FAST MEDIA-SCALE MULTI PASS SIMULATIONS

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ABSTRACT

For computational efficiency, current media-scale Multi Pass simulations of the Multi Pass test procedure ISO 4548-12 in ITWMs FilterDict Software work on *batches* of particles. Each batch consists of a fixed number of particles of test dust that are all transported based on the same flow field and that all get deposited on the same obstacle structure. The flow field is first computed for the initial fibrous obstacle structure given by the filter medium. Before each new batch previous deposited particles are added to the obstacle structure and the flow filed is updated.

Now an automated control accounts for the transition from depth to cake filtration by adjusting the numbers of particles / amount of test dust deposited in a given batch. The principal features of the method approach are currently shown for a small, scholarly test example. The old and new methodologies running with MANN+HUMMELs specialized UDFs are expected to yield similar results and to compare very well with experiments performed on a Multi Pass test stand. Yet the new methodology is expected to take much less computer run time than the original method.

KEYWORDS

Filtration Simulation, Multi Pass Test, Oil Filtration, CFD

1. 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 pressure drop and the filter efficiency with collected mass. Furthermore, the upstream particle size distribution and concentration 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.

The most critical point for simulating performance according to the Multi Pass Test is the shift from fibrous filtration regime to cake filtration regime at the collging point.

Best would be a different setup for each regime. But 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 (Lehmann et al. 2008). The build-up of particulate structures is modeled in detail, starting from a virgin fiber structure and then alternating flow field and particle trajectory calculation for each new batch of particles. The amount of particles is determined by the batch duration. Incidentally, we obtain the performance kinetics of the fibrous filter media, without having to prescribe a clogging point. Now, the transition at the clogging point from depth filtration to cake filtration is explicitly identified during the simulation and the previously constant simulation parameter “batch duration” is adjusted automatically.

2. 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. For comparison reasons, we selected input parameters based on real medium. The packing density of the medium 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.

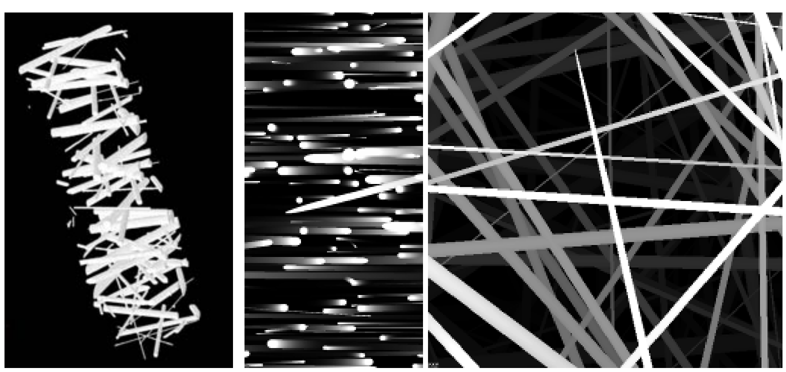

Fig 1 – 3D fiber structure and cross sections of a virtual medium generated with GeoDict (from Lehmann et al, 2008).

FilterDict computes the flow field for a given obstacle structure which consists of the filter medium and deposited particles from previous batches. Based on this flow field, particle trajectories are computed in batches, that is for groups of particles that travel and deposit independently of each other. If a particle hits the surface of a fiber or the surface of a previously deposited particle, the new particle can either stick or bounce back based on the physical model. The collected particles are then added to the obstacle structure. Based on the changed obstacle geometry, the flow field is recomputed and the particle tracking is started again. This loading of the filter medium – 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. It was seen earlier (Lehmann et al., 2008) that the simulation results agree qualitatively and quantitatively with experiments. Figure 2 (from Lehmann et al., 2008) shows the typical pressure drop evolution for two different filter media.

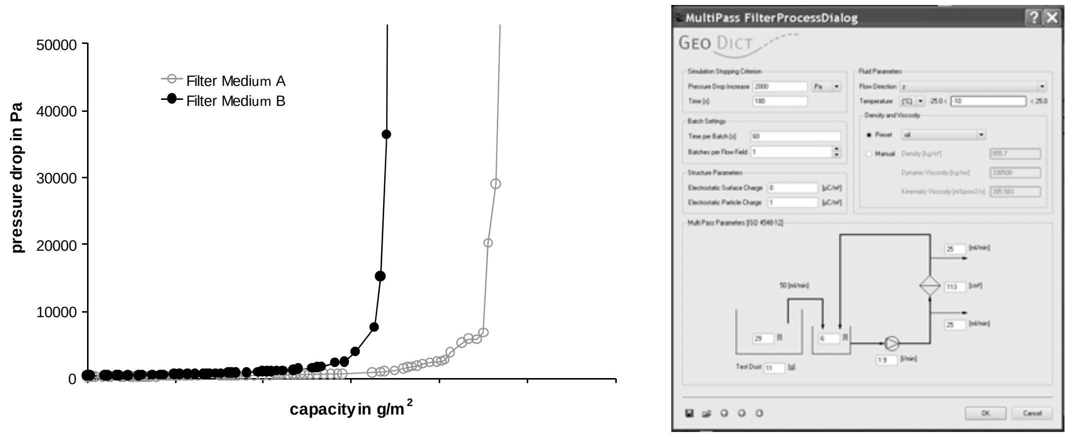

Fig. 2 – Typical slope of the loading kinetics of a fibrous filter medium shown for two virtual samples (Lehmann et al. 2008) and Input mask of the FilterDict Multi Pass module

In our enhanced approach for Multi Pass simulation we make use of (1) the effect of collecting just a few particles and of (2) identifying the transition from depth to surface filtration. The filtration performance of the virtual medium was then simulated using the Multi Pass mode of FilterDict (Lehmann et al. 2008), with two modifications.

1. The flow fields in modified obstacle structures (after particles have deposited) are computed using a new flow solver (Cheng at al. 2010) that can use the previous flow field as initial guess for the computation of the current flow field.

2. The duration of a batch is dynamically adjusted, based on the particle deposition locations computed for the previous batch.

3. Results

We primarily focus on the methodology and consider a very small structure that warrants better and easier visualization of results. Two particle sizes of diameters 6 µm and 12 µm are used. Simulations for more realistic structures and comparisons with experimental data will follow (Becker et al., submitted for AFS 2011).

Rather small numbers of particles are used per batch to ensure that newly deposited particles do not overlap. A constant number of particles for the entire simulation does not use the knowledge of the clogging point, the transition from depth filtration to cake filtration. During depth filtration, the amount of test dust per batch may be larger because a three-dimensional volume is available for deposition. For cake filtration, only a two-dimensional surface is available for deposition. With a fixed amount of test dust per batch chosen appropriately for surface filtration, the simulation is inefficient because many more flow fields are computed than necessary during depth filtration. For larger amounts of test dust per batch, the simulation has to be halted at the clogging point and manually restarted with different parameters because too many particles per batch yield unrealistic overlapping particles and too high pressure drop for cake filtration.

Figure 3 shows a run with our enhanced approach of adjusting the batch duration. During depth filtration (left), large and small particles of current batch (black) deposit throughout the particle loaden filter medium (grey), and some even penetrate. During surface filtration (right), all particles deposit on the filter cake, no particles penetrate. In the middle data of z-position of collected particles, the mean value per batch and the pressure drop evolution are illustrated. During depth filtration, more particles are considered concurrently while avoiding overlapping deposition locations than during surface filtration, simply due to the available space for deposition. The transition automatically happens as soon as the mean value of z-positions moves outside the filter medium. After this, the pressure drop increases much more rapidly than during depth filtration. Thus the automatic transition takes place around the clogging point. The criterion for change of batch duration adjustment can be set by UDF or GUI.

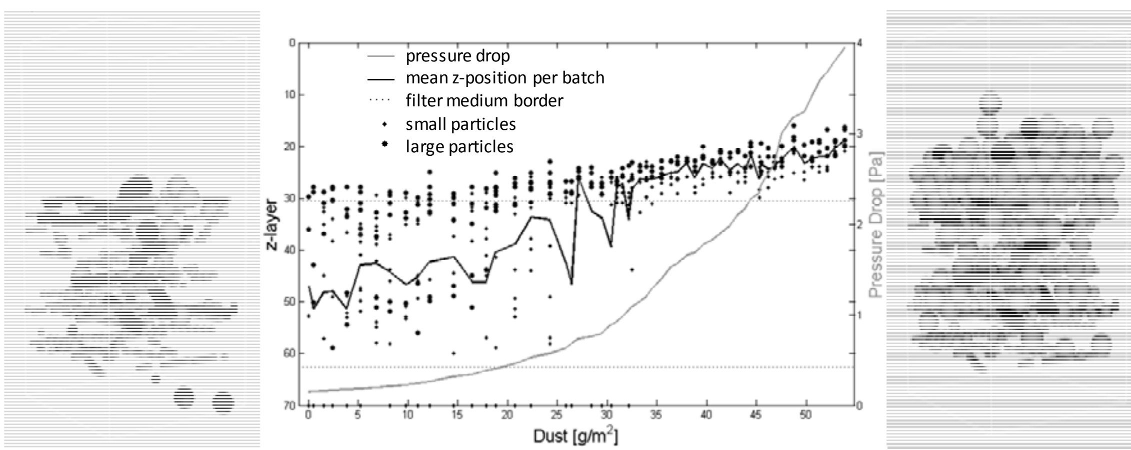

Fig. 3 – (Left) example of deposited particles for depth filtration regime: current batch – black, previous and initial obstacle - grey; (middle) z-position of deposited particles and pressure drop evolution as function of deposited dust; (right) example of deposited particles for cake filtration regime.

4. Conclusions

The number of particles in filtration simulations should be chosen according to the regime. For depth filtration, more space is available and more particles can be simulated than for surface filtration. The mean depth coordinate of the deposition location is a first, promising candidate for predicting when the simulation should switch parameters from the depth filtration regime to the surface filtration regime.

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