Professor solves 140-year fluid mechanics enigma

October 7 2015, by Emil Venere

A Purdue University researcher has solved a 140-year-old enigma in fluid mechanics: Why does a simple formula describe the seemingly complex physics for the behavior of elliptical particles moving through fluid?

The findings have potential implications for research and industry because ellipsoid nanoparticles are encountered in various applications including those involving pharmaceuticals, foods and cosmetics.

Like a sphere, the oblong ellipsoids undergo "rigid body motion" when submerged in a fluid, meaning they do not deform while moving from side to side and rotating. However, because an ellipsoid is not perfectly spherical, it is counterintuitive that its rigid-body motion in a fluid could be described using the same simple mathematical expression as spheres.

"In general, you would expect a very complicated expression because an ellipsoid is not a perfect sphere," said Sangtae Kim, a distinguished professor in Purdue's School of Chemical Engineering.

Yet, that is not the case, presenting a quandary that Kim has been pondering since his days as an undergraduate in the 1970s.

"It's been gnawing at me since then," he said.

MIT chemical engineer Howard Brenner wrote a paper in 1964 showing the mathematics behind the simple formula, but it took pages of

complex calculations to arrive at the simple result.

"Dr. Brenner highlighted this simplicity," Kim said. "But the simplicity of the result could only be shown by going through five to 10 pages of very messy algebra and calculations. In the end, everything cancels and you get this final very simple result. It's almost like a miracle, which has bothered me for a long time."

He has solved the enigma in a new paper appearing in November in a special issue of the American Chemical Society (ACS) journal *Industrial & Engineering Chemistry Research*. The special issue honors the 50th anniversary of Purdue's Doraiswami Ramkrishna's doctoral dissertation, which is considered a landmark in the history of chemical engineering. Ramkrishna is Purdue's Harry Creighton Peffer Distinguished Professor of Chemical Engineering. Kim's paper was highlighted as an ACS "editor's choice."

The ellipsoid enigma begins in 1876 and 1892, when scientists described how an ellipsoid moves through surrounding fluid while traveling side-to-side and rotating, respectively, causing pressure and stress on the object's skin referred to as surface traction. Brenner later unified the mathematics for both the side-to-side motion and rotation.

The new research demonstrated how an ellipsoid's interaction with fluid can be described using the same type of simple mathematical pattern that applies to spheres.

"The pattern has been known for 140 years, and the fundamental underlying reason for why this simple pattern has to be true is now apparent because of this new work being published," Kim said.

John Anderson, president emeritus of the Illinois Institute of Technology and a professor of chemical engineering, said, "Dr. Kim's paper

definitively finalizes the 140-year development of intriguing relationships among hydrodynamic properties of ellipsoids, relationships that have proven invaluable to theorists trying to model the motion of particles in flowing liquids and electric fields. A fascinating backstory is that Professor Kim maintained his interest in proving the exactness of these useful relationships even during his years in executive management in the pharmaceutical industry and the National Science Foundation. The crucial spark was reignited last fall when he was invited to speak in memory of his late colleague Howard Brenner."

Anderson visited Purdue to give a guest seminar in September.

Professor Henry Power of the University of Nottingham, an expert who provided an important discovery in the field in 1987, said: "Professor Kim's elegant solution also provides a new and efficient way for solving for the motion of these nonspherical particles."

More information: Ellipsoidal Microhydrodynamics without Elliptic Integrals and How To Get There Using Linear Operator Theory: A Note on Weighted Inner Products, *Industrial & Engineering Chemistry Research*, 2015.

Provided by Purdue University