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Energy analysis for low-rank coal based process system to co-produce semicoke, syngas and light oil

Xiaohui Chen, Danxing Zheng*, Jing Guo, Jingxiao Liu, Peijun Ji

College of Chemical engineering, Beijing University of Chemical technology, Beijing 100029, China

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ABSTRACT

The low temperature coal pyrolysis technology and the atmospheric and vacuum tar distillation were combined to establish a low-rank coal based process system, which can co-produce semicoke, syngas and light oil. And then the simulation models of key units and whole system were also developed. As the calculation results, the lignite with 41.0% moisture can be converted to semicoke, syngas and light oil. Their yields are 42.31%, 8.47% and 4.10%, respectively. The distribution shows that the energy consumption and the exergy loss of drying unit are all the largest with 323.1 kW and 300.1 kW, and those of pyrolysis unit rank the second with 196.2 kW and 131.4 kW. Based on a graphic illustration of energy analysis, the reasons of energy consumption and depreciation were explained. The energy grades of products are increased or decreased at the cost of energy consumption and depreciation. A heat integrated co-production system was proposed to assess the energy saving potential of the original system. The energy consumption and the exergy loss for the whole system have been reduced by 14.9% and 10.9%, and the heat integration effect of drying unit has a relatively larger influence on that of the whole system.

1. Introduction

Among all of the parameters available to describe coal, the "rank" of coal is always taken into consideration when evaluating any coal quality. Recently, the exploration of coal resources has been concentrated on high-rank coal. With the growing demand for energy and the sharp decrease in the availability of high-rank coal resources, the highly efficient conversion of low-rank coal has become even more essential. The conversion processes can be realized by upgrading the energy grade of coal, such as the coal liquefaction, the coal gasification, the coal pyrolysis and other technologies [1]. Subsequently, the coal is converted to syngas, methanol, coke, oil and other value-added products [2].

The mature technologies of pyrolysis contain Toscoal, Char Oil Energy Development, Garrett, Encoal, Lurgi-Ruhrgas et al. [1,3]. Although these pyrolysis processes have a long history and a lot of efforts have been spent on overcoming their shortcomings, but they haven't been applied commercially. The distributions of product yields are greatly influenced by the grade or type of coal, reaction temperature, pressure, and etc [4–6]. The experiment [7] showed that yields of syngas, especially the components of H_2 and CO, increased with the increasing temperature. The thermal pretreatment can also affect the yields of tar and syngas [8]. Moreover, the yield of tar or syngas would be reached the highest at the special temperature and pressure. Although the pyrolysis processes have different conditions, it would not affect the establishment of calculation models.

The tar from the pyrolysis process can be converted to light oil and other chemicals through catalytic hydrogenation or distillation. The tar distillation technology is classified as the atmospheric distillation, vacuum distillation, atmospheric and vacuum distillation as related to different pressures [3]. Because the energy consumption of atmospheric distillation is high and the light oil yield of vacuum distillation is low, the atmospheric and vacuum distillations, such as the Ireland-Robinson & Hadley process, Koppers process and Ruetgers process, are utilized more widely in actual production. Although the tar can be used as the fuel, its commercial value decreases for the low combustion efficiency yield and the high pollutant levels [9].

Liu [10] used the Aspen Plus software and the mathematical model to simulate the coal combustion process in

Abbreviations: dr, dry based; Atm-dis, atmospheric distillation; Vac-dis, vacuum distillation; Lig-oil, light oil including alkene; Phe-oil, phenol oil; Nap-oil, naphthalene oil; Was-oil, wash oil; Ant-oil, anthracene oil.

* Corresponding author. P.O. Box 100, Beijing University of Chemical Technology, Heping Street, Beijing 100029, China. Tel./fax: +86 10 64416406.
E-mail addresses: dxzh@mail.buct.edu.cn, dxzh06@sina.com (D. Zheng).

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which the whole process contained the coal pyrolysis, the gasification and the combustion. Gao et al. [11] simulated the coal tar atmospheric and vacuum distillation process, and the energy consumptions of three above mentioned distillation technologies were also compared.

During the energy analysis of chemical process system, the first and the second laws of thermodynamics are mainly applied to calculate the energy consumption, the energy efficiency and the exergy loss [12]. The energy stream graph is also utilized to show the distributions of energy consumption and exergy loss. However, the concrete mechanisms for the energy utilization and consumption of process system are usually not enough thoroughly reviewed. As to the energy system optimization, the waste heat cascade utilization for the internal streams of a system and the heat coupling for different processes are always used. Aziz [13] studied the internal heat integration with the coal drying process, and Łukowicz [14] also recycled the waste heat from the coal-fired units to dry the brown coal. So the energy consumption of drying process decreases owing to the heat integration.

The focus of this paper is to study the energy performance of the low-rank coal based process which is established to co-produce the semicoke, syngas and light oil. The simulation models of the key units and the entire system are developed to calculate the product yields and the distributions of the system energy consumption and the system exergy loss. The energy utilized situation and the reasons of energy consumptions and depreciations are also investigated by a graphic illustration from the perspective of energy quality factor. In addition, a heat integrated co-production system is proposed to assess the energy saving potential of the original system.

2. Establishment of the co-production system

According to the reports of Bateman, Inc. [15]. and ConvertCoal, Inc. [16]. and the needs of following productions, this work attempts to establish a low-rank coal based process to co-produce the syngas, semicoke and light oil. The process consists of six sections: drying unit, pyrolysis unit, cooling and separation unit, dehydration unit, atmospheric distillation and vacuum distillation.

2.1. Descriptions of process

Fig. 1 shows the schematic diagram of co-production process system. The principal flowsheet and operating parameters of the six sections are determined by the data cited from the low-rank coal pyrolysis technology of ConvertCoal Inc. [16].

The raw coal is dried to 200 °C during the process of being lifted to the bunker. The dry coal is poured into the pyrolytic reactor through the screw charging machine, and then carbonized at 550 °C. In the realistic processes, the energy for pyrolysis reaction comes from the semicoke which is used as the heat carrier. However, that part of energy is supplied by the utility completely because the semicoke is considered as a product. In the pyrolytic reactor, the coal decomposes into the syngas, tar and semicoke. The syngas and tar are poured out from the top of reactor as the gas mixtures, and the semicoke is directly outputted as the product. Then syngas and tar are separated from each other by the cooler. The coal tar from the separation is sent to the dehydrating tower which makes the content of water dropped to 0.5%.

After the dehydration, the tar is dosed into the atmospheric distillation tower. The oil-gas fractions leaving from the top of

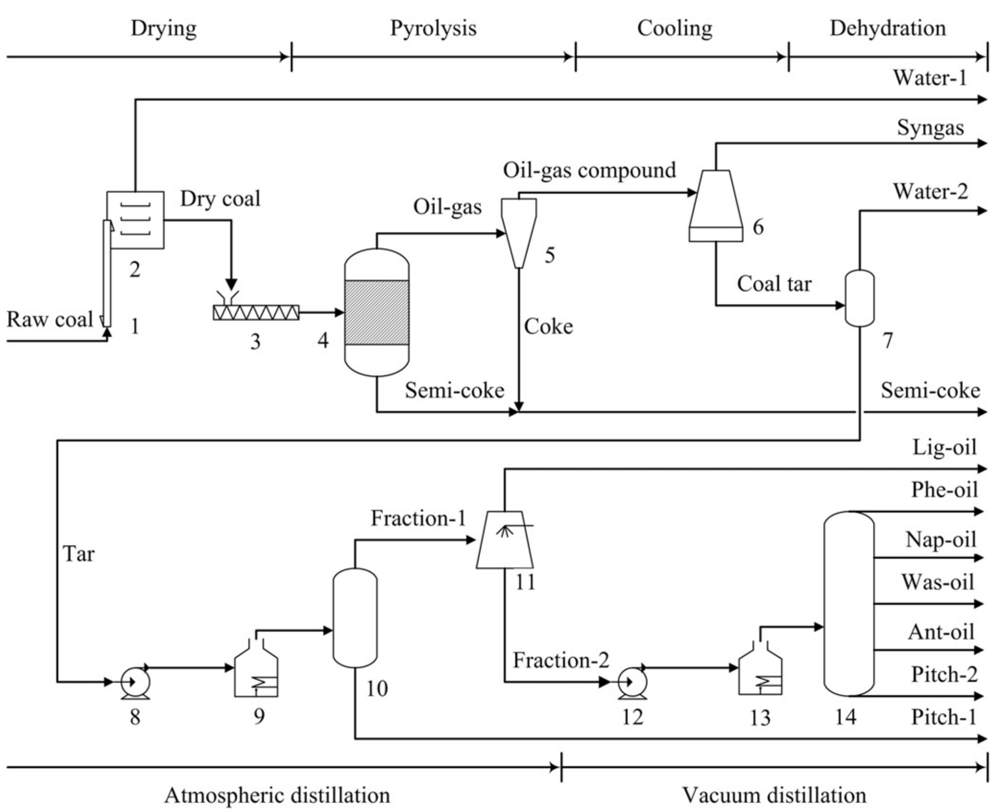

Fig. 1. Schematic diagram of the co-production process. The raw coal can be conversed to the semicoke the syngas, and the light oil through the process. And the name for every unit is listed as below: 1-Elevator; 2-Drier; 3-Screw charging machine; 4-Pyrolytic reactor; 5-Cyclone; 6-Cooler; 7-Dehydrating tower; 8-Pump 1; 9-Boiler 1; 10-Atmospheric distillation column; 11-Quench tower; 12-Pump 2; 13-Boiler 2; 14-Vacuum distillation tower.