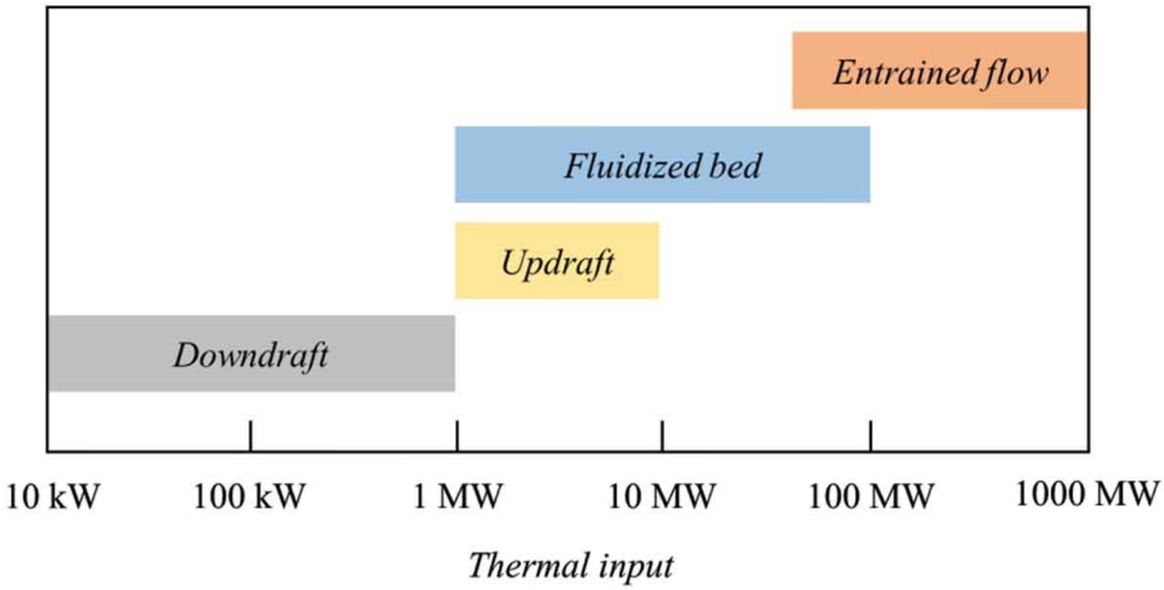

Figure 2.3: Thermal power capacity of the main type of gasifier [24]

2.4 Syngas composition

The syngas comes out from the gasification process of the biomass which is from Eucalyptus consist mainly of the hydrogen (H_2), carbon monoxide (CO), inert gas such as nitrogen (N_2) and carbon dioxide (CO_2). The folowing table 2.2 [35] present the properties of syngas.

Table 2.2: Syngas composition [35]

Gas	Mass (%)
CO_2	15.60
CO	17.30
H_2	0.18
N_2	65.40
CH_4	0.59
Sum	99.07

2.5 Thermodynamic analysis

2.5.1 1st law of thermodynamics

The first law of thermodynamics or conservation of energy asserts that energy can not be created or destroyed but only converted from a point to another. The movement of molecules causes the thermal or internal energy incorporated into a system. The transitional forms of energy are heats and work. The first law of thermodynamics states that any change in a system's internal energy (E) is equal to the sum of the heat (Q) that flows across its boundaries and the work (W) done on it by the environment[36] as shows equation 2.11.

$$\int \delta Q + \int \delta W = \int \delta E \tag{2.11}$$

2.5.2 Energy balance

By considering the system as a control volume, energy transfers can be quantified with an analysis at the boundary of the system through 3 forms: heat, work and mass flow. Therefore, the energy balance is given based on the differences between outputs and system inputs, as shown in equation 2.12 [37].

By also considering the steady-state flow system, that is to say invariable over time, we can see that the total variation of energy during the process is equal to zero. Therefore, the amount of energy entering the heat, work and mass transfer must be equal to the amount of energy leaving thus equation 2.13 [37].

$$E_i - E_o = (Q_i - Q_o) + (W_i - W_o) + (E_{m,i} - E_{m,o}) = \Delta E \tag{2.12}$$

$$Q_i + W_i + \sum m_i h_i = Q_o + W_o + \sum m_o h_o \tag{2.13}$$

Alternatively:

$$Q_i - W_o = \sum m_i h_i - \sum m_o h_o \tag{2.14}$$

It should be emphasized that the energy balance can also be given in the form of power when analyzed in a time interval delta T

$$\dot{Q} = \frac{Q}{\Delta t} \tag{2.15}$$

$$\dot{W} = \frac{W}{\Delta t} \tag{2.16}$$

$$\dot{\Delta E} = \frac{\Delta E}{\Delta t} \tag{2.17}$$

$$\dot{m} = \frac{m}{\Delta t} \tag{2.18}$$

2.5.2.1 Thermal potency

The thermal power represented in the control volumes can come from both the thermal energy transferred in the gasifier walls per unit time and also the thermal energy transferred in the heat exchangers per unit time.

- Thermal conduction:

  The heat loss in the gasifier walls due to temperature differences between the inside of the gasifier and the outside environment can be calculated according to the Conduction Heat Transfer Equations [38]

  $$\dot{Q} = \frac{KA\Delta T}{L} \tag{2.19}$$

  Equation 2.19 can also be applied to the heat loss at the walls of the exchangers.

- Thermal power of the fuel:

  In addition, the thermal input (Q) from the input biomass flow into the gasifier reaction, where its (LHV) can be defined as the amount of energy released in combustion by unit of mass of the fuel in question commonly expressed by kilo joule per kilograms (KJ/Kg) [39]. The calculation of the calorific value is obtained from the differences in the enthalpy values of the combustion products and reagents divided by the molar mass of the fuel, as can be observed in the equation 2.20 [40].

  $$LHV_{syn} = \frac{-(H_p - H_R)}{MM_{syn}} \tag{2.20}$$

  The latent heat of condensation of moisture present in the combustion products is not considered. In this work the fuel in question is biomass (Eucalyptus wood blocks)[37].

  $$Q = m \times LHV \tag{2.21}$$

- Thermal power of the flow:

  the mass flow of the air inserted into the gasifier is coming from the thermal power. In addition the heat power given up from the syngas flow through the heat exchanger and transferred to the water/air flow of the exchanger[41].

  $$\dot{Q} = \dot{m} \times \Delta h = \dot{m} C_p \Delta T \tag{2.22}$$

- Air mass flow in gasifier:

  The stoichiometric air volume (VA) needed for the complete combustion of 1 Kg of fuel is provided by the reaction combustion equation of the fuel elements[18] giving by equation 2.23

$$VA = 0.0889(C_t + 0.375S_t) + 0.265H_t - 0.0333O_t \tag{2.23}$$

The elements percentage of the Eucalyptus biomass showing in the table 2.1 will be used as a parameter in this study. the volumes resulting from the calculation refer to the conditions of 1 pressure atmosphere and 298K (25°C) which is a standard condition assigning the unit of measurement of Nm_3 per kg of fuel [18]. In a gasification process the air factor (AF) is required because it determines the actual amount of air relative to 25 stoichiometric amount needed for combustion[42]. This value it is estimated to be 0.30 [35].

2.5.3 Efficiency

Efficiency indicate how inputs are used by the system, it is expressed by the ratio between the desired results and the required supply [43] as showing in the flowing equation 2.24

$$\eta = \frac{Desiredresults}{Supply} \times 100 \tag{2.24}$$

The wood gasifier energetic efficiency depend upon the ratio of the syngas to the energy provided (biomass: Eucalyptus). The following equation 2.25 presents the gasifier efficiency [43].

$$\eta_g = \frac{\dot{m}_{sy} \times LHV_{sy}}{\dot{m}_{biomass} \times LHV_{biomass}} \times 100 \tag{2.25}$$

2.5.4 Entropy

Entropy is specified by the measure of the quantity of molecular randomness in a system. It is also considered to be the measurement of the thermal energy of the system per unit of temperature that is not available to provide useful work. Based on the second law of thermodynamics entropy variations which are expressed as follows [44].

$$S = \frac{Q}{T} \tag{2.26}$$

where Q refers to the quantity of heat transferred in a process and T is the absolute temperature.

$$S = S_{ch} + S_{ph} + S_{po} + S_{ki} \tag{2.27}$$

S_{ch} is the chemical entropy, S_{ph} refers to physical entropy, S_{po} is the potential entropy, and the S_{ki} is the kinetic entropy [44].

2.5.5 Exergy

Exergy is the highest amount of work that a system may create in a given environment. This idea is frequently used in process engineering to estimate (or design) a variety of energy systems, such as co-generation systems. One of the most commonly utilized goal functions in structural dynamic modeling is exergy. According to the definition of the exergy we have

$$E_x = \Delta U - U_0 \tag{2.28}$$

As

$$U = TS - PV + \sum \mu_c N_i \tag{2.29}$$

Where S is the entropy, U is the energy, V is the volume, N is the mole of various chemical compounds, T temperature, P pressure, and μ symbolises the chemical potential of the component.

In the gasification process the chemical energy from biomass is transformed into thermal energy from the syngas. Gasification have the highest conversion rate comparing with pyrolysis and combustion [45]. Exergy destruction is defined as difference between inlet and outlet exergy it is also defined as maximum work potential that can not be recovered for the useful because of irreversibilities [18]. Exergy balance obeys the follows equations[45]:

$$Ex_{in} = Ex_{out} + I \tag{2.30}$$

Where Ex_{in} represent the input energy (biomass and gasification agent) Ex_{out} defined the energy output (produced syngas, tar and ash) and I is the produced irreversibility during the conversion process which is related to the entropy generation as showing in the following equation:

$$I = T_0 \times S_g \tag{2.31}$$

Where T_0 is the ambient temperature and S_g is the entropy generation rate, the irreversibility could be also be written as follow [46]:

$$I = I_{ch} + I_{ph} + I_{po} + I_{ki} \tag{2.32}$$

Where the I_{ch} refers to chemical irreversibility I_{ph} physic irreversibility I_{po} is the potential irreversibility and I_{ki} refers to the kinetic irreversibility.

2.5.5.1 Work exergy

Work is a type of energy that is transported in an ordered manner, without carrying entropy and without creating changes in the system's entropy[44]. The work's exergy will be equal to the useful work as shows equation 2.33

$$\varepsilon_W = W_x + W_{ef} \tag{2.33}$$

In this work exergy is exactly equal to shaft work. If measured over a time interval, it can be expressed as work exergy flow ΔT [44] by equation 2.34

$$\dot{\varepsilon}_W = \dot{W}_x \tag{2.34}$$

2.5.5.2 Heat exergy

The exergy of a heat flux Q, transferred to a system and considered to coming from a thermal energy reservoir [44] is given by equation 2.35.

$$\varepsilon_Q = Q * (1 - \frac{T_0}{T}) \tag{2.35}$$

Similarly, the exergetic heat flux can be measured when evaluated over a time interval δT by equation 2.36 [44].

$$\dot{\varepsilon_Q} = \dot{Q} * (1 - \frac{T_0}{T}) \tag{2.36}$$

2.5.5.3 Exergy balance

During a process, certain types of exergy can be changed into other forms, allowing for exergy balance in the control volume. The difference in exergy flows in and out across the system border represents the rate of exergy increase within the control volume. Because exergy, unlike energy, is not preserved, it is necessary to account for exergy losses during the process, which are referred to as irreversibilities [44]. The exergy balance equation is as follows:

2.6 Economic analysis

The wood gasification plant coupled with the 2 types of internal combustion engines involves an economic analyse of syngas production cost that is related to the Eucalyptus gasification system investment and its maintenance. Also a studies of the electricity production cost by burning syngas in the ICE and its production cost. In addition, considering the ICE investment and maintenance. After this the annual savings expected (ASE) and the payback are determined.

2.6.1 Syngas production cost

The syngas production cost is associated with the investment and the maintenance of the Eucalyptus gasification plant which is determined according to Silveira methodology [47] in equation 2.37.

$$C_{syngas} = \frac{Inv_{wg.plant} * f}{H * \dot{E}_{syngas}} + COP_{wg.plant} + Cmain_{wg.plant} \tag{2.37}$$

2.6.2 Annuity factor

The annuity factor is a function of the annual interest rate and the repayment. The pension factor is calculated as mentioned in equation 2.38 [43]

$$f = \frac{q^k(q-1)}{q^k - 1} \tag{2.38}$$

where

$$q = 1 + \frac{r}{100} \tag{2.39}$$

2.6.3 Operation cost of the plant

The wood gasifier operation cost depend on the energy supplied by the syngas and the wage rate of electricity. Thus the operation cost is determined by the equation 2.40 [47]

$$C_{op} = \frac{wagerate}{EP_{gasifier} * H} \tag{2.40}$$

2.6.4 Maintenance cost

The equipment maintenance cost is considered 3% of the plants investment cost according to Silveira [48] recommendation. The following equation 2.41 shows the gasifier maintenance cost.

$$C_{main} = 0.03 * \frac{Inv_{wgplant} * f}{H * \dot{E}_{syngas}} \tag{2.41}$$

2.6.5 Electricity production cost

The electricity production cost bent on the engine investment operation time, the electric power generated, the annuity factor and the maintenance of the ICE. Thus it is calculated through the equation 2.42 by Selveira [47]

$$C_{el.ICE} = \frac{Inv_{ICE} * f}{H * \dot{E}p_{ICE}} + C_{opICE} + C_{mainICE} + (C_{op} * \frac{\dot{E}p_{ICE}}{\dot{E}p_{ICE} + \dot{E}_{syngas} + E_{HW}}) \tag{2.42}$$

The ICE maintenance is 0.00924 €/kWh according to [46].

2.6.5.1 Internal combustion engine investment

For the internal combustion engine Xavier [49] elaborated equation 2.43.

$$Inv_{ICE} = 400 * 10^3 * (\frac{\dot{E}p_{ICE}}{455})^{0,9021} \tag{2.43}$$

2.6.5.2 Internal combustion engine operation cost

The ICE operation cost is determined using the energy supplied by the syngas multiplied by the cost of the syngas and then divided by ICE electric power showing in equation 2.44 [49].

$$C_{opICE} = \frac{C_{syngasICE} * FP_E}{\dot{E}p_{ICE}} \tag{2.44}$$

Where

$$FP_E = \frac{\dot{E}p_{ICE}}{\dot{E}p_{ICE} + E_{HW}} \tag{2.45}$$

2.6.6 Hot water cost

The cost of producing the hot water was identified by the investment of heat exchanger, thermal energy of hot water, operation time, the rent factor and the hot water production factor per fuel consumed as shows equation 2.46 [47].

$$C_{HW} = \frac{Inv_{Exchanger} * f}{H * E_{HW}} + Cop_{HW} + C_{mainHE} + (C_{OP} * \frac{E_{HW}}{E_P + \dot{E}_{syngas} + E_{HW}}) \tag{2.46}$$

where

$$Cop_{HW} = \frac{C_{syngas} * FP_{HW}}{E_{HW}} \tag{2.47}$$

$$FP_{HW} = \frac{E_{HW}}{\dot{E}p_{ICE} + E_{HW}} \tag{2.48}$$

2.6.7 Annual savings expected

The annual savings is determined by the electricity and thermal production gain as showing in equation 2.49 [47].

$$ASE = G_{el} + G_{HW} \tag{2.49}$$

where

$$G_{el} = \dot{E}p_{ICE} * H(P_{el} - Cel.ICE) \tag{2.50}$$

$$G_{HW} = EP_{HW} * H * (P_{HW} - CHW) \tag{2.51}$$

2.6.8 Internal rate of return (IRR) and net present value (NPV)

The present value of future payments discounted at an acceptable interest rate, less the cost of the initial investment, is known as net present value (NPV) [50]. Meaning, it's figuring out how much future payments plus an initial cost would be worth now. We must analyse the concept of money's time worth. Time, since, for example, a million dollars today would not be worth a million dollars a year from now, due to the opportunity cost of depositing such a large sum of money in a savings account to collect interest. For capital budget analysis long-term investment planning it is a basic method in finance [51]. The net present value for uniform cash flows can be calculated using the formula below 2.52, where t is the amount of time (usually in years) that money has been invested in the project, n is the total length of the project (in this case 6 years), i is the cost of capital, and FC is the cash flow in that period [52].

$$NPV = \sum_{t=0}^{n} \frac{FC_t}{(1+i)^t} \tag{2.52}$$

The formula can be expressed as follows 2.53 if the cash outflow is merely the first investment: where FC_j denotes the values of cash flows of order "j," with j = 1, 2, 3,..., n; FC_0 denotes the starting cash flow; and "i" denotes the financial operation's interest rate or the investment project's internal rate of return.

$$NPV = \sum_{t=0}^{n} \frac{FC_t}{(1+i)^t} - InitialInvestment \tag{2.53}$$

We can use the equation 2.54 below to calculate uniform or non-uniform cash flows:

$$NPV = FC_0 + \frac{FC_1}{(1+i)^1} + \frac{FC_2}{(1+i)^2} + \frac{FC_3}{(1+i)^3} + ... + \frac{FC_n}{(1+i)^n} \tag{2.54}$$

The Internal Rate of Return (IRR) is the rate that equates the current value of an investment with its respective future returns or cash balances. It refers to a project's rate of return and is utilised in investment analysis [50]. The internal rate of return (IRR) represents the investment's return, or an interest rate at which we would acquire exactly the same rate of eventual profitability if the capital invested had been deposited at this rate. In other words, it represents a discount rate that makes the NPV equal to zero when employed as a discount rate. The investment decision is simply to accept those with an IRR larger than the cost of borrowing once the profitability of investment projects is understood.

The following equation 2.55 present the IRR

$$NPV = \sum_{0}^{n} \frac{FC_i}{(1+t)^i} = IRR = 0 \tag{2.55}$$

Where;

CF_i is the Cash flow of year i

t is the Internal Rate of Return.

Chapter 3

Materials and methods

3.1 Model design

Two systems will be used for thermodynamic and economic analysis, as illustrated in the figures 3.1 and 3.2 . Gasifier, gas/water heat exchanger (gas/liquid), wood sawdust filter, and RCX-210 engine from the Campeon MRX-50 motor pump are shown in Figure 3.2 .

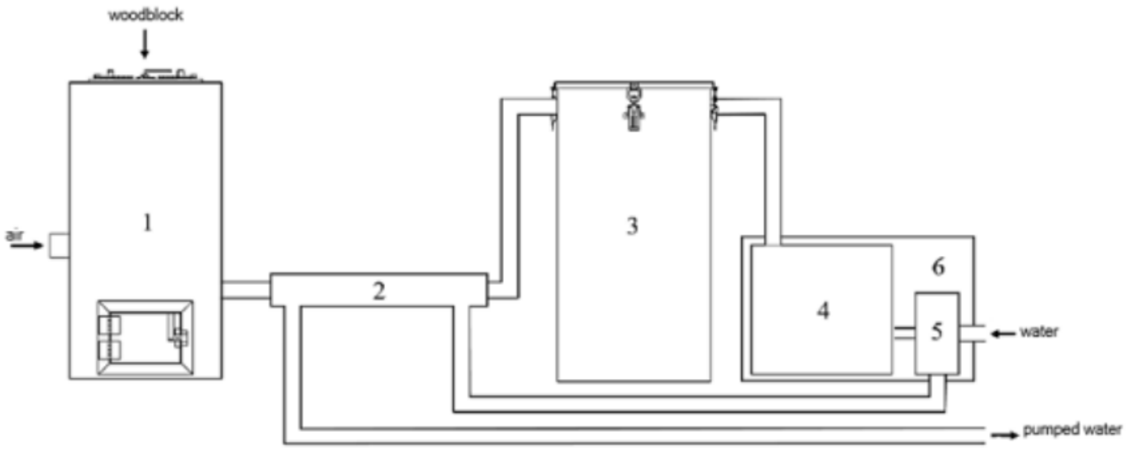

Figure 3.1: System 1 with RCX-210 engine [39]

Figure 3.2 depicts system 2, which also includes gasifier (1), gas/air heat exchanger (gas/gas) (2), wood sawdust filter (3) and a Honda CG 125 Titan motorcycle engine (4).

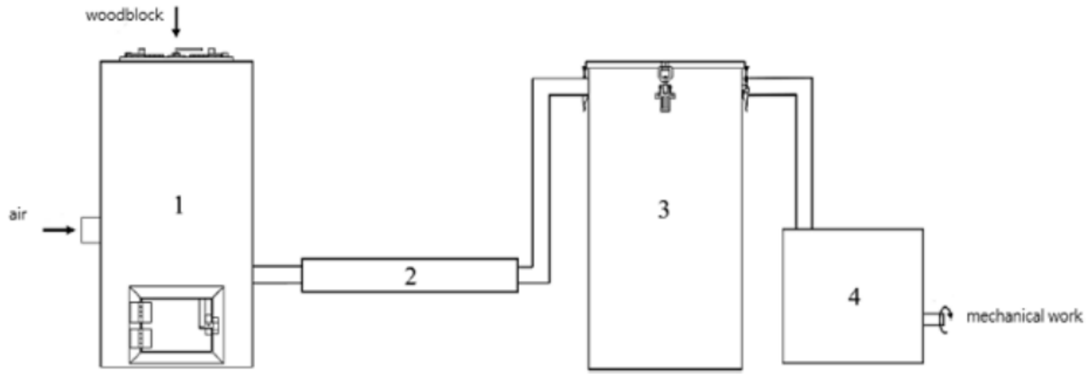

Figure 3.2: System 2 with CG Titan motorcycle engine [39]

The gasifier prototype was built by IPB students Daniel de Sousa Lemos [39]and Licnio Fontes [51] in the Laboratory of Mechanical technology.

The figure below 3.3 illustrates the system with 3 components to supply the pump with syngas:

a) Gasifier;

b) Water exchanger;

c) Filter.

Figure 3.3: Prototype of the gasification system to supply the Campeon motor pump with syngas

3.1.1 Engines

The gasifier used in this project was designed to deliver syngas to two engine models as an alternative fuel: the Campeon MRX-50 motor pump's RCX-210 engine and the Honda CG-125 Titan motorcycle's engine.

Figure 3.4 and 3.5 show two 4-stroke gasoline internal combustion engines that will be converted to run on syngas.

Table 3.1 shows their mechanical qualities.

Figure 3.4: Moter pump Campeon MRX-50

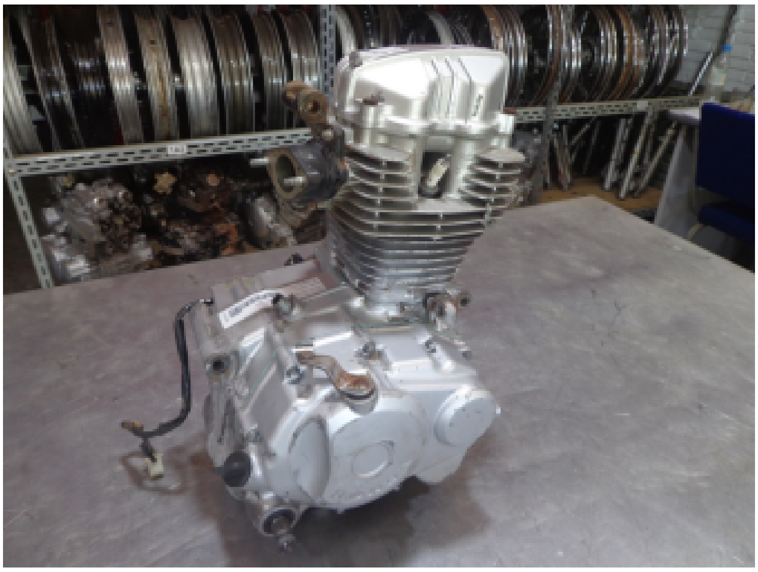

Figure 3.5: Moter cycle Honda CG-125 Titan

Table 3.1: Characteristics of the Campeon MRX-50 motor pump and Honda CG-125 Titan motorcycle

Properties	**Motor pump Campeon MRX-50**	**Motor cycle Honda CG-125 Titan**
Model's engines	RCX-210	
Maximum power (KW)	4.78	9.19
Cylinder (CC)	212	124.10
Rotation (rpm)	1800	9000

In the energy and exergy calculations, the percentages of thermal power losses in the motor, as well as the mechanical power given to the shaft in table 3.2 , will be employed as parameters.

Table 3.2: Percent of the output Power of a gasoline engine [35]

$\dot{\mathbf{Q}}_{conv}$	$\dot{\mathbf{Q}}_{ge}$	$\dot{\mathbf{Q}}_{arrg}$	$\dot{\mathbf{W}}_{x}$
6.7%	30%	30%	33.3%

The percentage of power transferred to the motor shaft is 33.3%, according to Table 3.2. This value refers to the engine's design circumstances, in other words a gasoline-fueled engine. The PCI and volume flow rate of the syngas that is injected into the engine to acquire the thermal power of the fuel are used to calculate the shaft power of each engine. The same proportions of power losses were evaluated at the output, as shown in Table.

3.1.2 Fluids characteristics

The temperature of the syngas leaving the gasifier is in the range of 300 °C to 400 °C, and the ideal temperature to feed the engine is 40°C.

The Cp of the syngas was estimated using the calculated mass percentages of each element in the syngas composition at a temperature of 673 K (400 °C) at the gasifier output. Only the elements with the most important values were taken into account table 3.3.

The products of the thermophysical properties of each gas (γ) and their mass percentage (λ) were added together to calculate these properties. The result of the previous sum were divided by the sum of the proportion by mass percentage of these gases, as given in equation 3.1

$$\theta = \frac{\sum_{n=1}^{4} \gamma_i * \lambda_i}{\sum_{n=1}^{4} \lambda_i} \quad (3.1)$$

Table 3.3: The characteristics of the gases that comprise syngas at 400 °C

Properties of Gases			
Gases	**Mass (%)**	**ρ (kg/m^3)**	**Cp (kJ/kgk)**
CO_2	15.6	0.7877	1.1138
CO	17.30	0.5010	1.1070
H_2	1.80	0.0362	14.594
N_2	65.40	0.5029	1.0918
Total	100	0.54	1.1354

The C_p of syngas at 673 K (400 °C) was computed using a weighted average relative to the mass composition reported in Table 3.3 by equation 3.1, yielding density and C_p of syngas values of 0.54 kg/m^3 and 1.1354 kJ/kgK, respectively.

A range of the low heat value (LHV) of syngas for the small scale gasifier is given by 5000 and 9000 kJ/m^3. The average of LHV has been proposed to be equal to 5500 kJ/m^3.

The amount of gas that the gasifier should produce from the engine's maximum power consumption of the air/syngas mixture was determined. As shown in Equation 3.2 , the volume flow rate of the mixture ($\dot{V}_{air/syn}$) may be estimated using the engine speed (R) and displacement (C).

$$\dot{V}_{air/syn} = \frac{1}{2} * R * C \quad (3.2)$$

The maximum amount of combustible that the gasifier must generate ($\dot{V}_{syn}$) in m^3/s, as calculated by Equation 3.3.

A stoichiometric ratio of 1.1:1.0 for the air/gas ratio has been used, and a volumetric efficiency (f) of 90% [27].

$$\dot{V}_{syn} = \frac{1}{2.1} * \dot{V}_{air/syn} * f \quad (3.3)$$

Table 3.4: Volume and mass flow rate of syngas

properties	**system 1**	**system 2**
LHV_{syn} (kJ/m^3)	5500	5500
ρ (kg/m^3)	0.54	0.54
C_p (kJ/kg.k)	1.1354	1.1354
$\dot{V}_{air/syn}$ (m^3/s)	0.0318	0.0093
$\dot{V}_{syn}$ (m^3/s)	$1.36 * 10^{-3}$	$3.99 * 10^{-3}$
$\dot{m}_{syn}$ (kg/s)	$0.734 * 10^{-3}$	$2.154 * 10^{-3}$

System 1 has a volume flow rate of 1.36 x 10^{-3} m^3/s and System 2 has a volume flow rate of 3.99 x 10^{-3} m^3/s at the gasifier outlet. For the engine supply of each system, these volumes flow rates will be considered the same.

The mass flow rate is $0.734 * 10^{-3}$ kg/s was obtained as syngas production in system 1 and $2.154 * 10^{-3}$ kg/s for system 2.

3.1.3 Downdraft gasifier

The fireplace and the reservoir were the two primary components of the gasifier. Its dimensions were determined based on the flow of syngas, which is directly proportional to the engine's fuel suction capacity, with the most powerful engine as a reference: the CG 125 Titan engine (motorcycle). The prototype was made of steel, which has a conduction coefficient of around 50 W/m^2.

A sectional drawing of the created model is shown below 3.6, showing the four primary zones [51].

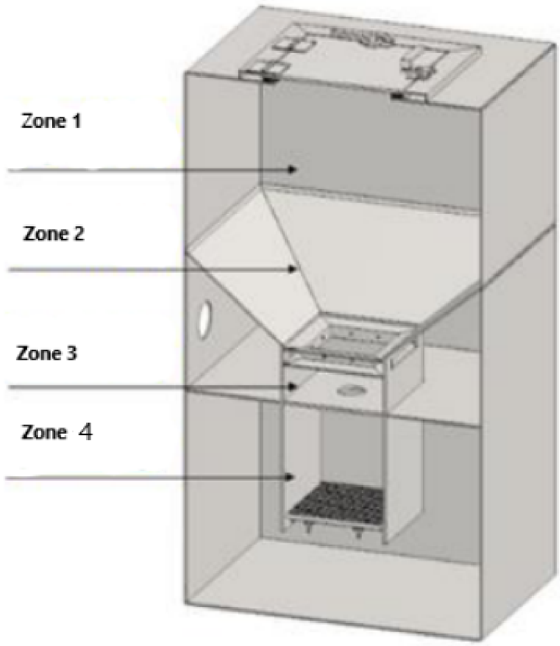

Figure 3.6: Design of the downdraft gasifier in cross-section with the various reaction zones[51]

As previously stated, the downdraft gasifier has four main zones. Figure 3.6 represents the model with Zone 1 as the biomass's drying region, which gets heat from Zone 3 and removes moisture from the wood. The pyrolysis reaction takes place in Zone 2 and uses heat from Zone 3 to decompose the fuel into carbonaceous residue, condensable and non-condensable gases. The oxidation zone, which extends from the air intake in the fireplace to the gasifier's throat, is located in Zone 3. Zone 4 is the area below the throat where the reduced area provides a heat concentration, resulting in high temperatures and allowing the tar to be thermally petitioned. As a result, it is also conceivable to employ simpler hydrocarbons and CO_2 as fuel gas for the system.

Table 3.5: Gasifier fluids properties

Gasification agent	**Pressure**	**Movement type**	**Gasifier**	**Temperature**
Air	Atmospheric	Concurrent	Downdraft	1203 K (930°C)
Steam	3 Mpa			

Eucalyptus wood was used as the fuel for the energy and exergetic analysis calculations, its LHV is 19400 kJ/kg , as seen in Table 2.1. Having the consumption of wood biomass in the gasifier by applying equation 2.25 to compute the efficiency of gasification, which can be assigned at 70% [39].

Considering the Low heat value of the syngas of 5500KJ/m^3 the folowing equation 3.4 is used to calculate the gasifiers's power

$$P_g = \dot{V}_{syn} * LHV_{syn} \tag{3.4}$$

Equation 3.5 shows the calculation of the wood consumption required by the gasifier to produce the engine's maximum power. Taking into account the gasifier's efficiency and the LHV of eucalyptus (with 14% humidity).

$$m_{eucalyptus} = \frac{P_g}{\eta_g * LHV_{eucalyptus}} \tag{3.5}$$

According to the work of Daniel Lemos [39] the dimensions of the gasifier are as showing in the figure 3.7

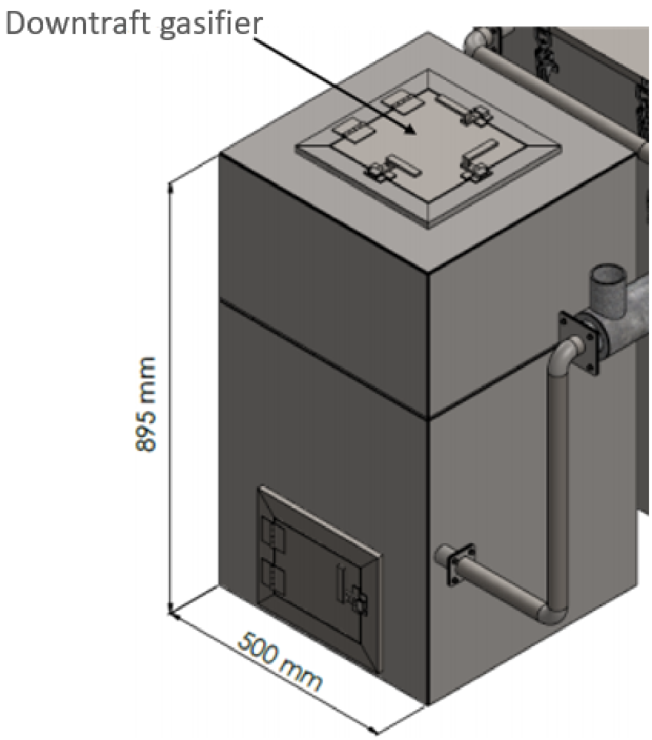

Figure 3.7: 3D downdraft gasifier [39]

Table 3.6 shows the dimensions of the gasifier reservoir, which was designed to supply the fireplace for 4 hours. During gasifier operation, the tank should be closed to prevent gases from escaping and air from entering through the lids.

Table 3.6: Gasifier dimensions

Properties	**units**	**system 1**	**system 2**
P_g	kJ/s	7.48	21.945
$\dot{m}_{eucalyptus}$	kg/s	$0.55 * 10^{-}3$	$1.6 * 10^{-}3$
$\rho_{eucalyptus}$	kg/m3	250	250
$V_{eucalyptus}$	m^3	0.031	0.092
L_g	mm	500	500
H_g	mm	895	895

System 1 has an eucalyptus mass flow of $0.55 * 10^{-3}$ kg/m^3 and for system 2 it is $1.6 * 10^{-3}$ kg/m^3 in the gasifier input.

The volume needed of the eucalyptus is 0.031 m^3 for system 1 and 0.092 m^3 for system 2.

The stoichiometric air volume (per kg biomass) was estimated using the percentages of chemical components in the eucalyptus biomass given in table 2.1 and equation 2.23, as shown in table 3.7 .

Table 3.7: Stoichiometric air volume

Composition	**Percentage**
C	49.00
S	0.01
H	5.87
O	43.97
VA (Nm^3/kg)	4.45

4.45 Nm^3/kg of air was measured. This value was approved for both systems.

Table 3.8 shows the air mass flow rate at the gasifier inlet for each of the two systems, given the air factor (AF) value of 0.30, the density of air (ρ_{air}) at 298 K (25°C) of 1.184 kg/m^3, and the biomass mass flow rate estimated for each of the two systems:

Table 3.8: Volume and mass flow rate of air

Properties	**System 1**	**System 2**
ρ_{air} (kg/m^3)	1.184	1.184
$\dot{V}_{air}$ (m^3/s)	1.34*10^{-3}	2.13*10^{-3}
$\dot{m}_{air}$ (kg/s)	1.58*10^{-3}	2.52*10^{-3}

System 1 has a mass flow rate of 1.58*10^{-3} kg/s and for system 2 is 2.52*10^{-3} kg/s.

Using Equation 2.22, the thermal power of the air flow in the gasifier is given in Table 3.9 , with the average temperature in the fireplace in the gasifier being 1203 K (930°C) for combustion and the ambient temperature being 298 K (25°C) , as well as the specific heat of air at normal atmospheric pressure conditions being 1.01 kJ/kg K.

Table 3.9: Thermal power of air flow in gasifier

Properties	**System 1**	**System 2**
$\dot{m}_{air}$ (kg/s)	1.58*10^{-3}	2.52*10^{-3}
$\dot{Q}_{air}$ (kJ/s)	1.44	2.31

The thermal power of the introduced air from the gasifier was found to be 1.44 kW for System 1 and 2.31 kW for System 2.

3.1.4 Equivalence Ratio ER

The syngas produced has an LHV of 5500 MJ/kg. Table 4.1 shows the mass of air and mass of wood flow rate. The air–fuel ratio for full combustion is known as the air–wood stochiometric ratio. According to [30] , the value for this parameter is 6.364.

The equivalence ratio is calculated using equation 2.9 and based on the values of mass flow rate of air and fuel (wood) as given in table 3.11.

Table 3.10: Equivalence ratio

Properties	**System 1**	**System 2**
LHV (kJ/kg)	5500	5500
$\dot{m}_{air}$ (kg/s)	1.58*10^{-3}	2.52*10^{-3}
$\dot{m}_{Eucalyptus}$ (kg/s)	0.55*10^{-3}	1.6*10^{-3}
Air wood ratio	2.872	1.575
Air wood stoichiometric ratio	6.364	6.364
Equivalence Ratio	0.4	0.24

3.1.5 Exchangers

A heat exchanger is an equipment that allows heat to be transferred from one fluid to another via natural convection. Because high temperatures in the gas can damage the engine, a cooling system is critical in the system. Furthermore, because gas is denser at lower temperatures, it can hold more fuel per unit volume.

In this case two heat exchangers was considered , one for the system that would supply the motor pump (water heat exchanger) and the other for the motorbike engine (air heat exchanger).

3.1.5.1 Gas / Water Exchanger

The water pushed by the motor pump was used as a cooling fluid in this exchanger, which was designed for the gasifier system. That is, the water should travel through the exchanger after being pumped and then exit the system. The shell-and-tube concept was utilised, in which water travels through the outer shell and syngas flows in the tubes countercurrently. The fluid inlets and main dimensions of the exchanger are represented in 3.8. As a safety precaution, the syngas was choosing to circulate through the inner tubes and the water through the outer shell. Otherwise, high temperatures would be left on the heat exchanger's external surface, posing the risk of accidental burns.

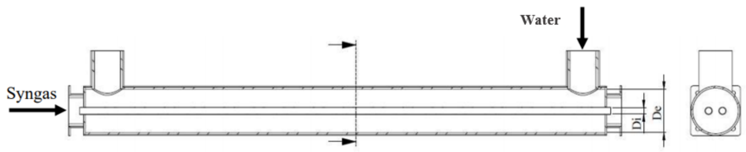

Figure 3.8: Representation of the shell-and-tube exchanger with the syngas and water inlet flows [39]

The fluid parameters utilised in the design of the water heat exchanger are shown in table 3.11

The entrance temperature of the syngas in the exchanger was assumed to be equal to the maximum outlet temperature of the syngas in the gasifier, 400 °C. The syngas temperature at the heat exchanger outlet was calculated to be 40 °C, which is the appropriate temperature for the engine supply.

Table 3.11: Water heat exchanger design parameters

Parameters	**Values**	**Units**
T_{iSyn}	400	°C
T_{oSyn}	40	°C
T_{iWater}	15	°C
$\dot{V}$Water	0.002	m^3/s
D_e	0.088	m
D_i	0.012	m
K_{inox}	18.1 [39]	W/m.K

The heat exchanger was sized depending on the quantity of heat ($\dot{Q}$) using equation 3.6 that had to be extracted from the syngas to reach a temperature of 40 ° C.

$$\dot{Q} = \dot{m}_{syn} * Cp_{syn} * (T_{iSyn} - T_{oSyn}) \tag{3.6}$$

By multiplying their respective volumetric flow rates by their density masses, the average flow rates of syngas and water were calculated. Then we estimated the water flow temperature (T_{oWater}) using the required heat exchange value by the following equation 3.7

$$T_{oWater} = \frac{\dot{Q}}{\dot{m}_{water} * Cp_{water}} + T_{iWater} \tag{3.7}$$

3.1.5.2 Gas/ Air heat exchanger

The Gas/Air Exchanger has a large contact surface with the air (via the fins), allowing the gas to cool naturally through convection. The syngas input attributes are the same as in the previous model, which aimed to chill the syngas to a temperature of 40 °C. The only difference is the average flow rate $\dot{m}_{syngas}$, which is higher since this engine consumes more fuel than the pump motor, requiring the gasifier to create more syngas. The fluid inlet and outlet are showing in the figure 3.9.

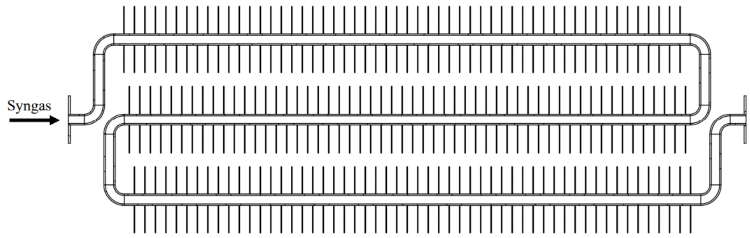

Figure 3.9: Representation of the gas/gas exchanger with the inlet and outlet flows of syngas [39]

Using equation 3.6 and the average flow rate of syngas $\dot{m}_{syngas}$ necessary to fuel the motorcycle engine, the quantity of heat to be extracted from the syngas in the exchanger $\dot{Q}$ was calculated.

The syngas inlet temperature to the exchanger was set at 400 °C, which is the highest syngas temperature at the gasifier output and a desired syngas outlet temperature of 40 °C as representing in table 3.12. The convection coefficient was estimated to be 8 W/m^2.K by [39].

Table 3.12: Gas/Air heat exchanger design parameters

Parameters	**Values**	**Units**
T_{iSyn}	400	°C
T_{oSyn}	40	°C
T_{air}	25	°C
h^{air}	8	W/m^2.K
K_{steel}	53.75 [39]	W/m.K

3.1.6 Filter

The filter is a box with a segment in the center, filled with sawdust to just beneath the syngas inlet and output pipes, and has the same dimensions as the gasifier. Two grids at the bottom are for homogeneity of the syngas stream, with acute cloth above the grids to prevent sawdust from falling to the bottom.

The figure 3.10 of the filter represent the proper flow of syngas.

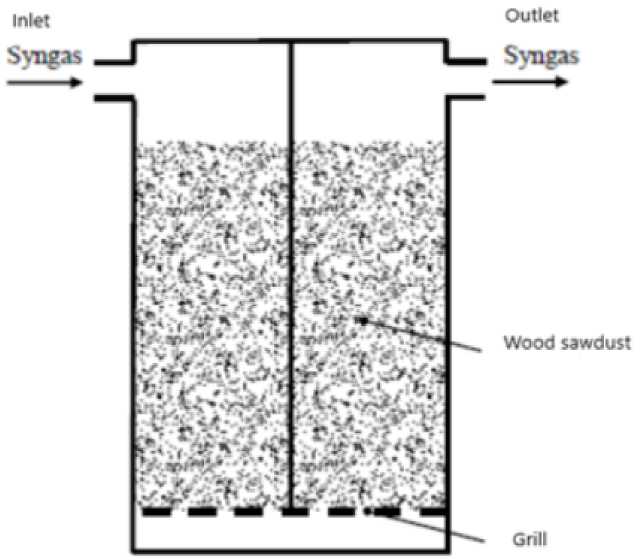

Figure 3.10: Filter [39]

Table 3.13 shows the sawdust properties that were used to calculate the pressure drop in the filter. For a temperature of 40°C, which is the estimated temperature of the syngas at the exchanger outlet, the gas parameters was determined in the table.

Table 3.13: Filter characteristics

Parameters	**Values**	**Units**
T_{Syn}	40	°C
V_S	100	mm^3
A_S	240	mm^2
L	500	mm
H	700	mm

3.2 Economic aspect tools

Any project that needs to get from paper to practice will need to be budgeted. Institutional support came from the Polytechnic Institute of Bragança (IPB), which made available the Mechanical Technology Laboratory (MTL) of the School of Technology and Management (ESTiG) as the project's mother institution, supplied all of the consumables, electricity, and equipment needed for the project's implementation, as well as the payment of 40€ in invoices to local businesses. The project's human resources were provided by the students who advocated it, dedicating their hearts and souls as well as many hours of hard work. The Mechanical Technology Laboratory of the IPB's Mechanical Technology Laboratory's technicians' availability and devotion were critical to the project's success, and INEGI - Institute for Science and Innovation in Mechanical Engineering and Industrial Engineering offered monetary support of 228€; Crowdfunding was started on the website PPL https://ppl.pt/biomassa, with a goal of raising 1200€, but it exceeded the expectations by 23%, achieving a total of 1470€. A 5000€ prize was won in an idea competition organized by the bank La Caixa/BPI as showing in table 3.14 [39].

Table 3.14: Budgeting for the remaining components of the prototype

Description	**Price**	**Units**
IPB	40.000	€
INEGI	280.000	€
Crowdfunding	1470.000	€
Loan CAIXA	5000.000	€
Total	6747.000	€

To obtain the Annual saving expected, the cash flow, the syngas and electricity production cost the following considerations was needed for the investment as showing in table 3.15 [51] and [39].

Table 3.15: Different investment for the prototype

Items	**price**	**Units**
Engine	430.000	€
Gasifier	280.000	€
Exchanger	152.500	€
Transport cart	283.000	€
Painting	78.000	€
Other [39]	175.000	€
Commission [51]	73.000	€
Commission (2% + VAT) [39]	110.700	€
Total	1783.000	€

Also the annual interest rate (r) was considered 12% it was calculated using the following equation 3.9 [52].

$$r = (1 + \frac{i}{n})^n - 1 \tag{3.8}$$

where;

i: Nominal interest rate which is obtained by subtracting the original investment value from the current market value of investment divided by the original investment amount.

n: Number of period (12 months).

The equivalent period was considered between 2000h/year which is 5.5h/d and 6000h/year equal to 16.4h/d, the average electricity costs in 2019 were 0.215 €/kWh and for sale 0.12 €/kWh was taken from the Pordata database (Pordata, 2020) , and it was projected that these prices would remain stable in 2021, the start of the study period[52], and biomass price is 0.00323 €/kg [47].

The wage rate for each operator time [47], and inflation rate [53] are showing in table 3.16.

Table 3.16: Set of assumptions for ICE/Gasifier economic analysis

Items	**price**	**Units**
Annual interest rate	12	%
Equivalent period	2000-6000	h/year
Wage rate	9.66;6.44;4.83;3.87;3.22	€/h
Investment amortisation	8	Year
Inflation rate	1.5	%
Biomass price	0.00323	€/kWh
Electricity tariff	0.21	€/kWh
ICE maintenance cost	0.00924	€
Hot water maintenance	0.030	€/kWh

The calculations for constructing the cash flow are as follows using equation from 3.9 to 3.20 [51].

$$A_w = A_1 * (1 + (\frac{x}{100})) \tag{3.9}$$

where;

A_w :Revenue for the second and consecutive years of the installation (€)

A_1 :Revenue for the first year of installation (€)

x :Inflation (%)

$$B = 0.03 * Y \tag{3.10}$$

Where;

B: Maintenance cost (€)

Y:Investment Cost (€)

$$D = A - B - C \tag{3.11}$$

Where;

D: Gross Benefit (€)

C: Cost of biomass (€)

$$E = \frac{0.7 * Y}{W} \tag{3.12}$$

Where;

E: Amortization cost (€)

W: Amortization and financing time (8 years)

$$F = D - E \tag{3.13}$$

Where;

F: Benefit before interest (€)

$$G = \frac{U}{100} * EM \tag{3.14}$$

Where;

G: Interest cost (€)

U: Interest (%)

EM:Loan (€)

$$H = F - G \tag{3.15}$$

Where;

H: Benefit before Taxes (€)

$$I = \frac{V}{100} * H \tag{3.16}$$

Where;

I: Tax Cost (€)

V: Taxes (%)

$$J = H - I \tag{3.17}$$

Where;
J: Total Benefit (€)

$$K_1 = \frac{EM_0}{W} \tag{3.18}$$

Where;
K_1: Outlay for year 1 of installation (€)
EM_0 : Loan for year 0 of the installation (€)

$$CF = J + E - K \tag{3.19}$$

Where;
CF: Cash Flow (€)

$$EM_W = EM_0 - K_1 \tag{3.20}$$

Where;
EM_W: Loan for the first and subsequent years of the facility (€)
EM_0: Loan for year 0 of the installation (€)

3.3 Aspen Plus Simulation

Through the use of simulators such as Aspen Plus processes, computer tools have become vital in the mechanical industry. They're employed to improve industrial units by simulating, optimizing, verifying, and sizing various engineering processes' equipment.

This section is divided into two units. We'll start with an overview of the Aspen Plus software. After that, we'll work on simulating the process under investigation.

3.3.1 Aspen Plus

(ASPEN) is an acronym for Advanced System for Process Engineering. It is based on a simulation of a flow sheet. A flow sheet simulator is a software program that allows you to model a chemical processing plant quantitatively. A chemical processing plant, in general, consists of a core reactor unit as well as many supplementary unit operations, such as pre- and post-treatment stages [54].

Aspen Plus is a very powerful tool in this regard, as it can be used to tackle a variety of chemical process and unit operation calculation-based tasks, such as modeling, simulation, optimization, data regression, design specifications, sensitivity analysis, solids handling, dynamics and control, energy savings, safety compliance, and finally process economic analysis.

3.3.1.1 Description of the simulation tool

In order to have a comprehensive analysis, a presentation of the Aspen software is needed.

Aspen Plus is a process modeling environment built for a variety of sectors, including the oil and gas and refinery industries. The creation of stationary or dynamic models with this software is possible . His dynamic interface allows to simply adjust the settings of numerous processes as well as different unit systems.

The software's primary features are as follows [54]:

- Calculation and prediction of thermodynamic properties.
- Smoothing of experimental data and analytical correlations establishment.
- Simulation, design and optimization of equipment and processes.
- Verification of the units' state of progress.
- Study of plant's control and regulation.

To perform these functions, the program has:

- A library of modules for the calculation of physical and thermo-dynamical properties of pure substances and mixtures.
- A library of numerical calculation methods for the systems' algebraic solutions.
- A library of standard modules simulation equipment (heat exchanger, reactors, separators, column ...).

3.3.1.2 Process of simulation

The following methods were followed while using Aspen Plus to simulate processes:

- Puting the chemical species presented in the processes.

- Choosing the adequate thermodynamic models for the calculation of thermodynamic properties of pure substances and mixtures.
- Establishment of the block diagrams of the process and description of unit operations presented within it.
- Selecting the operative conditions for the different equipment.

3.3.1.3 Thermodynamic model selection

There are several models to describe the thermodynamic behavior of the compounds. For this simulation, the IDEAL property technique was used to assume ideal behaviour, such as systems at vacuum pressures and isomeric systems at low pressures. Small departures from the ideal gas law are permitted in the vapor phase. Low pressures (below atmospheric pressure or pressures less than 2 bar) and extremely high temperatures cause these deviations. Molecules having very modest interactions or interactions that cancel each other out demonstrate ideal behavior in the liquid phase. For systems with and without non-condensate components, the IDEAL property technique is commonly utilised. Permanent gases can be dissolved in the liquid using this procedure [55].

The following figure 3.11 shows how to choose the models in the software.

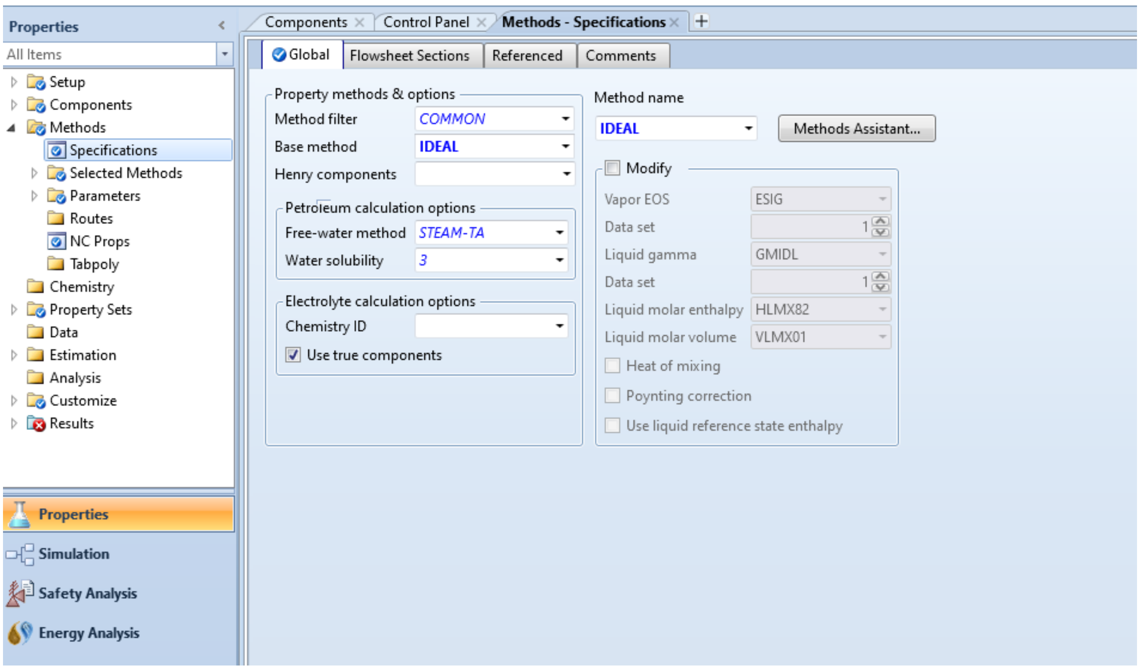

Figure 3.11: Choice of thermodynamic model

3.4 Simulation Steps

3.4.1 Description of the prototype

The Aspen Plus simulator models of the 2 systems were created. Material, input, and output streams of the blocks have been specified once they have been placed on the flow sheet and flowchart as models of specific process operations as showing respectively in the figures 3.15, 3.14 and 3.13. Due to the lack of a built-in gasifier model in the ASPEN Plus process simulator, a variety of reactor types defined in the software for each zone of gasification has been suggested to be used (figure 3.12).

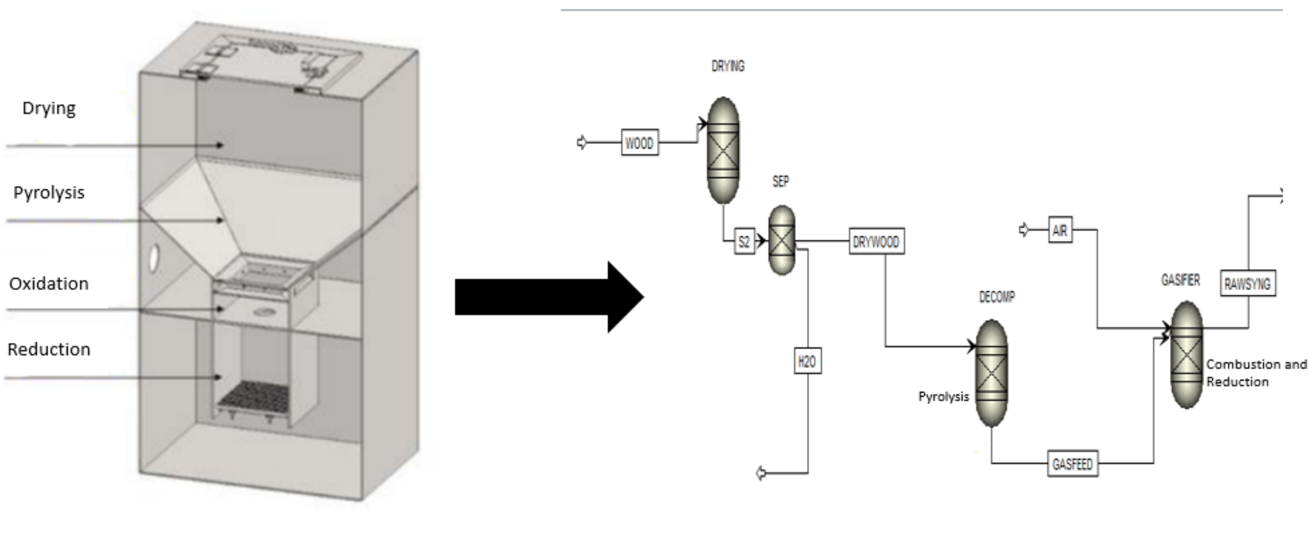

Figure 3.12: Gasifier model used in the software

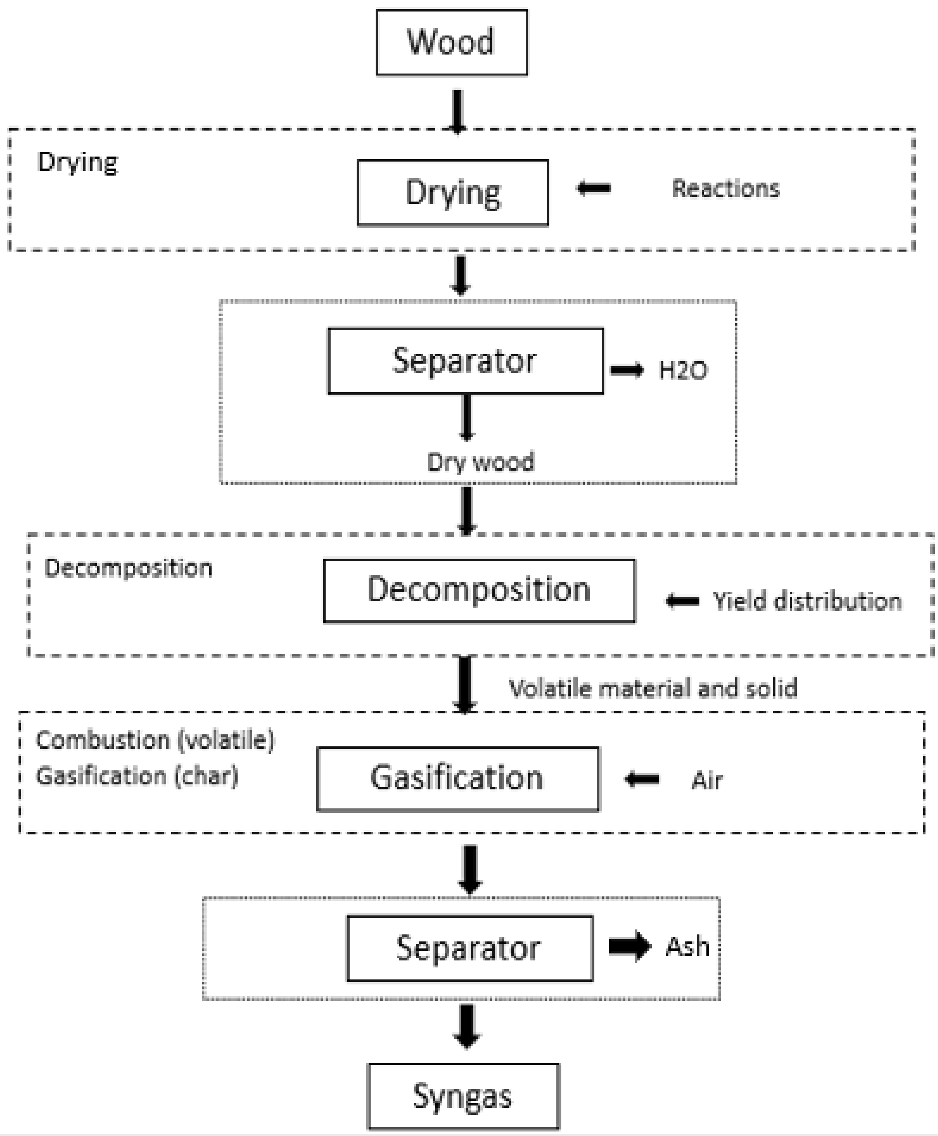

Figure 3.13: Flowchart process of downdraft gasification

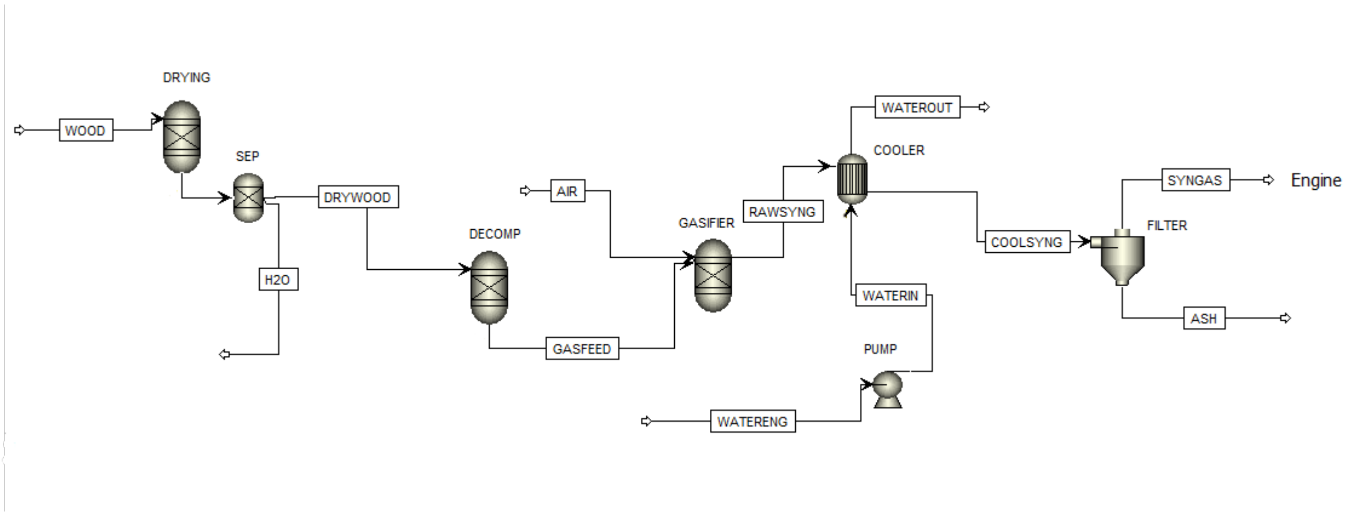

Figure 3.14: Flowsheet of the process system 1

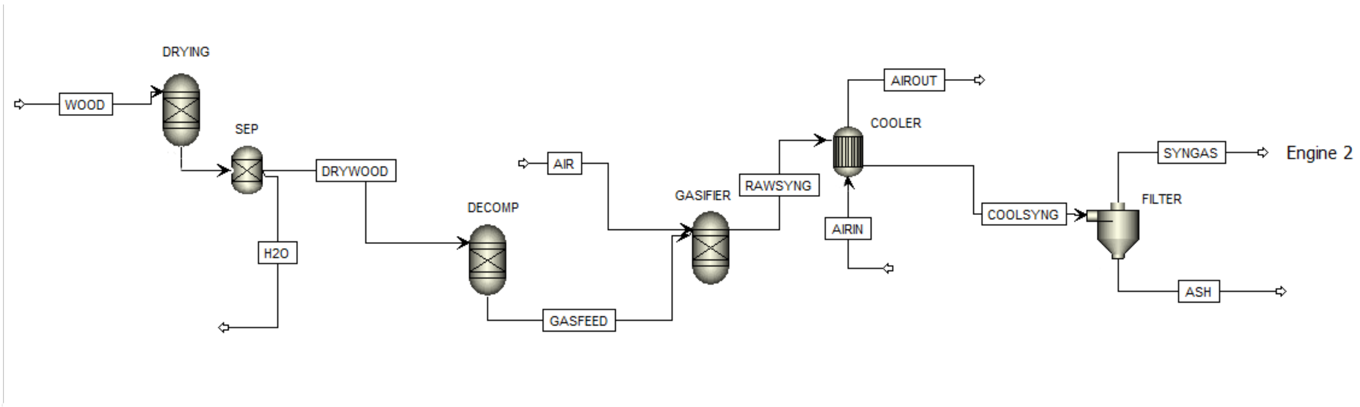

Figure 3.15: Flowsheet of the process system 2

The Aspen Plus model was developed using the following methods and techniques, which are briefly detailed below.

Five distinct blocks were evaluated in order to replicate Eucalyptus wood blocks gasification in a downdraft gasifier based on the experiment that was carried out figures 3.14, 3.15 for system 1 and 2, respectively.

The first one is Drying: Improving gasifier performance requires reducing moisture in the feed. To replicate the drying process of wood, an Aspen Plus block called RYield (block ID: DRYER in Figures 3.14, 3.15) was employed. The wood is fed into the block, which vaporises the water bound in the wood. The water content in the proximate analysis of wood determines the generation of gaseous water. Because the wood has a moisture content of 12%, the mass yield of gaseous water is set at 12%, based on the premise that the physically bound water is totally vaporised in this process. As a result, the mass output of dried wood is equal to 100% - 12% = 88%. The gaseous water and dried wood flow into SEPERATOR, a gas and solid separator, after drying. The gaseous water is drained from the process, and the dried wood is sent to the next block for breakdown of dried feed.

The second one: Wood decomposition (DECOMP block) is a process in the RYield reactor that converts wood into its constituents, such as carbon, hydrogen, oxygen, nitrogen, moisture, and ash, based on its final analysis. When the reaction stoichiometry or reaction kinetics are unknown or immaterial, but the yield distribution is known, this sort of reactor is used [55].

The third one: is within the RGibbs reactor, where the raw producer gas (RAWSG stream) is formed, volatile interactions with air (combustion and reduction stages) (GASIFIER block). When the reaction stoichiometry is unknown but the reactor temperature and pressure are known, this sort of reactor is utilised [55].

The fourth block is the Heat Exchanger (HEATEXC block), which transfers heat generated by breakdown (HEATDEC stream),

The fifth is the Solid Separator-Cyclone (FILTER block), which separates ash from raw producer gas, producing SYNGAS and ASH streams provided by the split fraction of MIXED and NCPSD. The following table 3.17 shows the different blocks used in the simulation

Table 3.17: List of blocks used in the simulation

Name of block	**Blocks**	**Description**
Drying	RYield reactor	Reducing moisture from feed
DECOMP	RYield reactor	Decomposition of wood by elements and product distribution
GASIFIER	RGibbs reactor	Minimizing Gibbs free energy to model chemical equilibrium
HEATEXC	HeatX	Heat exchange (cooler)
FILTER	Cyclone	Gas solid separation

3.4.2 Operating conditions

While modeling the gasification process, the following assumptions were taken into account:

- The entire process is steady state and isothermal;
- Char only comprises carbon and ash;

• Reactions reach chemical equilibrium with volatile products primarily comprised of CO_2, H_2, CO, CH_4, N_2, and H_2O.

• Tars are believed to be minimal in the producer gas and are not taken into account.

3.4.2.1 Characterisation of wood

In Aspen Plus, non-conventional components such as feed (wood), dry-feed, and ash are specified as non-conventional components and defined in the simulation model utilising ultimate and proximal analysis. Table 3.18 shows the qualities of feed.

Table 3.18: Characteristics of wood

Proximate analysis (Dry basis)	
Elements	**%**
Moisture	12.0
Volatile matter (VM)	17.2
Fixed carbon	78.1
Ash	4.7
Ultimate analysis	
Elements	**Mass%**
carbon (C)	46.4
H	5.38
N	0.29
Ash	4.70
S	0.05
Oxygen (O)	43.17

For both feed, dry-feed, and ash, which are non-conventional components, the NC properties: Enthalpy and Density model was chosen as HCOALGEN and DCOALIGT, respectively. In the Aspen Physical Property System, HCOALGEN is the generic coal/Wood model for determining enthalpy, which contains a number of distinct correlations for heat of combustion, heat of production, and heat capacity. DCOALIGT is a density model that uses ultimate and sulfur studies to calculate the real (skeletal or solid-phase) density of coal/Wood on a dry basis.

3.4.3 Input Parameters

Table 3.19 shows the input parameters for the relevant gasifier operating settings, which were similar to experimental measurements.

Table 3.19: INPUTS of streams and gasifier

Feed system 1		**Feed system 2**
Items	**value**	**value**
Flow Rate (kg/s)	0.0055	0.0016
Pressure (bar)	1.0130	1.0130
Temperature (°C)	25	25
AIR system1		**AIR system2**
Items	**value**	**value**
Flow Rate (kg/s)	0.0016	0.0253
Pressure (bar)	1.0130	1.0130
Temperature (°C)	25	25
Dryer system1		**Dryer system2**
Items	**value**	**value**
Pressure (bar)	1.0130	1.0130
Temperature (°C)	400	400
Decomposition system1		**Decomposition system2**
Items	**value**	**value**
Pressure (bar)	1.0130	1.0130
Temperature (°C)	400	400
Gasifier system1		**Gasifier system2**
Items	**value**	**value**
Pressure (bar)	1.0130	1.0130
Temperature (°C)	1000	1000

For the exchanger the inputs are presented in table 3.20

Table 3.20: Exchangers inputs

Exchanger system1	**Exchanger system1**	
Items	**value**	**value**
Pressure (bar)	1.0130	1.0130
T_{syn} (°C)	400	400
T_{water}/T_{air} (°C)	15	25
Flow rate syngas (kg/s)	0.734*10^{-3}	2.154*10^{-3}

Chapter 4

Results and discussion

4.1 Validation

A comparison of simulation findings with actually collected data using a pilot scale gasifier is presented in this section. The gasifier model's operating conditions were similar to the experimental measurement, as indicated in Table 4.1. Raw syngas composition, such as H_2, CO, CO_2, CH_4, N_2, and H_2O, was measured experimentally and will be compared to modeling results. By comparing current forecasts to the experimental results of [56] as shows table 4.1.

Table 4.1: Comparison of syngas composition between experimental measurement and modeling results with Aspen plus software

Measurement	CO_2	CO	N_2	H_2	CH_4
Experimental	15.1-18.3	12.5-15.2	48.8-56.7	10.1-14.7	3-4.2
Simulation 1	20.68	13	60.07	0.1334	0.0339
Simulation 2	21.25	10.92	51.58	0.933	0.000198

Figure 4.1 shows that the difference between measured and simulated outcomes is only about 2 to 9%. The model only underestimated the formation of methane and hydrogen, which is a common problem for equilibrium models that can't anticipate substantially more hydrocarbons (especially methane). As a result of the composition of syngas, it is reasonable to conclude that the constructed model can be used for further analysis with acceptable precision.

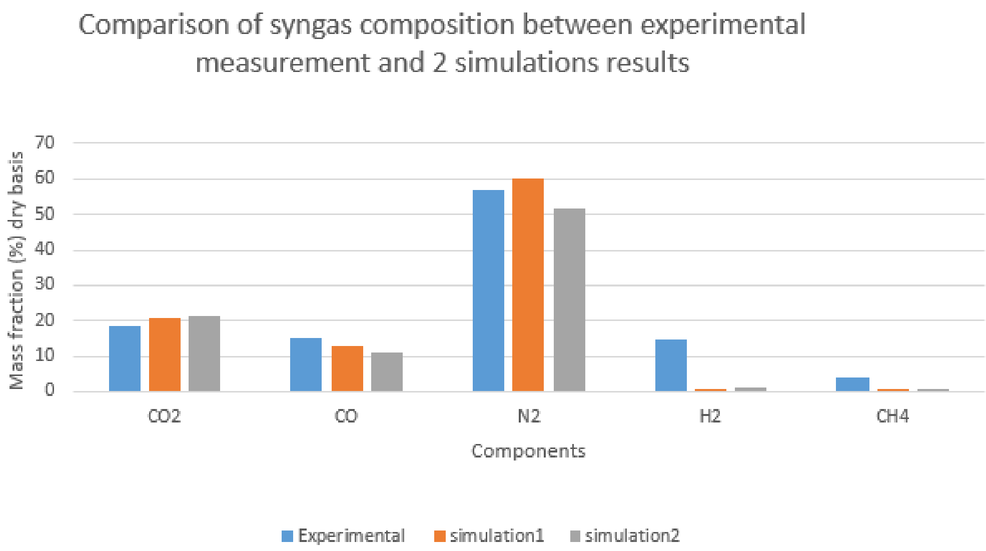

Figure 4.1: Syngas composition comparison between simulation and experimental measurements

4.2 Energy analysis results

The energy analysis was performed using the first law of thermodynamics to analyse the distribution of the energy flows of each stream in the gasification system-ICE. The mass and energy balances for the investigated feedstocks using the simulation of Aspen Plus are shown in the tables 4.2 and 4.3. The mass balance enables for the calculation of syngas and engine exhaust gas mass flows, as well as air flows for the gasification and syngas combustion processes. Given the mass flow of biomass capacity for the the gasifier system, which is roughly $0.55*10^{-3}$ kg/s, which is expected to be constant.

Table 4.2: Streams energy results

		Wood input dryer		
ṁ(kg/s)	**P(bar)**	**T(°C)**	**LHV (kJ/kg)**	**Q̇(kW)**
$0.5577*10^{-3}$	1.013	25	19400	11.19
		Air input gasifier		
ṁ(kg/s)	**P(bar)**	**T(°C)**	**LHV (kJ/kg)**	**Q̇(kW)**
$1.58*10^{-3}$	1.013	25	-	1.55
		Rawsyngas output gasifier		
ṁ(kg/s)	**P(bar)**	**T(°C)**	**LHV (kJ/kg)**	**Q̇(KW)**
$2.05*10^{-3}$	1.013	400	3701.88	7.55
		Syngas output cyclone		
ṁ(Kg/s)	**P(bar)**	**T(°C)**	**LHV (KJ/kg)**	**Q̇(KW)**
$2.02*10^{-3}$	1.013	40.33	4381.18	8.85

Table 4.3: Streams energy results for system2

		Wood input dryer		
ṁ(Kg/s)	**P(bar)**	**T(°C)**	**LHV (KJ/Kg)**	**Q̇(KW)**
$1.627*10^{-3}$	1.013	25	19400	31.56
		Air input gasifier		
ṁ(Kg/s)	**P(bar)**	**T(°C)**	**LHV (KJ/Kg)**	**Q̇(KW)**
$2.53*10^{-3}$	1.013	25	-	2.49
		Rawsyngas output gasifier		
ṁ(Kg/s)	**P(bar)**	**T(°C)**	**LHV (KJ/Kg)**	**Q̇(kW)**
$3.84*10^{-3}$	1.013	400	5109.37	19.62
		Syngas output cyclone		
ṁ(kg/s)	**P(bar)**	**T(°C)**	**LHV (kJ/kg)**	**Q̇(kW)**
$3.76*10^{-3}$	1.013	40.33	5468.08	20.56

The equipment's outputs simulation results are showing bellow in table 4.4, as mentioned in chapter 3 the gasifier has been divided into 3 equipment according to the reactions present in the gasifier.

Table 4.4: Gasifier energy output results

Dryer sys1 (RYield)	**Dryer sys2 (RYield)**	
Items	**value**	**value**
$\dot{m_{wood}}$ (kg/s)	0.0057	0.001627
Pressure (bar)	1.013	1.013
Temperature (°C)	400	400
Heat duty (kJ/s)	3.16	9.25
Decomposition sys1 (RYield)	**Decomposition sys1 (RYield)**	
Items	**value**	**value**
$\dot{m_{wood}}$ (kg/s)	0.466*10^{-3}	0.00473
Pressure (bar)	1.013	1.013
Temperature (°C)	400	400
Heat duty (kJ/s)	0.8	2.26
Gasifier (RGibbs)		
Items	**value**	
Pressure (bar)	1.013	1.013
Temperature (°C)	1000	1000
Outlet temperature (°C)	400	400
Heat duty (kJ/s)	7.03	10.22
$\dot{m}$ (kg/s)	0.204*10^{-2}	0.001315
Total heat duty (kJ/s)	10.99	21.73

The derived results for the energy analysis of the downdraft-ICE system based on the first law of thermodynamics and the Aspen plus simulation.

As showing in the previous tables 4.2, 4.3 and 4.4, the power heat biomass is 11.19kW for system 1 and 31.56 KW for system 2 depending on the LHV of the fuel, the power given by syngas is 7.55 kW for system 1 and 19.62 KW for system 2, meanwhile in the literature of [47] the power heat of syngas is 5.39KW means that the difference is just 2.16% for system1 and 14.23% for system2 ,the gasifier's heat power is 10.99, 21.73 kW for system 1 and 2, respectively.

The gasifier efficiency is 67.4, 62.16% for system 1 and 2, respectively which is 69% in the literature[47], means that it has a 1.6% for system 1 and 6.84% of difference.

It is possible to conclude that these values are acceptable.

4.2.1 Exchanger energy results

The syngas cooling results are provided in figure 4.2 using the software, and the amount of heat lost by the syngas attaining a temperature of 40°C.

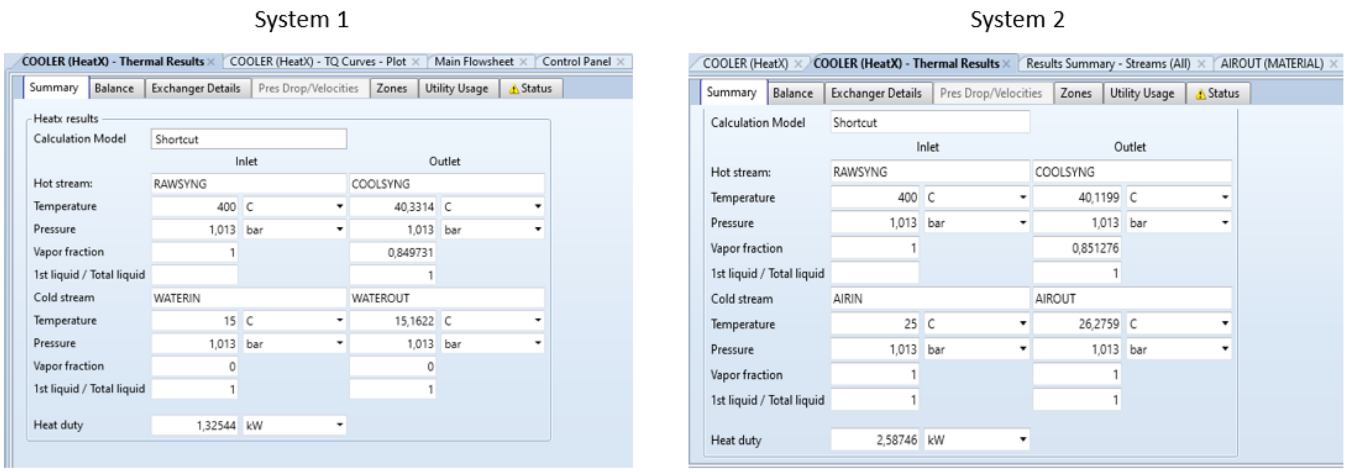

Figure 4.2: Exchangers simulation results

With the value of Cp 1.1354 kJ/kg.K the cooled syngas in the outlet of exchanger of the system 1 is 40.33°C and the system 2 is 40.11°C, the water outlet in the cold stream is 15.16°C and the air outlet is 26.27°C, the heat power of the exchanger of system 1 is 1.325 kW and its efficiency is 85.3%.

For system 2 the heat power is 2.58 kW and the efficiency is about 95.4%.

According to the work of Boloy and al. [47] it ranges from 65 to 85% means it is a validated value.

4.2.2 Engine energy results

According to the heat energy of syngas with the percentage of thermal power losses in table 3.2 and with the first law of thermodynamics represented in equation 2.11 the mechanical power results are showing in table 4.5

Table 4.5: Engine energy results

System 1	System 2	
Items	**value**	**value**
$\dot{Q}_{Syngas}$ (kW)	8.85	20.56
$\dot{Q}_{Conv}$ (kW)	0.501	1.46
$\dot{Q}_{Arref}$(kW)	2.244	6.57
$\dot{Q}_{ge}$ (kW)	2.244	6.57
$W_{X,syn}$ (kW)	2.561	6.40
η_{engine} (%)	29	31.12

The shaft power value is 2.561 and 6.40 kW for the systems 1 and 2, respectively , and the mechanical power values at the shaft were acquired. For the engine's efficiency, it is 29% for system 1 which is ranges from 20 to 30%, meanwhile for system 2 it is 31.12%, it is close with a difference of 1.12% according to the literature [47].

4.2.3 Global energy efficiency

The thermal power of the biomass was treated as an input content in the system for the energy balance, and the power given in the shaft of the systems was considered as an output content in the system. It was possible to determine energy efficiency using this methods.

Table 4.6: Global energy efficiency results

System1	system2	
Items	**value**	**value**
$\dot{Q}_{biomass}$ (kW)	11.19	31.56
$W_{X,syn}$ (kW)	2.561	6.40
η_G (%)	22.88	20.27

According to the results in table 4.6, system 1 has an overall energy efficiency of 22.88 % and system 2 has 20.27%. This value is validated because it has a difference of 1.58% and with -1.03% comparing with the 21.3% overall efficiency of literature [57].

4.3 Exergy analysis results

The Third Law of Thermodynamics was used to calculate the exergy balance in the gasifier, exchanger, and engine, with temperatures of 25°C and 40°C for the gasifier and exchanger, respectively. The temperature of the heat source was 673 K (400°C), which was the average temperature inside the gasifier. The heat and work exergy coefficients were calculated using the equations 2.36, 2.34, respectively. The values of the computed irreversibilities are shown in the table 4.7. According to Equation 2.36, the heat exergy of the biomass fed into the gasifier and of syngas introduced into the exchanger were taken into account for the input value, and the heat exergy of the syngas produced by the gasifier, as well as the thermal exergy of the thermal power yielded to the water/air in the cooling systems, were taken into account for the output value.

The engine's exergetic efficiency was determined for both systems.

The thermal exergy of the syngas injected to supply the system's motor was taken into account at the system input. The mechanical exergy of the shaft engine was taken into account at the output, which was equal to the mechanical power given to the shaft.

Table 4.7: Irreversibilities and exergies efficiency results

Gasifier system 1		**Gasifier system 2**
Items	**value**	**value**
$\dot{Q}_{biomass}$ (kW)	11.19	31.56
$\dot{Q}_{syngas}$ (kW)	7.55	20.56
T(°C)	400	400
$T_0(C)$	25	25
$\dot{I}_g$ (kW)	4.35	11
$\dot{\varepsilon}_{Q,g}$ (kW)	10.49	29.58
$\dot{\varepsilon}_{Q,e}$ (kW)	7.07	19.27
ψ_g (%)	67	65.51
Exchanger system 1		**Exchanger system 2**
$\dot{Q}_{syn,in}$ (kW)	8.85	20.56
$\dot{Q}_{syn,out}$ (kW)	7.55	19.92
$T_0(C)$	40.33	40.11
T(°C)	400	400
$\dot{I}_{exch}$ (kW)	1.3	0.64
$\dot{\varepsilon}_{Q,in}$ (kW)	7.95	18.49
$\dot{\varepsilon}_{Q,out}$ (kW)	6.78	17.92
ψ_{exch} (%)	85	96.91
Engine system 1		**Engine system 2**
$\dot{\varepsilon}_{Q,syn}$ (kW)	6.78	17.92
$\dot{W}$ (kW)	2.561	6.40
$\dot{I}_{eng}$ (kW)	4.22	11.52
$\dot{\varepsilon}_{Q,in}$ (kW)	17.92	
$\dot{\varepsilon}_{W,out}$ (kW)	2.561	6.40
ψ_{eng} (%)	38	35.7

According to Table 4.7 the irreversibility of system 1 in the gasifier is 4.35 kW. The system's exergetic efficiency was found to be 67%, which corresponds to the assumed energy efficiency of 67.4%. In the other hand the irriversibility of system2 is 11kW and the exergetic efficiency was found to be 65.51%.

The exchanger irreversibility os system 1 and 2 are respectively, 1.3 - 0.64 kW. The high exergetic efficiency of the exchangers (85 and 96.91%) corresponds to the exchangers' low irreversibilities. The engine's irreversibility value is 4.22, 11.52kW, with a value of exergetic efficiency of 38,35.7% for system 1 and system 2, respectively .

4.3.1 Global exergy efficiency

For the exergetic balance, the biomass thermal exergy was evaluated at the input of the system, and the mechanical exergy provided to the shaft at the output, just as it was for the global energy balance.

Table 4.8: Total exergy efficiency of both systems

	System 1	**System 2**
Items	**value**	**value**
$\dot{\varepsilon}_{Q,in}$ (kW)	10.49	29.58
$\dot{\varepsilon}_{W,out}$ (kW)	2.561	6.40
η_G (%)	24.4	21.63

Table 4.8 demonstrates that the overall exergetic efficiency of system 1 is 25% and for system 2 is 21.63%. Comparing these efficiencies values with a literature [58] (19%) shows that our results are over estimated by 5.4% for the first system and about 2.63% for system 2. Thus, these values are validated.

4.4 Economic model results

4.4.1 Maintenance and operation cost

In terms of cost, the overall gasifier maintenance and operating cost ranged from 0.003 €/kWh to 0.001 €/kWh during the gasifier's operation. This number is within the range of 0.00125–0.005 €/kWh stated in the literature [57], as showing in table 4.9

Table 4.9: Gasifier maintenance and operation cost

Cost €/kWh	**2000 h/year**	**4000 h/year**	**6000 h/year**
Maintenance	0.0025-0.0004	0.0019-0.0002	0.0008-0.0001
Operation	0.00044	0.00019	0.00005
Total	0.003	0.0014	0.0010

4.4.1.1 ICE and hot water operation costs

In case of the ICE operation cost it can be shown in figure 4.3 that as the payback period grow, the COP_{ICE} reduces. Also it is shown that it is ranged from 0.0145 to 0.0023 €/kWh in 2000h/year, from 0.0072 to 0.0011 €/kWh in 4000h/year and from 0.0048 to 0.0007 €/kWh in 6000h/year.

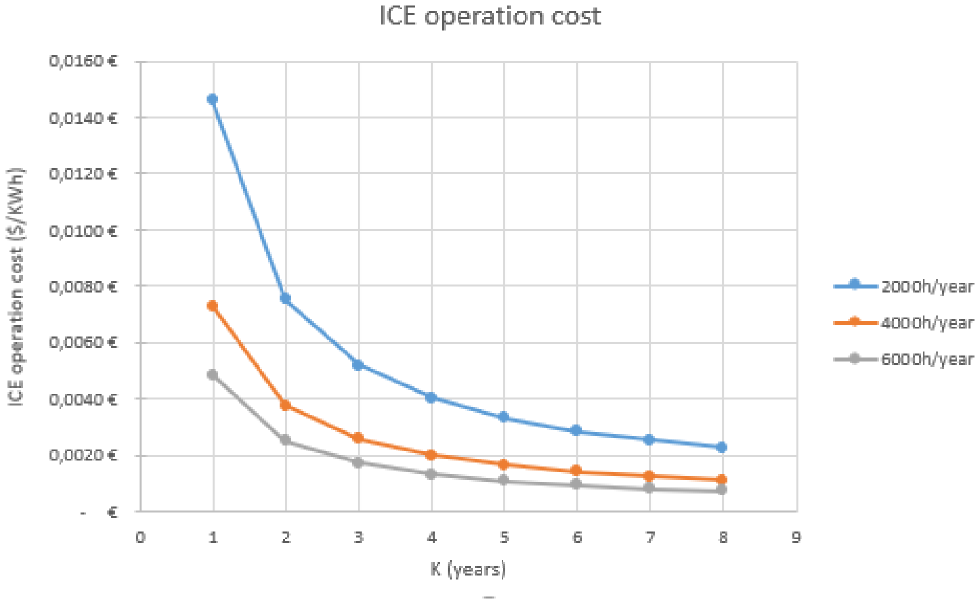

Figure 4.3: ICE operation cost

Figure 4.4 shows that as the payback period increases, the hot water operation cost decreases gradually.

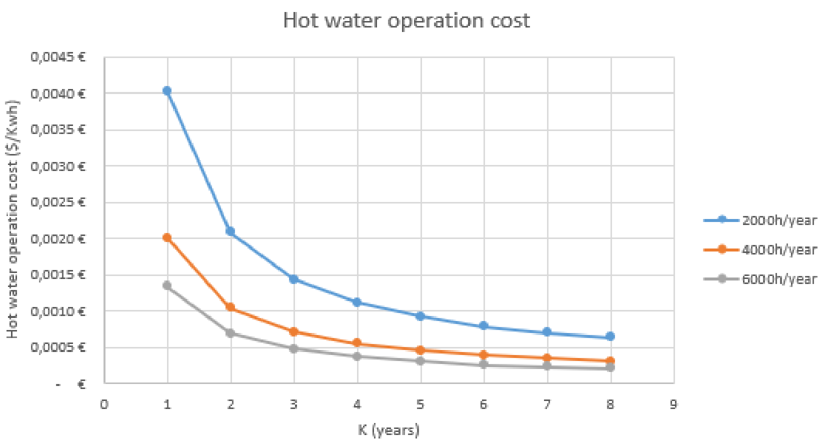

Figure 4.4: Hot water operation cost

4.4.2 Electricity, hot water and syngas cost

Figures 4.5 to 4.7 represent all costs calculated in the Gasifier/ICE system with the following conditions: eucalyptus price of 0.00323 €/kWh, annual interest rate of 12%, and payback range time of 1 to 8 years.

When it comes to syngas costs, it's worth noting that the time it takes each gasifier to operate gets shorter as the payback period gets longer as shows figure 4.5.

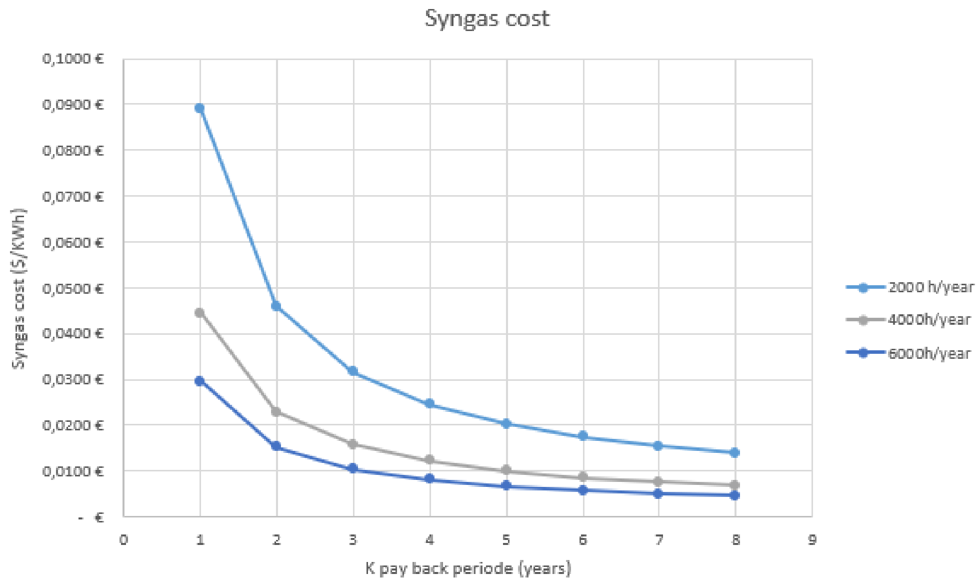

Figure 4.5: Syngas cost

In the case of energy costs, it can be shown that as the payback period lengthens, the gasifier operation duration reduces. From the first year of the payback period on wards, the power costs computed for each gasifier operation time are lower than the electricity tariff as shows figure 4.6

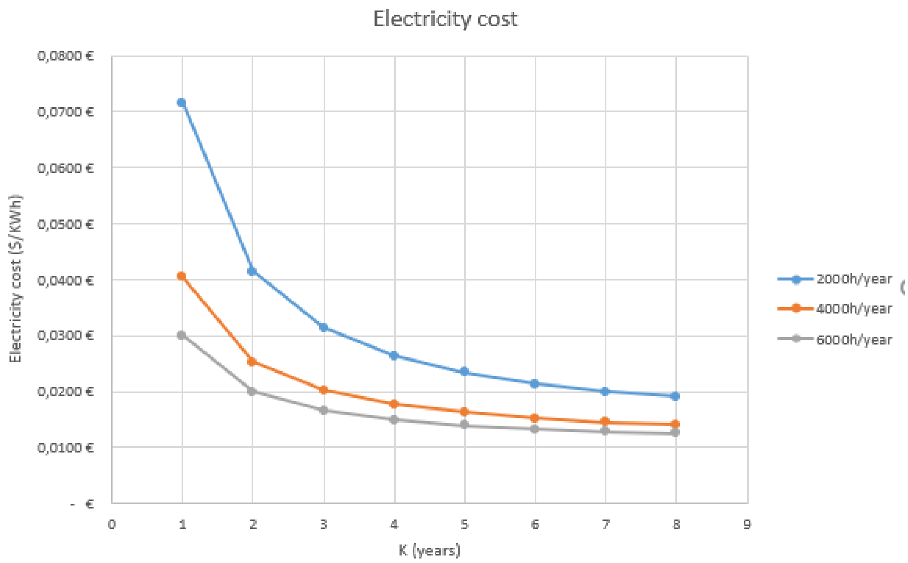

Figure 4.6: Electricity cost

The price of hot water given that the thermal energy of water is 1.03 kW of system 1, it can be shown in figure 4.7 that for each gasifier operation time tested, the cost of producing hot water for household use did fall below the hot water tariff (0.030 €/kWh), implying that the Gasifier/ICE system is provide hot water at competitive pricing.

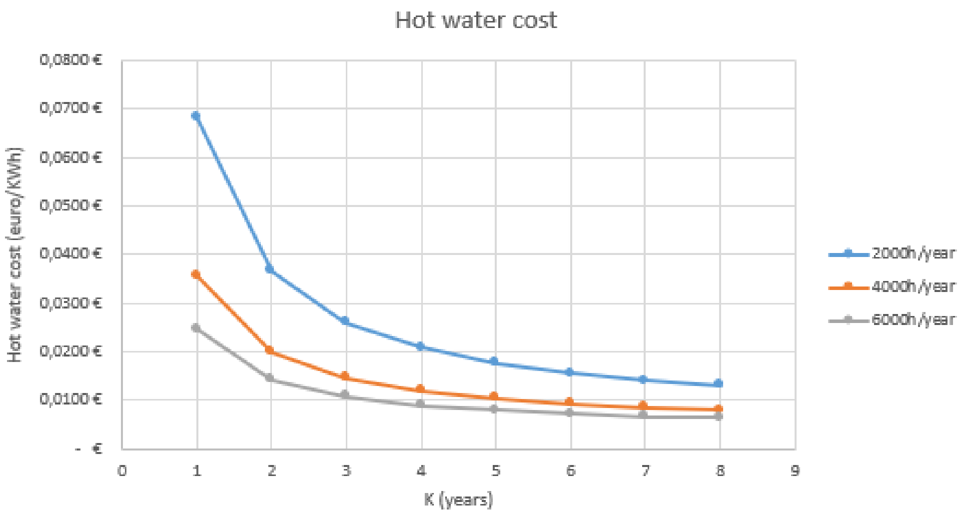

Figure 4.7: Hot water cost

4.4.3 Electricity and hot water gain

Figures 4.8 and 4.9 represent gains of hot water and electricity calculated for the system.

Figure 4.8 shows that the electricity gain increases with the increase of the payback period gradually due to the electricity cost. For the operation period of 2000h/year there is no gain it ranges from -541.41 to -39.50 €/kWh. In the 6th year of operation period 4000h/year the gain in electricity started and ranges from 4.88 to 16.50 €/kWh .In the other hand in the 6000h/year the electricity gain started on the 4th year and it ranges from 2.69 to 71.87 €/kWh.

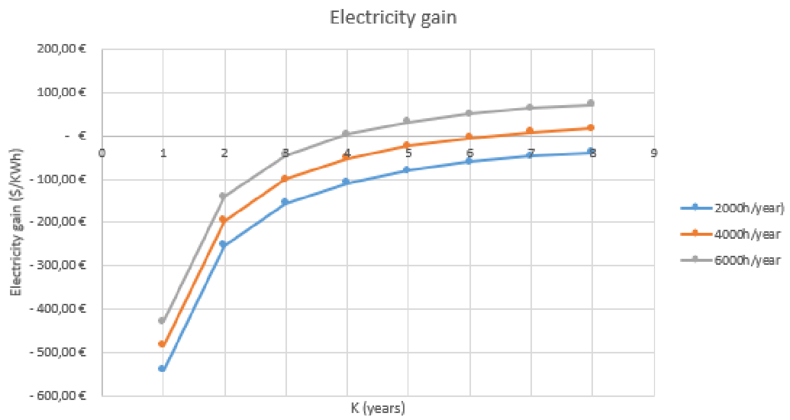

Figure 4.8: Electricity gain

It can be shown in figure 4.9 that as the payback period increases, the water gain rises with the operation periods, for 2000h/year the hot water gain started after the second year and it ranges from -16.57 to 7.34 €/kWh. In the other hand for 4000h/year and 6000h/year the gain started from the first year.

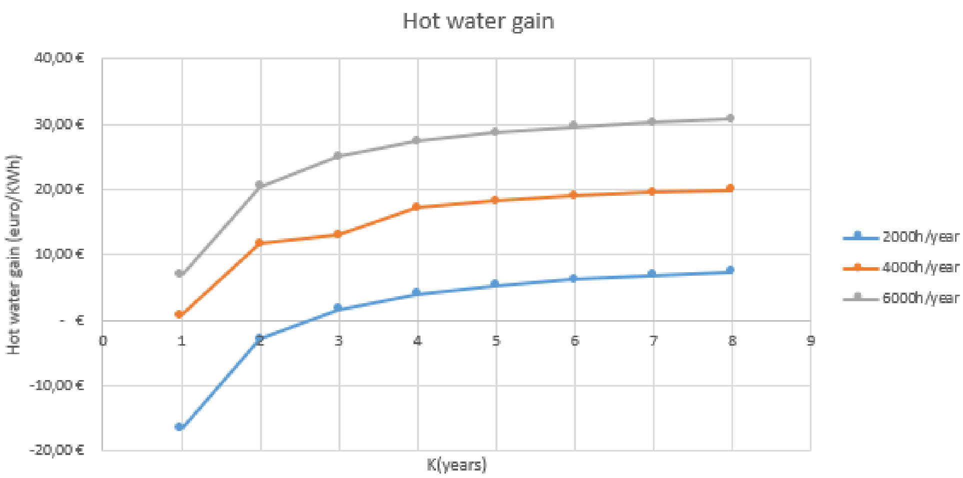

Figure 4.9: Hot water gain

4.4.4 Annual saving expected (ASE)

The annual predicted savings variation for the analysis parameters specified as: electricity gain, hot water gain, an interest rate of 12%/year, hot water production factor, and payback period of 1–8 years are shown in the figure 4.10. It can be observed that a Gasifier/ICE system operating at 6000 h/year is economically feasible with a payback period of 2.5 years.

Because it is impossible to operate a Gasifier/ICE system in isolated communities under these conditions, an operation time of 4000 h/year is considered adequate. Under these conditions, a Gasifier/ICE system is economically feasible for a payback period of 4.4 years; these results are based on literature estimates of 4 years [47].

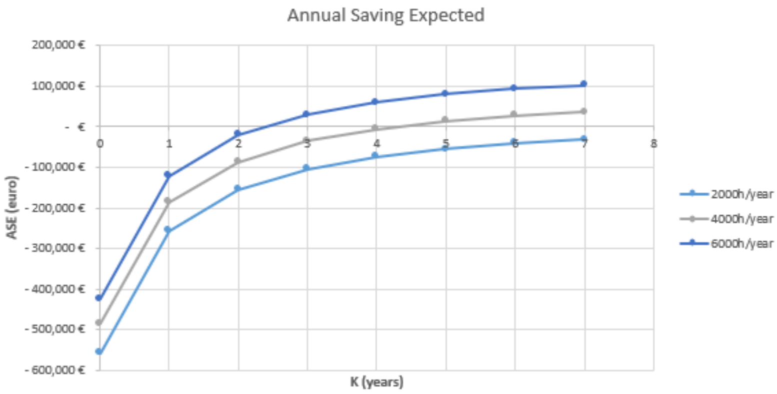

Figure 4.10: ASE

4.4.5 Cashflow, NPV and IRR results

From the first year for each operating period, the cashflow variation for the analytical parameters stated as: ASE, investment, and net income as illustrated in figure 4.11 becomes positive.

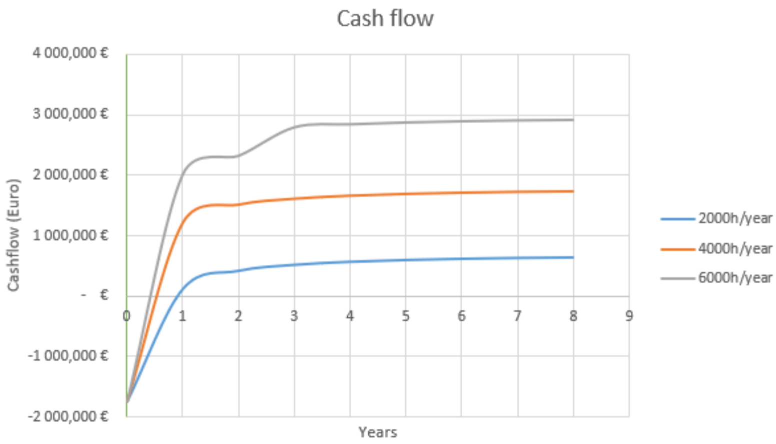

Figure 4.11: Cash flow

As a result, assuming a discount rate equal to the annual interest rate, a Net Present Value (NPV) ranges from 4 430.332 - 11 177.64€ in the literature [17] it is 28.25k€ which is under estimated with 16k€ and an Internal Rate of Return IRR of 20.30%, comparing this number to the results of IRR in the literature [17] which is higher with 1.02% shows that the system is realistic. Thus, the economic study reveals that the system with a payback time of 4 years and a 12% yearly interest rate is feasible.

Chapter 5

Conclusions and Future work

5.1 Conclusion

This work gives a numerical and theoretical study of a small-scale wood biomass gasification of two systems that uses an MRX-50 pump to supply syngas to a model of four-stroke internal combustion engine, the RCX-20 for system 1 and the engine of a Honda CG-125 Titan motorcycle for system 2.

Five blocks were used in the Aspen Plus software ; dryer (RYield reactor), decomposition (RYield reactor), gasifier (RGibs reactor), cooler (HeatX), and filter (Cyclone filter) to numerically simulate the prototype in order to assess the syngas composition, as well as the energy and exergetic performance of the biomass gasification system that will be installed in isolated communities.

The composition of syngas was 20.68% CO_2, 13% CO, 60.07% N_2, 0.133% H_2, and 0.0339% CH_4 of mass fraction with 5500 KJ/Kg of LHV_{syngas} for 0.577*10^{-3} Kg/s of biomass for system 1 and respectively, 21.25, 10.92, 51.58, 0.933, 0.000198 for CO_2, CO, N_2, H_2, and CH_4 for 1.6*10^{-3} Kg/s of biomass for system 2 using Aspen plus software under particular operating conditions.

In addition, the gasifier produces for system 1 10.99KW of heat power with a 67.4% efficiency, 11.9KW of biomass, 8.85 KW of syngas, and 1.325 KW of power heat exchanger with an 85.3% efficiency. For system 2 it produces 21.73KW of heat power with 62.16% efficiency, 31.56KW of biomass, 19.62KW of syngas, and 2.58KW of power heat exchanger with an 95.4% efficiency.

The engine's efficiency was computed theoretically based on simulation results and the first law of thermodynamics (29, 31.12% for system1 and system2, respectively), as well as the global efficiency of both systems (22.88, 20.27%).

The gasifier exergy balance irreversibility value of 4.35KW for system 1 and 11KW for system 2 were discovered using thermodynamic laws, with a gasification exergy of 67, 65.51% respectively for system 1 and 2. In the exchanger's exergy balance, irreversibility was determined to be 1.3KW, with an exergetic efficiency of 85%, and for system 2 0.64% of irreversibility and 96.91% of energetic efficiency.

The engine exergy balance value of irreversibility is 4.22KW, with a 38% exergetic efficiency for system 1 and 4.22KW, 35.7% for irreversibility and efficiency, respectively .

As a result, these results make Gasifier/ICE an interesting and technically possible device.

In the point of view of economic analysis, the cost of syngas ranges from 0.089 to 0.00454 euro/KWh, hot water from 0.095 to 0.033 euro/KWh, electricity from 0.0716 to 0.0124 euro/kWh, and the cost of operation of the gasifier from 0.003-0.0010 euro/KWh, as well as the engine from 0.0145 to 0.0007 KWh and the exchanger from 0.0045 to 0.000206 euro/KWh, according to the economic studies for an operation period of 2000 to 6000h/year. Obtaning the annual expected saving in the Gasifier/ICE system leaded to determine the cash flow which is from the first year with a payback period of 4 years using a 12% interest rate. The Net Present Value (NPV) ranges from 4 430.332 - 11 177.64€ for 2000-6000 h/year of operation period and the Internal Rate of Return IRR is 20.30%. Comparing all these values with a literature show that this system is economically feasible.

This study shows that the use of syngas as alternative fuel in the Gasifier/ICE system, from a thermodynamic point of view, is technically feasible and technologically a better choice for the isolated communities as well as it is economically viable.

5.2 Future work

- Evaluating the quality of syngas produced by biomass gasification besides wood, which has a lower heat value.
- Analysing the composition of syngas and the efficiency of the system using a heated air in the gasifier.

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