



# Techno-economic analysis of a coal to hydrogen process based on ash agglomerating fluidized bed gasification

Guang Li<sup>a,b</sup>, Zheyu Liu<sup>a,\*</sup>, Tao Liu<sup>a,b</sup>, Jie Shan<sup>a,b</sup>, Yitian Fang<sup>a,\*</sup>, Zhiqing Wang<sup>a</sup>

<sup>a</sup> State Key Laboratory of Coal Conversion, Institute of Coal Chemistry, Chinese Academy of Sciences, Taiyuan, Shanxi 030001, PR China

<sup>b</sup> University of Chinese Academy of Sciences, Beijing 100049, PR China

## ARTICLE INFO

### Keywords:

Hydrogen  
Ash agglomerating fluidized bed  
Coal to hydrogen process  
Techno-economic analysis

## ABSTRACT

Developing coal to hydrogen is a crucial way to alleviate the conflict between demand and supply of hydrogen. In this paper, a coal to hydrogen process based on ash agglomerating fluidized bed gasification is proposed and simulated. Based on the simulation results, the thermodynamic analysis and economic evaluation of the coal to hydrogen process are carried out to provide theoretical guidance for the development and investment of the coal to hydrogen process. The results show that the energy efficiency is 43%, the exergy efficiency is 40% and the total exergy loss is 73,315 kW. Gasification unit occupies 63.66% of the total exergy loss and should prefer to be improved. In addition, the total capital investment, total production cost, payback period, net present value and return on investment are estimated for four different plant sizes. The results show that the costs and profitability vary significantly with the plant size. Finally, the influences of coal price and hydrogen price on the economic performance of the coal to hydrogen process are investigated.

## 1. Introduction

Hydrogen, a key raw material for chemical processes such as ammonia synthesis [1] and oil refining, has the potential to be a clean fuel for power generation and transportation [2–4]. Rising concerns about the CO<sub>2</sub> emissions, the demand for hydrogen is growing rapidly in the world. According to the report of the International Energy Agency, the global hydrogen consumption will reach more than 300 Mtoe in 2050 [5]. Currently, 96% of the global hydrogen is derived from fossil fuels [6]. Among these fossil fuels, natural gas accounts for 48% and oil is responsible for 30% [6]. However, the energy structure for China is shortage in natural gas and oil but richness in coal [7]. Therefore, converting coal to hydrogen is an important way to satisfy the demand for hydrogen, while utilizing China's abundant coal resources.

The crucial equipment of the coal to hydrogen process is gasifier. The composition of the syngas is determined by the gasifier. The gas composition affects investment of the coal to hydrogen process and CO<sub>2</sub> emission [8]. There are three main types of gasifiers: fixed bed gasifier, entrained flow gasifier [9] and fluidized bed gasifier [10]. As one of the entrained flow gasifiers, the Shell gasifier has been applied in the coal to hydrogen process. Li et al. [11] evaluated the economic performance of a system coupled with the Shell gasifier to produce hydrogen and electricity. Although the Shell gasifier can achieve higher carbon conversion, the operation and equipment cost of the Shell gasifier are high

[12] due to extreme furnace conditions such as high temperature (> 1300 °C) and high pressure (20–70 bar) [13].

It is noteworthy that the ash agglomerating fluidized bed (AFB) gasifier, which is a kind of fluidized bed gasifier, has the advantages of low oxygen consumption (0.3–0.5 Nm<sup>3</sup>/kg-coal), moderate operating temperatures (900–1100 °C) [14] and high content of hydrogen (36–41%). High content of hydrogen is the advantage in the coal to hydrogen process. In addition, the AFB gasifier can handle most of the commercial coal, especially high ash content and high ash fusion temperature coal [14]. Previous studies have been carried out on slag formation mechanism and modeling of the AFB gasifier. Liu et al. [14] used Aspen Plus-based dynamics model to simulate the AFB gasifier. Cao et al. [15] used computational fluid dynamics to research the AFB gasifier. Li et al. [16] researched the slag formation mechanism of the AFB gasifier. However, there is no literature that analyses the economic performance of the commercial-scale AFB gasifier for the coal to hydrogen process in detail.

In this paper, a coal to hydrogen process, which integrates the commercial-scale AFB gasifier, is designed in Aspen Plus to calculate the energy balance and mass balance. Based on the calculation results of the process, the thermodynamic efficiency and economic performance are analyzed. The aim of this paper is to provide design parameter for the development of the coal to hydrogen process, and to provide theoretical guidance for the investment of the process.

\* Corresponding authors.

E-mail addresses: [zheyuliu@qq.com](mailto:zheyuliu@qq.com) (Z. Liu), [fyf@sxcc.ac.cn](mailto:fyf@sxcc.ac.cn) (Y. Fang).

### Nomenclature

AFB	ash agglomerating fluidized bed
ATCF	after tax cash flow, CNY/year
$C_{2014}$	equipment cost in 2014, CNY
$C_{ref}$	equipment cost in reference case, CNY
CEPCI	chemical engineering plant cost index
$CEPCI_{2014}$	CEPCI in 2014
$CEPCI_{ref}$	CEPCI in reference case
CNY	China Yuan
D	depreciation, CNY/year
f	domestic factor
FCI	fixed capital investment, CNY

i	discount rate
n	plant life period, year
N	scale factor
NPV	net present value, CNY
PAT	profit after tax, CNY/year
PBP	payback period, year
ROI	return on investment
S	actual capacity
$S_{ref}$	reference capacity
TCI	total capital investment, CNY
TPC	total production cost, CNY/year
WC	working capital, CNY

## 2. Description of the AFB gasifier

Fig. 1 shows the schematic of the AFB gasifier, which has been developed and commercialized by Institute of Coal Chemistry, Chinese Academy of Sciences. The commercial-scale AFB gasifier has a diameter of 2.4 m in the bottom section and 3.7 m in the upper section. The height of the AFB gasifier is 18.18 m. In addition, the height of the bottom section and the upper section is 8.36 m and 9.82 m, respectively. In order to produce syngas, the AFB gasifier is heated to 900 °C by liquid fuel or fuel gas in advance. Then the dried and crushed coal is transported to the AFB gasifier by  $N_2$ . After that,  $O_2$  and steam are transported to the AFB gasifier by compressor [17].

The AFB gasifier is coupled with the first cyclone and the second cyclone to enhance the carbon conversion. The technological key of the AFB gasifier is the special fluidics-separating structure which composes of two important parts in the bottom section, namely center tube and conical distributor. The local region of high temperature, which is caused by high concentration  $O_2$  injection, approaches the soften temperature of ash and makes ash gradually become larger. In addition, the bed temperature of the AFB gasifier should be operated below the ash melting point to prevent the slagging problems. The heavier and larger ash is separated from semi-char and then is collected in ash hopper. The fly ash captured by the first cyclone is transported to the gasifier. A mount of fly ash, which is collected by the second cyclone, is gathered in hopper.

The commercial-scale AFB gasifier can process 500 t/d of coal in the operating pressure of 0.5–2.5 MPa, and a temperature of 900–1100 °C, with a gas yield of 1.4–2.9  $Nm^3/kg$ . Additionally, the AFB gasifier can process kinds of coal such as Xiangyuan bituminous, Shenmu bituminous, Wenshan lignite, Houlinhe lignite, Xiaolongtan lignite, Tianxi anthracite, Jincheng anthracite and Yangcheng anthracite.

## 3. Modeling and simulation of the coal to hydrogen process

### 3.1. Conceptual design and description

As shown in Fig. 2, the coal to hydrogen process based on the commercial-scale AFB gasifier can be divided into eight units: (i) air separation unit, (ii) gasification unit, (iii) water gas shift unit, (iv) Rectisol unit, (v) Claus unit, (vi)  $CO_2$  compression unit, (vii) pressure swing adsorption unit, (viii) gas and steam turbine unit.

500 t/d of crushed coal is transported to the AFB gasifier by  $N_2$  and reacts with  $O_2$  as well as steam to produce syngas. The coal used in this paper is Houlinhe lignite, which is listed in Table 1. Then the syngas is sent to the water gas shift unit to convert CO into  $H_2$ . The shifted gas is transported to the Rectisol unit to get rid of  $H_2S$  and  $CO_2$ . The  $CO_2$  is transported to the  $CO_2$  compression unit to enhance pressure and then sent to storage place. The  $H_2S$  is transported to the Claus unit and reacts with  $O_2$  to produce sulfur. The steam from the water gas shift unit and  $N_2$  are used to regenerate methanol in the Rectisol unit. The  $H_2$ -rich gas

from the Rectisol unit is sent to the pressure swing adsorption unit to produce purity  $H_2$ . The tail gas from the pressure swing adsorption unit is sent to the gas and steam turbine unit to generate electricity. The coal to hydrogen process is designed in Aspen Plus and the key parameters for the coal to hydrogen process are listed in Table 2.

### 3.2. Unit operation models and property methods

The crucial models and property methods of each unit in the coal to hydrogen process are shown in Table 3. In addition, RYield and RCSTR are used to simulate the AFB gasifier as a dynamics model. The detailed description about this model of the AFB gasifier was provided by Liu et al. [14]. The simulation results of the AFB gasifier are verified by comparing the industrial data, as shown in Table 4. It can be seen that the simulation results are in good agreement with the industrial data.

### 3.3. Simulation results and analysis

Based on the mass balance and energy balance of Aspen Plus for the coal to hydrogen process, the crucial simulation results of the process

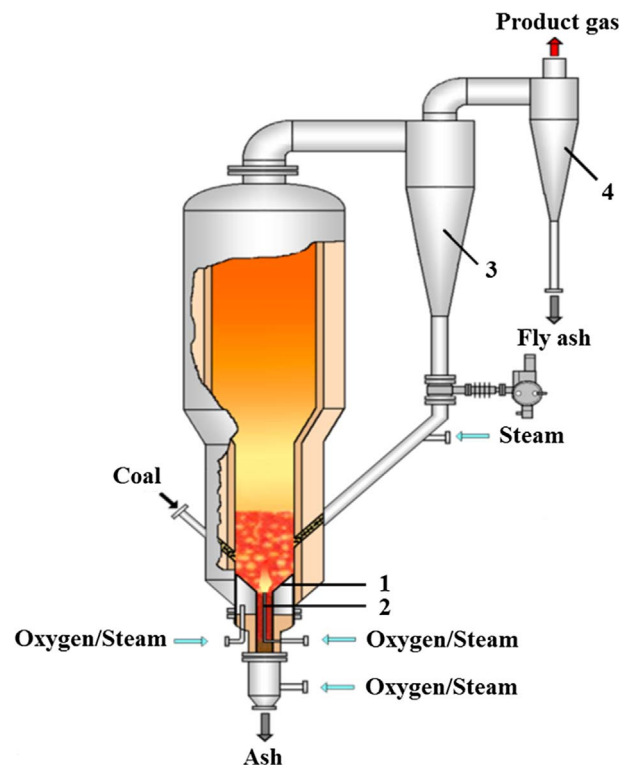


Fig. 1. Schematic of the AFB gasifier. The main parts: (1) conical distributor, (2) center tube, (3) the first cyclone, (4) the second cyclone.

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