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Innovative concept for gasification for hydrogen based on the heat integration between water gas shift unit and coal–water–slurry gasification unit

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ABSTRACT

In order to achieve the energy cascade utilization and improve the energy utilization efficiency of coal–water–slurry (CWS) gasification for hydrogen system, the heat integration scheme (HIS) between the water gas shift unit and the gasification unit is put forward. The effects of temperature change of CWS and oxygen on the gasification performance are investigated. Both the HIS and the non-heat integration scheme (NHIS) are analyzed by using gasification performance, energy conversion efficiency and exergy efficiency. The results show that the specific coal consumption and the specific oxygen consumption decrease by 2.7% and 6.5%, respectively, as the feedstock is preheated up to the temperature of 150 °C. The energy conversion efficiency of HIS and NHIS are nearly the same. The exergy efficiency of HIS (62.66%) is better than that of NHIS (62.02%). Therefore, the HIS is better than the NHIS by heat integration between the WGS unit and the gasification unit.

Introduction

Water gas shift (WGS) reaction is an important exothermic reaction to generate hydrogen-rich gas, which generates a large amount of low-grade energy. Therefore, recovering and properly utilizing the low-grade energy of WGS unit is always the key point of research.

According to the feeding mode, entrained flow gasification process can be divided into dry feed (Shell and GSP, etc.) and slurry feed (Texaco, DOW and OMB) [1–4]. The slurry feed process has the characteristics such as feed flexibility, operation convenience and low investment [5], and is suitable for gasification for hydrogen on a large scale.

Some studies have been reported about increasing temperature of feedstock into gasifier to improve the system gasification performance. Aiuchi [6] proposed a pre-heating vaporization technology of CWS to produce a two-phase flow of atomized coal and steam. Multi-Stage Enthalpy Extraction Technology (MEET) was put forward by Sugiyama [7] et al., in which preheated gasifying agent was used in the pebble bed gasifier to obtain high thermal efficiency. Pressurized spout-fluid bed using a high-temperature gasifying agent was reported by Xiao [8]. However, there is few reports

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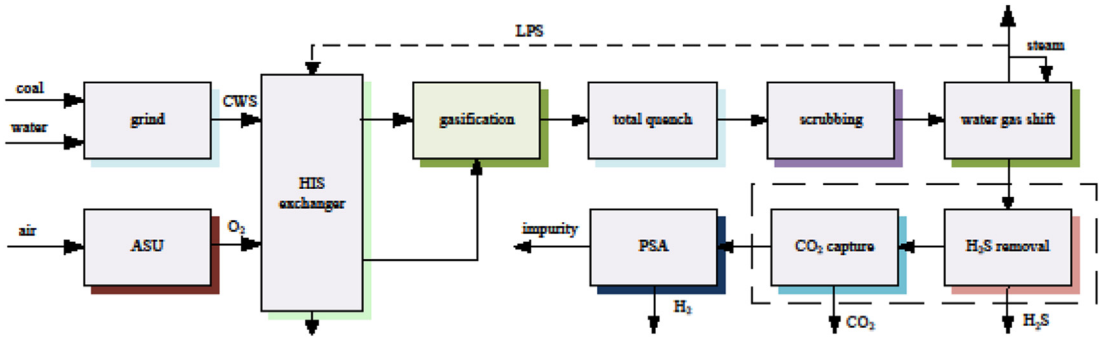

Fig. 1 – Schematic flow diagram of the gasification system for generation of H_2.

Table 1 – Coal analysis data.[a]

Proximate analysis and ultimate analysis/%(mass)										HGI	HHV/MJ kg^{-1}
M_{ar}	FC_d	VM_d	A_d	C_d	H_d	N_d	Cl_d	S_d	O_d		
10.00	58.37	32.66	8.97	74.29	4.20	0.87	0.00	0.23	11.44	55	29.54

[a] :d:dry basis, ar:as received basis, M:moisture, FC:fixed carbon, VM:volatile matter, ASH:ash, C:carbon, H:hydrogen, N:nitrogen, Cl:chlorine, S:sulfur, O:oxygen, HGI:hardgrove grindability index, HHV:high heat value.

on the heat integration between WGS unit and the gasification unit.

Therefore, the heat integration scheme between the WGS unit and the gasification unit is put forward to make properly use of the low-grade energy. The effects of temperature change of CWS and oxygen on the gasification performance are investigated. Both the heat integration scheme and the non-heat integration scheme are analyzed by using gasification process performance, energy conversion efficiency and exergy efficiency.

Process description

Overall process description

The original non-heat integration scheme (NHIS) of gasification for hydrogen is shown in the Fig.1. The gasification for hydrogen process model is developed by using Aspen Plus. The available throughput is 134375 $Nm^3(CO + H_2)/h$, which corresponds to the 450 thousand tons of synthetic ammonia. The whole system is composed of gasification, total quench, syngas scrubbing, acid gas removal, WGS, and pressure swing adsorption (PSA) [9–11].

The heat integration scheme (HIS) also involves the heat transfer process between the WGS unit and the gasification unit in addition to the basic units of the NHIS.

Thermal behavior of CWS depends on many factors, such as properties of coal and different heating rate. Generally, if the temperature is controlled in a certain range, the thermal behavior of CWS can be in the stage of moisture vaporization [12]. Therefore, the coking phenomenon of CWS can be avoided and there is no possibility of pipe blockage.

Coal is used as the gasification raw material, and the property analysis data of coal are shown in table 1. The supply conditions of the feedstock and the operating conditions of the gasification unit are shown in Tables 2 and 3, respectively.

Description of unit process

Gasification and gas clean-up unit

The gasification technology adopts the opposed multiburner (OMB) CWS entrained flow gasification process, which is developed by the Institute of Clean Coal Technology (ICCT), East China University of Science and Technology (ECUST). As shown in the Fig.2, the CWS is pumped into the gasifier featured with four horizontal impinging burners. The hot syngas from gasifier is first quenched in the quench chamber. This will provide plenty of wet steam for the WGS reaction in the shift converter. Then the raw syngas passes sequentially through a jet mixer, a cyclone and a water scrubber to remove entrained particulate, after which most of the solid particles are removed from the syngas. The slag is collected in the quench chamber and is discharged via a lock-hopper. The washing water is sent to the black water treatment process [2,13].

There are many models to describe gasifier, such as equilibrium model [14–17], the one dimensional [18,19] model and the multidimensional model [20]. The thermodynamic equilibrium model can give a better description for gasifier which already has some experimental data and operating experience. Compared with the one dimensional and multidimensional models, the equilibrium model is convenient for calculation and is widely used. As shown in the Fig.3, the

Table 2 – Supply conditions of the feedstock inputs.

	CWS	O_2
Temperature/°C	50	25
Pressure/MPag	6.0	6.0