Fighting fire with FireFOAM

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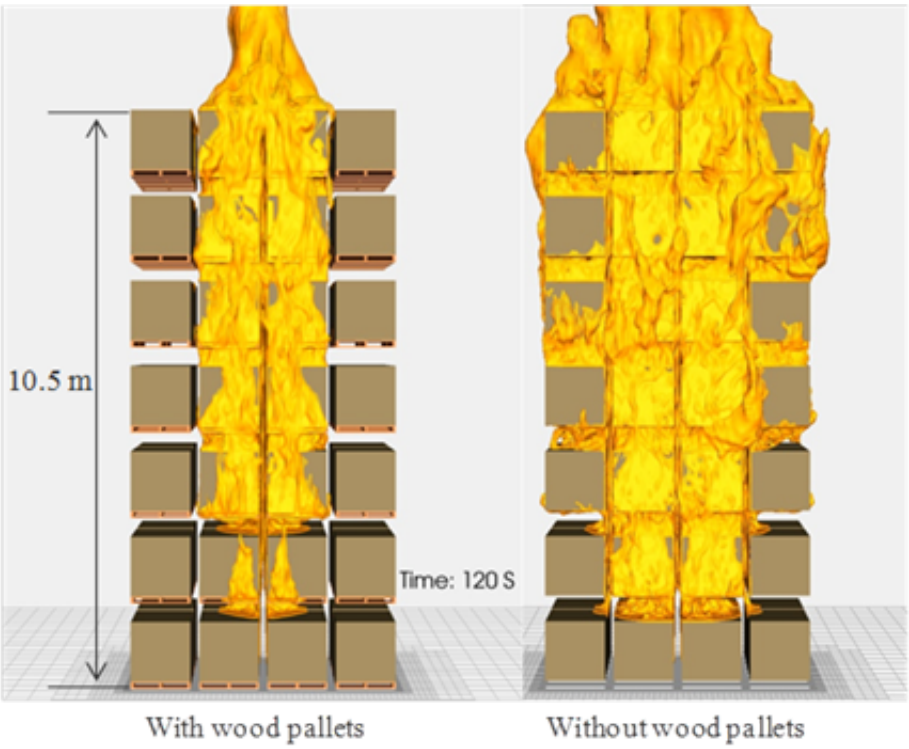

Stacking commodities on wood pallets (left image) slows horizontal fire spread, versus absence of pallets (right image).

Roughly 40 percent of all industrial property loss in the United States comes from fire, and fire is the leading cause of commercial property damage. For insurance companies, understanding how fires spread can help save their industrial clients from massive property and business interruption losses, ultimately saving both insurer and insured millions of dollars. Businesses with large warehouses are at particular risk, because

as storage warehouses get bigger, providing adequate protection using traditional ceiling-mounted sprinkler systems is becoming more challenging.

FM Global is one of the world's largest commercial and industrial insurance companies. Providing insurance to one in three Fortune 1000 companies, FM Global attributes its success to offering not only comprehensive property insurance products but also world-class loss prevention research and engineering services that help clients better understand steps they can take to prevent fires and minimize loss if a fire does start. However, for FM Global research scientist Yi Wang, fire suppression research affects far more than his business's bottom line.

"The goal of our research is to make protection standards and solutions better," Wang said. "We believe that the majority of property loss is preventable. We develop solutions to prevent losses, share these solutions, and promote improvement of protection standards." Some of these solutions Wang discovered came from research performed on the Titan supercomputer at the Oak Ridge Leadership Computing Facility (OLCF), a US Department of Energy Office of Science User Facility located at Oak Ridge National Laboratory.

Improving protection standards can be a costly process, though—insurers must build large testing facilities and conduct expensive fire tests or use high-performance computing to simulate how fires spread and how suppression systems perform. FM Global researchers are doing both.

Playing with Fire

To better understand how fires spread and the best methods to suppress them, FM Global built the world's largest fire technology laboratory at its property loss prevention research campus in West Glocester, Rhode Island. The entire laboratory is 108,000 sq. ft., with an enormous area

for fire tests measuring 33,600 sq. ft., or the size of a football field. These testing rooms have "movable ceilings" that can go from 15 to 60 ft. high, allowing researchers to evaluate fire hazards and test fire suppression techniques at a variety of heights.

In addition, FM Global owns the world's largest fire calorimeter—a large hood-like device that is hung above a fire to measure its heat release rate, or the rate at which it is releasing energy. This is the one of the best metrics to gauge fire size and is the main driver for determining how many sprinklers should turn on during a fire.

In recent years, FM Global has been considering how it might enhance its fire testing capabilities and gain more insight from each test. Its facility is invaluable for gaining insights into fire growth and suppression, but it is also in high demand—researchers often must reserve the space months in advance. In addition, these tests are expensive, with some experiments costing $100,000 or more.

And despite the company's football-field-sized fire testing room and world-class calorimeter, FM Global researchers found they might not be able to replicate fires for the world's newest, largest facilities. These industrial "mega" warehouses and distribution centers can exceed 100,000 sq. ft. and rise from 60 to 100 ft. in height. Many companies choose to use this extra height to store their commodities—in corrugated cardboard boxes— on wooden pallets stacked in tiers, each tier about 5 ft. high.

As these facilities stack the pallets increasingly higher, they run the risk of helping a fire spread faster. Wang noted that once storage facilities reach a certain height, sprinkler systems may not prevent catastrophic damage as effectively. "Typically, when sprinklers are on the ceiling during a fire, the smoke reaches the ceiling to set off the system," he said. "But when warehouses get very tall, the time of the protection

system activation can be delayed. In addition, the strong fire plume can prevent the ceiling water spray from penetrating through and reaching the base of the fire in time to achieve effective suppression."

Complementing Tests with Simulation

The high costs of large-scale fire tests, along with the challenges in generalizing and extrapolating test results, prompted FM Global research scientists in 2008 to develop computational models and simulate fires on an internal cluster computer. Using OpenFOAM, a fluid dynamics code, the team developed FireFOAM, its flagship code for simulating all of the complex physics that occur during an industrial fire.

And in keeping with the firm's commitment to sharing important research results, the researchers made their code "open source," available to any researcher studying fires and fire suppression. "Our goal is to develop an efficient computational fluid dynamics (CFD) code for the fire research community which has all the components to catch all the physics that are important for fire suppression, such as heat transfer, material flammability, water spray, chemical transport, and radiation in larger fires," Wang said.

Using supercomputers to simulate industrial fires is more complicated than just virtually igniting a fire and letting it burn. Researchers have to account for the roles of soot formation, oxidation, radiation, and sprinkler spray dynamics, among other processes. In addition to calculating so many different physical processes, researchers also require very fine resolution—small time and spatial scales—to fully capture all of the subtle chemical and physics-related processes happening during a fire.

Early results for smaller-scale fire simulations using FM Global's internal cluster were encouraging—the simulations showed very good

agreement with actual physical tests. However, as the team progressed in its fire modeling experience, it realized the need for substantially more computing power than it had internally to accurately model the much larger fires that could occur in clients' large warehouses. In addition, the team needed access to a very large high-performance computing system to scale FireFOAM up to meet the computational challenge.

Partnering for Progress

While attending a scientific conference on combustion, Wang and the FM Global team met Ramanan Sankaran, a computational research scientist and combustion expert at the OLCF. After discussing their research interests, Sankaran told them about the OLCF's Industrial Partnerships Program, which offers researchers in industry the opportunity to access America's most powerful supercomputer for open research.

FM Global researchers knew that gaining access to a larger supercomputer was necessary to improve their simulations, but it was only part of the challenge—knowing how to make efficient use of a supercomputer with over 299,000 cores was the other part. They successfully scaled FireFOAM from 100 CPUs to thousands of CPUs. And the team's relationship with Sankaran continued paying dividends. "We got support from Ramanan early on and identified a bottleneck in the pyrolysis submodel in our code, which deals with solid fuel burning," Wang's colleague Ning Ren said. "He worked with us to improve the efficiency of that submodel significantly, and that allowed us to scale our model up so we could simulate 7 tiers (35 ft. high) of storage." Through those simulations, the team discovered that stacking storage boxes on wooden pallets impedes the horizontal flame spread, substantially reducing the fire hazard in the early stages of fire growth.

As with many large-scale simulations, the team used FireFOAM by

dividing its simulations into very fine mesh, with each cell calculating the processes for a very small area and sharing the data with neighboring grid points. The finer the grid, the more computationally demanding the simulation becomes.

Wang credits his team's successful simulations to OLCF computing resources. "Without access to leadership computing resources at the OLCF, the team would have no way to accurately study fire spread dynamics in the larger warehouses," he said. "With Titan, we are doing predictive simulations of 7-tier stacks and gaining important information about the fire hazard that we simply can't gather through our experimental fire tests."

After receiving a second award for computing time, the team has been collaborating with OLCF staff to incorporate the Adaptable I/O System (ADIOS) for its FireFOAM code. OLCF staff developed ADIOS to transfer data more efficiently on and off the computer. The team took the improved FireFOAM code and began simulating other commodities stored in warehouses, beginning with simulations for large paper-roll fires in 2015.

Wang sees the collaboration between his group and OLCF staff as a relationship that benefits both parties and society at large. "Our project was the first step, and I think the work we've done is very promising," Wang said. "The collaboration with OLCF adds a lot of value to our research; access to Titan and the experts at the OLCF are enhancing our research capabilities so that we can offer better fire protection solutions for our clients."

More information: N. Ren, J. de Vries, K. Meredith, M. Chaos, and Y. Wang, "FireFOAM Modeling of Standard Class 2 Commodity Rack Storage Fires," published in the *Proceedings of Fire and Materials 2015* (February 2–4, 2015): 340.