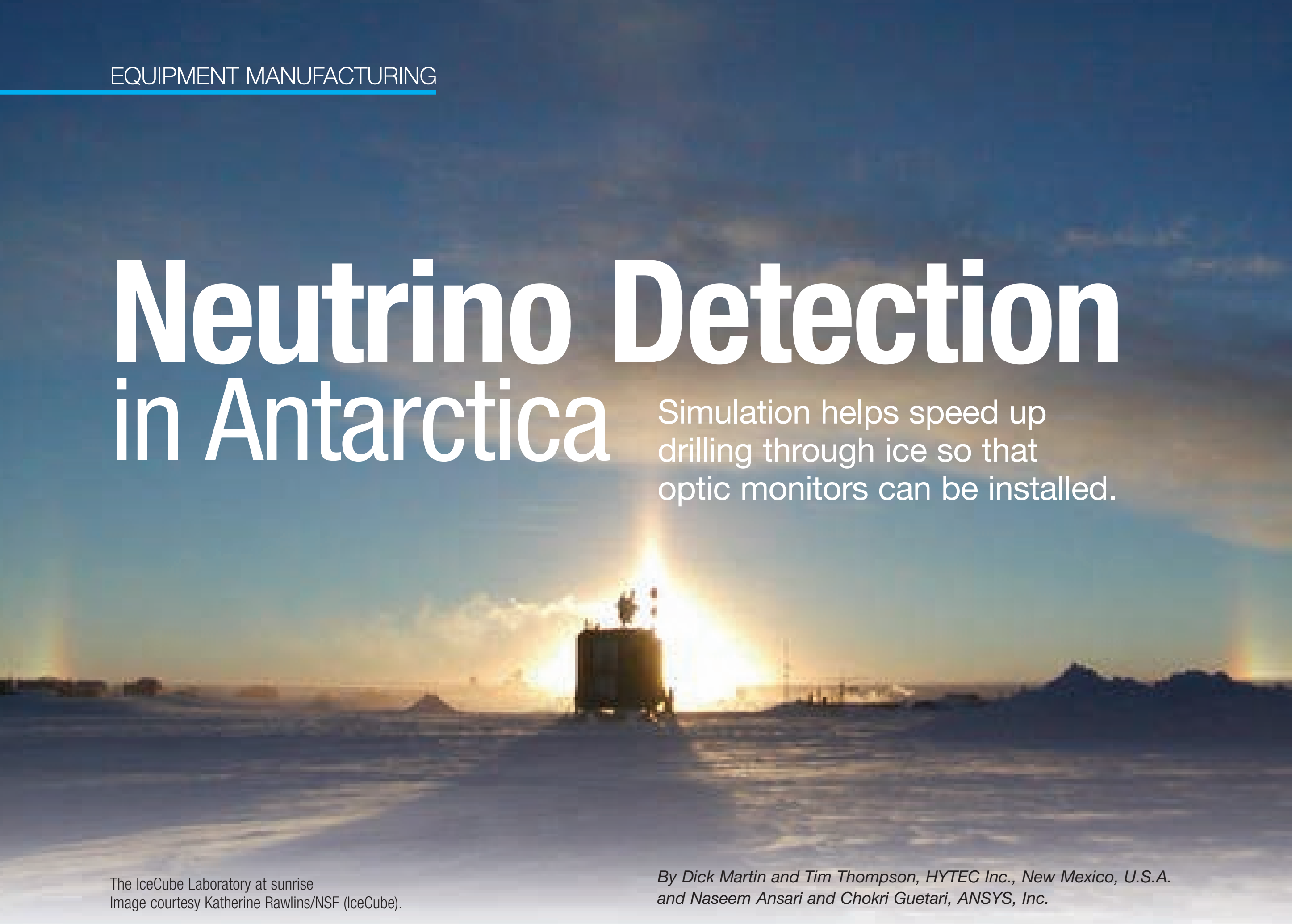
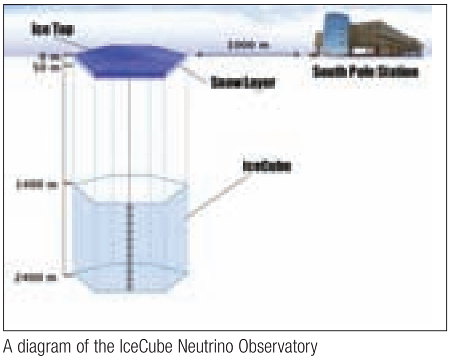


Neutrino Detection in Antarctica

Simulation helps speed up drilling through ice so that optic monitors can be installed.

The IceCube Laboratory at sunrise
Image courtesy Katherine Rawlins/NSF (IceCube).

By Dick Martin and Tim Thompson, HYTEC Inc., New Mexico, U.S.A. and Naseem Ansari and Chokri Guetari, ANSYS, Inc.



A diagram of the IceCube Neutrino Observatory

A hose going down into an IceCube hole drilled with the hot-water nozzle

Images courtesy NSF (IceCube).

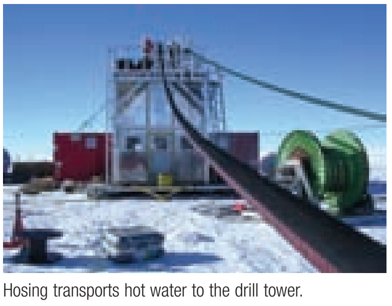
Neutrinos are elusive particles. Nearly massless, they travel cosmological distances at nearly the speed of light, passing through most material without making a mark. Neutrinos are produced in nuclear reactions in the sun or in dying stars; by studying them, scientists can learn about extra-galactic events such as supernova explosions, gamma-ray bursts and black holes. Polar ice, which is exceptionally pure, transparent and free of radiation, has emerged as an ideal medium for detecting elementary particles like neutrinos. Rather than capture neutrinos directly, evidence of collisions between the particles and ice can provide important information about the particles and their history.

To take advantage of the special properties of Antarctic ice, the IceCube Neutrino Observatory is currently under construction at the South Pole. The observatory, designed by the University of Wisconsin and funded by the National Science Foundation in the United States, will gather information from cosmic neutrinos that originated in outer space above the earth's northern hemisphere. The earth itself will be used as a filter to exclude atmospheric neutrinos, and high-energy cosmic neutrinos will pass through the earth's layers, on to the ice cap of the South Pole, and upward to the IceCube detectors.

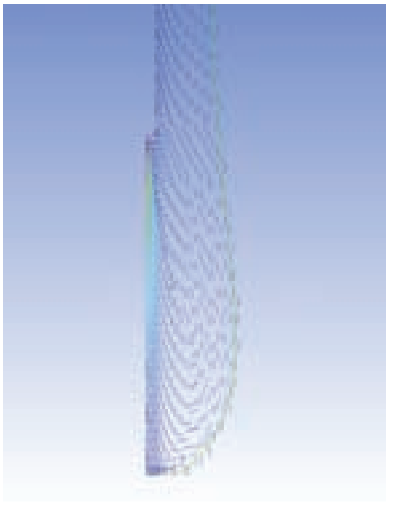
The neutrino observatory will consist of a matrix of digital optic monitors (DOMs) buried in the ice. To create this matrix, 4,800 DOMS are being suspended on vertical strings in 80 holes that have to be individually drilled into the ice. Each hole is 2,400 meters deep. The holes are created with a hot water drill consisting of a nozzle and 2,400 meters of hose connected to a water heating plant on the surface. The descending hose melts through the ice as 90°C water is pumped through the nozzle at a given spray angle. The water cools to about 1 to 2°C as the ice melts to create the hole and this water is pumped out the top of the hole. After the string of 60 DOMs is lowered in the hole, the water freezes around them, creating a permanent installation.

The drilling phase of the process occurs as the drill melts through the ice. During the ream phase, the drill is raised with the hot water continuing to flow, enlarging the hole and providing more time for the heat to conduct into the ice. By warming the ice surrounding the hole, it takes longer for the hole to close. This is critical, as there must be adequate time after producing the hole to insert and lower the optical module string before the hole gets too small.

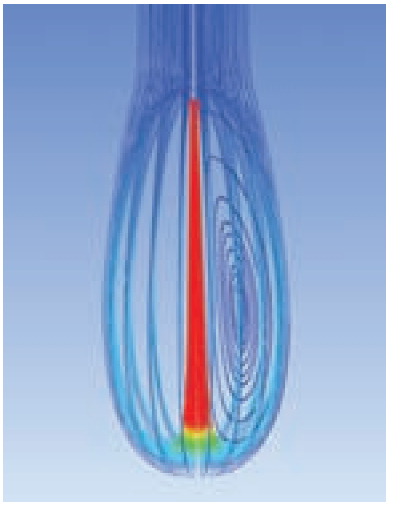
HYTEC Inc. took on the challenge of performing a CFD study to examine the complex drilling process. HYTEC's engineering teams conceive, design, build and test ingenious solutions to unique challenges. They meet customers' technical, cost and quality expectations in a wide range of high technology projects. For the IceCube project, they focused on the water–ice melting process at the bottom of the drill hole in hopes of better understanding the influence of nozzle size, spray angle, water flow rate and water temperature on hole shape in order to increase the drilling speed. Because



Hosing transports hot water to the drill tower.



Velocity vectors showing the hot water jet and the flow of melted water surrounded by ice



Pathlines illustrate the flow of water emanating from the nozzle, stagnating at the bottom of the hole, flowing upward, and being partially re-entrained into the jet.

the drilling season is limited (from December through February) and the cost to fuel a water-heating plant at the South Pole is extremely high, even a 10 percent increase in drilling speed could save the project large amounts of time and money.

ANSYS CFX software was applied to this problem because it has the ability to solve turbulent multiphase flow with conjugate heat transfer in an axisymmetric domain. Multiphase sensitivity studies determined that the heat transfer coefficients on either side of the water-ice interface were the most influential parameters in obtaining results that compare well with site data. A series of steady-state computations were performed for two nozzle diameters, two drill speeds and one spray angle. The runs were modeled at 1,292 meters, to allow comparison with site data.

By reducing the nozzle diameter from 1 in to 0.75 inches at the same flow rate, the hole depth was increased by 16 to 20 percent. The ANSYS CFX results showed that using a spray angle of 25° made little difference in hole depth or diameter. Increasing the drill speed at a fixed nozzle diameter caused the drill hole depth and hole diameter to decrease. Thus, an Ice-Cube drill model was developed to evaluate the performance of nozzle designs and to specify drill speed versus depth.

During the 2004-2005 South Pole drilling season, drilling speed was between 3.5 and 4.0 ft/min. During the 2005-2006 season, a smaller diameter nozzle was used based on the ANSYS CFX analysis. The drilling speed almost doubled to 6.9 ft/min, which will save the project over 1 million dollars. ■

Suggested Reading

Martin, Richard A.; Thompson, Tim; Ansari, Naseem; Guetari, Chokri: IceCube CFD Drilling Model. Proceedings of 2006 ASME Joint U.S.-European Fluids Engineering Summer Meeting: FEDSM2006-98042. Miami, FL, July 17-20, 2006.