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Enhanced electricity production from rice straw

Arif Darmawan[a,b,*], Anggoro Cahyo Fitrianto[a,c], Muhammad Aziz[d], Koji Tokimatsu[a]

[a]*Department of Transdisciplinary Science and Engineering, Tokyo Institute of Technology*
[b]*Agency for the Assessment and Application of Technology (BPPT)*
[c]*Geospatial Information Agency (BIG)*
[d]*Institute of Innovative Research, Tokyo Institute of Technology*

Abstract

Developing an approach of electricity production can lead stakeholders to make proper and appropriate decisions in the future. This research proposes an integrated system of electricity production from biomass waste which could bring to both economic and environmental benefit. As case study, straw yield of rice is investigated. In this study, an enhanced integrated system of power generation is proposed. The integrated system consists of a torrefaction, entrained flow gasification, gas cleaning module, and combined cycle for power generation. As an effort to optimize the heat circulation and minimize the exergy loss throughout the proposed system, enhanced process integration technology (EPI) is also implemented. By adopting the EPI, the unrecoverable energy or heat in a single process can be recovered and utilized in other processes through process integration. Furthermore, the influences of torrefaction temperature to the total generated power and power generation efficiency are also investigated. Results of calculation and modeling show a very high energy efficiency of integrated system. A positive energy harvesting with the total power generation efficiency of about 43% can be achieved.

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Keywords: rice straw; energy efficiency; process integration; exergy recovery; gasification

1. Introduction

The demand for energy sustainability has encouraged researchers to study the use of renewable energy sources in replacement of fossil fuel. A variety of process technologies can be used, including chemical, biological, electrolytic,

* Corresponding author. Tel.: +8180 8191 8922;
E-mail address: arifdarmawan33@gmail.com, arif.d.aa@m.titech.ac.jp

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photolytic and thermo-chemical. Each technology is in a different stage of development, and each offers unique opportunities, benefits and challenges.

In Indonesia, among numerous available energy sources, biomasses including agricultural wastes play an important role in the energy matrix. Recently, rice plantation is constantly increasing due to high demand as main food resources in this country. According to data from the Indonesian Ministry of Agriculture, the total area of rice plantations was around 8,114,829 ha in 2014 [1]. Annual production of rice straw in Indonesia was 91.753 million tons in 2012, which is equivalent to approximately 50.974 million tons of coal [2]. Rice plantations is mainly located in Sumatera (27.34%) and Java-Bali (17.66 %) islands [1]. The high rice production has led to production of huge amount of agricultural waste consisting of straw and husk. It leads to many problems associated with the improper disposal practices of the rice waste products such as burning in the open fields during the peak harvesting season [3]. Among these wastes, straw rice has the largest share, which is about 50% of the total rice plantation product and has the most potential economic value. Advanced utilization of rice straw, including energy harvesting, is urgently required from both economic and environmental point of views.

Recently, some researchers have performed studies and proposed the utilization systems of wastes from rice for energy production. Gasification of rice straw and/or rice husk has been selected as one of the energy conversion technologies by previous researchers [4] [5] [6] [7] [8] [9].

However, to the best of authors' knowledge, the studies dealing with the effort to evaluate integrated power generation employing exergy recovery from rice straw are very hard to find. In addition, a novel integrated system consisting of gasification and combined cycle is proposed based on enhanced process integration (EPI). EPI is a technology combining both exergy recovery and process integration with a purpose of minimizing the exergy destruction throughout the system.

2. Proposed integrated system

In order to reduce the exergy loss throughout the integrated system significantly, an enhanced process integration technology (EPI) is utilized. It mainly consists of two combined technologies: exergy recovery and process integration [10]. Exergy recovery relates to the circulation of the energy involved in any certain process through combination of exergy elevation and effective heat pairing. This technology has been evaluated in several processes including biomass-based power generation [11] [12], algal drying [13], and coal-to-hydrogen conversion [14].

Figure 1 presents the conceptual diagram of the overall integrated-system proposed in this study. The integrated process consists primarily of fluidized bed torrefaction, entrained flow gasification, gas cleaning module and power generation. The solid, dashed, and dotted lines represent material, electricity and heat, respectively.

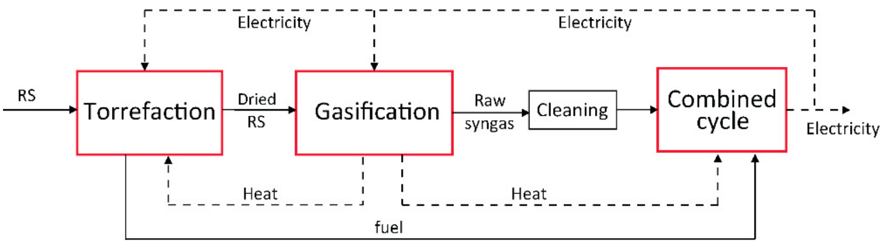

Fig. 1. Conceptual diagram of the proposed integrated-system

The feedstock is flowing into torrefaction reactor and furthermore fed to gasification module. Therefore, it is converted to syngas which consists of fuel gases including hydrogen and carbon monoxide. In the gasifier, pyrolysis, volatilization, combustion and char gasification reactions subsequently take place and the syngas is sequentially produced. Overall chemical reaction in the gasifier is shown below,

$$Biomass\ (wet) + O_2\ (21\%\ of\ air) \rightarrow \alpha_1 CH_4 + \alpha_2 CO + \alpha_3 CO_2 + \alpha_4 H_2 + \alpha_5 H_2O + tar \quad (1)$$