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Comparative studies on steam gasification of ash-free coals and their original raw coals

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ABSTRACT

Catalytic gasification of raw coals at mild condition is not realized yet mainly due to deactivation of catalysts via their irreversible interaction with mineral matters in coal. As a means to achieve repeated use of catalysts, four different ash-free coals (AFCs) containing less than 0.2 wt% ash are produced in this work. Steam gasification of ash-free coals (AFCs) and their parent raw coals of various ranks ranging from lignite (Eco) to coking coal (Posco) is performed in a fixed bed reactor at 700–900 °C. Regardless of the rank of the parent raw coals, all the AFCs behave like a highly carbonized coal such that their gasification rate are similarly slow and they exhibit relatively low H_2/CO ratio. The steam gasification and associated CO to CO_2 conversion of the AFCs are, however, significantly enhanced by K_2CO_3, resulting in the higher H_2/CO and CO_2/CO molar ratio.

Introduction

More than 50% of electricity generation worldwide has been achieved by burning fossil fuel, which in most cases brings about pollution problem hazardous to environment and human health [1,2]. A coal-fired power sector is responsible for ~35% GHG emission and has been continuously blamed as a main culprit of global warming [3]. Moreover, the world is gradually running short of fossil fuels. This situation has given rise to vigorous R&D activities to find more efficient alternatives. A series of measures that can be done without damaging the energy security and the economy have been explored as a temporary solution on its way to the pollution-free and renewable.

Integrated gasification combined cycle (IGCC) uses a coal with reduced CO_2 emission, as is highly efficient (~45% thermal efficiency) [4]. Many of 50–600 MW scale IGCC plants have been operated successfully, mostly in USA, EU, and Japan [5]. It is now considered a realistic generation technology for the

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Table 1 – Proximate/ultimate analysis and calorific value of an Eco, Cyprus, Drayton, and Posco raw coal and ash free coals (*dry basis, **daf: dry & ash-free).

Name	Sample (wt%)	Moisture	Volatile matter*	Ash*	Fixed carbon*	C**	H**	N**	O**	S**	Heat value (kcal/kg)
Eco	Raw	11.1	53.4	4.2	42.4	70.4	5.2	0.9	23.4	0.1	5880
	AFC	1.4	47.2	0.2	52.6	90.7	5.3	0.7	3.2	0.1	8298
Cyprus	Raw	13.2	45.3	6.1	48.6	76.4	6.3	1.3	15.7	0.3	6700
	AFC	3.6	61.6	0.2	38.2	84.3	6.5	1.0	8.1	0.1	8440
Drayton	Raw	2.9	33.6	12.7	53.8	84.6	5.8	1.8	7.2	0.6	6530
	AFC	8.7	49.9	0.2	49.9	85.8	6.7	2.2	5.0	0.3	8460
Posco	Raw	1.3	21.3	9.8	68.9	86.2	4.1	1.5	1.1	7.1	8596
	AFC	2.3	34.8	0.1	65.1	92.7	4.8	1.0	0.9	0.6	8670

transition period. Conversion of coal to syngas (H_2 & CO) is the most critical process of IGCC system [6]. Hydrogen is one of the most promising next generation fuels because it is abundant and environment-friendly. A PEMFC and SOFC that are building blocks of the coming hydrogen economy are expected to be major consumers of hydrogen. Around 30% of industrial hydrogen is also produced by commercialized coal gasification process. The majority of the gasification processes scaled up for commercialization have adopted an entrained-flow slagging gasifier operating at harsh condition (~1400 °C and 20–70 atm) in order to boost gasification rate and cope with slagging issue [7]. This severity demands high capital investment. In addition, the supply of heat by exothermic combustion of a coal with oxygen reduces the conversion efficiency.

At the lower temperature ($T < 900$ °C), the conversion kinetics is generally slow and therefore of no practical use, unless the catalyst-aided coal gasification is performed. Catalytic coal gasification has been extensively studied for many decades [8,9]. The kinetics of coal to gas conversion can be significantly improved by introduction of alkali, alkali earth, and Ni/Fe based catalyst [9]. Potassium carbonate is the most pronounced among them and potentially applicable to most of solid carbonaceous resources because it is catalytically active and also free from the mass transport limitation [10]. However, the catalytic activity is commonly non-repeatable due to deactivation of the catalyst by irreversible interaction with the mineral matters in coal. Therefore, the recovery of the catalyst becomes difficult [11].

The ash in coal is also ill-natured in many cases, decreasing the power efficiency and also being discharged as an air pollutant [12]. A lot of works have concentrated on the development of efficient methods to prepare ash-free coals (AFCs) [13]. Among them, thermal extraction with organic solvents has produced AFCs most successfully [14]. Recently, AFCs have found new applications in catalytic coal gasification, direct coal-fired gas turbine, and direct carbon fuel cell (DCFC), thanks to their ashless character [15–17]. In this work, the ashes in four coals of various ranks (Eco, Cyprus, Drayton, and Posco) were removed by the thermal extraction method. The resulting AFCs were gasified non-catalytically and also catalytically, feeding steam. Referring to the previous work, the gasification behavior of AFCs was compared with that of the parent raw coals, and discussed regarding the catalytic effect of K_2CO_3 [18].

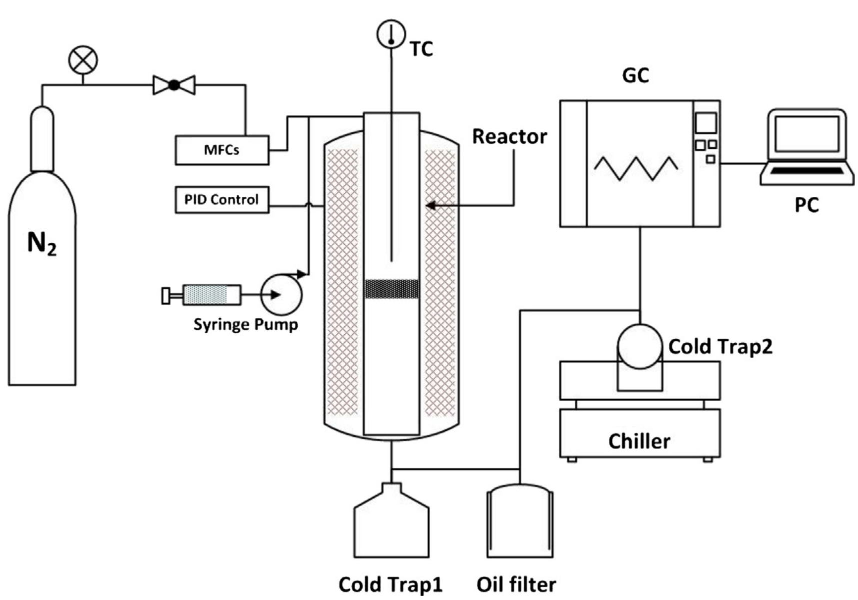

Fig. 1 – Schematic diagram of a fixed bed coal gasification system.