Proceedings of the Canadian Society for Mechanical Engineering International Congress
32nd Annual Conference of the Computational Fluid Dynamics Society of Canada
Canadian Society of Rheology Symposium
CSME-CFDSC-CSR 2025
May 25–28, 2025, Montréal, Québec, Canada

RHEOLOGY AS A TOOL TO PREDICT EFFICACY OF LIQUID EMBOLICS FOR BLOOD VESSEL OCCLUSION.

Julie Bertucceli[1,2], Werner Taillades[1,2], Elie Daoust[1,2], Sophie Lerouge[1,2,3*]
[1]Department of Mechanical Engineering, École de Technologie Supérieure (ÉTS), Montréal, Canada
[2]Research Center, Centre Hospitalier de l'Université de Montréal (CRCHUM), Montréal, Canada
[3]Department of radiology, Université de Montréal, Montréal, Canada
*sophie.lerouge@etsmtl.ca

ABSTRACT

Embolic gels are injectable materials used in vascular embolization to selectively block blood flow. Unlike rigid embolic agents (e.g., coils), these hydrogels conform to vessel geometry, ensuring controlled occlusion. Their shear-thinning behavior is critical for smooth injection through microcatheters while preventing premature solidification or fragmentation.

Shear-thinning and recovery tests provide key insights into injectability and occlusion properties. Recovery tests assess a material's ability to regain its initial structure after deformation, making them valuable for embolization performance. However, conventional recovery tests lack realism, as they do not account for shear rate variations due to catheter diameter, shear duration linked to injection speed, or temperature changes during injection. In practice, embolic gels experience multiple external forces, including injection pressure and shear fluctuations, while thermosensitive gels also undergo temperature-induced changes, all affecting their final behavior. This study develops a rheological approach to characterize thermosensitive embolic gel flow through catheters and optimize injection conditions for controlled and effective embolization.

Shear rates ($\dot{\gamma}$) experienced during injection were estimated using a modified Hagen-Poiseuille equation (1) for non-Newtonian fluids:

$$\dot{\gamma} = \frac{4Q}{\pi R^3}\frac{3n+1}{4n}, \tag{1}$$

where Q is the volumetric flow rate, R the catheter's inner radius, and n the flow behavior index, from viscosity versus shear rate curves. This provides a more accurate assessment of the mechanical stresses applied to the gel.

To better replicate real injection conditions, a customized rheological protocol was developed with a rotational approach using a concentric cylinder geometry. The recovery protocol includes an initial resting phase, followed by a ramp and plateau at the calculated shear rate, sustained for a duration matching injection, and a final resting phase to measure recovery. A temperature ramp from 22°C to 37°C simulates the preparation at room temperature and injection at body temperature. Injection rates ranging from 0.2 to 4 mL/min were tested.

Tests showed that a slow injection rate better preserved gel properties, with faster recovery and an unaltered gelation process after shear application. However, the presence of an artifact, a transient viscosity peak, complicate the results interpretation. It results from a sudden stop in the shear rate when transitioning from the shear application to the resting phase. To overcome this, an oscillatory-rotational-oscillatory sequence is being implemented to minimize artifacts and improve recovery analysis. A change in geometry should further enhance test reliability.

By linking rheological testing to real injection conditions, this approach enables a more reliable assessment of embolic gel performance, facilitating a confident transition to animal trials.

Acknowledgments: Funding by NSERC