Roll-to-Roll Operations in a Clean Room Extended Abstract

Ken McCarthy   101617

There has been a great deal of recent discussion about the following new products and how roll-to-roll processing can help deliver quality products at a reasonable price. The products are: Lithium ion batteries; a variety of display coatings; photovoltaic materials; digital printing materials; and printed electronics products. All these products require uniform, clean coatings.

The topics covered in this presentation are:

Recent updates to the ISO Cleanliness Standards;

Measurements of Cleanliness Levels;

Three Types of Clean Environments;

A Discussion of Product Performance and What is Acceptable;

Operational Considerations;

Control of Static; and

An Actual Case Study in a Clean Room.

Recent updates to the ISO Cleanliness Standards

In 2015, there were several updates to the ISO standards relating to clean room operations. In particular, major changes were put in place for ISO 14644-1 (Cleanliness Designations) and ISO 14644-2 (Testing Requirements). The changes for 14644-1 are shown in the table below. The 209FSE designations are shown in the left column. While discontinued for some time, many people refer to these 209FSE designations when talking about cleanliness levels. Note the values in the right column are per cubic meter. Converting them to per cubic foot gives values equivalent to 209FSE.

Roll-to-Roll Coating Operations in a Clean Room

209FSE

		ISO 14644-1:2015 Designations			
		Maximum Concentration Limits (Particles/m3)			
			0.5 um		
		ISO Class 1			
		ISO Class 2			
Class 1		ISO Class 3	35		
Class 10		ISO Class 4	352		
Class 100		ISO Class 5	3,520		
Class 1000		ISO Class 6	35,200		
Class 10,000		ISO Class 7	352,000		
Class 100,000		ISO Class 8	3,520,000		
Room Air		ISO Class 9	35,200,000		

1 m3 = 35.3 ft3

from Particle Measurement Systems

Measurements of Cleanliness Levels

The measurement of cleanliness levels is covered in 14644-2. There are several commercial counters available, as shown below. Cleanliness values should be measured as follows: “at rest” – no activity; “in operation” – equipment running; “full operation” – includes personnel. If the operation has a HEPA or ULPA filter bank for incoming air, check each filter unit at least once/year. It is important to check several points in the process, to check people in “clean room” suits, and to check dryer air. Below is pictured a particle measuring device from Particle Measuring Systems.

Three Types of Clean Environments

There are three types of clean environments that we want to look at: clean rooms, clean spaces, and enclosed clean web paths. In a clean room, all functions are contained in a large space and the air is conditioned and cleaned for the whole space. In a clean space, such as the Softwall clean cabin shown below, all operations are contained within one or more of these or similar cabins and the air is cleaned just for these spaces.

In an enclosed clean web path, such as pictured below (with the enclosure opened to show the web path), the web passes through an enclosed path through the whole operation. Only the air in the enclosed path is cleaned.

A comparison of the three options follows:

	Comparison of the three approaches	
	Advantages	Disadvantages
Clean Room	Easy machine access	Cost (Capital, on-going)
		Long tax write-off
		Requires most discipline
		Signicant maintenance
Clean Space	Lower cost	Less flexible
	Immediate tax write-off	
	Intermediate maintenance	
Clean Web Path	Lowest capital cost	Need web conveyance
	Lowest operational cost	
	Lowest maintenance cost	

The enclosed web path may be the optimum choice for many operations. If the enclosed web path is chosen, the operation needs to have a mechanism to move web through the enclosed space during the start-up of the operation. The same mechanism is needed when a web break occurs. If the operators open the enclosed web path, i.e., clamshell ovens, for any reason, it may take hours to get back to the desired cleanliness level. This situation occurs because the room air is often nowhere near as clean as the air in the enclosed web path.

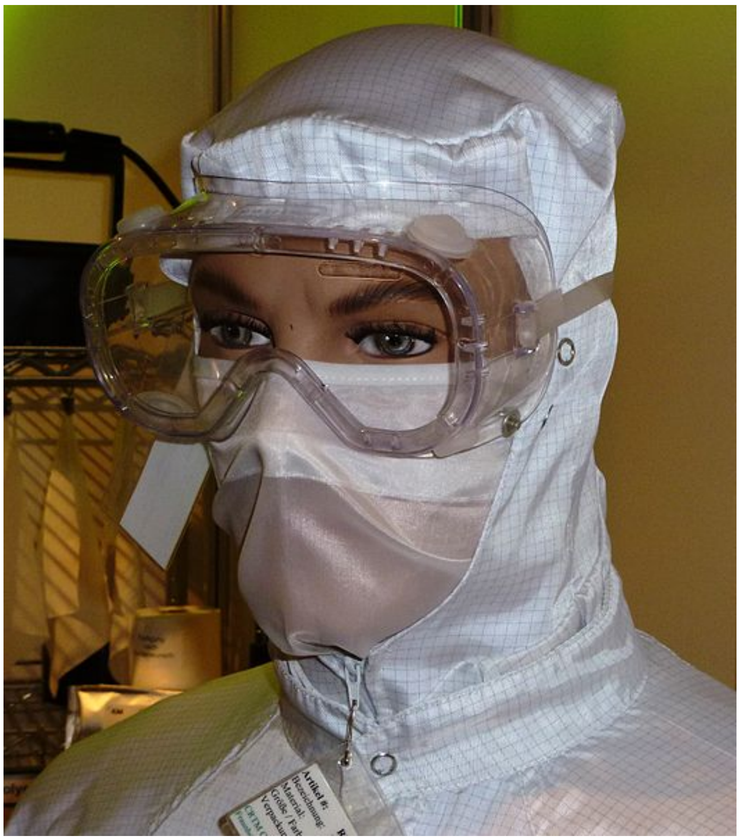
A Discussion of Product Performance and What is Acceptable

When an operation is looking at product performance and specifications with a prospective customer, it is vital to determine what is acceptable in terms of defects caused by particulates. It is especially important to determine if ISO certification of clean room performance is necessary for the customer. For ISO certification, cleanliness levels for any class must be met for all operational situations (first, operation at rest but the air flow on; second, the air flow on and the operational equipment running; third, the air flow on, the operational equipment running and the normal personnel in place). The tighter the cleanliness classification, the higher the capital cost and the higher the operational cost. Therefore, meaningful product requirements are essential. A corollary is that manufacturers operate so that operational standards and product requirements are met all the time.

Operational Considerations

Now, we will discuss some operational considerations. The topics include: operational personnel in a clean room; air flows; delivery of materials to the clean operation from within the plant; record-keeping materials in the clean room; and a unique way to look at the coating process in a clean room operation.

Having operational personnel in a clean environment is challenging; here's why. The human body is an exquisite thing but not in a clean room. People generate particulates at the following rates:
Standing: - 100,000 particles/minute
Walking slowly - 5,000,000 particles/minute
Vigorous activity - 100,000,000 particles/minute
Clean room suits are essential, even beard masks, especially for the cleaner classifications in 14644-1, unless the whole web path is in an enclosed space. See picture below for clean room garments typical of the cleanest classifications.



- For air flows for clean spaces, there are three considerations worth mentioning. First, it is vital to maintain positive pressure in the clean spaces. The positive pressure relative to the surrounding spaces keeps "unclean" air out of the clean space. Next, there is some debate about this issue, but I believe that maintaining laminar flow in the clean space is key to keeping large particles out of the air stream. For laminar flow, due to gravity, most particles greater than 0.5U will fall out of the air stream to the floor or other horizontal surfaces. There is evidence (which is somewhat counter-intuitive) that operating at the lower levels of the air flows required in 14644-2 results in cleaner air than operating at the higher levels. Lastly, for safety reasons in solvent operations, it is important to keep dryer air isolated as much as possible from other parts of the clean space.
- One of the most important areas for clean room operations is the delivery of materials. Often, the packaging materials for rolls to be run in the process have lots of particulate possibilities, from dirt that is picked up during shipment to the packaging material itself, which is often

partially shredded or tears easily during removal. It is best to remove packaging materials outside any clean operations. Then, vacuuming the roll before entry is a good next step, and having the roll enter the clean space through a lock is helpful to minimize the chance that particulates from outside the clean area come along with the roll. While discussing the handling of rolls, it is important to note that roll cores are often overlooked as sources of particulate contamination. Clean plastic cores are the best solution to minimize this issue.

- Operations need to maintain records as part of their business. Often, paper based records are kept, but paper products are a major source of particulates. It is best to not have any of these materials in a clean space. Computers or terminals can be used to record information. If written records are necessary, clean room paper is available to minimize particulate generation. Also, any diagrams, procedures, and protocols that need to be in the clean space can be overlaminated to seal the paper.
- Cleaning procedures are an important part of clean space operations, especially for Class 6 and lower operations. Floors and horizontal surfaces need to be cleaned frequently, at least weekly, to minimize particulate contamination (see Static section below). Cleaning materials should be ones that do not leave a residue, and it is best to use water as the last cleaning step. Care here pays off in product quality.
- In an overview sense, one of the ways to evaluate a clean operation is to follow a roll through the process in this way. Envision yourself sitting on a roll (shrunken down to 1 mm). Follow the roll through the process and note where the roll comes in contact with dirt or debris.
- It may be useful at this point to look at two cases of questionable clean room practices. In one case in a clean operation an incoming roll was put on the floor and rolled to the unwind. Examining a piece of cloth that was wiped across the floor for about one foot showed significant levels of particulates Each of the incoming rolls most likely picked up some of those particulates on their way to the unwind. In the second case there was an operation with a two-step coating with slitting in the warehouse in between. The first operation was done in a clean room, then the material was bisected in a warehouse that was not in a clean room, then the material went through a second operation. As one might guess, there were many quality issues with this operation.

<u>Control of Static</u>

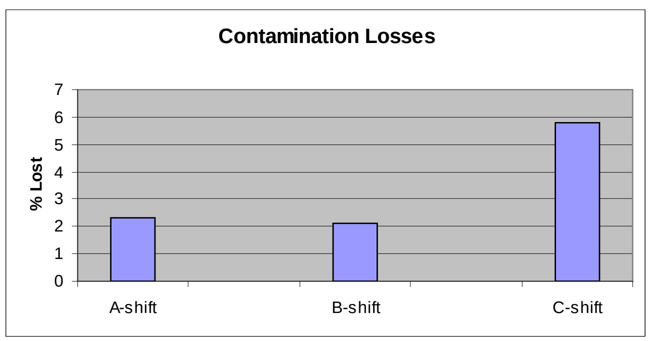
Next, we will examine the control of static in clean room operations. We will look at how static is generated; what problems are caused by static; how we can measure static; and finally how we can control static. In static generation, static charges are generated any time two materials separate. Once the charge is generated, the amount of charge remaining over time depends on the conductance of the material surface. Static charges are not good for coating in a clean room because of the interaction with particulates. Many substrates used in coating are excellent dielectrics, eg., PET. As such, they can hold large amounts of charge. Measured potentials of 10-20,000 volts are common. Charges in this range attract particulates. As an example, oil droplets can be pulled from 1-2 feet away from the substrate.

The measurement of static is a topic that deserves attention. Because of the impact of static on particulates being attracted to the web, any operation needs to know static levels throughout their machine. A static meter can be purchased or rented. Once obtained, static levels throughout the machine need to be measured (safely of course) with the web running. Once characterized, any changes in web speed or substrate can change static levels. AIMCAL's Kelly Robinson is a knowledgeable expert for measuring and controlling static.

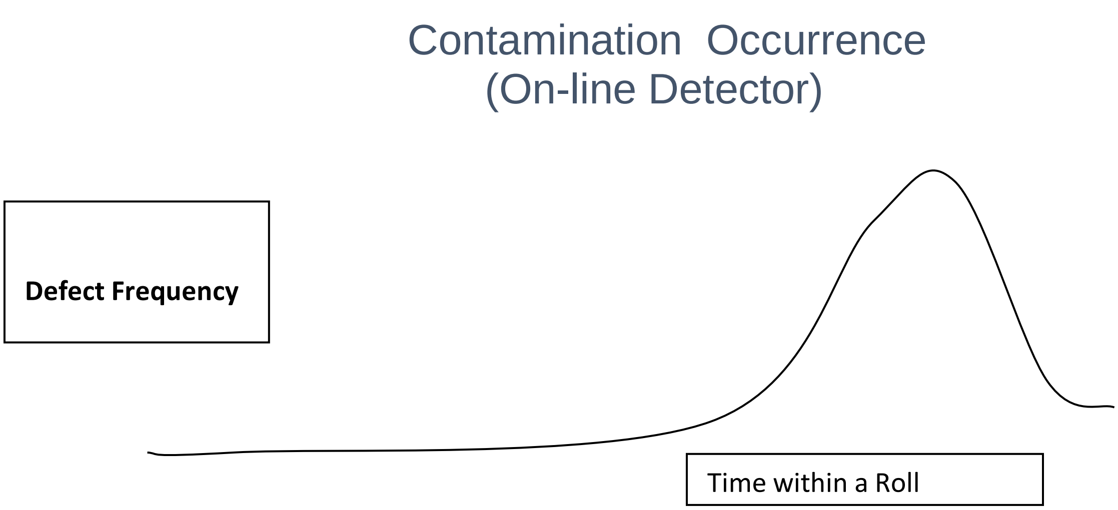
If the static measurements indicate an issue, there are three options to consider. First, the operation could change the base material, but the customer may not be open to that option. The second option is to use a substrate with an antistat added or coated. This option is generally the most effective, but there is a slight increase in cost. Compatibility with the product needs to be checked before this option may be employed. The last option is to add static control measures to the machine. Controlling the humidity is an important aspect of reducing static, since static charge is often dissipated more quickly in environments of 40% Rh or higher. Static brushes or wires (static string) can also reduce static levels to 1-2K volts. To get below that level (often required for the lower Cleanliness Classes) ionized air or ionizing sources, such as Americium bars (make sure safety precautions are taken), are the most effective to reduce static to low levels.

<u>An Actual Case Study in a Clean Room</u>

In the last section of this paper, a case study will be described involving a mystery contaminant. Based on an on-line inspection system, defect losses were 2.8 times greater on the C-shift than on A- and B-shift, as shown in the chart below.



Data from the on-line detector, as shown below, demonstrates a similar pattern on each roll.



Several problem-solving techniques were employed to understand this unusual “mystery” contaminant and then to eliminate it. The Kepner-Tregoe problem analysis and decision analysis method was employed to look at this issue. Cause and effect diagrams were also employed. And Failure Mode Effect Analysis was done. None of these methods led to a solution. Finally, an investigator went out on the floor to observe the operation. The observer noted that one of our best technicians was using Windex spray on a clean room cloth pad near the end of each roll to prepare to clean the die lips during the head-back as the splice went by that coating station. Due to the negative balance in the oven right after the coating station, the windex spray was being drawn into the coating station, landing on the web, and disrupting the coating before it could dry in the oven. Eliminating the windex spray eliminated the defect problem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