# Nanofluids promise efficient heat transfer

## Next-generation fluid may revolutionize heat transfer

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Heat transfer is not the most frequent topic of domestic conversation. But if, on a 90-degree day, your air conditioner breaks down or your car radiator boils over, it is immediately clear how critical it is to move heat efficiently from one place to another.

Steve Choi (left) and Jeff Eastman are working with industry to improve the understanding of nanofluids.

Engineers have been working for decades to develop more efficient heat transfer fluids for use in car motors and industrial equipment. Improved oils and coolants would make possible more efficient engines. Such engines would be smaller and cheaper, and their lower fuel demands and emissions would do less damage to the environment.

Now, by manipulating atoms on the smallest of scales, *Argonne National Laboratory* scientists have created a next-generation fluid that may revolutionize heat transfer. By adding tiny spherical particles to a conventional fluid, researchers can improve by up to 40 percent its ability to transfer heat.

"Tiny" means no larger than a few nanometers — billionths of a meter. Steve Choi of Argonne's Energy Technology Division and Jeff Eastman of the Materials Science Division developed these nanofluids. They are made by suspending materials like copper or copper oxide in liquids such as water or ethylene glycol (radiator fluid).

Preliminary tests show that nanofluids may solve a number of problems plaguing the heating, ventilation and air conditioning (HVAC) industry. But their use could go beyond heat transfer in automobiles and manufacturing equipment. With continued research, Choi and Eastman envision nanofluids improving the efficiency of high-heat flux devices like supercomputers and providing new cancer treatment techniques.

**Nanofluids could aid industry:**

Scientists have tried adding particles to fluids to improve thermal conductivity for a century, but the particle size caused trouble.

In the past, due to manufacturing limitations, engineers could only create microparticles — large enough still to be visible to the naked eye and with a diameter a thousand times greater than nanoparticles. These microparticles were so large that, like stones in a river, they would quickly settle out of the fluid and sink to the bottom of a pipe or tank. If the fluid was kept circulating rapidly enough to prevent much settling, the microparticles would damage the walls of the pipe, wearing them thin.

The difficulty facing engineers was to create particles small enough that they would remain suspended for long periods of time, but also able to absorb large amounts of heat quickly. Choi had long been frustrated with microparticles himself, so when he read an article in logos Vol. 11 No. 1 that Eastman and former Argonne researcher R. W. Siegel were creating and studying nanometer-sized crystals, he jumped at the chance to try them in heat transfer fluids.

"We found that you could first condense gaseous metal oxide into particles between 30 and 50 nanometers in diameter, then mix them into a fluid afterward," Choi said. "It was a two-step process. But our best results came when we made the nanoparticles from pure copper in a single step."

In this one-step process, the materials scientists heated copper to a vapor inside a vacuum chamber. A cooled heat transfer fluid was placed nearby in the chamber, and the copper vapor condensed when it touched the cooled fluid, forming metal spheres around 10 nanometers in diameter in the fluid. When Choi and Eastman used ethylene glycol, the copper nanoparticles improved the rate at which the fluid conducted heat by 40 percent. And the metal particles remained suspended. The elusive combination of small particles and high thermal conductivity had been found.

While Eastman and Choi were inspired in part by research techniques pioneered in Japan and Germany, using nanoparticles to improve heat transfer in fluids was their own innovation. They hold a patent on the idea that dispersing nanoparticles into fluids can improve heat transfer properties.

**Nanoparticle mysteries:**

Much remains unknown about nanoparticles. Argonne researchers have determined that materials made from nanoparticles differ from their larger counterparts. They appear to be stronger and more reactive than larger particles (see logos Vol. 18 No.1, Vol. 18 No.2 and Vol. 19 No.1 for more information on nanomaterials research at Argonne). To help us better understand the mysteries of nanoparticles, Argonne is preparing to build the Center for Nanoscale Materials to fabricate nanostructures and to measure their structural, physical and chemical properties.

Nanofluids research continues. Both scientists are working with other institutions to broaden their knowledge base. To develop nanofluids for industry, Eastman has received a Small Business Technology Transfer grant to work with Nanopowder Enterprises of Piscataway, N.J.;

Argonne will test the thermal properties of the fluids the company produces. Choi is working through a cooperative research and development agreement with the Valvoline Co. to investigate the physical capabilities of nanofluids. He is also collaborating with Purdue University and Rensselaer Polytechnic Institute to investigate the heat transfer mechanism in nanofluids. Together, these efforts will allow Argonne researchers to develop a database of nanofluid properties and create accurate models of their behavior.

Manufacturers will need such information if nanofluids are to be developed for the market. One appealing possibility is to create fluids whose thermal properties can be engineered to specific tasks, but at this point, basic facts about nanoparticles remain unclear. Eastman, for example, would like to know why the molecules of a base fluid keep nanoparticles suspended so well, since nanoparticles are still dramatically larger than individual molecules.

Also unclear is the reason nanofluids conduct heat so effectively. Eastman speculates that it may be related to the increased surface interaction. "Since, for a given volume of material, there are a greater number of particles as their size decreases, perhaps there is more opportunity for the nanoparticles to conduct the heat," he said.

Another reason research must continue is to bring costs down. Nanofluids are expensive, in part because the equipment used to manufacture them is one-of-a-kind. The fluids must be made affordable if they are ever to see widespread use. But immediate, less orthodox applications of nanofluids could encourage such research.

**Possible long-term research:**

One such application Choi envisions would use a nanofluid to cool miniaturized high heat-flux devices such as supercomputer circuits and high-power microwave tubes. Industry is under constant pressure to make technology faster and smaller, which is a challenge because of the heat such devices generate. A nanofluid coolant could flow through tiny passages in the system without the need for wide cooling channels.

A particularly exciting potential application would be as a cancer treatment. Eastman is collaborating with Luis Nuñez of Argonne's Chemical Technology Division and others to use iron-based nanoparticles as delivery vehicles for drugs or radiation.

"We could guide the particles up the bloodstream to a tumor with magnets," Eastman said. "We hope it would allow doctors to deliver high local doses of drugs or radiation without damaging nearby healthy tissue, which is a significant side effect of traditional cancer treatment methods."