A Step-by-Step Approach for Choosing the Best Cleaning System and Process for Your Specific Requirements

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Choosing the right cleaning method, process and system can be quite overwhelming. With the phasing out of solvent cleaning, cleaning chemistries and cleaning equipment options have increased dramatically. If your task is to implement a new cleaning system or improve on an existing system, this course offers a step-by-step approach that will simplify your task. The approach addresses volume requirements, part configurations, base-metals/materials, soil types, in-process cleaning versus final cleaning, cleaning processes/chemistries and budgeting issues to assist you in gathering all the information needed to make an informed decision that best fits your company's requirements.

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Overview
Cleaning applications can be broken into two basic categories: cleaning of components in an OEM application and cleaning in an overhaul or refurbishing application. Cleaning requirements and the emphasis that is put on the cleaning portion of the manufacturing process can differ greatly between these two cleaning applications.

Original equipment manufacturing processes that involve machining, drilling, stamping, cutting and grinding of metal usually involve applying lubrication of some form during the process. Depending on the application, the lubricant is either used for cooling of the part and the tooling, in addition to reducing friction (which results in longer tool or die life) and/or removal of chips and fines from the work piece. In an OEM application, the soils are predictable and known. Secondary processes such as assembly, painting or inspection require these soils to be removed. Unfortunately, the cleaning portion of the manufacturing process is commonly viewed as a necessary evil and not really a step that produces parts or profit. It is not uncommon to see million dollar machining centers next to $400 sink-on-a-drum cleaning stations.

In overhaul and refurbishing cleaning applications, the soils may not be known and/or they may vary greatly. In applications such as engine or pump overhaul, the cleaning is no longer a tedious requirement, but an integral, important part of the process. If you cannot get the parts clean, you cannot rebuild or inspect them. In these types of rebuild or overhaul applications a greater emphasis is put on cleaning because the cleaning process is the “money-making” portion of the operation. It is quite common to see more emphasis placed on cleaning equipment and chemistries in these rebuild applications than in OEM operations.

Trends in the industry are prompting companies to take a much closer look at their cleaning processes and equipment. Cleaning is no longer simply a “necessary evil.” Insufficient cleaning and improper cleaning techniques have the potential to be very costly in the form of customer rejects and high costs associated with having to clean parts more than one time.

This paper addresses key issues to be considered when upgrading an existing cleaning process or installing a new one. The goal is to provide the reader with enough information to make an informed decision on the cleaning system that best fits the company’s unique requirements.

Cleaning Industry Trends
Recent trends in the cleaning industry have prompted companies to review, update and modify their cleaning processes and equipment. These trends include:

The Reduction and Elimination of Solvent Cleaning
For quite some time, environmental regulations have been prompting companies to reduce or even eliminate solvent cleaning processes. An example is the 1990 Clean Air Act Amendment, which contains approximately 800 pages of text with some sections addressing the regulation and elimination of some solvents that are frequently used in industrial cleaning applications.[1] In many of these applications, a “drop-in” replacement chemical usually is not an option. In a vapor degreasing system, what used to take place in a single stage (both cleaning and drying), may require numerous stages in an aqueous cleaning system, in addition to requiring significantly more floor space and capital investment.

New environmental regulations on certain base solvents have required companies to look for new ways of cleaning without solvent-based cleaners.

Example: A common method to clean jet engine bearings has always been to soak the bearings in a solvent-based cleaning solution. These solvents are very effective at removing the carbon, grease and oils that are the typical contaminates on an engine bearing. Regulatory changes have prompted the engine and bearing manufactures to update the cleaning specifications to include procedures that utilize aqueous-based cleaning solutions, with a series of water rinses and a water-displacing oil step. What was once a single-step soak process in a solvent, is now a three-to-four step process. Engine manufacturers such as Pratt & Whitney, have written entire sections in their engine overhaul procedures manual on this specific issue.[2]

Cleaning times of several hours were quite common in this bearing-cleaning example, when using solvents. The new aqueous methods have improved the cleaning, while significantly reducing the cleaning time. Some bearings, which used to require up to eight hours in a solvent cleaner, are being cleaned in the aqueous process in less than 30 minutes.[3]

Increased Process Control and Part Traceability

A much greater emphasis is being placed on tighter, more accurate process control of the cleaning system's temperature, cycle times, chemical concentrations and rinse water purity. By ensuring that these parameters are in the optimal ranges, the final cleaning results can be maximized and the potential for part damage minimized.

Newer automated cleaning systems utilize control systems and software that have the ability to track a hundred or more data inputs per process batch. What was once just a basic log for documenting when a part was cleaned and through what procedure, can now include precise cycle times, temperatures, drip times and transfer times, to name a few. This helps to develop a record for critical parts, which may need to be traced and followed throughout their working life. This technology is becoming very common in military and aerospace applications.

Improved Cleaning Methods

One common method of cleaning is simply dipping parts in process tanks. Process tanks, commonly referred to as "soak tanks," are usually large, heated tanks designed to soak parts until the soils are removed. Some systems may incorporate a means of filtration that will introduce some solution movement in the tank, but the actual cleaning is taking place by combining the cleaning chemical action with heat over a specified period of time. An existing cleaning system, which utilizes the "soak method," can be greatly improved upon by introducing some form of mechanical energy into the process tank. Common forms of agitation are solution agitation, part movement through the solution, or ultrasonic energy. This energy not only improves the cleaning results but also can greatly reduce the overall cleaning time.

Improved Cleaning Specifications

Historically, when developing a cleaning specification, not a great deal of focus has been placed on defining what is "clean," or what level of cleanliness is required. This question is being more closely addressed in today's cleaning applications. In many applications, the cleaning specification has moved from a subjective level such as an operator's opinion, to a quantitative specification. Methods/tests such as FTIR (Fourier Transform Infrared) and water-break tests are two tests used which will provide quantitative measurements of organic residue (oils), while other tests are available that provide quantitative measurements of particulate levels (solids). Tests such as these can help to establish a baseline cleaning level that is no longer subjective from operator to operator. Over time, these tests will improve the bottom-line, because they help ensure that the proper level of cleanliness is being met on a continuous basis. It is important to remember that there are direct costs associated with insufficient cleaning, in addition to over cleaning.

Cellular Cleaning

Many companies are investigating the feasibility of moving from a single large central cleaning line to independent cellular cleaning systems within a given work cell or component area. This reduces the load on the central cleaning line, brings the control back to the cell and usually reduces costs (in time and dollars) associated with in-process material handling.

This sounds like a great concept and in some in-line processes or simple cleaning processes, it may be advantageous. However, it is not practical for every application and can be extremely cost prohibitive. In some instances, this design would require the duplication of the entire cleaning line in several different locations in the plant. The cost savings associated with cellular cleaning maybe offset by the huge initial equipment investment.

Moving from Manual Cleaning to Automated Cleaning

Manual cleaning where machine operators produce a part, then personally clean the part on a sink-on-a-drum system or hand dip the parts, may no longer be feasible with the regulation changes, or simply is no longer able to provide the level of cleaning or the cleaning capacity being required. Advancements in automation have brought the cost of automated cleaning systems down to levels that make automation more affordable. Automated cleaning enables the operator to focus on the money making task of producing parts, not parts cleaning. It also provides more process control, repeatability and traceability than manual cleaning, which can be very labor intensive, subjective and influenced by outside variables.

Basic Cleaning Formula

When designing or upgrading a cleaning system, it is helpful to understand the basics of the Cleaning Formula. The four factors of the Cleaning Formula are time, temperature, chemistry/concentration and the method of cleaning. Common methods of cleaning include, spray, soak, hand wipe and immersion agitation. When one of these factors is changed, it has a direct and sometimes exponential effect on the others.

Time

Tank time or process time is usually one of the first variables to be addressed. Typical cleaning times can range from 2 minutes to upwards of 30 minutes depending on the soils and the cleaning method. Reducing the cleaning time can increase the cleaning system's volume capacity. In addition, exposing a part to some of the cleaning chemicals for an extended period of time can be detrimental to the part's integrity. For this reason, it is quite common to have maximum cleaning cycle time specifications.

The overall process time, which includes cleaning, rinsing and secondary chemical applications, is the period of time the part is in process from loading to unloading. The total time is usually dictated by the initial cleaning cycle time which tends to have the longest wet process time requirement. If the system incorporates a forced air drying stage, depending on the part configuration or the number of parts in a process batch, this could also be the "bottleneck" in the overall process time.

Temperature

The manufacturers of the cleaning compounds recommend optimum operating temperatures. These are specific to each product, as they are frequently formulated with surfactants or a combination of surfactants, which are most effective in certain temperature ranges.

An increase in temperature will have a direct effect on the cycle time and can reduce the required chemical concentrations. Too much of an increase (over the recommended operating temperature) can have an adverse effect on the cleaning chemistry and can actually "split out" the surfactants in the cleaners, leaving the bath "dead." Depending on the formula, the bath may or may not be able to be revived by lowering the temperature back to the recommended operating range and mixing the solution.

Chemistry/Concentrations

A significant percentage of cleaning chemicals currently being used in industrial cleaning applications is water-based. Their recommended concentrations can range from 5% to 50%. In general, cleaning in a 5% to 10% concentration range is common. In applications where more aggressive cleaning is required, percentages of 40% to 50% concentrations maybe required. Again, the cleaning chemical manufacturer specifies these ranges.

Because such a large percentage of the cleaning solution will be comprised of water, it is very important to understand the makeup of the water that will be mixed with the cleaning chemical. In some cases, the water may have levels of dissolved solids or contain undesirable chemicals that are not conducive for aqueous cleaning and/or may even be detrimental to some base metals. The chemical supplier will recommend the quality of water needed for mixing with their cleaning compounds.

Method of Cleaning or Mechanical Energy

The Cleaning Formula factors in what type or method of cleaning is being used to add mechanical energy into the process. Adding or increasing mechanical energy helps to improve the cleaning and reduces the cleaning cycle time. Common methods/forms of aqueous cleaning are:

- Part movement – vertical part agitation
- Solution agitation
- Ultrasonic energy
- Spray

The part size, configuration, contaminates/soils, material handling issues and production volumes are just a few of the factors that will dictate the most effective method for your application.

Designing a New Cleaning Line

When designing a new cleaning system from the ground up, several factors need to be addressed. These include:

- Level of Cleaning – In-process versus final cleaning
- Method of Cleaning - Immersion versus spray
- Process tank/stage sizes - Volume requirements
- The Cleaning Process - Number of process stages
- Process Robustness
- Materials of Construction – Carbon steel versus stainless steel
- Method of Heating
- Method of Material Handling and Degree of Automation
- Process Controls and Traceability
- Ancillary Equipment
- Vendor Selection
- Pricing/Budgeting

Level of Cleaning: In-Process versus Final Cleaning

The ultimate degree or level of cleaning required needs to be determined before the cleaning equipment and chemistry can be specified. For in-process cleaning, the part/piece just has gross soil removed before proceeding to another machine operation and will usually require a much lower level of cleaning. This may include only a single wash stage of a light manual spray or short immersion dip. Higher levels of cleaning are required if the secondary processes need extremely clean base metals or materials. For example, parts which go through porcelain enameling or electroplating will require a cleaning system and process that will provide sufficient cleaning to enable these secondary procedures to work properly. Cleaning systems for these types of applications will require more equipment and more process stages that may include two or more final rinse stages.

Method of Cleaning (The form of mechanical energy)

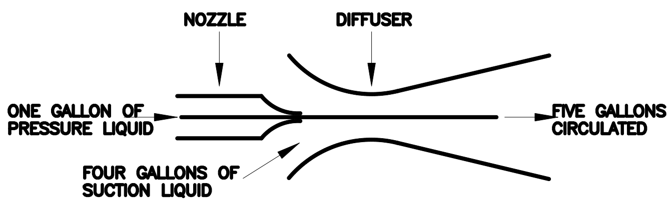
There are two basic forms of aqueous cleaning; immersion and spray. The part size, configuration and soils will usually dictate which method best suits your application. In general, immersion systems are batch oriented and are good at cleaning parts with intricate configurations and geometries. Spray systems are a good method of choice for in-line cleaning of common simplistic part configurations, such as sheet metal formed parts or large parts which would require immersion tanks so large that they would not be practical.

The soils may also dictate one form of cleaning over another or may require a combination of both. A good example is the cleaning of rubber or rubber-based soils. The contact time and application of the cleaning chemicals is needed to soften and loosen the rubber, but it may not be sufficient for 100% rubber removal. The impingement energy of a secondary high-pressure spray may be required to break the loosened/softened rubber free.

If you have an existing system utilizing simple soaking process tanks or you are contemplating this method of cleaning, the addition of agitation will greatly enhance the cleaning results and reduce the average cleaning cycle time. If you are starting from square one with a new process line, there are three basic methods to consider. If you are attempting to modify your existing process tanks, not all methods will be practical without significantly reducing the working envelope of the process tank.

Liquid agitation is one of the least costly methods, especially if it is a retrofit for an existing cleaning line. The most simplistic form is a circulation pump, which will create liquid movement in the tank. This method can be greatly improved upon by using a series of eductors connected to a manifold header. The eductors enable smaller pumps to circulate large volumes of tank solution. Due to their venturi design, they can have a circulation rate of four to five times the pump rate.[4] This greatly increases the circulation rate, thereby increasing the cleaning action. If these eductors are mounted on ball joints, they can be positioned in such a way to create an efficient circulation pattern or a whirlpool-like effect.

Theory Behind Eductor Agitation



When designing this type of system, it is critical to ensure that the cleaning chemicals are compatible with the pump seals. Due to the aggressive nature of some cleaning compounds, improperly specified seals will eventually start leaking. One way to ensure that the seals are compatible, is to eliminate them altogether with a seal-less vertical pump design. This not only eliminates the seal, but also reduces the amount of external plumbing and therefore, the potential for leakage at pipe joints and unions.

The flow rate requirement is very subjective. If the tanks are already existing soak tanks that are being retrofitted, any flow rate will be an improvement. When specifying the pump flow rate for a new process tank, it needs to be enough to enhance the cleaning but not so much that it creates the potential for part damage. Several turnovers of the solution per hour are recommended for best results.

Vertical part agitation is also an efficient method to introduce mechanical agitation into the solution tank. By moving the part through the solution, you create a scrubbing action that is very effective at removing soils. In addition, this method is very effective at ensuring that the intricate part configurations are thoroughly drained and flushed numerous times in the cleaning cycle. In some instances, the part configuration or the batching of large volumes of small parts with threads and holes, may require rotation in conjunction with the vertical agitation, to ensure that all surfaces areas of the part come in contact with the cleaning solution.

When designing a system with vertical part agitation it is highly recommended that all mechanical parts, such as pneumatic or hydraulic cylinders, do not come in direct contact with the aggressive chemicals. This will reduce the required maintenance and extend the system's operating life. If properly designed, vertical part agitation systems are very dependable and will last for years or even decades. In addition, insist on a method of part agitation that enables you to control both the speed of the agitation (the frequency of stroke), as well as the length of stroke. Some part configurations clean better at different stroke lengths and some parts may be damaged if the stroke speed/frequency is too aggressive.

Another type of agitation that is an option, is ultrasonic energy. Ultrasonic transducers operate at a high-frequency range above the upper range of human hearing. Operating frequencies between 20 kHz and 80 kHz are quite common and effective. When determining what frequency is best for your specific application, it is best to work directly with the ultrasonic manufacturer and rely on their experience and recommendations.

In ultrasonic cleaning, a generator works in conjunction with a transducer that is mounted in the process tank. Ultrasonic pressure waves propagate through the solution causing alternating high and low pressure areas at the part surface. The low pressure causes a cavitation bubble to occur. The high pressure then causes the bubble to implode. Temperatures inside the cavitation bubble can reach 9,900°F, with pressures up to 500 atm. The implosion event creates a jet stream that travels up to 400 km/hr.[5] The combination of pressure, velocity and temperature create very effective cleaning energy.

When specifying the ultrasonic frequency, it is best to consult the experts. They will need to know details such as part size, weight, cleaning solution, soils and base metals. Some frequencies may be too aggressive for the base material, such as thin aluminum parts, while others may not be able to penetrate into the crevices and cavities or between nested parts.

The number of watts per gallon of ultrasonics required is directly related to the amount of soil, the type of soil, the base metal and the allotted cleaning time. However, due to the costs of ultrasonics, budgeting may also become a factor. In some larger cleaning applications, it is possible to have process tank volumes more than 1,000 gallons and operating ranges of 10-15 watts per gallon are quite common. Using a low estimated cost of $8 per watt, a single 1,000 gallon tank fitted with 10,000 watts (10 watts/gallon) of ultrasonics, will cost $80,000.

If the process tanks are existing soak tanks and they are being upgraded to include a form of agitation, certain types of ultrasonics are designed as drop-in retrofit units. In addition to the ease of installation, they are also low profile and do not require a great deal of space, so the tank's working envelope size may not be compromised. The ultrasonic supplier should review the tank design to determine the ultrasonic installation location that will provide the greatest cleaning effectiveness.

It is important to note that process tanks that are retrofitted with ultrasonics must be fabricated out of stainless steel, because over time, mild steel will not hold up to the aggressive nature of the ultrasonic cavitation bubbles' scrubbing action.

Spray cleaning represents a significant percentage of all aqueous cleaning applications. The part configuration, volume, cleaning process/soils, footprint/floor space are several of the issues which need be considered to determine if spray cleaning is the preferred method of introducing the mechanical energy into the cleaning process. Spray cleaning may be best for parts that are too large for practical immersion cleaning, parts that are flat, or have simplistic configurations. In addition, tenacious soils may be more efficiently removed utilizing the impingement/shearing action of the spray, especially if the base metal is not compatible with aggressive cleaner chemistries.

Properly designed in-line belt and conveyor spray cleaning systems can provide high levels of production and include a degree of automation by their pass-through design. More simplistic turntable type spray systems are excellent for in-process cellular cleaning. These usually require a small footprint and can provide a basic wash, rinse and even a quick dry, in a single chamber.

In general, a spray system consists essentially of a solution holding tank or tanks, a hood or enclosure which houses a pressure spray system through which the work passes, a motor, a pump with a series of spray nozzles to discharge the cleaning solutions against the parts and a conveyor or turntable for holding the work. The pressure of the spray is dependent on the pump and can be changed by varying the speed at which the pump is driven or with valving. The pressure and volume requirements may vary significantly depending on the specific cleaning application.

The direction of the spray nozzles is critical. They should hit the work piece being cleaned at every angle. They should be properly balanced to reduce the potential for lighter parts being tossed around during the cleaning cycle. The action of many small spray nozzles is usually preferable to heavier streams from a few spray nozzles. High velocity and direct action upon all surfaces of the work are the important points. In addition, the position or angle of the spray nozzles should be adjustable so the direction of the jets in the wash zone can accommodate the work being cleaned.

Sizing Process Stages for Immersion Systems
In immersion applications, the process tank size is directly related to the maximum part size to be processed in the tank, in the orientation that promotes the best cleaning. Some parts will clean better in a particular orientation.

First, determine the maximum part size to be processed and the “envelope” it occupies in the desired orientation. This will dictate the maximum basket or carrier size to be used for material handling. Second, there will be minimum recommended tank clearances, space for ancillary equipment and a desired liquid level above the part during processing. Each individual cleaning system manufacturer will have their own requirements and recommendations, specific to their equipment.

One basic principle commonly used in the cleaning industry is the 80/20 rule. To apply this rule to this application, one must first closely review the mix of parts and the range of sizes. If the majority of the parts are small, it may be more practical and cost effective to design the system’s size around the smaller parts. The larger parts could then be cleaned with alternative means such as hand scrubbing or spraying.

Sizing Process Stages for Spray Systems
When specifying the process stage sizes for a spray cleaning system, both the cleaning chamber area and the solution reservoir size need to be addressed. In-line belt or conveyor spray systems need sufficient length in each stage to provide ample contact time for cleaning. Faster belt or conveyor speeds will require longer stages as compared to slower transfer speeds for comparable cleaning times.

Example: If two minutes of cleaning contact time is required to sufficiently clean a small motor housing and the transfer mechanism (belt or conveyor) needs to move at 10 feet per minute to produce the desired volume of cleaned parts, the “cleaning zone” would need to be at least 20 feet long.

A draining zone follows each spray stage so that the parts drain relatively free of liquid before they enter the next stage. This helps to reduce carryover and cross-contamination of solutions. There are industry standards on the optimum length of this zone. In general, the length of this draining zone is directly related to the required drip time, the transfer speed and the part size. In the above example, the motor housing is small and due to its simplistic configuration, the drain time is minimal. Therefore, the drain zone may only need to be 2 feet in length. Optimizing the drain zone length is critical. Overextended drain zones may cause drying and the formation of flash rust, while insufficient drain zones lead to heavy carry-over from tank to tank and may compromise the quality of cleaning and waste chemicals.

When specifying the holding tank sizes (the chemical reservoir tanks), a rule of thumb is that the tank volume should be 3 times the pump circulation rate. This gives adequate volume for soil absorption, cleaning volume flexibility and temperature control. The tank should also be baffled, (in addition to filtration on the spray system) to reduce the potential of solids being re-deposited on the cleaned parts.

If the spray system is of a turntable design, the table should be large enough to accommodate the part’s maximum height and width, while allowing the recommended clearances from the spray nozzles to ensure complete spray coverage. The reservoir size requirements that apply to the in-line spray system also apply to the turntable style of spray washer. In the single chamber style of spray washer, drain times are controlled via a cycle timer versus a drain zone.

Number of Process Tanks/Stages
When reviewing recommended or required process times, you might note that there are one or two steps that require significantly more process time than the other steps. If this time requirement is seen as a potential volume limitation for the cleaning system, a second or even a third stage maybe justifiable. For example, if one stage requires 30 minutes and the others are 15 minutes or less, by adding a duplicate stage, the limiting process time can be reduced to two steps of 15 minutes. The total process time of 30 minutes is still met, yet the volume capacity of the system has doubled for the cost of one more process tank.

By specifying cleaning chemistries that can clean the widest range of soils and have multi-metal compatibility, the number of process tanks/stages can be minimized. If the process tanks cannot be "shared," or if it is preferred to have dedicated cleaners, then it will be necessary to have dedicated tanks for each cleaning chemical. It is recommended that when developing a cleaning process, work closely with a chemical supplier and an equipment manufacturer to determine the optimum cleaning process. These suppliers will have a wide range of cleaning experience and should provide test cleaning to verify and confirm that the recommended process and equipment meets your cleaning requirements.

In most aqueous cleaning applications, after the soils have been removed in the cleaning process, the parts will need to be rinsed to remove the cleaning solution and soil residue. A good analogy would be washing your hands with soap. If you did not rinse with clean water, your hands may be cleaner, but you would still have a soapy residue left on your hands. You will have some flexibility when specifying the number of rinse tanks. Some levels of cleaning may have a minimum requirement of one rinse stage, but rarely will you see a maximum requirement. It is quite common to have at least one rinse stage between chemical stages, with one or more rinses for the final rinsing. Keep in mind, your parts will only be as clean as your final rinse.

One simple method of waste reduction is to have a series of two or more final rinse tanks counterflowing. This not only reduces rinse water usage, but also helps to ensure a cleaner final product. This theory holds true whether the process incorporates treated water or tap water.

Dilution Ratio	One Rinse (gal)	Counterflowing Rinses			
		2	3	4	5
100:1	99	10.0	4.3	3.0	2.3
1,000:1	999	31.0	10.1	5.4	3.8
5,000:1	4,999	70.0	17.0	8.2	5.3
10,000:1	9,999	100.0	21.0	10.0	6.1
20,000:1	19,999	141.0	27.0	12.0	7.0

For two gallons of dragout, multiply water figures by two, for 1/2 gallon multiply by 0.5 etc.

Table 1: Water Required to Dilute One Gallon of Dragout[6]

After final rinsing, a water film remains, which may need to be removed by drying. In some instances, if water is not properly removed, tarnish, rusting, water stains and similar problems may occur. Water may be evaporated using heat, moving air, or both. Water may also be removed mechanically by absorbing, blowing off with compressed air, or centrifuging. Generally, the two methods of heat and moving air are used together for the most satisfactory and economical results.

The primary requirements for drying are:

1. The last rinse is clean and pure water.
2. Most of the water is removed mechanically.
3. The remaining film is rapidly and evenly evaporated.
4. The drying is done below certain temperatures on highly finished brass, etc., where color is a factor.

In drying by heat, it is necessary to supply enough heat to heat the parts to the desired temperature and to evaporate the water. Therefore, it is advantageous to remove as much water by mechanical means to reduce the total volume of water.

In an immersion application, the simplest method of drying is to first leave the work immersed in a final, heated (up to boiling), clean rinse until it reaches the same temperature as the water. Next, drain, shake or blow it free of all water possible and allow the parts to dry with their own heat. This is possible only with work that does not entrap much water and with metal pieces of comparatively heavy weight. Parts of light weight such as light-gauge sheet metal, or with a large surface in proportion to their weight, cannot absorb sufficient heat to be self-drying.

Drying, or removal of the water film by evaporation, means that this water has changed from a liquid to a vapor state and has evaporated into surrounding air. The condition and amount of the surrounding air are important factors in drying. The amount or water vapor that a given volume of air can hold when saturated increases with higher temperatures. Atmospheric air varies from day to day and variations are recorded as humidity. The humidity is the ratio of water vapor contained in a unit volume of air, to the amount that it would contain at the observed temperature if the air were saturated with water vapor.

Obviously, air of low humidity is a better drying agent than air of a high humidity and saturated air of 100% humidity, cannot dry at all. If the temperature of the air is increased, its humidity is thereby lowered, because increase in temperature gives it greater capacity to hold water vapor. Thus, air that is highly humid, at room temperature, can readily be used for drying if its temperature is substantially increased. At 62°F, air may hold 0.00088 pounds of water (vapor) per cubic foot, but at 162°F, it can hold 0.0134 pounds per cubic foot, or fifteen times as much. In other words, air that is saturated at 62°F and has no drying ability would be only 1/15 saturated if it were heated to 162°F and would become a good drying medium.

When drying with air it is necessary to provide circulation by some mechanical means, such as a blower, fans, or convection currents from a heating unit. The effect of setting air in motion, regardless of humidity or temperature changes, is to increase its drying efficiency many fold compared with still air.

When other conditions are constant, the rate of evaporation increases in nearly direct proportion to the air velocity. With transverse airflow (airflow at right angles to the wet surface), the rate of evaporation is nearly twice as great as at corresponding velocities for a parallel flow. The air film in immediate contact with a wet surface quickly becomes saturated. It must be continually replaced for satisfactory drying. In general, both heating and displacement of the air are the best method for efficient and effective drying.

There is a point of balance between the amount of heat supplied to the drying air and the volume of air displaced over the parts being dried. Conditions should be such that the cost of heating the air, plus the cost of moving the air, are minimized. It is common that drying will take longer as compared to any single wet portion of the cleaning process. This has the potential to cause a bottleneck in the cleaning process. Increasing the size/speed of the blower fan, adding more heat (BTU), recirculating a smaller fraction of air, or adding additional drying area in the drying chamber (adding a second or third stage) can increase the drying capacity.

Process Robustness

An issue directly related to the process specifications and the number of process tanks, is ensuring that the entire cleaning process is not compromised by relying too heavily on a single stage for one of the processes, when two stages of the same process would make the system more flexible, more forgiving (the ability of the system to produce clean parts even when highly contaminated with soils), improve the overall cleaning and reduce chemical usage. This design technique can be referred to as the system's "process robustness."

Example: In a basic wash, rinse and dry system, it may be determined that only four minutes in the wash stage are required to meet the cleanliness specification. However, the parts tend to be heavily loaded with soil and they will very quickly contaminate the single wash stage. So, in a very short time period, the parts will begin to require more cleaning time, or they simply will no longer come clean. If the same system were designed with a second wash stage, the first stage would "pre-clean" the gross soils, while the second cleaning stage would perform the "final-clean." This design technique will lengthen chemical bath life, improve cleaning and may even shorten the overall cleaning process time if the wash process was the overall cleaning process's maximum cycle time.

Materials of Construction
The two most common materials used in the construction of cleaning systems are carbon steel or a series of stainless steel. The proposed chemical supplier should be consulted as to what materials of construction are most compatible with their chemistries.

Some process chemicals maybe of an aggressive nature (highly acidic or highly caustic) and require high operating temperatures. In these instances, highly chemical resistant materials of construction are required. The most common is 304 stainless steel. The chemical supplier may recommend other series of stainless such as 316. It is common to have the support structure fabricated out of mild steel with a chemical resistant paint and all wetted parts fabricated in the recommended stainless steel series. Note PP PVDF ETC

If the process includes water rinsing, especially deionized water, stainless steel construction is required in these stages to eliminate the potential of tank corrosion. In other processes such as the application of rust inhibitors, or mild alkaline cleaners, carbon steel construction can be a personal preference or a budgeting preference. On average, stainless steel systems can cost 25% to 50% more than the same system in carbon steel.

The service life of stainless steel over carbon steel construction can be measured in years and even decades. A major airline overhaul and maintenance facility currently has process tanks that are fabricated out of ¼ inch plate, 304 stainless steel. They have been in operation for close to 30 years. Due to the integrity of the tank itself, these process tanks, with a little refurbishing, could possibly last another 30 years.[7]

Process tanks can also be fabricated out of some types of plastic. When designing a cleaning system with plastic tanks, make sure that the operating temperature is not too high for the plastic material. At high temperatures, the tanks may degrade, and they will tend to bow or bulge. Tank support structure in the form of bands or frames, may also be required. In addition, ensure that the plastic material is compatible with the cleaning chemical.

One design feature to consider when purchasing a new cleaning system is that all support structures that come in contact with the floor should be fabricated out of stainless steel. It is inevitable that chemicals will come in contact with the support structures. Over time, this may have a detrimental effect on the integrity of the cleaning system. If a stainless steel base is designed into the support structure, these chemicals can be periodically rinsed down without any ill effect on the tanks. This also helps facilitate a safe and clean working environment.

One other method to make the process tanks more chemical resistant is to line them with a chemical resistant material such as polypropylene. If an alternative material is considered for liners, factor in not only its chemical resistance characteristics, but also its temperature limitations.

Method of Heating and Heat Requirements
Not all of the process tanks will require heat. For those that do, they may have operating ranges between 120°F-200°F. A common mistake is under-sizing the BTU capacity of the heating system. When specifying the BTU requirements, factor in:

- Tank volume
- Operating temperature requirements
- Anticipated pounds of product per hour
- Type of metals being processed
- Temperature of incoming parts
- Heat loss due to evaporation
- Desired heat-up times

- Make up water temperature and volume/hour
- Plant humidity
- Velocity of air across the tank (exhaust system)
- Ambient air temperature
- Tank insulation value

Steam, gas and electricity are the most common methods to heat process tank solutions. The method chosen is usually made based on usage costs, availability and the corrosive characteristics of the solution.

If steam heat is available and there is sufficient capacity to heat the new cleaning system, steam is a very efficient and flexible method of heating. In a steam-heated system, steam coils are made of pipe embossed metal plates with steam passages as the heat transfer surface. With steam heat coils, the heat can be spread out over a large surface area. This is referred to as "low heat flux density," which is the amount of heat transferred per unit area of the heating surface. Low heat flux density (also known as low watt density) is desirable, as it reduces the frequency of which the steam coils need to be cleaned and the tank has a limited maximum input temperature (i.e. maximum steam inlet temperature). In addition, steam heat coils can be designed in such a way that they can be easily removed for routine cleaning and maintenance, and they have flexibility in shape and size to fit a variety of tank requirements. The disadvantages are the requirement for a boiler system, steam and condensate piping and the efficiency of the steam- heated systems will vary depending on the type of boiler and steam system selected.

When specifying the materials of construction for the steam coils, factor in which chemicals will be used in the process tank. Stainless steel 316 series is recommended for all steam coils and for some chemical solutions, more corrosive resistant materials and exotic metals maybe warranted.

Gas heat is a very common method for heating large volumes of solution. Gas, usually natural or propane, is burned in a chamber or immersion gas coil. The efficiency of the heating is based upon the firing rate of the burner and the length of the gas coil. Maximum efficiencies are usually about 80% (above 80% there will be condensation in the gas coil). The heat flux density can vary depending on the surface area of the gas coil and the firing rate. Some of the newer pressurized burner systems are capable of firing into small diameter gas coils and achieving very high heat transfer rates (high heat flux density) especially near the burner entrance where the gas temperature is the highest.

If the gas tube gets fouled and the heat transfer is restricted, the temperature of the heat transfer surface will rise and the efficiency of the heater will go down (flue gas temperature will increase). With high heat flux densities, the burner tube may be damaged or burn out because of fouling. Gas burner controls should be specified based on insurance carrier requirements and local codes. The advantage of gas, in some cases, is lower fuel costs and possibly low heat flux density. Disadvantages are lower efficiency than electric heat, the need to vent combustion gasses and burn out potential.

In an electric heated system, an electric current is passed through a resistance element resulting in heat. The heat is conducted through a sheath material that separates the resistive heating element from the solution. A contactor controls the flow of electric power to the heating element in response to tank temperature and set point. Electric heaters are made in a variety of watt densities and sheath materials. Unlike steam, the maximum heater temperature is not limited to the nature of the energy supply. The electric heater will supply a constant amount of heat. If the heat transfer is restricted, the temperature of the heat transfer surface will be forced up until the heat does transfer or until the heater burns out due to over-temperature.

The advantages of electric heat are the relatively small size, easy installation, ease of control, and low capital costs. The disadvantages are generally higher heat flux density and burn out potential due to no natural limit of maximum heat transfer surface temperature. Electric heaters are 100% efficient in that all energy supplied to the heater is released to the tank as heat.

Material Handling/Automation in Immersion Processes
In any aqueous cleaning application, the part to be cleaned is moved through a series of chemicals, rinses and maybe a form of drying. This type of system may require a great deal of emphasis on and investment in the material handling from process stage to process stage. There are basically two forms of material handling: manual and automated.

If it is a low-volume cleaning operation and advanced measures of process controls and documentation are not required, then a manual transfer system maybe sufficient. All transfers are timed and controlled via an operator. This basic system has the greatest operator objectivity and potential for operator error. However, the advantage is that the operator interfaces directly with the system and can visually inspect the parts between each process. If more process time is required and the recommended maximum process time has not been exceeded, the operator can increase the cycle time by putting the parts into the tank for additional cleaning.

In immersion cleaning applications, there are basically three automated methods to transfer a part from stage to stage: a hoist system that lifts the part from stage to stage, an indexing system that "pushes" the part from stage to stage and a conveyor system that dips the part in the process tanks and "drags" the part though the solution and onto the next stage.

In applications with large parts, overhead hoist systems tend to be the most common method of transferring loads from stage to stage. These systems can range from simple manual hoists to fully-automated, three-axis systems in which all movements are computer controlled and monitored. Depending on the level of controls, these systems can have a high degree of process flexibility but can have high sticker prices.

Process tanks that incorporate vertical agitating platforms or an automated method to raise and lower parts into the process tanks, are candidates for a part transfer system that pushes the parts from stage to stage. These systems are good for high-volume applications that have similar tank process times that do not vary significantly from part to part.

The overhead conveyor "dip-and-drag" method may be the method of choice if the parts require a secondary process such as painting. A properly designed conveyor can move the parts directly from the cleaning system to an in-line painting application that utilizes the same conveyor system. Applications for these systems are very rare and these systems have a very large footprint.

Material Handling/Automation in Spray Washer Systems
Inherent in in-line spray washers, by their design, is automated parts transferring. In both the belt-style design and the overhead conveyor design, the parts are automatically transferred through each process stage at a rate of speed measured in feet per minute. The parts exit the cleaning system in a finished state. At this point, it is up to the operator to transfer the parts to the next process. In the overhead conveyor system, the conveyor may be in-line with secondary operations, which wouldn't even require the parts to be removed from the conveyor.

Process Controls and Traceability
When a higher degree of automation, process control and documentation are required and/or the anticipated cleaning volumes are high, fully automated transfer systems can meet these requirements. The more advanced transfer systems in an immersion cleaning line use a control process commonly referred to as "dynamic scheduling." Dynamic scheduling features enhance the process engineer's ability to perform complex recipe mixing with high production and high flexibility requirements. Hundreds of different process recipes can be intermixed. With databases of several thousand part numbers, the user can run any combination of racks or loads in any sequence and get consistent quality on every part, automatically. Simple to fill out menus for immersion times, drip times and desired min/max times can be employed. With the proper software and process controls, detailed logs are automatically saved and customized reports can be generated. This enhances the traceability of each part as it is processed though the cleaning system.

In some industries, such as the airline industry, more of an emphasis is currently being placed on better record keeping and traceability of a part's cleaning history. In a high-profile aerospace engine overhaul case, 8,200 engine blades that were improperly cleaned were recalled. It was found that an improper cleaning process caused fatigue cracks in the blades. Because of the high degree of traceability, the actual day that the blades were cleaned and the cleaning process that the blades went through were identified and notices were sent to all airlines affected. As a result, new procedures and regulations have been implemented for cleaning this engine component.[8]

Ancillary Equipment & Waste Minimization
One method to reduce waste treatment volumes is to extend the chemical bath's operating life. By removing suspended solids and floating contaminates, one can reduce the frequency of having to dump or waste treat thousands of gallons of chemical solutions.

Suspended solids can be efficiently removed with basic cartridge or bag-type filtration. Recommended total tank turnover rates of 2-5 times per hour are common. With process tanks that see excessive soil loading (usually the first wash stages), higher GPM volumes are recommended.

Filtration in these types of applications commonly takes place at the macro particulate range of the filtration spectrum. Sand and grit fall into this range. The smaller the filtration media's micron rating, the greater the amount of soils that can be removed. Most filtration systems are designed with enough flexibility to allow the user to use a wide range of filtration media sizes. "Polishing" filtration systems operate in ranges as low as 50-100 microns (about the size of a human hair), while the systems designed for large soil loads may operate well above 1000 microns. When specifying the desired level of filtration, it is best to work closely with the equipment manufacturer and the chemical supplier.

If filtration of a higher level is required, ultrafiltration can remove contaminates in the 0.001 to 0.1 micron size range.[9] These types of systems are designed to remove contaminates such as emulsified oils, rather than standard carbon dust and dirt. When considering this form of filtration, work very closely with the chemical supplier to ensure that their products are compatible.

Floating contaminates can be removed by incorporating a side stream coalescing system. A coalescing system is designed to use the natural gravity differences between oil and water to separate the oil and water as well as incorporating the oleophilic (oil attracting) properties of coalescing elements (such as polypropylene), to separate the oil. On a continuous basis, solution on the top of the process tank is sparged to an overflow trough, which drains to the coalescing tank. This tank is designed to create a "quiet zone" which provides ample time for the floating contaminates (some oils, carbon, dust, etc.) to float to the top of the solution, where they can efficiently be removed with an overflow weir. The cleaned solution is then pumped back to the process tank. Its return flow is what creates the sparging effect across the top of the solution. When considering coalescing as an option, it is imperative that the cleaning chemical formula promotes the splitting/floating of oils and is not an emulsifying type of cleaner.

Some cleaning requirements, such as a part being "spot-free," may require that the rinse water be treated for dissolved solids such as minerals and salts. Methods such as reverse osmosis and deionizing resin bed systems are quite common. However, deionized water is the most common form used in final rinse stages where high levels of rinse water purity are required.[10] These systems are usually leased from a local water treatment provider, who will maintain them as part of their service. Some local water supplies are so high in dissolved solids that treated water may not be an option, as their mineral content can have adverse effects on the final product.

Vender/Supplier Selection
After determining the basic requirements for the cleaning system, such as the number of process tanks, the method of cleaning, volume requirements and the level of automation, it is time to solicit potential suppliers for bids. Selecting the preferred company or companies to build the new cleaning line is a critical step in the process of designing and installing a new cleaning line.

Thorough Understanding of Your Application

The chosen vendor should have a thorough understanding of the following issues, if the system is to be properly designed:

- Required level of cleaning; In-process versus final clean
- Footprint issues
- Volume requirements
- Part workflow; how the cleaning line interfaces with other areas of the plant.
- Available utilities
- Water characteristics
- Who will be operating the system
- Your anticipated/desired life expectancy of the system
- The process chemicals
- Process control requirements
- The mix of parts and base materials of the parts to be cleaned
- Plant environment issues

Industrial Cleaning Experience

There are many issues that separate the cleaning industry from other chemical processing applications such as plating or coating lines. Effective cleaning systems require industrial-designed process tanks with dependable industrial mechanical agitation in the form of liquid agitation, part agitation, ultrasonics or spray. Cleaning lines are no longer just large soak tanks or sink-on-a-drum systems. The supplier should have proven experience with one or more of these methods of cleaning.

Customer References

References are a good way to find out about the company's product and what type of after-sales support can be expected. As environmental issues and cleaning requirements change, it is critical that the supplier be positioned to address these changes. Obviously, a potential vendor will provide satisfied customers as references. It is probably a given that the references will speak highly of the supplier and the product. For this reason, it is important to inquire on other issues such as why this vendor was initially chosen over others, what is the percentage of operating uptime/downtime, what are the typical maintenance requirements and how user-friendly is the system. It is also helpful to visit some of these references in person.

Pricing/Budgeting

Traditionally, price has been a driving factor for cleaning acquisition projects. When considering costs, factor in more than the purchase price. Consider the cost of ownership, which will include process efficiencies, usage costs (power requirements, chemical usage estimates, etc.) and cleaning yields. 100% first-time cleaning versus the need to re-clean, represents a significant usage cost savings. In addition, factor in costs associated with warranties, extended warranties and guarantees.

When comparing pricing between two or more vendors, whenever possible, ensure that apples are being compared to apples. Ask for as much detail as possible in the proposal so that an educated, objective comparison can be made. For example, one vendor may consider a sufficient liquid agitation rate to be 50 GPM, while another may have quoted 300 GPM. If the process tank sizes are comparable, the differences between these rates in this example are significant and so are the costs associated with building them.

Summary and Conclusion

The cleaning industry is unique. The cleaning portion of manufacturing is commonly viewed as a necessary evil and not a process that contributes to the bottom line. However, there are costs associated with poor cleaning that can reduce profits. There are several trends in the industry and regulations that are prompting companies to take a closer look at their cleaning. Current trends include:

1) The reduction and elimination of solvents due to environmental regulations
2) Increased process control and higher levels of traceability to meet today's higher standards
3) Improved cleaning methods
4) Improved cleaning specifications
5) A move towards cellular cleaning to minimize in-process material handling costs and to bring total control of the part back to the work cell
6) A move from manual cleaning to some form of automated cleaning

When designing a new cleaning line or improving an existing line, it is important to understand the basic cleaning formula of time, temperature, chemicals/concentration and method of cleaning. Each variable has a direct effect on the others. By changing one factor of the formula, it may have an exponential effect on others.

When designing a new cleaning line, one must determine:

1) The optimal number of process tanks
2) How to design "process robustness" into the system
3) The proper tank/stage size and dimensions to accommodate the parts in the best orientation for the most effective cleaning
4) The method of mechanical energy/agitation that is most effective in your specific application at removing the soils
5) Which method of heating best fits the application/situation and how to properly size the heating capacities of the process tanks to ensure that the recommended operating temperatures throughout the processes are maintained
6) What level of automation and/or material handling is needed to meet the volume requirements and provide the desired level of operator interface
7) What ancillary equipment may be advantageous to minimize the system's waste stream generation

One of the most critical decisions in designing a cleaning line is the selection of a vendor. When considering vendors, one should include the following in the decision making process:

1) Do they have a thorough understanding of your industry/application and those requirements that make it unique? 2) Do they have industrial cleaning experience?
3) Do they have strong references and experience cleaning and handling similarly sized parts, if not direct experience with cleaning in your industry?
4) Do costs include usage and initial purchase cost?
5) Has the vendor provided detailed proposals so an educated, objective decision can be made?

Projects of this size, complexity and magnitude require a great deal of research, time and effort. By thinking it through and using a step-by-step approach in the decision making process, it can simplify the complexity of the project and help to guarantee that the best system for your specific application is selected.

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