Propellants, Explosives, Pyrotechnics

NanoEnergetics: Hype, Reality and Future

Nanoscience and nanotechnology have become part of the lay vernacular over the last decade, with the promise of a fantastic new world of medicine, ultra fast computers and energy independence; an exciting sci-fi future. Nano has pervaded the popular press, and authors have found it a useful tool in fiction literature, albeit very often with a foreboding tonality that to some portends a frightening future.

On the other hand the actual impact on nanotechnology has been far less than its proponents promise or its detractors fear. From nanomedicine to new electronic devices the impact of nanotechnology has been less than awe inspiring, and unfortunately this also happens to be true for the area of energetics. There are sound technical reasons, as well as a natural reluctance by a community that is by most measures highly conservative and risk averse, for the slow progress.

The driving force to consider nanoenergetic materials beyond the "us too" approach lies in some fundamental thermodynamic limitations we have run up against in traditional CHNO systems. I believe it has become quite clear that from an energy output standpoint we are near the limit of the potential energy that can be stored in CHNO chemical bonds, and no amount of molecular engineering can significantly change that paradigm. We have reached the end of that road.

Let's first consider the promise of nanoscience and nanotechnology. The term "nanoenergetics" implies the use of components that have some dimensionality that nominally is less than 100 nm (usually a particle diameter). The criterion is of course arbitrary and nothing magically happens at this artificial boundary. While early considerations and commentaries implied some significant excess energy at small length scales associated with the high compressive forces small particles experience, it is now generally accepted that thermodynamically there is no significant advantage to the nanoscale. On the other hand, many of the component compositions proposed for nanoenergetic material have thermochemical energy release significantly higher than traditional CHNO systems. Thermites are the most obvious example, which have of course been around for a long time. Without giving the reader too much opportunity to revel in my ignorance of organic chemistry, in part the rapidity of molecular chemistry comes from the close proximity (a few angstroms) between the fuel and oxidizer components of an energetic molecule. The natural extension of this thinking is to use components that are known thermochemically to yield high energy release, but are kinetically slow, and then shrink the length scales between fuel and oxidizer to get speed. Ergo we have "nanoenergetics". So the promise is more energy release (than CHNO), and the challenge is kinetics and formulation science.

There is plenty of experimental evidence that nanoscale components offer speed advantages over their micron counterparts, but it is also becoming clear that the experimentally derived scaling laws suggest speed improvements less than expected by our current conceptual models. In part the science base for the justification of these materials is lacking. We do not have a good conceptual grasp of many of the initiation and propagation processes in such systems, which are significantly more heterogeneous than the molecular counterparts. There are significant processing challenges as well. Incorporation of nanocomponents with binders is a nightmare for formulators because the high surface area makes processing very difficult.

So what is the way forward? Well, if we return to the CHNO limitations as discussed above, and the fact that those 4 elements comprise just a few percent of available elements in the periodic table, it seems obvious that we have no choice but to explore different chemistries. Our ability to generate a wide array of particulates of fuel and oxidizers is rapidly increasing, but without a fundamental understanding of how these materials work, most of this effort relies on empiricism. We need research groups across the world to devote more effort to the fundamentals of initiation and propagation towards answering the question: What makes for a good nanoenergetic composite? The answer is not sufficient without the requisite formulation know-how. New strategies are needed to incorporate nanomaterials, which may imply packaging them into mesoscale materials that still retain the nanoscale character during use, but resemble the micron scale material we know how to process.

Nanoenergetics not only offers the opportunity to reinvigorate a disciple that has lost some of its luster, but more importantly, a pathway forward to significantly alter the trajectory of energetics research and its advancement.

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