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Study of Optimal Conditions of a Palm Waste Fixed Bed Gasifier for Power Generation

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ABSTRACT

Gasification is a thermo-chemical process that has long been used, but it remains a perfectible technology. It offers as an alternative to incineration. The gas produced from gasification is called syngas. The aim of this study was to develop a fixed bed gasifier of palm waste and to identify the optimal settings to produce electricity from syngas. In the simulation study, twooperating parameters, gasifier temperature and equivalence ratio (ER), were varied over a wide range and the effect of these parameterson syngas composition wasinvestigated.The equivalence ratio is defined as the ratio of the amount of air actually supplied to the gasifier and the stoichiometric amount of air. The results show that the optimum temperature is 900°C and the optimum equivalence ratio is 0.1.

Keywords: Gasification, thermo-chemical process, syngas, power generation, etc.

1. INTRODUCTION

The demand for energy in our daily life is increasing day by day [1]due to the growth of the population and of the economy. In this context, renewable energy is a real opportunity to meet our energy needs. Biomass is the most abundant and most versatile of the primary sources of renewable energy. It is considered as an alternative to fossil fuels. It can be converted to a variety of usable forms of energy such as syngas, biogas and liquidtransportation biofuels [2]. It can be exploited in various forms, as heat, electricity, or fuels. There are two main kinds of conversion technologies currently available, namely thermo-chemical conversion (pyrolysis, combustion and gasification) and biological conversion (e.g. anaerobic digestion, fermentation). The choice of the technology depends on the type and quantity of biomass available, the type of final energy desired, economic and environmental conditions and other factors.

The present work concerns gasification. This thermo-chemical conversion technology transforms solid fuel into gas through partial oxidation. The end product, syngas, is composed mainly of carbon monoxide (CO) and hydrogen (H2) which have a large number of industrial and household applications, such as the production of electricity, hydrogen, synthetic natural gas, etc [1]. The three main types of gasifiers are fluidized bed, entrained flow, and fixed bed gasifiers [3-4]. The main difference between these reactors is how the biomass and oxidizer are moved in the reactor. For large-scale operations the preferred and most reliable systems are fluidized bed and entrained bed gasifiers, while for small scale applications, a fixed bed gasifier is well suited [5].

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In this research, we studied a fixed bed gasifier of Tunisian palm waste. The date palm is a very abundant tree in Tunisia, with over 40,000 ha covered by more than 5 million date palms. Energy recovery of date palm waste would therefore give second life to a low-value waste product. Following the simulation of the gasifier, we varied the temperature and equivalence ratio to optimize the gasifier performance.

This study was based on the model used by Ramzan et al., who studied a downdraft gasifier of municipal waste, food waste and poultry waste [6]. Some recent control methods are discussed in [11-16].

2. SIMULATION OF A FIXED BED GASIFIER

2.1. Characteristics of the Biomass

For the simulation of the fixed bed gasifier, we used the software Advanced System for Process ENgineering "Aspen Plus™". In this software, biomass is specified as a non-conventional compound so it is defined by using ultimate and proximate analysis. The characteristics of palm waste are given in Table1:

Table 1
Ultimate and proximate analysis of palm waste

Proximateanalysis (Mass percent)		*Ultimateanalysis (Mass percent)*	
MC	5.8	C	44,52
FC	44,52	H	5,73
VM	48,18	N	0,17
ASH	1,5	CL	0
		S	0
		O	48,08
		ASH	1,5

The lower heating value of palm waste is LHV = 19660 kJ/kg.

2.2. Simulation of the gasification reactor

To simulate the gasifier, we first established the block diagram. This flowsheet together with the calculation procedure are given in Figure1. The simulation by Aspen Plus™ requires the input of a number of operating data. These parameters are given in Table2.

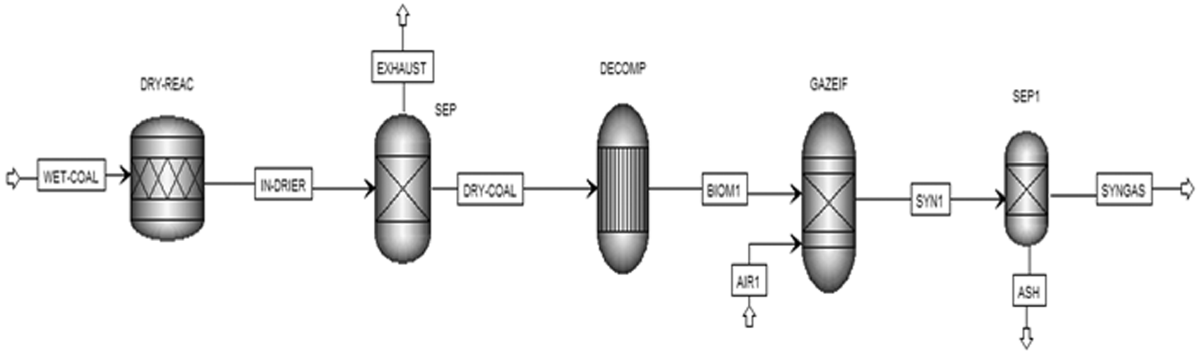
Table 2
Gasifier Operating Parameters

Biomass	Flow rate (kg/h)	10
	Pressure (bar)	1
	Temperature (°C)	25
Air	Pressure (bar)	1
	Temperature (°C)	25
Gasifier	Pressure (bar)	1
	Temperature (°C)	400-1400

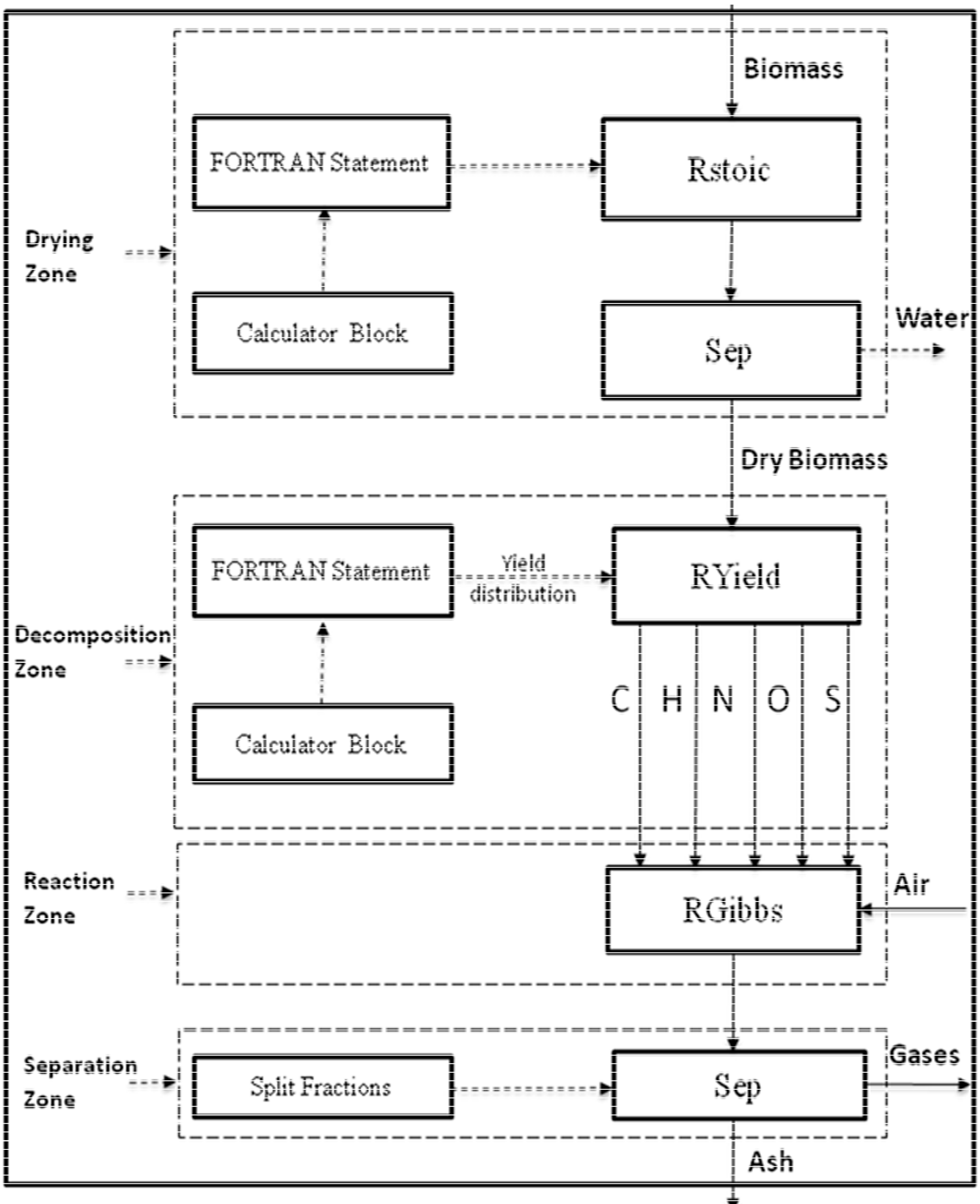
2.3. Assumptions

The following assumptions were made to simplify the simulations of biomass gasification:

1. Biomass gasification processes are in steady state and the reactions reach chemical equilibrium.
2. The heat exchange in a fixed bed is ideal and it is isothermal in the same section [7].



(a)



(b)

Figure1: (a) Flowsheet of the biomass gasification, (b) Aspen Plus Simulation Calculation procedure

3. All sulphur is transformed into H_2S,
4. Only NH_3 forms; no nitrogen oxides are produced [8-9].
5. Tars and other heavy products are assumed as non-equilibrium products to reduce the hydrodynamic complexity [10].

2.4. Main gasification reactions

C + H2O ↔ H2+ CO (water-gas) +132kJ/mol **(1)**

CH4 + H2O ↔ CO +3H2 (reforming) +206kJ/mol **(2)**

CO2 + C ↔ 2CO (Boudouard) +172.3kJ/mol **(3)**

CO + H2O ↔ CO2+H2 (CO shift) -41.1 kJ/mol **(4)**

2.5. Model description

The process of syngas production comprises three stages, namely drying, decomposition and gasification with partial oxidation. A number of Aspen Plus reactors were used to develop the model.

2.6. Drying

The purpose of this region is to reduce the moisture content of the biomass. To achieve this, we used theAspen Plus stoichiometric reactor, RStoic (model ID: DRY-REAC). This reactor converts part of the feed into water.Drying is controlled by a FORTRAN system introduced in the CALCULATOR block in the software.

2.7. Decomposition

The Aspen Plus yield reactor, RYield (model ID: DECMP), was used to simulate the decomposition of palm waste. This is one of the main steps of the gasification process. The yield reactor converts non-conventional feed into conventional components by using a FORTRAN statement. In fact, each feedstock is decomposed into its elements: C, H, N, O, S, etc. (a fictive decomposition) by specifying the yield distribution according to the feedstock's ultimate analysis. The decomposed elements mixed with air are then ready for gasification.

2.8. Gasification and partial oxidation

Gasification and partial oxidation were modelled in the same reactor 'Rgibbs' (model ID: GAZEIF). This reactor is a rigorous reactor for multiphase chemical equilibrium based on Gibbs free energy minimisation to calculate the syngas composition. It also assumes complete chemical equilibrium. The results of the simulation are given in Table 3:

Table 3
Characteristics of the syngas

Mol fraction (%)	H2	CO	CO2	H2O	N2	CH4	NH3
Compounds	35.19	42.25	2.24	2.37	17.89	5.31E-04	1.93E-05

3. OPTIMIZATION OF OPERATING PARAMETERS

The effect of gasifier temperature and equivalence ratio on the syngas composition was studied in order to define the optimal operating conditions for the production of electricity from this fuel gas.

3.1. Effect of gasifier temperature

The effect of gasifier temperature on syngas composition for palm waste at ER=0.4 is shown in Figure2. The temperature was varied from 400°C to 1400°C and had a strong effect on syngas production.To identify this effect, we studied the variation in the composition of three key elements, namely carbon monoxide CO, methane CH_4 and hydrogen H_2.

The concentration of these components resulted from a series of chemical reactions in the gasifier (essentially reactions (1)–(4)). The variation can be attributed to the laws of chemical reaction: higher temperatures favoured the products in endothermic reactions, and favoured the reactants in exothermic reactions.

First, it can be seen from Figure2 that the concentration of CO increased on increasing the temperature according to the endothermic reaction 'water gas' (1).Secondly, in accordance with the reforming reaction (2), which is a highly endothermic reaction, methane production decreased when the temperature increased (Figure2).

Thirdly, Figure2 clearly shows that H2 concentration increased with an increase in temperature due to endothermic reactions 'water gas' and 'reforming'. At higher temperatures, the yield of H2 started to decrease since the exothermic reaction 'CO shift' (4) outweighed the endothermic reaction 'water gas' (1), reflecting the decrease in H2 and CO2 concentration and the increase in CO and H2O.

The fraction of carbon dioxide decreased with increasing temperature in accordance with the Boudouard reaction (3).

3.2. Effect of equivalence ratio (ER)

The influence of the equivalence ratio on syngas composition is shown in Figure3. This ratio was varied from 0.1 to 0.9 at 700°C while keeping the biomass flow constant. As can be seen in Figure3, H_2 and CO

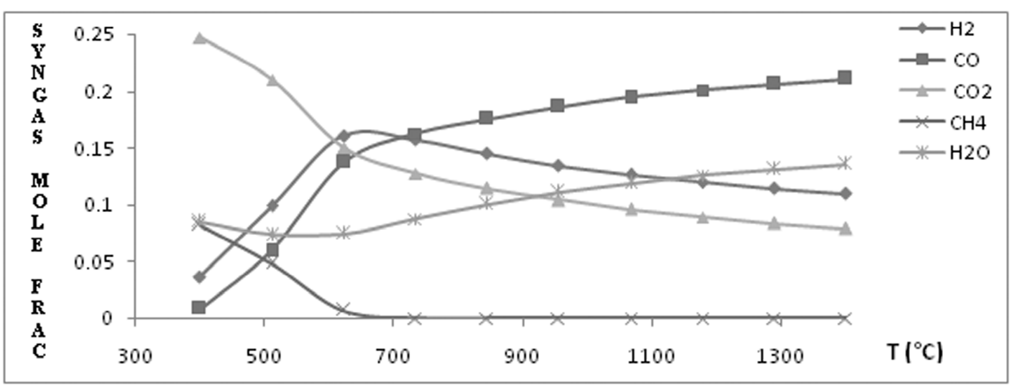


Figure 2: Effect of gasifier temperature on syngas mole fraction for ER = 0.4

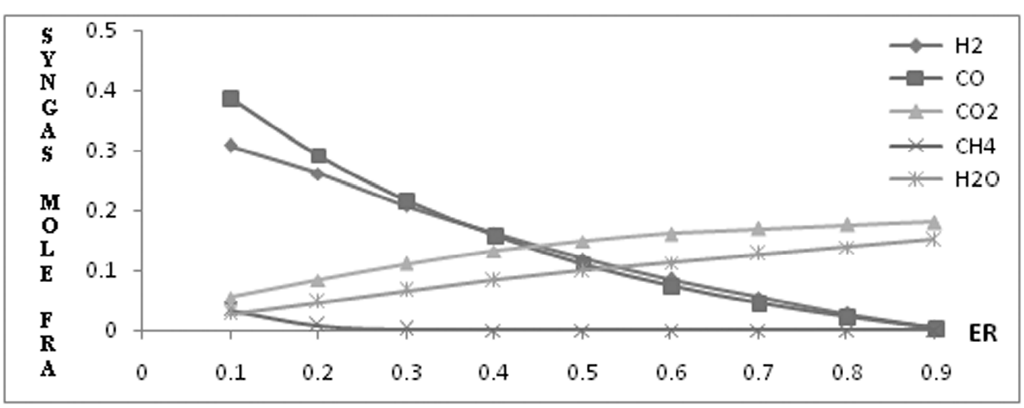


Figure 3: Effect of equivalence ratio on syngas mole fraction at T = 700°C

fractions decreased while those of $CO_2$and H_2O increased gradually with increasing ER. The reason for this is that, as ER is increased, the amount of oxygen supplied to the gasifier increases which enhances combustion and subsequently the production of $CO_2$and H_2O. An excess amount of oxygen oxidizes the fuel completely and the production of syngas declines, so we approach stoichiometry and only $CO_2$and H_2O are produced.

4. CONCLUSION

A steady state equilibrium model was developed for a fixed bed gasifier for palm waste using the Aspen Plus simulator. The objective of this study was to identify the optimal conditions for electricity generation from syngas. We studied the influence of gasifier temperature and equivalence ratio on syngas composition. The results show that the optimum temperature is 900°C with an equivalence ratio about 0.1. In these conditions the lower heating value is optimal.

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