PDHonline Course M299 (4 PDH)

Introduction to Designing Clean-in-Place Systems for Tanks and Vessels

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Introduction to Designing Clean-in-Place Systems For Tanks and Vessels

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Course Content

1. Introduction

This course presents the design approaches to designing solutions for cleaning the residues encountered inside process tanks and vessels. However, designing a system that combines the tank portion with the process pipelines, along with a supply system, is beyond the scope of this course. This course focuses on providing an understanding of the causes, conditions, and characteristics of the process and its residues needed to design a state-of-the-art cleaning system for the inside of the tank.

Legacy designs addressed the cleanability of a vessel by relying on the concept of cleaning fluid "coverage". These designs have usually disregarded the actual properties of the soils and residues inside the tank. The actual cleaning performance of legacy CIP designs for tanks has relied on cleaning chemicals, time, temperature, or some combination of the three. This may not always be the most cost effective or appropriate approach for today's vessels. Understanding the cleaning problem inside the tank before embarking on a design of the means of cleaning fluid distribution inside the tank yields many more design alternatives than adherence to the fluid coverage approach.

The possible effects of the design of the tank on its cleanability are frequently neglected during design of the vessel and the process. Vessel and tank builders generally work with the process designers and are insulated from the quality control concerns associated with proper vessel cleaning. This often relegates the designer of the cleaning system to the role of addressing the vessels' difficult to clean features after the tank design is essentially complete, and is often left with inadequate tools to do so.

The in-place cleanability of vessels and tanks is optimized when it is integrated into the process design. This has most recently been recognized in tank design standards from the American Society of Mechanical Engineers

(ASME) for the bio-pharmaceutical industry. The ASME standards include specific fabrication and construction guidelines for the vessel that serve as the foundation for improving its in-place cleanability. Unfortunately this is not yet the case in other industries or for tanks fabricated prior to about 1980.

2. Sanitary Process Tank and Vessel Construction

The vessel or tank's shape and orientation reflect the products' processing needs as much as any other vessel design feature. Its shape, configuration, and orientation are intricately related to the product's characteristics and the physical or thermal processes involved in manufacturing it. It is the most easily identifiable indicator of the potential complexity of the cleaning design.

Vessel shapes come in all dimensions and orientations. The in-place design should initially categorize the vessel according the direction in which their most eccentric dimension. Vertical tanks have their eccentric dimension oriented in the vertical direction and horizontal tanks have the same axis oriented horizontally. This may seem a minor distinction but is actually quite important to the eventual efficiency of the cleaning design. Tank orientations and eccentricities are relatively easy to address early in design review for Clean-in-Place (CIP) systems.

Figure 1 – Vessel Orientation, Vertical Tank

Complete disregard of the orientation of the tank may result in severe cleaning performance deficiencies. Very tall tanks (Height/diameter or Length/diameter ratios > 2.5) indicate that very little mixing or agitation may be involved. These tanks are usually used for storage and when rapid gravity discharge rates are needed. There are exceptions however. Many fermentation processes use these types of tanks and usually include complex agitation, heating or cooling, and other internals. Tanks with smaller ratios usually indicate high mixing energies are required for highly viscous products. These tanks present the highest degree of complexity to the designer.

In contrast to its shape, the types of process components on the inside of tanks, such as agitators, baffles, mixers, coils, and any feature that disrupts the surface profile of the internal vessel walls affects the overall cleaning performance of the CIP system dramatically. They often present the most physically challenging problems to cleaning the vessel without manual intervention. These components must be thoroughly evaluated against the particular cleaning standard or goal to properly design an in-place cleaning solution. The complexities of these tank components not only dictate the design but, more importantly, they may even exclude certain solutions.

The number and type of the penetrations through the top head of the vessel reflect the complexity of the internal components of tank or vessel. The positions and types of the penetrations through the shell wall in the top head are critical breaks in the shell barrier. The design of the penetrations is particularly sensitive if the vessel is certified to certain performance standards such as those of the American Society of Mechanical Engineers (ASME) codes and standards for pressure vessels. Changing or adding to them after the top head is fabricated and the vessel is certified is difficult. Cleaning solutions that may contemplate a dedicated penetration, which was not considered at the time of vessel design, may be constrained by the existing head design as well having to address complex process and product characteristics. In most instances, retrofitting updated methods to improve vessel cleaning that require new top-head penetrations must also be shown to justify this extra expense.

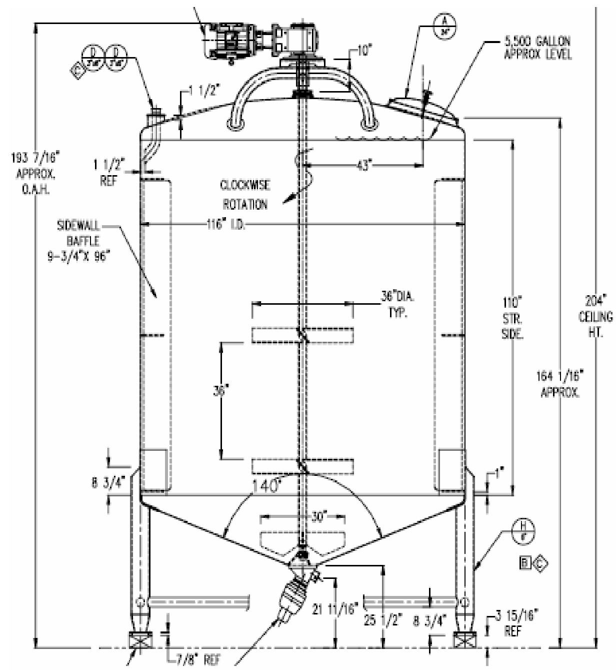


Figure 2 – Tank Construction Components

It is highly preferable to provide a cleaning design that addresses the process and product qualities at the time of vessel design. The retrofit of state-of-the-art in-place systems in most vessels in service today is a particularly difficult problem for the designer. It is rendered nearly impossible by the fact that these tanks may have been designed 20 to 30 years ago and may still not lived-out their current service life. Their upgrade or replacement is often delayed despite quality or efficiency problems associated with inadequate cleaning designs. The benefits of an up-graded CIP system for these tanks are product specific and can still often be justified given a sufficiently long payback period or product value.

The roughness or finish on internal tank surfaces has also come to be regarded as critical to cleaning a vessel. It is not uncommon for the smoothness in a new vessel with metal surfaces to be improved (polished), glass-like (image reflective), or even glass coated. Many design codes now incorporate surface roughness standards that significantly improve the surface compared to the mill finishes used in legacy designs. Improved surface finishes of internal surfaces affects product processing, the potential for contamination, and the cleanability of the tank. Processing is more efficient and effective because fluids and reagents blend more effectively and drain more completely. Improved drainability reduces the amount of product lost during cleaning, the harbors for bacteriological growth, the accumulation of substrate that feeds bacteriological growth, and the overall retention of residues during and after cleaning. Smooth or polished surfaces also make the vessel much more expensive and result in a longer mandatory service life to recover the costs sunk into its production.

Summary of Key Tank Construction Variables Related to Vessel Cleanability

- Materials of construction throughout the tank and vessel shell walls should be corrosion resistant (ASTM 316L or equivalent), be of documentable quality, and be of consistent metallurgy so that fabrication practices in welding, forming, and fittings are homogeneous.
- Seams, joints, and mating surfaces should be consistent throughout.
- All internal welds are to be integrated into transitions that are free of pits, consistently smooth, and gradual.
- Penetrations in the top head should be as far in-board (centered) as possible and be as shallow as possible. They should be perpendicular to the head surface at the point of entry unless the process requirements dictate another orientation.
- The cleaning protocols should be designed along with the locations for the penetrations. Process inlets should be no less than 1" in diameter.
- Man-ways and sight-glasses should have necks that are as shallow as possible and be positioned with one or more cleaning designs already selected. If possible, process penetrations should be located before the less essential penetrations for the man-ways and sight glasses.
- Ideally, internal surfaces should be finished to a minimum of 20 Ra μinches can be no less the #2B Mill finish.
- Sidewall penetrations, such as instrument wells, should be avoided if at all possible but, if needed, should be designed along with their locations.
- Deformities from dimple jacketing weldments should be minimized.
- Ledges, abrupt transitions, exposed bolt heads and nuts, couplings, and bolted mounting brackets should be avoided or ground smooth or coated whenever possible.

- In general, any protrusions into the vessel regardless of size should have rounded and smoothed edges. Baffles, agitators, supports, brackets, bearings, and level sensors should be coated or polished with connections and fittings specifically designed to gravity drain the product before cleaning and be physically accessible to fluids from the cleaning device whenever possible.
- Major internal structures should be staggered such they do not create overlapping shadow areas.
- Horizontal and vertical agitator supports should be as few as possible, circular, smooth, and the uppermost flights should be as far down into the vessel as possible.
- Sidewall wiping blades should have rounded edges and be designed in accordance with the guidelines listed above.
- Separate steam inlets should be provided if it is to be introduced to sterilize the vessel.

3. Process Variables

The challenge in the initial design of CIP solutions for vessels and tanks is to prioritize the multiple variables discussed in this course such that the solution has optimal efficacy. Some design philosophies may tend to over-simplify the design problem and thereby further compromise the cleaning result. This is no longer necessary given the cleaning options available today. However, a much more engineered approach must be used for today's more complex problems than has been the case in the past.

Few cleaning designs that solve the entire cleaning problem are inexpensive except in the simplest of cases (storage). And because there are multiple compromises to be made between all the competing priorities, this course can only serve to focus the designer on the criteria useful for deriving preliminary designs and cost estimates for effective clean-in-place systems.

The interaction between the products' individual ingredients and the process operations are crucial to the qualities of the final product. Ingredient processing also has a significant bearing on the cleaning problem presented to CIP designer. The process type and product ingredients are not typically within the control of the CIP designer. They can not be altered to any extent capable of significantly affecting the cleaning problem without affecting the end-products' efficacy or quality. Some process or ingredient variables certainly affect the cleaning problem to a greater extent than others, but few are within the CIP designer's control. This serves to emphasize the need to design the cleaning system along with the process and vessel.

The product service type is the method used by the product to deliver the products' benefit, use, or effect to the end-user. There are typically three delivery modes or methods: ingestion, dermal exposure (skin), or injection. The active ingredient or nutrient is suspended or dissolved in a carrier fluid or media to form a serum, viscous paste, cream, syrup, gravy, soup, cream, suspension, or gelatin (to name a few) with characteristics to match the delivery method. In some cases the form of the product is designed to be compatible with subsequent processing equipment, as in the case of tablet forming and drying. In most of these cases the delivery mode is the same and only the physical form of the product changes.

The base carrier fluid and its properties usually depend on the product's delivery mode. The process of adding product reagents to the tank usually begin with the addition of the carrier fluid into which the lower-volume constituents and solids are added. The effects from solids and powder blowback and splashing during addition often contribute or create cleaning problems that differ from the problems associated with the residues left after the product has been drained from the vessel. Manual additions usually require some form of man-way access that breaks the plane of the vessel during solids addition. Automated addition occurs in a closed system and is limited to fluids or pneumatically or mechanically conveyed solids. Powders and solids tend to travel throughout the headspace volume and contact head and wall surfaces. These solids can accumulate into crusty layers, particularly at the fill level of the carrier liquid if not effectively removed at frequent intervals roughly corresponding to each discharge cycle. Liquid additions tend to splash more locally but travel greater distances vertically into the head penetrations.

The cleaning design should be most directly related to the characteristics of the final product residues inside the tank. Product factors such as viscosity, temperature, density, solubility, and other physical properties are typical product quality design characteristics. These same properties have not traditionally been considered in designing tank cleaning systems. These final product characteristics dictate the hydraulic dynamics needed to produce them, such as the degree of mixing energy, ingredient solubilities, temperatures, and liquid/liquid miscibilities to name a few. Product fluid characteristics also affect the dynamics that generate the residues on the tank surfaces. Fluid capillary pressures, surface retention, fluid and solids dynamics, and liquid vapor pressure influence the presence and properties of the residues left behind on the vessel surfaces.

Blending and mixing operations radically expand the vessels' capabilities and increase the complexity of cleaning problem. The viscosity and miscibilities of the fluids and solids dictate the design complexity of the agitator and mixing systems and the related challenges associated with cleaning them. Since liquids blend more rapidly into the carrier fluid than do solids, the mixing operation may be less energetic and complicated for liquid-only processing.

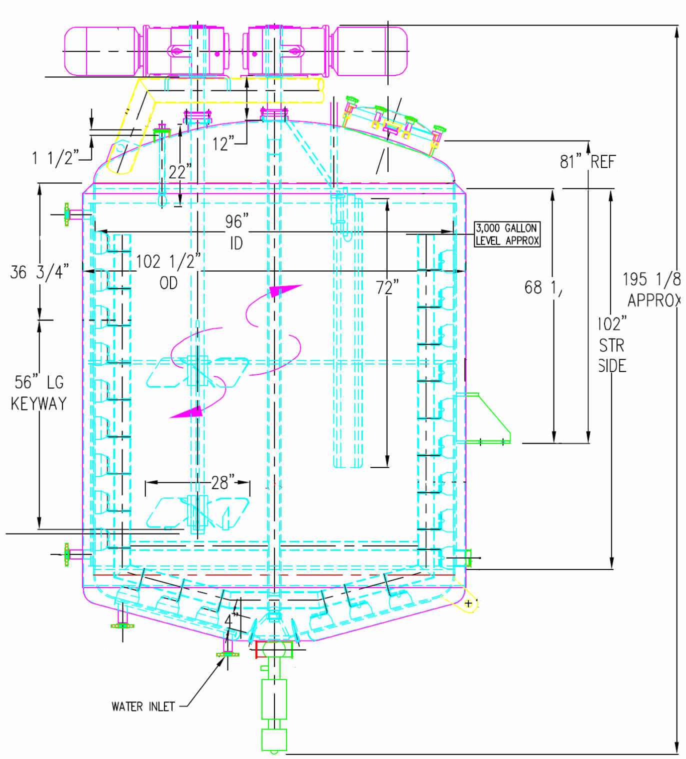
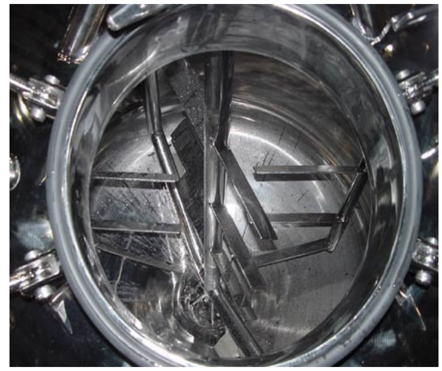


Figure 3 – Complex Mixing and Blending Operations

Mixing and blending operations are one of the biggest advances in the processing capabilities in tanks. The fluid properties of the ingredients and products following processing vary greatly, ranging from those with low viscosities that are well suited to tanks, to something much less liquid, sometimes including non-Newtonian fluids. As a result, the mixing and blending operations inside tanks have become more complex as the products they manufacture evolve. All the above product characteristics affect the surface retention of products after they have been discharged from the vessel.

4. Tank and Vessel Operating Conditions



Operating conditions vary widely, ranging from quiescent storage to a rolling boil at high temperatures to highly agitated. Multiple fluid and thermal dynamics are involved in process operations that take place in the tank or vessel and, most frequently, they are interdependent. For example, severe mixing or agitation of a finished product in storage is probably a bad idea since any changes in the product so induced are detrimental. Tank operating conditions are related to the cleaning design through their effect on the residues left behind when the vessel is emptied. It is these residues that must be addressed in the cleaning design.

The actual walls of the tank and vessel are typically smooth surfaces that are uninterrupted by ledges or other abrupt changes that affect flow direction or act to divert fluid sheet or cascade flow regimes. Consequently these surfaces are relatively easy to drain under gravity conditions, though special attention should be paid to surface features such as sidewall penetrations and aggregation points caused by high temperature surfaces such as "hot spots". Exceptions to these easily drained conditions are primarily related to the fluid properties and the reagent addition conditions discussed above. Highly viscous fluids, highly dense fluids (high solids content), or high operating temperature conditions can alter free gravity flow conditions even on smooth vessel walls. High operating temperatures with residual heat during draining of the product exacerbate these conditions. High viscosity fluids are readily concentrated; depositing the solids as aggregation sites for future accumulation that also may serve as dams to gravity-flow during subsequent drain cycles. The accumulation of solids or liquids related to reagent addition may cause local conditions that are unique from the product drainage areas.

Figure 4 – Viscous Product on Vessel Surfaces

The product fluid properties have their greatest influence on surfaces other than the tank or vessel walls. Surfaces that are not readily drained by gravity such as agitator blades, agitator couplings, agitator bearing boxes, man-ways, mixing blades, baffle supports, wiping blades and their supports present a greater likelihood of accumulating fluid residues between cleaning operations. Their effects are exacerbated if they occur along with elevated operating temperatures and when residual heat is present in vessel walls or from process steam.

The processing of the components into the final product frequently utilizes thermal energy to reduce the viscosity or otherwise alter the physical properties of the product or synergize ingredient reactions. The need to cool or heat the product indicates that the carrier fluid needs to be physically modified to meet the needs of the delivery mode or facilitate the fluid properties needed for proper mixing. Residual heat in the tank or vessel shell may facilitate draining of the liquid, evaporate residual liquids leaving densified solids, or both. Residual cooling increases the fluid viscosity on the tank walls and reduces natural drainability and leaves more residuals to be removed during cleaning.

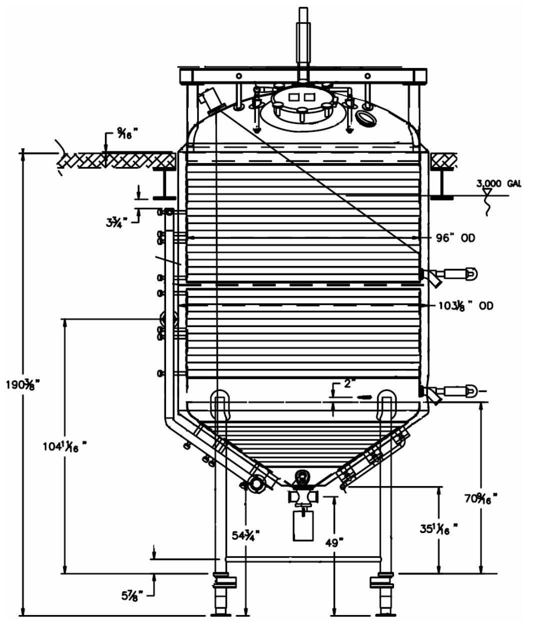


Figure 5 – Vessel Wall Cooling/Heating Jacket Product on Vessel Walls

The discharge method, once again, is typically designed to meet the down-line process requirements even though it significantly influences the amount and form of the residual left behind on vessel surfaces. The discharge method also may determine the rate at which cleaning fluids are removed from the tank. In many cases the product discharge pump can not remove the cleaning media at a high enough rate. This is often the case if there are dramatic differences in the properties of the two fluids. Peristaltic, progressive cavity or diaphragm pumps that may be best suited to protecting product qualities during the product pumping may not be equally well suited to removing low-viscosity water at higher rates. This is a particular problem for tanks that depend on gravity for fluid discharge. Inadequate discharge rates may allow a heel of fluids to accumulate in the bottom. A “bath-tub” ring of residues may then be left on the tank wall at the accumulation level once the introduction of fluids is stopped. Discharge rates should match the cleaning media supply rates during cleaning to prevent the formation of a heel of contaminated media in the bottom of the tank. A high-rate centrifugal pump, dedicated to CIP fluid discharge/return, should almost always be considered for these cases.

The capability to remove fluids, both product and cleaning media, is important to increasing the number of process batches. Shortening the "turnaround" time of a vessel, from product discharge through CIP to a final process-ready condition, maximizes the economies of scale offered by production in tanks. This is particularly the case for larger vessels. Many times the economics of a batch from a large volume vessel (>10,000 USG) are lost through the use of long and inefficient manual or fill-and-boil cleaning methods. These less-effective cleaning methods also may lead to product ingredient carryover that contaminates subsequent products, forms bacteriological growth sites, requires compensatory sterilization procedures, or leads to out-of-specification batches that must be discarded. The total additional costs of a poorly designed cleaning method should be considered when evaluating the cost of a properly conceived in-place CIP system.

5. Standard Cleaning Targets and Goals

Cleaning standards, targets, and goals vary according to market and the intended use of the product. If the product is to be ingested as a nutrient, the standard is usually to prevent contamination from biological infections caused by residuals and organism growths throughout the system. If it is to be ingested as an agent to elicit a biological reaction, either through an injection or orally, then it is to eliminate trace contaminates of potentially toxic substances that may cause unintended reactions. Product quality criteria are often defined according to one of these same two criteria – bacteriological viability (sterility) or trace compound detectability. In some cases, such as in the bio-pharmaceutical industry, both criteria may apply.

A third criterion is sometimes used in applications with less stringent sanitary criteria. This method was used in the early 1950s to visually inspect for residues on the device or piece of equipment that had been cleaned-out-of-place. It initially found its most relevant use in the dairy industry when all equipment had to be disassembled and manually cleaned. This standard obviously relies on the equipment being small enough to be handled manually, which is certainly not a description that applies to tanks. When this standard was applied to more complex or large equipment in more sanitary industries later in the 20th century, it was found to be lacking. Neither bacteriological organisms nor trace contaminants could be visually detected at the level for which they could be analyzed using laboratory methods. The "visibly clean" criteria have been adapted in recent years to fit the larger-scope environments but had fallen out of favor in the more stringent applications. Most recently it has found some support for its use as screening or indicator criteria in some applications.

Both the bacteriological and contaminant criteria can be met according to today's standards using current cleaning technologies and designs. But doing so is made more complex by the products' characteristics and the surface geometries from which the two types of contamination must be removed. The challenge to meeting these goals in complex tanks and vessels is partly addressed through the standardization of equipment standards that provide more cleanable designs. Solutions to cleaning challenges are also supported in some manufacturing process design guidelines that specifically address the cleanability of the resulting system (Good Manufacturing Practices). However, when the large number of product types is combined with the proprietary nature of their ingredients, a large degree of latitude must still be exercised by the designer in selecting a cleaning goal and designing a CIP system that will meet it.

Figure 6 –Static Spray Balls

Figure 6 – Swab Testing for Bacteriological Contamination

6. Approaches to Cleaning Design – Types of In-Place Devices

All cleaning design relies on a combination of four variables and three methods to mobilize soils and organisms off of tank and vessel surfaces. Cleaning fluids are distributed onto or over vessel surfaces using one of three methods: an in-place device, fill-and-dumping the entire vessel volume, or using manual procedures. These methods distribute cleaning media fluids that are designed to remove the residues through time, action, chemistry, or temperature (TACT). These methods and media variables are interdependent. A final design emerges as the cleaning media volumes, cleaning times, and costs of the different combinations of various methods are calculated. Manual procedures and fill-and-dump methods are not discussed further here since this paper addresses only an in-place component for the tank or vessel.

Legacy designs of in-place cleaning systems for tanks and vessels typically approached the cleaning problem having to rely on a single type of in-place device, the static spray ball or nozzle. These systems were also typically designed after the process design was complete. This approach is still valid today for vessels that have relatively open architectures or simple cleaning standards. For example, a storage tank that must only be visually clean before putting more of the same product back into it would not need a complex CIP system. Most milk and milk product tanks and wine storage tanks fit this category. Designing according to this approach typically removes visual residues and is not be overly concerned with trace compound contamination. Sterilization using steam (temperature) or sterilizing chemical (chemistry) cycles may have been added to form a sequence of cleaning media applications if removing bacteriological contamination or growth conditions was part of the cleaning goal.

It is curious that the legacy design approach continues to be used in a one-size-fits-all philosophy for the more complex designs of today's process vessels. The distribution of fluids to the tank wall using the static spray ball (see Figure 7) is relatively passive. Subsequent flow down the tank wall surfaces depends largely on cascade and sheet flow across surfaces that are smooth enough for the chemical and temperature of the fluid to reach and act on <u>all</u> the residues. Volumes are relatively high due to the number of the holes and nozzles in the ball and their hydraulic inefficiency (42% to 60% of theoretical). Sheet flow then must carry any residues that slough off the vessel walls to drain. Thorough fluid distribution methods are critical to reaching all of the appropriate surfaces in effective design. Distribution efficiency becomes even more important if chemicals and sterilizers in the fluids are critical to removing or killing the target residuals.

While these are the least expensive of the in-place devices, the designer should be concerned with their actual cleaning performance. When the design regime is found to need a sterilizer, either chemical or steam, then the presence of bacteriological growth is an accepted part of the cleaning design. In this case it could be assumed that the cleaning design is ineffective since the harbors and/or the growth medium (residues) needed to sustain growth are not being removed. There is also a case to be made that the static ball can act as a potential source of carryover since most of their designs can not include a self-washing function. These devices have also been found to be inadequate to the task of cleaning viscous or tenacious residues quickly. Ultimately, additional time must be allocated when using the static spray balls to distribute the fluids to compensate for the passive flow regimes on the tank wall. The inexpensive cost of the static spray balls can be more than offset by the increased cost of the TACT variables.

Design guidelines for the static spray ball devices are derived from historical experience with their application. They are typically sized according to total flow rates assumed to provide adequate coverage of the tank or vessel walls. Static spray balls sizes are typically based on a 0.1 to 0.4 USPGM/ft2 of tank wall surface or 2.5 to 5.0 USGPM/ft of circumference. The latter standard was derived for horizontal tanks but can also be used for more difficult to clean residues when the application of the former specification indicates that multiple devices are required. Notice that these guidelines do not specifically consider complicated surfaces and appurtenances. The exact hole positions, jet directions, and overall coverage positioning are not specified for static spray balls with these guidelines. This part of selecting or designing the in-place CIP device is typically dictated by the manufacturer as part of a standard product. In many cases the standard holes are supplemented by custom-drilling. Their pattern must usually be modified in the field to address specific coverage need specific to each vessel. One result of the static jets of these devices is that each one is uniquely necessary to complete coverage of the vessel. These devices can not usually be made overly robust or conservative without significantly increasing the total flow and costs of the system.

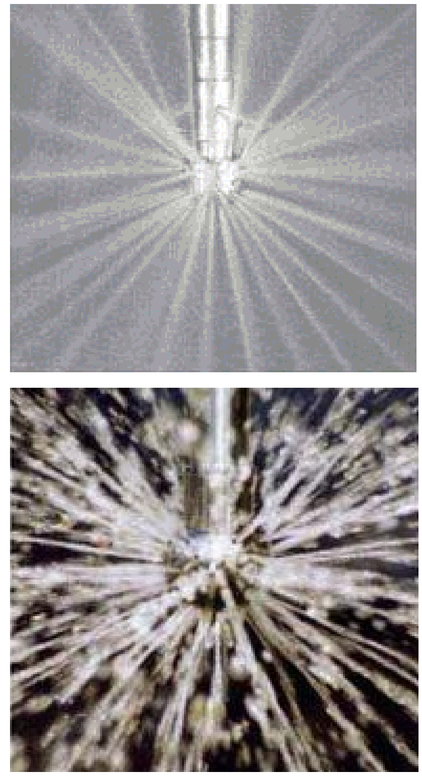


Figure 7 –Static Spray Ball Jets

Cleaning the vessel surfaces with these devices proceeds in a "moving front", beginning from the point where the fluids reach the surface. A zone of fluid develops where the temperature or chemistry of the media transitions from the design level or concentration to an effectively depleted one. This zone moves down the tank wall as the residues are dissolved or inactivated. The loosened residues must also be carried to drain by the cascading fluids. These devices must be installed near the very top of the tank wall so that the front can fully develop at the design temperature or concentration before it flows down the tank surface.

Typical operating pressures for these devices are 15 to 35 PSIG. These devices must also be protected against clogging of individual holes to avoid degradation in the distribution pattern. The static nature of the jets from these devices makes any clogging of even individual holes a concern to the designer. Filtration of the cleaning media may be driven in part by the size of the holes in the cleaning device and the effect on coverage by any clogging. Filtration to some levels for these devices is more similar to a process component than is typically considered for CIP systems.

The distribution of the cleaning media may also be accomplished using alternative devices that have been developed over the last 20 years. These alternative devices have been specifically designed to address the coverage issues related to the use of static spray balls in CIP systems for tanks and vessels. These devices are particularly viable alternatives for today's complex vessels but the legacy application design habits must be abandoned in order to utilize them effectively.

Figure 8 – Rotating Spray Devices

In almost all cases these alternative in-place devices introduce some form of rotation to the device and fluids or jets. The simplest of these alternative devices is a freely spinning "spray" device. The jets or sheets of water generated by their orifices become droplets with a velocity imparted by the centrifugal force of the rotation. They are commonly driven by the momentum of the exiting fluid but may also be operated by a relatively simple turbine/gear drive (Figure 8). The configuration types of these devices are too numerous to detail in this course. One of the benefits of these devices is that some come with a built-in ability to wash their outside surfaces, eliminating this potential source of carryover. The CIP designer is well-advised to become familiar the advantages and disadvantages of the major types of RSDs since their cleaning effectiveness does vary.

Rotating spray devices (RSDs) distribute water in a fan-like pattern with little or no definable jet as is visible from the static spray ball. The main result of the velocity imparted by the rotation is that the fluid is distributed directly to a greater part of the tank's surface compared to the limited points of contact from a static spray ball. The concentration or temperature of the fluid is at the design level at all locations where the fluid directly reaches the surface. The cleaning radius (distance from device) is also slightly greater than from that available from the static spray ball.

When larger droplets can directly reach a surface their impact also disperses the fluid across the local surfaces. However, the effect of the impact from this velocity varies according to soil types, surface location, and surface topography. Fluids distributed to the tank surface also cascade to drain so some passive contact between the product residues and the cleaning media at the design levels occurs during the entire operating time in all areas of the tank and there is no moving-front of efficacy. The result can be generally taken as being 25% more efficient than a design based on static spray balls. Typical operating pressures for these devices are also 15 to 35 PSIG, making them a ready retrofit for the static spray ball with limited changes to the rest of the system. However, the RSDs may introduce the need for performance monitoring in cases where a high degree of certainty in the function of the in-place device is required. The RSD is relatively inexpensive and monitoring systems for them in these cases can cost more than the device itself. The type of soil being cleaned and the conditions of the cleaning media being used should be considered when selecting these types of devices. The actual design effort using this technology is more rigorous than can be addressed further in this paper.

Figure 9 –Rotating Jet-Head Devices

A more mechanized rotating device is also available for cleaning tanks in-place. This device type is called a rotating jet head (RJH), so-called because it rotates a limited number of hydraulic jets projected through engineered nozzles. These nozzles are specifically designed to convert the higher operating pressures (65 to 120 PSIG) used with these devices into very high velocities (95 ft/s to 120 ft/s) compared to the static spray ball or RSH (20 ft/s to 45 ft/s). This device is particularly effective on the types of surfaces and residues associated with state-of-the-art process vessels and products.

Use of these devices represents the apex of the engineered approach to designing in-place systems for tanks and vessels. Their patterns are complex and the coverage is sometimes difficult to envision, particularly for the more complex cases of internal tank components. Nevertheless, they represent the most robust design alternative when considered strictly from a coverage perspective. Other issues, such as operating conditions, flow rates, sterility, cleanability, and cleaning times related to their operation often raise controversial issues compared to the legacy design approach.

It may be difficult to believe, demonstrate, or verify the performance improvements offered by these devices prior to installation. They function primarily through their ability to direct a high impact jet in a pattern throughout the tank. The higher impact from these devices cleans with distributed turbulence, not through the some vague mechanism of "impact". The application of these devices is more sophisticated because it is based on an understanding of turbulent flow regimes and complex surfaces. Analog computer models have been developed by some manufacturers to simplify design understanding and to corroborate the performance of these devices prior to installation. The designer should focus on reducing the TACT cleaning variables through proper application of the operating times of these devices. Further application design guidance for these devices is beyond the scope of this course.

Verification of performance in the field can be useful for these devices. Once the vessel is designed and constructed it is on a rigid schedule for delivery to meet production and capital requirements. In-place testing after installation may be used to supplement extensive design efforts, but production schedules after the tank is installed also usually limit this practice. However, performance testing for RJHs is much less critical than the field adjustments needed for designs based on static spray balls. Designers would be well advised to test prototype applications of RJHs if possible before selecting a device of any type. This is usually conducted as part of the Factory Acceptance Test (FAT) of the tank but, normally, little time is realistically available for major redesign or application corrections if coverage performance complications are identified.

7. Clean In-Place Design Criteria

The most important variables to a successful design naturally sort themselves into a hierarchy based on their importance and complexity. The most complex are the most important and the simplest are least critical. The most easily defined and understood variables related to designing in-place systems are the least difficult to incorporate into the design. Traditional approaches invert the emphasis in the design, as does the design guidance derived for them, because they assumed simple storage vessels were being cleaned. This was appropriate for designs from the 1950s through the 1970s. They could ignore the more complex problems because they occurred infrequently and viable solutions for cleaning them did not exist anyway. However, as product quality and liability has come to the forefront of sanitary product processing, the need to clean more complex vessels is an ever growing dilemma. It is this complexity that makes the design of the CIP systems for today's process systems so challenging.

Tables 1 and 2 summarize the TACT design criteria and prioritize them into tools for use in selecting and designing around the available in-place cleaning methods. They are extensively inter-related and reflect the complexity of designing an in-place solution for cleaning product resides from today's process tanks. As one TACT variable is emphasized in the design, the need for another may decrease or change. Determining the optimal type and extent of these trade-offs in the cleaning protocol is the job of the designer.

8. Pipe Cleaning and Supply System Design

The design options offered in this paper so far have focused on the effects of the process and product design on the residues inside the tank. Many legacy systems designed for tanks are integrated with the system used to clean pipes, valves, and pumps. These systems use turbulent flow conditions in the pipelines which mandate greater and greater flow rates according to the pipe diameter.

The CIP fluids from cleaning pipelines are frequently routed to clean the tanks in legacy designs. However, supply system flow rates and sometimes their chemistries, are irrelevant to the soil condition of the tank. In the opposite case, chemistries that are designed for cleaning the tank may be overdesigned for the pipeline. In either case, it is frequently difficult to design a fluid regime that is optimal for both systems. The ideal design conditions in terms of chemistry, flowrates, or temperatures for the systems are just too different. This is often the source of many cleaning problems in tanks associated with cleaning systems designed according to the legacy approach. While the pipelines may continue to be cleaned after years of operation by the same system and cleaning design the problems inside the tanks, neglected at the time of design, begin to increase.

TABLE 1

TACT Design Criteria Priorities
By
Types of Methods Used to Clean Tanks

	TACT Design Criteria			
	Time	**Action**	**Chemistry**	**Temperature**
Cleaning Method	Cleaning Problem Property Affected			
Manual	Chemical, Thermal	Physical	Time, Action	Thermal, Chemical
Fill, Boil, Agitate, & Dump	Hydraulic, Chemical, Thermal, Physical	Hydraulic, Chemical, Thermal, Physical	Time	Thermal, Chemical
Static Spray Ball	Chemical, Thermal	None	Time	Thermal, Chemical
Rotating Spray Ball	Chemical, Thermal	Hydraulic, Chemical, Thermal	Time, Physical	Thermal, Chemical, Physical
Rotating Jet Head	Hydraulic, Chemical, Thermal, Physical	Hydraulic, Chemical, Thermal, Physical	Chemical, Physical	Thermal, Chemical, Physical

TABLE 2
In-Place Cleaning Methods for Tanks and Vessels
Sources of Variability

	Method				
Source	**Manual**		**Automated**		
	Hand	**Fill & Boil**	**Static Spray Balls**	**Rotating Spray Balls**	**Rotating Jet Heads**
Residue Type	Yes	Yes	Yes	Some	Limited
Tank Internals	Yes	Yes	Yes	Some	Limited
Methodology	Yes	Yes	Yes	Some	Limited
Monitorability	Yes	Yes	Yes	Some	Limited
Repeatability	Yes	Some	Some	Some	Limited
Cleaning Materials	Yes	Some	Some	Some	Limited
Testing	Yes	Yes	Yes	Some	Limited

9. CIP Device Variables and Supply System Design

The supply systems for in-place devices are relatively common and their design is comparatively unsophisticated. The design of the CIP system for tanks and vessels focuses on the distribution of cleaning fluids and temperatures while the design for pipelines focuses on flowrates. The flows needed to clean the process pipelines usually govern the sizing of the pumps, valves, and tubing of the clean-in-place (CIP) supply system in a combined system. Most of the supply fluids from pre-rinsing the process systems are sent directly to drain as it is the most contaminated. If properly designed, most soils are removed in a pre-rinse step to prevent contamination of subsequent cleaning fluids.

CIP systems that are designed to clean both pipelines and tanks using static spray balls typically are designed to provide the flow rates that are required to clean the pipelines. They are also operated at the low pressures of product pipelines which are usually less than 50 PSIG. Only relatively clean fluids should be recirculated to the in-tank portion of the cleaning system in these designs to avoid clogging of the device orifices thereby compromising their coverage performance.

The fluids used to clean pipelines are either discharged to drain at the CIP system or are drained through the process tank discharge line. Volumes associated with pipeline cleaning not recirculated through the cleaning devices are frequently routed to drain through the process tanks. Cleaning the bottom of the tank will be compromised if the excess cleaning fluids are allowed to pool in the process tank such that a heel of fluids forms. Pooling is often exacerbated by an inadequate withdrawal rate of the tank discharge pump or the lack of a pump dedicated to returning CIP fluids to the CIP supply source.

Figure 10 – Large CIP Fluid-Recirculating System

CIP tank volumes used to recover the fluids in CIP systems that combine tank cleaning with line cleaning are typically very large (>500 USG) due to the volumes needed for the pipelines (system volume). Larger process systems are cleaned in circuits to reduce the size of the system volume handled by the CIP tanks. If multiple chemicals are recirculated and/or recovered, the overall CIP systems can become very large. For example, a CIP system that recovers the post-rinse water (to be used as a pre-rinse in the next cleaning cycle) and as well as reuses a chemical and a sterilizing agent requires a three-tank recirculating system. These systems are referred to a multi-tank, recirculating systems. Such systems are very common in processes that ferment large volumes of product (brewing).

Chemicals or sterilizers can either be added in-line and sent to drain or formulated in batches and recirculated. Heating of fluids by the supply system requires a recirculation design unless enough hot water is available from plant utilities. If the system is designed to recirculate fluids, then the designer can opt to recover the fluids in a tank dedicated to the purpose for each fluid as part of the CIP system. Systems that route fluids directly to drain are referred to as being "once-through", as are any steps in a multiple step system that does not recirculate the fluid once it has been used to clean the target tank system component.

Tank cleaning can be separated from pipeline cleaning most easily by using the process tank itself as the make-up tank for chemicals that are then recirculated through a pump on a cart back into the tank. The only option for recovering any fluids used in this design is to discharge it to additional process tanks in a cascade style of operation.

Systems designed around the rotating spray heads have individual device flow rates very similar to static spray balls. However, there are typically 25% fewer devices required for a better coverage performance in the same tanks. A larger system using rotating spray heads can be designed to clean multiple tanks that still reduce the flowrate for the in-tank portion of the cleaning system. The system volume for the in-tank portion of the cleaning operation can be reduced by up to 50% when their improved performance leads to reduced operating time compared to that required using static spray balls. Recirculation/recovery tanks to handle these reduced system volumes are likewise reduced in size. The design of recirculation flows and sequencing is usually the same as that used for the static spray balls. Therefore the overall design of a CIP system using spray head only differs from designs based on using

Figure 11 – Automated Recirculation CIP

static spray balls in the size of their recirculation/recovery tanks and CIP system piping.

Figure 12 – CIP Systems for Low-Flow, High Pressure Tank CIP Systems

CIP systems based on rotating jet heads (RJHs) are rare but are the most advanced of the CIP designs. In most cases they clean the tanks or vessels separately from the pipelines, sometimes even being a portable system that is self-contained with controls, chemical addition, and process monitoring integrated in a system that be moved from tank to tank (Figure 10). These systems are the most sophisticated when they take the greatest advantage of the performance characteristics of the RJHs. They operate at higher pressures (>70 PSIG) and much reduced flowrates (< 50%) compared to static spray balls and rotating spray heads. In some cases the flows can be reduced so dramatically that recovery is unnecessary and all flows can be directed to drain once the recirculated fluid has completed the cleaning step. These systems are particularly suitable for pharmaceutical applications. But they should not be rejected out-of-hand for any application since their performance is extremely effective as well as efficient.

10. Conclusions

In-tank soil and residue conditions should be the primary criteria for in-place design of cleaning systems for tanks and vessels. They should be thoroughly evaluated in the process of selecting the in-tank cleaning device. The in-tank cleaning device should then govern the operating parameters of the CIP design. However, if pipeline cleaning is integrated into the design, the in-tank cleaning design loses focus in the design of the CIP system. This has been the bias and basis of the design of legacy CIP systems.

The complexity of tanks being fabricated for today's processes may overwhelm the simple design approach using static spray balls when they focus on cleaning pipelines. The cleaning design should be capable of evolving with the product cleaning needs. A more robust CIP system is capable of adjusting to product changes but a less robust system is not since it assumes a relatively constant coverage condition. As tanks reach the end of their design service lives and are targeted for replacement, cleaning design for the actual in-tank conditions should be a greater focus for the designer, up to and including designing separate systems if the conditions warrant.