Development of Bio Jet Fuel Production System

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The use of carbon-neutral biomass energy for decarbonization is attracting more attention. In the aviation industry, introducing bio jet fuel is also considered essential for the reduction of greenhouse gas emissions from aviation fuel. Under such circumstances, Mitsubishi Power, Ltd. (Mitsubishi Power) succeeded in applying an integrated production system in which an entrained-bed biomass gasifier is combined with FT synthesis to produce bio jet fuel using woody biomass in a stable manner in this research and development. The effectiveness of the system was also verified.

1. Introduction

The aviation industry, from which demand is expected to rise in the years to come, is facing a pressing challenge to reduce carbon dioxide emissions in order to mitigate global warming. The International Civil Aviation Organization (ICAO) set a long-term goal for curbing carbon dioxide emissions (i.e., no increase in emissions after 2021), assuming the promotion of introducing bio jet fuel to be vital to fulfilling this goal. In Japan, alternative aviation fuel is mentioned one of the 14 key areas in the “Green Growth Strategy” for a carbon-neutral society, and extensive application of bio jet fuel is shown to aim at popularization.

2. Development of the bio jet fuel production process

Regarding bio jet fuels, some of the production systems from modified biological oils and fats have already been implemented commercially, while the production systems for those deriving from algae or through gasification and Fischer-Tropsch (FT) synthesis are currently under development.

Of these, the production of bio jet fuel using gasification and FT synthesis is easy to scale up and is therefore considered promising as a production system enabling supply in quantities large enough to handle increasing demand. **Figure 1** is a simplified flow diagram of the gasification and FT synthesis process.

Figure 2 shows a bio jet fuel production process with gasification and FT synthesis. After being pulverized, woody biomass is fed into the gasifier. This is followed by the production of syngas consisting mainly of hydrogen (H_2) and carbon monoxide (CO), which will be the feedstock for FT synthesis. Firstly, the syngas, which is at normal pressure, is pressurized by the compressor so that the partial pressures of these gases in the syngas are elevated to facilitate the FT synthesis reactions. The next step is to remove poisons for FT synthesis catalyst in the syngas. After that, syngas is fed into the FT synthesis process and hydrogen is added to these produced hydrocarbons to have an appropriate carbon number. After the distillation process, jet fuel and light oils such as diesel and naphtha are produced.

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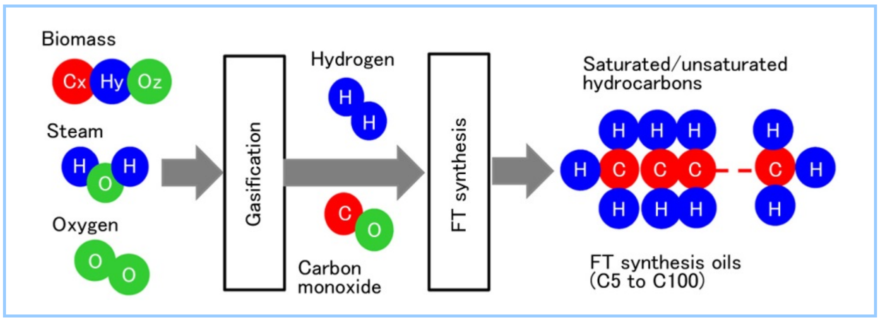

Figure 1 Simplified flow diagram of gasification and FT synthesis process

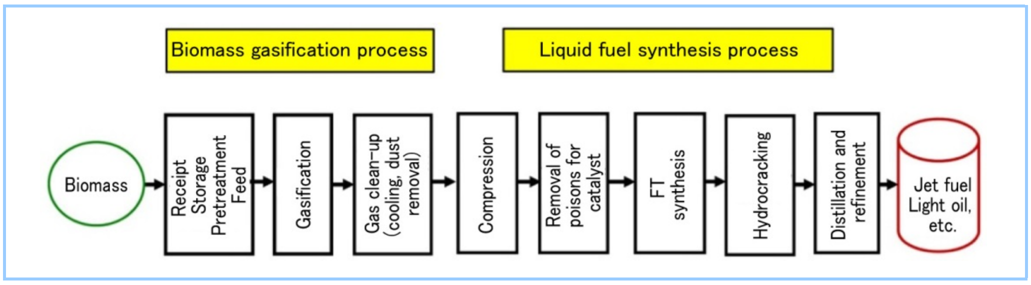

Figure 2 Bio jet fuel production process

2.1 Development of biomass gasifier

Having considered from early on that environmentally-friendly and clean biomass energy is important to reduce greenhouse gas emissions, we have worked on the development of gasification technology—the key thermochemical conversion process for biomass—since the late 1990s.

Employed in the gasification process is an entrained bed gasifier, which is suitable for bio fuel synthesis because its high-temperature gasification can produce less tar and the gasification in a short time allows the gasifier to be relatively compact and easy to scale up.

In conventional entrained-bed gasifiers, biomass needed to be pulverized finely and uniformly before feeding. Such uniform pulverizing, however, requires a significant amount of pulverizing power. As shown in **Figure 3**, we have resolved this matter by changing the contours of the gasifier gradually from the bottom to the top in such a way that the ascending gas velocity (superficial velocity) in the gasifier becomes high at the lower part and low at the upper part.

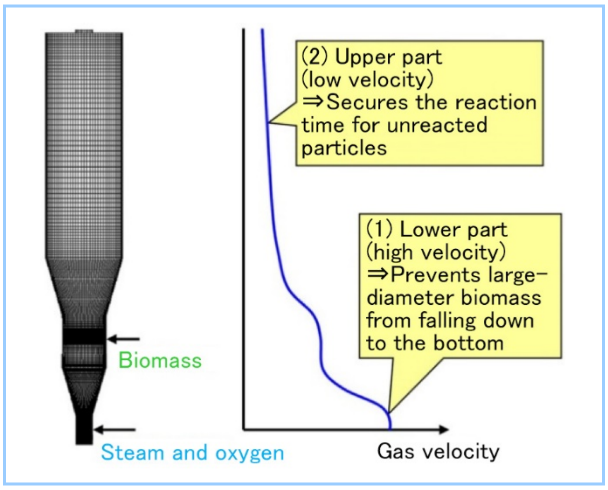

Figure 3 Entrained-bed gasifier structure

As characteristically shown by the computational fluid dynamics (CFD) analysis in **Figure 4**, the high gas velocity at the lower part of the gasifier prevents large-diameter particles from falling down to the bottom, while the low velocity at the upper part of the gasifier allows only small particles to move with gas flow. Thus, feedstocks requiring longer reaction times such as large particles will be circulated inside the gasifier and therefore be kept therein until their reactions are completed, before eventually being discharged as sufficiently small particles. A high carbon conversion rate is therefore achievable despite biomass feedstocks having diverse properties. Even biomass containing large-diameter particles with a broad particle size distribution can be fed into the entrained-bed gasifier, making more varied types of biomass applicable.

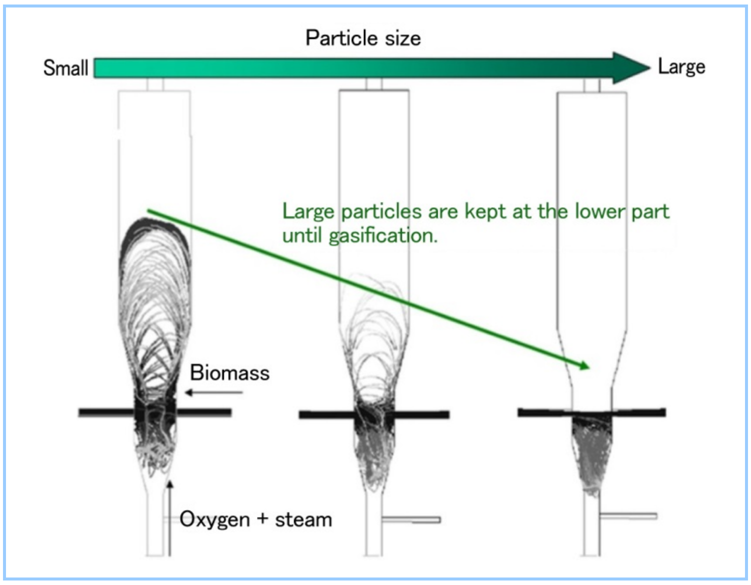

Figure 4 Biomass particle behavior inside a gasifier

2.2 Lab-scale testing for integrated production process of biomass gasification and FT synthesis

To demonstrate the concept of the gasifier referred to in the previous section and verify the liquid fuel production process in which gasification is combined with FT synthesis, we carried out lab-scale testing for the integrated process of biomass gasification and FT synthesis.

In this study, which was jointly conducted with the University of Toyama, the test facility used (**Figure 5**) was installed on the premises of MHI's Research & Innovation Center (Nagasaki District). It is the integrated test facility which is a biomass gasification facility designed with the aforementioned concept, coupled with FT synthesis facility. The test was conducted a total of four times mainly using woody biomass.

The results show that a high carbon conversion rate of 95% or higher can be achieved regardless of the type of feedstock or gasifier operation conditions (O_2/C). It is considered that the structure of our gasifier has secured an appropriate retention time (reaction time). The gasification and FT synthesis processes were operated in a combined manner for about 100 hours using actual gas, which indicates the successful demonstration of producing FT crude oil from biomass.

The results of this study were obtained from the FY 2012-2015 project (JPNP14025) commissioned by the New Energy and Industrial Technology Development Organization (NEDO).

Figure 5 Biomass gasification and FT synthesis integration test facility

2.3 Pilot-scale testing for integrated production process of biomass gasification and FT synthesis

In recent years of increasing global expectations for market creation and the extensive introduction of bio jet fuels, it is indispensable to develop a low-cost production system that satisfies standards such as lifecycle assessment criteria (fossil energy balance of production) and carbon dioxide emission reduction rates to face these newly created markets head on.

Under these circumstances, we carried out pilot-scale testing of the integrated bio jet fuel production process as a joint research project with JERA Co., Inc., Toyo Engineering Corporation, and Japan Aerospace Exploration Agency (JAXA) between FY 2017 and 2020. Our goal is to make the practical application of bio jet fuel viable by around 2030.

In this test, we built a pilot-scale testing facility for integrated production in which a partial oxidation-type entrained bed gasifier suitable for scaling up is combined with a microchannel FT synthesis system with a reactor which a size that can be made considerably compact (biomass feedstock processing capacity of 0.7 tons per day, and pure bio jet fuel production of approximately 20 liters per day). Through the demonstration operation, the verification of the production system was evaluated. Regarding the product fuel, the performance was assessed by conducting a combustion test with an actual engine.

(1) The pilot plant has a gasifier with a processing capacity of 0.7 tons per day and a syngas production of approximately 1000 Nm^3 per day. For lab-scale testing mentioned above, pilot-scale testing focuses on confirming the viability of scale up and long hours of operation. Wood chips (pulverized woody biomass before pelletizing) were used as biomass feedstock. The amount of jet fuel produced by FT synthesis after distillation is estimated to be 27 liters per day, and co-products such as diesel and naphtha are also produced.

(2) The pilot plant was built on the premises of JERA's Shin-Nagoya Thermal Power Station in Nagoya City, Japan. Construction was started in December 2018 and the facility installations took place from April 2019. After the trial operation in September 2019, the demonstration operation was completed in November 2020. In March 2021, the pilot plant was demolished and removed completely. **Figure 6** shows the pilot plant at the completion of construction, while **Figure 7** is a photograph of the biomass gasification facility.

(3) Having started with the test-operation of the gasification facility, which was installed before the others, we injected the first biomass feedstock in November 2019 to start gasification operation. Entering 2020, a combined test operation of the gasification facility and FT synthesis facility was executed. In June 2020, our first reformate was produced. Jet oil distillate was extracted from this reformate and was analyzed according to ASTM. The analysis results confirmed that all the quality requirements were satisfied. We thus succeeded in producing bio jet fuel. In July 2020, the demonstration operation was started. By the time of completing the demonstration operation in November FY 2020, the gasification facility achieved a total of 3079 hours of operation including about 33 days of continuous operation, while the FT synthesis facility achieved a total of 1543 hours of operation including about 30 days of continuous operation. The production of bio jet fuel amounted to 2366 liters, which considerably exceeds the target level (**Figure 8**).

(4) Test biomass feedstock used was wood chips of three tree types, four production areas and two neighboring suppliers (**Figure 9**). According to the elemental analysis results, the main components are almost identical to common woody biomass, although the fluidity and transport characteristic differ because of the influence of shape and particle size distribution.

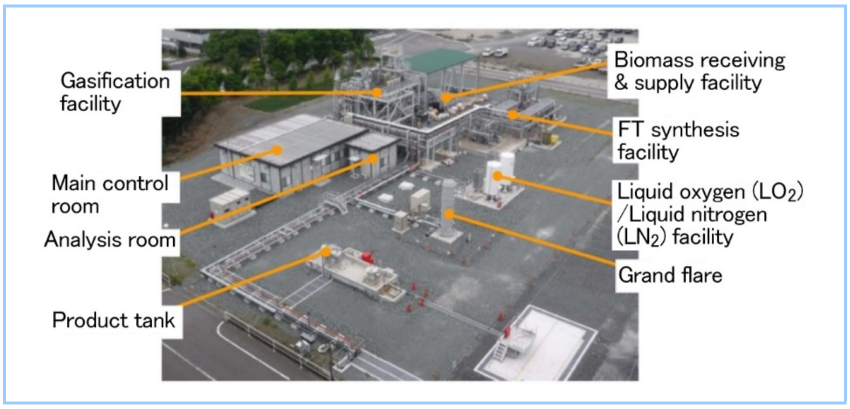

Figure 6 Full view of the pilot plant

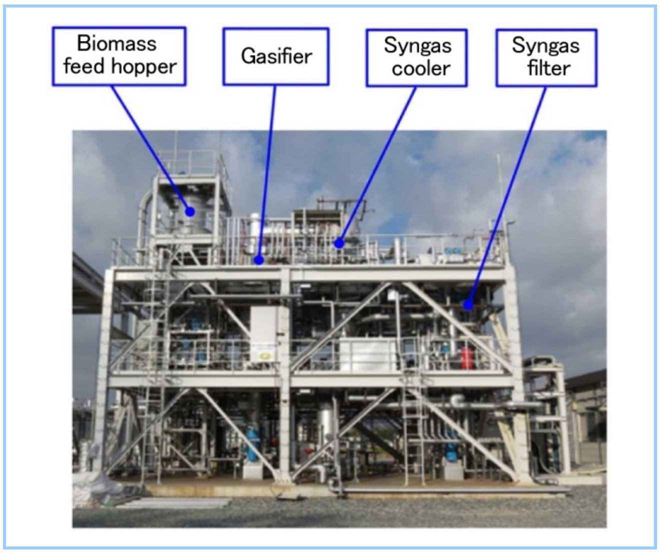

Figure 7　Biomass gasification facility

Figure 8　Bio jet fuel

Sawdust feedstock (producing area)	Cedar, pine, cypress (Gifu)	Pine (Hokkaido, Russia)	Cedar (Ishikawa)
Appearance			

Figure 9　Test biomass

(5) The results of this study are summarized as below:
- The feasibility and usability of jet fuel production by a combined process of biomass gasification and FT synthesis were successfully demonstrated.
- The gasification performance was verified to be as good as expected in terms of both the cold gas efficiency and the carbon conversion rate, thus confirming the validity of facility design. Regarding syngas composition, it was confirmed that an appropriate H2/CO molar ratio for FT synthesis can be adjusted and maintained in a stable manner by regulating the operation parameters, whereby the advantage of using an entrained bed gasifier was demonstrated.
- Regarding FT synthesis, the results were also as good as or better than expected. It was confirmed that jet distillates from all the production batches satisfied the ASTM D7566 standards.

- For the combined operation of gasification and FT synthesis, we achieved an operation record of more than 1 500 hours including 30 days of continuous operation. Through this experience, we have obtained extremely valuable knowledge to make future practical application successful.
- The results of this study were obtained from the FY 2017-2020 project (JPNP17005) commissioned by NEDO.

3. Conclusion

As a production system enabling the commercialization of bio jet fuel around 2030 under the circumstances mentioned at the beginning of this report, we carried out pilot-scale testing for the integrated production process. This pilot-scale testing also included identifying the challenges for the realization of highly-efficient industrialization and assessing their possible countermeasures. We examined the viability of stable, long-term continuous operation, production cost reduction, and other aspects.

We hope that the development of this system will facilitate the introduction of bio jet fuel and the effective utilization of biomass resources, and contribute to reducing greenhouse gas emissions in Japan.

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