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Packed bed chemical looping platform: design and operation of $30kW_{th}$ pilot unit

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Abstract

Chemical looping combustion is a novel flameless combustion, where the conventional combustion is divided into reducer and oxidizer with assistance of the oxygen carrier. Due to its instinctive CO_2 separation, high efficient and environmental-friendly property, chemical looping combustion attains more concerns. Large-scale experimental unit is a vital to chemical looping combustion, especially the commercial development. The reactor configuration of the worldwide pilot units are fluidized bed or moving bed, and the pilot unit with packed bed has not been reported. In this study, the pilot scale chemical looping packed bed unit with a nominal thermal capacity of $30kW_{th}$ is designed on the basis of previous laboratory scale investigation. The pilot unit includes four parts, which is gas system, reaction system, tail gas treatment and gas analysis system, and auxiliary electrical system. The pilot packed bed reactor is made from 310s stainless steel tube with a 0.089 m o.d., a 0.079 m i.d., and 2.0 m height. A K-type thermocouple with 13 measurement points is located at the center of the packed bed reactor to obtain the axial temperature profile. The packed bed chemical looping platform is constructed to demonstrate the feasibility of generating high purity hydrogen from syngas derived from biomass wastes with on-site carbon capture. Two testing runs were presented using 5 mm × 4-6 mm cylindrical oxygen carriers comprising of 50 wt % iron oxide (Fe_2O_3). The pure CO and the mixture of CO and H_2 with a flow of 15 SLPM are the fuels of the two tests. The first test resulted in a full CO conversion with a 25.0% conversion of the oxygen carriers during reduction, the production of 3.82 mol hydrogen with an average purity of 98.0%, and the maximum temperature rise is 219 K during air combustion. The second test leaded to a full fuel conversion with a 35.7% conversion of the oxygen carriers during reduction, the production of 4.67 mol hydrogen with an average purity of 98.0%, and the maximum temperature rise is 290 K during air combustion. The two testing runs, the first operation of packed bed chemical looping pilot unit, supported syngas-based chemical looping application for hydrogen and power co-generation with in suit carbon capture and also demonstrated the design of the $30kW_{th}$ pilot chemical looping platform with packed bed reactor.

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1. Introduction

Biomass is one kind of renewable energy which is regarded as a possible substitute for fossil fuel[1,2]. Biomass waste has the property of energy and pollution simultaneously. The energy utilization of biomass waste is vital meaning. In China, the annual production of biomass waste is nearly 5 billion tons[3,4]. Most of the biomass waste is difficult to biodegrade. Thermo-chemical technology is the main route to deal with these hard-biodegraded biomass waste. Due to low exergy efficiency and serious secondary pollution, the traditional combustion of biomass waste is limited. Thus, the biomass waste pyrolysis-chemical looping hydrogen generation process (p-CLHG) is proposed, which is low-carbon, low-NO_x and low dioxin[5,6].

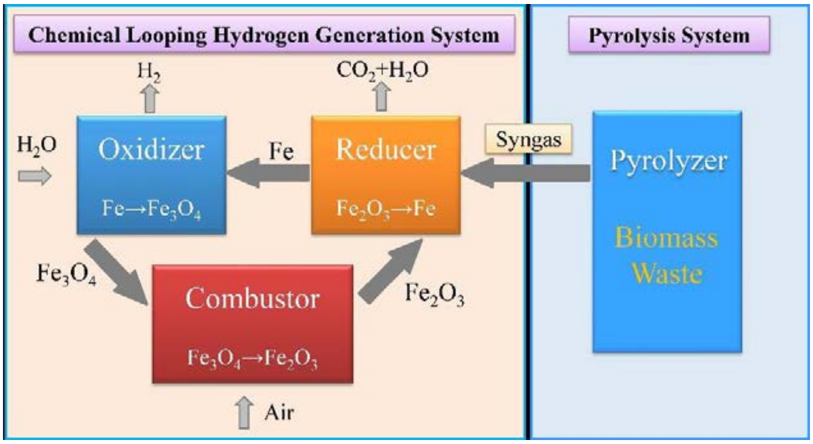

Fig. 1. The schematic diagram of biomass waste pyrolysis-chemical looping hydrogen generation process.

Fig. 1 shows the schematic diagram of the biomass waste p-CLHG process. In the pyrolysis reactor, biomass waste is pyrolyzed under anaerobic conditions to obtain the syngas. Syngas is used as the CLHG fuel, which carries out the capture of CO_2 during hydrogen generation. The p–CLHG process is attractive because it restrains the formation of dioxin, generates high purity hydrogen, and realizes carbon management.

The syngas CLHG includes fuel reduction, steam oxidization, and air combustion. And the oxygen carrier in CLHG is iron-based oxygen carrier. The theoretical reactions in the three steps are as follows.

Fuel reduction:

$$Fe_2O_3 + syngas \rightarrow Fe + CO_2 + H_2O \tag{1}$$

Steam oxidization:

$$Fe + H_2O \rightarrow Fe_3O_4 + H_2 \tag{2}$$

Air combustion:

$$Fe_3O_4 + Air \rightarrow Fe_2O_3 + N_2 \tag{3}$$

From these reactions, the CLHG is one kind of derived processes from chemical looping combustion (CLC)[7]. The test facility is vital to the development of CLC. The worldwide operating facilities are shown in Table 1[8]. It can be seen that the test facilities are main fluidized bed reactor[9-14], and the packed bed reactor[15-18], especially large-scale packed bed, is rare.