Resin Transfer Molding (RTM): Use of PAM-RTM Software for Process Simulation, and Development of an Analytical Model To Verify Linear and Radial Flow Results

Khalid Aldhahri

Department of Chemical and Materials Engineering

University of Dayton

Abstract

The main thrust of this study was to demonstrate the effectiveness of PAM-RTM simulations of RTM for understanding how to choose the right location of injection and vent ports, cure development, and monitoring the position of resin. These results were validated with analytical solutions using Darcy's Law applied to 1-dimensional linear and radial flow models of simple geometry systems. This study compared results of these two approaches (analytical vs. commercial numerical models) for flat panel molds and using two different resin injection strategies for each: constant pressure and constant flow rate. The results showed that the pressure distribution for linear flow model at the injection port for constant flow rate was linearly increased with time to a value exactly double that used for constant injection pressure. The pressure distribution of constant flow rate for radial flow model at the injection port demonstrated 8.45% higher than constant injection pressure.

Background

Liquid composite molding processes are among the most commonly used processes in composite manufacturing, including resin transfer modeling (RTM) and vacuum-assisted RTM (VARTM). RTM involves four essential steps to produce the composite part: loading the fiber preform into the mold, injecting the mold with resin, resin curing, and composite demolding. The final composite properties are affected by these steps of production, especially the mold filling and resin curing steps. Numerical process models offer potential benefits for use in RTM, such as improving the mold design, optimizing the location of resin injection gates and vents, controlling the position of the resin flow front, and improving part quality. Numerical modeling allows for initial viewing of the expected flow patterns and cure profiles before the actual resin injection experiment. The commercial PAM-RTM software is used to simulate key process variables, including resin velocity, pressure distribution, filling time, and process parameters.

Model Data for Flow

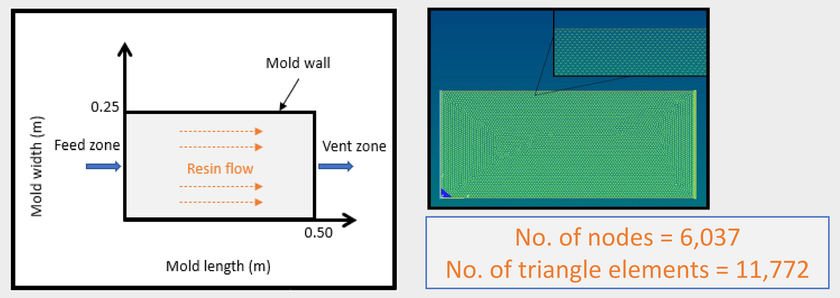
	Linear flow model		Radial flow model	
	Constant pressure	Constant flow rate	Constant pressure	Constant flow rate
resin viscosity, μ (cP)	100	100	100	100
Permeability, K (m²)	1×10^{-9}	1×10^{-9}	1×10^{-9}	1×10^{-9}
Preform porosity, Φ	0.50	0.50	0.50	0.50
Injection pressure, P_{inj} (Pa)	1×10^{5}	2×10^{5}*	1×10^{5}	1.11×10^{4}*
Injection flow rate, Q_{inj} (m³/s)	2.5×10^{-5}*	5×10^{-5}	1.08×10^{-5}*	8.95×10^{-4}

- * *value at the end of mold filling*

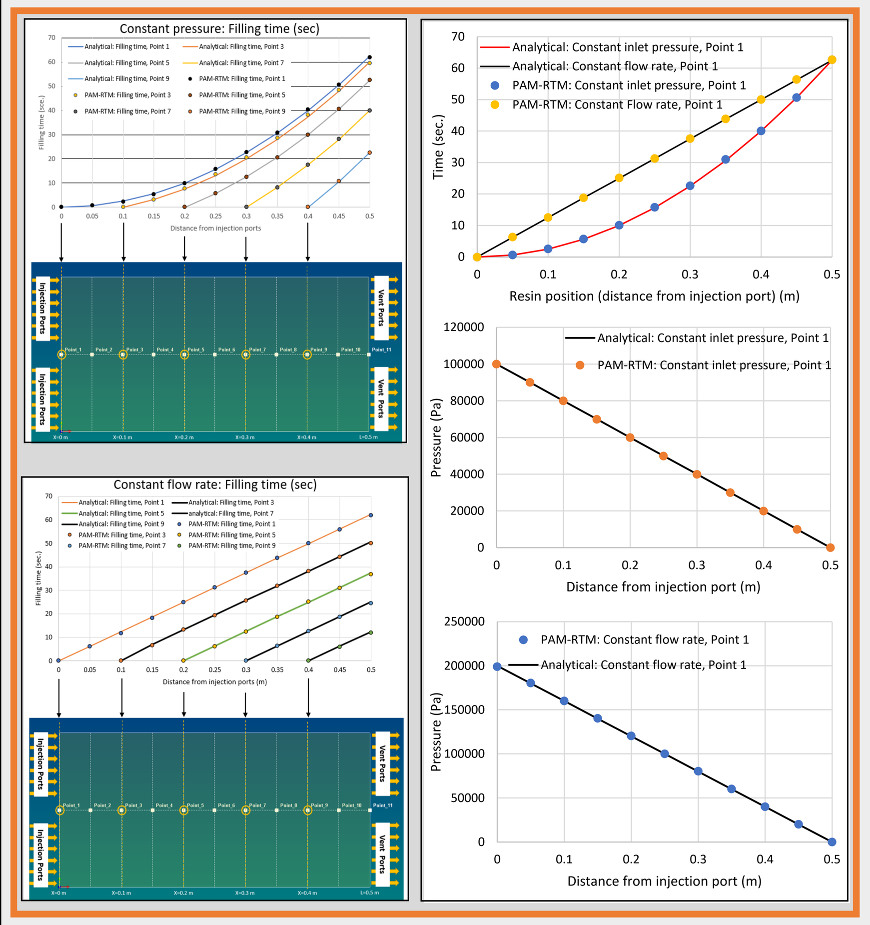
The following steps are required for PAM-RTM simulation

Results

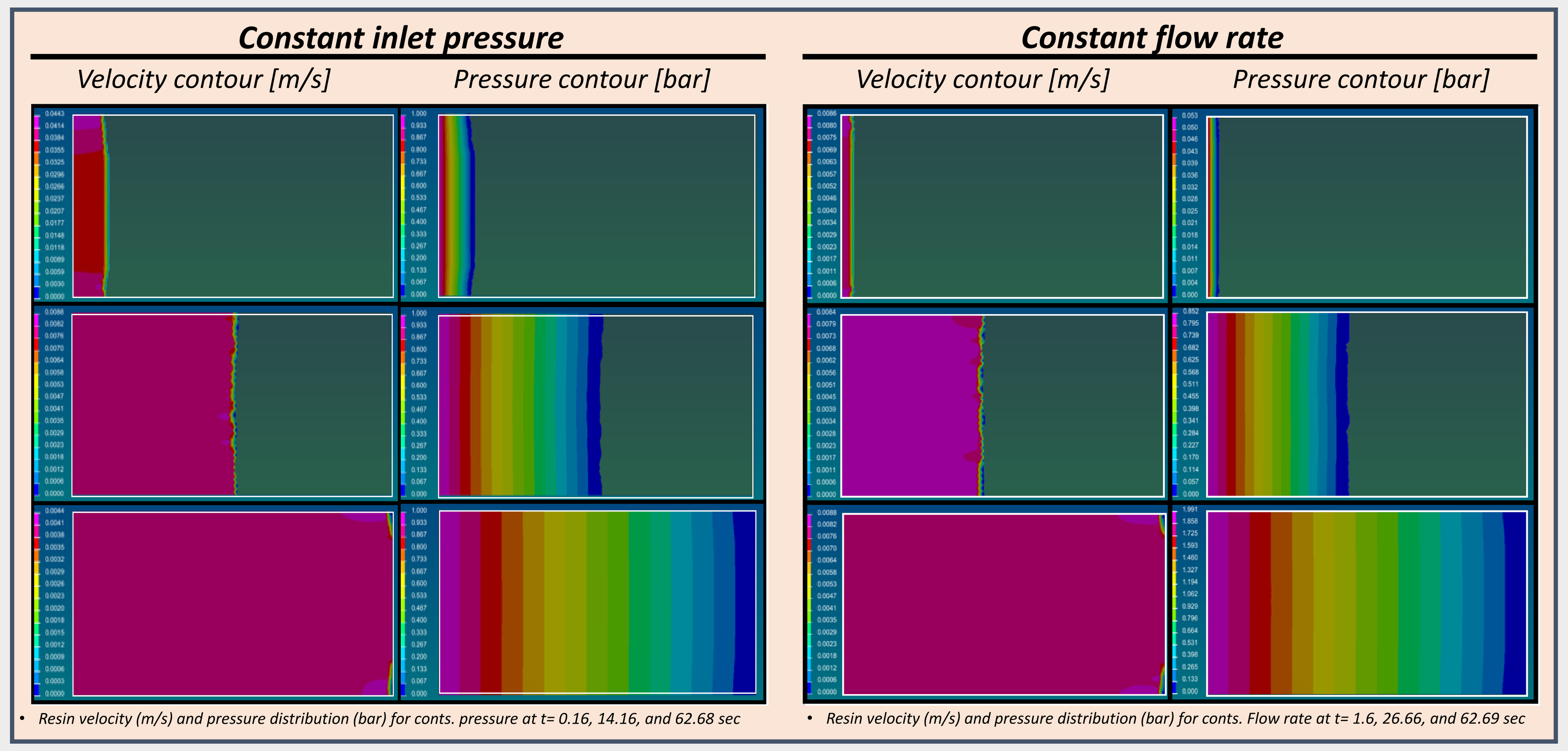
Linear Flow Model



Mold geometry and mesh for 1D flow analyses for linear flow model

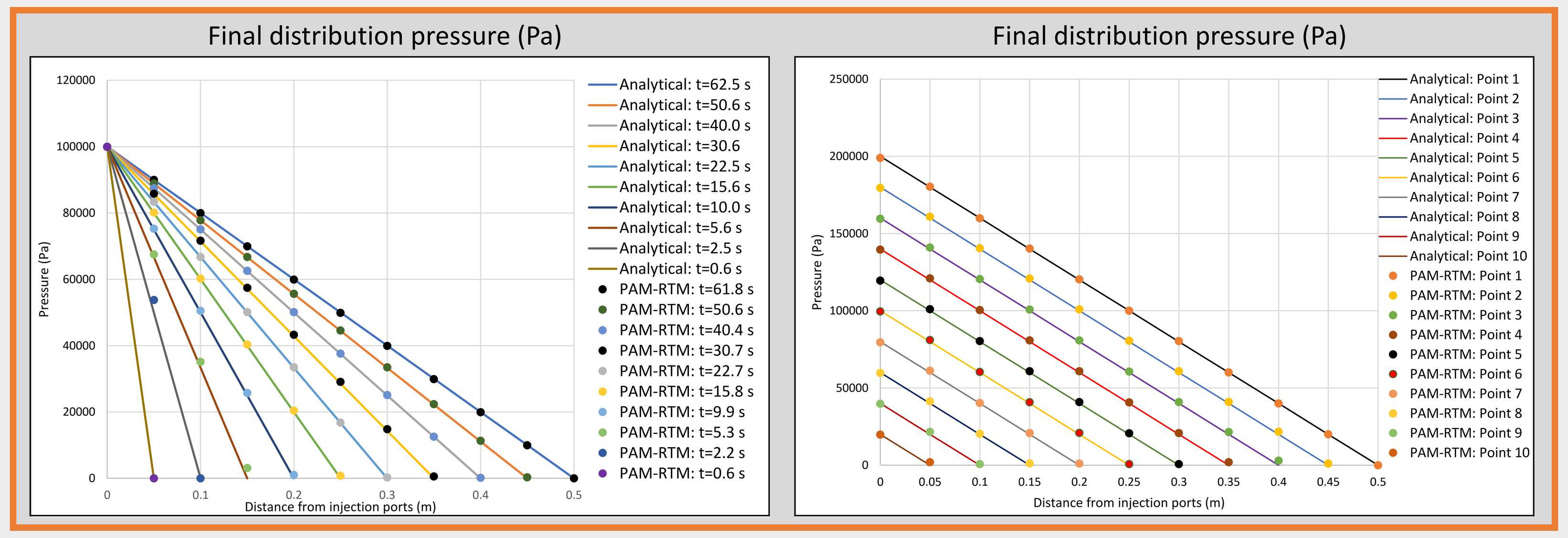


Predicted fill times with increasing flow path length



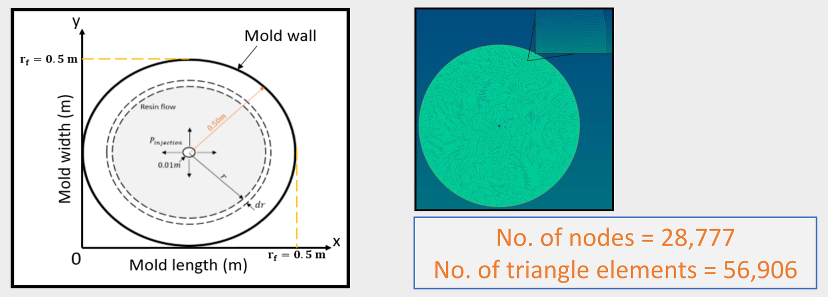
- Resin velocity (m/s) and pressure distribution (bar) for conts. pressure at t= 0.16, 14.16, and 62.68 sec
- Resin velocity (m/s) and pressure distribution (bar) for conts. Flow rate at t= 1.6, 26.66, and 62.69 sec

Top view of PAM-RTM shows the resin velocity and the pressure distribution of the resin for constant pressure and constant flow rate

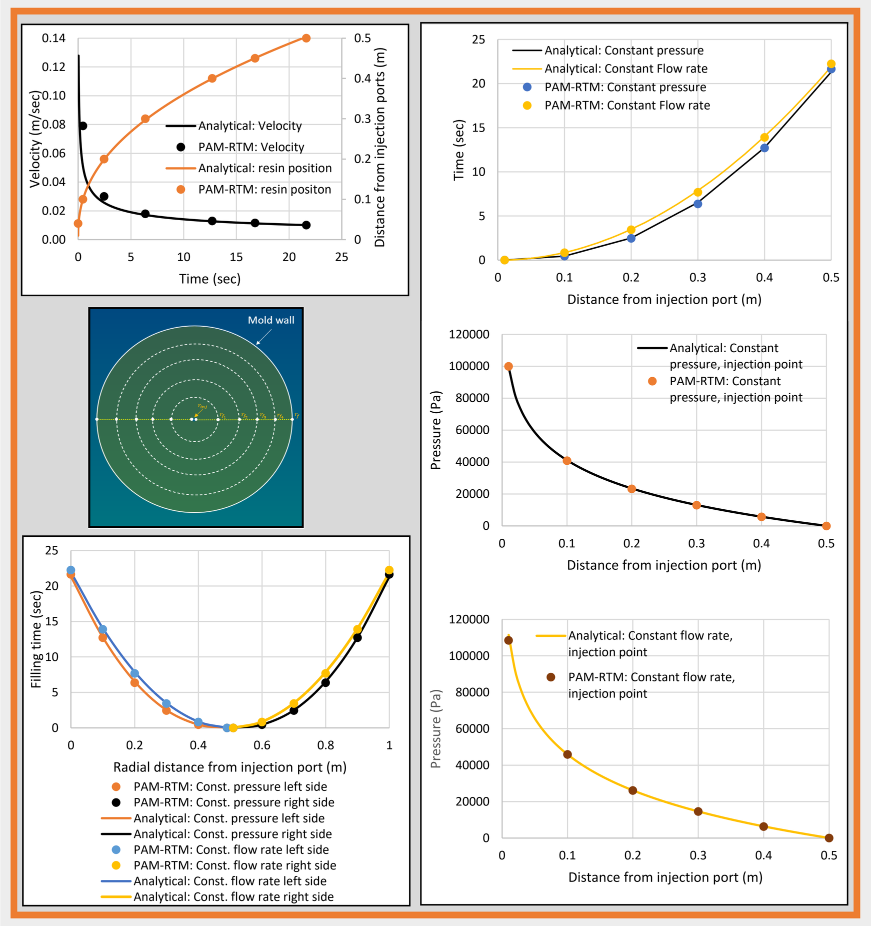


Predicted pressure during part filling for a linear flow model for constant pressure and constant flow rate

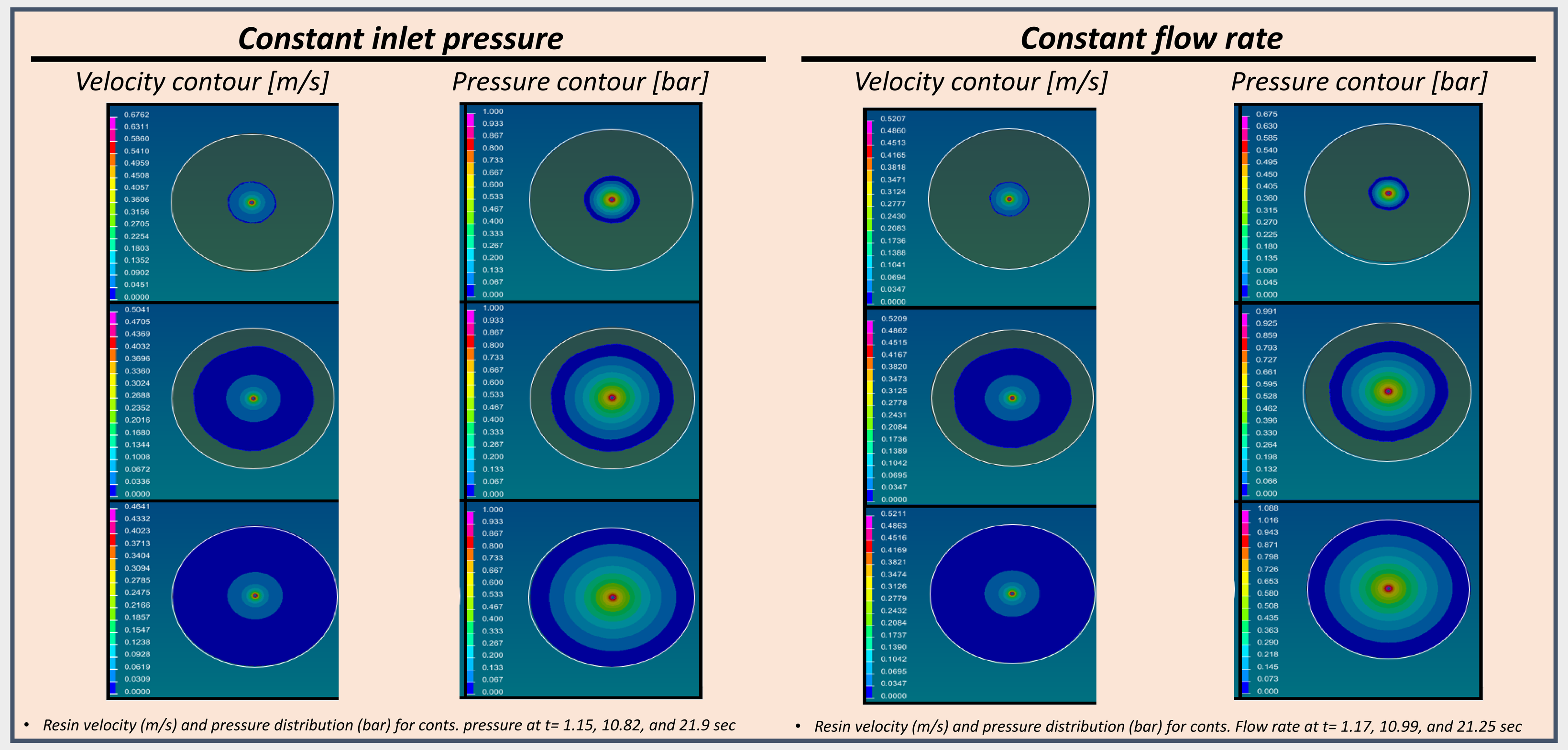
Radial Flow Model



Mold geometry and mesh for 1D flow analyses for radial flow model

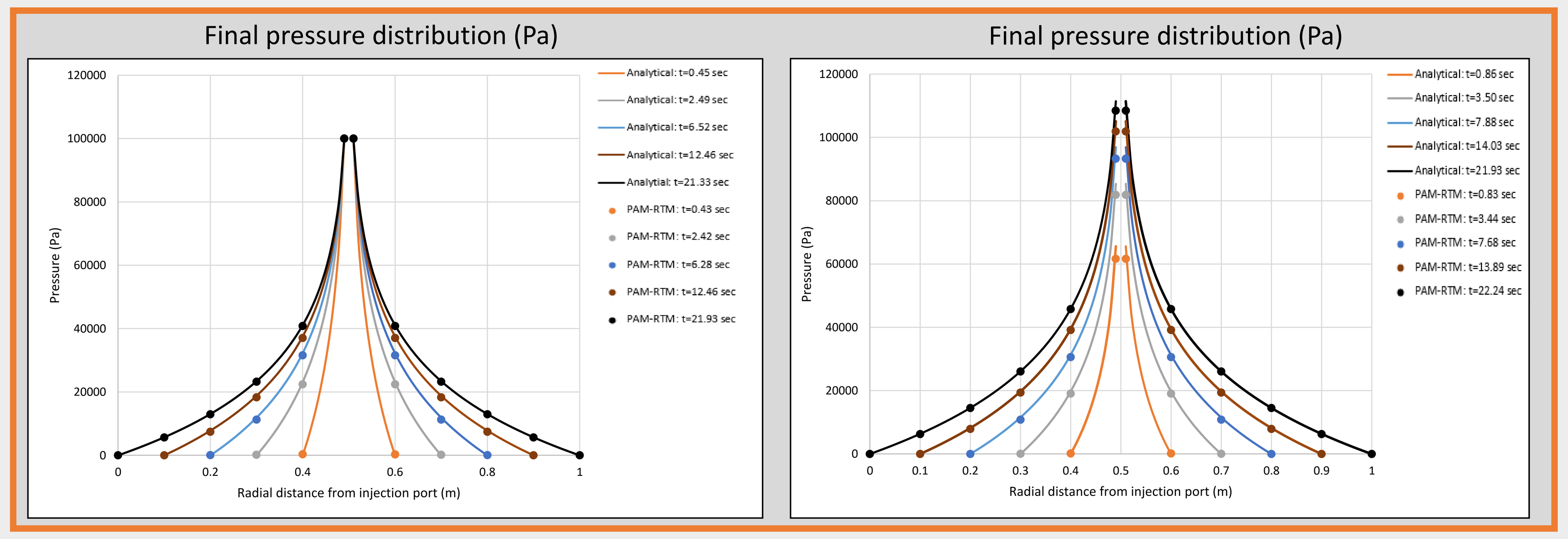


Predicted fill times with increasing flow path length



- Resin velocity (m/s) and pressure distribution (bar) for conts. pressure at t= 1.15, 10.82, and 21.9 sec
- Resin velocity (m/s) and pressure distribution (bar) for conts. Flow rate at t= 1.17, 10.99, and 21.25 sec

Top view of PAM-RTM shows the resin velocity (m/s) and the pressure distribution of the resin for constant pressure and constant flow rate

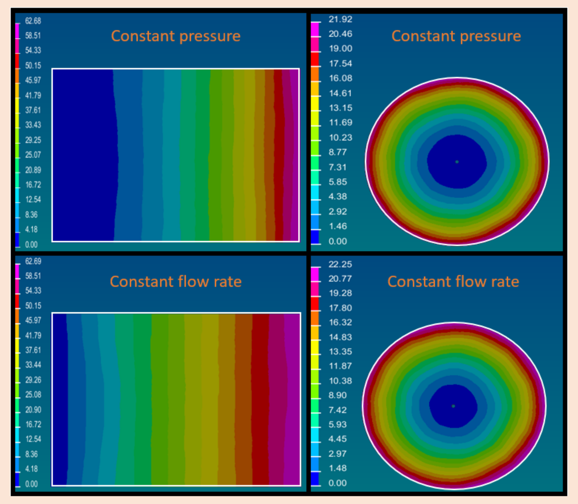


Predicted pressure during part filling for a linear flow model for constant pressure and constant flow rate

Table 1. filling time for analytical solutions and simulation approach

	Filling time for constant pressure flow model		
	Analytical (sec)	PAM-RTM (sec)	Error [%]
Linear flow	62.50	62.68	0.28
Radial flow	21.33	21.92	2.69

	Filling time for constant flow rate flow model		
	Analytical (sec)	PAM-RTM (sec)	Error [%]
Linear flow	62.50	62.69	0.30
Radial flow	21.93	22.25	1.43



Top view of PAM_RTM shows filling time for 1D flow model in linear and radial direction in an isotropic porous medium: constant pressure; constant flow rate

Summary & Conclusions

- The pressure distribution, velocity history, and fill time for two simple mold designs and injection scenarios (constant pressure, constant flow rate) were predicted by PAM-RTM software as part of an initial training and education effort.
- An analytical process model was developed to verify the PAM-RTM results. There was no significant difference between the analytical result and PAM-RTM simulations.
- The injection rate for a constant injection flow rate was chosen to provide the same fill time as for constant injection pressure.
- The predicted fill time for linear flow model showed constant flow rate injection was a linear, but constant pressure injection displayed a quadratic relationship.
- The pressure distribution at each point for linear flow model was linear for both constant injection strategy. The flow rate injection example appeared that the pressure increases linearly with time at the injection port to a value exactly double that used for constant injection pressure.

Future Work

- Identify and obtain information on realistic composite parts, fiber preforms, and resin viscosity especially for low melt.
- Perform literature search to obtain kinetic reaction constants for aerospace resin systems.
- Develop viscosity and cure model for low melt viscosity resins and determine how to interface them with PAM-RTM

Faculty Advisors/ Collaborators

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University of Dayton

Department of Chemical and Materials Engineering

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