Agriculture and Nanotechnology

By Alan Johnson

Nanotechnology will leave no field untouched by its ground breaking scientific innovations. The agricultural industry is no exception. So far, the use of nanotechnology in agriculture has been mostly theoretical, but it has begun and will continue to have a significant effect in the main areas of the food industry: development of new functional materials, product development, and design of methods and instrumentation for food safety and bio-security [5]. The effects on society as a whole will be dramatic.

Materials

Recent advances in materials science and chemistry have produced mastery in nanoparticle technology, with wide ramifications in the field of agriculture. One area in particular is that of the cotton industry where current techniques of spinning cotton are quite wasteful. From harvesting the cotton to finalizing the fabric it's made into, over 25% of the cotton fiber is lost to scrap or waste [2]. However, Margaret Frey, an assistant professor of textile science at Cornell University, has developed a technique called electrospinning that makes good use of the scrap material that would otherwise be used to make low-value products like cotton balls, yarn, and cotton batting [3]. At Cornell University, polymer scientists have used this technique of electrospinning to spin nanofibers (figure 1) from cellulose ($(C_6H_{10}O_5)_n$), a complex carbohydrate composed of glucose units that makes up 90% of the cotton material. The technique of electrospinning cellulose on the nanoscale was successfully used for the first time about two years ago. "The technique relies on electrical rather than mechanical forces to form fibers. Thus, special properties are required of polymer solutions for electrospinning, including the ability to carry electrical charges" says Frey [2]. The process involves dissolving cellulose in ethylene diamine, a relatively benign solvent, squeezing the liquid polymer solution through a tiny pinhole while applying a high voltage to that pinhole. This charge pulls the polymer solution through the air into a tiny fiber, which is collected on an electrical ground (see figure 2) [3]. The fiber that is produced is less than 100 nanometers in diameter, which is 1,000 times smaller than what is produced in conventional spinning [2]. If Frey's process meets its expected potential, possible applications of electrospun cellulose may include air filtration, protective clothing, agricultural nanotechnology, and biodegradable nanocomposites [2]. Another application that the scientists have speculated upon is using the biodegradable cellulose mats to absorb fertilizers and pesticides. These materials would then release the fertilizers or pesticides at a specific time and location for targeted application [2].

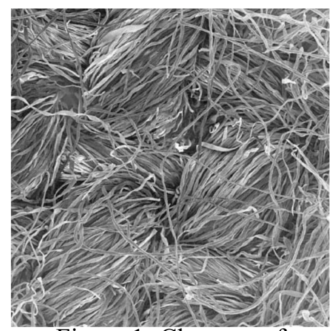

Figure 1: Close-up of nanofibers from electrospun cotton

Products

A major problem in food science is determining and developing an effective packaging material. Using nanoparticle technology, Bayer has developed an even more airtight plastic packaging that will keep food fresher and longer than their previous plastics and the plastics of their competitors. Researchers at Bayer Polymers refer to this new plastic as a "hybrid system" as it is enriched with an enormous number of silicate nanoparticles. When this plastic is processed into a thin film and wrapped over food, it does a better job than previous plastics of preventing food from going bad on the shelf and it helps prevent odors from one food mixing with another.

What is most problematic for food packaging engineers is oxygen because it spoils the fat in meat and cheese and turns them pale. Due to the nature of the nanoparticles in Durethan®, Bayer's new plastic material, air cannot penetrate it like other conventional plastics (Figure 3). The embedded particles have a maze like arrangement in the plastic, acting like barriers, which makes it difficult for gases, like oxygen, to pass through the packaging. They actually increase the distance the gas molecules have to travel by causing those molecules to zigzag around the silicate plates in effect increasing the amount of time it will take for the molecules to completely penetrate (see figure 4) [6].

Impregnating the polyamide 6 (the base polymer Bayer uses for Durethan®) with the layered silicate platelets is not as simple as just blending them together. A few technical tricks are needed to ensure that there is uniform blending of the polyamide and the layered silicates. In the past, the engineers have used a process called compounding in which the silicates are kneaded into the viscous, dough-like, plastic melt, which has been moderately unsuccessful until now. In this process, it is still difficult to separate the individual layers of the silicates and to distribute them homogeneously throughout the polymer [6]. To get around this problem, Bayer researchers instead mix the silicates in the polyamide base material. This works well because caprolactam, the starting material for polyamide 6, is fluid and quickly penetrates the small spaces between the silicate particles in the stack. Once the plastic goes through polymerization, the viscous polymer that forms scatters the individual platelets, but in order for the caprolactam to diffuse the platelets, the silicates have to be chemically modified. That is the metal ions that form the bonds between the platelets have to be replaced by an organic acid, which increases the distance between the individual silicate stacks [6]. Once the mixing is done, the silicate stacks are broken down almost completely and the individual platelets are distributed uniformly throughout the polyamide. When the plastic is extruded into a film, the platelets orient themselves parallel to the surface, allowing minimum penetration of oxygen through the material [6].

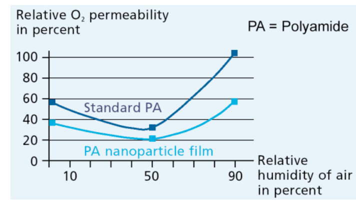

Figure 3: Permeability to humidity ratio graph

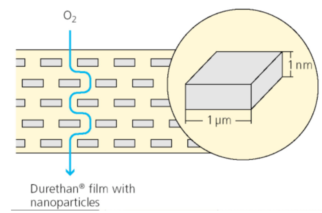

Figure 4: Oxygen molecules must traverse through the nanoparticles to get through the Durethan

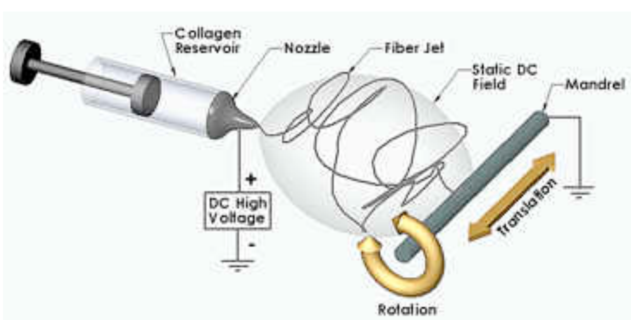

Figure 2: Electorspinning mechanism

Adding to this protection is the dimension of the silicate particles themselves. Each platelet is only a few nanometers thick but is about 1,000 micrometers long, which means the gases will have to go a long way around the platelets while the overall material remains quite flexible [6]. This shows excellent promise to the food industry, as it will allow retailers to store and preserve the quality of meats, and other food items that expire easily, for a longer period of time.

Bio-security

As important as waste materials and preservation of food is in the agricultural field, a major concern is that of the safety of the food products. Far too often food contains bacteria and viruses, which frequently ends in illness and sometimes fatality. According to Mark Modzelewski, executive director of the NanoBusiness Alliance:

> the most likely area in which nanotechnology will initially enter the agricultural industry is the world of analysis and detection, such as bio-sensors to detect the quality of and the health of

> agricultural products and livestock, [adding] advanced nano-sensors that can detect surface and airborne pathogens are already leaving the lab...[4]

A biosensor is composed of a biological component, such as a cell, enzyme or antibody, linked to a tiny transducer, a device powered by one system that then supplies power (usually in another form) to a second system. The biosensors detect changes in cells and molecules that are then used to measure and identify the test substance, even if there is a very low concentration of the tested material. When the substance binds with the biological component, the transducer produces a signal proportional to the quantity of the substance. So if there is a large concentration of bacteria in a particular food, the biosensor will produce a strong signal indicating that the food is unsafe to eat [7]. With this technology, mass amounts of food can be readily checked for their safety of consumption.

Societal Effects

Coming nanotechnologies in the agricultural field seem quiet promising. However, the potential risks in using nanoparticles in agriculture are no different than those in any other industry. Through the rapid distribution of nanoparticles to food products – whether it be in the food itself or part of the packaging – nanoparticles will come in *direct* contact with virtually everyone. The environmental group ETC (Action Group on Erosion, Technology and Concentration) is deeply concerned with the implications and regulation of nanotechnology used in food. Currently, there are none. Their main concern is that of the unknown. In a publication in November 2004, the ETC stated that "the merger of nanotech and biotech has unknown consequences for health, biodiversity and the environment" [1]. Since there is no standardization for the use and testing of nanotechnology, products incorporating the nanomaterials are being produced without check. The ability for these materials to infiltrate the human body is well known, but there is really no information on the effects that they may have. While there is no evidence of harm to people or the environment at this stage, nanotechnology is a new and evolving area of study that could cause a great deal of harm due to its still ambiguous chemical properties.

With the current application and advancements soon to come, nanotechnology will have a great impact on the direction that agriculture will take. Scientists are blazing a trail for a new technology and looking at every possible avenue to improve upon current methods in every possible field. In the field of agriculture, there are still many possibilities to explore and a great deal of potential with up-coming products and techniques.

This student-produced report is part of a larger pamphlet on nanotechnologies circa 2005, the partial output of a course on "Nanotechnology and Society" (Science and Technology Studies, Section 84405, by C. Tahan) which was taught in the spring semester of 2005 at the University of Wisconsin-Madison. Visit http://tahan.com/charlie/nanosociety/course201/ for the other reports and more information.

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Figure 1: Dennis Kunkel. <http://ehp.niehs.nih.gov/members/2004/112-13/ innovations.html>.

Figure 2: <http://www.people.vcu.edu/~glbowlin/electrospinning.htm>

Figure 3, 4: <http://www.research.bayer.com/mediem/pages/2999/polyamides.pdf>.