Aachen 2010

Filter and Particle Simulation for Hydraulic Systems

Karl Wartlick

Argo-Hytos GmbH, Kraichtal-Menzingen, Germany

René von Dombrowski

RWTH Aachen University, Germany, Institute for Fluid Power Drives and Controls

Andreas Schindelin

Argo-Hytos GmbH, Kraichtal-Menzingen, Germany

ABSTRACT

Within the German government-funded research project “Fluidtronic” a commercial system simulation tool for hydraulic systems has been set up for particle simulation. Models for particle transport, particle entrainment and filtration have been developed and implemented. This offers the possibility to simulate the dynamic distribution of particles also in more complex hydraulic systems. It allows efficient filtration design and enables to check the purity levels of sensitive components, such as servo valves. Other advantages are the better planning of maintenance intervals and the possibility to have a look at different operating conditions, e.g. cold starting conditions in mobile hydraulic systems. In this paper, the models for particle and filter simulation are described. Furthermore, first simulations and verifications are shown.

NOMENCLATURE

A_{eff}	effective filter area	cm²
β	filtration ratio	1
Δp	pressure drop	Pa
m	specific particle mass	mg/cm²
M	absolute particle mass	g
x	particle diameter	µm (c)
Ψ_{WA}	sphericity (WADELL)	1

1 INTRODUCTION

Due to more and more highly developed and complex hydraulic systems, and the fluid power sector being a very important business branch in Germany, the urge came up to make development processes more efficient. That’s one main motivation for the German government-funded project “Fluidtronic” [1, 2].

An important part in designing hydraulic systems is to find an adequate filtration concept. Therefore operating and ambient conditions are important. Equally important are requirements on oil purity and filter life time which affect maintenance intervals. Considering the increasing complexity of hydraulic systems the design of adequate filtration concepts becomes more difficult. This complexity becomes a greater challenge for designers because until now the design of a filtration system has mainly been based on experience.

To get better predictions and insights especially in complex hydraulic systems and different filtration concepts a particle and filter simulation has been developed as one part of the “Fluidtronic” project. The main steps from choosing a basic hydraulic simulation tool, describing particles and particle entrainment as well as the detailed filter modeling are described in the following chapters. First verifications and simulations are shown in chapters 5 and 6.

2 SIMULATION ENVIRONMENT

The particle simulation environment is set up within the commercial system simulation tool DSH*plus*, provided by FLUIDON. One reason for choosing this tool is the open and editable program code of DSH*plus*, which allows an easy implementation of additional equations and models.

The particle simulation, like the hydraulic system simulation is based on a lumped parameters simulation. The hydraulic circuit can be defined within the simulation tool by integrating different hydraulic components via drag and drop. The components are connected through volume nodes, where the main particle calculations take place. Here the particle mass currents are balanced and integrated to particle concentrations.

3 PARTICLE MODELING

The basis for particle simulation is to set up an adequate particle description. The main steps are defining particle diameters, mass and number concentrations as well as transport equations.

3.1 Particle Diameter and Particle Shape

Automatic particle counters for hydraulic applications are calibrated by the projected area of the measured particles [3]. This is the reason, why the equivalent diameter of the projection (defined as µm(c)) was chosen to describe the particle in the simulation.
The simulation tool works with particle mass concentrations. Additionally it is necessary to calculate particle quantity concentrations. Therefore the particle density and a shape factor are required. To allow a diameter conversion from projection equivalent diameters (x_A) into volume equivalent diameters (x_V) the particle sphericity (WADELL) [4] is used to describe the particle shape.

$$x_V = \frac{x_A}{\psi_{WA}^{0.5}}$$

3.2 Particle Classes

To get a decent image of the whole particle spectrum it is necessary to divide the particle distribution into enough particle classes. The default setting is 20 different particle classes from 2 up to 70 µm(c). The classes are freely adjustable to focus on interesting particle sizes. Particles bigger than the maximum diameter and smaller than the minimum diameter are calculated in separated equations in order to guarantee mass conservation. In Figure 1 the particle classes for an exemplary distribution are shown.

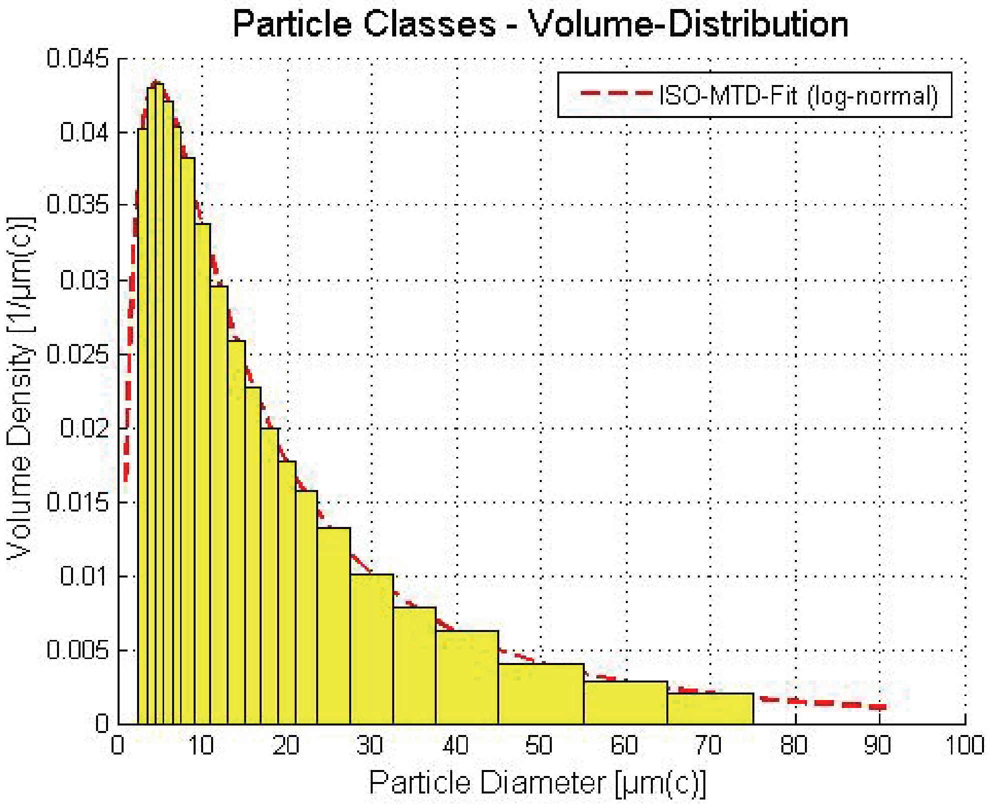


Figure 1: Default particle classes (Volume density distribution)

3.3 Particle Entrainment

One important requirement for good results in particle simulation is reliable information on particle entrainment in real hydraulic systems. Therefore two test benches were built at the Institute for Fluid Power Drives and Controls in Aachen (Germany).

3.3.1 Breather test bench

In different operating conditions the oil level in the hydraulic tanks changes. An air exchange is therefore necessary. In the often dusty environment, breathers are being used to prevent most particles from entering the hydraulic tank.

On the test bench a differential cylinder was used to change the oil level and get an air exchange with the environment. Different breather filters and dust concentrations (ISO 12103: medium test dust [5]) have been examined. A particle counter recorded the increasing particle quantity up to over 1000 cylinder strokes.

This way it was possible to set up a breather model for the particle simulation tool. The breather model describes the particle entrainment dependent on the exchanged air flow rate, the air particle concentration and the filter fineness of the breather.

3.3.2 Dust entrainment test bench

Another way particles can enter the hydraulic oil is through the sealing systems of cylinders. A test cylinder has been examined using different piston rod diameters, sealing systems as well as dust and operating conditions.

Additionally a first particle transfer function model from the ambient air into the hydraulic oil by the cylinder has been built up for the particle simulation. Therefore a sealing specific transfer function was defined, similar to a filtration efficiency function.

4 FILTER MODELING

Hydraulic filters are necessary to filter particles from the hydraulic oil and to make sure that the required purity level (ISO 4406 [6]) can be hold. But the filtration ratio is not the only important value for filter modeling. Another important parameter is the pressure drop, which increases through the amount of particles captured in the filter media until its dust holding capacity is reached. To prevent the filter media from being overstressed and destroyed the differential pressure is usually limited by a bypass valve. This is also useful for special operating conditions like a cold start.

Figure 2 shows a typical sectional view of a pressure filter including the housing, the filter element and a bypass valve.

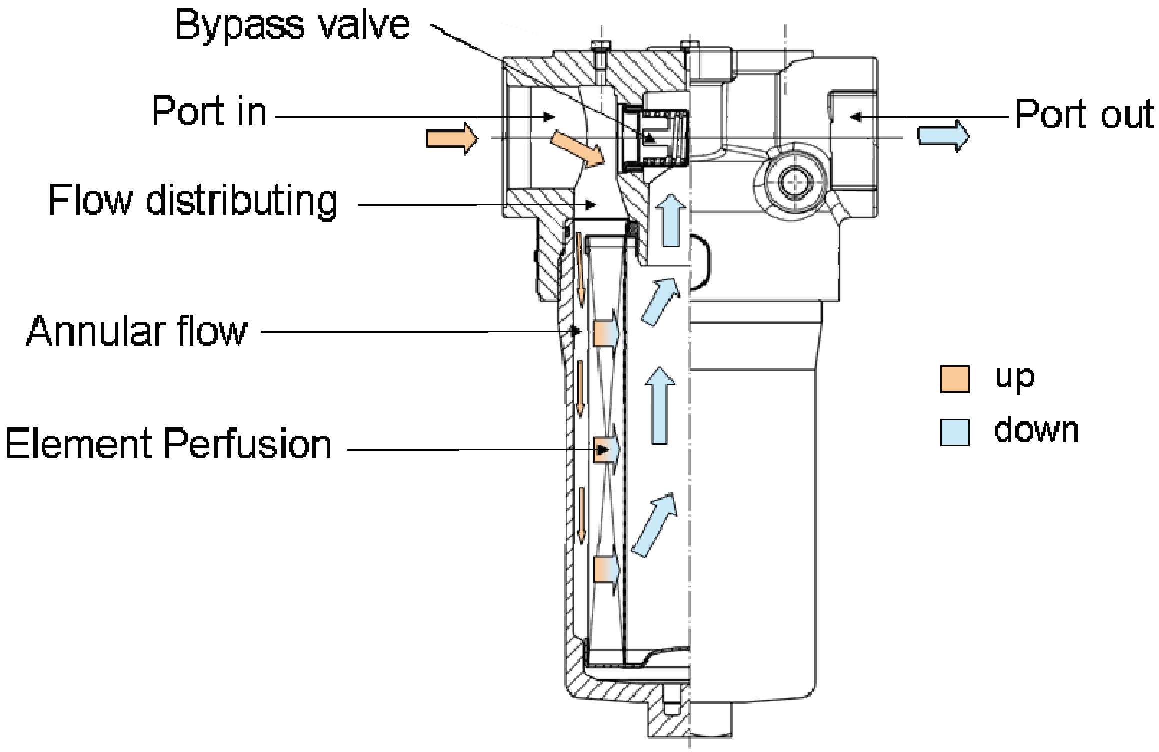


Figure 2: Argo-Hytos pressure filter (sectional view)

4.1 Filtration Ratio

The filtration ratio of a hydraulic filter is usually defined by the ratio of particles (larger than a determined particle diameter) before and after the filter media.

$$\beta_{x,c} = \frac{\text{Particles} > \text{x before filter}}{\text{Particles} > \text{x after filter}}$$

The particle simulation uses fractional particle classes. Therefore the cumulative measured filtration ratios have to be transferred to fractional filtration ratios.

In the next step a curve fitting is getting an analytical equation for the fractional filtration ratio in dependence on particle diameters.

$$\beta_{x,f} = \frac{\text{Particles} = \text{x before filter}}{\text{Particles} = \text{x after filter}} = f(x)$$

4.2 Pressure Drop

4.2.1 Uncontaminated Filter element

The basic pressure drop for the uncontaminated filter element is measured and modeled depending on the kinematical viscosity and the volume flow rate based on an equation similar to Darcy’s law.

$$\Delta p_0 = f(\upsilon, Q)$$

4.2.2 Contamination factor

To describe the increasing pressure drop while filtering, a contamination factor was defined and adjusted to test results. This factor is mainly dependent on the specific particle contamination.

$$\Delta p_{element} = f_{con}(m) \cdot \Delta p_0 \qquad \text{specific particle contamination} \quad m = \frac{M}{A_{eff}}$$

4.2.3 Housing

In the simulation the complex geometry of the filter housing can not be reproduced one on one. Therefore the simulation uses an alternative flow setup consisting of laminar and turbulent flow resistances. They depend on the kinematical viscosity and the flow rate.

4.2.4 Bypass Valve

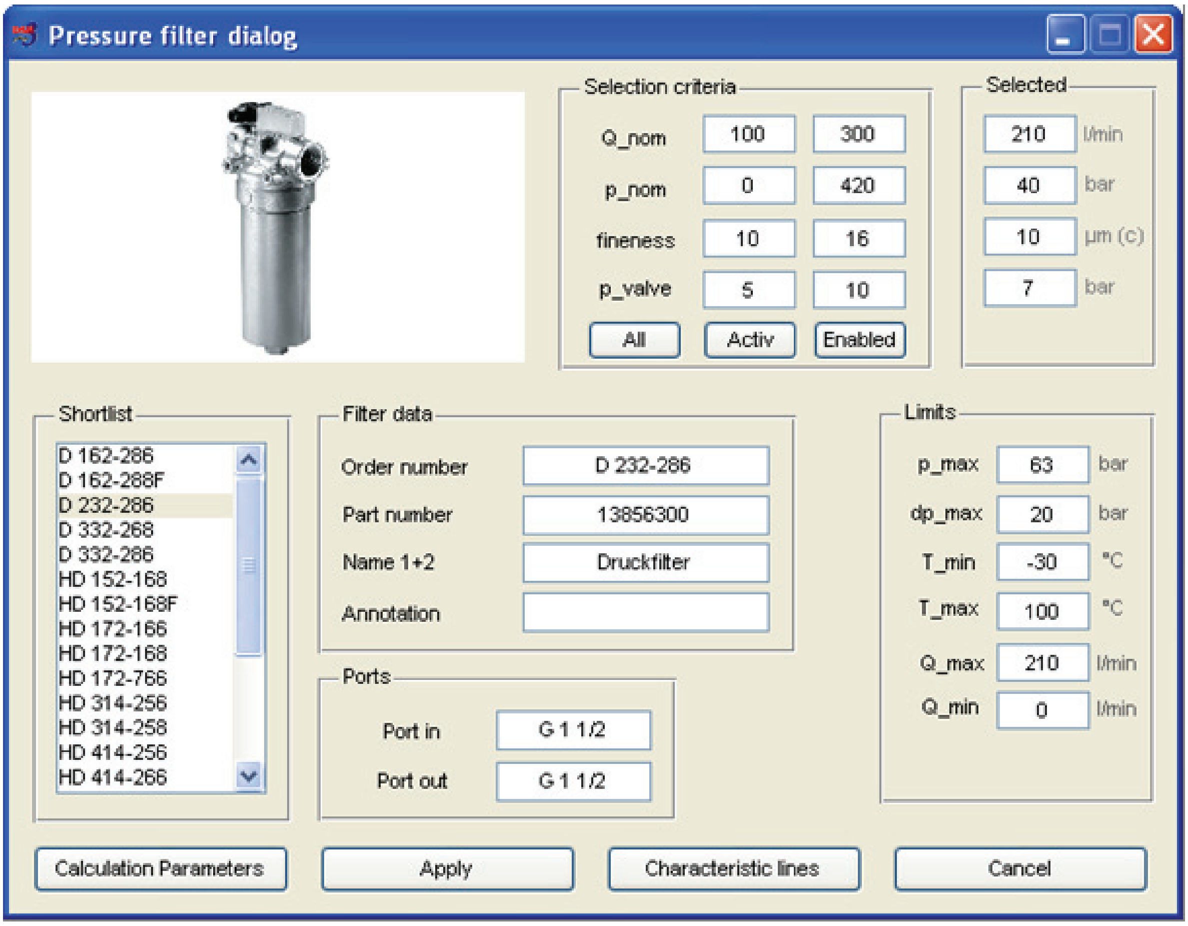
The bypass valve is mostly independent from viscosity. The simulation uses a model, which is defined in multiple sections. Each of theses sections describes the pressure drop depending on the flow rate.

4.3 Filter Parameterisation, Simulation Database and Dialog

A standard testing method for filter elements, the so called multi pass test (ISO 16889 [7]) is used get the performance characteristics of the filter elements. On the one hand the filtration ratio is measured. On the other hand the pressure drop during increasing contamination is documented. Beside the multi pass tests the parameters for the uncontaminated filter element, the bypass valve and the housing are being recorded.

The parameters of the simulation models are adopted to these results and saved in a filter database.

This database consisting of Argo-Hytos filters is integrated into the simulation environment DSH*plus*, via an especially programmed filter dialog (see fig.3), for easy choice and parameterisation of appropriate filters.


Pressure filter dialog

Selection criteria
Q_nom 100 300
p_nom 0 420
fineness 10 16
p_valve 5 10

Selected
210 l/min
40 bar
10 µm (c)
7 bar

Shortlist
D 162-286
D 162-288F
D 232-286
D 332-268
D 332-286
HD 152-168
HD 152-168F
HD 172-166
HD 172-168
HD 172-766
HD 314-256
HD 314-258
HD 414-256
HD 414-266

Filter data
Order number: D 232-286
Part number: 13856300
Name 1+2: Druckfilter
Annotation:

Ports
Port in: G 1 1/2
Port out: G 1 1/2

Limits
p_max 63 bar
dp_max 20 bar
T_min -30 °C
T_max 100 °C
Q_max 210 l/min
Q_min 0 l/min

Figure 3: Filter dialog (Argo-Hytos Filters for simulation)

5 VERIFICATION – MULTI PASS TEST

To verify the simulation models a multi pass test (standard testing method for hydraulic filter elements) was designed in the simulation (Fig. 4). It's a simple hydraulic circuit consisting of a tank, a pump, the filter element and a dust entrainment component. A beta calculation component is implemented for the calculation of filtration ratios.

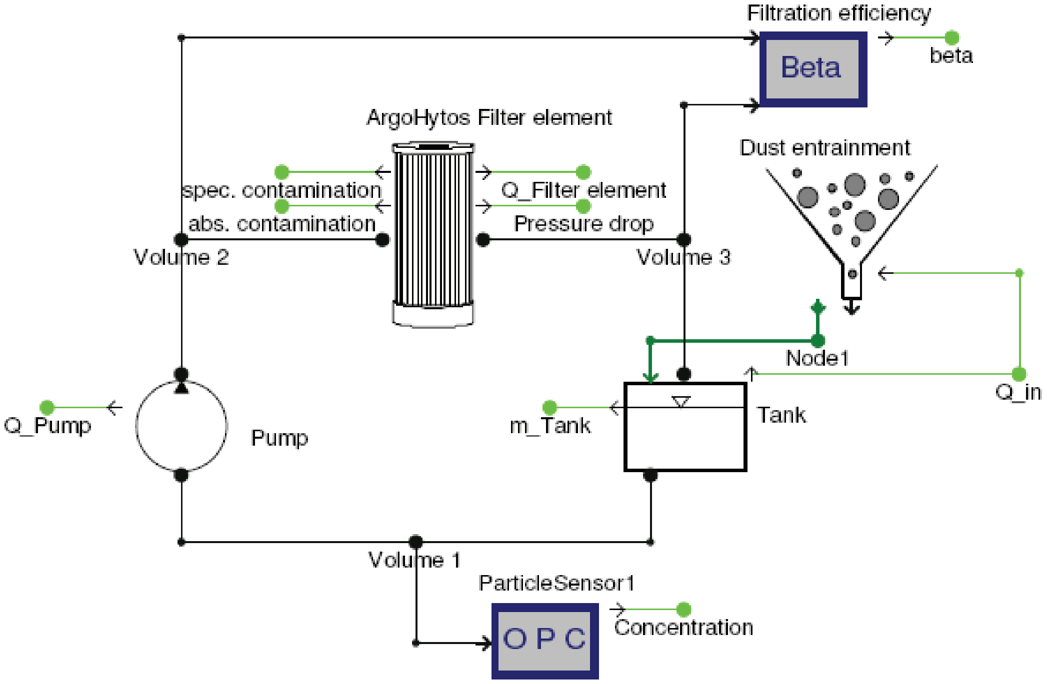


Figure 4: Multi pass test in DSHplus

The comparison of the results of the simulation and the actual multi pass test shows a very good correlation regarding particle numbers, filtration ratios and pressure drop. (Fig. 5+6)

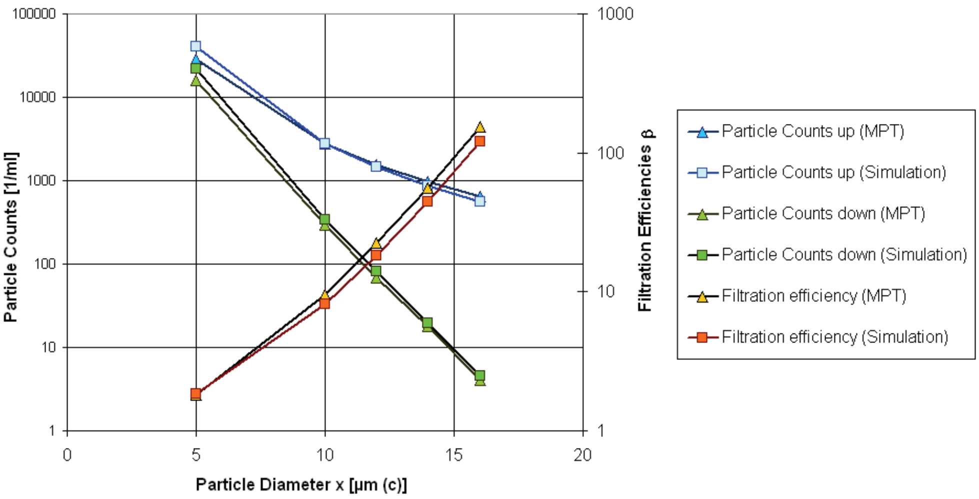


Figure 5: Simulation and multi pass test results (1)

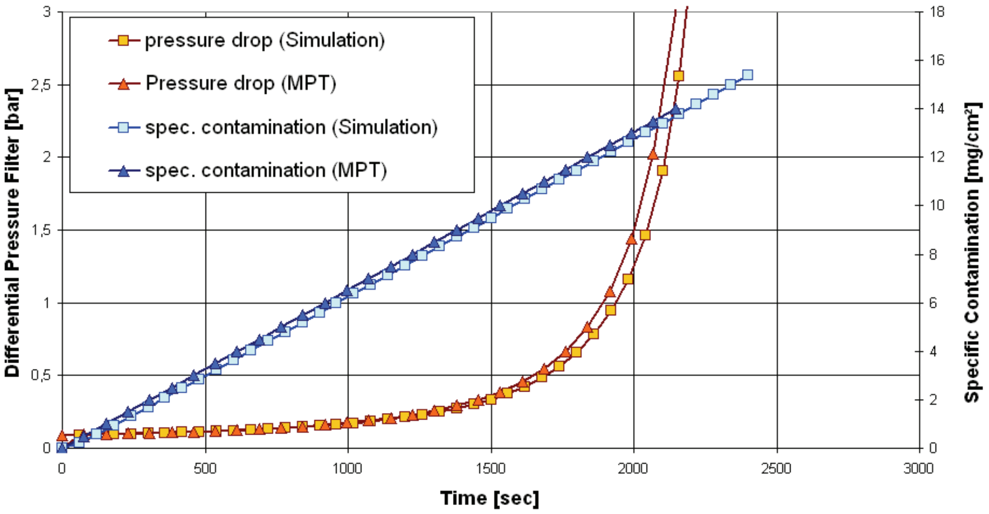


Figure 6: Simulation and multi pass test results (2)

6 SIMULATION WITH TWO FILTERS

Figure 7 shows another exemplary simulation circuit. In this case two completely parameterised filters (including models for housing pressure drop, annular gaps and bypass valves) are embedded into a multi pass test setup.

Figure 8 is recorded at equilibrium, meaning the amount of particles entrained into the system is equal to the captured particles of both filters. The interesting point is to see how the entrained particles are distributed between both filters. The particles first pass the suction filter which collects the rather large particles of the entrained particle distribution. The rest of the particles are being captured in the pressure filter which tends to collect the smaller particles.

In Figure 9 the pressure drop for both filters is shown. The pressure drop increases with increasing contamination of the filter elements, until the bypass valves open. This indicates that the maximum dust holding capacity of the filter element is being reached. Although the suction filter takes about twice the mass of particles when compared to the pressure filter the bypass valve opens later due to the larger effective filter area. This case shows the optimization potentials of the simulation tool. Generally, the more complex the system becomes, the more the simulation can be helpful in order to find a good filtration concept. It can be used to check required purity levels at different parts of the system as well as getting information about required dust holding capacities which result in maintenance intervals.

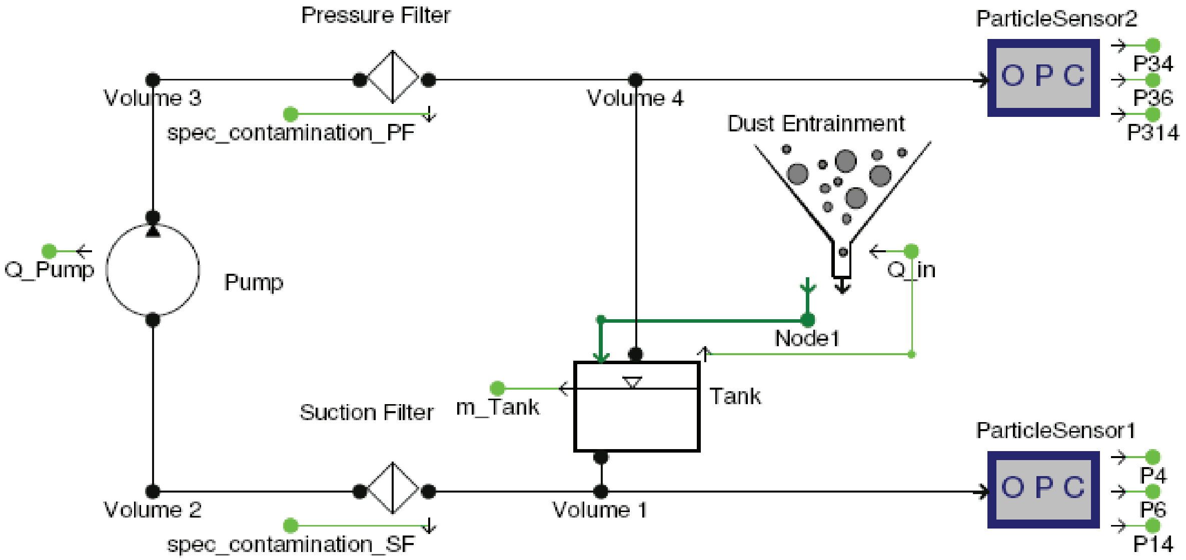


Figure 7: 2-filter simulation model: suction filter and pressure filter

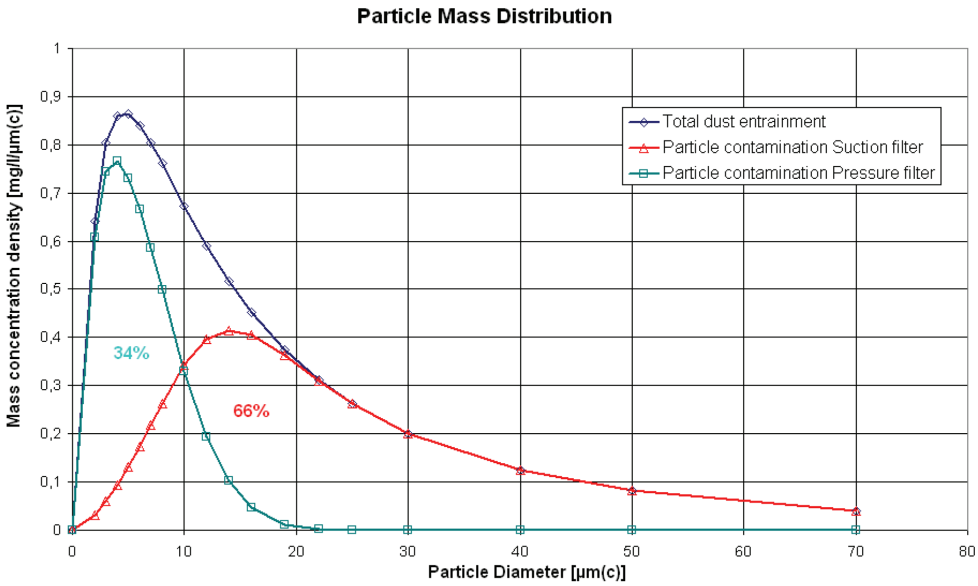


Figure 8: 2-filter simulation results suction filter and pressure filter

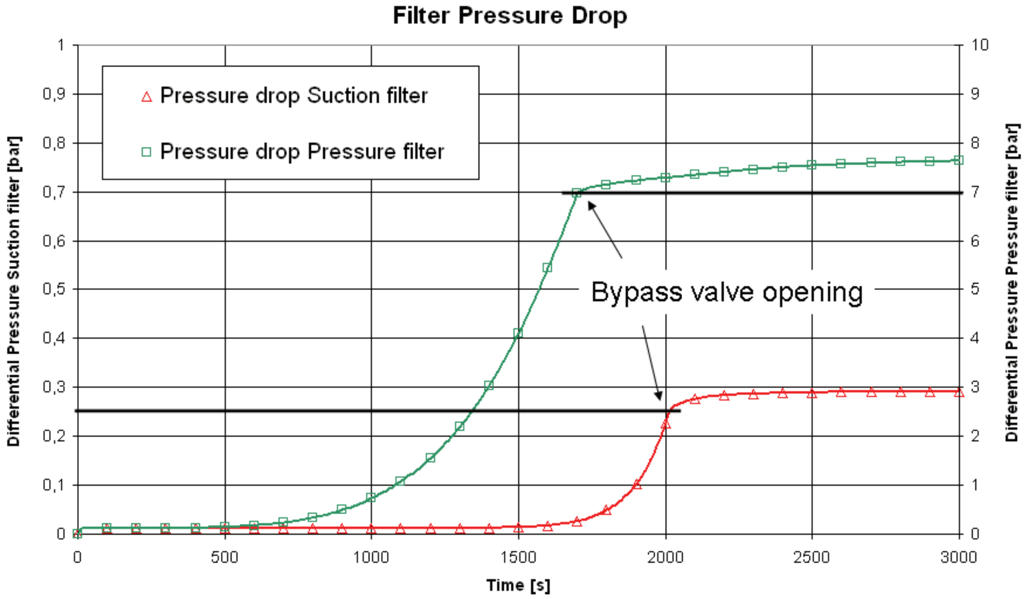


Figure 9: 2-filter simulation results under multi pass test conditions

CONCLUSION

The main aspect of this paper is to show the possibility of creating a simulation which is capable of presenting an optimized filtration concept in regards of the specific hydraulic system as well as the demanded oil cleanness level.

The system simulation tool (DSH*plus*) has been upgraded to the capability of particle simulation. As a requirement test benches have been set up at the Institute for Fluid Power Drives and Control in Aachen in order to develop models for particle entrainment.

The models of particles and filtration and the verification of these models have been shown as the necessary steps in the process of creating such a simulation tool.

Particle numbers, purity levels, dirt holding capacities, pressure drops and other interesting parameters can be checked anywhere in the system during different operating and ambient conditions by this tool.

ACKNOWLEDGEMENT

The work described in this article is part of the research and development project “Fluidtronic”. The project was funded by the German Federal Ministry of Education and research (BMBF) within the concept “Research for Tomorrows Production”. It has been managed by the project management agency Forschungszentrum Karlsruhe Production and Manufacturing Division (PTKA-PFT).

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