A Unique Gasification Technology
towards Commercialization of the Plant:
“Norin Green No. 1” and “Norin Biomass No. 3”

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(Received November 15, 2016)

A gasification technology, that utilizes partial oxidation (using O₂ and H₂O as gasifying agents) and implementation of a new high calorie gasification (using only H₂O as a gasifying agent) technology, has been developed and focuses on perfect gasification of various biomass feedstocks at 900-1,000 °C with less production of soot or tar. The result of this technology is the production of a superior mixture of biogases for producing liquid biofuels through a synthetic reaction with Zn/Cu-based catalyst; or the generation of electricity through a generator. The first test plant, named “Norin Green No. 1”, began operation on April 18, 2002. A second plant named “Norin Biomass No. 3” having a new high calorie gasification technology, began operation on March in 2004. In 2009, with the support of Ministry of Agriculture, Forestry and Fisheries (MAFF), a large commercial plant was established in Nagasaki to utilize discarded woods for potentially capable of producing biomethanol (100 L/hr). The future of these technologies and the practical plants, production and utilization of the mixture of gases from the technologies within these plants is discussed.

Key Words
Partial oxidization, High calorie gasification, Gasifying agent

1. Introduction
About 13 billion tons of fossil fuels (oil equivalent) are consumed in the world in 2015 1) and these fuels influence the production of acid rain, photochemical smog, and the increase of atmospheric carbon dioxide (CO₂). Researchers warn that the rise in the earth's temperature resulting from increasing atmospheric concentrations of CO₂ is likely to be at least 1% and perhaps as much as 4% if the CO₂ concentration doubles from pre-industrial levels during the 21st century 2). To address these issues, we need to identify alternative fuel resources.

Stabilizing the earth's climate depends on reducing CO₂ emissions by shifting from fossil fuels to the direct or indirect use of solar energy. Among the latter, utilization of biofuel is most beneficial 3). Utilization of biomass to date has been very limited and has primarily included burning wood and the production of bioethanol from sugarcane in Brazil, maize in the U.S.A., or biodiesel from oil crops mainly in the

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EU countries. Since these crops for bioethanol and biodiesel oil production are primary sources of human nutrition, we cannot use them indiscriminately for biofuel production. Although bioethanol production through fermentation of lignocellulosic materials are being attempted by improving pre-treatment of the materials, yeast and enzymes, establishment of the technology with low cost and high ethanol yield will be required. At the end of the last century, a new method of gasification by partial oxidation and production of biomethanol from carbohydrate resources had been developed. This gasification process enables any source of biomass to be used as a raw material for methanol production.

In this report, we discuss the estimated gas mixture and methanol yield using this new technology for biofuel production from gasification of biomass resources. Contents and higher heating values of gasified gas generated by our new technology are discussed and the commercial operation of the plant is introduced.

2. A new gasification technology and the test plants

Our methods of gasification through partial oxidation and implementation of a new high calorie gasification technology, have been developed focusing on the perfect gasification at 900 - 1,000 °C without the production of soot and tar. The result of these technologies is the production of a mixture of biogases for producing liquid biofuels or electricity. The “Norin Green No. 1; Fig. 1 (later renamed as the “Norin Biomass No. 1”) began operation in 2002 and the “Norin Biomass No. 3” in 2004. In this gasification process, the biomass feedstocks must be dried and crushed into powder (ca. 1 - 3 mm in diameter). When the crushed biomass feedstocks are gasified at 900-1000 °C with steam (H2O) and oxygen (O2) as gasifying agent, all carbohydrates are transformed to hydrogen (H2), carbon monoxide (CO), carbon dioxide (CO2) and vapor (H2O). The mixture of gases is readily utilized for generating heat or electricity and is transformed by thermo-chemical reaction to biomethanol under pressure (40-80 atm) with Cu/Zn-based catalyst, too. That is,

\[ \text{CO} + 2\text{H}_2 \rightleftharpoons \text{CH}_3\text{OH} + \text{Q (Radiation of heat)} \]  \hspace{1cm} (1)

\[ \text{CO}_2 + 3\text{H}_2 \rightleftharpoons \text{CH}_3\text{OH} + \text{H}_2\text{O} + \text{Q (Radiation of heat)} \]  \hspace{1cm} (2)

This process enables any source of biomass to be used as a raw material for methanol production.

2.1 “Norin Green No. 1” test plant

The “Norin Green No. 1” (Fig. 1) comprises a supplier of crushed biomass, a gasifier, and an apparatus for gas purification and methanol synthesis. The practical methanol yield of crushed waste wood (ca. 1 mm in diameter) was measured by operating both the “Norin Green No. 1” test plant with a gasifier capacity of 240 kg dry biomass/day and another test plant with a gasifier capacity of 2 t dry biomass/day.

Table 1 indicates the heat yield (percentage of heat value of gas mixture to that of raw material) and methanol yield (Percentage of weight of methanol to that of raw material) of the two test plants with different gasifier size, that is 240 kg/day of dry biomass (the “Norin Green No. 1”) or 2 t/day (a plant constructed by Chubu Electric Power Co., Inc.) by operating these plants. The values of a hypothetical commercial scale plant (a gasifier capable of processing 100 t/day of dry biomass) was estimated from these operational data. The commercial scale plant is large enough to maintain a critical temperature (900 to 1,000 °C) within the gasifier by adding the raw materials for supplemental heat. Our data indicate that the estimated heat yield of methanol production by commercial scale plants is 54 - 59%. However, the real heat yield of a commercial scale plant after reducing the energy needed for crushing of the biomass feedstocks (1.0 - 5.0% of the quantity of heat), operation of the plant (5 - 10%), and heat loss from the surface of the gasifier (1-2%), estimated by simulation using the test plant data will be ca. 40%.

2.2 “Norin Biomass No. 3” test plant

The “Norin Biomass No. 3” test plant (Fig. 2), which represents a “Suspension/ external heating type” with a

Table 1

| Item                      | Test Plant (240 kg/d) | Practical PL (100 t/d) |
|---------------------------|-----------------------|------------------------|
| Heat Yield (High Heat Value %) | 60-70%                | 65%                    |
| Methanol Yield (by weight) | 9-13%                 | 20%                    | 40-50%                |

Fig. 1 “Norin Green No. 1” Test Plant located in Nagasaki Res. & Dev. Ctr., Mitsubishi Heavy Industries Ltd, Nagasaki, Japan
A gasifier (1-2 Dry t/day) was developed for improving the disadvantages associated with the “Norin Green No. 1” test plant through the introduction of a new type of gasification called “high-calorie gasification reaction”.

In this gasification method, finely crushed biomass of 1-3 mm in diameter is subjected to the gasification reaction together with steam in an atmosphere of 800 – 1000 °C within the reaction tube (a blue tube of left structure and right of Fig. 2). At this time, the reaction tube is heated using a high-temperature combustion gas that is separately combusted using additional rough biomass feedstocks (inside a brown structure (left) of Fig. 2). The introduced biomass raw materials leave only ash, and all organic content is gasified without soot or tar, resulting in a clean, high-calorie gas (approximately 14 - 18 MJ/Nm³) (Fig. 3).

The gas composition varies with gasification reaction conditions such as reaction temperature, residence time (reaction time), and the [steam]/[biomass carbon] mode ratio, but an example is represented by the following reaction formula.

\[
\text{(Endothermic reaction)} \quad C_{1.3}H_2O_{0.9} + 0.4H_2O \quad \text{(Biomass)} \quad (\text{Steam}) \\
\rightarrow 0.8H_2 + 0.7CO + 0.3CH_4 + 0.3CO_2 + 165.9 \text{kJ/mol} \quad (3) \\
\text{(Resulting gas fuel)} \quad (\text{Absorbed heat})
\]

In this process, the total biomass material reacts with steam and is converted to a gas mixture of H₂, CO, CH₄, C₂H₆, and CO₂. The application of external heat is required because the gasification reaction is endothermic. However, the potential heat stored in the gas mixture generated in this reaction is greater than that contained in the raw biomass material, such that the cold gas efficiency (Ec) surpasses 100%. The Ec (η (%)) was calculated as the following formula.

\[
\eta(\%) = \frac{GH}{(GB + HB)} \times 100 \quad (4)
\]

GH (MJ/hr): Low heating value (LHV) of generated gas at normal temperature (MJ/Nm³) × Total amount of generated gas (Nm³/hr)

![Fig. 2 Suspension/external heating type high-calorie gasification of the “Norin Biomass No. 3” test plant](image)

![Fig. 3 Composition (dry Volume %: below) and higher heating value (MJ/Nm³: below) of high calorie gasification gas (No. 3) with different temperature, partial oxidation (No. 1) and conventional gasification gas (CG). No. 1: “Norin Green No. 1”: gasification by partial oxidation using O₂ and H₂O as gasifying agents; No. 3: “Norin Biomass No. 3”: high calorie gasification using only H₂O as a gasifying agent at 800, 900, and 1000 °C; CG: Conventional gasification using air as a gasifying agent](image)
GB (MJ/hr): LHV of Gasifying feedstocks (MJ/kg) ×

Amount of supply (kg/hr)

HB (MJ/hr): LHV of biomass feedstocks for heating reaction tube (MJ/kg) × Amount of supply (kg/hr)

In the formula (3) shown above, a figure of approximately 115% is obtained by solving for Ec. On the other hand, the externally supplied heat used in the reaction, is not considered in the calculation of Ec, and the total gasification efficiency is about 85% when this external heat is taken into account.

While the gasification technology of the “Norin Green No. 1” test plant uses the partial oxidation technology, this high-calorie gasification technology enables the production of a high-calorie gas fuel that was not possible with the conventional method due to the formation of an exhaust gas.

According to the results obtained by the operation, it has been confirmed that the output gas mixture possesses the properties indicated in Fig. 3. Conventional gasification technology that uses atmospheric air containing ca. 80% of nitrogen (N₂) generates ca. 70% of N₂, each less than 10% of H₂, CO, CH₃, C₂H₆, and H₂O. As a result, its high heating value is only ca. 5 MJ/Nm³. The “Norin Green No. 1” technology, that uses steam and oxygen as gasifying agents, generated gas mixture is very pure H₂, CO, CO₂ and H₂O and the heating value is doubled to that of conventional gasification technology and ca. 10 MJ/Nm³. While, the high-calorie gas featuring 15-18 MJ/Nm³, that could not be achieved by gasification by the “Norin Green No. 1” test plant through partial oxidation can be produced when the reaction temperature is 800-900 °C, H₂O/C mole ratio is lower than 5.0, and the reaction time is approximately 2 seconds. In addition, this gas mixture contains over 20% hydrogen (H₂). This value is higher than the threshold value of 10% for applicability in terms of ignition and combustion rate for gas engines and micro gas turbines, which indicate that the gas mixture is a high-quality gas fuel. In addition, if the compositional ratio of H₂ to CO is higher, the threshold combustion temperature is 90 °C higher than that of methane.

As the gas mixture generated with the “Norin Green No. 1” and high-calorie gas produced with the “Norin Biomass No. 3” using the high calorie gasification technology is temporarily stored in a cold gas state, it can be used in a manner similar to natural or city gas, with widespread applications. Since the “Norin Biomass No. 3”, which efficiently converts biomass into high calorie gas mixture with a small system, can be easily used as a fuel for gas engines and micro gas turbines, it can also be used for small-scale power generation and co-generation.

Accordingly, high-efficiency and small-scale power generation can be achieved.

One “Norin Biomass No. 3” plant processing 4-6 dry t/day of biomass feedstocks (mainly by using demolished woods) for potentially capable of producing biomethanol (100 L/hr) and generating electricity (250 kW) for 8,000 hr/year (in 330-340 days) was constructed in Nishiumi-cho, Nagasaki-city, Nagasaki, Japan by CHUO-KANKYO Inc. in 2009 (Fig. 4). Furthermore, the other 7 smaller plants have been constructed all over Japan by Biomass Energy Corporation (BME).

The “BME-100” was constructed in Singapore for generating 100 kW of electricity by gas engine power generation by the Asia Biomass that is a subsidiary of Biomass Energy Corp Japan in 2015. This plant was designed based on the technology of “Norin Biomass No. 3”. Following totally 2,000 hours of the trial runs (1,000 hours, 300 hours and 700 hours continuous operations), an actual demonstration will be initiated in September, 2016.

![Fig. 4 The "Norin Biomass No. 3" Plant constructed in Nagasaki, Nagasaki (Curtesy of CHUO-KANKYO Inc.). Conveyor of raw materials, gasifier and gas holder (top); Methanol reactor and operation room (below)
3. Conclusion

This study demonstrates that the unique gasification of readily available biomass materials both by partial oxidation technology and by high calorie gasification technology could be optimized for generation of gas mixtures primarily composed of H₂, CO and producing methanol yields ranging theoretically from ca. 40 to 60% by dry weight. This creates an opportunity to utilize a wide range of high yielding grasses such as Erianthus and Miscanthus. Lignocellulosic byproducts such as sawdust, straw and husk of rice would also have suitable application. Sawdust, refuse of sugarcane mills and rice husks are particularly attractive and provide a ready-to-use biofuel resource in Asian countries as well as in Japan. It is anticipated that the cultivation and utilization of biomass crops will be attractive as carbon neutral biomass feedstocks for biofuel production in the future. Japanese energy policy was dramatically changed from biofuel production for automobile to electricity and heat generation in Japan after 3.11 following the East Japan Earth Quake and an accident of Fukushima Daiichi Nuclear Reactors, because approximately 30% of electricity in Japan was provided by the 50 nuclear power plants prior to 2011. 3.11.

The potentially positive economic impact of biomethanol production on Japanese farming and social systems from planting grasses and trees in under-utilized land is immense 3). Reduced CO₂ emissions, recycling of abandoned upland and paddy field and woodland in mountainous areas, and recycling of wastes of agricultural products would all be possible by promoting an electricity generation and biofuel production system based on our gasification technologies. Our technology is particularly attractive in Asian countries since electricity can be generated by gas engine power generation from a wide range of biomass raw materials, as well as biomethanol production.

Acknowledgment

Authors would like to express their sincere thanks to Dr. Bryan Kindiger, USDA-ARS, Grazinglands Research Laboratory for his critical reading of the manuscript. Authors also would like to express their thanks to CHUOKANKYO Inc., Biomass Energy Corporation and Asia Biomass for providing us the photos and operation data.

These studies were mainly supported by grants from Ministry of Agriculture, Forestry and Fisheries (MAFF) of Japan, named “Development of sustainable ecosystem for primary industries towards the 21st century” (2000-2002), “Bio-recycle of wastes from agriculture, forestry, and fisheries” (2003-2005), and “Rural Biomass Research Project. BEC (Biomass Ethanol Conversion)” (2006-2010).

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