# MOLD FILLING SIMULATION IN RTM PROCESSING OF NATURAL FIBER COMPOSITE MATERIALS

G. Francucci[1*], J. Moran[1], E.S. Rodriguez[1]

[1] *Composite Materials Group (CoMP), Research Institute of Material Science and Technology, INTEMA-CONICET, Engineering Faculty, National University of Mar del Plata. Solís 7575, B7608FDQ Mar del Plata, Argentina.*
**Corresponding author's e-mail: gfrancucci@fi.mdp.edu.ar*

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**Introduction**
When natural fibers are used, the permeability decreases as the infiltration process takes place because the fibers absorb fluid and swell, decreasing the porosity of the preform as the open paths for flow are reduced [1-3]. This work presents an approach for the simulation of a one dimensional mold filling stage during RTM processing, considering a representative variation in preform´s permeability as the fibers absorb fluid and swell.

**Permeability field model (PFM)**
The model presented in this work takes into account the difference in porosity between the fully saturated and the partially saturated zones, leading to a field of porosity and permeability along the length of wetted reinforcement. The movement of the flow front is modeled using the "Volume of Fluid" technique (VOF) with a fully convective scheme and SUPG stabilization [4]. The model is solved using the finite element method. The numerical calculation is performed in three steps. First, the pressure distribution, P(x), is calculated over the entire domain by using Darcy´s Law. Then, the fluid velocity field, V(x) is calculated from pressure field. A variable ($\alpha$) that determines the filling fraction is transported (locating the flow front where $\alpha$=1/2). The material derivative is equal to zero, because neither source nor sink exist along the process domain (Equation 1).

$$\frac{d\alpha}{dt} = \frac{\partial \alpha}{\partial t} + V\ \nabla\alpha = 0 \qquad (1)$$

Finally, the filling fraction, $\alpha$, is advected by the local average values of the velocity field. The advection time is calculated for every step, and is chosen adequately to keep the Courant number close to unity. The time step is modified as the flow front advances, ensuring the algorithm stability. Dirichlet boundary conditions are imposed at the injection and vent nodes. The permeability value in the wetted region of the preform depends on the instantaneous porosity of each element of the mesh. The permeability in the dry region of the preform is assumed to be $10^3$-$10^4$ times higher than the initial permeability, $K_0$. This allows setting a pressure value almost null at the front flow without the need of moving boundary conditions, simplifying the algorithm. Every time a new element is "filled" by the fluid ($\alpha$>1/2), a local flag is raised and a local "element wetting time" starts to be computed by the algorithm. Then, the porosity of each element in the domain is calculated using an empirical relation obtained from swelling tests (fiber diameter vs. time data) performed with the same fluid being modeled. The permeability can then be computed applying the Carman-Kozeny model which empirical parameters were determined with a non-swelling fluid. Results were compared to those obtained using an Homogeneously Variable Permeability Model (HVPM) where the permeability of the entire wetted preform is calculated by using the time since the injection begins)

## Results

In the PFM, each element of the mesh has its own permeability value, which is only a function of immersion time. Despite the pressure drop is linear within each element, the global pressure distribution does not follow a linear behavior, as expected from models that consider a constant permeability value (Figure 1). The PFM predicts a higher pressure drop in the zones where the fibers experienced higher swelling than in the zones where fiber swelling was less significant. The models that reflect the decrease in porosity due to fiber swelling led to lower velocity curves tan the classic Darcy's Law model. Despite the velocities predicted by both models are not significantly different, this small difference in velocity persists over a long period of time. As expected, Darcy's Law predicts a faster mold filling that the other models. For a 1D one meter long mold being filled with a 25% V/V water/glycerine solution and a dry porosity $\phi_0$=0.7 the PFM predicted a filling time 14% lower than the HVPM. Figure 2 shows the flow front position vs. time curves predicted by Darcy's law and the PFM, as well as the experimental data corresponding to the permeability tests done with SAE 20 motor oil and the water/glycerine solution. If SAE 20 oil is used as the test fluid, the constant permeability model will not predict accurately flow front movement when the water/glycerine solution is used in the test.

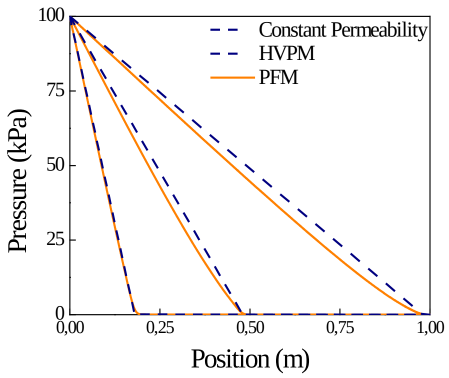


**Figure 1:** *Pressure gradients vs Position*

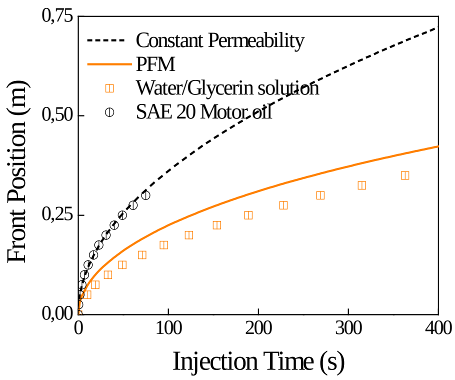


**Figure 2:** *Polar vs. non-polar fluids injections*

## Conclusions

In this work, two models that consider the effect of fluid absorption and fiber swelling on the porosity and permeability of the preform were proposed. These models predict a much slower flow front movement that the model that assumes a constant permeability value. Comparing the two proposed models, the PFM predicts a greater flow rate than the HVPM, but this difference in the velocity field is minor and occurs only during a certain time range. The experimental data was fitted more accurately by the PFM for polar fluids.

## References


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