Evaluation of Wood Chip Gasification to Produce Reburn Fuel for Coal-fired Boilers

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Abstract: *Gasification/reburn testing with biomass and other wastes is of interest to both the U.S. Environmental Protection Agency (EPA) and the Italian Ministry of the Environment & Territory (IMET). Gasification systems that use wastes as feedstock should provide a clean, efficient source of synthesis gas that has the combined benefit of producing energy or feedstock chemicals in an efficient manner while reducing the volume of wastes and minimizing their environmental impact, including reduction of oxides of nitrogen (NO_x) and carbon dioxide (CO_2). EPA has performed reburn tests with natural gas, oil, and pulverized coal in the past and both parties are interested in biomass and waste fuels due to the low cost of the fuel source and the impact on our landfills. EPA has a 4-million Btu/hr pilot-scale combustor that is capable of firing a variety of fuels. EPA will perform tests on this facility to evaluate the gasification of biomass to generate syngas for reburn to control NO_x emissions while also displacing fossil fuels and reducing the associated CO_2 emissions. With funding provided by IMET, Solar Heat and Power (SHAP) of Italy has worked with INETI of Portugal to design a pilot-scale gasification unit and syngas line that will deliver raw syngas to EPA's combustor. The project will examine the feasibility of using syngas from gasification of wood as a reburn and attempt to optimize the gasification/reburn process for reducing emissions from coal-fired industrial and utility boilers. The objective of this project is to demonstrate the feasibility of using wood chips as a feedstock (CO_2 neutral) in a gasifier to provide a NO_x reducing reburn fuel for coal-fired boilers. A NO_x reduction of 50 to 65% or greater is anticipated in existing boilers.*

Keywords: gasification, combustion, reburn, biomass, wood chips

1. INTRODUCTION

Biomass represents a large potential source of renewable energy with significant resource, economic, and environmental benefits. Advances in recovery of agricultural and forestry residues and industrial wastes, the production of dedicated energy crops, and the development of biomass conversion technologies improve the competitiveness of biomass energy over conventional fossil energy. Also, biomass energy can provide major environmental benefits compared with fossil energy use with regard to emissions of pollutants and greenhouse gases in particular. The cost of waste disposal has increased recently due to a combination of environmental concerns in conjunction with the availability and cost of landfills. The use of biomass waste materials as the feedstock in a gasification process becomes increasingly attractive for its potential of eliminating the waste disposal costs while producing clean and renewable energy [1]. A wide range of biomass such as agricultural and forest residues and industrial wastes from pulp and paper and furniture industries are potential readily available biomass gasification feedstock. Biomass gasification is highly versatile with widely different process designs such as fixed- and fluidized-beds, air- and oxygen-blown, and product gases including low and medium Btu gases for adapting to different feedstock and end use requirements [1].

Gasification and reburning testing with biomass waste fuel is of interest to both the EPA and IMET. EPA has performed reburning tests with natural gas, oil, and pulverized coal in the past and both parties are interested in biomass fuels due to the low cost and renewable properties of the fuel source. The Air Pollution Prevention and Control Division (APPCD) of EPA has a pilot-scale combustor that is capable of firing a variety of fuels. APPCD will perform tests on this facility to evaluate the gasification of biomass for reburning to control nitrogen oxides (NO_x) emissions. IMET will design, fabricate, and install a pilot scale gasification unit and syngas delivery system that will connect to APPCD's combustion facility. The gasification and reburning project will examine the feasibility of using syngas from gasification of waste, in this case wood chips, as a reburning fuel. The project will use the EPA's facilities to maximize the environmental benefits of gasification/reburning technology for reducing emissions from coal-fired industrial and utility boilers. The objective of this project is to demonstrate the use of biomass in a gasifier to produce a reburning fuel for coal-fired boilers to reduce their NO_x emissions. A 50% to 65% NO_x reduction is anticipated in existing coal-fired boilers.

2. BIOMASS GASIFICATION REBURNING PROJECT

2.1 Reburning for NO_x Emissions Control

Reburning is a combustion modification technology that removes NO_x from combustion products by using fuel as a reducing agent. To implement the reburning process in a combustor, the combustion air and fuel are divided into three zones that stage the fuel and air addition to the furnace. In the primary combustion zone, the main fuel is burned under normal fuel-lean conditions to release about 80% of the total heat input to the furnace. The reburning fuel, which accounts for the other 20% of the fuel input, is injected into the reburning zone that is located downstream of the primary zone to form a slightly fuel-rich zone where NO_x from the primary zone is reduced. The hydrocarbon free radicals generated from breakdown of the reburning fuel under fuel-rich conditions react with NO_x to form molecular nitrogen (N_2) and water in the reburning zone. Additional combustion air is added in the final burnout zone to oxidize CO and any remaining fuel under overall fuel-lean conditions. In addition to syngas (CO and H_2), significant quantities of tar and oil are produced from the biomass gasification process. These liquids (aerosol) tend to breakdown into smaller hydrocarbon fragments in the combustion process. The potential for using these liquids as a reburning fuel for producing reactive hydrocarbon free radicals for effective NO_x reduction will be evaluated in the joint EPA/IMET reburning study.

2.2 EPA Combustion Research Facility

A gasification system will be added to APPCD's existing Multi-pollutant Control Research Facility (MPCRF) to study gasification of biomass for reburning to control NO_x emissions. The MPCRF, shown in Figure 1, is a state-of-the-art facility that can be used to examine the formation and control of nitrogen oxides (NO_x), sulfur dioxide (SO_2), mercury (Hg) and other heavy metals in coal-fired boilers. The MPCRF is located in the High Bay of EPA's Research Triangle Park, NC campus and its combustor (4 MMBtu/hr) can be operated on natural gas, No. 2 fuel oil, or pulverized coal. The MPCRF is currently equipped with a low NO_x burner, electrostatic fabric filters (ESFF), electrostatic precipitator (ESP), and a wet scrubber. A selective catalytic reduction (SCR) unit is also used for deep NO_x control. The MPCRF's unique design enables it to perform parametric studies on the controls of multiple pollutants under a variety of conditions. The facility is equipped with continuous emissions monitors (CEMs) for measuring carbon dioxide (CO_2), carbon monoxide (CO), oxygen (O_2), SO_2 and NO_x. State-of-the-art mercury CEMs are also installed for collecting real-time results during Hg emissions and control testing, under a variety of test conditions.

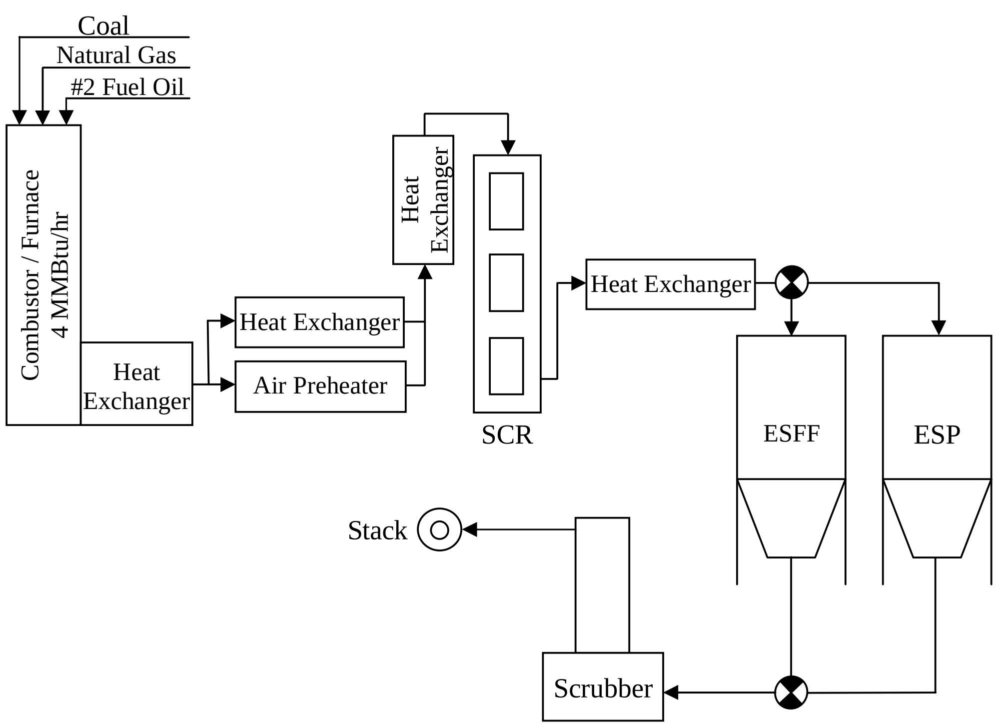

Figure 1 Schematic of MPCRF

2.3 CFD Modeling Study

A computational fluid dynamic (CFD) modeling study of the technical feasibility of adding a reburning system to the MPCRF furnace was performed by Reaction Engineering International (REI) [2]. The objectives of the study were to analyze the flow and temperature patterns in the furnace burning an Eastern bituminous coal, and to identify the optimum locations and port sizes for introducing overfire air (OFA) and injecting the syngas products as the reburning fuel to reduce NO_x emissions produced by the pilot-scale gasification unit that will be co-located with the MPCRF. The furnace section is 20 ft in height and 3.5 ft in inner diameter, with a swirl burner installed at the top of the furnace. The burner is patterned after the original movable block swirl burner developed by the International Flame Research Foundation. The furnace is designed to generate 1,000 SCFM flue gas at full firing rate, however recent removal of in-furnace cooling coils to control unburned carbon in ash (LOI) will result in a firing rate of 2.75 MMBtu/hr for these tests with 750 SCFM flue gas. The reburning system is required to be capable of contributing 20 % of the total heat input to the MPCRF furnace with up to 65% or greater NO_x reduction.

Multiple reburn configurations were modeled using an REI in-house CFD-based coal combustion code, GLACIER, to simulate staged combustion with syngas injection in the MPCRF furnace. Performance metrics tracked included predicted flow patterns and mixing, particle burnout and LOI, particle deposition patterns, gas temperature profiles, and CO, O_2, and NO_x concentration profiles. Locations for syngas and OFA injection were determined as 47 in and 126 in respectively downstream of the burner face, consistent with existing access openings in the furnace. A series of five syngas injection cases were modeled in conjunction with OFA, using the predetermined port locations. These simulation results are summarized in Table 1 [2].

Configuration OFA4S3 was chosen as the best case to pursue for the combination of performance metrics benefits and ease of furnace modification. In this configuration OFA is introduced through a 2 x 5 in rectangular port at an inlet velocity of 90 ft/sec, and syngas is injected through a 3.4 in ID circular pipe at a velocity of 40 ft/sec. Efforts to modify the MPCRF furnace for this configuration are currently ongoing.

Table 1 Summary of CFD Predictions (Furnace Exit Conditions)

	Baseline	**OFA1**	**OFA2**	**OFA3**	**OFA4S1**	**OFA4S2**	**OFA4S3**	**OFA4S4**	**OFA4S5**
Firing Rate (MMBtu/hr)	2.75	2.20	2.20	2.20	2.75	2.75	2.75	2.75	2.75
BSR*	1.21	0.9	0.9	1.05	0.9	0.9	0.9	0.9	0.9
OFA Vel (ft/sec)	--	50	80	26	90	90	90	90	90
OFA Fan Angle (α)	--	35°	40°	35°	45°	45°	45°	45°	45°
Syngas Vel (ft/sec)	--	--	--	--	70	70	40	29	70
Syngas Fan Angle	--	--	--	--	30°	0°	0°	0°	0°
Syngas Injection	--	--	--	--	horiz.	horiz.	horiz.	45° uptilt	45° uptilt
Gas Temp (°F)	2,659	2,431	2,458	2,446	2,571	2,565	2,558	2,576	2,571
CO (dry ppm)	171	156	110	221	120	113	128	246	116
O_2 (dry %)	3.8	4.0	3.8	3.9	3.8	3.8	3.8	3.8	3.7
NOx (dry ppm)	713	381	389	478	242	218	226	222	234
NOx (lb/MMBtu)	0.97	0.52	0.53	0.65	0.34	0.31	0.31	0.31	0.33
LOI (%)	7.9	26.5	26.0	14.7	<<1	4.1	5.7	<<1	4.3
Burnout	0.995	0.981	0.994	0.989	>0.999	0.999	0.998	>0.999	0.999

* Burner Stoichiometry

2.4 Biomass Gasifier Design

Working with the National Institute for Engineering, Technology and Innovation (INETI) of Portugal, Solar Heat and Power (SHAP) of Italy has designed a pilot-scale downdraft dry-ash, single-stage, fixed bed gasifier for the reburning project. Ash removal and automate feed systems are to be included with the gasifier. The design work, initiated in mid-2008, was completed in January 2009. Fabrication of the gasifier and ash removal system was completed in March 2009. Figure 2 shows a general schematic of the gasifier main body and picture of the completed assembly. Design and fabrication of the system control panel and automated fuel feeder are currently ongoing. Delivery to the USEPA RTP facility is anticipated for summer 2009.

Biomass fuels are generally more reactive and have higher moisture content than coal. The raw gas conversion efficiency of the single-stage fixed-bed gasifier is in the range of 80 to 90 percent of the energy feed being delivered to the reburning zone as gas and pyrolysis liquids, depending on the moisture content of the fuel [3]. The syngas is expected to result in a significant NO_x reduction in the reburning zone, and the intent of the research is to establish the operational requirements to optimize (maximize) the NO_x reduction.

The composition of the syngas, which is delivered to the reburning zone, will be continuously monitored by using CEMs. An Electrostatic Gas Cleaning System (EGCS) designed and supplied by Hamilton Maurer International, Inc. (HMI) will be used to remove tar and moisture from the sampled raw gasification products to produce a clean gas sample for the CEM measurements. The EGCS first cools the raw gas sample to nominally 100 ^oF to insure that all pyrolysis liquids (tars) are condensed within the gas sample (10 L/min sample flow). The tar droplets (aerosol) are completely removed (99.99%) from the sampled gas using electrostatics by the EGCS based on HMI's demonstrated wet electrostatic precipitator design [3]. The gas is further dried and filtered prior to delivery to the CEMs. The tar/water mixture removed by the EGCS is collected and the water separated from the tar prior to preparing the tar sample for ultimate analysis. The analysis will provide heating value and the elemental composition of the oil/tar component of the syngas, which will be used for calculating the mass and energy balance of the gasification process and the detailed composition of the reburn fuel. The tar fog created by the gasifier and injected into the combustor is important because it is expected to significantly enhance the NO_x reduction via the tar's high reactivity within the reburning zone as demonstrated by early syngas reburn work performed for ENEL in Italy by Ansaldo Ricerche which motivated this IMET-U.S. EPA collaboration. Those bench-scale tests resulted in a NO_x reduction of 70% or greater.

The reburning process is designed to be operated at a nominal 20% heat input provided by the reburning fuel produced from gasification of biomass. The energy fraction of the tars contained within the raw product gas will be included in the total energy delivered with the syngas to the reburning zone. The tar content (fraction in the raw product gas) and the tar composition will be biofuel specific. The biomass gasification unit is designed to be operated at a nominal rate of 140 to 170 lb/hr of biowaste fuels with a heating value in the range of 4,000 to 7,000 Btu/lb to deliver nominally 0.8 MMBtu/hr heat input required by the reburning process in the MPCRF furnace.

A key aspect of this project will be the continuous monitoring of the gaseous and liquid products generated within the gasifier and delivered to the reburning zone of the boiler. The gasification unit will be operated to deliver syngas and liquids (oil and tar) at a total flow rate in the range of 80 to 110 standard cubic ft per minute (scfm) for injecting into the reburning zone of the MPCRF furnace to achieve the 0.8 MMBtu/hr maximum energy input for NO_x reduction. The typical design output of the gasification unit is listed in Table 2. The dry syngas produced by the gasification of a biofuel (wood) contains 20.0% CO, 16.0% H_2, 10% CO_2, 47.0% N_2, and trace hydrocarbons (CH_4, C_2H_2, C_2H_6) with a higher heating value (HHV) of 157 Btu/scf. The tar fog has a droplet mass mean diameter of 2.6 micron[2]. The small tar droplets with high surface area are highly reactive to provide effective NO_x reduction in the reburning zone of the boiler. The fabrication and installation of the gasifier at RTP is expected to occur in the summer of 2009. Testing with gasification of wood chips is scheduled to begin in 2009 following installation. Initial tests will be run with the combustor firing natural gas followed by tests with pulverized coal. Additional tests may be performed with gasification of other waste materials depending on the outcome of the initial tests and future funding.

Table 2 Summary of Typical Output of the Biomass Gasifier

Output	**lb/hr**	**MMBtu/hr**
Dry Gas	404	0.99
Water in Gas	9.00	0.01
Oil and Tar	0.35	0.01
Fly Ash	0.22	
Total Mass	413.57	1.01
Total Flow	107 scfm	

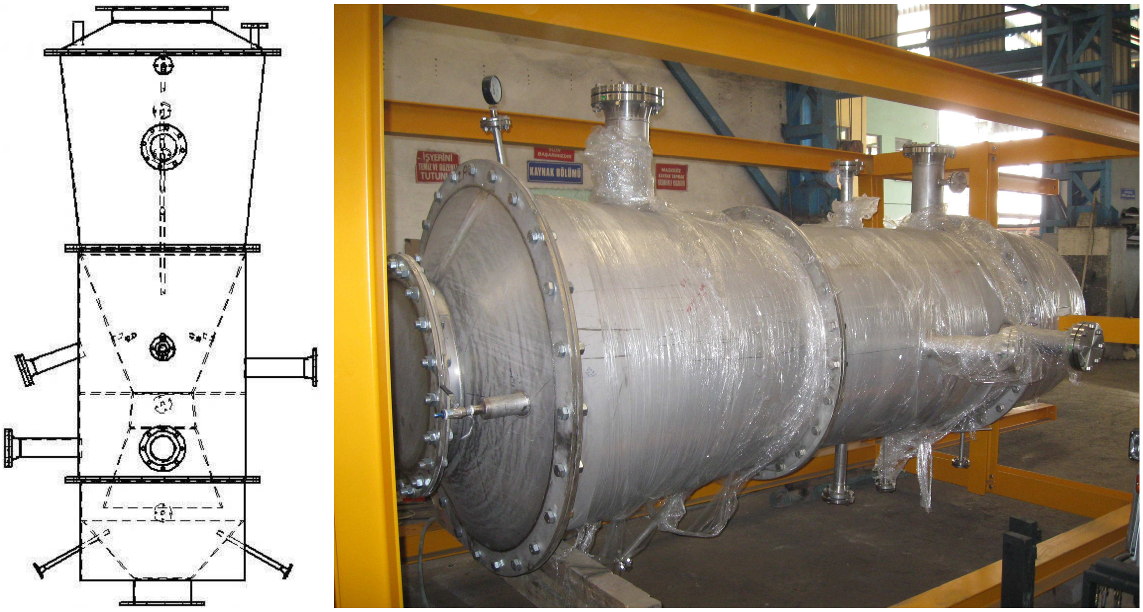

Figure 2 Gasifier Schematic and Completed Main Assembly

3. REFERENCES

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