Purdue miniature cooling device will have military, computer uses

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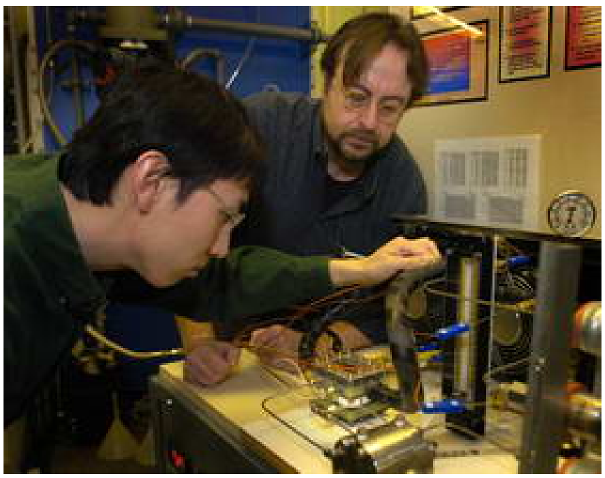

Mechanical engineers at Purdue University have new findings offering promise for modifying household refrigeration technology with small devices to cool future weapons systems and computer chips.

Image: Jaeseon Lee, at left, a doctoral student in mechanical engineering at Purdue, and Issam Mudawar, a professor of mechanical engineering, test a "micro-channel heat sink" designed to replace conventional "evaporators" in standard refrigeration systems.

The devices, called "micro-channel heat sinks," circulate coolant through numerous channels about three times the width of a human hair. Such devices might be attached directly to electronic components in military lasers, microwave radar and weapons systems, as well as in future computers that will generate more heat than present computers, said Issam Mudawar, a professor of mechanical engineering who is leading the research.

The researchers are adapting refrigeration systems by using the micro-channel heat sinks to replace conventional "evaporators" – components in household refrigerators that contain a labyrinth of tubing. As coolant circulates through the tubing, heat is removed from the refrigerator to cool the food inside.

"We are substituting these conventional evaporators – which might be well over a meter long in the typical refrigerator – with a heat sink that's only about 1 inch square," Mudawar said. "The challenge is how to unplug this large evaporator and put in its place this tiny heat sink and make the whole system work."

Recent findings were detailed in two research papers that appeared in the February issue of the International Journal of Heat and Mass Transfer. The papers were written by mechanical engineering doctoral student Jaeseon Lee and Mudawar.

Electronics for new weapons systems, as well as chips in future computers, will generate five to 10 times more heat than chips in conventional electronic products, requiring better cooling systems. Computers and other electronic equipment are typically cooled with bulky assemblies that use metal fins to dissipate heat and fans to circulate the hot air away from components. But electronic components in new weapons systems, such as advanced lasers and chips in future computers, will generate too much heat to be cooled with conventional systems that use fans, Mudawar said.

One possible solution is a "two-phase" cooling system – the same basic technology used in a conventional refrigerator – in which a liquid coolant absorbs heat, turns into a vapor and is then pressurized by a compressor and condensed back into a liquid to begin the cycle over again.

In work funded by the U.S. Office of Naval Research, Mudawar's team has successfully incorporated the micro-channel heat sink into an ordinary refrigerator. The device, which was attached to a heating element that simulates a hot electronic component, has been tested with a refrigerant called R134a, which is used in household air conditioners and refrigerators.

"This system successfully combines the cooling attributes of a two-phase micro-channel heat sink with the low-temperature capability of a fairly standard refrigeration system," Lee said. "The result is a high-performance cooling system capable of removing large amounts of heat while maintaining low chip temperatures unattainable by any competing cooling technology."

The research papers provide information for other engineers interested in designing similar systems, Mudawar said.

"They show the methodology, the design relationships, the merits of the system – basically how it works – information including what temperatures to expect and what pressure drops will occur inside the micro-channels," he said. "The work is quickly maturing for deployment within the next three years."

Findings reported in the papers include information about new mathematical tools to predict the performance of a particular design depending on the required cooling capacity. The researchers also discovered that so-called "throttling valves," which are already present in standard refrigeration systems, help to alleviate a problem with micro-channel devices: pressure tends to increase and decrease dramatically along the parallel channels, hindering performance. But the throttling valves in conventional refrigeration units have been shown in the experiments to "virtually eliminate" those pressure oscillations, Mudawar said.

Such a miniature refrigeration device would keep electronic components cooler than conventional cooling technologies, enabling them to operate faster and perform better, said Mudawar, who has been working on cooling technologies since the 1970s and in 1984 formed the Purdue University International Electronic Cooling Alliance. Researchers in the alliance have developed various cooling technologies, including methods for the most demanding applications – cooling rocket nozzles and components in nuclear fusion reactors.

"So, we have gained a lot skill and experience in developing these tiny, micro-channel evaporators over the years," said Mudawar, who last year completed the 434-page technical handbook "Mini/Micro-Channel Thermal/Fluid Transport Phenomena." The work, published by the alliance, summarizes the various technologies developed through Mudawar's lab.

The micro-channel heat sink is a copper plate containing numerous grooves 231 microns wide – or about three times as wide as a human hair – and 713 microns deep.

The tubes in conventional air conditioner evaporators have diameters measured in millimeters or centimeters, depending on the size of the unit, meaning the conventional tubes are several times larger than the micro-channels.

"This is really pushing the envelope in how small you can go with these channels and still have a working device," Mudawar said. "But there is another issue. In conventional systems, the evaporator is actually a very long tube that is wound around many times. So the tube might be a meter in length or more.

"In the micro-channel heat sink, we are doing everything in 1 inch square. Working on such small size scales presents various design challenges. First of all, you don't have the technical know-how. You don't know where to start and what equations to use. The physics that we learned from macro-systems do not work for the micro-systems. So you start from scratch."

Fluids flow differently in micro-channels than they do in larger tubing, and bubbles form differently, which changes how heat is dissipated.

"So you have to design new systems to pump coolants through these micro-channels and develop new mathematical tools to predict how well designs will perform," Mudawar said.

One advantage of modifying conventional refrigeration systems is that most of the technology is already available.

"We are not trying to reinvent the wheel with respect to the refrigeration cycle," Mudawar said. "We want to use existing technical know-how for the refrigeration loop and then implant our new technical know-how for this micro-channel device."

Chips are generating more heat as they are becoming more sophisticated, packing more transistors into increasingly compact circuitry.

"The rapidly increasing use of electronics in military hardware is resulting in unprecedented thermal management needs," said Mark S. Spector, Thermal Management Program officer for the Office of Naval

Research. "Future all-electric warships and combat vehicles are envisioned to have high-power electrical systems for propulsion, pulsed-power weapons and sensor arrays. Such systems are expected to generate waste heat densities approaching 1,000 watts per square centimeter. Innovative methods such as those being developed at Purdue are necessary to acquire, transport and dissipate these heat loads."

Micro-channel heat sinks could help solve future heating problems because conventional refrigeration is a proven and effective technology that could remain viable for decades, Mudawar said.

"One of the big dilemmas I see is that industry and government spend a fortune trying to develop a particular technology just to meet the needs for today, and when the heat dissipation goes up, there goes all of your investment because you have to invent something entirely new," he said. "So why not begin to develop cooling schemes that are so capable they will stay with you for 20 years?

"That is really the mission of our lab. We consider not only the short-term but also the long-term approach to solving these problems."

Source: Purdue University

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