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Review article

Hot gas filtration – A review

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ABSTRACT

This paper provides a detailed survey on hot gas filtration. Fundamental aspects of filtration at higher temperatures are described first, including the influence of the temperature on dust properties and filtration behaviour. The main focus is on the review of hot gas filter media as well as hot gas filter systems. Moreover, applications of hot gas filtration are presented and discussed in detail, for example advanced coal gasification as well as biomass gasification and pyrolysis, incineration of low-level contaminated radioactive waste from nuclear power generation, waste incineration, fluid catalytic cracking in oil refineries and other processes.

By using hot gas filters, downstream equipment, such as heat exchangers, catalyst units, turbines and scrubbers, are protected from erosion and fouling, processes can be intensified or simplified as well as blocking by condensation or desublimation can be prevented.

Energy efficiency, process intensification, PM 10 and PM 2.5 emission values, water shortage and water quality as well as overall process costs are topics which raise an increasing interest in hot gas filtration.

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1. Introduction

Hot gas filtration has been attracting more and more attention in a wide variety of processes over the last years. Main reasons for that are higher demands on emission levels, such as PM 10 and PM 2.5, the possibility to simplify or to intensify processes, problems to supply and to clean wash waters for wet scrubbing as well as the development and application of new processes, such as e.g. biomass gasification.

In advanced power generation systems, in chemical industry, in oil refineries, in incinerations, metal refining and metal recycling, the need for hot gas cleaning is driven by the requirements of increased process efficiency, process intensification, product quality and environmental legislation.

It has been shown that product quality and process efficiency and economics can be improved by using hot gas filtration. For example using hot gas filtration for fly ash removal instead of wet scrubbing, increases the efficiency of a coal gasification process by about 3%. In many processes, high filtration temperatures are required to avoid undesirable condensation or desublimation reactions, which result in the fouling and blocking of filters or the polluting of products. One example for this is the condensation of tars in biomass gasification (see Section 5). The filtration of high temperature process gases also generates the opportunity to utilise particle free, high temperature gas in coupled or subsequent process steps. Furthermore, the economic and process-technological advantages of hot gas filtration are obvious in high temperature processes that involve the circular movement of substances or process gases as well as the recovery of products or expensive materials, such as catalysts or noble metals. Protection of downstream heat exchangers or catalyst units by hot gas filters increases the energy efficiency or the reaction performance, respectively. Moreover, some processes can first be realized by using hot gas filters.

The only disadvantage of hot gas filtration is the higher investments for the filter system due to the increased demands on the materials and the higher gas volume at higher temperatures. Furthermore, the pressure drop is higher caused by the increased viscosity of the gas with temperature. However, in most cases the advantages dominate as well as higher investments for the filter system are compensated by a reduction of the overall process costs.

The first technical application of hot gas filtration was for the incineration of low-level contaminated radioactive waste from nuclear power generation. At the beginning of the 1970s, hot gas filtration was used for example at the former nuclear research centre of Karlsruhe in Germany [1] and in some incineration plants in France [2]. Since 1978 hot gas filtration is used in nuclear power plants in Japan [3].

The development of advanced coal based power generation techniques such as the pressurized fluidized bed combustion (PFBC) and the pressurized integrated gasification combined cycles (IGCC) from the end of the 1980s until the end of the 1990s has significantly influenced the development of hot gas filtration. At this time, many big research and demonstration projects have been started in the USA, in Japan and in Europe for development, investigation and testing of different hot gas filter media and filter systems.

Meanwhile more than 25 large hot gas filter units are in operation or in commissioning in coal gasification plants worldwide. About 20 of them were installed in China in the last 8 years. The hot gas filter with the longest operating time in an IGCC plant was installed in 1994 in Buggenum in the Netherlands.

The total number of hot gas filters worldwide installed in many different applications is in the order of some hundreds.

This paper aims to provide a detailed survey on hot gas filtration and to raise the awareness of hot gas filtration. Hot gas filter media and filter systems are reviewed and described as well as details and particularities of filtration at higher temperatures are discussed. An overview of applications and some detailed examples are presented.

2. Filtration at high temperature

Filtration at temperatures above 260 °C is called hot gas filtration according to the draft of the VDI guideline 3677-3 [4]. High temperatures place high demands on the properties and the mechanical, thermal and chemical stability of the materials which are used. The filter media as well as the vessel material have to be stable against temperature, pressure and chemical composition of gas and dust. The higher the temperature is the higher the demands on the materials are. Hot gas filtration is performed at temperatures ranging typically up to 900 °C, at pressures up to 8 MPa, in both oxidising and reducing atmospheres, and often with chemically aggressive compounds.

At low filtration temperatures, dust properties, such as particle size distribution, adhesion and cohesion forces as well as compressibility of the dust determine the pressure drop and the detachment behaviour of the dust cake. At higher temperatures, the thermal properties of the dust influence the filtration behaviour.

Dust softening or sintering of the dust can occur at higher temperatures which results in a sticking dust layer on the filter element surface and correspondingly in an instable filtration. Dilatometer [5] or high temperature rheometer measurements [6] of dust samples can show at which temperature softening of the dust starts. Softening temperature depends on the chemical composition of the dust. Chlorides, such as NaCl, KCl or $CaCl_2$ decrease the softening temperature. In case of a eutectic mixture, softening temperature can be decreased significantly.

By an increase of the sticking force of the dust with increasing temperature, also dust bridging can occur. This can cause an instable filtration due to incomplete regeneration of the filter elements. In the worst case, breakage of filter elements can result from bridging. Measurement of the tensile strength of a dust cake as a function of the temperature can give a rough indication whether a dust cake tends to bridging or not. However, a better measurement for the likelihood of dust bridging, proposed by Hurley and Dockter [7], is the ratio of the tensile strength to the density of the dust cake as a function of the temperature. They called this ratio the critical thickness index (CTI) and showed by measurements with different dusts that this index is a better indicator of the likelihood of a dust cake to form bridges. If the index is high, the strength of the dust cake corresponding to his weight is high and it is more likely that the dust cake tends to bridging. The investigation of two different fly ashes from a PFBC coal combustion by Hurley and Dockter showed a significant increase of the CTI index for one of these ashes from 700 to 750 °C which indicates an increase of the tendency to form bridges at the higher temperature. This result was in good agreement with the filtration experience with this dust. The second fly ash which had a much higher density showed a lower CTI index and no increase of the CTI index by increasing the temperature from 700 to 750 °C. The filtration experience with this dust showed no bridging at these temperatures.

Filtration tests at a 4 MW_{th} PFBC coal combustion of other researchers showed no bridging and no problems of regeneration at 800 °C, however, at 950 °C bridging of the dust was detected [8].

At high temperature, the dust cake properties can be changed by chemical solid phase reactions in the dust. By means of dilatometer, thermo-gravimetric analysis and differential scanning calorimetry, thermal expansion, loss of weight and relative heat flux of the dust can be analysed, respectively. Using these analysis