Available online at www.sciencedirect.com
ScienceDirect
Powder Technology 181 (2008) 67 – 73
POWDER TECHNOLOGY
www.elsevier.com/locate/powtec

Temperature effect on the pressure drop across the cake of coal gasification ash formed on a ceramic filter

Jin-Hyung Kim, Yu Liang, Kyoung-Min Sakong, Joo-Hong Choi *, Young-Cheol Bak

Department of Biological and Chemical Engineering/ ERI/BK21 for ECT, Gyeongsang National University, Jinju 660-701, South Korea

Received 14 August 2006; received in revised form 14 June 2007; accepted 15 June 2007
Available online 26 June 2007

Abstract

In order to predict the pressure drop across the cake of coal gasification (CG) ash formed on ceramic filter, an empirical equation was developed taking into account several factors, such as the face velocity, ash load, shape factor and size of particles, and especially the operating temperature. The hot air stream of well classified fine particles of CG ash was simulated as the syngas derived from the coal gasification process. The pressure drop behavior and cleaning efficiency of the filter were carefully investigated within the temperature range from room temperature to 673 K. The pressure drop across the ash cake was dominantly governed by the air viscosity, which increased with temperature. It was well expressed by the previously reported-empirical equation [J.H. Choi, Y.C. Bak, H.J. Jang, J.H. Kim, and J.H. Kim, Korean J. Chem. Eng., 21(3) (2004) 726.] with the modification of the viscosity term in the equation for different temperatures. The residual pressure drop rate across the ash cake also increased while the cleaning efficiency of the ceramic filter decreased as temperature increased.

Keywords: Temperature effect; Pressure drop; Cake; Filter; Gasification; Cleaning

1. Introduction

The pressure drop is a primary factor in the design and operation of a ceramic filter unit. However, predicting the exact pressure drop can be difficult, as it depends on many co-dependent factors that originate from the design of the filter unit, the particle and gas properties, as well as the operating conditions. Moreover, the compression property of the ash cake accumulated on filter surface makes the situation even more complex. The compression phenomena of ash cake have been reported by several investigators [2–6]. Höflinger et al. [7] reported that reduction in the cake thickness occurred when particles became compacted by the exceeding shear force developed by the latterly formed-ash layers. Neiva et al. [8] proposed a cake build up model and reported that the compression of a given ash layer was related with the drag forces of its upper layers. Compression of the ash cake leads to compaction of the ash layer, which results in a reduction of the cake porosity as well as an increase of pressure drop across the cake. Some computer programs [3,7,8] have been developed to calculate the pressure drop across ash cake (ΔP_c), based on the theories mentioned above, which have shown good agreement with experimental results in limited cases or valid by specific parameters. Schmidt [3] considered local compressions of the cake for the progressive increase of pressure drop with filtration time. The model contains two empirical parameters that have to be determined by experimental results. Höflinger [7] applied the Mohr–Coulomb deformation criteria to spherical particles. The model proposed by Neiva et al. [8] based on cake build up to calculate the pressure vs. time, which requires the settling factor depending on the geometry of the filter vessel, process conditions such as velocity, concentration, density, particle size, agglomerates formation and gas dynamic viscosity. Additional works observed that the compression of ash cake depends on many co-dependent factors, including the particle properties (shape, size, and density) [9–11], the filter [12], the gas properties (density, viscosity and humidity) [13] and the operating conditions (the face velocity and the cleaning method) [14,15].

* Corresponding author.
E-mail address: jhchoi@gnu.ac.kr (J.-H. Choi).

0032-5910/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.powtec.2007.06.006

Endo et al. [5] derived an explicit equation for predicting the ΔP_c of poly-dispersed particles taking into account the geometric mean diameter, the dynamic shape factor of particles and the particle size. However, his assumption of uniform porosity throughout the entire ash cake restricts its application. Choi et al. [1,2] developed a more general modified-Endo equation by adopting an extra two empirical equations, with respect to; (1) the ash cake porosity depending on the particle size, the face velocity and the ash load, and (2) the void function depending on the ash cake porosity and particle size. The predicted-values obtained using the modified-Endo equation showed good agreement with the experimental data found for CG fly ash at room temperature [1]. However, the effects of temperature to investigate the pressure drop across the ash cake have rarely been studied.

The aim of this study is to develop an empirical equation for prediction of the pressure drop across the CG ash cake on a ceramic filter at moderate temperatures under 723 K in order to apply on the particle removal in a coal gasification process. Of the factors responsible for the pressure drop across the ash cake, the decrease in the porosity due to the particles sticking together should be dominant at high temperature, as a kind of liquid bonding due to the sintering effect. It has been pointed out that the sintering effect of fly ash is dominant above 1073 K, depending on the ash composition, especially in the case of particles originating from the PFBC (pressurized fluidized bed combustion) process, where the particles collection is carried out above 1023 K [19]. For gasification processes, such as the IGCC (integrated coal gasification combined cycle), the particles removal is preferably carried out under 823 K to meet the optimal conditions in combination with the dry-desulfurization process which is carried out below 873 K [20]. Therefore, this study mostly focused on the removal of particles at the elevated temperature under 673 K in a coal gasification process.

2. Experimental

Fig. 1 shows the schematic diagram of the experimental unit employed to measure the pressure drop across the ash cake at moderate temperature (RT −673 K) using the CG ash from a coal gasification unit. The constant volume of CG ash was fed into the air stream at room temperature using a screw feeder. Two cyclones were sequentially used to obtain the particles loaded-air streams of selected-particle sizes. The diameters of the first and the second cyclones were 64 and 48 mm, respectively. Consequently, the mean diameter of particles in the air stream decrease in the order of S2>S3>S4, where S2 and S3 are the flow streams originated from bottoms of the first and the second cyclone, respectively. S4 is the overflow stream from the second cyclone. The large particles in the raw ash were previously eliminated at the settling chamber (S1). One of the three streams was selected as the particle stream entering the filter unit.

A ceramic filter was mounted between two flanges and tightened using long bolts as shown in Fig. 2. The particles loaded-air stream was introduced into the filter vessel, which approach the filter from the outside and were then passed through the filter toward the inside, with clean gas finally passed to the outlet. The air flow was generated using a vacuum pump located downstream of the outlet. The face velocity across the filter was constantly controlled using a mass flow controller, even when the pressure drop changed during the run time. Using this method, the particles accumulated on the outer surface of the filter during filtration. The ash cake formed on the filter surface was dislodged by a pulse injection of air, via a pulse nozzle, at a pressure of 200 kPa. The pulse nozzle consisted of a 1/4 inch straight-tube located on the inside of a 1/2 inch co-centric tube. The pulsed amount of air was 0.65 g per pulse, with pulse duration of 0.6 s.

The filter chamber was heated by an electrical heating unit. Temperature in the filter cavity measured with a 1/16 inch type K thermocouple. The temperature of the filter chamber was controlled using a PID controller connected to a thermocouple located in the filter chamber.

The pressure drop across the filter was measured using a differential pressure transmitter connected to the filter chamber and the outlet of the filter unit, respectively. A pressure drop verse time ($\Delta P-t$) curve was constructed at a constant face velocity. Part of particle stream entering the filter chamber was accepted for introduction into an aerodynamic particle size analyzer (API Aerosizer, manufactured by Amherst Process Instruments, Inc., Amherst, MA) to measure the particle size distribution under the experiment conditions.

A cylindrical SiC filter (Dia-Shumalith 10–20, manufactured by Schumacher Umwelt-und Trenntechnik, Germany) [16], with outside and inside diameters of 60 mm and 40 mm, respectively, and a 50 mm long filter mounted inside the filter unit. The filter was comprised of a thin membrane layer on the outer surface, with a mean pore size of about 10 μm, which maintained collection efficiency of more than 99.0% for 0.5 μm sized particles [17]. The mass load (W) of accumulated-particulates on the filter surface was calculated by measuring the weight difference before and after the run using an electrical balance. The mass load was preliminarily confirmed to increase linearly with increasing run time in the short term, normally less then 30 min, but the feed rate then remained constant.

The CG ash used in this study was obtained from the process development unit (PDU) of a coal gasification located at the Institute for Advance Engineering (IAE), Korea, and was collected using the filter unit with the SiC filters (Dia-Shumalith 10–20). The PDU was composed of an oxygen blown-entrainment type of gasification unit; with a coal feed capacity of 3 ton/day. Also, the dry coal was gasified at about 1573 K and 800 kPa. Fly ash from the gasification of Kideco coal at 1473–1623 K and 700–900 kPa was used in this study. The main gas composition during the gasification process was CO 57–65%, H_2 20–30% and CO_2 of about 20%. The ultimate analysis (moisture free basis) of the ash showed a composition of C 42.77%, H 0.12%, N 0.01%, S 0.19% and unburned-materials 56.91%. The physical properties of the classified-particle streams are shown in Table 1.