BTL LABORATORY AT MID SWEDEN UNIVERSITY

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ABSTRACT: This paper presents the BTL (biomass to liquids) laboratory of MIUN (Mid Sweden University) for production of bio-automotive fuels through biomass gasification. The process is intended to be realized in laboratory scale at MIUN with focus on key issues in the BTL technology development. Thus, the BTL laboratory becomes a resource for BTL education, research and development. The BTL laboratory is based on indirect gasification and the gasifier is a combination of a BFB steam gasifier and a CFB combustion riser. The biomass feeding system is unique in application. The syngas is automatically sampled and analyzed on-line on demand. Considering small & medium scale bio-automotive fuel plant, an oxygen plant would be too expensive to be integrated in BTL systems. An indirect gasifier is thus the choice for development to obtain a good quality high energy content synthesis gas. Based on calculation work performed by TPS, the most energy effective gasification technique is indirectly fluidized bed gasification with steam as the gasification agent. Integration of the gasifier and FT/DME/EtOH-reactors will be emphasized and a theoretic BTL model will be developed. The plan is to develop an effective and a reliable BTL technology under 100 MW possible for bio refinery integration.

Keywords: bio-based products, bio-syngas, gasification

1 INTRODUCTION

A BTL (biomass to liquids) laboratory for production of bio-automotive fuels through biomass gasification is built up at MIUN (Mid Sweden University) in Härnösand, Sweden. This paper presents the BTL laboratory of the present state.

The synthetic bio-automotive fuels (e.g. FT-fuels (Fischer-Tropsch), DME and alcohol fuels) as the second generation bio-automotive fuels become more and more attractive over the first generation bio-automotive fuels such as bioethanol and biodiesel from food and oil crops, which already exist in the market. This can be attributed to the effectiveness of GHG reduction, and the utilization of huge potential agricultural and forest biomass as well as various residues.

Bio-automotive fuels such as FT-diesel is refined and upgraded from waxes and paraffin that are synthesized from synthesis gas by a catalytic process. The synthesis gas can be produced from natural gas, coal and biomass etc via several steps of feedstock preparation (drying and grinding), gasification, gas cleaning and conditioning to achieve high quality synthesis gas. The synthesis technologies so-called GTL (gas to liquid) and CTL (coal to liquid) are well established based on fossil fuels, which have been realized in large scales over 500 MW.

For biomass and wastes, however, the so-called BTL is under development. The biomass feedstock is widely sparse and has relatively low density, low heating value and high moisture content [1], which limit the size of bio-automotive fuel plants. An S&M (small or medium) scale biofuel plant close to the feedstock resources involves a smaller collection region of the biomass, and thus shorter transport distances. Furthermore, the waste heat from a S & M scale biofuel plant can be easily utilized by e.g. a district heating system.

Hence, 100 MW scale BTL technology seems promising for biomass, which requires simple, reliable and cost-effective production technologies.

Regarding S&M scale BTLs, there are a number of critical problems related to ash, alkali metals, sulfur, particle dust and tar. The problems related to ash (e.g. corrosion, slagging, fouling and bed material agglomeration) need to be solved in the gasifier. The synthesis gas cleaning and tar and methane reforming need to be studied in detail. As an example Taylor Biomass Energy, USA, cracks the tars within a gas conditioning reactor which connects the indirectly heated steam gasifier reactor and the combustor reactor. In the conditioning reactor the outgoing product gas contacts the reheated high temperature solids that are circulating from the combustor into the gasifier. The hydrogen content is simultaneously increasing by WGS (water gas shift) as the solids are a catalytic medium [2].

The lab-scale BTL laboratory provides useful tools for experimentally studying biomass thermo chemical conversion and catalytic process in the BTL research and development. The lab-scale can also generate inputs to mathematic modeling and scaling-up of BTL system.

2 FACILITIES OF THE BTL LABORATORY

The BTL system at MIUN is sketched in Fig. 1.
2.1 Biomass feeding system

The feeding system is an important part to the success of biomass gasifier operation. In the BTL laboratory, the feeding system (see Fig. 2) is custom-designed with respect to the gasifier.

A PLC (Process Logic Controller) operated feeding system is designed for constant biomass feeding. The normal feeding rate is 30 liters of biomass per minute. The standard feedstock is wood pellets from SCA BioNorr AB, Härnösand, Sweden – but other biomass fuels and fuel blending can also be fed easily. There are three feedstock storages (each 730 liters) and a blending storage of 300 liters. The biomass is fed into a pneumatic oscillatory vane feeder (unique for this purpose) to achieve high precision. In the feeder, air can be displaced by inert gas (N$_2$, Ar or H$_2$O) to avoid analysis disturbance due to air addition in the reactor.

A double screw feeder (a coaxial left- and right-handed thread) thereafter provides for a steady stream of biomass into the next screw feeder without plugging the pipe. This screw feeder is rapidly feeding biomass into the gasifier to avoid reaction in the screw feeder and particle congestion. The feeding rate can be controlled easily by frequency-controlled motors of screw feeder. Biomass is fed in the bed bottom to reduce the potential for the biomass to float on the bed surface.

Nearest to the gasifier the last screw feeder may be cooled or heated by water flow through a cylindrical jacket.

2.2 The gasifier

The BTL laboratory is based on indirect gasification. The gasifier (see Fig. 3) is a combination of an endothermal bubbling fluidized bed (BFB) steam gasifier and an exothermal circulating fluidized bed (CFB) combustion riser – so called dual fluidized bed (DFB) gasifier.

A number of DFB gasifiers have been built worldwide, Guessing gasifier in Austria by Hofbauer and his co-workers, in The Netherlands by ECN (Milenia), in Trisaia, Italy, by ENEA’s research center and in Ohio, USA, by the Battelle Columbus Laboratories (BCL) [4]. The most recently, in Gothenburg, Sweden, an DFB gasifier (2–4 MW$_{th}$) has been built by Göteborg Energi and Chalmers University of technology [3]. In Japan there is a DFB gasifier in Yokohama, by Xu et al. and in China there are some examples in Beijing by the Chinese Academy of Sciences, in Dalian by Xu et al. and in Hangzhou by Fang, Cen and co-workers [4]. The Taylor Gasifier, mentioned in the introduction, is another example of a DFB gasifier.

In the MIUN gasifier, the heat carrier between the reactors is silica sand or a catalytic material of about 150 µm diameter. The fluidization agent is added via own-produced sintered iron plates in the BFB, the CFB and the upper pressure lock. The BFB and the CFB have a height of 2.5 and 3.1 m respectively, and diameters (Di) of 300 and 90 mm. The gasifier is manufactured with 6 mm thick high-temperature steel identified as “Outokumpu 4845” (alternatively “EN 1.48.45” or “ASTM 310S”) for use at up to 1100 °C by loose flange. Bolts and nuts are made in acid proof steel. The steam gasifier is surrounded by electrical heater. There are no lining in the reactors. Starting fuel can be used for the combustion riser.

The gasifier has a biomass treatment capacity of 150 kW, i.e. approx. 30 kg wood pellets feed per hour, which leads to 30 m$^3$/h synthesis gas. The BFB is operated at approx. 850°C. The fluidization agent is steam and the synthesis gas is drawn of from the top of the gasifier. Some of the syngas can be recycled.

The residual biomass char is then transferred by bed material into the CFB through the lower pressure lock (v-valve). The bed material circulating rate is controlled by the pressure drop over the two bed bottoms.

In the CFB the fluidization agent is air, which results in an oxidation of the char and produces heat at a temperature of 950-1050°C. The hot bed material separates from the flue gas in a cyclone to be recycled.
into the BFB through the upper pressure lock (seal pot), which prevents gas leakage between the separate environments in the BFB (reducing) and in the CFB (oxidizing). A differential pressure of 2 kPa between the reactors is noted. The fluidization agent in the upper pressure lock is steam or recycled syngas. The circulating rate of bed material needs to be 20 to 30 times the mass flow of biomass for sufficient heat supply to the biomass gasification. This has been achieved by a wide margin.

2.3 Syngas treatment

A minor stream of the syngas is auto sampled and analyzed in on-line GC-system with FID and TCD detection in a sequence. The light tars are analysed in a GC with FID detection according to the SPA (Solid-Phase Adsorption) method. The heavy tars are analysed according to a new method developed by KTH (Royal Institute of Technology) Stockholm, Sweden.

To avoid condensation in the pipes, electrical heaters preserve a temperature that keeps the tars volatile. The heaters are controlled by a regulator (Advanced Temperature/Process Controller & Programmer model 3504) by Eurotherm.

Equipment for clean-up processes and FT/DME/EtOH-reactors will be installed according to the plan described in Section 5.2. At the present situation the syngas is led to a combustion laboratory unit. A heat balance can be calculated by measure the flow and differential temperature of the inlet and outlet cooling water of the unit. Furthermore the residual oxygen in the syngas can be measured for additional calculations.

2.4 Auxiliary equipments

An electrical steam generator, Zeta Ånggenerator 1978, provides the gasifier with steam of approx. 12 bar and 150 °C through insulated pipes. Air (6 bar and 25 °C) is provided by a screw compressor, Atlas Copco.

The cooling water for the system is supplied via a closed loop cooled in a 450 m³ water tank. Alternatively the cooling water is supplied via percolation by municipal water.

3 INSTRUMENTATION

There are about 30 measurement points in the system to register the flow-, pressure- and temperature. A load cell situated on the biomass storage makes it possible to measure the amount of biomass fed into the gasifier.

3.1 The fuel feeding system control

The PLC (Process Logic Controller) system MELSEC FXos30MR-ES, Mitsubishi Electric provides constant biomass feeding and accurate control of the feed rate, and hence a uniform gasifier operation.

3.2 Electrical heater

The electrical heater to the steam gasifier has a total effect of 20 kW, consists of two heating modules that surround the gasifier with two heating elements each, manufactured by Kanthal AB. The heating modules are placed in height and constitute two regulating ranges at heating.

A feedback value, i.e. the temperature measured at 330 mm respectively 555 mm above the bottom plate, from each regulating range sends to a regulator (Advanced Process Controller/Programmer model 2704) that controls two thyristors (Single Phase Solid State Contactor model 7100L). Each regulating range has one thyristor and an actual value. The software iTools render graphical configuration possible. The thyristors, regulator and the software are manufactured by Eurotherm.

3.3 Flow measurement

The mass flow rate of the steam into the gasifier is measured by a Rosemount 3051SMX MultiVariable mass flow transmitter. The flow rate of the steam into the upper pressure lock is measured by a Rosemount 3051SFP scalable pressure transmitter. Each transmitter has a Rosemount 1195 integral orifice. The flow rate of the air into the combustor riser is measured by a Rosemount 3051SFP scalable pressure transmitter with a Rosemount 1195 integral orifice.

The mass flow rate of the syngas after the gasifier at about 400°C and the flue gas at 180°C are measured by Coriolis meters by Micro Motion, Inc. Boulder CO, USA, model respectively F050A (high temperature sensor model) and CMF100M. The Coriolis meters measure the mass flow of the gas independent of its contents.

3.4 Pressure measurement

Differential pressure measurements are performed in several steps from the bed bottom to the top of the BFB and the CFB, between the BFB and the upper pressure lock and between the upper pressure lock and the cyclone. The measurement ranges of the employed transmitters are 0-100 Pa alt. 0-250 Pa, 0-500 Pa, 0-1 500 Pa alt. 0-2500 Pa alt. 0-5000 Pa. The differential pressure transmitters are manufactured by HK INSTRUMENTS ltd. Purge gas is used to avoid plugging of the pressure taps.

3.5 Temperature measurement

In the present time, temperatures are measured at 22 points using thermocouples. Similar to the differential pressure measurements, the temperature measurements are allocated at points from the bed to the top of the BFB and the CFB, at the upper pressure lock and at the cyclone. In addition to these points are the temperatures measured at the flue gas pipe and at the flue gas cooling system.

Some of the thermocouples are sheathed transmitters TM1 type K, and the rest of them are BM type K. The thermocouples are manufactured by Danelko.

3.6 The data collection system

The data collection system consists of a data logger (that saves the latest 800 000 data points) and the software Busmanager, EasyView 5 Pro and an OPC server. The data logger is a TopMessage basic device with a TopMessage extension device equipped with two modules each: one ADIT module and three ADVT modules. The ADIT module has 10 analog channels inputs (Volt/mVolts, 20mA, Pt 100, thermocouples), one analog channel outputs (20mA) and one switching outputs with the sampling rate 800 Hz/module. The ADVT modules have 15 analog inputs (Volt/mVolts, 20 mA, thermocouples) with the sampling rate 800 Hz/module.
4 DEVELOPMENT WORK

Direct gasification with air produces a fuel gas of heating value 4-7 MJ/m$^3$ – not suitable for synthesis of transportation fuels. Pure oxygen gasification generates a fuel heating value of 10-12 MJ/m$^3$ which is used for fossil fuel-based liquid fuel production. However, an oxygen plant could be too expensive for plant size smaller than 100 MW [5]. The gasifier has to be as simple as possible but still be able to generate high quality syngas with high energy content (a low content of N$_2$).

12-20 MJ/Nm$^3$ heating value syngas can be provided by indirect gasification with steam [5] Based on an extensive calculation work performed by TPS, commissioned by MIUN, the most energy effective gasification technique turned out to be an indirectly fluidized bed gasification with steam as the gasification agent. Other indirect gasification techniques e.g. heat exchanging by tubes, and high temperature steam as gasification agent resulted in a lower efficiency. Furthermore, a fluidized bed is very flexible regarding varying feedstock quality, contents of ashes and moisture content. The heat and mass transfer is high, and the bed material renders catalyst (e.g. Fe or Ni) blending possible.

The gasifier has been designed by Wennan Zhang and Ulf Söderlind at MIUN. The unique design of the gasifier is an in-built tar catalytic reformer that will be studied intensively in the project for effect improvement and to optimize its design. A parallel development with CH$_4$ reforming will also be performed. Once tars are absent, other impurities in the syngas, such as NH$_3$, H$_2$S, COS, HCl, volatile metals, dust and soot, can be removed by standard wet gas cleaning technologies.

5 THE WORKING PLANS

The future work is to develop an effective and a reliable BTL technology (<100 MW), possible for bio refinery integration. The following working packages Feedstock flexibility, Gasification and reforming, FT/DME/EtOH synthesis and Modeling of BTL have been scheduled for the coming 3 years.

5.1 Feedstock flexibility

Various biomass feedstock will be tested in the combustor/gasifier. Biomass feedstock flexibility will be studied in detail, in connection to ash behavior and additive effect in order to solve problems such as corrosion, slagging, fouling, and bed material agglomeration. Furthermore co-combustion and gasification of biomass fuels with peat and coal etc. will be studied as well.

5.2 Gasification and reforming

The raw gasification gas, produced by many of the previous DFB biomass gasifiers, has high tar and low H$_2$ contents [4].

The objective of this working package is to develop a biomass gasifier that can produce clean and high CO+H$_2$ concentration (>80%) syngas – suitable for FT/DME/EtOH synthesis. Thus, tar and methane reforming need to be studied in detail.

Apart from the CO and the H$_2$ the syngas among others will contain CO$_2$, H$_2$O and N$_2$. CO$_2$ can be a carbon source for FT synthesis, H$_2$O can be removed through gas cooling and condensation and N$_2$ in the syngas is close to zero.

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5.3 FT/DME/EtOH synthesis

The integration of the gasifier and FT/DME/EtOH-reactors will be emphasized in this working package. By integrating the gasifier to FT/DME/EtOH synthesis reactors, a BTL laboratory scale will be realized. The FT-process will be optimised for wax production by a low temperature FT-synthesis via a fixed bed reactor containing catalyst (i.e. Fe or Co).

The synthesis reactor will be studied for the best fit in the gasification system. Furthermore, the whole BTL system will be investigated in a systematic and simultaneous way in order to find synergy effects for system optimization. Hence, a cost effective, reliable FT/DME/EtOH production system fueled with biomass will be the result.

5.4 Modeling of BTL

A theoretic BTL model will be developed – which can be applied for technical & economical analysis, BTL efficiency calculations and for support of optimal design, operation and up-scaling of BTL system. The analysis of the fuel production efficiency will be made to provide information how to improve the efficiency. To calculate the system efficiency an energy balance is needed over the whole system, where off gas can be used for electricity production and low grade heat from the system can be recovered as i.e. feedstock preheating and district heating integration. The project activity in the working packages is showed in Fig. 4.
6 CONCLUSION

A BTL laboratory has been built up at MIUN, which is directed to S&M scale bio-automotive fuel plants under 100 MW. The S&M scale plants are suitable for biomass resource and for easier integration in a bio refinery concept.

MIUN gasifier takes use of catalytic medium as heat carrier possible. Furthermore the improvement of the in-built tar catalytic reformer and the parallel development with CH$_4$ reforming make S & M scale biomass gasifiers possibly to produce clean and high CO+H$_2$ concentration syngas.

The lab-scale BTL laboratory provides useful tools for experimentally studying biomass thermo chemical conversion and catalytic process in the BTL research with focus on key issues in the BTL technology development. Furthermore the lab-scale also will generate inputs to mathematic modeling and scaling-up of BTL system.

7 REFERENCES