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The treatment of waste gas from fertilizer production - An industrial case study of long term removing particulate matter with a pilot unit

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ABSTRACT

This manuscript covers an on site industrial case study focused on the dry filtration of particulate matter (PM) from the waste stream of fertilizer production. In the industrial plant producing fertilizers, it was necessary to exchange the old wet scrubber with new cleaning equipment for PM disposal. A filter unit with bag filters and pulse-jet cleaning was chosen as the new waste-free technology. Unfortunately, one step in the production involves granulation with steam and water, therefore the waste gas stream was quite humid. Filter bags captured 10 g and 40 g of H_2O/kg of dry gas for GR-SA and NPK fertilizers respectively. Due to dry filtration feasibility concerns, a long term pilot unit test was conducted. The impact of operating conditions, especially the inlet stream temperature and humidity was evaluated. A inlet temperature 100 °C for GR-SA and 110 °C for NPK fertilizers was necessary to prevent clogging of the filter bags. We found that different cleaning pulses periods and pulse pressures have a minimum impact on the filter pressure difference (ΔP). Based on the results of the pilot test, recommendations for usable technological conditions were given, in order to avoid problematic deposits on filter material associated with increased ΔP. In addition to this, a straightforward comparison method was proposed in this paper for filter clogging according to ΔP between cleaning pulses.

1. Introduction

Particulate matter (PM) gets to the air from both natural and anthropogenic sources. One of the major anthropogenic sources of PM pollution is industrial production, however, PM emissions emerging from such sources are often easily treatable. The selection of the technology which would be the best for treating PM emissions in each particular case is often not an easy task. The cleaning device selection is guided mainly by these factors: inlet PM concentration, required removal efficiency, distribution of the particles diameter, temperature of the filtration, steam humidity and dust properties (vapour explosive properties, adhesivity, abrasivity and so on). If the initial concentration of PM in the waste stream is quite high, it is possible that it will be necessary to clean the air waste stream with subsequently placed devices. In these devices, the first step significantly lowers the PM concentration, removing a large part of the coarser particles with a diameter of more than 10 μm (e.g. cyclones). This lowers the burden of the second step device which lowers the PM concentration even further to meet legislation limits for a stationary source. Fabric filters, electrostatic precipitators (ESP) or wet scrubbers are the most frequently selected as the main or final (second step) device [1].

Dry cleaning techniques have indisputable advantages over wet techniques. Wet scrubbing creates water pollution while simultaneously dealing with air pollution [1]. The advantage of wet scrubbers lies in how they cope very well with uneven PM loading or extreme peaks of PM [2]. On the other hand, using the filtering device or ESP it is often possible to reintroduce the captured PM back into the production, which is of course related with positive economic consequences for production. The ESP is sensitive to change in the operating parameters, such as the gas flow rate or temperature. An increase in gas flow lowers the PM collecting efficiency of ESP [1]. Filtering elements such as fabric or rigid bag filters (baghouses) provide very high PM removal efficiencies in some optimal cases exceeding 99% or even more [3,4]. Fabric filters are made from flexible materials, so this makes them less susceptible to thermal shocks, rough handling and excessive temperatures, which can lead to premature material damage [5]. They are most versatile and thereby very frequently used to treat industrial PM emissions [3–6]. The limitation of such filter applications lies in the maximum allowable temperature in which can filter material hold out [3,5].

The temperature upper limit for natural fibres is about 90 °C whereas fabrics made from glass and synthetic fibres are more thermostable and usable up to 260 °C [7] during continuous operation – Polypropylene (PP) – 90 °C, Polyacrylonitrile (PAN) – 125 °C, Polyester (PES) – 140 °C, Acrylic homo-polymer – Dralon® – 140 °C, Polyphenylene-sulfide (PPS) – Ryton® – 180 °C, m-Aramide (m-AR) – Nomex® – 200 °C, Polyimide (PI or P84) – 240 °C, Polytetraflourethylene (PTFE) –

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Teflon® – 250 °C and glass – 260 °C [1,3,8,9]. For higher temperatures in the filtration up to 1000 °C, rigid or flexible ceramic filtration material [1, 10] or metal fibres [10] can be used. Apart from the operating temperature, the filter material differs in other parameters such as: chemical resistance, abrasion resistance, air permeability, tensile strength and finishing treatment [11].

Fabric filters were widely used for very long time, so many of the challenges that arise during filtrations of PM (with various problematic properties) have already been solved and can currently be dealt with. When dust is very adhesive, it can make filtration unfeasible due to the possibility of clogging of the filter material pores completely with deposits which are very difficult to remove. Dusty materials can be divided into four groups sorted by their different layer breaking strength: I – non-adhesive, II – weakly adhesive, III – medium adhesive and IV – strongly adhesive [9]. Dust adhesiveness is connected with the humidity of the dust stream. With an increase in relative humidity, electrical forces are weakened, which leads to substantial increase in the adhesiveness. Dust streams, which are quite dry (less than 10% relative moisture content) usually belong to group I. To filtrate the dust from more humid steams belonging to group II and III, it is necessary to use a filter material with heat finishing treatment (calendering, glazing or singeing) or microporous membrane coating [12]. The heat finishing treatment is used because of the fact that with the increase in the gas relative moisture from 50 to 80%, the efficiency of the untreated cloth regeneration is reduced by 8–24% [12]. For treatment of group IV dusts, it is necessary to apply PTFE or another anti-adhesive membrane coating on the filter material [9].

Droplets of condensed water are formed on the filter surface especially when the moisture content in the dust stream is high and the filtration is carried out below the dew point temperature of the gas. This can create a deposit of particles which could be very difficult to remove or even irremovable with the filter regeneration technique and is associated with a significant loss in filter permeability and a steep increase in ΔP, leading to production outages and the need to exchange the bag filters. Long-term proximity to the dew point is not permissible for the filtration. In order to avoid this, it is recommended to maintain the filter outlet temperature at 15 to 30 K higher than the dew point temperature of the treated stream [9].

For regenerating filter elements and detaching the filter cake, the reverse-flow pulse jet cleaning is most commonly used [13–15]. The short bursts of high-pressure backpulse air (at a pressure of 3–7 bars) [13] are injected directly into the opening of the bags (through the Venturi tube) in the opposite direction of the normal operating flow of the gas [15]. The effect of the pulse–jet is affected by filtration velocity, initial pressure, pulse duration, compressed air tank volume, placement of the injection nozzle and the nozzle diameter [13]. Through the use of pulse jet pulse, part of the cake is detached, which leads to a step decrease in ΔP. This cleaning is commonly uneven – "patchy", leaving the un-detached part of the cake with a different height in different places of the filter element [16]. If the cleaning is patchy, the gas flow is preferably directed onto the low-resistance zones, which creates a steep and sharp rise in ΔP [17]. Also it has been observed that cleaning of different filter bag parts is not even. Regeneration is most efficient in the top and bottom sections [18]. Patchy cleaning is an even bigger issue with higher pleat ratio filters or filters with large filter surfaces. Higher pleat ratio filters suffer from incomplete cleaning mostly in the top part of the filter cartridge [19].

Among the researchers which deal with dust filtration, there is a consensus about the fact that within the experiments using commercial filters, the operating conditions and device setup should be as close as possible to expected full-scale planned implementation [3,13,14].

Results that originate exclusively from the pilot test equipment incorporating only few bags (often only one), may provide very different operating characteristics to real industrial dust collectors [13]. Therefore, an experimental setup that is under very similar or the same operating conditions as industrial installations is clearly valuable [14].

Furthermore, there is a demand for the prediction of the long-term performance and service life of the filter elements using as short laboratory tests as possible. The service life of the filter media lies in the range of 2 to 4 years, depending on the particular application. This corresponds to 200–400 thousands of cleaning cycles [20].

To predict the long term behaviour of the filter media, even hundreds of the cleaning cycles are definitely not enough. The filter degradation could be accelerated in a process called "ageing" or "seasoning" using rapid pulse cleaning. Pulse-jet cleaning is a source of stress for the filter material and a 5 second filtration cycle time is recommended by national standards in order to shorten the ageing time period [16,20]. After several thousand cleaning cycles, the particles on the filter become more difficult to detach [20] and pressure air pulses may affect downstream particle emissions when used over long periods [16].

However, it would be preferable to monitor the performance of an industrial filter bags dust collector over a long period instead of using ageing techniques, to truly get representative results, as we tried to achieve in our industrial case study.

Both the distribution fractions of the PM – PM 2.5 and PM 10.0 have well known and already described adverse effects on human health [3, 21–23]. PM adverse effects on human health are related to the financial and non-financial welfare losses and a significant part of gross domestic product (GDP) is lost due to this fact. This is the main reason, why PM coming from industrial sources have to be treated to the concentration levels that meet local legislation directives or standards [21].

This paper explores the possibility of dry filtration of a humid waste stream from fertilizer production, using a fabric filter material (filter bags) and supported by rigid wire cages with reverse-flow pulse jet cleaning as the waste-less technology. To simulate real industrial conditions as closely as possible, a long-term test on a pilot unit with fifteen bags was performed directly on the industrial plant premises.

2. Theory and calculation

The industrial filter units are usually operated at a constant flow and as the differential pressure on the filter material increases due to the particles deposition on the filter bags forming a cake, the downstream blower must be present for pressure compensation [4,13]. This blower is commonly called the ID blower or induced draft blower [11]. The energy consumption of the ID blower accounts for 60–80% of the total filter operating costs, so to achieve a reasonable ΔP is really important from an economic point of view [1].

When the filtration starts, dust particles are captured on the filter material and form cake, whose properties depend on particle size distribution and particle shape which also plays a role in the cake structure and detachment [14].

The filtration process can be divided into three phases: seasoning (or conditioning), stable operation and blinding [24]. In the initial seasoning phase, ΔP increases during individual cleaning cycles. Stable operation can be defined as the state when the number of pulses which are necessary to overcome the created ΔP during filtration cycles remains constant [25] (this applies to the clean-on-demand cleaning mode, i.e. the filter material is cleaned when ΔP reaches a pre-set value [24]) or ΔP doesn't rise over time (this applies to the clean-on-time cleaning mode, i.e. filter material is cleaned at set time intervals [24]). In the long term, changes on the surface of the filter material cause the formation of cakes which are difficult to remove and the operation of the filter becomes unstable. This is associated with an increase in both the filter medium resistance and the filter cake resistance [25]. In the blinding phase, ΔP further rises and offline cleaning should be applied to recover the filter when an excessive ΔP level is reached. The stable filter operation can be, in some cases, very short or hardly noticeable at all [10].

The developed cake is often fragile [14]. The cake properties, as well as increase in ΔP, further depend on many factors, such as filtration