BUSINESS IS BOOMING

Multiphysics simulation helps to design a thermal diffuser that converts explosion into long-lasting heat.

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Pyrotechnics are used for more than fireworks. Pyrotechnics are employed in products for the defense and aviation, security system, mining, seismic, quarry and construction sectors. Development of pyrotechnic applications making use of controlled explosions presents enormous engineering challenges. A recent application in the security field required using pyrotechnic properties lasting a few milliseconds and generating temperatures greater than 900 C to heat a liquid for 30 minutes to about 100 C. The challenge for Davey Bickford's engineering team was to design a heat exchanger that could do the job at a reasonable cost. This required tracking the heat flux generated by the device through a solid thermal diffuser into the liquid to be heated.

Davey Bickford used the ANSYS Mechanical thermal transient model to determine the heat flux generated by the combustion of the pyrotechnic device in the thermal diffuser. The team then used an ANSYS Fluent computational fluid dynamics (CFD) model to evaluate the volume of liquid that the thermal diffuser could heat. Simulation helped the engineers to quickly demonstrate the feasibility of the application and evaluate the relative performance of alternative design concepts. This method substantially reduced the time required to bring the product to market.

Fusehead of a small pyrotechnic device

UNUSUAL PYROTECHNIC APPLICATION

Typical applications for Davey Bickford include actuators and fire extinguishing systems for aircraft, electronic detonators for mining applications, detonators for seismic exploration, inflators, and explosives for tunneling. Davey Bickford's customers are becoming more and more demanding as they try to achieve higher performance and greater reliability at a lower cost.

This application is somewhat paradoxical because pyrotechnics is typically the last thing that an engineer would consider to generate a relatively low temperature for a long time period. However, pyrotechnics is being used more frequently for this type of application because it generates high temperatures and pressures with a very low electrical or mechanical energy input. The challenge for Davey Bickford engineers was to control the heat transfer from the combustion reaction to the liquid, evaluate several design alternatives within a short time, and confirm the feasibility of the application before making the considerable investment required for detailed design and manufacturing tooling.

Davey Bickford selected ANSYS solutions to design the heat exchanger because the simulation tools cover the full range of physics capabilities required to investigate advanced pyrotechnic devices. The pyrotechnic engineering team worked closely on this particular application with the Institut

Française de Mécanique Avancée (IFMA), which trains engineers in advanced mechanics and industrial engineering; the institute also works extensively with ANSYS solutions.

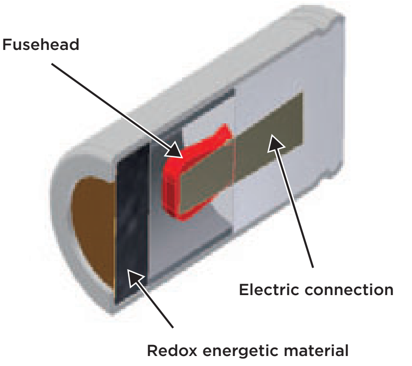
PICKING THE RIGHT MATERIAL

The first step in the project was selecting a pyrotechnic material. This application requires a kinetic combustion reaction that generates high temperatures and low pressures, so the team decided to use a redox material pair. A very small quantity of the selected pair when ignited generates high temperatures for a few milliseconds. The next step was designing the pyrotechnic chain. In this device, electrical initiation of a fusehead sets off combustion of the compressed redox powder. Over 1,000 C is generated with only 1 amp to 2 amps power input.

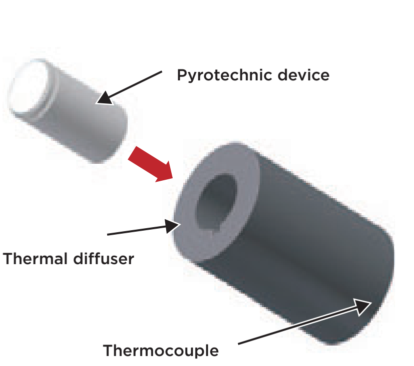
The huge amounts of energy and high temperatures released by the pyrotechnic device were controlled by enclosing it in a thermal diffuser that governs the heat transfer to the liquid volume. The team connected a K-type thermocouple to a multimeter linked to a Labview® station to measure the temperature increase in the surrounding medium as a function of time.

After determining the experimental temperatures for a simple initial concept design, engineers created a virtual prototype to explore the design space and optimize the design using the ANSYS Mechanical transient thermal solution. First, the team imported the initial design geometry created in Autodesk® Inventor® Pro 2009 into ANSYS DesignModeler and then simplified it slightly to remove all features that were not relevant for the virtual prototyping concept, ensuring accurate but fast simulation. They meshed the geometry and defined initial conditions. The initial temperature was set at ambient, and a heat transfer coefficient representing natural convection of 5 W/(m² C) was applied to the 3-D geometry. Engineers modeled the heat flux generated by the pyrotechnic device by mapping the transient heat flux in accordance with experimental results. Then they used the ANSYS thermal transient model to simulate the experiment. The simulation results correlated well with experimental results.

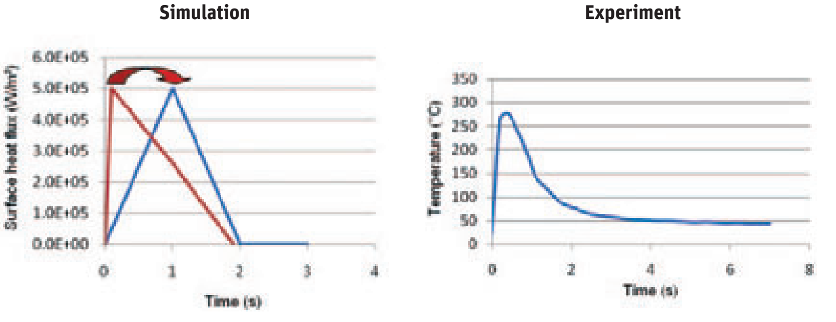
Engineers applied the transient thermal model to determine the temperature distribution around the external envelope



After receiving an electrical signal, the fusehead ignites an energetic redox material.



The pyrotechnic device is enclosed by a thermal diffuser.



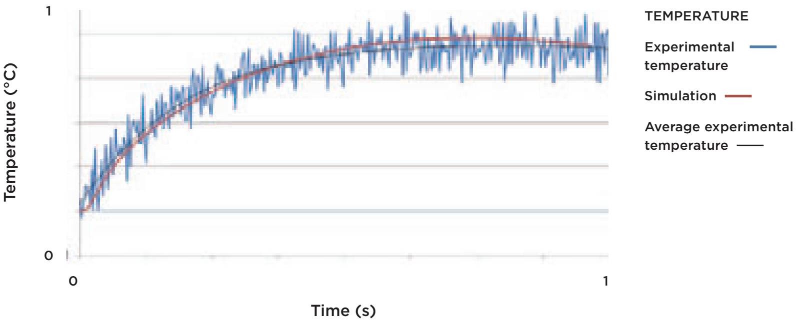
Engineers modeled the heat flux generated by the pyrotechnic device based on experimental results.

of the thermal diffuser. Simulation showed that the initial design of the diffuser produced high temperatures around the bottom of the diffuser and low temperatures toward the top. The customer required much greater uniformity in temperature distribution throughout the liquid, so the Davey Bickford team focused on the thermal diffuser's material properties in an effort to conserve the heat generated in the pyrotechnic reaction and to reduce the rate at which it was transferred to the volume of liquid. Engineers selected four materials with high thermal effusivity and low thermal diffusivity as candidates for use in the thermal diffuser. Thermal effusivity provides a measure of a material's ability to exchange thermal energy with material around it. Thermal diffusivity is the thermal conductivity divided by density and specific heat capacity at a constant pressure.

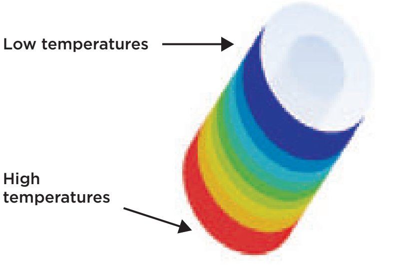
The team evaluated each material using the ANSYS transient thermal model. Materials 1 and 3 produce relatively large temperature variations, so they were quickly eliminated. Material 4 exhibited interesting thermal properties, but because it could not be easily machined, manufacturing costs would be too high. Engineers decided to focus on material 2, which provides a homogeneous temperature profile and is highly machinable.

OPTIMIZING THE DIFFUSER GEOMETRY

The next step was optimizing the geometry of the thermal diffuser. Davey Bickford engineers used design exploration capabilities, including the goal-driven optimization tool provided in ANSYS Workbench, to find the dimensions of the diffuser that would best achieve a uniform temperature distribution over the liquid volume. The first study used the thermal transient model to follow heat transfer through the solid–solid interface between the pyrotechnic device and the thermal diffuser. The optimization tool automatically



There was very good correlation between the numeric model and experimental results.



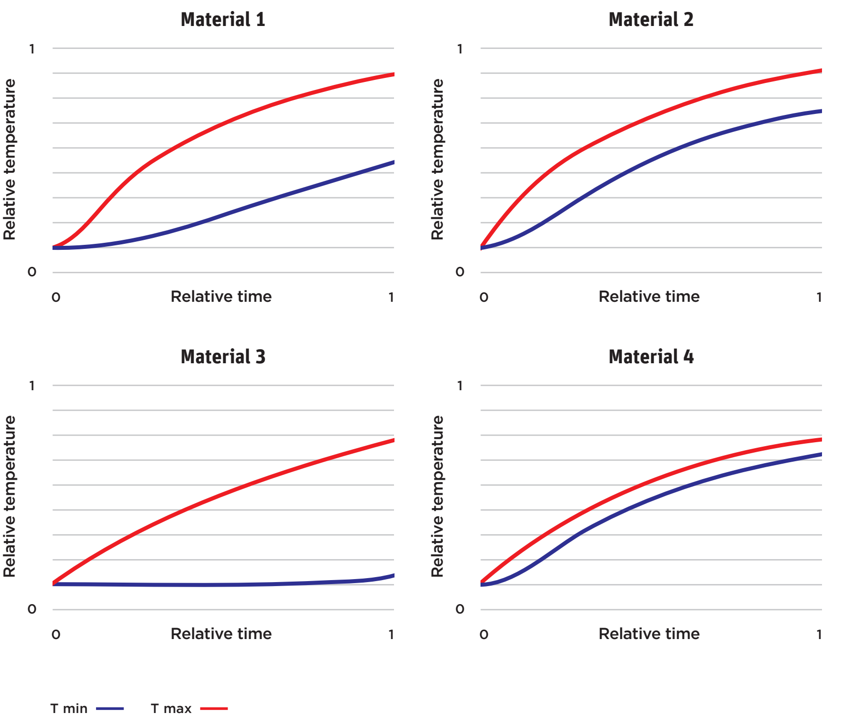
Temperature distribution around the external envelope of the initial thermal diffuser design concept

explored the design space and set the diffuser dimensions to best achieve the goal of a uniform temperature profile.

Engineers then used ANSYS Fluent to evaluate heat transfer between the solid–fluid interfaces and determine the volume of liquid that the thermal diffuser could heat. They modeled the container that held the liquid around the thermal diffuser. They exported results from the transient thermal analysis to the CFD software and set the initial conditions and thermal properties of the liquid. Simulation results showed that the optimized design provided a uniform temperature distribution in the liquid, meeting the customer's requirements.

Simulation demonstrated the feasibility of controlling thermal transfer from combustion of an energetic material to a liquid by optimizing the material properties and geometry of the thermal diffuser. Of course, other constraints must be taken into account, and the team will further tune and tweak the geometry. ANSYS solutions allowed engineers to anticipate development risks and enabled them to quickly make a pragmatic decision about the feasibility of producing the product.

In addition, the success achieved through simulation in this project led to developing a new process to determine the heat flux of energetic materials. Transient thermal analysis was used to establish a database of the heat flux functions of energetic material formulations and configurations. This database enables the applications team to quickly propose solutions based on specific customer requirements.



Thermal diffuser maximum (red) and minimum (blue) temperatures as a function of time. The objective was to minimize the difference between the two to heat the largest possible volume of material. Materials 2 and 4 had good thermal properties. Material 2 was selected because of its superior machinability.

Temperature distribution in the liquid was predicted by CFD.