Reprinted from
PHARMACEUTICAL ENGINEERING
THE OFFICIAL TECHNICAL MAGAZINE OF ISPE
OCTOBER 2015, VOL 35, NO 5

www.PharmaceuticalEngineering.org

AUTOMATED WASHING PRINCIPLES AND COMMON MISTAKES

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This article will explain how some key process parameters, such as time, temperature, chemistry, coverage, and mechanical action, can affect the performance of an automated washing system. It will also discuss best practices for selecting appropriate chemistries and loading accessories and how to avoid common mistakes when using automated washing systems.

Automated washing systems are often used for critical cleaning and drying applications in research, pharmaceutical, and biopharmaceutical manufacturing facilities. Typical applications include the cleaning of laboratory glassware and parts from equipment used in the manufacturing processes of parenteral (injectable), oral liquid, and solid dosage drugs. A good understanding of basic principles of washing can help with making the best use of automated washing systems as well as avoiding typical mistakes that can lead to inconsistent cleaning performance, lower productivity, and higher operation and maintenance costs. Such knowledge represents an important step toward operational excellence.

Some key process parameters, such as time, temperature, chemistry, coverage, and mechanical action, can affect the performance of an automated washing system. Best practices from over three decades of cleaning and automated washing experience will be shared for selecting appropriate chemistries and loading accessories. Finally, ways to avoid common mistakes when using automated washing systems will be discussed.

Applications

Applications that are considered here include the cleaning and drying of various laboratory glassware used in research facilities; cages, racks, and other items commonly used in laboratory animal research environments; and components that come in contact with the manufacturing process of drugs in pharmaceutical and biopharmaceutical setups. Automated washing systems can be used to address the cleaning of parts from filling lines, packaging lines, stainless steel drums, fermentation containers, freeze dryer trays, tablet punches and dies, vials, and ampoules and change parts from blistering, packaging, and counting equipment. This article focuses on automated washing; however, a lot of the information can also be applied to manual cleaning.

Basic Washing Principles: TACCTS

A common acronym used in the industry to remember the factors to be considered in establishing an effective cleaning program is TACT (temperature, action, chemistry, time), but a more fitting acronym is TACCTS, which includes coverage and soil.

Soil

Cleaning parameters need to be established based on the effective removal of residue on the surface, so soil, and understanding the nature of it, should be considered first, even though it is the last letter in the acronym. Common questions such as:

- What is the nature of the soil?
- Is it organic in nature (such as fats, oils, waxes, blood, organic acids, sugars, and protein)?
- Is it inorganic in nature (such as minerals, carbonates, and metal oxides)?
- Does it contain both organic and inorganic components?

These are important questions to ask when deciding whether to use alkaline or acid cleaning agents or both chemistries in series.

What is the quantity of soil on the surface? A light or thin coating may be much easier to clean than a heavy or thick coating. What is the condition of the soil on the surface? An air-dried soil may be much easier to clean than a baked-on residue. A rougher surface is generally more difficult to clean than a smooth, nonporous surface.

Temperature

The critical parameter of temperature can apply to the pre-wash phase, detergent wash phase, and rinse phases. The temperature of the pre-wash phase may vary based on the nature of the soil. A high temperature, around 180°F (82°C), is recommended for fats, oils, and greases, while a moderate temperature, around 150°F (65°C), is recommended for minerals. A pre-wash temperature around ambient is helpful for proteins and sugars. A typical temperature range for a detergent wash is between 140°F and 180°F (60°C and 82°C). The graph in Figure 2 displays the effectiveness of different cleaning temperatures in the removal of wax/petrolatum soil.[1]

As the temperature reaches the melting point of the wax, around 140°F (60°C), the soil is easily removed from the surface. Lower temperatures, from ambient to 140°F (60°C), can be used for the wash phase depending on the soil and cleaning chemistries. Lower-temperature cleaning, if possible, is desirable in order to lower energy consumption and reduce the time spent on preheating the water. Hot rinses following the wash phase can reduce drying time. Overall, optimizing temperatures at every stage of the process may result in shorter cycle times.

Figure 1 (a and b). Typical dirty laboratory glassware

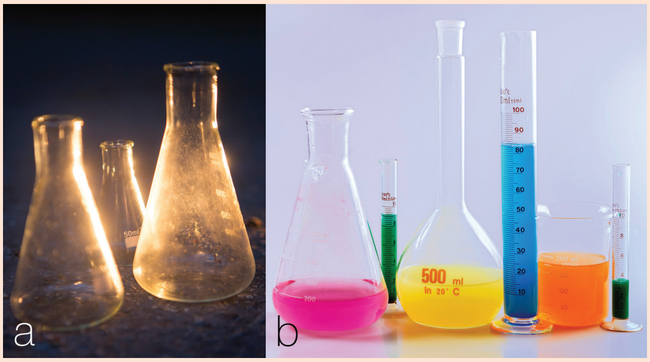


Figure 2 Effect of cleaning temperature

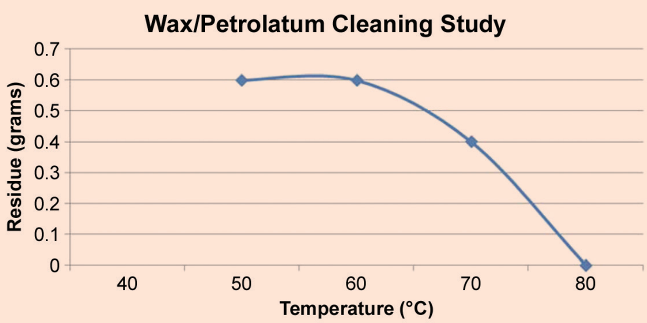
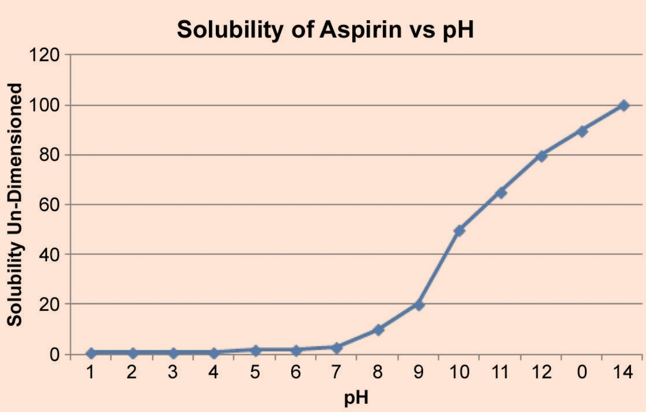


Figure 3 Effect of pH on solubility



Mechanical (Action)

Action or force applied to the surface through a dynamic spray device, such as a revolving spray arm or fixed spray devices such as a spindle, will help dislodge residues mainly through direct impingement and cascading flow. Monitoring the pressure from the recirculation pump to the spray devices ensures consistent operation. Routine inspection of the spray devices and spindles is important to ensure that they are free from debris. Cleaning items such as tubing and hoses requires flow velocity of about 1.5 m/s to ensure turbulence along the inner diameter and prevent air entrapment.[2]

Chemistry

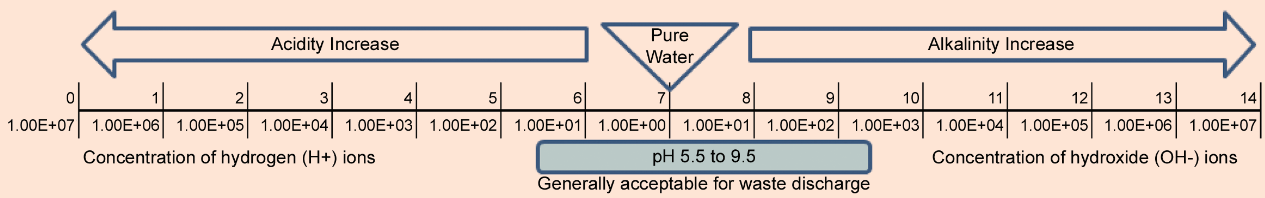
Several properties of cleaning agents can be manipulated in formulations in order to improve efficacy. The pH of a solution is an important chemical property that can influence the solubility of the soil in the cleaning agent. Figure 3 displays the solubility of aspirin; as the pH increases, the solubility drastically increases.[3] It is also important to assess material compatibility to avoid deterioration of the items being cleaned.

The pH scale ranges from 0 to 14, with 0 being the most acid and 14 being the most alkaline. A pH of 7 is a true neutral. As a side note, a pH range from 5.5 to 9.5 is generally acceptable for waste discharged; however, you should confirm with local municipal discharge regulations.4 The pH scale is logarithmic, as indicated in Figure 4. Alkaline and acid cleaning agents (high and low pH cleaning agents) can break soil down into smaller, more reactive components through hydrolysis. These smaller components are then more susceptible to other cleaning mechanisms present, such as solubility.

To continue with chemistry properties of cleaning agents, the role of surfactants in formulated cleaning agents needs to be discussed. Surfactants can improve many functions of cleaning, such as the wetting characteristics of the cleaning agent. Surfactants reduce the surface tension of liquids, which helps in displacing particles, penetrating soil, and addressing irregularities on target surfaces. If the cleaning agent cannot come into contact with the soil, then it is not going to be effective at removing the residue to acceptable limits. Figure 5 displays the impact of reducing the surface tension with surfactants.

The droplet on the left contains no surfactant, and the water beads on the surface. The images in the middle and to the right contain different surfactants and display different wetting and better coverage of the droplet to the surface. Surfactants also contain hydrophobic and hydrophilic ends, which bind and trap water-insoluble residues in micelles or bubbles, known as "emulsification." Dispersants can also be added to cleaning agents to prevent the aggregation of particles. Chelating agents help bind and break down inorganic components within the soil that may interfere with the role of surfactants or other components within the cleaning-agent formulation. Figure 6 illustrates wetting properties of surfactants within the cleaning-agent formulation.[5]

Figure 4 pH Scale



The brown circles are soil within a groove of an irregular surface. The water, as depicted by the dotted line, is not able to wet or penetrate the groove on the surface, so the soil is not in contact with water; therefore, the residue is going to be more difficult to clean. The cleaning agent with surfactant wets more of the surface irregularities and will be more efficient at cleaning this soil.

Coverage

One of the most critical principles is coverage. Despite using the best cleaning chemistry and optimum cleaning temperature, if the cleaning chemistry doesn't come in contact with the soil, then the soil will not be removed and subsequently rinsed from the surface. Coverage is very important, and it can lead to consistent cleaning performance or consistent failures in automated cleaning. The cleaning chemistry should reach all internal and external surfaces. Items of concern may be those with small openings, cannulated items, and hoses. Understanding the items to be cleaned and the load configuration within the washer is an important part of standardizing the loading configuration and ensuring coverage. Sophisticated accessories and/or customized rack design are available to eliminate coverage issues. Riboflavin, or vitamin D, can be prepared in water at 0.2 grams/liter and applied to the surface, inspected with an ultraviolet (UV) light (at 565 nm) and then rinsed off the surface and re-inspected with the UV light to highlight areas with coverage issues.[1] The roughness and material of the surface to be cleaned can also influence coverage.

Time

Similar to the cleaning parameter of temperature, time can apply to the pre-wash, wash, post-wash rinse, second wash, post-second-wash rinses, final rinse, and dry time of an automated wash cycle. The length of time may be based on the amount of soil, the condition of the soil, and temperature. Generally, increasing temperature of the wash step allows for reducing cleaning time. Increasing cleaning concentration (still within the recommended use dilution) can also reduce cleaning time. General recommendations or rules are a one- to two-minute pre-rinse, followed by a five- to 10-minute wash and then one-minute rinses. Process analytical technology tools, such as conductivity and total organic carbon (TOC) (maybe even Ultra High Performance Liquid Chromatography, or UHPLC),[6] can be incorporated in-line or off-line for continuous monitoring of the final rinse to complete the cycle.[7]

Washing Functions

A typical washing cycle includes five phases: pre-wash, wash, rinse, final rinse, and drying. Each of these phases will have an effect on the overall cleaning results. The following are some of the parameters that must be considered to ensure the optimal performance of a washing system.

Pre-Wash

This is the first cycle phase and allows for removing the soil. For this phase, using lower-quality water is generally acceptable, which can help reduce operating costs. City water is commonly used; pure water is not required for this treatment. The idea here is to allow for the water to saturate the soil, which can typically be achieved in one minute or so. It is recommended to use cold or ambient-temperature water to prevent protein-based soils from being baked on surfaces, warm water for mineral-based soils, and very hot water for fats, oils, and greases.

Wash

The next step is called the wash phase. It is intended to thoroughly remove all remaining dirt particles on processed items. During this phase, a predefined amount of detergent is automatically injected into the washer chamber. Typical water temperature ranges from 140°F to 180°F (60°C to 82°C), while optimum cleaning results can be obtained at 150°F to 160°F (65°C to 71°C). It is important to select the right water temperature for the detergents in use in order to ensure that the detergents release their active ingredients and reach their optimal cleaning efficacy. Time and cleaning agent concentration are often adjusted based on the temperature and nature of the soil. Five to 10 minutes is typically enough to achieve acceptable cleaning results.

Rinse

The rinse phase follows the wash phase. At this stage, there should be no soil remaining on the parts. The rinse phase essentially allows for the removal of detergent residues. It is generally not necessary to use very hot water for this phase, unless sanitization at high temperature is required. When water is supplied to the washer at a lower temperature, rinsing at high temperature can increase the overall cycle time since a few minutes are usually required for the washer sump heating coils to heat up the water to the set point. It may not be necessary to use very high-quality water for this phase, and one or two rinses of one to two minutes each are typically sufficient to obtain the desired results. Since the water used for the rinse phase is recirculated in the chamber, longer rinses would simply redeposit residues on the load items. Extending the rinse time generally does not improve rinsing efficacy since the same "dirty" water is recirculated for the set time before being drained. A better approach consists of repeating the rinse phase using fresh water.

Final Rinse

This phase removes all remaining residues and is usually performed at a higher temperature to accelerate the subsequent drying phase. High-quality water, such as reverse osmosis (RO) or Water for Injection (WFI), is often used for this phase. The pure water is typically heated to around 122°F (50°C) and sprayed on the load items, preventing spotting and stains on glassware and parts. In most cases, one or two rinses are sufficient to remove all remaining detergent residues. At this stage, single-pass rinses are preferred over recirculated rinses because this method has the advantage of reducing the level of residues more rapidly than the usual recirculated rinsing. With this option, residues that are removed from the surface of load items are not redeposited on the glassware or parts because a continuous flow of fresh water is distributed inside and outside the items. It is always a good practice to measure the final rinse water quality using standard online conductivity or TOC monitoring systems. These process analytical technology (PAT) tools can help to achieve Quality by Design (QbD) goals and provide ongoing assurance over the life cycle of the cleaning process.[7]

Drying

The last phase consists of drying load items. It eliminates moisture on the load, chamber, accessories, and piping. The air temperature can reach up to 240°F (115°C) but may be limited to lower levels for heat-sensitive items such as plastic ware. It is important to force the air inside components to accelerate drying and position items to facilitate draining. Standing water or pooling is drying's worst enemy so it is critical that items be properly positioned on the loading rack.

Common Mistakes

The following is a list of common mistakes that result from a lack of understanding of the principles described above, a description of the outcomes, and ideas/suggestions as to how these mistakes can be avoided.

Figure 5 Effect of surfactants

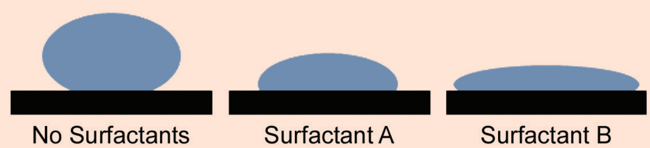
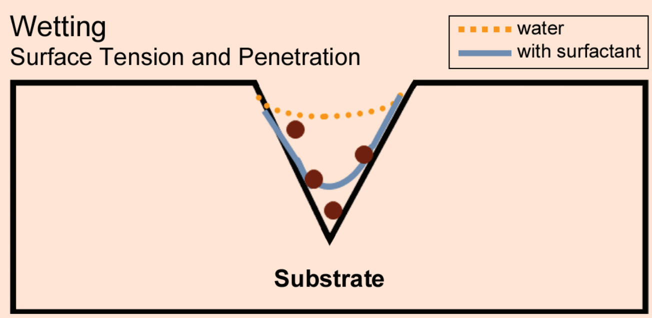


Figure 6 Effect of surfactants



Mistakes:

1. ***Using hot water in the pre-wash phase to clean protein-based soil.***
   Result: Soil is cooked on surfaces, making it more difficult to remove during the subsequent wash phase.
   Solution: Select cold water for the pre-wash phase.

2. ***Using cold or hot tap water in the wash phase to clean oily or grease/fat-type soils.***
   Result: Soil is not removed from surfaces, or an extremely long cycle time is required.
   Solution: Select very hot water for the pre-wash and wash phases.

3. ***Washing with a water temperature that is outside of the operating range of the chemicals being used.***
   Result: Soil is not removed from surfaces, or an extremely long cycle time is required.
   Solution: Check the operating range on chemical container labels and adjust the temperature accordingly.

4. ***Performing the final rinse with cold water.***
   Result: A very long drying time is required.
   Solution: Adjust the temperature of the final rinse phase as high as possible.

5. ***Using chemical(s) with the wrong pH.***
Result: A very long wash time or improper cleaning.
Solution: Use alkaline chemicals for protein and organic soils and acidic chemicals for inorganic, mineral-based soils.

6. ***Using acidic or alkaline detergents to clean aluminum containers or pH-sensitive load items.***
Result: Containers or load items will degrade/deteriorate rapidly.
Solution: Use neutral pH chemistry for these types of materials.

7. ***Trying to clean heavily soiled and dried load items with a low detergent concentration.***
Result: Wash time may have to be significantly extended.
Solution: Increase the detergent concentration until a reasonable result/time ratio is reached.

8. ***Using chemistries that create foam in the chamber.***
Result: Foam creates cavitation in the pump, resulting in lower pressure and possible damage to the pump. The presence of foam can also increase the volume of rinse water needed as well as cause issues with sensors and probe readings.
Solution: Use chemicals and wash temperatures recommended by the manufacturer or non-foaming detergents.

9. ***Setting long time for rinse phases.***
Result: A longer total cycle time.
Solution: If rinse water is recirculated, increasing time does not improve rinsing efficiency. It is recommended to shorten the rinse time and add rinse phases if required.

10. ***Setting high temperature for all rinse phases.***
Result: A longer total cycle time.
Solution: Higher temperatures do not typically improve rinsing efficacy. Reducing the temperature shortens rinse phases and reduces the stress on equipment. However, the final rinse should be heated to accelerate drying. There may be a need for achieving some level of thermal disinfection, for example: cages in the laboratory animal research industry.[8] In this case, heating only the last rinse phase is a common practice.

11. ***Using low-quality water for all phases.***
Result: Poor cleaning performance, spotting due to mineral deposits, higher detergent usage
Solution:

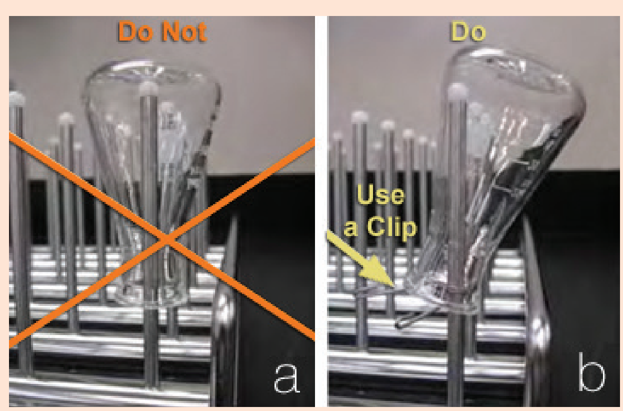
- Follow the washer supplier's recommendations for water quality.
- Adjust detergent concentration based on water hardness. Hard water is likely to require a higher concentration of chemicals to achieve acceptable results.

Figure 7 Example of the washer manufacturer's recommendation chart

Glassware Processing Capacity

Accessory	Volumetric Flasks	Erlenmeyer Flasks	Graduated Cylinders	Beakers	Carboys and Bottles
M-2 Spindle Header	500 ml to 2,000 ml	500 ml to 6,000 ml	500 ml to 2,000 ml	---	4 L to 20 L
M-5 Spindle Header	500 ml to 2,000 ml	500 ml to 6,000 ml	500 ml to 2,000 ml	---	500 ml to 20 L
M-8 Spindle Header	500 ml to 2,000 ml	500 ml to 1,500 ml	250 ml to 2,000 ml	---	500 ml to 4 L
M-18 Spindle Header	10 ml to 250 ml	250 ml to 400 ml	50 ml to 100 ml	---	200 ml to 400 ml
M-32 Spindle Header	100 ml to 250 ml	250 ml to 400 ml	50 ml to 100 ml	---	200 ml to 400 ml

Figure 8 (a and b). Examples of laboratory glassware on spindle racks



- Use mineral-free water, at least for the final rinse phase (RO, deionized, distilled, WFI).
- Incorporate a formulated acid cleaning agent second wash following a post-primary-wash water rinse.

12. Using the wrong accessory for the application.
Result: Inadequate coverage and poor cleaning performance.
Solution: Follow the washer supplier's recommendations for the selection of accessories. See Figure 7 as an example. Perform riboflavin coverage testing to confirm that there is sufficient coverage of the glassware and parts.

13. Positioning load items incorrectly.
Result: Inadequate coverage and poor cleaning performance.
Solution: Follow the washer supplier's recommendations for the positioning of components on accessories. See examples in figures 8 and 9. Perform riboflavin coverage testing to confirm that there is sufficient coverage of the glassware and parts.

14. Overloading baskets and accessories.
Result: Limited coverage will produce inconsistent cleaning results. (See Figure 10.)
Solution: Avoid overloading, position items to prevent overlap, and run more cycles if necessary.

Conclusion

Mistakes can be avoided by understanding and applying basic principles of cleaning, by following the manufacturer's recommendations for loading items to be processed and by ensuring that equipment is properly maintained. The effectiveness of the automated cleaning of laboratory glassware, animal cages and racks, and components used in the drug manufacturing process is very much influenced by the cleaning parameters used: temperature, mechanical (action), chemistry, coverage, time, and factors such as the nature and condition of the soil (TACCTS). Setting these parameters properly will ensure consistent cleaning results, increase productivity, and lower operation and maintenance costs.

Figure 9 Examples of fully loaded wash rack

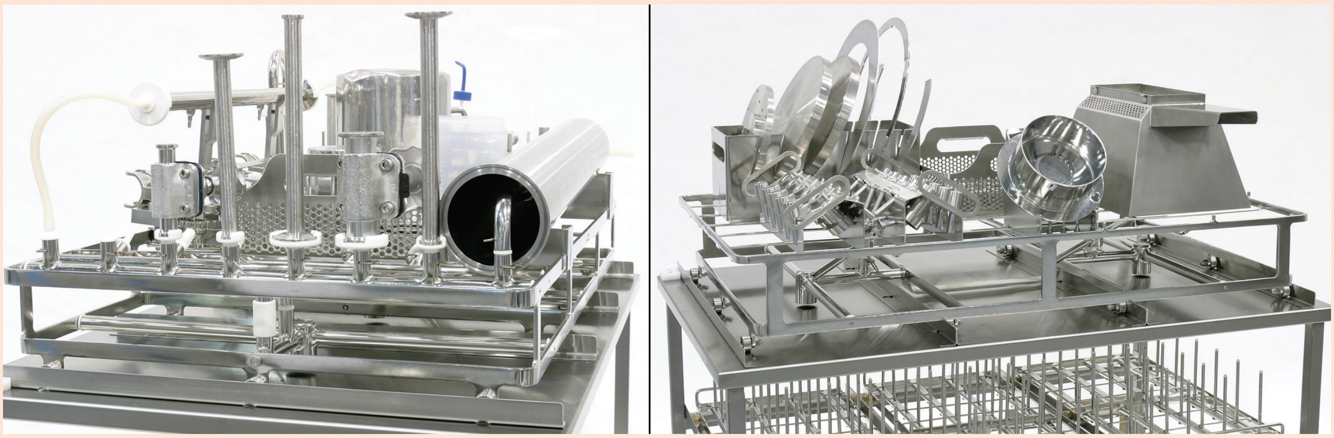
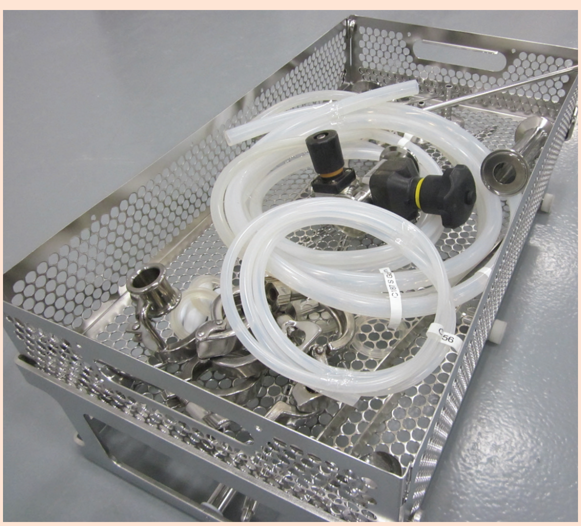


Figure 10 Example of poorly loaded basket



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