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**PART 1 – NEXT TO GODLINESS**

Surely cleanrooms qualify. Air filtered everywhere. Operators garbed from head to foot with only a portion of their faces exposed. Spotless stainless steel and plastic surfaces everywhere. No paper or cardboard anywhere. Manufactured product protected. Surely this is cleanliness next to Godliness.

Appearances are deceiving. Despite the advances made in the High Efficiency Particle Air (HEPA) filters used in cleanrooms, there’s no such thing as a totally particle-free environment. The cleanroom looks clean but particles too small to see with the naked eye are present in the cleanroom and settle on all exposed surfaces.

As semiconductor and pharmaceutical manufacturers will attest, in the cleanroom these particles can settle on exposed silicon wafers (“witness wafers”) and bacteria (viable particles) can settle on agar-coated petri dishes (“settling plates”). After exposure, the wafers are laser-scanned to measure particles per unit area and the settling plates are incubated for 5-7 days and the number of colony forming units (CFUs) counted. These methods permit determination of the number of particles/bacteria that deposit on surfaces in a given cleanroom zone.

The deposition mechanism can range from sedimentation (gravitational effects), diffusion (movement from high concentration to low concentration) or electrostatic effects (attraction of opposite charges). The details of the deposition mechanism need not concern us. What we worry about is that even in the cleanest cleanrooms with superb air filtering, particles will deposit on surfaces possibly contaminating and compromising the end manufactured product. We need to focus on what keeps those particles bound to surfaces and how do we most effectively remove those particles?

**PART 2 – THE TIES THAT BIND**

In *Particles on Surfaces – Part 1*, witness wafer and settling plate data showed that particles and bacteria (i.e. viable particles) will settle on cleanroom surfaces. From this we can infer that particles do NOT behave as hard microscopic billiard balls, striking surfaces and rebounding into the air. Rather, through inelastic collisions with the surface, they “stick” there and remain bound to the surface by various forces. Unless some effort is made to remove them, the particle surface density will increase over time. The particles will not disappear from the surfaces by themselves.

Obviously, some binding forces keep the particles on the surfaces and by understanding the nature of the binding...
forces, we will be better positioned to remove particles from surfaces. Once settled on the surface, particles remain bound through a combination of van der Waals forces, double layer forces, electrostatic imaging forces and capillary forces. Of these, it is the capillary forces that exert the greatest attraction between particles and surfaces. Capillary forces arise from a very thin liquid layer that forms between particles and surfaces. As it happens, the magnitude of the capillary force is directly proportional to the surface tension of the liquid layer. Since the most common liquid to interpose between particles and surfaces is water (originating from the water vapor in the cleanroom) and since water has a relatively high surface tension, it follows then, that the binding force between particles and surfaces will be high.

To recap, particles are primarily held to surfaces by strong capillary binding forces originating from the surface tension of the thin liquid layer between the particles and surfaces. If we want to rid the surfaces of particles (i.e. “clean” the surface), we should examine ways in which we can reduce the surface tension of the water film and simultaneously provide a mechanical means of removing and capturing the particles. Perhaps by wiping?

Isopropyl alcohol (IPA) - as discussed in detail in “Pre-Wetted Wipers Optimized for Application-Specific Cleaning” and in “Cleaning Solvents Parts 3 and 4” – will serve this purpose admirably. But merely irrigating a surface with IPA and leaving it untouched will not solve the problem; true, the surface tension of the thin liquid layers will be reduced until the IPA evaporates, but nothing will cause the particles to leave the surface. Energy must be applied to the surface along with the IPA to remove the particles. Furthermore, the removed particles must be trapped to avoid particle re-deposition. A cleanroom wiper, dampened with an IPA solution is the perfect tool to accomplish this. The wiping action removes the particles which are then held in the fabric’s interstices.

What concentration of IPA is optimum? How damp should the wiper be? These questions were addressed in “Pre-Wetted Wipers Optimized for Application-Specific Cleaning” and the case for pre-wetted wipers will be seen to be quite persuasive.

PART 3 – CLEANROOM WIPER + IPA

In Particles on Surfaces – Part 2, we learned that thin liquid layers between particles and surfaces serve as the binding forces between the two. By lowering the surface tension of this liquid layer – typically water – we can decrease the binding force and assist in the removal of particles.

PART 4 – OPTIMUM WIPING TECHNIQUES

Before we address wiping techniques, we might well question the need for wiping. After all, if capillary forces hold particles to surfaces strongly enough that the particles can’t easily get airborne, why the great concern to remove the particles by wiping? The simple answer is
embodied in two words: Contact Transfer. That’s the means by which surface particles are unwittingly moved from one area of the cleanroom to another. Contact transfer occurs when objects (gloved hands, notebooks, etc.) touch one surface in the cleanroom and then another. The objects will pick up particles from the first contact and transfer them to the second. Wiping surfaces prevents or minimizes the undesirable cross contamination and the inadvertent contamination of the second surface.

**How best to wipe?**

1. Wipe gloves before wiping surfaces, then discard the wiper.
2. In linear strokes whenever possible.
3. From known clean areas to known dirty areas.
4. From dry areas to wet areas.
5. Using a clean wiper surface for each wiping stroke.

**Explanation:**

Linear strokes with a cleanroom wiper prevent inadvertent transfer of particles and contaminants from dirty areas back to clean areas. This can be proven using a few drops of food coloring on a sheet of clean aluminum foil. Wiping the food coloring with a dampened wiper in circular strokes (the method used to wipe kitchen counters) will show the color transferred to all portions of the aluminum sheet. Wiping with linear strokes (refolding the wiper after each stroke) minimizes or eliminates the transfer of food coloring back to the clean area of the aluminum sheet.

Wiping from clean to dirty and dry to wet areas is reasonably intuitive. The reverse method would transfer contamination from dirty/wet areas to clean/dry areas. Not good.

Quarter folding a dampened 9”x9” wiper provides a convenient size. There are 8 clean wiping surfaces in each wiper (using both sides of the wiper). Exposing a fresh wiper surface after each stroke minimizes cross contamination from the previously used surfaces.

So there are optimum methods to wiping. If you have to wipe surfaces in a cleanroom – and you do, to avoid the possibility of contact transfer of contamination – it’s best to follow the 5 rules listed above.

Download Berkshire’s “Proper Cleanroom Wiper Folding & Surface Cleaning Poster”.

**PART 5 – CLEANING FLOORS AND WALLS**

In a cleanroom, cleaning floors and walls is like cleaning other surfaces, only more so – larger surface areas and corresponding larger wiping cloths. Let’s start with floors.
The same principles apply to wiping floors as described previously in **Particles on Surfaces Part 4** – use linear wiping strokes and wipe from clean to dirty. To achieve linear wiping strokes, flat surface mops using pre-wetted mop covers ("booties") are most convenient. The mop covers are changed when they become visibly dirty or after a prescribed surface area has been cleaned (perhaps 100 m² but this depends on the cleaning protocol for the particular cleanroom). Mopping from clean to dirty is easy to figure out. The dirtiest area of the cleanroom is the entry door adjacent to the gowning area, since it gets the most traffic. The cleanest area is either a very lightly trafficked zone, or the area furthest from the door. So mop from those areas toward the door. The entry door area should be cleaned at least daily.

Walls are generally cleaned less frequently than floors since they do not encounter contact transfer of contamination like floors do. (If your people are constantly bumping into walls, you may have another problem.) The same flat surface mops work well here also. A little thought reveals that the cleanest area of the walls is at the ceiling at the output of the HEPA filters. The dirtiest area is the wall adjacent to the floor. Two wiping patterns are available. Vertical wiping is the most convenient and ergonomically satisfying, since gravity assists the downward wiping motion. Horizontal wiping works well too and has the advantage that mop covers may need to be changed less frequently than for vertical wiping, since it is expected that the top two thirds of the wall surface is likely very clean and new mop covers should not be required for cleaning those areas. Obviously, soiled mop covers must be changed immediately.

**PART 6 – HOW CLEAN IS CLEAN?**

The surfaces have been wiped and the obvious question is: How clean are they? Start with what you see. Do the surfaces look visibly clean? If not, the wiping activity is not yet done. Wipe to the absence of visible soil on both the surface and the wiper. Keep wiping until the last wiper shows no visible soil after it has contacted the surface. If desired, the last wiper to touch the surface can be a black inspection wiper. This permits light-colored contaminants to be detected, since they will show up on the black wiper. Sort of the reverse of the "white glove test." Black inspection wipers are usually made from color-fast, knit polyester, so that the wiped surface is not re-contaminated in the inspection process.

Visualizing the surface contamination is a problem. The eye can detect particles only down to 50 μm in size (approximately 0.002 in). Another visual metric is the inability of the eye to detect the surface residues smaller than about 1-4 μm/cm². Either way, the eye can do only so much. While some may bemoan our limited visual resolution, this indeed may be a good thing. If you were able to see the very small bacteria on the face of your loved one, the human race may never have procreated!

Illuminating the wiped surface with bright light can help identify areas that need further attention. However, if the residues/particles/soils happen to fluoresce we can illuminate the surface with ultraviolet light (Caution: Eye damage! Wear protective goggles!). In this case, the offending material will show up as bright spots on a purple background.

These inspection procedures work well for viewing cleanroom surfaces such as counter tops, benches, tables, carts, measurement equipment, etc., but they also work well for examining more critical surfaces such as the interior of processing equipment. In **Particles on Surfaces – Part 7 and 8**, we will deal with other specialized methods used by the pharmaceutical industries and the microelectronic industries, respectively, to verify surface cleanliness of manufacturing equipment after wiping.
called “parenteral drugs”. These materials must be made in environments that are absolutely clean and sterile, because there is no opportunity for the drugs to be sterilized after packaging – i.e. no possibility of “terminal sterilization”. Not only that, but after a manufactured lot is completed, the equipment and the room housing it must be cleaned so that no traces of either the manufactured drug or the cleaning agents are left on the surfaces… and you thought keeping a clean kitchen was difficult!

How clean is clean for a manufacturer of parenteral drugs? Obviously, the surfaces must pass the visual criteria described in Particles on Surfaces – Part 6:

(i) wipe to the absence of visible soil, either on the surface, or on the last wiper used,

(ii) examine the surface with bright light or UV light (with eye protection)

Such activities are necessary but not sufficient for these manufacturers. They must be certain, as described above, that there are no lingering traces of the active drug, or the cleaning agents on production equipment. Actually, “no lingering traces” must be qualified. One cannot prove the complete absence of chemical substances (either the active drug or the cleaning agent), only that they are below acceptably low levels, often the limit of detection of a particular measurement.

Since invisible residues may be left on surfaces after cleaning, the industry has resorted to using swabs to sample the cleaned surfaces and subsequently analyzing the swabs.

Obviously, the swabs must be extraordinarily clean for this application and must be efficient at picking up any surface residues of the active drug or the cleaning agents. The sampling swabs are tested using sensitive analytical instruments such as UV-visible spectrophotometers (for active drugs), or Total Organic Carbon (TOC) analyzers (for cleaning agents). If the swab contaminant levels detected by these instruments are below established criteria, then there is no risk of cross contamination for future manufactured lots. That’s clean by pharmaceutical industry standards.

We conclude the series “Particles on Surfaces” with a discussion of how surface cleanliness is determined by microelectronic companies, specifically semiconductor manufacturers. As we did for the previous article, we focus on some of the most critical manufacturing processes for this industry - the production of integrated circuits (ICs) on silicon wafers.

The largest silicon wafers in use today measure 300 mm (approximately 12”) in diameter – roughly the size of a dinner plate. Wafers this size are extremely pure and can be made extraordinarily clean, with only a few particles residing on the wafer. The value of bare silicon wafers (also known as “prime” wafers) increases by orders of magnitude when the IC circuitry is incorporated into the wafers. The need to protect these wafers from particle contamination is paramount, since even submicron-sized particles (those with diameters well below 1 μm) can ruin the complex circuitry on the wafer. The procedures described below for surface cleanliness verification were developed to ensure the extremely high value of the finished wafers and to guarantee that defects are absolutely minimized.

The manufacture of ICs involves hundreds of sequential steps in which thin films are deposited, etched, patterned and smoothed to ultimately form memory chips, controllers, logic circuits, etc. This is accomplished in a variety of sophisticated, robotically-controlled process tools. Periodically, this equipment must be cleaned using physical and chemical treatments and where appropriate, very clean, ultra-low ion, polyester knit wipers. These treatments remove the process residues and particles which otherwise might ruin future wafers. Given the extraordinary value of the wafers as they move through the process cycle, the need to remove residues and accompanying particles is cardinal.

Finally, we have arrived at the nub of the issue. How do the IC manufacturers know that the equipment has been
cleaned sufficiently and that particle levels within the cleaned equipment are at acceptable levels?

Fortunately, they can rely on a well-established property of particles on surfaces – i.e. particles will scatter light impinging on them. If you can detect and measure the scattered light, you can identify the presence of particles. To capitalize on this, a logical and clever procedure for assessing particle levels in process equipment has been developed.

A prime wafer (with no circuitry on it) is placed into a computer-controlled, laser-scanning instrument to record a particle map of the entire wafer surface. Any particles on the prime wafer will scatter the laser beam and show up on the wafer map as dots. The instrument automatically counts and records the number of dots on the prime wafer. As mentioned above, prime wafers have very few particle counts, so this establishes a low baseline for the next measurement.

The prime wafer is then passed through the process equipment that has been cleaned. No processing is done on this wafer – the sole objective is to cycle the wafer through the equipment to have the wafer collect any particles that impinge on it (mimicking what would happen if a wafer containing ICs were passed through the equipment). The wafer is then measured again in the laser-scanning instrument and the particles again counted and recorded. The net increase in particle counts from the two measurements on the prime wafer represents the particles contributed by the equipment during the cycling activity – the so-called particle “adders”. If the adders are within acceptable limits, the equipment can be returned to the line for processing more wafers. If not, the equipment must be re-cleaned. The cost of the prime wafers for these measurements is negligible compared with the value of future finished wafers incorporating ICs.

The reader will note that the methodology developed by the semiconductor industry for verifying surface cleanliness is totally different from the methodology used by aseptic pharmaceutical manufacturers. Each industry uses the approach that serves its needs best.

In this series of articles, we have covered topics such as the deposition of particles on surfaces, the binding forces that hold particles to surfaces, the optimum methods for removing particles from surfaces using wipers and mops, and finally, the verification of surface cleanliness.