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SIMULATION OF BIOMASS GASIFICATION REACTOR FOR FUEL IN GAS TURBINE

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ABSTRACT

Energy produced from biofuels or there conversion products represent an important part among today's energy sources. As biofuels are renewable, abundant and has domestic usage, the sources of biofuels can help the world reduce its dependence on petroleum products and natural gas. Biofuels can be converted into liquid, solid and gaseous fuels with the help of some physical, chemical and biological conversion processes. The conversion of biofuel material has a precise objective to transform a carbonaceous solid material, which is originally difficult to handle, bulky and of low energy concentration, into fuels having physico-chemical characteristics that permit economic storage and transferability through pumping systems. The use of biofuel products provides substantial benefits as far as the environment is concerned.
A simulation study has been carried out to arrive at the power output under limiting conditions as well as perform changes in the fuel gas system for the augmentation. The simulation study has been carried out on the simulation software Aspen HYSYS and the findings show that, the available fuel gas obtained from the biomass can be optimally used for the power generation in the gas turbine.

Keywords: mathematical optimization, computer simulation, biomass gasification, gas turbines

1. INTRODUCTION

Process simulation of a plant is a set of equations that describe the operations of the plant and predict its performances. This set of equations includes material and energy balances, rate equations, and equilibrium relations. The material balances describe the conservation of mass in the individual units of the process, and the energy balance equations describe the conservation of energy in these units. In the material balances, there are terms that describe the rate of conversion of components by chemical reactions. These terms are given by the rate equations from chemical kinetics. In energy balances, there are terms that describe the exchange in energy with the surroundings and the work done by the unit. The energy exchange is described by rate equations for heat transfer, and the work performed is described by the method used for fluid movement, e.g., compressor.

1.1 Resources of Biomass as Biofuel

The term "biomass" means any plant derived organic matter available on a renewable basis, including dedicated energy crops and trees, agricultural food and feed crops, agricultural crop wastes and residues, wood wastes and residues, aquatic plants, animal wastes, municipal wastes, and other waste materials. Handling technologies, collection logistics and infrastructure are important aspects of the biomass resource supply chain.

1.2 Benefits of Biomass

1. Reduced Air Pollution- Like other forms of renewable energy, such as wind or solar, biomass resources produce less emissions than their fossil fuel counterparts. Biomass contains less sulfur than coal, and consequently produces less SO_2. Emissions of NO_x are usually lower as well.

2. Reduced animal, Food processing and Municipal wastes - Anaerobic digestion can be used to convert wastes from livestock, food processing and households into energy. Using this biomass as energy can yield the following benefits: production of heat or electricity, odor reduction, reduced risk of water contamination, and reduced exposure to disease-causing organisms.

3. Reduced use of landfills-A portion of landfills consists of woody biomass from construction, lumber mill activities, disposal of wooden palettes, etc. Wastes from food processing, paper industries and household garbage also contain organic matter that could be converted to energy. Using these materials to create energy means less landfill space is needed.

4. Reduced risk of wildfire-The risk of catastrophic wildfire can be reduced by removing small diameter trees that act as a fuel for the flames. The removal of trees is a labor intensive and costly process, but the use of these biomass materials can create a market outlet and thereby help defer the costs of forest thinning activities.

5. Improved watershed quality-Reducing waste flows from livestock; food processing and city sanitation services can contribute to improved water quality. Preventing wildfires can improve water quality. Wildfires reduce the ability of soil to absorb water that leads to increased debris and sediments in the riparian area.

6. 2. Power Generation

The Combined Cycle is a generic type of plant that uses a gas turbine (GT) to produce electric or mechanical power and whose exhaust is used in a heat recovery steam generator (HRSG) that produces steam at different pressure levels. The steam can be used in steam turbines for producing additional electricity or mechanical power and/or for the supply of heat loads in a process plant. The design of a power plant needs the optimal configuration of process operations and parameters, which can lead to the most economic design. These methods are reviewed as follows:

2.1 Thermodynamic Approach

The traditional way of designing power plants is to maximize the thermal efficiency of the plant. For this purpose analysis methods based on both the first and the second law of thermodynamics have been extensively discussed in literature. The analysis reveals the thermal inefficiencies of the various subsystems of the plant. Once the inefficiencies have been identified, heuristic rules are applied to improve the performance of the plant. These heuristics form the basis for both parameter and structural modifications to the plant. The capital cost of the plant is assessed after the thermally best design is achieved.

2.2 Thermoeconomic approach [1]: This is an extension of the thermodynamic approach. The capital cost of the units and the prices of product streams of the units are included in the second law analysis model of the plant. This approach tries to address the trade-off between thermal efficiency and capital expenditure. The model is subjected to NLP-optimization for finding the most economic operating parameters. Although this approach provides the economically best parameters, the methodology still relies on trial-and-error, when addressing structural changes to the existing process.

2.3 Thermochemical Combustion Process: Gasification

Gasification requires biomass to undergo partial oxidation at high temperature to produce a gas containing carbon monoxide, hydrogen, methane as well as carbon dioxide, nitrogen (from the air, if used) and water vapour. Air or oxygen may be used for the oxidation, and steam may be added. Gasification reactions are mostly endothermic (requiring heat), whereas the combustion reactions are exothermic (releasing heat). Heat is not the product in the gasification process, and in fact must be added or produced by combustion of some of the fuel, but the result is that the biomass is transformed into a gaseous fuel. Gas is easier to handle than solid fuel and burns at higher temperatures. The gasification chamber can be the same as that used for combustion. Whether gasification or combustion occurs depends on the oxygen/fuel ratio: Therefore, approximately 1/3 of the oxygen is required for a gasification process. Gasification converts solid organic material into a combustible gas that is generally used in an engine or gas turbine.

2.4 Hydrogen from Biomass

Thermal, steam and partial oxidation gasification technologies are under development around the world. Feedstock include agricultural and forest product residues of hard wood, soft wood and herbaceous species. Thermal gasification is essentially high-rate pyrolysis carried out in the temperature range of 600–1000°C in fluidized bed gasifiers. The reaction is as follows:

Biomass + $O_2 \rightarrow CO + H_2 + CO_2$ + Energy.

Other relevant gasifier types are bubbling fluid beds and the high-pressure high-temperature slurry-fed entrained flow gasifier. However, all these gasifiers need to include significant gas conditioning along with the removal of tars and inorganic impurities and the subsequent conversion of CO to H_2 by water gas shift reaction.

$$CO + H_2 \longrightarrow CO_2 + H_2O$$

A study of almond-shell steam gasification in a fluidized bed reveals that over the range 500–800°C, smaller particle size yields more hydrogen than that of at higher temperatures. Catalytic steam gasification of biomass has also been studied in a bench-scale plant containing fluidized bed gasifier and a secondary fixed-bed catalytic reactor. The catalytic converter using different steam-reforming nickel catalysts and dolomite can be tested over a temperature range of 660–830°C. Fresh catalyst at the highest temperature yields 60% by volume of hydrogen.

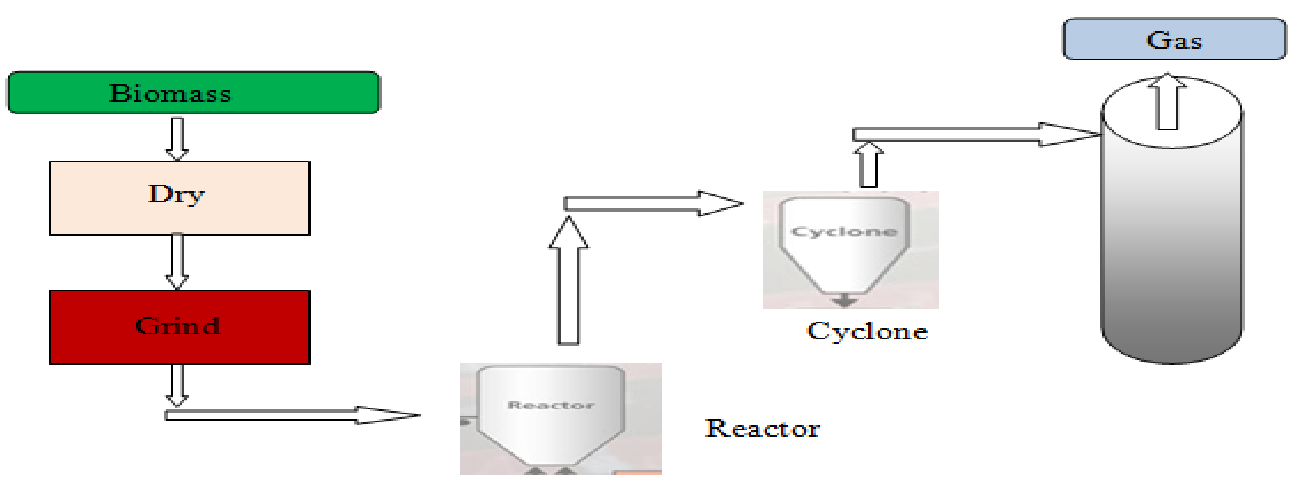


Fig 1 Fuel gas generation using biomass

3. Modeling and Simulation of Gasification

This model indicates that the biomass decomposes to volatiles, gases and char. The volatiles and gases may further react with char to produce different types of volatiles, gases and char where the compositions are different. Therefore, the primary products participate in secondary interactions, resulting in a modified final product distribution.

The kinetic equations for the mechanism shown above are as follows:

$$\frac{dC_b^{\,n1}}{dt} = -K_1 C_b^{n1} - K_2 C_b^{n1} \qquad (1)$$

$$\frac{dC_{g1}}{dt} = K_1 C_b^{n1} - K_3 C_{G1}^{n2} C_{C1}^{n3} \qquad (2)$$

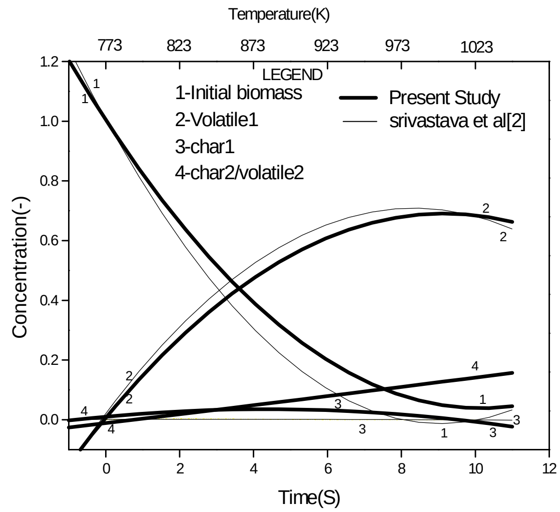
$$\frac{dC_{C1}}{dt} = K_2 C_b^{n1} - K_3 C_{G1}^{n2} C_{C1}^{n3} \qquad (3)$$

Where

$K_1 = A_1 \exp [(\frac{D_1}{T}) + (\frac{L_1}{T^2})]$

$K_2 = A_2 \exp [(\frac{D_2}{T}) + (\frac{L_1}{T^2})]$

$K_3 = A_3 \exp [-(\frac{E_3}{RT})]$



Plot-1 Concentration Vs Time/Temperature under non-isothermal condition

4. Model of Power Plant

4.1. Gas Stream

As gas turbines were modeled, gas streams had to be considered. These contain:

- Air (as N_2, O_2 mixture).
- Gas fuel (containing CH_4).
- Exhaust gas components, including products of combustion and dissociation reactions

The stream definition contains N=6 variables (where N is the number of components for a given gas stream). They are F,H,T,P,h,s,y_i (i=1,…,N), respectively, molar flow (which is convenient for modeling the combustion process), enthalpy flow, temperature, pressure, specific enthalpy, specific entropy, and mole fractions.

4.2. Gas Turbines

This is a complex model consisting of three sections:

- a compressor;
- a combustion chamber with a pre-mixer for air and fuel; and
- an expansion section.

The full model for a gas turbine including these subsections and the relationship between work produced by the expansion section, work required by the compressor section and the external load (e.g., an electric generator) is given in Rodrı´guez-Toral (1999) [2]. In modeling the combustion chamber, we consider first the mixing of air from the compressor section with fuel and steam where appropriate, in steam injected gas turbines [3], and then a combustion reaction section. The combustor model requires energy balance and reaction equilibrium equations to get the temperature and composition of the combustion products.

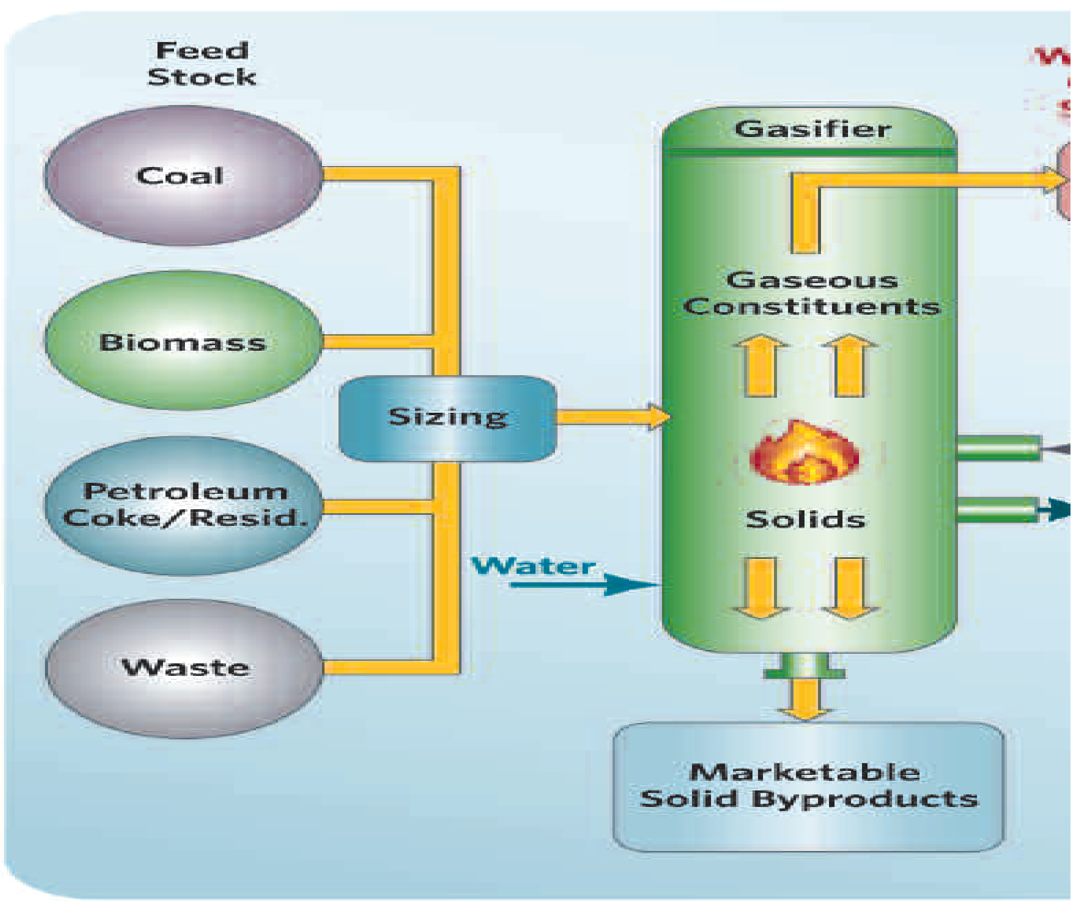


Fig.2. Overview of a gasifier for power production with relevant processes

5. SIMULATION OF A FULL GAS TURBINE (GT)

The equipment sections and streams needed to model an open-cycle gas turbine are:

1. The compressor section where air is compressed and then mixed with fuel
2. the combustion chamber where fuel is burned with a high excess of oxygen at high temperature (around 1200°C) and high pressure (above 2.8 MPa); and
3. The expansion section where the combustion gases are expanded to produce shaftwork for electric power generation or mechanical power, and to drive the compressor section of the gas turbine. We first simulated this equipment in its individual sections [2], due to the complexity of the combustion chamber model. This was the most difficult subsection to converge since the equations relating the combustion temperature and composition and including dissociation reactions are highly non-linear [4,5]. The chemical reactions involved in the process are very complex as many components are involved, and there is a network of irreversible consecutive and competitive reactions. The model uses a relatively simple approach to represent the reaction set as some trace reaction products, like CS_2, are not considered. The reactors are modeled with the Aspen HYSYS®.

5.1 Operating parameters of fuel system for GTG:

Table 1. Gas Turbine operating parameters

Design Capacity (m^3/hr)	Pressure (barg)		Temperature (^OC)	
	Operating	Design	Operating	Design
11.37	7.5	13.5	50	95

Table 2 Effect of humidity on power generation-winter conditions

GAS ANALYAIS, %	GTG 1-4, kW
17	**24993.5**
35	**25003**
50	**24993.5**

Table 3. Data for simulation of the power plant

Process	Parameters	Values
Turbine of GT	Power	100MW
	Inlet Temperature	1421 ^oC
	Isentropic Efficiency	93.3 %
GT Compressor	Pressure Ratio	9.09
	Isentropic Efficiency	59.99 %

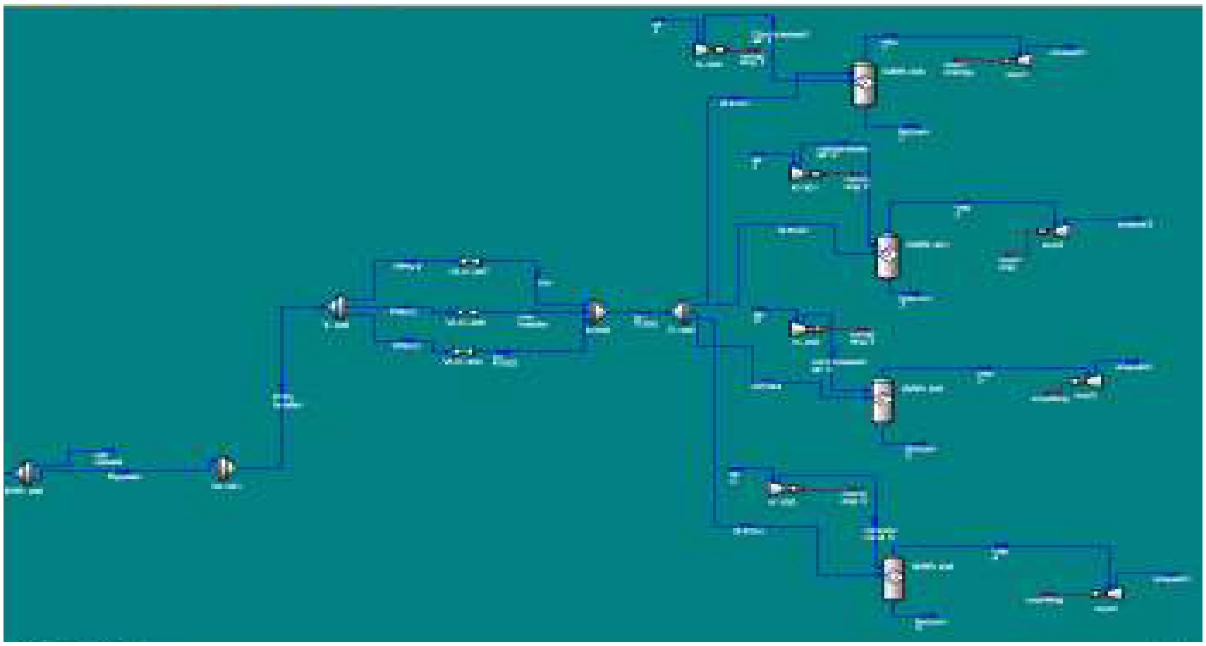


Fig. 3 Simulation of biomass generated fuel gas operated gas turbines

CONCLUSIONS

Based on the importance and promising nature of the gasification of biomass, modeling and simulation has been performed for finding the optimum parameters of the process. The qualitative trends obtained for the concentrations of initial biomass, volatile 1, char 1 and volatile 2 are found to be the same as those reported by earlier investigators. The small quantitative differences are attributed to the numerical methods used and the assumptions made. A wide range of heating rate and temperature are used to simulate the model equations with small step sizes for both the isothermal and non-isothermal process conditions with different orders of reactions. Some interesting trends have been obtained, especially with respect to the effect of net heating rate and temperature on the final combustion time. The range of operating conditions used for simulating the model equations is small in the case of the earlier investigators work, but the results obtained using a wide range of operating conditions in the present study show that the final combustion time initially decreases and then increases as the net heating rate or temperature is increased, giving an optimum final combustion time corresponding to the optimum net heat rate or temperature. The simulation study shows that maximum possible power is generated with 55630 NM^3/hr of fuel gas flow bypassing the heater skid which saves energy on heating the gas which saves 900 kWh electric power. Maximum possible power generation in each GTG is approx 132 MW. The gasifier efficiency is enhanced using lumping parameter models for reactions by maintaining inlet temperature below 1500 ^oC. This helps for complete conversion of CO and NOx, which in turn reduces pollution and makes this as a process of clean power production.

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