Physicists make discovery about temperature in convection

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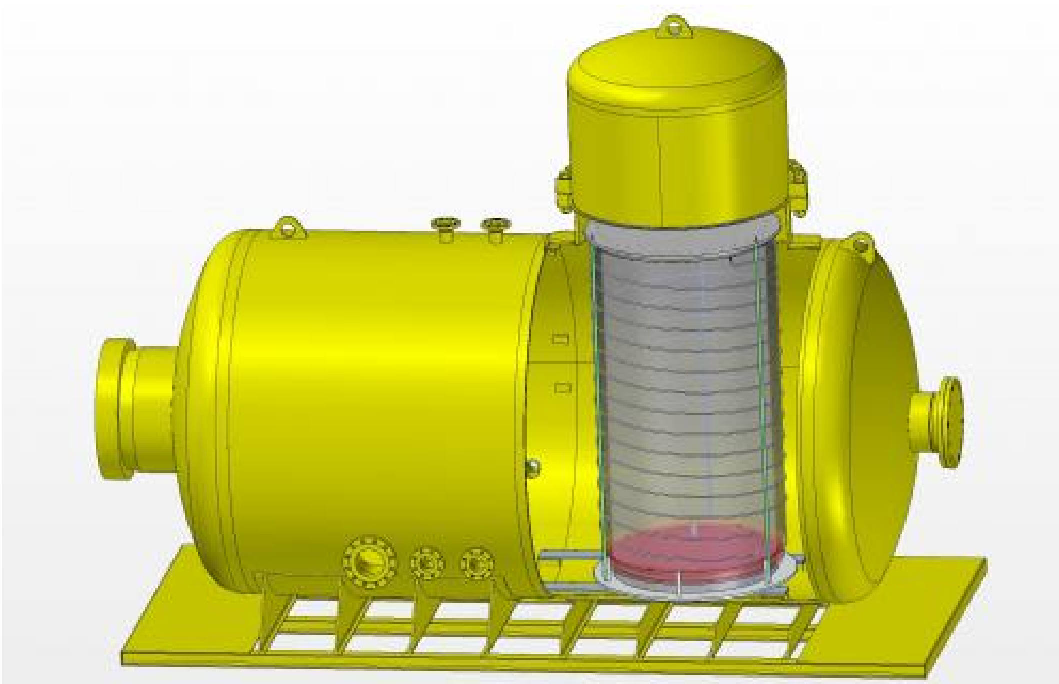

This is a drawing of the container used to study convection. The 8-foot tall cylinder was heated at the bottom and cooled at the top. Credit: UCSB

An international team of physicists is working to ascertain more about the fundamental physical laws that are at work in a process known as convection, which occurs in a boiling pot of water as well as in the turbulent movement of the liquid outer core of the Earth. The team's new finding specifies the way that the temperature of a gas or liquid varies with the distance from a heat source during convection. The research is expected to eventually help engineers with applications such as the design of cooling systems, for instance, in nuclear power plants.

Guenter Ahlers, professor of physics at UC Santa Barbara, worked with his team at the Max Planck Institute for Dynamics and Self-Organization in Goettingen, Germany, on this important discovery about turbulent convection. The results will be published in the September 7 issue of Physical Review Letters, and are available online now.

The experiments took place in a cylinder that was placed under the turret of a large pressure container. The 8-foot tall cylinder was heated at the bottom and cooled at the top. There were about 100 thermometers inside it, and it was pressurized with sulfur hexafluoride, an inert gas. Convection occurred inside the cylinder because, in the presence of gravity, the warmer gas at the bottom tends to rise to the top, while the colder gas tends to sink.

"We like sulfur hexafluoride because it is harmless — not poisonous, not chemically reacting — and because it is a heavy molecule," said Ahlers. "A heavy molecule enables us to produce more vigorous convection with the same temperature difference. The strength of the convection is measured by a parameter called the Rayleigh number. We go to Rayleigh numbers as high as 10 to the 15 — a million billion — which is very large by our standards."

Ahlers enjoys the ability to oversee and even run the continuing experiments remotely on a computer in his office at UCSB (or anywhere else in the world), even though the laboratory is 5,000 miles away.

He explained that convection occurs naturally in astrophysics and in Earth systems. For example, the outer layer of the sun is composed of convection cells. Convection occurs in the Earth's atmosphere and oceans. The liquid iron in the outer core of the Earth undergoes vigorous convection and has Rayleigh numbers well above 10 to the 20. That convection generates the magnetic field of the Earth.

In their paper, the scientists present experimental and numerical data that show that, except for a very thin layer in the immediate vicinity of the plates, the temperature of this system varies linearly with the logarithm of the distance from the confining plates. They discovered this profile and measured it in detail.

This is Guenter Ahlers with the container used to study convection. Credit: UCSB

The findings are especially intriguing because they echo an important discovery from 1930 by Theodore von Kármán and Ludwig Prandtl, known as the "Law of the Wall." This discovery involved the study of a gas or liquid flowing along a wall, where its speed must be zero at the wall because of friction. The speed of the fluid parallel to the wall increases as the distance from the wall increases. Von Kármán and

Prandtl showed more specifically that the speed increases linearly with the logarithm of this distance when the flow is fast enough so that the fluid becomes turbulent. This result is called the Law of the Wall and is of great importance in many engineering applications.

Ahlers compared the new findings about the way temperature varies in convection to the way speed varies with the Law of the Wall, noting that they are similar, although the precise relationship has yet to be understood. "They behave in the same way," said Ahlers. "But just because two things look the same doesn't mean they are the same, so we still need to build the theoretical foundation that connects them. That's what makes this a very active, very exciting field, with theorists as far apart as Beijing (China), Marburg (Germany), and Twente (the Netherlands) already trying to explain the experimental results. You make an experimental discovery, and then theorists get excited. Then they start working on it, and who knows what we will have six months down the road?"

He explained how the Law of the Wall is of importance in engineering applications. "Pumping oil from Alaska down to the United States costs billions of dollars," said Ahlers. "And if you can understand what causes the resistance that you have to overcome, then maybe you can reduce that. Even if you only reduce it by 2 or 3 percent, you've saved hundreds of millions. So it's very, very important."

Ahlers went on to say that understanding the temperature in turbulent convection is also very important because there are many applications where turbulent convection is used to cool things. In nuclear reactors, for instance, cooling is done by turbulent convection. "There are many applications of this turbulent convection system in industry, where you would also like to understand what's going on inside, what the temperature gradients are," he said. "So I can see relevance for this in applications. Although I must say that is not our motivation; our motivation is to understand the fundamental physics."

Eberhard Bodenschatz, one of the authors, was a postdoctoral fellow with Ahlers at UCSB about 20 years ago and is now director of the Max Planck Institute for Dynamics and Self-Organization in Goettingen. Co-author Xiaozhou He is a postdoctoral fellow with Ahlers and is based in Goettingen. Scientists from The Netherlands, Italy, and France are also involved.

Provided by University of California - Santa Barbara

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