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Gasification of pine sawdust: Effect of temperature, oxygen rate and vapor

Gasificación de aserrín de pino: efecto de temperatura, tasa de oxígeno y vapor

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Abstract

The study of biomass gasification has gained great interest in recent decades, representing an attractive process for the production of energy and heat and the production of hydrogen and second-generation biofuels. The objective of this work is to characterize the composition of the producer gas, as well as its energy potential. Experiments are carried out in a fixed bed gasifier on a pilot plant scale, and bulk sawdust from pine wood is used as gasification raw material. The influence of process temperature (650-900 °C), oxygen rate (0.3-0.6) and steam / sawdust ratio on the gasification of pine sawdust are investigated. Results of this study show that the hydrogen content, both hydrogen and carbon conversion, the calorific value and the efficiency of the cold gas increase by increasing temperature and decreasing oxygen rate. The use of steam in the gasification process increases thermal efficiency and hydrogen content of the producer gas.

Keywords: Gasification; Sawdust; Oxygen; Temperature; Hydrogen.

Resumen

El estudio de la gasificación de biomasa ha cobrado gran interés durante las últimas décadas, representando un proceso atractivo para la producción de energía y calor y la producción de hidrógeno y biocombustibles de segunda generación. El objetivo de este trabajo fue caracterizar la composición del gas pobre así como también su potencial energético. Las experiencias se realizan en un gasificador de lecho fijo en escala planta piloto y se usa aserrín a granel de madera de pino como materia prima de gasificación. Se investiga la influencia de la temperatura del proceso (650-900 °C), la tasa de oxígeno (0,3-0,6) y la relación vapor/aserrín sobre la gasificación del aserrín. Los resultados del estudio muestran que el contenido de hidrógeno, los porcentajes de conversión de hidrógeno y carbono, el poder calorífico y la eficiencia térmica del gas aumentan cuando aumenta la temperatura y disminuye la tasa de oxígeno. El uso de vapor en el proceso de gasificación aumenta la eficiencia térmica y el contenido de hidrógeno del gas pobre.

Palabras clave: Gasificación; Aserrín; Oxígeno; Temperatura; Hidrógeno.

Introduction

Biomass is defined as a green energy source due to its renewable character. Biomass resources are widely distributed in nature and can be processed directly or indirectly into gas, liquid fuel and solid fuel [1,2].

In the Argentine Republic, the energy matrix is still highly dependent on fossil fuels. As of May 2020, according to data from the General Mosconi Argentine Energy Institute, it is divided into thermal with 62.2%, hydro with 21.2%, renewables with 8.3% and nuclear with 8.3%.

In the case of the province of Misiones, the total potential of feasible biomass generators is 4,725,000 tonnes/year, forest plantations contribute 64% and the indirect

supply for energy generation is estimated at 1,721,000 tonnes/year, with 88% of the contributions coming from the forestry sector.

The biomass balance shows a surplus of 3,940,068 tonnes/year, leaving room for biomass power generation projects [3].

The biomass gasification process consists of the conversion of a solid/liquid organic compound into a gas/vapour phase and a solid phase. The synthesis gas has a high calorific value with uses such as power generation or biofuel production. The solid phase, char, comprises the unconverted organic fraction and the inert material present in the processed biomass [2].

In the gasification process, partial oxidation of the

carbon in the feedstock takes place in the presence of a gasifying agent, such as air, oxygen, steam or carbon dioxide. The synthesis gas generated is a mixture of carbon monoxide (CO), hydrogen (H₂), methane (CH₄), carbon dioxide (CO₂), light hydrocarbons such as ethane and propane and heavy hydrocarbons (tars) [4 - 7].

Hydrogen production by biomass gasification can provide a sustainable renewable energy source as a clean energy carrier. Its transport, liquefaction and safe handling still encounter unresolved difficulties [8 -10].

The main gasification reactions (homogeneous and heterogeneous) are endothermic (drying, pyrolysis and reduction stages), the energy is mainly provided by the oxidation stage of part of the biomass (exothermic reaction).

The design of the gasifier plays an important role in the gasification process to obtain a high reaction rate with uniform temperature and conversion profiles throughout the reactor.

The aim of the work is to study the thermal gasification

of pine sawdust, focusing on the influence of process temperature and oxidant (air, steam) on the conversion of carbon and hydrogen as well as on the thermal efficiency of the gas and the calorific value.

Materials and Methods

Process equipment

The gasification unit, Figure 1, consists of the main reactor and its material storage, dosing and conveying system as well as handling devices and accessories for the measurement and control of variables.

The sawdust storage container, for feeding the reactor, is a cone-shaped hopper with a diameter of 188.6 mm and a height of 484.6 mm, made of 1 mm thick AISI 310 stainless steel sheet. The sawdust is transported to the gasifier by means of augers connected to the hopper outlet, which

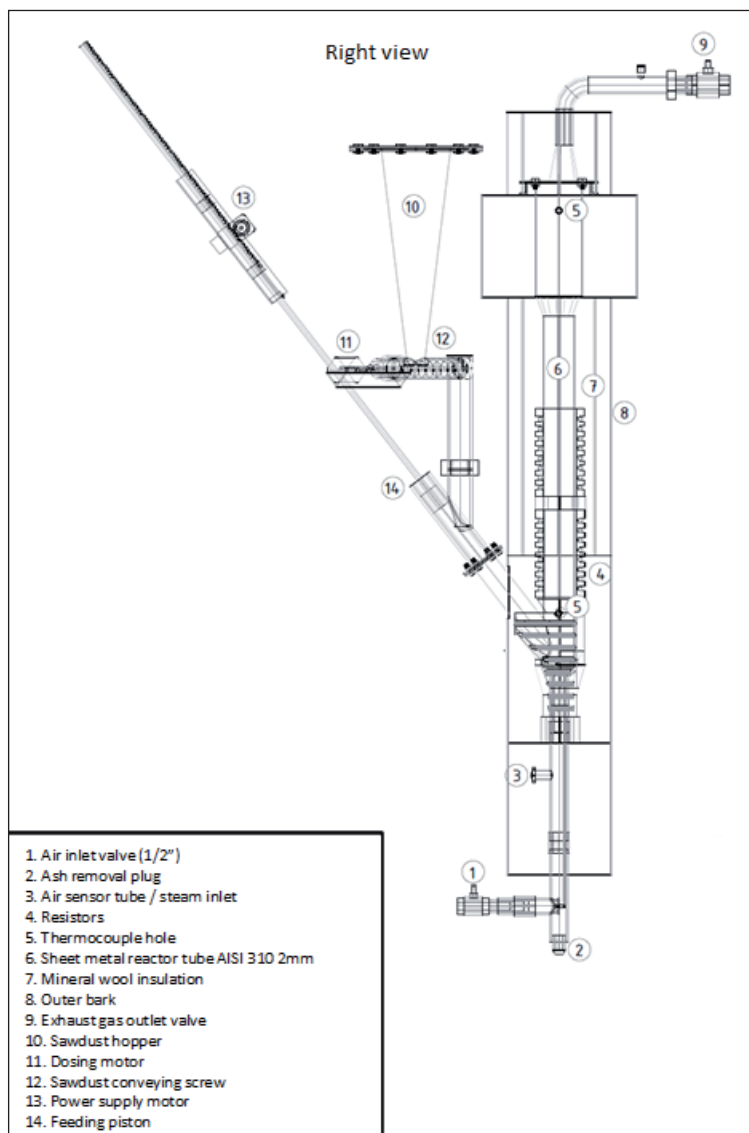


Figure 1: Sketch of the gasifier system.

feed the sawdust into a vertical tube (closed transparent). The sawdust slides gravitationally until it enters the reactor, a mechanical action carried out by a feed piston inserted in an inclined stainless steel tube.

The dosing motor is of the stepper type, controlled by an Arduino system that regulates the motor pulses to control the feed rate.

The gasifier has two distinct parts: the bed and the free zone. The bed (reaction zone) is 536 mm high and has an internal diameter of 56 mm, limited at the bottom by a grate where the sawdust falls.

The free zone is a widening of the primary tube with an internal diameter of 90 mm and a height of 217 mm, and its function is to avoid the dragging of particles in the bed and to favour the mixing of the gas, increasing the residence time, which represents the possibility of a post-gasification chamber, with secondary air inlet.

The gasifier is heated by a resistive system, resistors (Kanthal A-1 wire) inserted in cylinders made of a mixture of 70% clay and 30% crushed ceramic, with a diameter of approximately 1.5 mm. The total available power is 2.1

kW. The bed and the free zone are thermally insulated with a 25.4 mm thick ceramic blanket. The whole assembly (reactor, heating elements, insulation) is enclosed in an epoxy painted steel casing, mounted on a metal ring structure. The air velocity is measured with an anemometer-flowmeter at the bottom of the gasifier, modifying the free sections to adapt the inlet flow rate. The steam generation is carried out in a container heated by resistances and with an outlet bypass to the reactor and purge in PPN piping, with a production capacity suitable for the steam/biomass ratios of the feed system. Figure 2 shows a schematic picture of the movement of fluids and materials.

For the control system, an Eaton Easy 822 DC-TC PLC model is used, to which two Novus TxRail transducers are connected to their respective K-type thermocouples, to control the reaction temperature and detect the gas mixing temperature.

Gas sampling is performed with a 500 ml Tedlar bag fitted with a flexible aspirator and a glass rod to access the gas intake, at a temperature of approximately 350°C. The bag is located in a vessel that acts as a vacuum chamber.

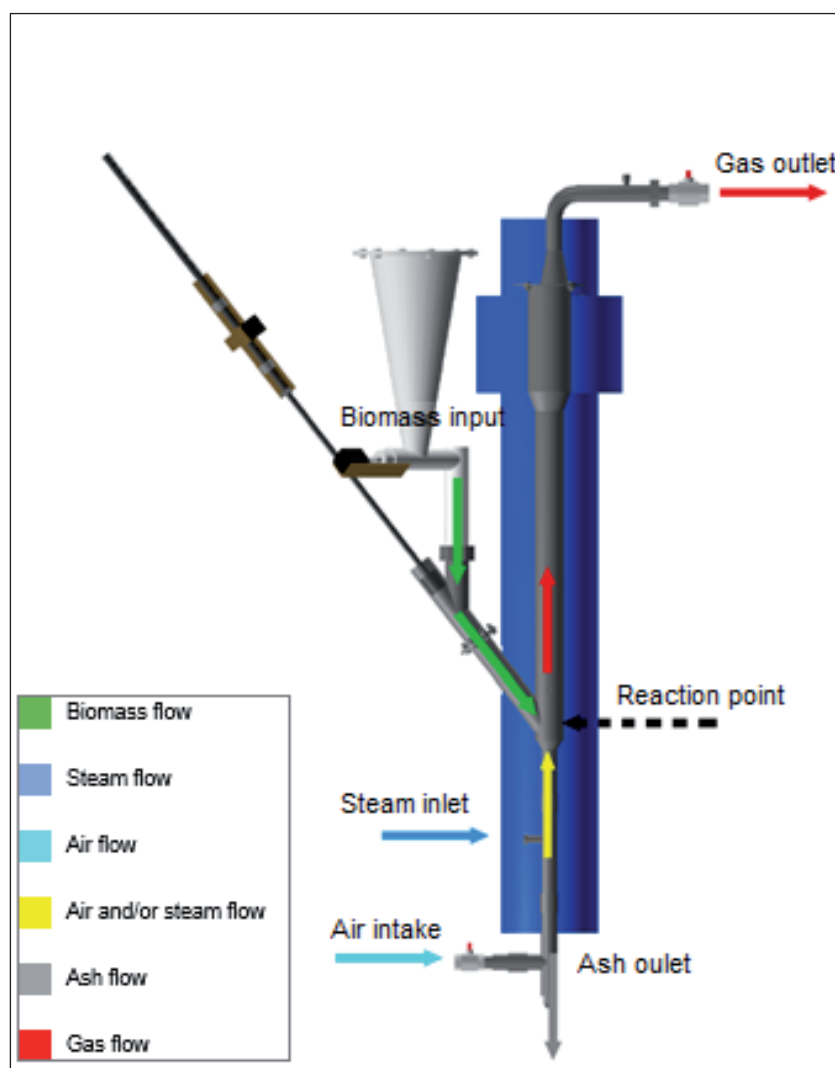


Figure 2: Biomass-fluid flows.

Experimental procedure

Biomass conditioning

The biomass is obtained from a medium-scale sawmill in the city of Posadas. The sawdust is selected from the twin, multiple circular and edge band sawing machines, which are part of the log processing line. The sawdust is homogenised outside on a flat surface before storage.

The moisture content of the sawdust is determined using the difference in weight process. With the wet and dry weights, the moisture content on a dry basis of 110% of the original sample is obtained.

Nº 8 and Nº 5 sieves (2.38-4.00 mm respectively) are used for classification and subsequent oven drying. This fraction represents 65% of the total collected, and the fractions which, due to their size, are difficult to handle, are discarded. Sorting is carried out for a moisture content on a dry basis of 10%.

The basic density of the sawdust is determined by the weight/volume ratio, the sample being previously dried at 103°C for 24 hours. Average basic density values of 370 kg/m³ are obtained.

Process experiments

Once the regime temperature of the gasifier reactor, selected by the controller, is reached, the sawdust stored in the hopper is fed into the reactor at the height of the reaction zone grid. The gaseous product outlet pipe has a sampling point, located in the section downstream of the cyclone solids separator. Samples are collected by in-line method, using Tedlar bags for chromatographic analysis. A gas chromatograph SRI GC 310C with thermal conductivity detector and packed column RESTEK ShinCarbon ST with carrier gas (He) is used to determine the concentration of the lean gas components.

The operating levels for the experimental activities are as listed:

- Sawdust feeding: up to 0.4 kg sawdust / h. Sawdust moisture: 10% dry basis.
- Surface velocity of gasifier (air): 0.06-0.12 m/s, steam flow: 0-0.5 by weight steam/sawdust.
- Temperature of the gasifier reactor: 650-900 oC.

The final analysis of the sawdust is shown in Table 1.

Table 1: Sawdust composition.

Sawdust composition % weight					
C	H	O	N	S	H ₂ O
51,80	6,10	41,19	0,30	0,01	10,00

Results and Discussion

Experimental values in the temperature range (650 – 900° C), at oxygen rates between 0.3 and 0.6 (ratio of air flow supplied to the gasifier to air flow required for complete combustion), with and without steam input, are processed to perform mass and energy balances using the graphical interface (GUI) Sawdust gasifier balance, designed in Matlab environment, with experimental input values and parameters required for the balances, generating outputs (expressed in percentage) such as cold gas efficiency (ratio of calorific value of lean gas to total heat input), hot gas efficiency (heat output without losses), thermal efficiency (ratio of enthalpy gas produced to heat input), carbon conversion rate (ratio of carbon in lean gas to carbon in biomass), hydrogen conversion rate (ratio of hydrogen in lean gas to hydrogen in biomass), all based on unit weight of carbon. Figure 3 shows (screenshot) the loading of data into the interface for the calculation routine of the programme.

The screenshot shows a software window titled 'Balance Gasificador aserrín'. It contains a 'PARAMETROS' section with multiple input fields for various parameters such as biomass weight, gas composition, and operating conditions. Below this is a 'Panel' section which appears to be a display area for the results of the calculations. A 'Calcular' button is located at the bottom right of the window.

Figure 3: Graphical interface Sawdust Gasifier Balance.

Table 2 shows the lean gas composition at different temperatures at an oxygen rate value of 0.4.

Table 2: Experimental values of lean gas component concentrations.

T (°C)	Gas concentration % V/V				
	Carbon Dioxide	Carbon Monoxide	Methane	Hydrogen	Nitrogen
650	33,66	8,10	4,92	10,73	42,59
750	24,90	11,03	4,12	12,10	47,85
800	19,83	18,00	4,05	14,39	43,73
830	18,44	11,14	3,16	9,57	57,69
850	17,64	16,37	4,31	12,55	49,13
870	18,26	13,62	3,11	15,06	49,95
900	17,16	20,76	2,61	20,54	38,93
800 with steam	23,53	13,22	4,26	24,84	34,16

The results obtained for hydrogen conversion, carbon conversion, calorific value, thermal efficiency of hot gas, thermal efficiency of cold gas, at different temperatures and oxygen rate are shown in Tables 3 and 4 and Figures 4-9.

Table 3: Hydrogen and carbon conversion, calorific value, hot gas thermal efficiency, cold gas thermal efficiency, at different temperatures (oxygen rate 0.4).

Temperature °C	Conversion Hydrogen %	Conversion Carbon %	Calorific Value Kcal/nm ³	Thermal efficiency hot gas %	Thermal efficiency cold gas %
650	26,81	85,97	3027	86,34	40,89
750	29,89	82,16	3451	88,02	48,74
800	30,15	79,34	3807	89,14	56,13
850	30,73	78,66	3903	89,41	57,24
900	34,49	78,56	4172	90,01	62,55

Table 4: Conversion of hydrogen and carbon at different oxygen rates and temperatures.

Rate Oxygen	Conversion H ₂ %	Conversion C %	Temperature oC
0,34	30,06	76,87	830
0,39	25,32	77,93	830
0,61	18,10	87,68	830
0,30	34,7	74,68	850
0,39	25,46	81,70	850
0,61	14,79	90,63	850
0,34	43,95	77,13	870
0,45	34,76	80,78	870
0,60	20,15	86,57	870
0,31	35,20	76,01	900
0,47	32,86	80,28	900
0,56	26,09	81,69	900

Figure 4 shows hydrogen and carbon conversion, respectively, as a function of temperature. Hydrogen conversion increases with increasing temperature, decreasing carbon conversion. This conversion trend changes with increasing oxygen rate, for the whole temperature range.

The reactions favoured with increasing temperature are the Boudouard reaction (carbon gasification with carbon dioxide), the primary water gas reaction (carbon gasification with steam with production of carbon monoxide and hydrogen) and the methane reforming reaction, disfavours the methanation reaction [2, 4, 6].

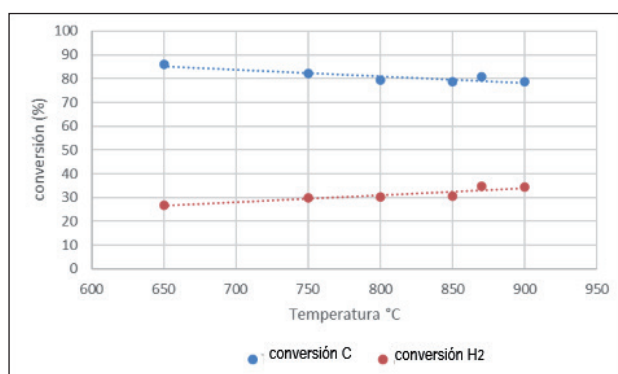


Figure 4: Hydrogen and carbon conversion as a function of temperature.

One of the most widely used efficiency indicators is the cold gas efficiency, which measures the energy efficiency of the gasification process considering the gas produced at ambient temperature. Figure 5 shows the cold gas and hot gas efficiencies (heat production without losses) as a function of temperature, showing a similar trend resulting from an increase in the concentration of carbon monoxide and hydrogen in the gas composition.

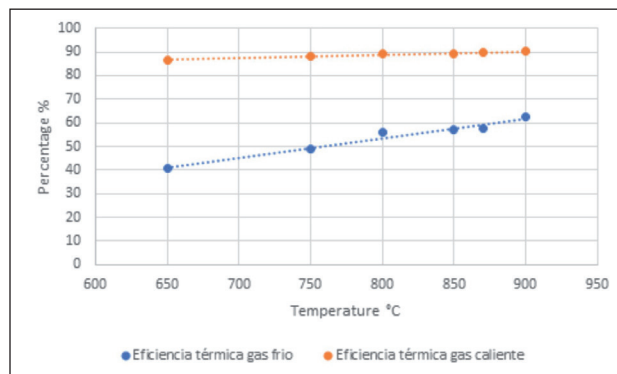


Figure 5: Thermal efficiency of hot gas and cold gas as a function of temperature.

With increasing temperature, the contributions of the calorific value of hydrogen and carbon monoxide in the lean gas increase the calorific value of the gas, which can be seen in Figure 6.

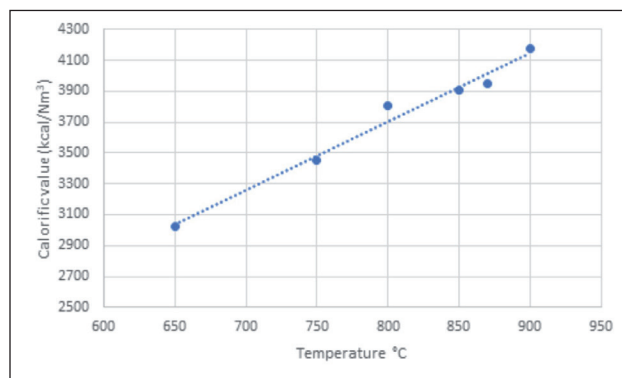


Figure 6: Calorific value of gas as a function of temperature.

Figure 7 shows hydrogen and carbon conversion as a function of oxygen rate at 830°C and 900°C.

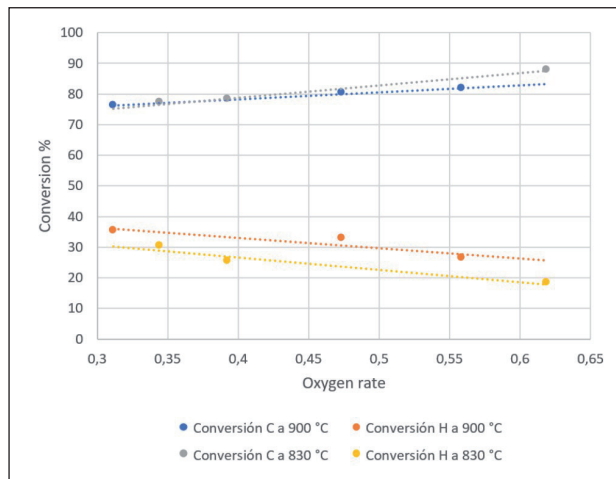


Figure 7: Conversion of hydrogen and carbon as a function of oxygen rate, at 830 and 900 °C.

The decrease in oxygen rate leads to high gas production, growth in hydrogen content and at the same time the equilibrium temperature decreases, favouring the reaction of carbon with oxygen to produce carbon dioxide.

Figure 8 shows the calorific value of lean gas as a function of oxygen rate. Higher values of the calorific value of the gas are observed for reducing process conditions, lower oxygen rate, considering the relative contents of the lean gas components under these conditions. In the same sense, there is an increase in thermal efficiency as the oxygen rate decreases.

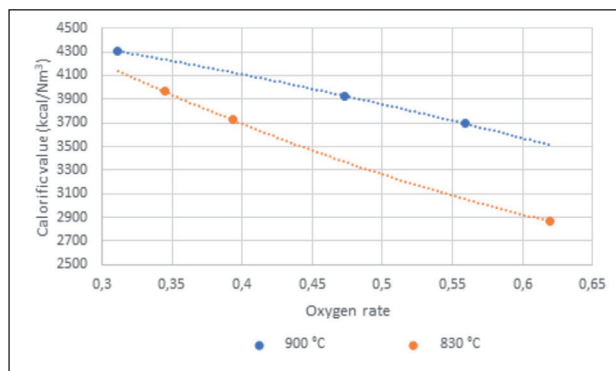


Figure 8: Calorific value of gas as a function of oxygen rate.

Figure 9 shows the effect of steam use on the thermal efficiencies of the gas and the hydrogen and carbon conversions at 800 °C.

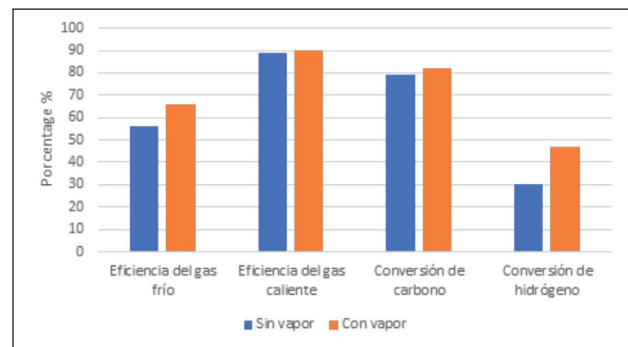


Figure 9: Effect of steam at 800°C.

For the conditions of using steam at atmospheric pressure as the gasifying agent, steam-to-biomass ratio of 0.5 by weight, there is an increase in the thermal efficiency of the cold gas as well as the conversion of hydrogen.

The production of CO₂ and H₂ increases, with CO decreases, as the gasification process occurs in a H₂O-rich environment that favours heterogeneous and homogeneous carbon-water and water-reversible gas (WGS) reactions [8-13].

Conclusions

The gasification of pine sawdust in bulk, from the point of view of the increase of hydrogen content, calorific value, as well as the thermal efficiency of the lean gas, is shown to be sensitive to the temperature levels of the gasification process, together with the oxygen contribution and the presence of steam in the oxidant, which leads to the conclusion that appropriate operating conditions, temperatures between 800-900 °C, oxygen rate in the order of 0.3-0.4 and vapour input of 0.5 by weight referred to the sawdust, combine the benefits in terms of mass and heat transfer and the equilibrium of the reactions involved.

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