

COMPARATIVE ANALYSIS OF THE THERMAL EFFICIENCIES FOR THE USE OF DOWNDRAFT GASIFICATION PRODUCTS BY FUEL CELL AND GAS TURBINE

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Resume: Biomass as an alternative and environmental friendly energy resource will gain an important roll in total energy consumption of society. There are many different ways for the use of biomass. This paper examines the concept of using downdraft biomass gasification in conjunction with gas turbines or fuel cells to generate electricity. The syngas used in this paper is obtained from downdraft gasification of woody biomass.

Key words: *gasification, downdraft gasification, gas turbine, fuel cell*

INTRODUCTION

The use of biomass energy emits fewer amounts of pollutants than fossil fuel combustion. Green plants again use carbon dioxide produced by biomass combustion during photosynthesis reactions, while emissions of sulfur and nitrogen oxides can be ignored. Biomass gasification represents the process of obtaining gas fuel by thermal disintegration of solid particles at high temperatures in the presence of medium for gasification. As a media for gasification can be used: air, water vapor, oxygen, carbon dioxide and hydrogen. The gas gained by gasification can be used for power generation, in industry, in metallurgy or for syngas production.

There are many different types of gasification reactors. However, commercially and technically the most important are: updraft (countercurrent), downdraft (co-current) and fluidized bed gasifiers. For the purpose of this paper, experiments on the half-industrial downdraft gasifier were generated.

In downdraft gasifier the combustion zone is in the upper part of the gasifier, while the produced gas leaves the reactor at the bottom (figure 1). For that reason, the products from devolatilization zone, which is located above the combustion zone (figure 1), must pass through the high temperature combustion zone, where degradation of tar and volatiles takes place. Another advantage of downdraft gasifiers is the possibility for use of biomass' moisture. That can substantially reduce the cost of the reactor usage.

For the reason of low organic contaminant loadings, downdraft gasifiers represent less danger for environment.

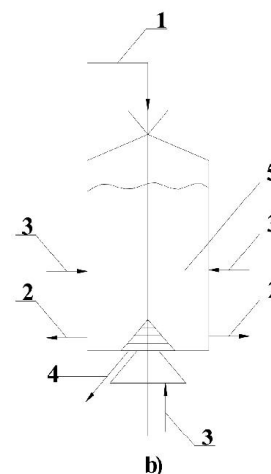


Figure 1 Biomass downdraft gasified

1- Biomass, 2-gas outlet, 3-gasification medium, 4-ash, 5-reaction zone

Downdraft gasifiers have their own deficiencies. The reduction zone is placed near the gas outlet (figure 1) for that reason, the gas temperature at the outlet is very high concerning updraft and cross draft gasifiers. This reduces the gasifier efficiency. However, with the development of fuel cells especially molten carbonate and solid oxide fuel cells the high outlet temperature of the gas is no more deficiency and intrudes coupling a downdraft gasification reactor with a fuel cell in a system for electricity generation. Downdraft gasification reactors also demand the adequate dimensions of biomass particles.

Downdraft gasifiers are relatively simple, low cost, low-pressure devices, which produce relatively clean gas suitable for power generation. Figure 2 is a schematic of a downdraft gasifier system, and Table 1 compares gasification technologies and gas contaminant levels.

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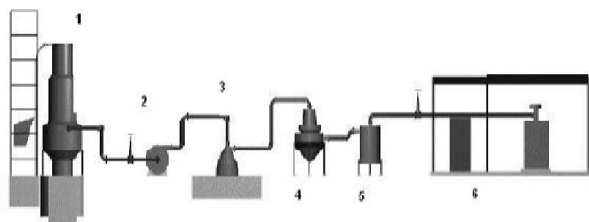


Figure 2 Downdraft gasification system
1- downdraft gasifier, 2 – blower, 3 – venturi scrubber, 4 - fine filter, 5 – check filter, 6 – power generator and room

Table 1 Gasifier contaminant loadings

Gasifier type	Tar production	Relative particulate loadings
Updraft	50000-200000ppm	intermediate
Downdraft	100-1000ppm	low
Fluidized bed	1000-50000ppm	high

In next sessions of this paper will be analyzed employment of the downdraft gasification process in systems with a gas turbine or a fuel cell for electrical generation.

All analyses were generated with the gas obtained from the downdraft woody biomass gasification. As the representative gas was taken a gas with the following volume composition: CO = 14.9 %, H₂ = 15.3 %, CH₄ = 1.6 %, CO₂ = 10.5 %, O₂ = 0.9 %, N₂ = 46.3 %, H₂O = 10.5 %. This gas was obtained by the downdraft gasification of woody biomass with the lower heating value of 14283 kJ/kg. 1 kg of this biomass produced in half industrial downdraft gasifier 2.839 m³ of the gas. This presents chemical coefficient of efficiency 81.6%.

THE USE OF GAS TURBINES FOR ELECTRICAL GENERATION

The efficiency of gas turbines for electrical generation is 30%-35%. The advantage of these turbines over fuel cells is that they can use the syngas with much lower purity. A downdraft gasification system is coupled to a turbine power system, which consists of the components shown in the Figure 3.

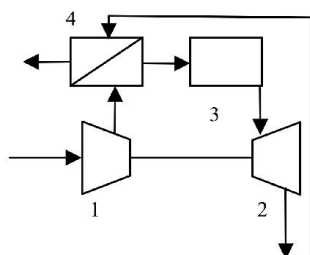


Figure 3. Generation of electricity by gas turbine
1 – compressor, 2 – turbine, 3 – combustion chamber, 4 – heat exchanger

If the average efficiency of a gas turbine is 33% from 1kg of woody biomass, with the lower heating value of 14283 kJ/kg, is obtained 3848 kJ of electrical energy or 1.07 kWh.

FUEL CELLS AND TYPES OF FUEL CELLS

A fuel cell is an electrochemical device that converts the chemical energy of a fuel directly into electrical energy by an oxidation reaction in which energy is liberated as electrical work rather than as a heat. Therefore, a fuel cell is not a heat engine and consequently is not subject to the severe efficiency limitation of the Carnot cycle. Fuel cell energy conversion efficiencies can approach 100% under the proper conditions.

Fuel cells are classified primarily by the kind of electrolyte they employ. This determines the kind of chemical reactions that take place in the cell, the kind of catalysts required, the temperature range in which the cell operates, the fuel required, and other factors.

Polymer electrolyte membrane (PEM) fuel cells deliver high power density and offer the advantages of low weight and volume, compared to other fuel cells. PEM fuel cells use a solid polymer as an electrolyte and porous carbon electrodes containing a platinum catalyst. They need only hydrogen, oxygen from the air, and water to operate and do not require corrosive fluids like some fuel cells. They are typically fueled with pure hydrogen supplied from storage tanks or onboard reformers.

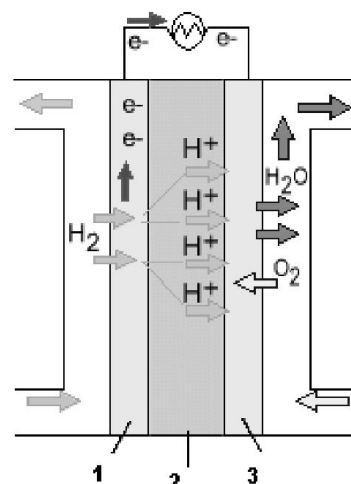


Figure 4. Polymer electrolyte membrane fuel cell
1- anode, 2 – electrolyte, 3 - cathode

Polymer electrolyte membrane fuel cells operate at relatively low temperatures, around 80°C. Low temperature operations allows them to start quickly (less warm-up time) and results in less wear on system components, resulting in better durability. However, it requires that a noble-metal catalyst (typically platinum) be used to separate the hydrogen's electrons and protons, adding the cost. The platinum catalyst is also extremely sensitive to CO poisoning, making it

necessary to employ an additional reactor to reduce CO in the fuel gas. Therefore, these fuel cells are not suitable for use when as fuel is used the gas obtained from the process of downdraft gasification.

The most suitable fuel cells for the use of downdraft gasification gas are molten carbonate fuel cells and solid oxide fuel cells.

Molten carbonate fuel cells are high-temperature fuel cells that use an electrolyte composed of a molten carbonate salt mixture suspended in a porous, chemically inert ceramic lithium aluminum oxide (LiAlO_2) matrix. Since they operate at extremely high temperatures of 650°C and above, non-precious metals can be used as catalyst at the anode and cathode, reducing costs.

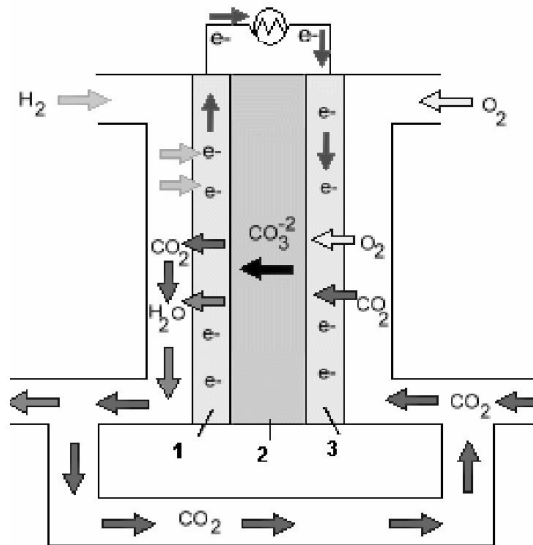


Figure 5 Molten carbonate fuel cell
1- anode, 2 – electrolyte, 3 – cathode

Molten carbonate fuel cells can reach efficiency approaching 60%, but when the waste heat is captured and used, overall fuel efficiencies can be as high as 85 percent. Molten carbonate fuel cells are not prone to carbon monoxide or carbon dioxide “poisoning” they can even use carbon oxides as fuel, making them more attractive for fueling with the gas made from gasification of biomass. They are more resistant to impurities than other types of fuel cells. The primer disadvantage of current molten carbonate fuel cells is durability.

Solid oxide fuel cells use hard, non-porous ceramic compound as the electrolyte. These fuel cells are expected to be around 50-60 percent efficient at converting fuel to electricity. In applications designed to capture and utilize the system’s waste heat, overall fuel use efficiencies could top 80-85 percent.

Solid oxide fuel cells operate at very high temperatures around 1000°C . High temperature operation removes the need for precious-metal catalyst, thereby reducing cost.

These fuel cells can tolerate several orders of magnitude more sulfur than other cell types. They can

even use carbon monoxide as a fuel, which allows them to use gasification products as a fuel.

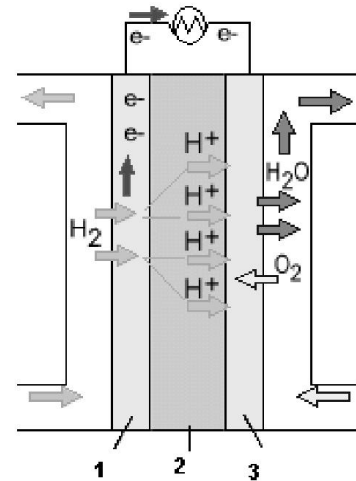


Figure 6 Solid oxide fuel cell
1 - anode, 2 – electrolyte, 3 – cathode

Table 2 delineates the different electrochemical reactions of PEM, MCFC and SOFC technologies.

Table 2 Electrode reactions for various fuel

Fuel cell	Anode reaction	Cathode reaction
PEM	$\text{H}_2 \rightarrow 2\text{H}^+ + 2\text{e}^-$	$0.5\text{O}_2 + 2\text{H}^+ + 2\text{e}^- \rightarrow \text{H}_2\text{O}$
MCFC	$\text{H}_2 + \text{CO}_3^{2-} \rightarrow \text{H}_2\text{O} + \text{CO}_2 + 2\text{e}^-$	$0.5\text{O}_2 + \text{CO}_2 + 2\text{e}^- \rightarrow \text{CO}_3^{2-}$
SOFC	$\text{H}_2 + \text{O}^{2-} \rightarrow \text{H}_2\text{O} + 2\text{e}^-$ $\text{CO} + \text{O}^{2-} \rightarrow \text{CO}_2 + 2\text{e}^-$ $\text{CH}_4 + 4\text{O}^{2-} \rightarrow 2\text{H}_2\text{O} + \text{CO}_2 + 8\text{e}^-$	$0.5\text{O}_2 + 2\text{e}^- \rightarrow \text{O}^{2-}$

ANALYTICAL AND REAL OVERALL COEFFICIENT OF EFFICIENCY FOR DOWNDRAFT GASIFIER-FUEL CELL SYSTEM

We can calculate the maximal coefficient of efficiency with the following formula:

$$(\eta_{fc})_{\max} = \frac{\sum_i (n_i/n_{fuel})\bar{g}_i^* - \sum_j (n_j/n_{fuel})\bar{g}_j^* + RT \ln \left[\frac{\prod_i (p_i/p^0)^{(n_i/n_{fuel})}}{\prod_j (p_j/p^0)^{(n_j/n_{fuel})}} \right]}{\sum_i (n_i/n_{fuel})\bar{h}_i - \sum_j (n_j/n_{fuel})\bar{h}_j}$$

Where:

\bar{g}_i (kJ/kmol)– molar specific Gibbs functions at 25°C and 0.1 Mpa

$R = 8.314$ kJ/kmolK universal gas constant

T (K)– the reaction temperature

P_i (Pa) – partial pressure of each gas component

$P^0 = 0.1\text{MPa}$

Since it is assumed that the reaction takes place at 0.1MPa and that all present gases are ideal gases that obey the Gibbs-Dalton ideal gas mixture law then partial

pressures can be expressed in terms of the mole fractions as: $(p_i/p^0) = x_i$, where x_i is the molar fraction of the component in the mixture.

Using the above formula for $t=25^0\text{C}$ and $p=0.1\text{MPa}$ and a molten carbonate fuel cell we can gain the fuel cell efficiency of 85.2%, but for the reactions at $t=650^0\text{C}$ this coefficient of efficiency slightly decrease to 81.8%. These efficiencies are very high and can not be obtained in a real fuel cell that operates with approximately 50 to 60 percent of efficiency. Which for our syngas, and efficiency of a fuel cell of 55%, allows obtaining of $6412.6 \text{ kJ} = 1.78\text{kWh}$ electrical energy, which makes overall coefficient of efficiency 44.9%.

CONCLUSION

As it was expected, the system downdraft gasifier-fuel cell would be more efficient than the system downdraft gasifier-gas turbine. However, the lower cost of the system downdraft gasifier- gas turbine makes it more attractive. The purpose of this paper is to show the different possibilities for the use of the gas obtained from downdraft gasification for generation of electricity,

and to evaluate the value of this gas for this kind of systems.

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