Aqueous Cleaning Alternatives to Vapor Degreasing

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ABSTRACT

This seminar is intended to present the manufacturing engineer or manager the tools to select and implement aqueous cleaning methods as an alternative to vapor degreasing methods. Since the advent of the Montreal Protocol, nearly every industrialized nation in the world has passed legislation phasing out the use of chlorinated solvents for cleaning of components and assemblies. In the U.S., the Clean Air Act Amendments of 1990 call for the elimination of Freon solvents (CFC-113) by the end of 1995 and 1-1-1 Trichlorethylene by the end of 1997. These two solvents comprise the bulk of the solvents used for vapor degreasing. In this seminar, cleaning chemicals, i.e. saponifiers, surfactants, detergents, and non-ozone depleting solvent emulsions, will be discussed for suitability for various cleaning tasks. The general types and configurations of aqueous cleaning equipment will be presented. Finally, waste water discharge, post treatment methods, and recycling methods will be discussed. An overall look at the systems with the expected problems in changing from vapor degreasing to aqueous cleaning will be presented.

1.0 Introduction

Since the advent of the Montreal Protocol, in the interest of the protection of the atmospheric Ozone, industry worldwide is forced into abandoning current vapor degreasing methods and replacing these systems with alternative cleaning methods. The use of aqueous based cleaning systems is by far the most popular and environmentally conscious solution to elimination of chlorinated solvent use. Aqueous cleaning methods have advanced far beyond the "good old soap and water" systems of a century ago into modem, effective cleaning methods.

The change from vapor degreasing to aqueous cleaning is not without its pitfalls, though. Vapor degreasers were almost universal in their effectiveness whereas aqueous cleaning systems and chemistries must be selected carefully to match the specific cleaning process with the cleaned product materials and cleanliness needs. Certain chemistries and equipment may be entirely suitable for degreasing components machined with water soluble cutting oils, yet fail drastically when used against more aggressive soils such as rosin soldering flux or polishing compound waxy residue. Conversely, aggressive chemistries such as saponifiers may be ideal for printed circuit board defluxing but will remove anodized coatings on aluminum.

This seminar will familiarize the engineer or manager with the available chemistries and equipment for aqueous cleaning so that he or she may make an informed choice about the process and equipment required for his or her specific cleaning needs. In addition, the disposal of waste water following the cleaning process will be discussed. This is an issue important today and destined to become more and more vital to aqueous cleaning systems as the regulations for water disposal become increasingly tighter.

2.0 Definitions

Prior to the start of studying any topic, a discussion of the terminology of the subject is vital. This lays a groundwork for a common understanding of the principles to be discussed.

Batch Machine -A machine holding parts essentially static while they are cleaned.

Clean (verb) - The act of spreading soils over a part thinner and thinner until the concentration of the soils meets a stated objective.

Clean (noun) - The condition of concentration of soils on a part meeting some stated objective, for instance a certain number of micrograms per square centimeter, or no visible particles when viewed under a 10 power magnifying glass, etc.

Note

Clean does NOT mean: no soils present. The question of how clean is clean, is essential to answer prior to selecting an alternative cleaning chemistry.

Detergent -A synthetic soap having a polarized nature with one part of the compound water soluble and the other oil soluble. Detergents allow the dissolution of normally water insoluble oils into water.

In-Line Machine -A continuous motion conveyorized cleaning machine generally with moving parts and static wash, rinse and dry stations.

Saponifier - An alkaline compound, either organic or inorganic, used to act upon an organic oil or fat to produce a soap. In aqueous cleaning, saponifiers are used to convert organics, normally not water soluble, into soaps, water soluble for rinsing away with water.

Soap - The result of the chemical reaction of a caustic (alkaline) on fats or oils. Soaps have the ability to dissolve oils while themselves being soluble in water.

Soils - Undesirable materials on the surface of a part

Spray In Air - A term used to describe a cleaning machine where the mechanical action consists of the spraying of wash solution against a part not submerged in the wash solution.

Spray Under Immersion -A term used to describe a cleaner using directed sprays of wash solution against a part submerged in the wash solution.

Surfactant -A chemical used to reduce surface tension. In effect it makes water "wetter" allowing the removal of more tenacious films and oils.

Ultrasonics -Cleaning machines using ultrasonic transducers acting on a bath of cleaning solution to provide the mechanical cleaning action.

3.0 Cleaning Chemicals

Though many recommend the selection of an appropriate cleaning chemistry as the very first step in specifying a replacement process to vapor degreasing, this procedure should be concurrent with the selection of equipment. The cleaning equipment and chemistry go hand-in-hand and operate as different elements of a complete cleaning system. Some chemistries may work fine when tested in a lab yet are impractical when applied to a production process. An example is terpene type chemistries. While they function as excellent organic solvents when a part is immersed in a laboratory setting, when the chemistry is heated and sprayed, an explosive mixture is formed. If this chemistry were selected, the equipment would require inerting and specialized training for the operators; not normally a cost effective replacement for vapor degreasing. Many terpenes, however can be used successfully in solvent emulsions without the risk of fire and explosion if proper equipment and precautions are used.

Aqueous cleaning chemistries can be broken down into three basic categories: saponifiers, surfactants, and solvent emulsions. Each has its own benefits and limitations. Each operates very differently and are, in general, used for different types of soil on products to be cleaned.

3.1 Saponifiers

Saponifiers are alkaline compounds used to convert fats and waxes into soaps. The use of saponifying agents can be traced to prehistoric times where Sodium Hydroxide (readily made by percolating water through wood ashes) was reacted with animal fat to form soap.

Saponifiers are excellent cleaners for many types of organic soils. For use in removing rosin flux (pine tar) from printed circuit board assemblies, saponifiers are the simplest and most effective of all fully aqueous chemistries. Many types of tars and waxes, normally very difficult substances to remove, can be easily saponified and rinsed away.

Once the organic material has been saponified, it becomes a soap. This soap then becomes a surface activating agent able to dissolve oils and then able to be dissolved by water. Many oils cannot be saponified; however the act of saponifying waxes, tars, etc. creates soaps able to dissolve oils then themselves able to be dissolved in water.

A saponifier would be a poor choice for removing oils since many cannot be saponified. In the case of oils combined with waxes, as in the case of polishing compound, or such tenacious films as rosin flux and adhesives, it remains as the best choice for cleaning. The saponified compound forms a byproduct, soap, actually assisting the cleaning process.

3.2 Surfactants

Surfactants are surface activating agents. In fact the word, surfactant is a combination of these three words. All liquids and solids have some surface tension between them. A drop of oil on a machined part, for instance, has a relatively strong bond. For water to intercede in this bond, the surface's affinity for the water must be stronger than its affinity for the oil. Enter the surfactant. It makes the water the most desired substance and allows it to penetrate under the surface of the oil, lifting it off.

Surfactants have components in their molecular structure capable of dissolving oils. The surfactant lifts the oils from the surface then dissolves them. Following this action determines whether the surfactant is called a surfactant or a detergent. If the surfactant/oil molecule dissolves in water the chemical is referred to as a detergent. If the surfactant puts the oil into an emulsion, i.e. small droplets of oil suspended in water, it is termed a surfactant.

Using a non-detergent type surfactant, that is, an emulsion creating surfactant has benefits for aqueous cleaning systems. It is far easier to remove suspended droplets of oil from the wash and rinse than to .remove the oil from solution.

3.3 Solvent Emulsion

A brand new type of aqueous cleaning chemistry is currently starting to appear. It is called solvent emulsion cleaning chemistry and it appears to have many advantages over saponifier or surfactant cleaning systems. The first equipment to use this chemistry' is intended for circuit board defluxing. Both terpene type solvents and the new non-flammable cleaning solvents developed by DuPont may be emulsified into the wash solution and used for cleaning. Solvents offer very reactive and aggressive chemical energy to remove organic soils on the surface of the products while being completely inert to the material being cleaned.

With the high pH of saponifiers, the base part will eventually be attacked if the contact time of the wash solution is too long. With solvents, this cannot occur. Solvent emulsion cleaning methods produce excellent results with many types of cleaning previously processed by vapor degreasing.

3.4 Water

The primary component of aqueous cleaning of parts and assemblies is water. Water is an excellent solvent of inorganic compounds. Hot water mechanically impinged onto a part will dissolve all of the ionic soils on the part.

The purer the water, the more effective its cleaning ability. Water can carry only a certain amount of ions before they begin to precipitate out of solution and deposit back on the parts. Starting with water without any ions, i.e. deionized (DI) water, the maximum amount of ions can be collected.

Deionized water has an additional benefit. If parts are cleaned with tap water, typically carrying 500 parts per million of dissolved solids, the parts may get clean, but once the water evaporated when the parts are dried, the water will leave its dissolved solids on the part. Using deionized water and rinsing the parts until no additional ions are being picked up by the water, yields spot free dried parts.

Water also acts as a suspension media for insoluble soils such as dust and dirt. Certain agents such as Sodium Tripolyphosphate (STTP) assist the water to keep many of the soils cleaned from the part in suspension until they can be carried away from the part. These agents are commonly used in many cleaning surfactants and saponifiers to assist in the removal of this type of soil.

4.0 Cleaning Equipment

The selection of cleaning equipment demands careful examination of a number of factors. Some of these include: part size and configuration, nature of the soils, level of cleaning needed, production rates, floor space availability, post cleaning water processing required, and process control requirements (ISO-9000/9001 compatibility, etc.)

As with all capital equipment, the sophistication, complexity and costs of cleaning equipment increases as higher production rates, stricter cleanness requirements, and greater process control needs are added. Available cleaning equipment ranges from $100 bath parts washers to half million dollar sophisticated, nitrogen inerted, in-line high production cleaners, and every level in between. Emphasis should be placed on obtaining the lowest complexity and cost system capable of meeting the cleaning criteria and production rates desired.

Three forms of energy are needed for nearly all aqueous cleaning systems. They are: thermal energy, mechanical energy, and chemical energy. The chemical energy is supplied by the type and amount of the cleaning chemistry as described in section 3 of this seminar.

The efficiency of an aqueous cleaning system is proportional to the temperature of the wash solution. For efficient cleaning the wash solution must be HOT. If the solution is sufficiently hot, less chemical energy is required. Witness steam cleaners. They normally operate without the addition of detergents, saponifiers or surfactants yet are able to remove even tenacious oily films. The majority of aqueous cleaning systems operate in the 140 to 180 F range for efficient removal of soils. This means for most cleaners, the parts may not be manipulated by an operator while being cleaned. This is an obvious difference from vapor degreasing systems where the parts are handled by the operator during cleaning.

In addition to the chemical and thermal energy, mechanical energy is required for aqueous cleaning. With a vapor degreaser, this energy was provided by the use of a brush and operator. As mentioned above, this is impractical for most aqueous cleaners. For aqueous cleaners, the mechanical energy is provided by either an energetic spray of wash solution or ultrasonic energy transferred to the wash bath. The least energetic of the cleaning equipment to be discussed is the bath type. This type relies on either the swirling of the wash bath around the part or some type of agitation of the part. Next on the scale of mechanical energy is the spray under immersion type of cleaners. Here, jets of wash solution are directed at the parts to be cleaned while they are immersed in solution. Next on the scale of mechanical energy are the "spray in air" aqueous cleaners. These use fixed or rotating sprays directed at the parts held in the air. Finally, the ultrasonic cleaners impart the most mechanical energy into the cleaning process. In some cases, such as PCB defluxing, ultrasonics deliver too much mechanical energy and damage can be caused to some sensitive components.

4.1 Bath Type Cleaners

Bath type cleaners are the simplest and lowest cost cleaning systems. Most intended for aqueous use were originally designed for cold solvent cleaning. In general, bath cleaners rarely have built-in water heating systems and most rely on operator agitation of the parts for removal of soils. This type of cleaner is suitable for only the most rudimentary cleaning of soils or oils of the surface of very simply shaped parts.

No provision is made in bath type cleaning systems for any rinsing or drying. The user is left to his own devices to remove the wash solution and dry the parts.

For production cleaning tasks or any type of precision cleaning, bath type cleaners are not suitable. The rudimentary controls and operator dependent process control leave too much room for error. These devices are more suited to service stations and tool rooms than manufacturing facilities.

4.2 Spray Under Immersion Cleaners

Spray under immersion cleaners represent the next step up in utility and complexity from bath type cleaners. These are normally offered with built-in heating systems to maintain the wash solution temperature. The directed jets are normally not adjustable. Once the part is immersed in the wash solution, pumps circulate the wash s91ution through jets of water directed at the parts.

Spray under immersion cleaners are a step up from bath cleaners in controls also. Many have provisions for rinsing with timers and shutoff devices for unattended operation.

The configuration of spray under immersion cleaners limits their usefulness.

They are most suited for two dimensional parts such as bare printed circuit boards, surface mount solder stencils, and other similarly configured parts. The ability to clean under a part or inside a cavity is minimal.

Spray under immersion aqueous cleaning systems are suitable for production work if the parts being cleaned have the appropriate configuration. In these cases, the process control is tight enough to produce consistent results. Most spray under immersion cleaners have no provision for part drying.

4.3 Spray In Air Cleaners

Spray in air cleaners are the most popular and often the most effective aqueous cleaning systems. Most are built using computerized control to program in various cleaning parameters, and replay these programs at will. This allows a tight control of the process. Often this process control data can be extracted via a communication line directly from the onboard computer into a computerized data collection system. This permits compliance with Statistical Process Control systems such as are required for ISO-9000/9001 compliance.

Spray in air systems come in two basic styles: batch and in-line. Batch systems use a fixed or rotating basket with fixed or rotating spray nozzles such that all surfaces of a three dimensional part are exposed to the spray jets. For the most mechanical energy transfer, high pressure sprays are the most effective.

In-line systems utilize a conveyor carrying the parts through the wash, rinse and dry stages of the machine. They are ideally suited for high production runs. In-line systems often use cascading rinse tanks. With a cascading rinse, deionized water is introduced into the last rinse tank. Following being sprayed onto the parts in their last rinse, the water drains into the second rinse tank. It is then sprayed on the parts again then flows into the first rinse tank where it again is sprayed on the parts leaving the wash stage.

In-line cleaners have a distinct advantage when used with relatively thin parts such as printed circuit board assemblies. High pressure air knives can be used to remove the bulk of the water remaining on the parts following the rinse cycle. This makes drying of the parts a far more simple task.

For lower production rates, batch spray in air cleaning systems are available. Batch cleaners generally wash, rinse and dry in the same chamber. Generally more rinses are needed in batch systems because the inside walls of the chamber must also be rinsed clean of wash solution. The better systems have a programmable number of rinses. Some even feature a resistivity controller in the cleaning chamber sump to allow automatic rinsing. The resistivity controller monitors the cleanliness of the rinse water, then signals the computer controller to continue rinsing the parts until the rinse water achieves a user preset level.

Some batch cleaners come with a built-in convection or heated forced air dryer to dry the parts following wash and rinse. Other companies sell a standalone dryer used for this purpose. Most of these machines use a removable rack or basket for carrying the parts. This rack is removed from the wash/rinse chamber and placed into the drying chamber for drying.

Spray in air systems are the most sophisticated and most reliable of the production equipment used for aqueous cleaning. The process control capabilities of these machines are the highest of any of the cleaners. For precision cleaning of most parts, the spray in air systems are unmatched.

4.4 Ultrasonic Cleaners

Another type of aqueous cleaning system suitable for vapor degreaser replacement is the ultrasonic cleaner. Though these machines have been in use for many years, recent new technology has been incorporated into their design and improved their effectiveness greatly.

Ultrasonic cleaners operate by immersing the parts to be cleaned into a wash bath. Ultrasonic transducers on the sides or bottom of the wash bath tank induce strong ultrasonic standing waves into the wash solution. This imparts a powerful mechanical agitation to the water loosening soils and suspending them in the solution. As with other cleaners, organics removal is accomplished with surfactants or solvent emulsions.

Ultrasonic cleaners come in a wide variety of shapes, sizes and sophistication levels. Few have provisions for rinsing or drying. For the cleaning of parts with small diameter holes, blind cavities and other difficult to clean configurations, ultrasonic cleaners are unmatched. The mechanical action loosens and suspends particles such as machining chips and other soils quite effectively.

For many cleaning needs, ultrasonic cleaners simply impart too much energy to the parts being cleaned. Water cavitation in the wash bath while being ultrasonically energized can cause pitting damage on soft surface components. For printed circuit board defluxing, sensitive electronic components can be damaged by the high energy waves. Microscopic wire bonds in microchips have been known to come loose when too much ultrasonic energy is used. For many types and configurations of parts, ultrasonic cleaning systems remain the only effective way to clean and if the parts are sturdy, ultrasonic cleaners remain one of the best choices for aqueous cleaning replacement of vapor degreasers.

5.0 Water Disposal

One of the most important yet most often overlooked aspects of converting from vapor degreasing to aqueous cleaning is the disposal or reuse of the water used for cleaning. Increasingly strict environmenta1 regulations on industrial wastes are a major concern to companies cleaning with water.

The key to selecting chemistries and processes is to look ahead. Certain chemistries and processes are conducive to future improvements while others are not. For instance d-Limonine, a natural terpene extract from orange peels is an excellent organic solvent. Once thought to be harmless, it has now been discovered to kill fish. Rumors say new regulations are in the works to limit the discharge to 4 parts per billion! This will effectively eliminate d-Limonene from use as a cleaning agent.

Many companies have discovered the hard way, the expense in cleaning up toxins once dumped entirely legally. Many of the aerospace companies now abandoning California are getting slapped with huge cleanup bills for government specified processes back in World War II.

5.1 Discharge to Drain

Many aqueous processes are still conducive to discharge to drain. This is especially true of saponification processes where the product is soap. Publicly Owned Treatment Works (POTW) are equipped to handle soaps since most municipal waste water soapy. Different municipalities have different regulations regarding discharge water. Know before you go. Contact your local POTW and ask for their discharge requirements. Obtain water samples from cleaning equipment suppliers and have them analyzed cleaning your or similar parts to yours to know for sure.

Some municipalities are extremely tight on industrial waste. In fact, in several cities in Southern California, the tap water the city supplies to industry is too dirty for discharge to the drain!

One advantage and POTWs in the know, appreciate is: aqueous waste water is generally alkaline. Since most industrial waste is acidic, the POTWs like alkaline discharge to neutralize the pH of acidic waste water being discharged in the area.

5.2 Water Treatment prior to Discharge

If the discharge water does not meet POTW requirements, certain simple water treatment methods will very likely bring the concentration of undesirable chemistries in the water to a sufficiently low concentration for later discharge. The two most common of these conditions is excessive organics and a lead content too high for discharge.

High organics in discharge water is a relatively simple condition to correct. If an emulsifying surfactant (as opposed to a dissolving type surfactant) is being used for soil removal, the equipment to separate the oils from the water is relatively uncomplicated and inexpensive. Simplest is the decanter. If the water is allowed to sit in an open drum, the lower specific gravity oils will float to the top. The water underneath may then be discharged. An oil/water separator using a coalescing filter may also be used to separate the oil in suspension.

For dissolved organics or slow separating emulsions, Granulated Activated Carbon (GAC) will readily adsorb most of the organics in the water. GAC is inexpensive and effective. Once the GAC is loaded, however, it is considered toxic waste and must be disposed of properly.

The other primary concern in waste water is ionic lead. This gets in the water when alkaline saponifiers and surfactants come into contact with soldered joints, especially for defluxing cleaning tasks. Since lead is a major environmental concern, allowable limits are very low. Certain filters may be used for lead removal. In particular a specially treated ceramic and carbon element is one of the best for lead removal. A new filtration media known as KDF is also excellent for lead removal.

Another popular method for disposal of water in aqueous cleaning process is to evaporate the water. In many cases the wash solution can be evaporated after use and the rinse water, often simply deionized water, can be put down the drain. Evaporators are available in all shapes and sizes and for all budgets. The residue after evaporation, however must be disposed of properly.

5.3 Closed Loop Systems

For areas with very strict discharge requirements, especially such areas as the San Francisco Bay Peninsula and Long Island, New York, closed loop systems for treatment and reuse of aqueous cleaning water is a must. Several suppliers of systems for removing the contaminants from the wash and rinse water offer systems specifically designed for aqueous cleaning systems.

Most recycling systems utilize GAC for the removal of organics and deionizer resin for removal of the ionic contaminants in the water. These systems, while effective require the constant monitoring and changing of the GAC and resins. Where large quantities of water are used, in-line spray in air cleaning machines, for instance, the monthly expense of maintaining the closed loop system can get high.

A radically new system is currently in the development stage using a combination of technologies for recycling aqueous rinse water. It uses electrically. generated Ozone to attack and break down the organics into water and gaseous Carbon Dioxide, Ionic removal is accomplished through the use of reverse osmosis (RO) membranes and electrical deionizers (EDI). The reject water from the RO and EDI systems is then recovered by distillation. The contaminants are removed from the water as a solid scale and the operation is entirely electrical, requiring no regular servicing. The machines should be available by the end of 1994 and while not inexpensive in initial investment, with minimal operating costs, the system is far cheaper in the long run than traditional water treatment systems.

6.0 Conclusion

Aqueous cleaning systems are a viable replacement for vapor degreasers. With vapor degreasing chemicals becoming more and more expensive as the deadlines for elimination draws near, companies must make decisions soon. Being informed about cleaning chemistries, cleaning systems, and water discharge requirements gives the specifier of this new process a place to start to begin his or her search for a process suitable for his or her cleaning needs. The vast array of currently available products with new manufacturers cropping up daily has left a confusing array of choices. The purpose of this seminar is to arm the specifier of aqueous cleaning systems with the tools to make decisions early and correctly.