Rewriting the Formula for Fireworks

What is the secret for making fireworks shows look more spectacular? By leveraging simulation to reduce the amount of fireworks smoke, the displays will be brighter and more dynamic than ever. Mitsuo Koshi, a highly respected chemical kineticist and fireworks contest judge, tackled this problem.

By **Mitsuo Koshi**
Professor Emeritus
University of Tokyo
Japan

Every summer in Japan, dozens of "Hanabi" aerial fireworks festivals light up the night sky. These events attract hundreds of thousands of visitors, with many camping out hours in advance to grab the best viewing spots. However, during calm weather, spectators suffer from reduced visibility due to large clouds of smoke generated by the explosive combustion of black powder within the fireworks. The issue worsens every year as the festivals — and fireworks manufacturers — compete by creating bigger and more elaborate fireworks displays to sell more tickets.

To solve the problem, ANSYS Chemkin-Pro — software predominantly used for creating combustion simulations — was used to model the smoke formation within the fireworks and investigate the chemical reactions. This data provided invaluable insights that led to recommendations for smoke reduction.

Without simulation, predicting particle size, distribution and density would have been nearly impossible. Determining these values using experiment only would have been very expensive. Additionally, simply focusing on experiments would not have permitted an analysis of smoke formation. Understanding the chemistry and physics behind potassium salt particle formation in black powder combustion was vital to answer the critical questions.

SIMULATING SMOKE FORMATIONS

The first attempt to understand the phenomena involved used classical nucleation theory (CNT) to crack the smoke formation code, hoping to reveal the mechanisms for particle formation and the related physics. Unfortunately, CNT could not be applied to examine the fireworks' very small particles and predict how black powder generates smoke.

To overcome this challenge, an unconventional approach was attempted using Chemkin-Pro, the same combustion modeling tool that automobile manufacturers use to predict soot formation in their car engines. Soot is composed of hydrocarbons, and fireworks smoke is composed of potassium salt.

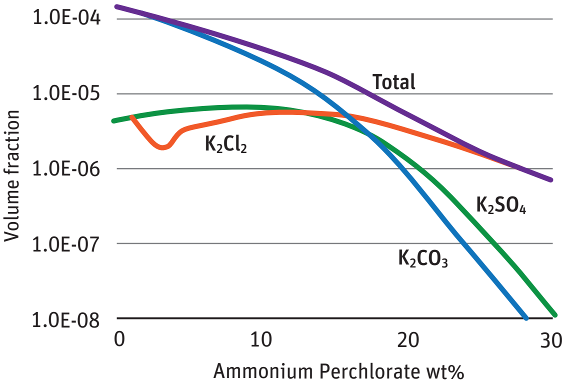
Modeling research efforts began by predicting the gas concentration within the fireworks' chemicals. By creating a simple reaction/kinetics model as an input to Chemkin's particle tracking system, Chemkin predicted the smoke's particle sizes and particle number densities based on processes such as coagulation and aggregation, leveraging Chemkin-Pro's particle tracking system to enable particle calculations. This approach produced a holistic view of the problem, leading to a solution of the master equation for the particle population and a recommendation to mitigate smoke generation, all in just one month.

Introduction to ANSYS Chemkin for Chemical Kinetics Simulation
ansys.com/chemkin-intro

ENGINEERING A NEW RECIPE FOR FIREWORKS

Simulation led to a recommendation to alter the formula for fireworks chemistry, substituting ammonium perchlorate for large amounts of black powder while reducing the amount of potassium salt in the black powder recipe. This approach slashed the number of smoke particles and reduced emitted smoke by nearly 90% — leading to higher-quality fireworks displays.

Next, researchers from the Yokohama National University and the University of Tokyo will conduct extensive experiments based on these models, using state-of-the-art instruments to measure the smoke and test the conclusions derived from the modeling.



Average volume fraction of smoke particles after black powder combustion obtained by solving the Smoluchowski equation using ANSYS Chemkin-Pro as a function of added ammonium perchlorate.

> ***"ANSYS Chemkin-Pro was used to model the smoke formation within fireworks and investigate the chemical reactions."***

Interestingly, this fireworks research can be applied to other applications, processes and industries. For example, the beauty industry consistently seeks new methods to reduce the size of hydrogen dioxide, titanium dioxide and aluminum nitride nanoparticles in makeup, which in turn produces a higher-quality product. To accomplish this, a reaction/kinetic model input into Chemkin-Pro would enable the modeling of particle coagulation and other key processes, providing researchers with key insights for shrinking the nanoparticles.

Japanese fireworks festivals will soon brighten and have more visibility than ever thanks to this cutting-edge research. Simulation quickly enabled a feat formerly deemed impossible — nearly eliminating the smoke from fireworks — by rewriting the formula.

Reacting Flows and Combustions
ansys.com/reacting-flows

ABOUT MITSUO KOSHI

Professor Mitsuo Koshi is a world-renowned chemical kineticist and chairman of Japan's Fireworks Festival Committee, responsible for judging the most prestigious fireworks competitions in Japan. An expert on combustion reaction modeling and chemical kinetics/reactions of explosives and former chairman of the Japan Explosives Society, Koshi recently offered his expertise to the Japanese fireworks industry to help overcome the engineering challenge of reducing fireworks smoke, enabling every fireworks show in Japan to deliver the highest-quality experience.

Reference

Koshi, M. Smoke Generation in Black Powder Combustion. **2018**. *Science and Technology of Energetic Materials*, Vol. 79, Issue 3.