SETTING A NEW MILESTONE IN FILTER MEDIA DESIGN: SIMULATING PERFORMANCE ACCORDING TO MULTI PASS TEST BASED ON 3D FIBER STRUCTURES

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ABSTRACT

The performance of filter media for automotive oil filtration is determined according to the Multi Pass test procedure ISO 4548-12. Simulating the Multi Pass test has been an elusive challenge in the past, due to the lack of appropriate models for the loading kinetics of the entire media. For years, simulation of loading single fiber structures is promising to solve the issue by detailed build-up of particulate structures. Recent progress in the software development of GeoDict/FilterDict and the implementation of MANN+HUMMEL's filtration knowledge have led to successful simulations of the performance of a virtual media according to the Multi Pass test. The results closely correspond to measured data on the test rig. Thus, the former elusive goal has been reached and a new milestone in virtual filter media design has been set.

KEYWORDS

Fibrous Filter, Filter Design, Oil Filtration, Multi Pass Test, CFD Simulations

INTRODUCTION

Today's requests for lower CO_2 engine emissions demand more efficient oil filters with increased dust holding capacity at lower pressure drop. The preferred standard test for ranking the performance of an (automotive) oil filter media is the Multi Pass Test according ISO 4548-12. Simulating this test to match actual measurements has been a huge challenge in the past. The obstacle has been the ongoing change of the filter efficiency with collected mass. Furthermore, the particle size distribution and concentration in front of the filter change over time, as the oil is pumped in a circuit and as fluid volumes taken out for measurement are replaced by fresh contaminated oil. This has an effect on efficiency, too.

A common approach for simulating filter efficiency based on analytical equations is to start with particle collection by a single fiber. Many equations have been published primarily for air filtration, but are only valid for small ranges and even then often vary in their predicted results (Hoferer et al. 2007). Furthermore, filtration in oil is different from filtration in air (Banzhaf 2004) and requires a special approach, such as implemented in the program **[auto*efficiency*]** (Banzhaf et al. 2007). The next step is to simulate the loading of the media by collecting particles. But despite ongoing research no equation is available that would overcome the previous issues (Kasper et al. 2002).

The most critical point for simulating performance according to the Multi Pass Test is the missing clogging point, when fibrous filtration turns into cake filtration. As long as it is unknown how to describe the clogging point, there is no need to bother about equations of loading kinetics for either fibrous or cake filtration.

Consequently, as filtration theory does not offer analytical equations we selected CFD to simulate media performance according to the Multi Pass Test. The build-up of particulate structures is modeled in detail, starting from a virgin fiber surface up to cake formation. Incidentally, we obtain the performance kinetics of the fibrous filter media, without having to prescribe a clogging point. In the following chapters we will briefly describe our approach, present and discuss first results.

APPROACH

The performance of fibrous media is determined by its fiber structure. To enhance the media performance nowadays layers of different fiber structures are combined to produce a MULTIGRADE media. The characteristics of these fibrous structures have been studied for a long time. Major work was contributed by Schweers and Löffler (1993). Recently, new methods have been applied such as MRI and XCT (Hoferer et al. 2006), both illustrating the apparently random fiber configuration. Such 3D fiber structure can be virtually replicated by modern computer software such as GeoDict (Wiegmann et al., 2005) and algorithms therein (Schladitz et al., 2006).

Virtual 3D fiber structures were generated with GeoDict for simulation according to the Multi Pass Test procedure. The step of generating the virtual media is similar to obtaining filter media from a supplier for a later test on the rig. For comparison reasons, we selected input parameters based on real media. The packing density of the media layer, its fiber size distribution and orientation were derived from our standard paper test or SEM images. Fig. 1 shows the 3D fiber pattern and SEM image of such a virtual replica.

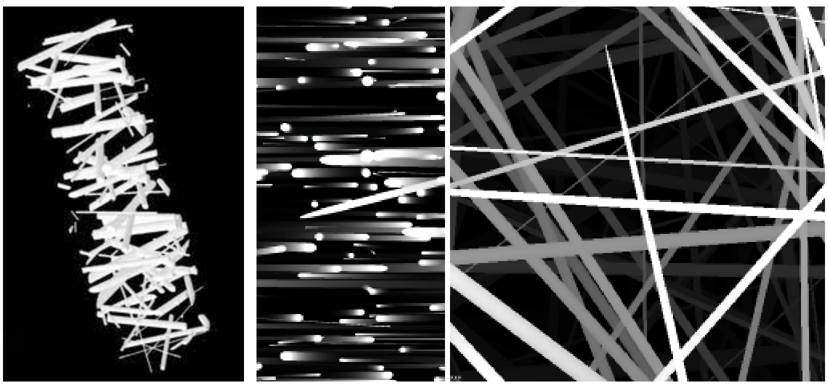

Fig 1 – 3D fiber structure and cross sections of a virtual media generated with GeoDict

The filtration performance of the virtual media was then simulated with FilterDict. Originally, this module of the GeoDict software suite has been designed for air filter media, being tested by a single pass procedure. Therefore, virtually challenging a media according to the Multi Pass Test required additional tasks. A module was developed for MANN+HUMMEL, remodeling the standard test procedure within the FilterDict environment (Fig. 2). This Multi Pass module is part of the front end for simulations with the GeoDict and FilterDict solvers.

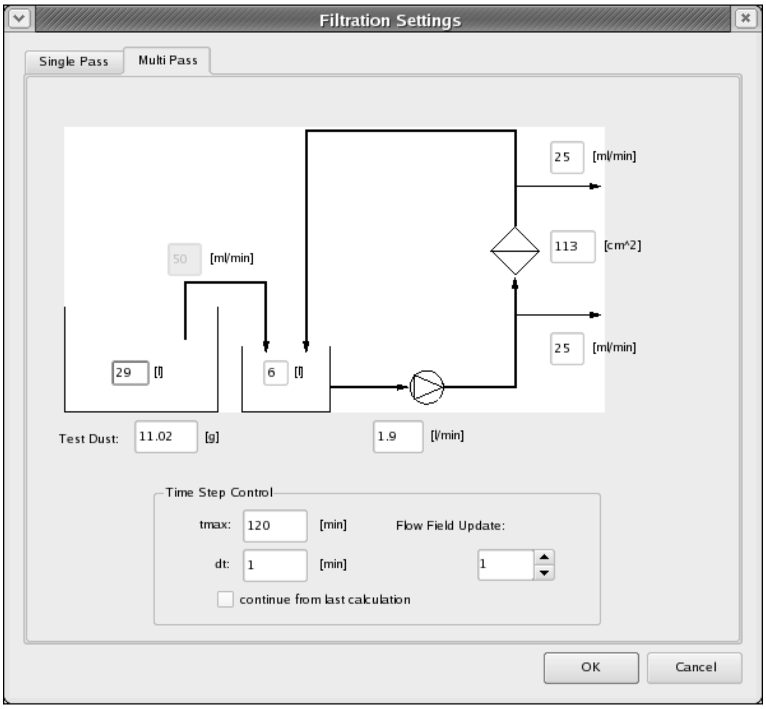

Fig. 2 – Input mask of the FilterDict Multi Pass module

For the flow field and pressure drop simulation the GeoDict solvers were used. Typical solvers are a Finite Difference Solver (Wiegmann, 2007) or the Lattice Boltzmann solver (Kehrwald, 2004).

The FilterDict module was used for simulating particle filtration. It calculates particle tracks based on the flow field of a previous GeoDict simulation. If a particle hits the surface of a fiber or a particle deposited in a previous time step, the particle can either stick or bounce back based on the impinging velocity. We enhanced the treatment of particle capture/bounce by a MANN+HUMMEL proprietary User Defined Function (UDF). It implements a more advanced theoretical model for particle capture and adds particle re-entrainment, both primarily based on Banzhaf (2004). This UDF is essential for an accurate prediction of efficiency as it accounts for the particular physics of particle filtration in oil. The collected particles are then added to the deposit's structure. Based on the changed solid volume the flow field is recalculated and the particle tracking is started again. This loading of the filter media – almost particle by particle – is repeated until the final pressure drop of 200,000 Pa is reached, the same limit as in the Multi Pass Test rig. We thus obtain the loading kinetics of the virtual filter media. The results are presented in the next chapter.

RESULTS

We simulated the performance according to the Multi Pass Test for a variety of virtual filter media. In this paper we will only focus on two filter media, as the results are quite similar. The typical slope of the loading kinetics is illustrated in Fig. 3. Both start with a linear increase of pressure drop during the fibrous filtration phase and display a strong increase during the cake filtration phase. In Fig. 4 the measured capacity of the two filter media is compared to the capacity obtained by simulation. Taking into account that only a very small sample of the media surface, 0.1 mm x 0.1 mm, was simulated, the results are quite good.

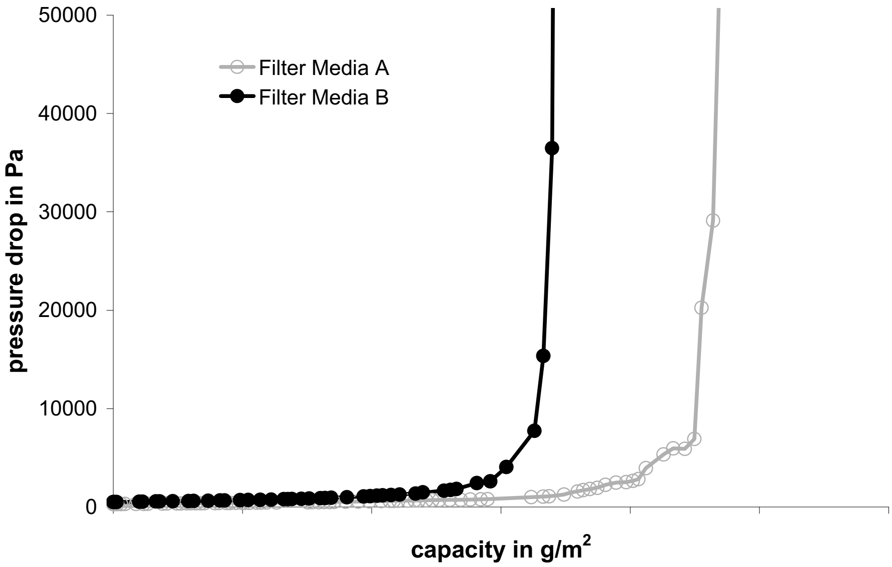

Fig. 3 – Typical slope of the loading kinetics of a fibrous filter media shown for two virtual samples

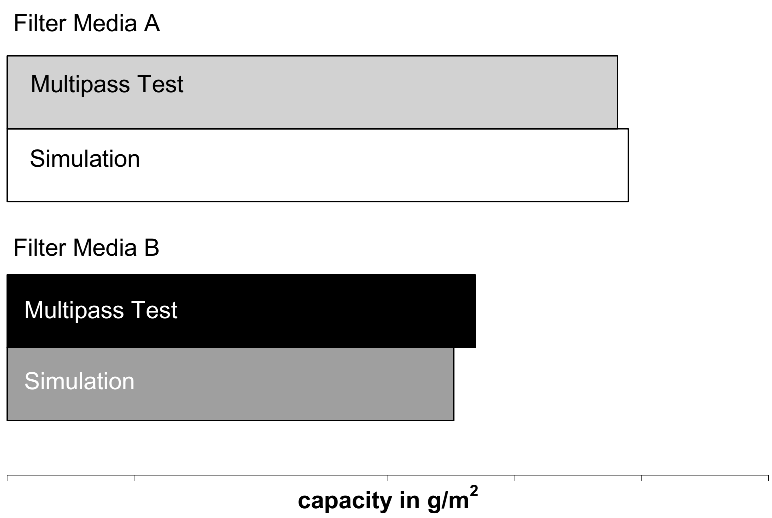

Fig. 4 – Capacity obtained by measurement on the test rig compared with simulation

CONCLUSION

For the first time, the loading kinetics of a virtual oil filter media can be predicted which closely correspond to measurements. By combining the software tools GeoDict/FilterDict and a MANN+HUMMEL UDF we obtain detailed information about all performance parameters, i.e. efficiency, pressure drop and dust loading over the life time of the filter. This enables us now to virtually optimize MULTIGRADE filter media for tomorrow’s applications with regard to performance and cost.

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