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BASELINE TECHNICAL AND ECONOMIC ASSESSMENT OF A SMALL SCALE STEAM HYDROGASIFICATION PROCESS WITH FISCHER-TROPSCH LIQUIDS FACILITY

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Abstract:

A combination of Steam Hydro-gasification Reaction (SHR) and Steam Methane Reforming (SMR) can be used to produce synthesis gas (H_2+CO) from carbonaceous feedstock. This technology, developed at the University of California Riverside, Center for Environmental Research and Technology (CE-CERT) operates at moderate temperatures and pressures when compared to other similar processes and can be used to produce Fischer-Tropsch liquids. The technical and economic feasibility of a commercial 4,000 metric ton per day Coal To Liquids (CTL) facility using this new technology is being evaluated by CE-CERT and the National Energy Technology Laboratory (NETL). Detailed ASPEN Plus simulations have been performed for a plant with a capability of 4000 tons/day coal feed. The simulations include a reactor and a regenerator section for the SHR. The SHR is assumed to be a fluidized bed reactor and the sand material is heated in the regenerator section to enable heat supply to the reactor. The simulation also has a gas cleanup system that will remove the sulfur and other contaminants that are detrimental to the steam reforming and Fischer-Tropsch catalysts.

The feedstock used in the simulations is sub-bituminous coal from southern regions of the state of Utah. The simulation includes a Fischer-Tropsch unit complete with hydro-treating units and hydro-cracking units. The CTL facility produces approximately 5,488 bbl/day of commercial-grade diesel liquid and 2,352 bbl/day of naphtha liquid, which could be shipped to a refinery for further upgrading into commercial-grade end products or to produce other chemicals of commercial value. The CTL plant also generates 107 MW of electric power that can be exported. Simulations were also performed to explore a plant design that includes equipment to separate and compress carbon dioxide for injection into a pipeline and potential sequestration. Facility with CO_2 capture and sequestration off-site (65% capture) is included in this analysis. The overall plant thermal effective efficiency for the process configuration is 53.4 percent, on an HHV basis. This paper presents the overview of the material & energy balances and the other results of the simulation.

Introduction

Gasification of carbon containing feedstocks in a hydrogen environment is called hydro-gasification. This process has been investigated since the 1930s for Synthetic Natural Gas (SNG) production from dry coal and dry biomass. The required hydrogen in this process is usually produced internally by reaction of residual char with steam or supplied externally.

The Center for Environmental Research and Technology at the University of California, Riverside (CE-CERT, UCR) has been engaged for many years in the development of methods for the thermo-chemical conversion of carbonaceous materials into synthetic fuels and process heat (hereafter referred to as the CE-CERT process). The strategic competitive advantages of CE-CERT process are its performance and cost benefits. Through several years of focused research, the CE-CERT research team has identified key innovative elements that impart the following advantages:

- The process uses (recycled) hydrogen and steam as the reactants and employs unique operating conditions by utilizing water content in the feedstock.
- In contrast to mainstream gasification technology, which requires high temperatures, external energy input, and a source of pure oxygen (expensive air separation unit required) for creating fuel gas, our technology operates at moderate temperatures and requires no oxygen. This may reduces both capital and operating costs compared to competitive technologies
- The composition of synthesis gas can be easily controlled by changing the water to carbon ratio of the slurry - so it can be used in any downstream fuel process that requires careful control of the synthesis gas composition

The key step in the CE-CERT process is the Steam Hydrogasification Reaction (SHR) that generates a methane rich product gas. SHR is the hydrogasification reaction carried out in the presence of steam. It has been shown that the presence of steam increases the rate of methane formation up to 13 times compared to conventional dry hydrogasification processes[i]. It is believed that the superheated steam enhances the decomposition of the carbon containing compounds and provides a highly porous solid surface that enhances the reactivity with hydrogen.

The CE-CERT process is an integrated system of three steps. The SHR step is followed by the Steam Methane Reforming (SMR) step to produce the syngas and a last optional step of liquid fuel synthesis like a Fischer-Tropsch reactor (FTR).

The SHR step utilizes a water-based slurry as the source of carbonaceous feedstock and combines it with steam and recycled hydrogen to produce a methane rich gas. The exothermic SHR of the carbonaceous feedstock in slurry can be represented chemically in a simplified manner as:

$C + H_2O + 2H_2 \rightarrow CH_4 + H_2O + \text{Others} \quad +75\text{kJ/mol} \qquad (1)$

Others: CO, CO_2 and C2+

The SMR that converts products formed in reaction (1) into synthesis gas can be characterized as:

$CH_4 + \text{others} + H_2O \rightarrow 3\ H_2 + CO \quad - 206\text{kJ/mol} \qquad (2)$

$CH_4 + 2\ H_2O \rightarrow 4\ H_2 + CO_2 \quad - 165\text{kJ/mol} \qquad (3)$

The reactions (1) – (3) are idealized reactions used for the purpose of illustration. The actual process is much more complex than shown here. It is important to note that the SMR step requires high temperature steam together with methane rich gas to produce the synthesis gases. Thus, there is no need to remove steam after the SHR in the conversion process. The introduction of water in the form of slurry into the reactor is one of the most unique features of the CE-CERT process. Water can be the carrying medium for the carbonaceous feedstock into the SHR reactor by utilizing a conventional slurry pumping technology. It also enhances the product gas yield as well as the reactivity of the hydro-gasification process as described in the previous section. Finally, it is consumed by the SMR as a feedstock to produce the synthesis gas. The SMR produces syngas with a ratio higher than the necessary 2.1 ratio required for down stream fuel production. The excess hydrogen of the SMR product gas can then be separated in a straightforward manner and fed back to the first step making the process self sustaining. (i.e., no needs for an external source of hydrogen after initial start up).

The product synthesis gas can be used for the fuel gas to generate the electricity or sent to the optional process that converts the product synthesis gas into synthetic liquid fuels and process heat. Examples of such synthetic fuels are methanol, Dimethyl Ether (DME) and Fischer-Tropsch diesel. Figure 1 presents a block flow diagram of the CE-CERT process with the addition of optional gas to liquid process. Synthetic fuel (methanol, DME, or FT diesel) and water are produced from the synthesis gas made in the SHR & SMR reactors coupled with a warm gas cleanup unit.

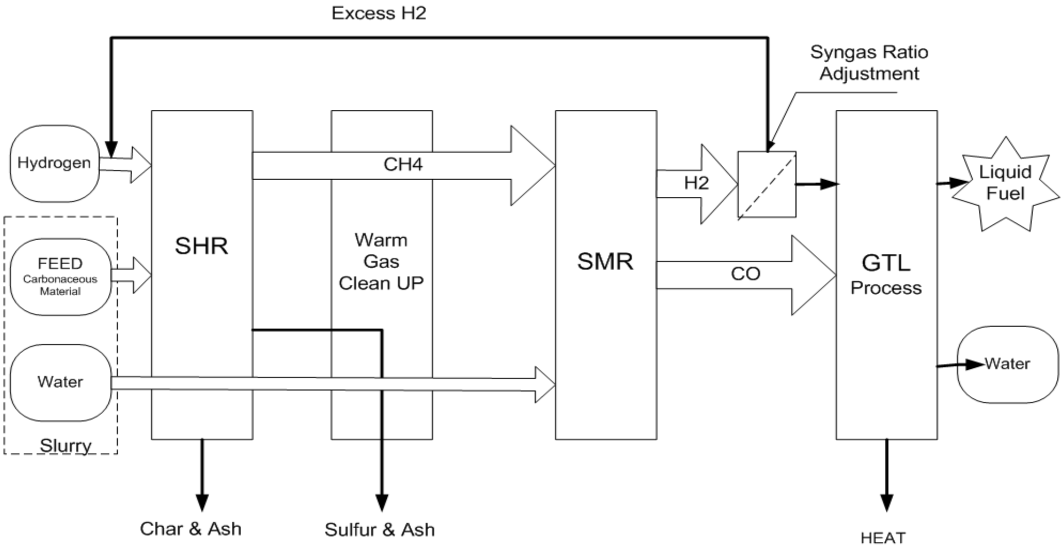

Figure 1 Process Flow Diagram of CE-CERT Process

National Energy Technology Laboratory (NETL) within the Department of Energy (DOE) recently reviewed the CE-CERT process through a Cooperative Research And Development Agreement (CRADA). The purpose of the CRADA is to provide the independent review on the CE-CERT process by validating the equilibrium model, process flow sheet for the several different configurations, and the estimation of Total Project Cost (TPC) for the economic analysis. NETL also agreed to provide the design of the pilot scale reactor with their proprietary reactor design tool. The next critical step in the commercialization process is to construct and operate a Process Demonstration Unit (PDU) of the size of a few tons/day. This is necessary to obtain the engineering information necessary to move forward to the pilot plant, eventually commercialization and confirm the theoretical estimates of process efficiency and cost done by CE-CERT and NETL.

Methodology & Design Basis

This section presents the application of the CE-CERT process to integrated conceptual flow-sheets of plant designs that produce quantities of Fischer-Tropsch liquids and/or electric power. The critical SHR reactor input parameters, operating conditions, and physical properties are summarized in the Table 1 and Table 2

Table 1, Design Criteria for CE-CERT Process (SHR to FTR)

Hydrogen Production Plant Parameter	Hydrogen Production Plant Design Basis
Coal Feed	Utah bituminous slurried with water
Gasifier	CE-CERT SHR with primary stage adjusted for 1382℉
Coal Feed Rate	400 TPD and 4000 TPD dry basis
Hot Gas Temperature	~1380℉
Gasifier Outlet Pressure	435 psia
warm gas cleanup	Recuperator, Candle filter, Chloride guard, Mercury removal, RTI warm gas cleanup system with direct sulfur reduction process.
Steam Methane Reformer	ZnO Sulfur polisher; single stage catalytic reactor heated externally w/furnace fired by light hydrocarbons from F-T unit
Overall CO_2 Removal,	65%, 2,200 psia (CO$_2$ Product Pressure)
Hydrogen Production	315 psia H_2 at recycle compressor inlet
Auxiliary Power Block	Steam turbine generator using steam from excess H_2 fired HRSG
Plant Size	Maximum diesel/naphtha production from 1:1 H_2:CO inlet specification

Table 2 Feedstock Analysis – Utah Bituminous Coal

Ultimate Analysis	Dry, %	As Received, %
Carbon	68.85	58.40
Hydrogen	4.74	4.02
Nitrogen	1.04	0.88
Sulfur	1.18	1.39
Ash	10.57	9.94
Oxygen	11.39	13.43
Proximate	**Dry Basis, %**	**As Received, %**
Moisture	--	15.18
Ash	10.55	8.95
Volatile Matter	40.00	33.93
Fixed Carbon	49.45	41.94
Sulfur	3.07	2.89
Btu Content	12,077	10,244

ASPEN Plus integrated flow-sheets previously developed by NETL were used as starting bases in this study. The plant designs are based on producing the maximum amount of F-T fuels from 400 and 4000 tons per day of dry coal respectively. The Aspen Plus Fischer-Tropsch model for the prediction of diesel/naphtha liquid fuels was based on an iron-based catalysts, which requires a 1:1 ratio of syngas composition. This model was developed by Noblis, Inc. The coal used in this case is Utah sub-bituminous from the City of Alton, Utah. To arrive at a cost estimate for fuels, the design includes commercially available process technology obtained from other verifiable sources. Processes utilized include commercially available technology except for the SHR and the RTI warm gas cleanup system with direct sulfur reduction process (DSRP) sulfur production. However, the RTI process has been tested extensively on a pilot plant scale slipsteam at the Eastman Chemical gasifier site in Kingsport, TN in testing supported by NETL/DOE.

Result and Discussion

Overall performance for the 4000 TPD CE-CERT process with nominal 65% capture of CO_2 was shown in the Table 3. The plant produces 107.3 MW_e net plant output power after plant auxiliary power requirements are deducted amounting to 15.9 MW_e. The overall plant thermal effective efficiency for this configuration is 53.4 percent, on an HHV basis. The CE-CERT process has a high percentage of input carbon that does not end up in liquids production but instead ends up as flue gas that is converted into steam and eventually power generation. The carbon content in this flue gas is a product of combustion of the C1 to C4 components separating from the F-T outlet prior to gas recycle to the F-T reactor units. See Figure 2 for a block flow diagram with major input and output flows.

For the comparison with conventional process, a CTL plant utilizing the same Utah coal and a dry feed entrained flow gasifier based F-T liquids plant was studied[ii]. The plant processes 3707 TPD of coal and includes 88% capture of CO_2 to yield the same 7143 BBL/day of liquids as CE-CERT 4000 TPD plant. The plant produces 10.3 MW_e net plant output power after plant auxiliary power requirements are deducted amounting to 102.8 MW_e. The overall plant thermal effective efficiency for this configuration is 47.6 percent. In table 3, comparison of these two processes was presented.

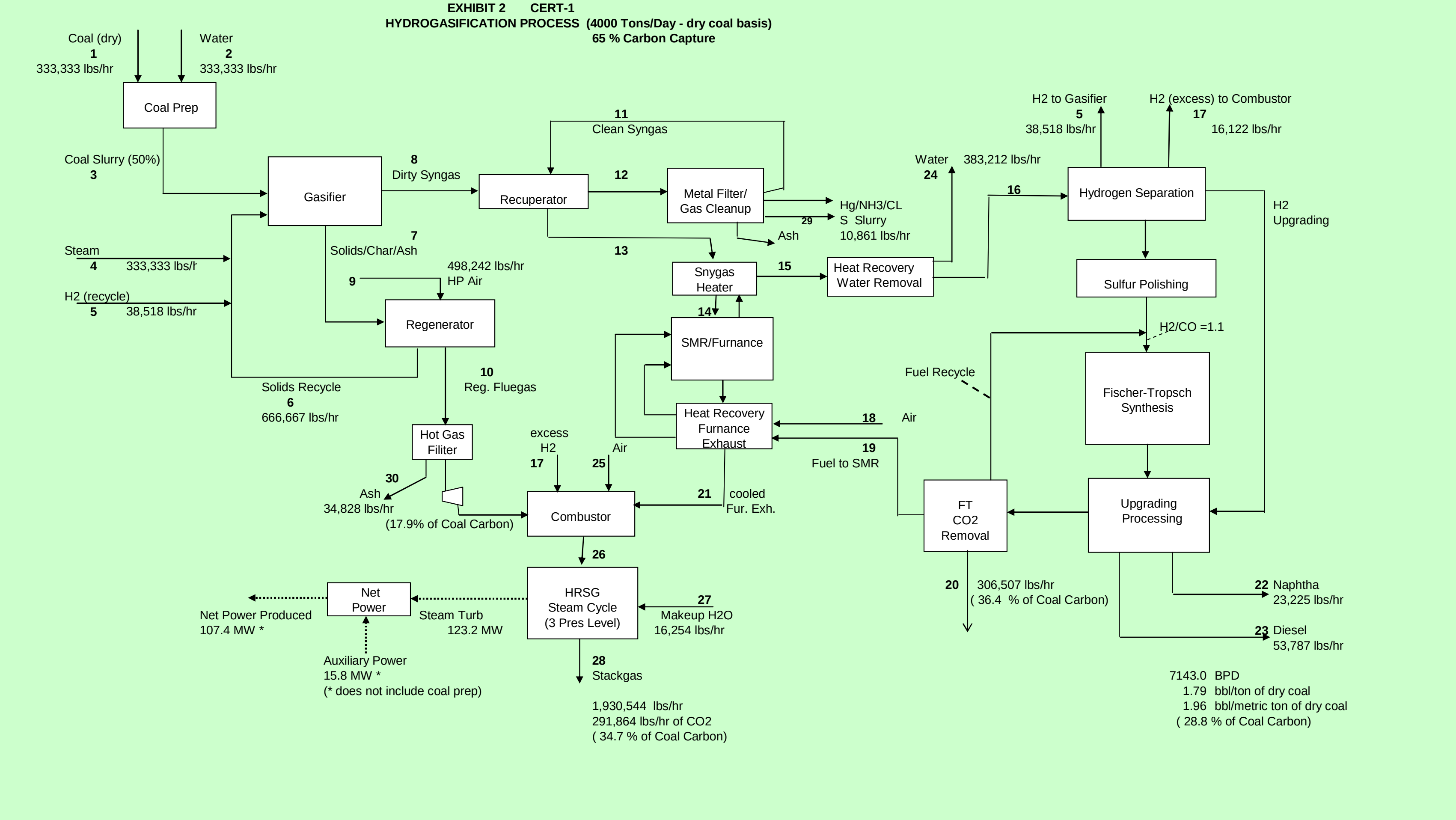

Figure 2, CE-CERT 4000 TPD SHR-FT Plant with nominal CO_2 Capture

Table 3 Major Plant Parameters

	CTL w/ CE-CERT Process	CTL w/ Conventional Entrained type Gasifier
input	4000 TPD CTL Plant	3707 TPD CTL Plant
output	107 MW electricity 7143 BPD (2.8 BPD/Metric Ton of Coal)	10.3 MW electricity 7143 BPD
HHV η	53.4%	47.6%
TPC/ TCR	$1,026 MM/$1,512 MM (Jan. 2008 $)	$1215 MM/$1,764 MM
IRR*	17% (@ $38/T) 20% (@ $18/T)	7% (@ $38/T) 12% (@ $18/T)

* The IRR for selected liquid fuel product prices and input coal costs were calculated using a model derived from the Power Systems Financial Model prepared for NETL by Nexant, Inc.[3]

Conclusion

It was shown that the CE-CERT process could produce the diesel/naphtha and electricity more efficiently than the conventional CTL process combined with entrained type gasifier by 12%. It was also shown that the CE-CERT process could achieve the decent process economic index at the smaller scale plant size (4000 TPD) from the benefits of a lower gasifier operating temperature and no need for an ASU plant.

Acknowledgement

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