Novel application of particulate filters: coupling with a biogas steam reformer reactor

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The removal of particulate matter from gaseous streams in several different processes can be efficiently achieved with the use of particulate filters similar to those applied at the exhaust of Diesel vehicles for particles emission control. The most common characteristic of Diesel Particulate Filters (DPFs) is the honeycomb monolithic structure with channels alternately closed, that allows the efficient filtration of soot particles entrained in the exhaust gases through the channel walls.

A process with potential formation of carbonaceous particles as by-products that may cause adverse effects and need to be removed from the product gases is the reforming of biogas (e.g. autothermal steam reforming (ATR) of 60%CH_4 and 40%CO_2). Adaptation of a wall-flow filter close coupled to the ATR reactor, could entail effective filtration and conversion of any carbonaceous particles eventually generated by hetero-homogeneous reactions in the inlet part of the ATR reactor during normal operation or oxygen rich cleaning phases induced by air pulses. Main role of the filter would be to protect the downstream equipment from any generated carbon particles while at the same time to promote the conversion of the collected “soot”, with the aid of an appropriate catalyst deposited on the filter, by either the Boudouard reaction or the gasification with water vapor present in the ATR outlet.

The first step in the filter development was to characterize the carbonaceous particles derived from such a process, especially in terms of their size and morphology. In parallel to this, digital representations of candidate filter materials were reconstructed, taking into account the several structural characteristics (pore or grain size, porosity, wall thickness) that are available, to predetermine suitable material parameters on the basis of permeability and filtration efficiency. Given the availability of commercial samples of the candidate materials, the computations with digital reconstructions of the filter materials were complimented by flow resistance, filtration efficiency and loading experiments on laboratory scale uncoated and catalyst coated filter samples. For the coating of the filters, a carbon gasification catalyst ($LiFeO_2$) was in-situ synthesized and deposited on small scale filters via an aerosol route (Aerosol Based Deposition, ABD) (Karadimitra et al., 2001, Lorentzou et al., 2009). In the ABD method a solution of the appropriate precursors is atomized into micron-sized droplets that pass through a heated tube reactor. The particles that are formed deposit on the filter which is placed within the flow of the particles. The aim was to appropriately deposit the catalyst on the filter so that it would limit the effect of the catalytic layer on the development of unacceptably high pressure drop.

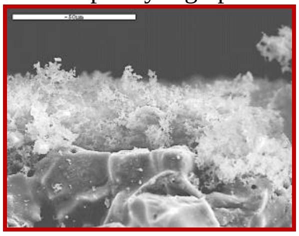

Figure 1. $LiFeO_2$ catalyst layer on filter channel wall

Additionally, Computational Fluid Dynamics (CFD) models were set-up using material properties derived from the preceding work to investigate the geometrical characteristics and the positioning of the filter within the ATR system. The aim was to identify the critical parameters that would impact on the flow distribution in the reactor and adjust appropriately the filter-reformer integration. Having identified all the parameters the next step was to prepare the full scale catalytic filter.

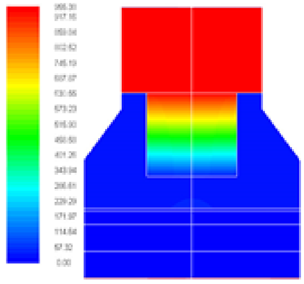

Figure 2. CFD analysis of the full-scale filter coupled to an ATR reactor: pressure drop

A specially designed pilot-scale unit equipped with an in-house made atomizer, for the production of aerosol droplets, was employed for the catalyst deposition on the full-scale filter that was further characterized by flow resistance measurements on a dedicated test rig and developed pressure drop at acceptable levels for the process (<80 mbar). The full-scale catalytic filter was coupled to the ATR system and the overall performance of the integrated system was assessed.

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