Maintaining a Stable Engineered Nanomaterials Process through Material Characterization during the Nano Product Life Cycle

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ABSTRACT

Nanomaterial synthesis, end-product formulation, and nanomaterials' wide range of applications are outpacing regulations and standard methods. No matter what your nano-end-product application may be, from food to pharmaceuticals to petrochemicals, there are seven key characteristics and two additional qualities that are unique to nanomaterials. One or more of these characteristics or qualities may be very important to characterize for control, during the manufacturing process. In addition to meeting end-product specifications, controlling nanomaterials during the manufacturing-process will minimize process scrap and waste. Process waste has always been a manufacturing issue, but nano-waste and scrap present different issues than bulk-waste and scrap. There is increasing review and concern within industry and the environmental field as to the fate, transport, and transformation of nanomaterials in the environment. Risk areas that can be addressed through nanomaterial-characterization in the manufacturing process are discussed in this paper.

Keywords: characterization, life-cycle, manufacturing, nano-waste, nanomaterial

1 INTRODUCTION

In recent years there has been ever increasing activity and excitement within the scientific and engineering communities, driven heavily by government investment, about engineered nanotechnology applications. The U.S. National Science Foundation has estimated that the global nanotechnology market could be worth U.S.$1.2 trillion by 2020 [1]. In parallel, much has been written and presented about the excitement and possible dangers of these materials. The tone of these media articles range from how these wonder materials are going to revolutionize all aspects of our lives to how they might harm us! What follows is a basic introduction to engineered nanomaterials. It provides insight and appreciation of some of the potential new applications of these materials. In addition, understanding the wide range and types of measurements needed to characterize these nanomaterials along with what solutions PerkinElmer has to support customers working in this field.

2 WHY DO WE CARE ABOUT NANOMATERIALS?

Engineered Nanoparticles are of great scientific interest. They effectively bridge a gap between bulk materials and atomic and molecular structures. Nanoparticle mechanical properties are different than bulk material. Surface area is disproportionate to weight, for instance, an 8nm gold material has a surface area of 32 square meters per gram.

There is a diverse field of applications over a broad range of industries:

- Energy, energy-conservation, pharmaceuticals, chemicals, catalysts
- High performance-composite engineered materials – military to leisure time applications
- Coatings, electronics, sensors & displays

3 WHAT NANOMATERIAL PARAMETERS SHOULD BE CHARACTERIZED?

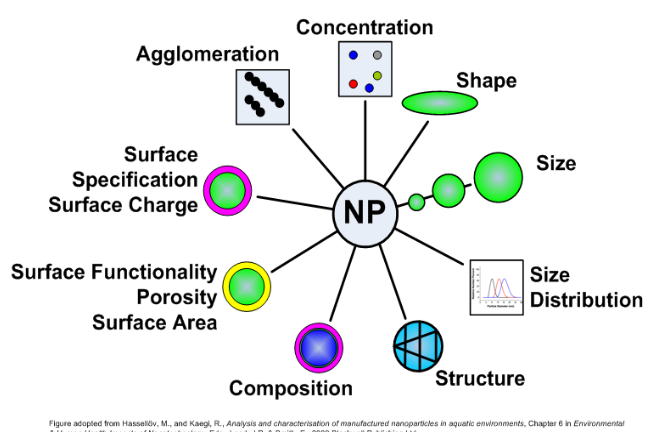

Figure 1. Key Nanomaterial Pararmeters [2]

To completely characterize nanomaterial it is necessary to know a multitude of chemical and physical pararmeters including: the size of the particle, their shape, surface characteristrics, the presence of surface coatings, and the presence of impurities.

Consequently, at the nanoscale, analytical measurement challenges are considerable. The choice of just one analytical technique for manufacturing quality control maybe insufficient. An example is choosing to measure the elemental concentration of gold in a suspension by inductiively coupled Plasma-mass spectrosmetry (ICP-MS) as the only metric. This maybe incomplete to control a manufacturing process. Complementary characterization of size, size distribution, or shape may be required to best controle the process.

4 HOW ARE ENGINEERED NANOMATERIALS MEASURED?

Seven of the nine nanomaterial characteristics: **Particle Size Distribution, Surface Charge, Surface Area, Shape, Agglomeration, and Structure**, are characterized by one of the following analytical techniques:

- Scanning Electron Microscopy (SEM)
- Transmission Electron Microscopy (TEM)
- Atomic Force Microscopy (AFM)
- Confocal Microscopy (CFM)
- Dynamic Light Scattering (DLS)
- Field Flow Fractionation (FFF)
- Molecular Gas Adsorption (BET)
- Electrophoresis Particle Size

Note: ***Ultraviolet/Visible Spectroscopy*** and ***Fluorescence Spectroscopy*** are used for particle size identification as long as the material is known and it is reflective. ***Fluorescence Spectroscopy*** is also used for agglomeration studies

Nanoparticle Concentration and Composition are two nanoparticle characteristics that that are not covered by the analytical techniques described in the paragraph above. There are many analytical techniques that do cover concentration and composition. The correct analytical technique is determined by the material, coatings, and nano application. For **Nanoparticle Concentration** you might choose one or several of the following analytical techniques:

- ***Indutively Coupled Plasma and Mass Spectroscopy (ICP-MS)***
- ***Liquid Chromatography and Mass Spectroscopy (LC-MS)***
- ***Ultraviolet/Visible Spectroscopy (UV/Vis)***
- ***Fluorescence Spectroscopy (FL)***

For **Nanoparticle Composition** you might choose one of the following analytical techniques:

- ***Inductively Coupled Plasma and Mass Spectroscopy (ICP-MS)***
- ***Liquid Chromatography and Mass Spectroscopy (LC-MS)***
- ***Ultraviolet/Visible Spectroscopy (UV/Vis)***
- ***Fluorescence Spectroscopy (FL)***
- ***Thermogravimetry (TGA)***
- ***Differential Scanning Calorimetry (DSC)***
- ***Dynamic Mechanical Analysis (DMA)***
- ***Fourier Transform Infrared Spectroscopy (FTIR)***
- ***Raman Spectroscopy***
- ***Thermogravimetry, Gas Chromatography, and Mass Spectroscopy (TGA-GC/MS)***
- ***Thermogravimetry and Mass Spectroscopy (TGA-MS)***

For **composition**, you may be concerned with purity of the nanomaterial or the characterization of the funtionalized coatings on nanomaterials.

The analytical techniques listed in ***Italics*** are nano-characterization instruments that PerkinElmer supplies today. The multitude of nano-characterization instrumentation reminds us that there is not one analytical technique that can characterize a nanomaterial.

5 WHY IS CHARACTERIZATION IMPORTANT FOR NANOMATERIAL MANUFACTURING?

Engineers know that, *"If you can't measure it, you can't build it."* To understand this, an overview of the nanomaterial manufacturing process and value chain is necessary. This includes:

- Source and quality of raw materials (QA/QC)
- Control the nanomaterial manufacturing process (QA/QC)
- End product formulation (QA/QC)
- Incorporation into another product
- End use

Along this manufacturing chain are a variety of points at which material and hazardous waste may need to be disposed of and there is potential for environmental exposure.

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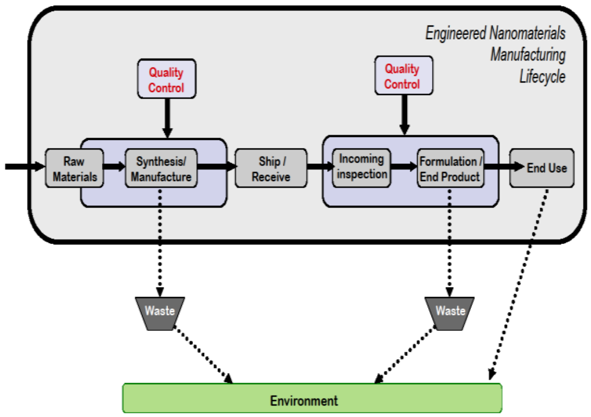

Figure 2. High Level Overview of the Engineered Nanomaterial Manufacturing Process

First and foremost is to know why characterizing materials is important for a stable process. Without material characterization (QC and QA), the end product manufacturing process will be difficult to control. This results in products that do not meet specification and manufuacturing inefficiencies.

6 WHAT'S IMPORTANT FOR THE ENVIRONMENT?

Process waste has always been a manufacturing issue. It is slightly different today when NMs are considered. Nano-waste is different than bulk material waste. Laboratory experiments have shown that nanomaterials can enter the human body by dermal exposure, inhalation, and ingestion. While there are no NMs regulations yet, there is increasing review and concern both within industry and in the environmental field as to the fate and behaviour of these materials. [2].

In the United States, the EPA and other government agencies are proactive in regards to nanotechnology. The Federal Government has established the National Nanomaterial Initiative (NNI) where government agencies and private industry meet to discuss and understand nanomaterial implications of the environment and human health [3].

The waste interaction with the environment could occur from material taken to a land fill, incinerated, or washed down the drain. Environmental Health, and Safety (EHS) applies to nanomaterial-workers as human exposure could occur during the manufacturing process [2, 3, 4, 5].

7 CONCLUSION

It will take time for manufacturers to identify what nanomaterial characteristics are important for their manufacturing process. In general, we are learning more about the important NM characteristics; next steps are how to apply this knowledge to specific nano-business processes. Skilled people will be needed to operate the existing analytical instruments and new instruments on the horizon. Lastly is environmental stewardship, to enable nanomaterial applications to realize their full potential, there must be safe guards for the environment where needed. [5, 6, 7]

8 ADDITIONAL READINGS AND WEBSITES

- Nanotechnology and Engineering Nanoparticles-A Primer www.perkinelmer.com/nano
- Nanopharmaceutical Applications Library www.perkinelmer.com/nano
- U.S. National Nanomaterials Initiative (NNI), http://www.nano.gov/
- University of California Center for Environmental Implications of Nanomaterials, USA,
- http://cein.cnsi.ucla.edu/pages/
- International Standards organization, http://www.iso.org/iso/home.htm

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