CASE STUDIES

RESEARCH AND DEVELOPMENT OF PRODUCTION EQUIPMENT FOR AEROSOL COATING/DEPOSITING

1. Case metadata

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2. Organisations involved

Beneq is a supplier of production and research equipment for the preparation of thin film coatings. The company, a technology start-up from 2005, primarily serves the cleantech and renewable energy fields and is actively developing applications in solar power technology, energy conservation and flexible electronics. There are about 24 people working on these applications in Vantaa (Finland), where the main office is located. Beneq has overseas sales offices in Germany, China and the United States of America (USA). In addition, Beneq has a global sales presence via its network of more than thirty regional representatives.

3. Description of the case

3.1. Introduction

The applications and target industries of Beneq include transparent conductive oxides (TCO), barriers and passivation layers, LED and OLED, glass strengthening and optical filters. Beneq also offers complete coating and development services to its customers.

The equipment and applications offered by Beneq are based on two nano-enabled technology platforms: atomic layer deposition (ALD) and aerosol coating (nAERO® and nHALO®). ALD is a sequential gas phase coating method capable of depositing a wide array of materials as conformal and pinhole-free coatings, with nanometre accuracy, on any shape and most materials, including particles and powders. Beneq aerosol coating is an in-house developed atmospheric pressure deposition for large-area continuous coating operations, such as TCO coating on flat glass, which can be done either off-line or in-line.

For one type of aerosol coating, Beneq uses a coating process called nHALO, or Hot Aerosol Layering Operation. In nHALO, the process reagents, which are usually nitrate salts dissolved in water or alcohol, are vaporised in a hydrogen-oxygen flame. In the flame, particles nucleate and grow via condensation and coagulation into nanosized particulate matter. The particles produced may be metal, metal oxide or multicomponent. The particles are targeted directly onto the substrate being coated. If the substrate is glass and heated (above 600 °C), the particles predominantly diffuse into the surface layer of the glass. If the substrate is not heated, the particles deposit on the surface and create a porous and friable surface layer.

3.2. Aims

Based on a comprehensive survey of risk assessments for use with nanomaterials conducted by an external consultant, Beneq drew up some main conclusions, policies and directions for developing nHALO (not in order of importance):

1. the process contains/produces/emits nanosized particulate matter
2. exposure of personnel to nanomaterial resulting from the process must be minimised, preferably eliminated
3. Beneq needs more information, input, knowledge and understanding of the nanoaspect of the process, especially in terms of occupational safety and health. This need is valid both for internal operations and for use together with customers, who rarely understand the nano-aspect of the process.

3.3. What was done, and how?

Understanding of risks

Since the development of nHALO in the 1990s, it has been obvious that a majority of the particles created in the process are of nanosize. Therefore, when Beneq started to develop nHALO for coating applications, it was acknowledged within the company that the process involved nanoparticles and that the implication was that the possible emissions of the nanoparticles had to be understood, investigated and controlled before implementing the process internally and launching it as part of commercial production.

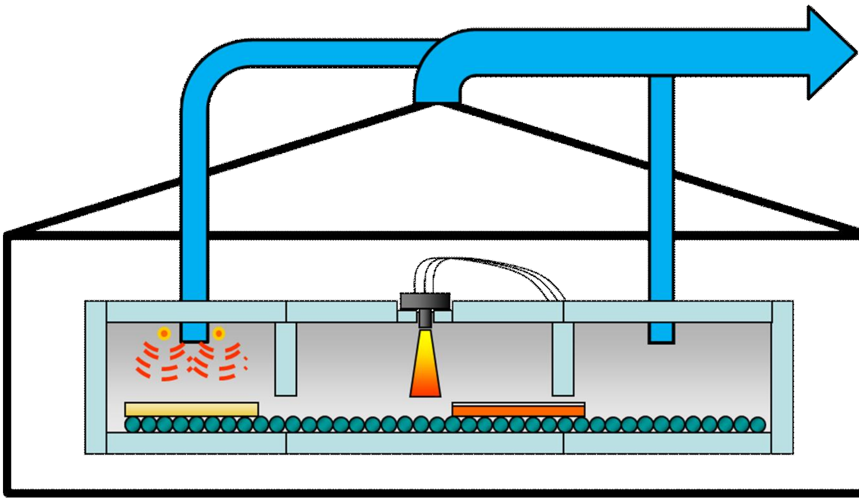
Technical measures; prevention at source

Largely based on the generic *modus operandi* applied by Beneq in all work, it was decided that the exposure of operators and others to the nanosized materials produced by the process would best be controlled by boxing in all phases of the process. Literally, and based on investigation and planning, this meant building an enclosure (hood) over the coating chamber and all related equipment as well as ventilating the hood externally. If possible, the enclosures were to be doubled, with both being ventilated.

Building a hood is not an economically cheap option, especially when the coating equipment is large, but from the very beginning the management has showed a strong will to A) protect workers from an identified risk, B) acquire knowledge about protection from nanomaterials before customers ask them about it and C) if possible, Beneq wanted to act as a good example to others.

Figure 1 is a schematic representation of how the hooded coating equipment was planned and what the line looks like in real life. The air pressure inside the external hood is kept lower than that of the outside air, ensuring the correct flow direction of all process-related effluent gases.

Figure 1: Schematic of Beneq coating equipment inside a closed tube furnace (enclosure 1) **inside an external hood** (enclosure 2).



Source: Courtesy of Beneq (1)

In Figure 2 the external hood (enclosure 2) with its sliding access doors and multiple ventilating exits on the roof is clearly visible in the background.

Figure 2: The enclosed coating equipment at Beneq

Source: Courtesy of Beneq (copyright Beneq)

Proof of concept

Beneq has joined in and participated actively in national and international nanosafety projects, *e.g.*:

- On-going internal investigations and measurements started in 2006
- NanoBAT ('Best available technology in manufacturing and handling nanomaterials'), national Tekes-financed, four participants from industry, 2008–2009.
- Nanoturva ('Nanoparticle detection and assessment of exposure in industrial facilities'), national Tekes-financed, three participants from industry, 2008–2010.
- NANODEVICE, European Commission-financed (FP7) research project, numerous participants from industry, Beneq is a member of the Annual Forum for Nanosafety, 2009–2013.

As an example, the project Nanoturva (literally, 'nanosafe') contacted Beneq and asked whether the project could use Beneq as a case study for occupational exposure to nanomaterials. Beneq agreed and has from this project acquired much valuable measurement data, understanding and advice both for assessing the level of the current measures of protection and how to improve on its organisational practices. The same project has published many of its measurement results in scientific journals and at conferences (2-6). One result emerging from this project is that the risk management measures, which Beneq uses (i.e. building an enclosure over the aerosol coating equipment with ventilation) has proven to be very functional and efficient (6).

An external consultant also conducted a risk assessment survey concerning the use of nanomaterials in Beneq.

3.4. What was achieved?

Prevention at the source of particles

By enclosing the aerosol coating equipment called nHALO® together with efficient ventilation, Beneq prevented emitted nanoparticles from spreading into the surrounding air. This reduced any potential contamination by nanoparticles meaning that the equipment is safe for the workers at Beneq and for those who buy the equipment. The measurements of how many airborne particles were emitted during the aerosol coating process in a project called Nanoturva demonstrated the level of contamination (2-6). In addition, several in-house measurements have been conducted on the co-initiative of the Beneq management, occupational safety and health personnel and workers. The in-house investigations have led to a better understanding of the prevailing conditions and led to improvements for increasing safety at work.

Safety attitude forming along the value chain

Given the nature of its business, Beneq has, been faced with a not-unexpected set of safety-related questions on the impact on the entire value chain from coating raw materials to consumer and final waste disposal of the coated product. However, Beneq manufactures coating equipment, with which high-tech industries coat specific products and sell them onwards to the next stage in the value chain. Only after perhaps 4 to 5 steps, does the coated product come in contact with the consumer. Therefore, Beneq is far removed from the actual end user and the everyday use of the coated product. Strictly speaking, the main responsibility for the coated product is held by the party that coats the product and sells it onwards. However, Beneq has taken the courageous stand and moral responsibility to ensure that it is aware of what happens with the coated product and that all products coated with Beneq equipment are safe.

Concerning the coated product in the specific case of flat glass heated to 600°C (or more) and treated with nHALO (dealt with in this case study), Beneq is able to assure the safety of the coating equipment as well as the end product. This is because in the case where the particles are deposited on hot glass, all particles that actually deposit on the glass diffuse into it, leaving no mobile particles on the surface. The diffused particles become an integral part of the glass matrix, either as a network builder or modifier, or then as a colloidal network of particles in the glass. Therefore, single particles cannot be removed by force or detach themselves. The only way to free the particles is to break the glass, but even then they cannot be released as discrete nanosized particles. For cases where the substrate temperature is such that the deposited particles do not diffuse into the glass, but rather create a porous and friable layer on the surface, the product is in an intermediate condition and is subjected to post-processing before it becomes the final end-product, where the particles are definitely immobilised.

3.5. Success factors

1. The first factor was that the management of the company acknowledged and understood that Beneq, whose business idea is to develop, manufacture and sell coating equipment for thin film applications, can have a so-called nanoaspect.
2. Secondly, the company needed to understand that the field of 'nanotechnology' is so broad, diverse and fragmented that no generic classification, directive, rule or recommendation in nanosafety as such could comprehensively apply to all the work done at Beneq.
3. Thirdly, the company needed to fully comprehend the implications of their decisions to the other players in the value chain, *i.e.*, is this safe for workers (Beneq workers), is it safe for the customer (who buys the coating equipment), is it safe for the intermediate stages (those companies who buy the coated products) and is it ultimately safe for the consumer at the end of the value chain.
4. Another success factor was the determined search for the needed information. Beneq drew up a basic list containing: A) Information (documents, standards, research results, international reviews); B) Support (helpdesk, firm opinions, measurement services and access to research projects) and C) Codes of conduct (practical solutions, Best Available Technologies and Standard Operating Procedures). They also listed the places where the information could be found: national and international projects (e.g. NanoBAT, NanoTurva, Nanodevice, Nanosafe), companies (e.g. Dekati), customers, consultants, conferences and seminars within the European Union, Organization for Economic Cooperation and Development (OECD), expert organisations (e.g. Finnish Institute of Occupational Health, VTT Technical Research Centre of Finland, Institute of Medicine (IOM)), authorities, industry organisations (e.g. NIA Nanotechnology Industries Association), international standards (e.g. International Organization for Standardization (ISO), The British Standards Institution (BSI)), eminent scientific research, less serious scientific reports/articles, 'grey goo', in-house technical studies (filtering efficiency, ventilation efficiency), in-house clinical studies (e.g. biomonitoring, thorax and spiro)
5. Then they needed to understand which functions in Beneq would be affected by their findings. These are: occupational safety and health (OSH), design, marketing, customer interface, research and development, training, environment, which represent most of the functions undertaken by any company. In addition, nanosafety findings have come, via communication between OSH and top management, to influence the Beneq business model, strategic planning and future endeavours.

3.6. Further information

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For more information about Beneq, please visit the homepage www.beneq.com. The contact person in OSH issues at Beneq is Joe Pimenoff.

3.7. Transferability

The approach taken by Beneq from the very beginning has been one formed and guided by the basic principle that it is necessary to acknowledge the potential risks of nanotech-related materials. None of the work they have done has been especially demanding or expensive; it has involved basic understanding and straightforward investigations.

The results and understanding acquired as a result of Beneq's engagement in nanosafety, from past to present and beyond, have led to more coherent internal work routines, better guidelines for equipment design, a more tangible nano-understanding in all R&D and better products for the customer. The results as such have not been documented on a regular basis and not according to any master plan, which in practice means that they are part of a pool of 'common knowledge', in-house praxis, documented guidelines and external knowledge sources. Transferability is therefore not straightforward as such, especially outside Beneq. However, a plan has been drawn up for organising all nanosafety data and making sure it is available, understandable (for all levels of workers) and up to date.

4. References, resources:

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