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Liz Nickels

Promethean Particles, which makes nanomaterials using a continuous-flow production process, is collaborating with the healthcare industry to develop new applications for its copper nanoparticles.

One result of the Covid-19 pandemic is that companies specializing in metal additive manufacturing and powder manufacturers have been able to show and develop the potential of their technology and products for healthcare applications.

In April, UK manufacturer Promethean Particles reported its collaboration with textile companies and research facilities to explore the antiviral effects of its copper nanoparticles designed for use in fabrics and personal protective equipment (PPE). Previously, the company developed nano-copper for the printed electronics market, due to the conductive properties of copper; while its other nanomaterial products can be used in a range of markets, including inks and pigments, functional nanoceramics, printed electronics, and energy capture and storage.

Promethean’s work on copper nanoparticles for textiles and PPE was part of the ACTIn project, funded by innovation investor Newton Fund, which was a collaboration between Mexican and UK companies and research institutes to develop durable antimicrobial textiles for the healthcare sector by embedding nano-copper into polymer fibers, such as nylon, via a melt extrusion process.

According to Promethean Particles, the antimicrobial effect lasted longer than other similar antimicrobial fabrics which were surface-coated, and therefore lost functionality with each wash. As well as this, when using nano-copper, as opposed to larger copper particles, a smaller mass of active material is reportedly required to achieve the same antimicrobial effect due to the increased ratio of surface-area-to-volume in smaller particles.

Improved protection

The company next sent the material to independent laboratories in the US and UK for anti-viral testing to ISO standards. ‘If certified, it could open the door to the manufacture and supply of nonwoven fabrics and [PPE], such as garments, face masks, hats, uniforms and bed linen, which is resistant to viruses – such as the coronavirus that causes Covid-19 – and will offer much needed improved protection for frontline health workers,’ a press release said.

’If we can show evidence of antiviral properties from the testing currently being carried out, then it’s particularly relevant to the current Covid-19 outbreak, and we may see a lot more urgency in its development,’ said Dr Selina Ambrose, Technical Manager at Promethean Particles. (Fig. 1.) ‘Prior to the Covid-19 pandemic, this research was a strategically important focus area for both the UK and Mexico due to the significant economic and social impact of healthcare acquired infections that lead to extended patient stays in hospitals, higher healthcare costs, and thousands of deaths globally each year. With current events, clearly it has become absolutely critical that progress is made now.’

The company says that there is potential to further develop its nano-copper materials for use in coating applications for door handles, handrails and beds within the healthcare sector, and is reportedly in talks with a manufacturer to develop a transparent antimicrobial coating containing its nano-copper technology suitable for glass. The coatings could also be incorporated into a range of touchscreen personal devices, as well as those found at train stations, cinemas and fast-food restaurants, and by using nano-copper particles, glass transparency is retained, Dr Ambrose said.

‘For most applications, having both antimicrobial and anti-viral functionality will be of huge benefit to manufacturers,’ she said. ‘Our nanomaterials offer many advantages over others on the market. Our liquid dispersions are easier to process and provide a more effective, functional final product.’

Promethean makes nanomaterials using a continuous-flow production process, and the nanoparticles manufactured are

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reproducible on a large scale, the company said. Its plant in Nottingham, UK features what it says is the world’s largest, continuous, multi-material nanoparticle manufacturing plant, with manufacturing capacities in excess of 1,000 tons of nanomaterials per year.

The company's technology was initially researched 20 years ago with a collaboration between chemical engineers and chemists at the University of Nottingham in the UK. The research focused on the development and scale up of continuous hydrothermal synthesis (CHS) as a route to manufacturing nanomaterials. Promethean said that it was able to overcome issues relating to fluid mechanics to allow continuous hydrothermal synthesis to become a viable process.

According to Promethean, CHS combines an aqueous metal salt solution with a superheated water stream to create nanoparticles suitable for a range of applications. For years, the development of the process was hindered by dangerous blockages forming within the system, caused by mixing two fluids with completely different physical properties, the company said. To overcome the problem, the researchers used pseudo-fluid modeling to understand the nature of the mixing inside the reactor, using dyed sugar water and methanol inside Perspex reactors to simulate the events inside a high-pressure, high temperature steel reactor. This allowed the scientists to better understand the issues around fluid partitioning, roping and back mixing, and allowed the process to be tested before building a real system.

More recently, the company installed a solvent recovery system that it says allows it to reuse more than 95% of the organic solvents used to manufacture nanomaterials.

‘At Promethean, where the chemistry allows, we always aim to manufacture and process our products using water, rather than organic solvents, to minimize our environmental impact,’ said Lewis Neve, Engineering Manager. ‘However, in some instances, the chemistry isn’t compatible or there is no other option but to use organic solvents to achieve the final desired outcome. For example, when activating our metal organic frameworks (MOFs) to achieve greater surface area and adsorption potential, organic solvents are a must.’

Metal Powder Report spoke to Dr Ambrose about the company and its new collaboration with healthcare companies.

What is the potential of nanoparticles, especially copper?

Nanotechnology has opened a wide opportunity in the area of materials science. The development of materials at nanometric scale has been increasing in different fields, and the properties of these nanomaterials are critical for the global technological revolution.

There are multiple benefits to using nanoparticles, rather than larger, ‘bulk’ particles. The larger surface area-to-volume ratio in nanoparticles typically means a smaller mass or weight of active material is required to achieve the same performance or functionality compared to larger particles. Furthermore, the ability to adjust the size of nanomaterials allows them to be incorporated into a wide range of materials to improve their properties.

‘Nano’ refers to the size of the particles, so nanomaterials can be comprised of a wide range of chemical compositions, both organic and inorganic. Promethean’s technology can be used to manufacture a wide range of nanomaterial chemistries and the company principally focuses on the production of inorganic nanomaterials such as metals, metal oxides, metal hydroxides and metal phosphates. These include, but are not limited to, copper, nickel, zinc oxide, iron oxide, zirconium oxide and a calcium phosphate known as hydroxyapatite.

There is great interest in copper nanoparticles due to their optical, catalytic, electrical and antimicrobial properties. Copper is a good alternative material for noble metals, such as silver and gold, due to its wider commercial benefits, highly conductive properties and the fact that it is much more economical to source. In addition, the properties of copper nanoparticles can be better controlled depending on the synthesis method.

There are two main ‘branches’ of application for nano-copper that Promethean has been exploring, with a focus on either the conductive properties or antimicrobial properties of the metal.

Initially, Promethean developed nano-copper for use in printed electronics because of its conductive properties. The development of nano-copper has garnered much interest because of its huge potential for replacing expensive nano silver inks used in conductive printing.

Copper nanoparticles have been a strong focus for health and medical applications due to their antibacterial properties and antifungal activity, in addition to their catalytic, optical, and electrical properties.

The antimicrobial potential of copper nanoparticles makes them excellent components for application in biomedicine and more recently, they have been investigated for applications as drug delivery agents in cancer therapy and other chronic conditions.

The team of scientists at Promethean is developing nano-copper for a variety of antimicrobial applications. The natural antimicrobial properties of copper typically help to combat the spread of bacteria, and some viruses too, by destroying the outer membrane of the microbe.
Coatings is another option for nano-copper applications, for example, door handles or handrails in hospitals, on public transport and other public areas, to deliver antimicrobial performance. By using nanoparticles rather than the larger metal particle in this application, the coating finish is likely to be of a higher quality and smoother as big particles can make the finish bumpy and uneven.

The extraordinary antimicrobial potential of various metal nanoparticles also makes them an effective tool for the management of plant diseases for the benefit of the food and agricultural industries.

**Do companies know enough about how metal nanoparticles can be used?**

Nanotechnology is still an emerging technology in many industries outside scientific research laboratories. Its potential capabilities and benefits to business processes, products and applications are only recently starting to be fully understood and recognized by a wider audience. Over the past 20 years, new and improved nanomaterials have been designed, which can be more targeted and tailored towards applications in a way not possible before, thanks to advances in characterisation methodologies and analysis.

Today, nanoparticles can be incorporated into almost anything. They are used in the textile, healthcare, automotive, energy, food, retail, construction and aerospace industries, among others, delivering stronger, lighter, more durable, more reactive, more resistant and more sustainable products.

Some industries that are unfamiliar with nanoscience have a perception that it is something dangerous and to be feared. Manufacturers that may want to use nanomaterials in their processes could have concerns about the safety of their operators and the potential need for additional equipment to facilitate safe handling.

Until around 20 years ago, nanotoxicology was a poorly understood science and the safety of nanomaterials was questioned as a result. With the history of asbestos still front of mind for many, the widespread adoption of nanoparticles was challenged, because there was insufficient scientific evidence to allay fears of the consequences of skin contact or inhalation. However, research and funding into the sector have increased significantly in recent years and has indicated that, in general, it is the chemistry, not the particle size, that affects how nanoparticles behave in the body or environment.

While nanoparticles in dry powder form do increase any potential safety risk, Promethean manufactures its nanomaterials as liquid dispersions, using water or organic solvents as the reaction media. With a liquid dispersion, there is little or no likelihood of exposure by inhalation, thereby reducing any risk. There is also no requirement to invest in or implement additional equipment to handle the nanomaterials safely. (Fig. 2.)

**Has Covid-19 changed the industry for you?**

The pandemic has made everyone more conscious of how bacteria and viruses spread from one surface to another and the need for PPE. Since the COVID-19 outbreak, there has definitely been an increase in interest in our copper nanoparticles from companies looking to integrate antimicrobial or antiviral properties into their products. Textiles and fabrics have been the main focus, but antimicrobial nanomaterials for coatings and touchscreen applications have also generated enquiries and research.

Textiles with antimicrobial and anti-viral properties will be sought after, not only for the healthcare sector. Brands may look to include these solutions onto their products to build customer trust in a post-pandemic era, and that demand will travel up the supply chain to companies such as Promethean Particles that manufactures the functional additives.

**What challenges are affecting the production of copper nanoparticles?**

There are several crucial operational and commercial challenges that manufacturers must overcome in relation to nanomaterials in general, and more specifically nanocopper.

Within the wider nanotechnology industry, many nanomaterial manufacturers adopt dry synthesis techniques, for example, flame spray pyrolysis or plasma methods, which provide a dry powder product. Within a powder, there is a greater tendency for the nanoparticles to agglomerate, particularly when the nanopowder is being incorporated into a liquid matrix as is required for many applications (for example, paints, resins, or composite structures). This agglomeration of powder-form particles may be circumvented by functionalizing or coating their surfaces, but this typically means creating additional processing steps, thereby increasing costs.

New and innovative manufacturing techniques are today making it possible for nanomaterials to be produced in liquid dispersions. This significantly reduces the likelihood of particle aggregation and, as a result, ultimately removes process steps...
and complexity from the supply chain. Promethean Particles, for example, uses wet chemical techniques, namely hydrothermal or solvothermal synthesis, combined with a continuous-flow manufacturing process (as opposed to batch processing) to manufacture its nanoparticles as liquid dispersions. Having the nanoparticles in a liquid format makes solvent transfer and downstream processing – such as incorporation into a paint or resin – more straightforward. In addition, there is no need to dry the particles in between, limiting costly processing steps.

Regarding the commercial challenges presented by nanomaterials, one of the biggest difficulties centers around the reliability and consistency of large-scale supply. Most nanomaterial manufacturers use batch processes that are either not scalable or can only be scaled up with significant monetary investments, leading to extremely high pricing of the resulting materials. This then makes it less economical for product manufacturers to implement the technology into their processes.

The challenge of cost varies greatly between markets or sectors, mainly because some are more niche and able to tolerate higher prices, if the technical benefits are present. In others, where additives are more commodity-style goods, the cost is the bottom line which dictates if nanotechnology can be adopted.

Promethean’s continuous-flow reactor design, as opposed to batch processes, enables nanomaterial manufacturing to be scaled up without the usual surge in operating costs.

Copper nanoparticles specifically are quite a reactive material in that they can readily oxidize and form copper oxide if exposed to air or oxygenated conditions. At the nanoscale, with a higher surface-area-to-volume ratio than ‘bulk’ particles, the particles are even more likely to react. As such, copper nanoparticles – as oxide-free metallic copper – are traditionally difficult to produce and maintain through each processing step. Whilst copper oxide has been shown to demonstrate antimicrobial functionality, it is no longer electrically conductive. In the printed electronics industry, manufacturing oxide-free copper is important, but has been difficult to achieve in practice. Our manufacturing technology produces copper nanoparticles in a liquid dispersion; the solvent carrier acts as a barrier between the particles and air, meaning the dispersions can be handled in air without the need for special inert atmospheres.

How do you see the industry developing over the next 20 years or so?

While still classed as an emerging science, within 20 years, nanotechnology is likely to touch the lives of every person on the planet. Research and Markets ‘Global Nanotechnology Market Outlook 2024’ has projected growth at a compound annual growth rate (CAGR) of around 17% between 2018–2024. In 2017, the market size reached US$7.24 billion, and if it follows the predicted growth rate, it will increase to US$24.56 billion by 2025. Scientists predict that there will be four generations of advancement. The first focuses on material science and property enhancements achieved by incorporating ‘passive nanostructures’. The second generation makes use of active nanostructures, for example, by being bioactive to provide a drug at a specific target cell or organ. The third and fourth generations are yet to be reached and likely to go beyond the next 20 years! Third generation nanotech involves various complex nanomachines working together – the age of the nanobot. The fourth generation relates to a molecular, intricate nanosystem that can be applied to any industry. It is clear that nanoscience will create advances within every industry and transform everyday products. Deemed the ‘fifth technology revolution’, nanotechnology will help to create products that are smarter, cleaner, more cost-effective and better performing.

Promethean Particles;
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