# MULTIPHYSIC COUPLED IMPREGNATION SIMULATION FOR RTM PROCESS WITH NANOPARTILCE-MODIFIED RESIN SYSTEMS

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## Introduction

Nanoparticles (NPs) provide a promising way to effectively improve the performance of fibre reinforced polymer (FRP) structures or introduce certain functionalities to them. This is especially attractive for liquid composite moulding (LCM) processes, allowing for a cost-efficient production of high-performance FRPs [1, 2]. Nevertheless, depending on the chemical and physical characteristics, the NPs might show adverse effects of on the critical impregnation parameters e.g. cure kinetics, viscosity and the fibre preform permeability, which may negatively influence the pot life of the matrix and the impregnation quality [3, 4].

The flow simulation of the NP-filled fluid system is critical and complex as the NPs may dramatically influence the flow behaviour of the fluid system, considering the retention of the particles during the flow [5-7]. The focus of this paper is to model and simulate the impregnation of fibre textiles with NP-modified epoxy matrix systems. The simulation results are validated by real impregnation experiments. Furthermore, the model is applied to investigate the critical material/process parameters (critical particle size and textile compaction– filament distance distribution) with respect to the flow and retention behaviour of the NPs.

## Theory and numerical implementation

If the particles could be filtered during the flow, it leads to a change of the fluid density and viscosity characteristics and textile porosity. By separately considering the liquid and particle phase, it is possible to develop the governing mass balance equation for the liquid and NP phase, in a finite control volume (FCV). The flow and retention behaviours are coupled by the viscosity change of the matrix and the permeability change of the fibre textile, as shown in the following Figure 1. The flow front tracking is achieved by an extra level-set model that is coupled to the flow and retention models.

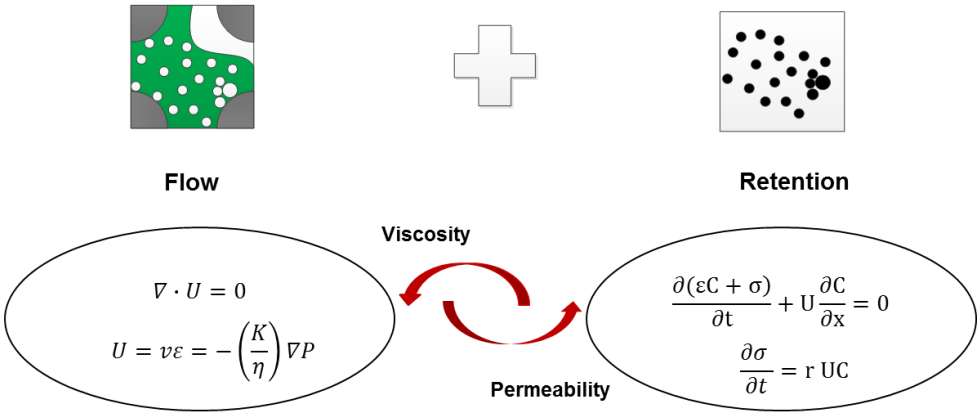


***Figure 1**: Flow and retention coupling during the impregnation process*

Therein, $U$ Darcy velocity, $v$ seepage velocity, $\varepsilon$ porosity, $K$ permeability, $\eta$ viscosity, $\nabla P$ pressure gradient, $C$ concentration of NP in the matrix, $\sigma$ NP retention, $r$ retention coefficient.

## Experimental

Boehmite NPs with primary particle size of 14 nm (DISPERAL HP14, SASOL Germany) are dispersed into the epoxy matrix a high-performance laboratory kneader HKD-T0.6 (IKA, Germany) to produce masterbatches with 40 wt% boehmite NPs, at the Institute for Particle Technology (IPAT), TU Braunschweig. The particle size within the produced masterbatch is measured by Nanophox (Sympatec, Germany) as described in the paper [8]. The $X_{10}$, $X_{50}$ and $X_{90}$ values of dispersed particle size within the produced masterbatch are separately 81 nm, 104 nm and 134 nm. The injection experiments are carried out in a permeability-measurement test rig and the flow front data and corresponding time are collected accordingly. For the experiments, the masterbatch is diluted to the desired particle concentration with a planetary mixing machine (Thinky Mixer ARV-310).

## Results and discussion

According to the flow simulation and validation results in Figure 2, the flow front development can be well predicted by the simulation. Regarding the NP retention behaviour, the model can also well describe the NP retention behaviour by fibre volume fraction (FVF) 50%, but it show certain deviation by FVF 60%. This is presumably due to the different NP retention mechanisms. Based on the filament distance distribution characteristic, the textile structure by FVF 50% show a dual-scale porous structure with both macro and micro channels, where the NP show a slight deep bed filtration. In comparison, by FVF 60%, the macro channels vanish with just micro channels left, correspondingly, the flow of NPs show a remarkable cake filtration mechanism. Further studies regarding filament distance distribution and particle size show that there is a threshold compaction state of the textiles regarding the particle size distribution, which is critical to the change in the retention mechanism of the NPs.

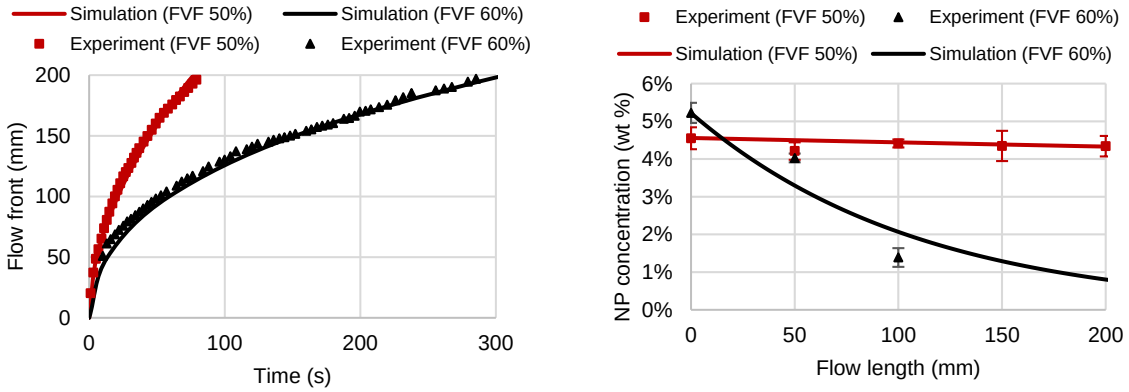


***Figure 2**: Flow simualtion validation with NP-modified matrix*


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