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Project Summary

Hynol Process Engineering: Process Configuration, Site Plan, and Equipment Design

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A bench scale methanol production facility is being constructed to demonstrate the technical feasibility of producing methanol from biomass using the Hynol process. The plant is being designed to convert 22.7 kg/h (50 lb/h) of biomass to methanol. The biomass consists of wood, and natural gas is used as a cofeedstock. Compared with other methanol production processes, direct emissions of carbon dioxide (CO_2) can be substantially reduced by using the Hynol process. This report covers the design of the hydropyrolysis reactor system of the Hynol process. Process flow rates and gas compositions are presented in process flow diagrams for the Hynol system and the hydropyrolysis reactor. Safety, permitting, and site development requirements are described for the Hynol facility. The details of instrumentation and controls for the hydropyrolysis reactor are presented in a piping and instrumentation diagram. Details of the equipment design, cost, and schedule are also documented.

This Project Summary was developed by EPA's National Risk Management Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Producing methanol from biomass offers significant environmental, energy, and economic advantages over other liquid fuel resources. Methanol is a clean fuel for transportation and its widespread availability will contribute to air quality improvement in most urban areas. Domestic production of methanol versus imported fuel supplies brings energy, security, local jobs, and fuel distribution advantages. Process simulation studies indicate that the Hynol process should result in improved efficiencies in methanol production through increased yields over conventional processes. The process involves production from combined use of biomass and natural gas as feedstocks, optimizing the stoichiometry for synthesis gas to produce the fuel. The use of biomass feedstock together with natural gas provides for reduced CO_2 emissions per unit of fossil fuel carbon processed compared with separate natural gas and biomass processes.

Production of methanol by the Hynol process, shown in Figure 1, improves the overall conversion efficiency compared to conventional biomass gasification processes, which do not use natural gas as a cofeedstock. Conventional biomass gasification produces a synthesis gas containing excess carbon monoxide (CO), which must be reacted with steam to form

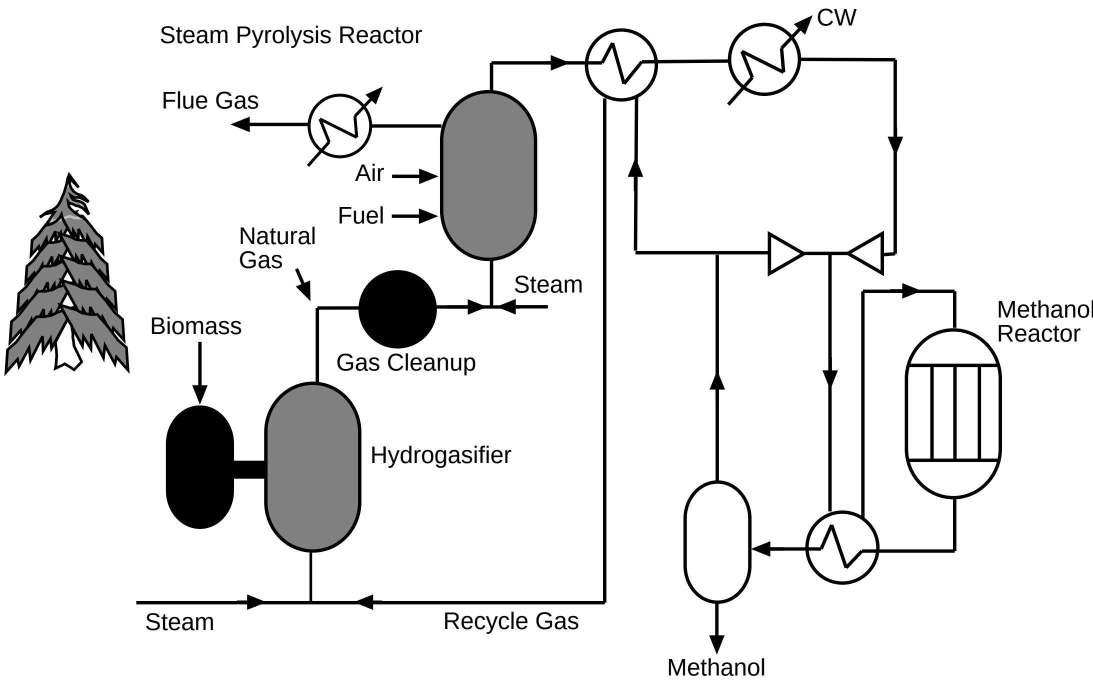

Figure 1. Hynol process schematic.

waste CO_2 and hydrogen (H_2); otherwise the H_2 yield is insufficient to convert all of the biomass carbon to methanol. Similarly, when methanol is produced from natural gas as the sole feedstock, the resulting synthesis gas contains an excess of H_2 that cannot be converted to methanol.

Part I. Design Basis, Safety, and Site Requirements

The Hynol process consists of the hydrogenation or hydrolysis of biomass to produce methane (CH_4) followed by the reaction of CH_4 with steam to produce H_2 and CO (steam pyrolysis). CO formed in the steam pyrolysis step is catalytically combined with H_2 in a third step to produce methanol. Excess H_2 is recycled as a feed gas for hydropyrolysis. Biomass is fed into the hydropyrolysis reactor (HPR) and fluidized with recycled H_2-rich process gas at 30 bar (3000 kPa) and 800°C. Additional steam can be fed into the HPR or the steam pyrolysis reactor (SPR). The independent reactions taking place in the HPR can be expressed as

$$C + 2H_2 \rightarrow CH_4$$

$$C + H_2O \rightarrow CO + H_2$$

$$CO_2 + H_2 \rightarrow CO + H_2O$$

Before entering the SPR, the process gas from the HPR is cleaned up to remove particulate and impurities that may contaminate catalysts in the subsequent reaction steps. Conventional hot gas clean-up methods can be used for this purpose. Feed natural gas can be added prior to the HPR filter to cool the gas stream and maintain a more filter-friendly operating environment. Other options include cooling the gas in a heat exchanger prior to the hot gas filter.

The process gas is then introduced to the steam reformer (alternatively called the SPR) where HPR outlet gas and natural gas (methane) feed react with steam to form CO and H_2. The steam reforming can be described by two independent reactions:

$$CH_4 + H_2O \rightarrow CO + 3H_2$$

$$CO_2 + H_2 \rightarrow CO + H_2O$$

The reactions take place at 30 bar and 1,000°C. A catalyst-packed tubular externally fired furnace reactor similar to a conventional natural gas reformer furnace reactor is used for the SPR. The cooled process gas is compressed and enters a conventional methanol synthesis reactor (MSR). Methanol synthesis occurs at 30 bar and 260°C. Methanol is separated from water in a condenser and fractionated to produce concentrated methanol. To increase the conversion of CO in the MSR, the uncondensed gas from the condenser is partially returned to the MSR through a recycle compressor. The remaining portion of gas exiting the MSR is introduced into a heat exchanger and recycled to the HPR. The reactions taking place in the MSR are

$$CO + 2H_2 \rightarrow CH_3OH$$

$$CO_2 + 3H_2 \rightarrow CH_3OH + H_2O$$

Facility Overview

The bench scale Hynol facility will be built at the University of California, Riverside, College of Engineering, Center for Environmental Research and Technology (CE-CERT). Acurex Environmental Corporation is working with CE-CERT on facility design, construction, and operation. The facility will use biomass (initially white wood) and natural gas as feedstocks. After the facility successfully operates on wood and natural gas, waste biomass feedstocks such as tree trimmings will be used as a cofeedstock. The feedstocks will be processed into synthesis gas for methanol conversion.

The facility requires a natural gas compressor, process gas compressor, air compressor, steam generator, and nitrogen supply. A compressed natural gas (CNG) fueling station will provide gas for CNG vehicle fueling and natural gas for the Hynol plant.

The system will initially operate with the HPR only, decoupled from the Hynol system. The HPR will require an external source of process gas. The process gas that is required for HPR feed contains H_2, CO, CO_2, CH_4, nitrogen (N_2), and water vapor (H_2O). For about 8 months, H_2, CO, CO_2, and N_2 will be provided on site. Tube trailers will be parked at the site for the duration of the test runs (about 2 weeks each) to provide the H_2, CO, and N_2. CO_2 will be stored as a liquid in high pressure cylinders. When operating the decoupled HPR (or HPR and SPR), the process gas will be burned in a flare. When all three of the Hynol reactors are operated as an integrated system, the methanol reactor will provide the process gas feed to the HPR.

Various materials will be received, stored, and shipped from the Hynol facility. When the facility is not operating, most materials will continue to be stored onsite. Ash, sludge, and waste water will be removed from the site. Methanol will be removed from the reactor system but will continue to be stored in the storage tank to service vehicle requirements. Natural gas and water will enter the facility via pipeline. Other materials will be shipped into and from the facility by truck.

The site plan calls for about 1 acre (4047 m^2), with appropriate grading, fencing, and landscaping. Precautions will be taken to deal with safety and environmental hazards as required. The methanol storage area, for example, would be lined and bermed to ensure containment of accidental spillage. The site plan identifies process areas that correspond to equipment on the process flow diagram for the Hynol system. Different configurations will apply when the HPR is initially operated without the other process units.

Part II. HPR System Description and Hardware

The HPR system demonstrates the hydropyrolysis of biomass as part of the Hynol process. Hot H_2 and other process gases are fed into the HPR, where they react with biomass in a fluidized bed. H_2, CO, and N_2 are metered to simulate recycle gas. The gas mixture is heated in a ceramic heat exchanger and then further heated with electric heaters. Steam is added to the gas mixture, and the entire mixture is heated to 1,000°C. Natural gas is fed into the system downstream of the heaters.

The report contains a piping and instrumentation diagram for the HPR system. This diagram shows all of the instrumentation and controls for the HPR system with the bottled gas feed. Each gas supply passes sequentially through regulator pressure indicators and control valves, an orifice flowmeter, a flow control valve, and a check valve. Bottled H_2, CO, and N_2 are fed from separate or mixed tube trailers or individual six-packs depending on cost and feasibility.

The layout for the biomass feed, HPR, and SPR structure is shown in Figure 2. The reactor vessels are arranged adjacent to each other to minimize pipe runs and reduce heat losses. The MSR system is located on a separate structure. The gasification system structure will be assembled on site. The process reactors will be delivered and assembled on site. The report includes design drawings for the HPR, hot gas filter, water scrubber, and desulfurization vessel.

Figure 3 shows the configuration of the HPR. The reactor has a 6-in. (15-cm) inner diameter that is made from refractory lined pipe in the fluidized section of the HPR. The freeboard and plenum sections of the HPR are lined with preformed fiber insulation. A mixture of hot H_2 and other gases is fed into the bottom of the HPR. The gases flow through a distributor plate and fluidize the bed material, which consists of biomass, unreacted char, ash, and sand that is used for heat transfer and improved fluidization. Biomass is fed into the HPR about 1.6 ft (0.5 m) above the fluidization plate. The top section of the HPR consists of a larger diameter section, which prevents solids carryover. The gas passes through an internal cyclone and then proceeds to the hot gas filtration system.

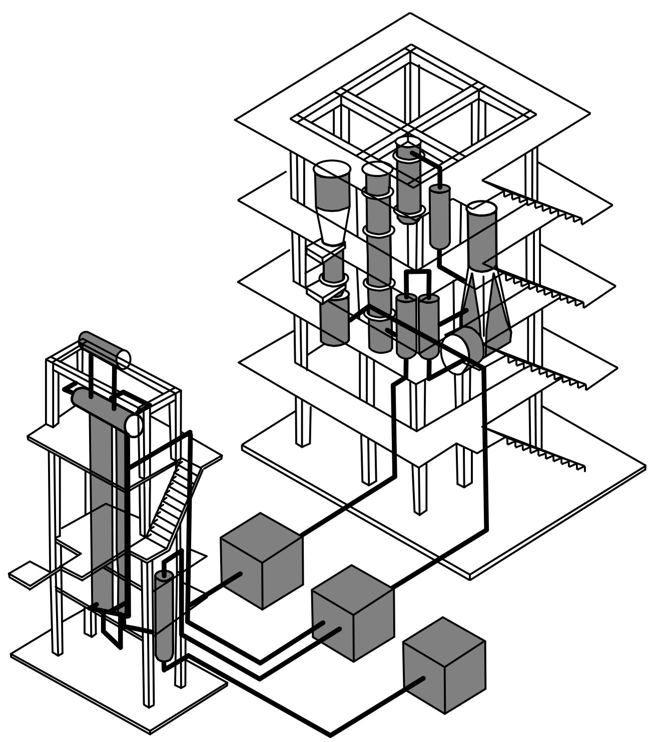

Figure 2. The Hynol facility with the methanol synthesis unit in the foreground, compressors in the middle, and the HPR/SPR/feed system in the background.

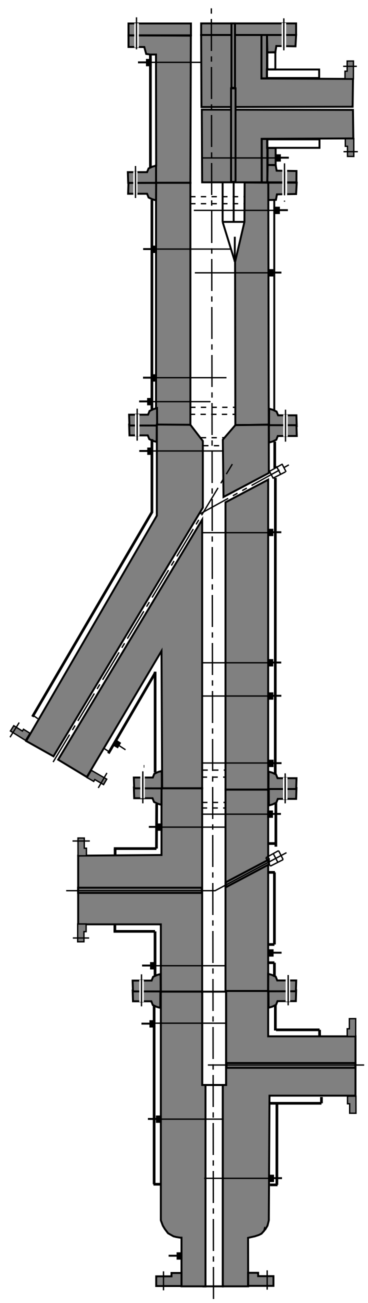

Figure 3. HPR Reactor vessel and insulation.

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***Robert H. Borgwardt** is the EPA Project Officer (see below).*
The complete report, entitled "Hynol Process Engineering: Process Configuration, Site Plan, and Equipment Design," (Order No. PB96-167549; Cost: $47.00, subject to change) will be available only from
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