CHAPTER VI. MAINTAINING CLEANLINESS:

Once record cleanliness has been established, the goal is to maintain cleanliness. The internet has many good recommendations for record care such as handling to avoid fingerprints on the grooved surface, avoiding sunlight, packaging in anti-static, and lint-free archival quality record sleeves. But very small particulate and static can be a challenge, and some practices can do more harm than good.

VI.1 In the technical paper *THE WEAR AND CARE OF RECORDS AND STYLI***,** *by Harold D. Weiler, 1954* (34) states "*Many methods have been devised and improvised to combat the problem of dust on records and to reduce its effect on wear and reproduction. However, none of these methods were ever completely effective, and they all passed into oblivion with one exception, the cleaning pad. Unfortunately, this device is in general use in 1954, despite the fact that it does not clean records! A record pad can actually damage records by scratching them and grinding microscopic particles of dust and grit into the grooves. In addition to causing excessive wear of records and styli, these dust particles also increase the noise level of the record. Since the particles of dust and grit are often as large as the recorded impressions in the record groove which create the sound, they will affect the stylus movement, causing random impulses which are translated as noise. This increase in noise level due to dust and grit is the biggest contributing factor to the hissing sound commonly and mistakenly referred to as "needle scratch*".

VI.2 In the paper *Record Contamination: Causes and Cure by Percy Wilson, 1965, (61)* it echoes what *Harold D. Weiler* wrote and discusses how dry cleaning can give back more than it removes. The dry-cleaning material will ultimately become saturated with particle/soil and then instead of removing, redeposits to the record. The paper also states that "…*repeatedly-used damp pad or like device can become a positive menace*.". And yet, the widely used Discwasher™ brush *US Patent 3,951,841 of 1976* (17) which makes no mention of the papers *Percy Wilson, 1965,* and *Harold D. Weiler 1954* states "*The brush of this invention is made of a developed fabric having a very fine, slanted and angularly oriented pile of sufficiently small fiber dimension to reach the bottom of the record grooves. The brush picks up and holds dirt when brushed against its angulated fibers, and the brush also soaks up, as in a form of capillary attraction, the fluid and the dirt mollified by the fluid. And, the angulated pile of this brush is designed to provide for release of its accumulated surface dirt and dust when brushed in an opposite direction on any other fabric surface.".*

VI.3 However, the use of record brushes and pads of various designs continues; used for the purpose of either removing some particulate or removing static charge through use of a conductive brush or wetted pad. One of the issues with static charge is that it causes the record to attract dust from the air that causes clicks and pops. *MIL-HDBK-263B Electrostatic Discharge Control (ESD) Handbook for Protection of Electrical and Electronic Parts, Assemblies and Equipment (48)*, for purposes of Electrostatic Discharge (ESD) uses the following definitions, noting that conductive and dissipative materials are considered anti-static.

VI.3.1 **Surface Conductive Material**. Materials with a surface resistivity less than 10^5 ohms per square, or materials with a volume resistivity less than 10^4 ohm-cm.

VI.3.2 **Surface Dissipative material**. Materials with a surface resistivity equal to or greater than 10^5 but less than 10^{12} ohms per square, or materials with a volume resistivity equal to or greater than 10^4 but less than 10^{11} ohm-cm. As a general note, dissipative in ESD terms generally implies that static charge is dissipated slowly - generally within a few seconds. Dissipative surfaces are used to prevent accidental shorting of sensitive semi-conductors if they were placed on a conductive surface.

VI.3.3 **Insulative material**. For the purpose of ESD protection, materials not defined as conductive or dissipative (greater than 10^{12} ohms per square or greater than 10^{11} ohm-cm) are considered to be insulative.

VI.4 **Triboelectric Effect (source *MIL-HDBK-263B (48)*)**: "*The generation of static electricity caused by contacting or rubbing two substances is called the triboelectric effect. A triboelectric series is a list of substances in an order of positive to negative charging as a result of the triboelectric effect. A substance higher on the list is positively charged (loses electrons) when contacted with a substance lower on the list (which gains electrons). The order of ranking in a triboelectric series is not always a constant or repetitive. Furthermore, the degree of separation of two substances in the triboelectric series does not necessarily indicate the magnitude of the charges created by triboelectric effect. Order in the series and magnitude of the charges are dependent upon the properties of the substance, but these properties are modified by factors such as purity, ambient conditions, pressure of contact, speed of rubbing or separation, and the contact area over which the rubbing occurs.* ***In addition to the rubbing of two different substances, substantial electrostatic charges can also be generated triboelectrically when two pieces of the same material, especially common plastic in intimate contact, are separated as occurs when separating the sides of a plastic bag. Some metals, can create significant charges from triboelectric generation. Aluminum, when rubbed with a common plastic can generate substantial electrostatic charges***."

VI.5 **Figure 29** is a Triboelectric series showing relative positions of various materials obtained from *Effect of the relative permittivity of oxides on the performance of triboelectric nanogenerator, Yeon Joo Kim, Jaejun Lee, Sangwon Park, Chanho Park, Cheolmin Park and Heon-Jin Cho, RSC Adv., 2017, 7, 49368*; modified to show the position of human hands.

Figure 29 – Triboelectric Series
(Image Courtesy of RSC Adv., 2017, 7, 49368)

VI.6 There are a number of published quantitative Triboelectric series, the most recent *Quantifying the Triboelectric Series* published 2015 (63). The table in this recent series compares similar to the previous widely accepted *The Triboelectric Series, Bill W. Lee, David E. Orr; ©2009 by AlphaLab, Inc (11)* which is provided as **Table IV** (*and is reproduced in whole*).

Table IV
TriboElectric Table
(courtesy www.alphalabinc.com)

Material	**Charge Affinity (nC/J)**	**Charge acquired if rubbed with metal (W=weak, N=normal, or consistent with the affinity**	**Notes: Tests were performed by Bill Lee (Ph.D., physics). ©2009 by AlphaLab, Inc. (TriField.com), which also manufactured the test equipment used. *This table may be reproduced only if reproduced in whole***
Polyurethane foam	+60	+N	All materials are good insulators (>1000 T ohm cm) unless noted.
Sorbothane™	+58	-W	Slightly conductive. (120 G ohm cm).

Material	**Charge Affinity (nC/J)**	**Charge acquired if rubbed with metal (W=weak, N=normal, or consistent with the affinity**	**Notes: Tests were performed by Bill Lee (Ph.D., physics). ©2009 by AlphaLab, Inc. (TriField.com), which also manufactured the test equipment used. *This table may be reproduced only if reproduced in whole***
Box sealing tape (BOPP)	+55	+W	Non-sticky side. Becomes more negative if sanded down to the BOPP film.
Hair, oily skin	+45	+N	Skin is conductive. Cannot be charged by metal rubbing.
Solid polyurethane, filled	+40	+N	Slightly conductive. (8 T ohm cm).
Magnesium fluoride (MgF2)	+35	+N	Anti-reflective optical coating.
Nylon, dry skin	+30	+N	Skin is conductive. Cannot be charged by metal rubbing.
Machine oil	+29	+N	
Nylatron (nylon filled with MoS_2)	+28	+N	
Glass (soda)	+25	+N	Slightly conductive. (Depends on humidity).
Paper (uncoated copy)	+10	-W	Most papers & cardboard have similar affinity. Slightly conductive.
Wood (pine)	+7	-W	
GE brand Silicone II (hardens in air)	+6	+N	More positive than the other silicone chemistry (see below).
Cotton	+5	+N	Slightly conductive. (Depends on humidity).
Nitrile rubber	+3	-W	
Wool	0	-W	
Polycarbonate	-5	-W	
ABS	-5	-N	
Acrylic (polymethyl methacrylate) and adhesive side of clear carton-sealing and office tape	-10	-N	Several clear tape adhesives have an affinity almost identical to acrylic, even though various compositions are listed.
Epoxy (circuit board)	-32	-N	
Styrene-butadiene rubber (SBR, Buna S)	-35	-N	Sometimes inaccurately called “neoprene” (see below).
Solvent-based spray paints	-38	-N	May vary.
PET (mylar) cloth	-40	-W	
PET (mylar) solid	-40	+W	
EVA rubber for gaskets, filled	-55	-N	Slightly conductive. (10 T ohm cm). Filled rubber will usually conduct.
Gum rubber	-60	-N	Barely conductive. (500 T ohm cm).
Hot melt glue	-62	-N	
Polystyrene	-70	-N	
Polyimide	-70	-N	

Material	**Charge Affinity (nC/J)**	**Charge acquired if rubbed with metal (W=weak, N=normal, or consistent with the affinity**	**Notes: Tests were performed by Bill Lee (Ph.D., physics). ©2009 by AlphaLab, Inc. (TriField.com), which also manufactured the test equipment used. *This table may be reproduced only if reproduced in whole***
Silicones (air harden & thermoset, but *not* GE)	-72	-N	
Vinyl: flexible (clear tubing)	-75	-N	
Carton-sealing tape (BOPP), sanded down	-85	-N	Raw surface is very + (see above), but close to PP when sanded.
Olefins (alkenes): LDPE, HDPE, PP	-90	-N	UHMWPE is below. Against metals, PP is more neg than PE.
Cellulose nitrate	-93	-N	
Office tape backing (vinyl copolymer ?)	-95	-N	
UHMWPE	-95	-N	
Neoprene (polychloroprene, *not* SBR)	-98	-N	Slightly conductive if filled (1.5 T ohm cm).
PVC (rigid vinyl)	-100	-N	
Latex (natural) rubber	-105	-N	
Viton, filled	-117	-N	Slightly conductive. (40 T ohm cm).
Epichlorohydrin rubber, filled	-118	-N	Slightly conductive. (250 G ohm cm).
Santoprene rubber	-120	-N	
Hypalon rubber, filled	-130	-N	Slightly conductive. (30 T ohm cm).
Butyl rubber, filled	-135	-N	Conductive. (900 M ohm cm). Test was done fast.
EDPM rubber, filled	-140	-N	Slightly conductive. (40 T ohm cm).
Teflon	-190	-N	Surface is fluorine atoms– very electronegative.

VI.6.1. From **Table IV**, PVC is very high (potential for negative charge) on the triboelectric series. The risk of static charging is the difference between two materials. The material with the most negative charge affinity will charge negative; the other material can be left with a positive charge. However, there can be substantial variation for natural products such as leather whose moisture level can change the material from low (positively charged) to moderately high (negatively charged). The record is very susceptible to developing a negative static charge, and the ambient humidity is probably the single greatest factor.

VI.6.2. When the ambient humidity drops below 35% (common during winter) the probability of developing static charge is high. Using a room humidifier has benefit, bacteria and particulate generation notwithstanding. A simple recommended practice by Dr. A.J. van den Hul https://www.vandenhul.com; is to place a sponge (recommend anti-bacterial) wetted with distilled water to increase the localized humidity in the vicinity of the turntable. Monitoring home humidity is worthwhile, and inexpensive devices such as the Acu-Rite™ Model 01083M are readily available (https://www.acurite.com/acurite-01083m-pro-indoor-temperature-and-humidity-monitor.html;).

VI.7 In the triboelectric series, human hands can be very positively charged (loses electrons) while vinyl records (mostly PVC) can be very negatively charged (gain electrons). Use of a conductive brush to remove static from a record that is intended to use the human body as the ground path may not work if the human body is not grounded, and even then, the human body depending on many variables may at best only be dissipative. Referring to **Table V**, in a humid environment, the human body resistivity can be low enough to be conductive, but in dry air when developing static on a record is common, the human body is at best dissipative. Otherwise, depending on the ambient conditions, the opposite may occur, the human body via the conductive carbon-fiber brush may actually charge the record. So, always ground yourself to something metal before using a conductive brush to remove static from a record.

Table V
Human Hands Electrical Resistance

Human Hands Condition	Resistance	
	Dry	Wet
Finger Touch	40 kΩ to 1 MΩ	4 kΩ to 15 kΩ
Finger-Thumb Grasp	10 kΩ to 30 kΩ	2 kΩ to 5 kΩ

VI.8 The article *Phonograph Reproduction 1978, James H. Kogen, Audio Magazine May 1978 (36)* goes into some detail on static; what causes it and what does not – the needle in the groove was not a source of static. The article indicates that static is not uniform, but exists as islands on a record. Additionally, once the static gets high enough to discharge to the cartridge it only reduces to about 4200 volts. A static charge on the record of 4200 volts will not create noise by itself, but it can by electrostatic attractive forces cause a transient increase in cartridge VTF as much as 0.375 grams leading to distortion and premature wear. So, managing static has many benefits. Deep wet cleaning as delineated in **CHAPTER V. MANUAL CLEANING PROCESS:**, **CHAPTER XIII. DISCUSSION OF VACUUM RECORD CLEANING MACHINES:** and **CHAPTER XIV. DISCUSSION OF ULTRASONIC CLEANING MACHINES:** will remove any and all static from the record. Then it becomes, an issue of maintaining cleanliness.

VI.9 **Brushes**: The three popular brush materials for anti-static (conductive brushes) and dust are carbon fiber and Thunderon® with the following details from Gordon Brushes® (32), and Corebrid®.

VI.9.1 **CARBON FIBER**: *A very fine [Ø 0.000283] (~7.6 microns) fiber of 95% pure carbon. Fiber has a tensile strength of 575 ksi, a tensile modulus of 35 msi, and an electrical resistivity of 0.00055 Ohms in. Popular in light touch to non-contact grounding brushes due to its high conductivity. Not recommended for uses with high flexural requirements since carbon fiber has low flex fatigue resistance and can break off rather easily*." This implies that carbon brushes should only be used to just lightly touch the record. Also, the carbon fiber diameter is small enough to deeply penetrate the record groove which could lead to fiber break-off creating particles instead of removing particles. There are many variations of carbon record brushes. The most efficient are those used by the ESD industry that have a full aluminum handle for maximum fiber conductivity such as Carbon Fiber Brushes (amstat.com).

VI.9.2 **THUNDERON®:** *An extremely soft acrylic fiber that has been chemically bonded with a layer of copper sulfide. This outer layer becomes a part of the host fiber itself, which precludes the 'flaking' problem experienced by other conductive fibers. The fiber diameter is available in two diameters, 0.07 mm (0.0028"/~*70 µm*) and 0.11 mm (0.0043"/~*110 µm*). Its conductive layer is a super thin 300-1,000 (angstroms). Thunderon® has an electrical specific resistance of* 10^1 *-* $10^2 \Omega$ *cm.*". Thunderon® while classified as conductive, is not as conductive as carbon fiber, but the bristle diameter will not deeply penetrate the record groove and the product flexibility is less prone to fracture and breaking off. The common brush design has the bristles embedded in a conductive plastic handle.

VI.9.3 **COREBRID™ B®**: A hollow acrylic fiber that is filled with a conductive material manufactured by Mitsubishi Chemical™. This fiber is 0.03 mm (0.0012"/~30 µm) diameter and its electrical resistance measures between 10^0 - $10^2 \Omega$ cm. This fiber is used in the Analog Relax™ record brush.

VI.9.4 A simple observation of a carbon fiber or Thunderon® record brush with bright white light or UV blacklight at 30 to 45-degree angle can observe that the brushes often only move the dust. This is consistent with the *NASA/TM—2011-217231, report on Evaluation of Brushing as a Lunar Dust Mitigation Strategy for Thermal Control Surfaces (58)* that evaluated the effectiveness and performance of various brush materials and designs to remove dust from thermal control paint or aluminized thermal control surface. The report summarized that "*Although there was only one carbon bristle brush tested, it had by far the poorest performance.*". The NASA study also tested Thunderon®. The Thunderon® was in laboratory conditions effective in removing dust from the aluminized thermal control surface, but not effective in removing dust from thermal control paint surface. The NASA report indicated that the best brushes for removing particulate were the Zephyr™ fiberglass fingerprint brush and the Escoda™ Nylon fan brush. However, these brushes penetrating the record groove potentially doing more harm than good but are very effective in removing dust that accumulates on the turntable.

VI.9.5 Nylon brushes such as the Record Doctor™ Cleaning Brush are beneficial as a 'wet' cleaning brush since the bristle diameter at 0.002" will not deeply penetrate the record groove. But used "dry" can cause a static charge to develop on the vinyl record because of the triboelectric effect with the Nylon having a strong positive charge and the vinyl record having a strong negative charge.

VI.10 **Removing & Preventing Static**: How to remove static and dust from the record surface without doing more harm than good? From the preceding discussion, removing static and particulate are two different problems. The simplest method to prevent static during use is to keep the ambient humidity above about 40%. The mechanism of how this works is discussed in greater detail **paragraph** VIII.10.2**.**

VI.10.1 Static can be removed from the record by using conductive brushes, but these should just barely contact the record surface and you should be grounded unless the brush has a separate ground wire. There are tonearm-like anti-static sweepers that use a conductive brush and ground-wire to continuous remove static during record play. How effective are conductive brushes in removing static – only partially effective. In the paper *SealezeTM SSG515AT2D Static Dissipation Brush Performance in an Operational Environment (72)* Thunderon™ bristles in a grounded metal frame were only able to reduce the static charge developed during a plastic film manufacture to about 4000 volts whereas the brush with an ionizing device was able to reduce the static charge to less than 300 volts. As previously stated, reducing the static to 4000 volts will be sufficient to prevent static inducted noise, but not enough to prevent affecting the VTF.

VI.10.2 Other methods to remove static are ionizing devices that neutralize static. Ionizing devices are commonly use in the electronics and manufacturing industries and range from compact benchtop units such as the Desco™ 60505 Bench Top Ionizer to ionizing air guns using compressed for large applications. Those powered by VAC will produce both negative and positive ions, while those VDC powered will produce either negative or positive ions depending on the anode charge; negative or positive. Record specific ionizing devices include the Milty Zerostat™ 3 Anti-static Gun, Furutech™ Destat III and the continuous DS Audio ION-001 Vinyl Ionizer. But be advised that any ionizing device can develop ozone and that Buna-N (nitrile) rubber is very sensitive to cracking when exposed to ozone; while EPDM (ethylene propylene diene monomer) rubber is not ozone sensitive.

VI.10.2.a Inexpensive plasma arc lighters such as the RONXS™ Candle Lighter RONXS Lighter, Candle Lighter with Multi-protect Safety System, Rechargeable | RONXS can be used to remove static. The reason they work is that the blue arc that is created is a corona. And corona's produce charged ions; and this device being VDC depending on the charge of the anode - can produce either negative or positive ions. Audio forums have stated that the RONXS™ device works which indicate that it is producing positive ions that neutralize the negative ions (static) on the record. For use, some have stated to circle the record for a few seconds, while others apply as the record is turning - move across the record for a few seconds both of which will bath the entire record surface in positive electrons; keeping the device about 1” above the record surface. For information, a small amount of ozone is produced; however only infrequent use (not more than a few seconds per 1/2-hr) should be of little concern.

VI.10.2.b For carpets and rugs, rubbing the surface near the turntable with a clothes dryer-softener sheet is an effective method for applying a temporary anti-static coating (residue) to a carpet or rug. Anti-static record sprays will likely leave a film on the record containing a quaternary ammonium salt ingredient that is also a cationic surfactant commonly used in strong disinfectants – see **CHAPTER VIII. DISCUSSION OF PRE-CLEANERS:** for discussion of surfactants and anti-static coatings.

VI.10.3 Grounding the record platter if metal can sometimes help to reduce static charge on the record. In this case, a ground strap/wire is connected between the platter bearing housing and an electrical ground point. Different ground locations can have different results. The first ground attempt should be to the phono-preamp ground connection. If this is not successful try a ground point closer to the outlet providing VAC power to the audio system and connecting to the VAC outlet ground via the cover plate attachment screws is an option.

VI.10.3.a In accordance with *NASA Electrical Bonding: A Survey of Requirements, Methods, and Specifications, NASA/CR-1998-207400, Mar 1998 (56),* effective bonding (grounding) for non-explosive electrostatic discharge should be 10 megohms or less resistance to ground. This is easily achieved with a simple single gauge wire. However, this industry ESD requirement is intended for safety, and is not designed to drain as much static charge as possible to minimize a vinyl record attracting dust that leads to clicks and pops. The NASA paper addresses that for fuel systems, the electrostatic discharge bonding should be 1-ohm or less resistance to ground.

VI.10.3.b Realistically, providing the lowest impedance path to ground is the goal. Tinned-copper braided cable at 1/4-inch wide is readily available and can be used to easily assemble a low impedance ground cable using appropriate end-connectors, 1/4-inch PET expandable braided sleeving for appearance and protection, and heat shrink to seal the ends. The 24-inch 1/-4-inch wide tinned-copper braided cable in **Figure 30** measured 0.1-ohms while the 24-inch green single gauge wire ground measure 0.3-ohms. For short distances, the difference is marginal, but if you need to ground back to a wall outlet that is 8-feet away, the difference may be more significant.

Figure 30 – Ground Cable

VI.11 **Static & Record Mats**: Various record mats have been reported to have various levels of success in removing or preventing static. I have success with a Do It Yourself (DIY) record mat material that is used for ESD Work Surfaces shown **Figure 31**. The material is Bertech™ ESD Vinyl Mats and Mat Kits, 3059 Series ESD-Vinyl-Mats-Datasheet-3059.pdf (bertech.com) -. The material is only 0.1" (3/32) thick but is 3-layers. The top is lightly embossed (gray or blue) vinyl that is formulated to be dissipative, the bottom is smooth vinyl that is formulated to be dissipative and the center is a conductive 'fleece'. The material is stiff (but the center is porous and not completely hard) with durometer of 85A so it has some damping, but can be cut with scissors. The center is electrically conductive. The Bertech™ 3-layer mat surface is specified as being impervious to just about any cleaner so durability of anti-static properties should be very good. Note: It comes rolled-up, and after cutting will take some time to fully flatten. Also, slightly undercut the spindle hole of the mat with a box cutter tip to make sure it makes good contact with the spindle. Additionally, without a recess for the record label, the mat is used with a reflex-type record clamp. My VPI™ turntable is provided with a screw-down reflex clamp. Reflex clamps for smooth spindles are available from Michell™, Record Doctor™, SOTA™, and others.

Figure 31 – Bertech™ ESD Vinyl Record Mat

VI.11.1 My aluminum platter/spindle is grounded as specified (**paragraph** VI.10.3) to a wall outlet and measured 0.5-ohm between the conductive mat center and the wall outlet. But the mat surfaces being vinyl match the record material but being embossed is not a tight seal to the record so static should not be developed. Any static on the record should be dissipated across the surface to the grounded spindle or through the top dissipative vinyl cover to the conductive center to the grounded spindle. Even though the platter shaft/spindle is grounded, any static charge that is conducted to the platter, the path of least resistance can be to the record if it is in direct contact (large surface area) noting that the platter bearing is lubricated which provides some insulation, and only the spindle is in direct contact with the platter. The top and bottom dissipative vinyl surfaces prevent triboelectric effect from the aluminum platter to the record. And, any static charge that may be conducted to the platter from the EPDM rubber drive belts is dissipated by the mat to the platter spindle.

VI.11.2 The mat material and use are not breaking any new ground; it just appears to be a good collection of anti-static and damping properties that follows established ESD such as ground all conductors and minimize insulating type materials. Unfortunately, the insulating vinyl record that as previously addressed is very negative on the triboelectric scale cannot be eliminated. The article *Do Turntable Mats Work? You Bet! Robert Stockton, Audio Magazine June 1979* (69) goes into a good summary on the topic and no reason to repeat here and further illustrates the flow of static charge and the benefits of damping.

VI.11.3 Prior to the Bertech™ ESD may, for a couple of years, I was using a very thin (~1mm) leather mat – suede side-up/skin side-down that I cut from a remnant. However, I started to notice that side-two of the record was noisy and overall, the records were noisy. A quick check with a UV light showed the problem (see **Figure 32**) – the mat was full of fibers and once it had become saturated with fibers it began giving them back; and no amount of brushing or beating was going to clean it. Before this thin leather mat, I "briefly" tried a store-bought thicker leather record mat. So much static developed that the record lifted the mat from the platter. So, the experience with the leather mat highlighted the need to be more careful with mat cleanliness.

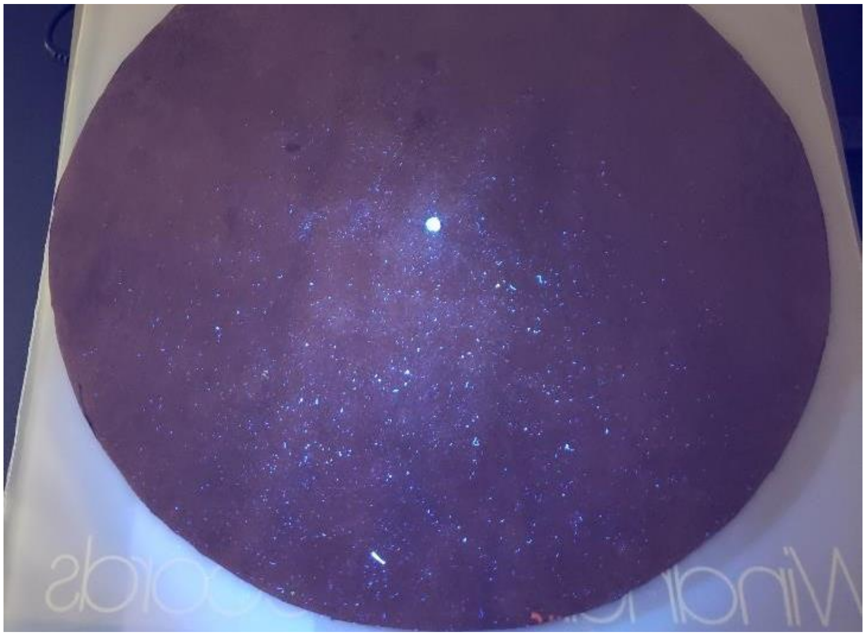


Figure 32 – Leather Mat Under UV Light

VI.11.4 Earlier in 2020 I tried the Technics/Panasonic™ mat PN RGS0008. This is a 3 mm thick relatively soft rubber mat. It is likely manufactured from nitrile rubber (near neutral on the Triboelectric scale) because it did not attract dust/lint/particulate and any was easily brushed away. So, this mat met the cleanliness criteria. However, it so affected the acoustic performance that after a while I found myself listening more to my digital sources than my vinyl; and my vinyl source by design is supposed to be better than my digital. The best way to explain the effect was that it softened and homogenized the music. It's that soft focus that makes everything look (and sound) good; but takes away all the interesting details. So, damping by the record mat can have a profound effect. However, this mat is now used as a covering after play for protection from dust or any hard objects.

VI.12 **Dust & Particulate:** As far as dust and particulate, there is an entire science for precision cleaning to remove particulate from surfaces, and good sources are the paper *Adhesion and Removal of Fine Particles on Surfaces, Aerosol Science and Technology, M. B. Ranade, 1987 (46)* and the 573-page book *Particle Adhesion and Removal, Editors K.L. Mittal and Ravi Ja, John Wiley & Sons, Inc, 2015 (62)***.** Curiously enough, the book makes no mention of any bristle type brushes for particulate removal; but the chapters on wipes is focused on flat surfaces associated with semi-conductor chips and cleanroom maintenance. The record with its finely grooved surface presents quite a challenge.

VI.12.1 The paper *Record Contamination: Causes and Cure by Percy Wilson, 1965, (61)* makes an observation that the record in motion draws contaminants to it. The observation was made by blowing tobacco smoke across the record and watching how it deposited. This observation is likely flawed since the density of tobacco smoke is about 1000X higher than air (77), so if exhausted over the record it will deposit/fall upon it by simple gravity; and the deposition will follow the spinning groove motion. The record motion is not fast enough to develop air currents large enough to counter the weight of the tobacco smoke. However, for many households, tobacco smoke is no longer a source of contamination (although cannabis/marijuana smoke may be a future issue). In the analysis *Rotating Disk Effect on Surrounding Airflow CFD* the following image link shows the air velocity vectors/arrows pointing away from the disc https://www.mr-cfd.com/files/uploads/2020/10/3-vector-.png.

VI.12.2 My own observations pre- and post-play with UV light shows no signs of particle deposition during play (also noting that household cooking grease/oil aerosols fluoresce brightly under UV light). If the record is allowed to sit stationary – yes, particles in the air will drop onto the record. Once the record is spinning it develops its own air current which should 'shield' the record from all but the largest particles depositing. Paraphrasing the article – *Airborne particle deposition in cleanrooms: Relationship between deposition rate and airborne concentration* (82)"…particle settling rate, the rate of surface accumulation is proportional to the airborne concentration which is differentiated by the particle size, the exposure time, and the orientation of the surface relative to the air flow. Surfaces parallel to the average direction of flow and at right angles to gravity sustain the lowest particle accumulation.". Figure 4 of the article shows the Deposition Velocity for the very small particulate <5 micron is very slow, but the large particles >25 micron is much faster. Placing a turntable under an air register is not prudent.

VI.12.3 Camera lens blowers may be OK for lens or delicate sensors, but the air flow is often not enough to dislodge fine lint that electrically attaches to the vinyl record or stylus, and very few have an inlet air filter to prevent depositing lint/particulate. Additionally, there is risk of blowing very fine particulate that is only on the record surface deeper into the record groove. The Orbit HEPA Blower https://photosol.com/products/orbit-hepa-blower/, does have a suction-side HEPA filter and uses an anti-static silicone air-bulb, and limited success has been noted with removing some dust.

VI.12.4 Ultimately, as stated in the opening paragraph of this chapter, the recommendations of *THE WEAR AND CARE OF RECORDS AND STYLI, Harold D. Weiler, 1954* (34) and *Record Contamination: Causes and Cure by Percy Wilson, 1965, (61)* are still applicable. In essence once cleanliness is achieved, the only item that should see the groove is the stylus. A very light brushing with anti-static brushes can remove some surface particulate. I have had some success using the Kinetronics™ Tiger anti-static lint-free microfiber cloth, and others have reported success with silk cloth. A smaller piece cut from the large cloth used as a swipe (just lightly touching the record surface) to essentially brush/dust the record can remove surface lint and particulate without penetrating the groove. Also, the orange color of the cloth allows easy observation of any fibers that may be deposited from the cloth. But I was not fully satisfied with the results.

VI.12.5 **Teflon Rod**: I am now using a 1/2" OD x 12" Teflon rod (Amazon.com: Sur-Seal PTFE-0.50x12-RD PTFE Teflon Rod, 1/2" Diameter x 12" : Industrial & Scientific) with about 4.5" wrapped with self-fusing silicone tape – there are many versions, I used Amazon.com: Bond It F4 Emergency Self-Fusing Silicone Tape, Repair Plumbing Pipe & Radiator Hose Leak, Electrical Insulation, Permanent Bonding, Waterproof, 1" x 36' x 20mil, Black : Everything Else. The silicone tape does not stick to the Teflon, only to itself. I used a simple nail-file to file the end-edge of the Teflon rod; see **Figure 33**.

Figure 33 – Teflon Rod w/Silicone Tape

VII.12.5.1 The exposed Teflon rod is rubbed with a felt-nylon cloth/fabric (wool can work as well) and then with the record spinning, the Teflon rod is placed crosswise the record as shown in **Figure 34**. While the record is spinning, the Teflon rod is slowly spin counter-clockwise for about 5-sec. Only the weight of the Teflon rod is used to hold it in light contact with the record - do not press-down.

a.

b. Figure 34 – Teflon Rod Applied to Record

VII.12.5.2 After each use, wipe the Teflon rod tightly with the Kinetronics™ Tiger Cloth. This removes most of the lint/particles from the Teflon rod. This does not fully discharge/remove the static charge from the Teflon rod which makes it easier to fully charge again with the nylon/wool cloth. An atomizer with DIW can be used to just slightly wet the Teflon rod and wiped with the Kinetronics™ Tiger Cloth to fully clean and remove any static charge but it's more effort to get it charged-up again. Periodically shake the Kinetronics™ Tiger Cloth to dislodge collected particles. The Kinetronics™ Tiger Cloth being anti-static (dissipative) does not hold on to particles.

VII.12.5.4 Rubbing the Teflon rod with nylon/wool causes the Teflon to charge with static very negative - much more negative than the record can charge. Teflon is the most negative material in the Triboelectric series as noted in **Table IV** - testing done by *The Triboelectric Series, Bill W. Lee, David E. Orr; ©2009 by AlphaLab, Inc (11).* The charge affinity units shown are nC (nano coulombs or nano amp sec) of transferred charge per J (joule or watt sec) of friction energy applied between the surfaces (nC/J).

VII.12.5.5 Since the Teflon rod is at a higher negative static charge affinity (-190nC/J) than the record (<-100nC/J) it can and it does attract particles/lint that are mostly positively charged from the record. This can be observed with UV light. The Teflon rod is not perfect but it's better than the Kinetronics™ Tiger Cloth at removing incidental lint/particles from records previously wet cleaned.

VII.12.5.6 The charged Teflon rod also appears to have anti-static properties. Since the Teflon rod is at a higher negative static charge affinity than the record it appears to pull away static charge that may be on the record or neutralize any positive charge on the record. But it does not charge the record with static. When first placing the Teflon rod across the record, sometimes a light crackling sound will be heard that quickly stops. The Teflon rod has only been tested with a turntable with 2" aluminum platter and the DIY ESD record mat addressed previous.

VII.12.5.7 The Teflon is softer than the record so risk of record damage is low and there is not enough pressure being placed on Teflon for it to wear. The pure Teflon rod is easy to clean and will essentially last 1000+ yrs. The self-fusing silicone wrap on the end insulates you from Teflon rod and provides a positive grip so the rod does not slip in your hand in-use (that 12" rod spinning on the record could easily take out a cartridge cantilever in its tonearm rest). Additionally, once charged, keep the Teflon rod away from the stylus to prevent any static discharge to the cartridge.

VI.13 **How Much Detritus is Expected from Record Play?** There will be some degradation during subsequent play, but this should be minimal and acceptable with maintenance of cleanliness. During play, how much dust is expected? Aside from what can drop out of the air, very little should be produced from play. If the record composition is similar to the RCA patent (61) detailed **CHAPTER X. DISCUSSION OF MATERIAL COMPATIBILITY:** there should be very little wear from the record, and a simple analysis can show very little will come from the diamond stylus.

VI.13.1 The Stylus Effective Tip mass can range from about as low as 0.17 mg (Shure V15) to about 0.4 mg. Not many companies report this data any more, but Soundsmith™ does and they report 0.3 mg to about 0.35 mg. The tip mass includes the cantilever and other items. The density of diamond is 3.5 g/cm^3; but boron is 2.5 g/cm^3 so the diamond at best is only about 33% of the reported effective tip mass.

VI.13.2 If we assume the maximum tip mass at 0.4 mg and the diamond is 33%, then the diamond weighs about 0.13 mg. If it takes 1000-hrs to wear the diamond to the point that facets are formed - for sake of analysis let's assume 20% of the diamond mass has been worn away. Therefore, (0.13 mg diamond)(0.2) = 0.026 mg = 26 ug. If it took 1000 hrs to do this, then the diamond is wearing away at about (26 ug/1000) = 0.026 ug/hr.

VI.13.3 If each record play/side is ~20 min (0.333 hrs), then for each record play (0.026 ug/hr)(0.333hrs/side) = 0.009 ug or about 9 pico-grams. This has to exist as a very, very fine powder and the finest diamond powder you can buy is 100,000 grit which is 0.25 micron. So, the diamond wear powder on the record is probably less which in the end becomes inconsequential so long as there is no cleaner residue.

VI.13.4 If whatever wear byproduct powder that is produced by the diamond and the record is kept dry and free of oily and sticky residue, the stylus should move through this without any affect – not unlike a light coating of very dry powder-snow, it just blows around.

VI.13.5 After all is said and done, for maintenance of cleanliness the best advice:

⁂

Once Cleanliness is Established - Stay Out of the Groove!

The only thing that belongs in the groove is the stylus.

---

*

I acknowledge that the above recommendation is quite contrary to what is considered 'best practice' with the many different record brushes available and in-use. But as of the date of this last revision, the combined effect of establishing cleanliness with a low residue precision cleaning process combined with static control using 'best practice' ESD methods and the oddly effective Teflon rod have proven very successful. But to echo what was written in the FORWARD, this is only "a" way not "the" way and as always – YMMV.

CHAPTER VII. DISCUSSION OF WATER QUALITY:

Table VI lists a variety of water quality specifications from potable/tap (drinking) water, to purified-water to pure-water to ultra-pure water. Detailed discussion of water purification methods is available in the *GE-Osmonics™ Pure Water Handbook (26)*.

Table VI
Water Quality Specifications

Specification	Resistivity (ohms-cm)	Total Dissolved Solids (ppm) (see Note 1)	Water Classification
EPA Drinking Water Standards	>1.0K	<500 ppm	2018 Edition of the Drinking Water Standards and Health Advisories Tables
MIL-STD-1330D Grade B (see Note 2)	>50K	<10 ppm	Purified Water by Distillation, Mixed-Bed Resin or Reverse Osmosis
ASTM D1193 Type 4 (see Note 3)	>200K	<2.5 ppm	Purified Water by Distillation, Mixed-Bed Resin, or Reverse Osmosis
MIL-STD-1330D Grade A (see Note 4)	>400K	<1.25 ppm	Pure Water by multiple steps of Distillation or Mixed-Bed Resin
ASTM D1193 Type 2 (see Note 5)	>1,000K	<0.5 ppm	Pure Water by multiple steps of Distillation and or Mixed-Bed Resin
ASTM D1193 Type 1 (see Note 6)	18,000K	<0.028 ppm	Ultra-Pure Water prepared by many steps such as triple distilled

Notes:

1. Total dissolved solids (TDS) listed is a conversion from resistivity and for purified water and better assumes only chloride and sodium salts, and uses a conversion factor of 0.5. The formula for TDS = (K) x (1/Resistivity).
2. The U.S. Navy MIL-STD-1330D Grade B water (51) is used for final rinse after cleaning of general high-pressure oxygen system components. The specification allows some degradation of purified water quality when used in a general environment; i.e., not within a cleanroom. Once purified water is packaged or exposed to a general environment, the quality can quickly degrade from the ambient contaminants.
3. ASTM D1193, Standard Specification for Reagent Water (8), Type 4 is achieved by distilled water (condensation of steam).
4. The U.S. Navy MIL-STD-1330D Grade A demineralized pure-water (51) is used for final rinse after cleaning of critical high-pressure oxygen and life support system components. The specification allows some degradation of Pure Water quality when used in a more controlled environment; such as a Class 100,000 cleanroom (see XII.13) with personnel wearing appropriate cleanroom clothing.
5. ASTM D1193 Type 2 pure water (8) is commonly used for preparation of precision cleaning solutions; and used in precision cleaning processes. But, once exposed to air will degrade from absorption of air contaminants such as carbon dioxide.
6. ASTM D1193 Type 1 ultra-pure water (8) is intended for critical laboratory analyses and often used for extreme precision cleaning of semi-conductors in carefully controlled environments such as a Class 100 cleanroom.

VII.1 The use of tap-water (drinking water) for the pre-rinse and rinse after each cleaning agent application is acceptable because while tap-water will have dissolved solids, the amount of insoluble particulate (suspended solids) is low. The occasional larger particles are removed by the faucet aerator that has a fine mesh strainer and tap-water is cheap and readily available in quantity. Additionally, tap-water is used only in a flowing stream that assists with particle and cleaning agent removal. Additionally, the ratio of tap-water volume to the cleaner being diluted/removed is very high eliminating any adverse reactions. Furthermore, once the cleaning process starts, the record is maintained wet throughout until the final spray with DIW, so there is no risk of dissolved solids (minerals) residue.

VII.2 Otherwise, for tap-water, there can be confusion between total dissolved solids (TDS), total suspended solids (TSS) and turbidity. The *EPA 2018 Edition of the Drinking Water Standards and Health Advisories Tables (18)* has TDS limits as noted **Table VI**, but no TSS limits because TSS are captured in the turbidity limit which includes suspended sediments, finely divided organic and inorganic compounds, plankton, and other microscopic organisms. The EPA turbidity limit is 5 nephelometric turbidity units (NTUs), and by some literature that has compared TSS to turbidity, a relationship of TSS being equal to about two times NTU can exist. Therefore, tap/drinking water TSS should not be greater than about 10 mg/L (~10 ppm); and by visual observation particle size is well below visible.

VII.3 There is a significant increase in the water quality from the variability of potable/tap (drinking) water to Purified water (distilled/demineralized water) with an excellent cost to value for preparing the cleaning agents and for the final DIW rinse. The quality of potable/tap (water) freshwater can vary significantly across many locales, and total dissolved solids (TDS) of 200 ppm and higher are not uncommon. However, for the vinyl record cleaning process specified in this document, the use of water quality greater than Purified-water is not considered necessary as shown **Table VII**.

VII.3.1 In **Table VII**, it shows the expected difference in TDS residue remaining after a given volume of various quality tap-water is allowed to dry on the record. The conversion of 1 ppm = 1 mg/L was used. Per **CHAPTER XI. DISCUSSION OF CLEANLINESS CRITERIA:** a record (less label) has an approximate surface area of 1-ft^2; and 1-mg/ft^2 = 0.1-micron thickness at density 1.0 g/cm^3. But TDS residue is predominantly calcium and magnesium carbonate with an average dry density of 2.85 g/cm^3 so that 1-mg/ft^2 TDS = 0.035-micron thickness was used.

VII.3.2 The red blocked data exceeds the cleanliness criteria discussed **CHAPTER XI. DISCUSSION OF CLEANLINESS CRITERIA:**. The yellow and orange blocked data is residue that exceeds the record surface roughness and being a mineral salt 'may' cause wear or if combined with cleaner residue 'may' be audible. However, the small reduction in NVR from Purified to using Pure and Ultra-Pure water is insufficient to appreciably improve the record cleanliness and this is further discussed in **CHAPTER XI. DISCUSSION OF CLEANLINESS CRITERIA:**.

Table VII
Residue Thickness Microns from Water Residue

Water Quality	ppm	mg/L	mL of Water Allowed to Dry on Record				
			0.25	0.50	1.00	2.00	3.00
Ultra-Pure	0.028	0.028	0.00000	0.00000	0.00000	0.00000	0.00000
Pure	0.5	0.5	0.00000	0.00001	0.00002	0.00004	0.00005
	1.5	1.5	0.00001	0.00003	0.00005	0.00011	0.00016
Purified	2.5	2.5	0.00002	0.00004	0.00009	0.00018	0.00026
	10	10	0.00009	0.00018	0.00035	0.00070	0.00105
Tap-Water	100	100	0.00088	0.00175	0.00351	0.00702	0.01053
	200	200	0.00175	0.00351	0.00702	0.01404	0.02105
	400	400	0.00351	0.00702	0.01404	0.02807	0.04211
	800	800	0.00702	0.01404	0.02807	0.05614	0.08421
	1600	1600	0.01404	0.02807	0.05614	0.11228	0.16842

VII.4 **Home Production of DIW**: In some locales or countries, where the quality of tap water is questionable with either high TDS or high suspended solids, or ready access to Purified water is not available, various alternatives are available. These alternatives are home water distillers or multi-stage filters that combine at least a sediment filter to remove particulate, a demineralizer to remove TDS, and sometimes a carbon filter to remove soluble organics (often noted as odor). The following are examples of a distiller and two filter-systems that can produce purified water. Similar if not the exact equipment is available EU/UK.

VII.4.1 Countertop water distillers are available such as the H20 Labs™ Models 100, 200 and 300 Countertop Water Distillers | Home Water Distiller Systems from H2O Labs. The model 200 can process 1 gallon (3750 mL) of tap water in approx. 5 hours using about 3-kW of power (0.6 kWh). Periodic cleaning and descaling with white vinegar or specific descaling chemical is required; some reporting after every 5-7 gallons. The H20 Labs™ Model 200 MSRP is $199; and each anti-scale pad is $9.90 and is good for 3-6 months and activated carbon pods (if using for drinking water) are $29.90 for six and last 30-gallons each. It's unknown how long the device will last, but some users report years of operation producing 1500+ gallons before failure. Assuming a 6-year use at 300-gal/yr; 1800-gallons total, the item cost would be about $199 for the unit; $299.90 for carbon pads, and $237.60 for anti-scale pads, and $396 for 300 cleanings with the H20 Labs™ cleaning crystals ($29.50 for 1-lb at $1.32/cleaning). The total life cycle cost could equal = $1,132.50 not including cost for power; resulting in a cost/gallon of ($1132.50/1800 gal) = $0.63/gallon.

VII.4.2 There are a number of vendors manufacturing countertop pitcher/filter systems that can produce Purified water. The ZeroWater™ units Water Filters & Water Filter Pitchers - Clean Water at Home – ZeroWater have the benefit of containing the most amount of demineralizer resin. Each filter can produce from 40-gals with very low TDS tap-water (<50 ppm) to about 8-gals with very high TDS tap-water (>400 ppm). The filter MSRP is two filters for about $33, and a 30-cup/240-ounce pitcher with one filter MSRP is about $45. Assuming a TDS of 150 ppm, each filter should produce about 30-gals of purified water; and the initial cost of purified water would be ($45/30-gals) = $1.5/gal. Follow-on cost based on the two-filter replacement cost would be ($33/80-gals) = $0.41/gal not including the cost of the tap-water.

VII.4.3 For those who process a lot of records, purchasing a large, refillable demineralizer can significantly improve access to and reduce the cost of purified-water; one example is DI Rinse Pro 50 Spot Free Rinse System that costs about $400 (plus installation) with replacement demineralizer resin about $200 for 2 resin refills. An outlet filter is generally recommended and a 10-inch Pentek™ housing and 1-micron filter (see **paragraphs** XIV.17 and XIV.19.1) will cost about $50 (plus installation), with replacement filters less than $10 each. If tap water is of reasonable quality, this demineralizer/filter should produce about 2000 gallons of demineralizer water at an initial cost of about $0.23/gallon (plus installation cost) and the valve arrangement makes a very convenient install. Follow-on cost would then be ($110/2000-gals) = $0.06/gal not including cost of the tap water. For those who wash their own cars, purified water systems such as this are often used to get a spot-free rinse.

VII.4.4 An alternative to a large demineralizer is a compact reverse-osmosis/demineralizer (RO/DI) system. These are popular with those that maintain aquariums. They are readily available from a number of vendors such as Whole House Water Filters, RO, Hydroponcs Filtration System - LiquaGen – LiquaGen Water. RO/DI systems start at 50 gallons-per-day (GPD) with prices about $100 and can be as large as 300-GPD. Note that actual purified water produced is generally about 80% of the rating.

VII.4.4.a There is a minimum of four (4) stages – sediment filter, carbon filter, RO-membrane and demineralizer cartridge and some can have multiple demineralizer stages to achieve high purity water specifications with some as many as seven (7) stages.

VII.4.4.b For RO, there is a water usage rate that is 3-4 gallons of water used for each 1-gallon of purified water produced. The 'brine' waste water is disposed to a drain.

VII.4.4.c Production rates can be impacted by the tap-water inlet temperature and pressure, and filter life will be dependent on inlet tap-water TDS. For homes with higher tap-water TDS, 2-stages of demineralization may be required.

VII.4.4.d Operating cost can be economical. Example: The unit price for the USA Made 5-stage LiquaGen™ Model 1-OT-75 (75 GPD) 5 Stage RO/DI Water Filter System - 75 GPD (1-OT-75) | For Fish Tanks, Aquariums, Reef, Water Filtration Machine | RODI – LiquaGen Water is about $200 (plus installation). The unit is rated for use with inlet tap-water TDS up to 300 ppm. All filter/RO elements are replaceable and the demineralizer can be refilled, with a total cost of about $55. If the unit can produce 1000-gallons, the initial cost is about $0.20/gal (not including cost of installation or water) with a follow-on cost of about $0.06/gal.

VII.5 **Deionizing Resin**: The following example with sodium-chloride salt (NaCl) illustrates how the deionizing/demineralizing process functions to produce pure water. An H/OH mixed-bed resin is used to exchange ions (such as mineral salts) for hydronium ions (H_3O^+) and hydroxide ions (OH^-) that combine to form pure water. Because resin exchanges ions, it has a limited life; and the amount it can purify is directly proportional to the resin bed size and the influent TDS. There are different grades of H/OH mixed-bed resin depending on use; demineralization of tap-water to produce purified water or polish to achieve pure water. Resin is recyclable by regenerating it with a strong acid backwash restoring the hydronium ions and a strong base backwash to restore hydroxide ions.

$$R^- - H^+ (H_3O) + Na^+ \longrightarrow R^- - Na^+ + H_3O^+$$

$$R^- - OH^- + Cl^- \longrightarrow R^+ - Cl^- + OH^-$$

$$H_3O^+ + OH^- \longleftrightarrow 2H_2O$$

VII.6 **USA vs EU/UK**: For reasons unknown, distilled water is readily available in most USA grocery stores while demineralized water is not. On the other hand, demineralized water is readily available in the EU/UK, but distilled water is not. There are subtle differences, the pH of distilled water tends to be slightly above pH-7, while the pH of demineralized water tends to be less than pH-7. For the purposes of record cleaning, either is acceptable for cleaner preparation and both will provide a spot-free rinse.

VII.7 An unrelated but common question that arises – Is purified (demineralized) water safe to drink? The World Health Organization (WHO) has studied the health aspects and the details are documented *WHO Nutrients in Drinking Water, 2005 (83)*. Long term use should be approached with caution due to chronic electrolyte imbalance. Using to rehydrate during and after any excessive sweating activity will not replace critical electrolytes and any number of acute electrolyte imbalance symptoms can occur. But Naval ships that can be at-sea for 90-days, all have some form of water purification – either distillation or reverse osmosis; and other than adding a disinfectant (bromine or chlorine) no other treatment is routinely performed (source *Manual of Naval Preventive Medicine, Chapter 6, Water Supply Afloat(44)*).

REMAINDER OF PAGE INTENTIONALLY BLANK

CHAPTER VIII. DISCUSSION OF PRE-CLEANERS:

Fundamentally, and consistent with the precision aqueous cleaning processes discussed *MIL-STD-1330D* (51) and *MIL-STD-1622B (52)*, any safe, compatible, and effective broad-based cleaner can be used for the pre-clean step.

VIII.1 Alconox™ Liquinox™ is recommended as a detergent pre-cleaner that is safe, effective, compatible (with appropriate exposure) with both the vinyl record and the final cleaner, and of known ingredients from a long-established supplier. Additionally, detailed technical information is readily available at https://alconox.com; and product is readily available to the consumer at a reasonable cost. Some general details of Alconox™ Liquinox™ are provided as follows:

VIII.1.1 The product is a combination of anionic surfactants (good for general detergency), nonionic surfactants (good for oil emulsion and wetting) and foaming agent (to lift and float debris from the surface).

VIII.1.2 The product is concentrated with about 50% active ingredients, the remainder water. So, a 1% solution is about 0.5%/5,000 ppm active.

VIII.1.3 The product mixes easily, rinses easily and the 1.0% neutral pH product surface tension is 29 dynes/cm, so it has excellent wetting capability.

VIII.1.4 The Alconox™ Liquinox™ surfactant blend of anionic and nonionic surfactants is compatible with the Alconox™ Citranox™ acid wash and ™ the Dow™ Tergitol™ 15-S-9 nonionic final cleaner and with appropriate exposure the vinyl record (see **CHAPTER X. DISCUSSION OF MATERIAL COMPATIBILITY:** for further discussion of material compatibility).

VIII.1.5 The product is non-flammable, is biodegradable, has no reported acute or chronic toxicity hazards, and has been widely accepted and used in many industries for many years, and product quality is very high.

VIII.2 To better understand the ingredients of cleaning agents, the following brief overview of surfactants is provided for information, but no attempt is being made to formulate cleaners. It is my position that there are adequate detailed formulations readily available for pre-cleaning such as Alconox™ Liquinox™.

VIII.2.1 The term "surfactant" is a contraction of "surface-active agent," and includes synthetic organic chemical products used for purposes such as wetting, emulsifying, dispersing, solubilizing, and foaming. Aside from cleaning agents there are 100's of different surfactants used in 100's of different products.

VIII.2.2 Surfactant molecules consist of two parts – the head that is water soluble often called hydrophilic (water-loving) and a tail that is oil-soluble often called hydrophobic (water-hating) or lipophilic (oil-loving). Surfactants when they are first added to water collect at the surface lowering the surface tension. There is a concentration when the surface tension will not decrease any further, and this point is known as the "critical micelle concentration" (CMC).

VIII.2.3 When the surfactant concentration is greater than the CMC, the surfactant forms aggregate cylindrical and spherical type structures called "micelles" as illustrated **Figure 35**. As the micelle forms, the surfactant hydrophilic heads position themselves so they are exposed to the water, while the lipophilic tails are grouped together in the center of the structure protected from the water. Micelles are what provide the detergency of a surfactant. As the surfactant concentration increases other micelle structures can form. The hydrophobic/lipophilic (oil-loving) tails of the surfactant micelle are what surrounds soils and releases them from the surface being clean, and depending on the specific ionic nature can perform functions such as oil emulsification, foaming, and antibacterial. To provide adequate reserve of micelles for cleaning, concentrations of 5 to 20 times the CMC are generally used. Basic spherical and cylindrical micelles can measure from about 4 to 15 nano-meters (nm) = 0.004 to 0.015 microns, while oil emulsions can measure 10 times greater.

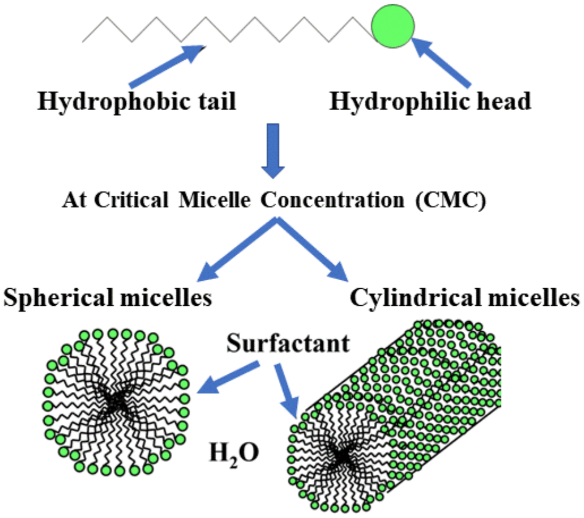


Figure 35 – Surfactant Micelles

(*Image from United States NIST Information*)

VIII.2.4 Depending on the electrical charge of the hydrophilic head, the surfactant is classified as anionic, cationic, nonionic or amphoteric.

VIII.2.4.a Anionic surfactants ionize in aqueous solutions so that the hydrophilic head has a negative (-) charge.

VIII.2.4.b Cationic surfactants ionize in aqueous solutions so that the hydrophilic head has a positive (+) charge.

VIII.2.4.c Nonionic surfactants for the most part do not ionize in aqueous solutions so that the hydrophilic head has a neutral charge. A unique property of nonionic surfactants is "cloud point". Cloud point is the temperature when the mixture starts to phase-separate, and two phases appear, thus becoming cloudy. The cloud point is the optimum temperature for nonionic surfactant detergency, but above the cloud point the surfactant comes out of solution and detergency drops.

VIII.2.4.d Amphoteric surfactants can ionize in aqueous solutions so that the hydrophilic head, depending mostly on the solution pH, is either anionic (-) or cationic (+).

VIII.2.5 Each type of surfactant has different strengths, and for general cleaners are blended along with other ingredients (commonly called 'builders') to achieve the desired performance. Blended surfactants can form blended micelles that can enhance the properties of the surfactants.

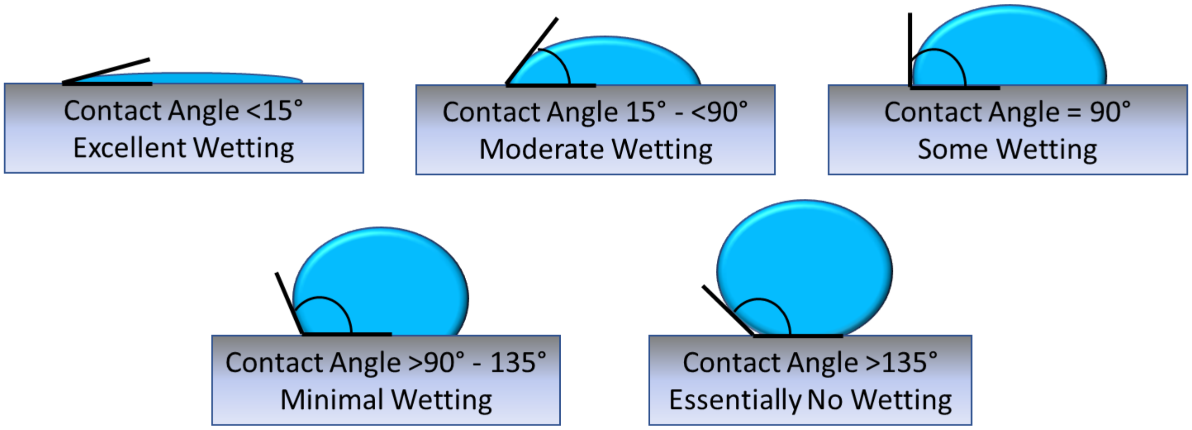
VIII.2.5.a Anionic surfactants are used to attack a broad range of soils. They are the primary ingredient of most general cleaning agents. Anionic surfactants have excellent foaming characteristics to float away soils, are very effective for displacing visible particulate, but are not as good at emulsifying oil, are generally not compatible with acidic solutions and tend to require relatively large concentrations for effectiveness.

VIII.2.5.b Cationic surfactant strengths are their disinfectant and anti-static characteristics, and these are very common in commercial and consumer antibacterial spray cleaners. Contact-time is required for cationic surfactants to work. Cationic surfactants (such as quaternary ammonium compounds) are generally not soluble with anionic surfactants, and if mixed in an aqueous solute (i.e., water) can form an insoluble – described as 'gooey' - precipitate/paste. This risk is generally not associated with a surface that has a thin layer of quaternary ammonium compound cleaned with a large volume of anionic surfactant cleaner. But, if a record had anionic surfactant residue from incomplete rinsing, and then a light spray of anti-static containing a cationic surfactant was applied, a precipitate/paste "could" form.

VIII.2.5.c Nonionic surfactant strengths are their ability to emulsify oil and to achieve very low water surface tensions at very low concentrations. Dow™ Tergitol™ 15-S-9 at 52 ppm can lower the surface tension of water to 30 dynes/cm. When cleaning very small and complex geometries – i.e., the record groove, the ability to wet the surface is crucial and is enhanced by a fluid with a low surface tension. For perspective, CFC-113 (Freon™ PCA) had a surface tension of 17.3 dynes/cm. Nonionic surfactants are soluble with either anionic or cationic surfactants.

VIII.2.5.d Amphoteric surfactants are most often used in personal care products such as shampoos and cosmetics.

VIII.3 Supporting the discussion of surfactants, is the concept of 'wetting'. All fluids have a surface tension measured in dynes/cm (English units); "*the attractive force exerted upon the surface molecules of a liquid by the molecules beneath that tends to draw the surface molecules into the bulk of the liquid and makes the liquid assume the shape having the least surface area*." All solids have surface energy that is likewise measured in dynes/cm and is often called "critical surface tension". Most metals have a very high critical surface tension (copper = 1360 dynes/cm), much larger than the surface tension of water (72 dynes/cm). But the PVC/PVA in a record is very low at 38/36 dynes/cm; much lower than water. When a fluid is placed on a solid surface, depending on the difference in surface tensions (and other factors), the fluid will form a contact angle with the surface, and this is illustrated in **Figure 36**.



Record Critical Surface Tension dynes/cm		Water Surface Tension dynes/cm	Measured Contact Angle
PVC (~80%)	**38**	**72**	**86°**
PVA (~20%)	**36**	**72**	**61°**

Record Critical Surface Tension dynes/cm		Alconox™ & Tergitol™ Cleaner Surface Tension dynes/cm	Estimated Contact Angle
PVC (~80%)	**38**	**29-32**	**<15°**
PVA (~20%)	**36**	**29-32**	**<15°**

Figure 36 – Contact Angles and Wetting

VIII.3.1 Absent any surface oil or similar contamination, if water (at 72 dynes/cm) is placed upon copper (at 1360 dynes/cm) it will 'wet' the surface. The contact angle will be essentially 0°. This concept of water wetting a surface is sometimes used in verifying metal surface cleanliness by 'water-break'. If water is sprayed on a clean metal surface it will wet the surface. If there is oil on the surface, the water will bead-up (large contact angle).

VIII.3.2 Given the proportions of a record, its critical surface tension is likely closer to PVC than PVA, but both are listed for completeness.

VIII.3.3 However, in **Figure 36**, the critical surface tension of the record's materials is much less than water, and the large contact angle produced by water is consistent with **Figure 23** that shows DIW beads-up when sprayed on the clean record.

VIII.3.4 But, the Alconox™ Liquinox™, Alconox™ Citranox™ and Dow™ Tergitol™ 15-S-9 low surface tension that is less than the record materials critical surface tension readily wets the record, and this is evident in **Figure 17**, **Figure 19** and **Figure 21**.

VIII.3.5 Wetting is important since it allows the cleaning fluid to fully contact the surface being cleaned. Wetting alone does not dictate cleaning performance; there is still the chemistry and its performance with various soils. Adding agitation enhances cleaning performance. However, a flowing fluid can overcome surface tension differences and this is evident in **Figure 16**. The initial flowing tap-water rinse wets the record surface.

VIII.4 There are a variety of different record cleaning solutions in the market whose effectiveness is discussed on the various audio forums. I make no assessment or recommendation of these products due to the absence of a Safety Data Sheet (SDS) with detailed ingredients. On the internet at various forums there is a lot of discussion of various do-it-yourself (DIY) mixed record cleaning solutions. As addressed in this paper's opening **Forward**, there are many 'opportunities' to experiment. The following discusses only some of the more frequently addressed products, and discusses only those that the SDS, or equivalent, has sufficient detail to analyze. This review is provided only as information to guide an informed decision, and to advise of any risks and environmental hazards.

VIII.5 HOUSEHOLD DISH DETERGENT: The ingredients of many household dish detergent can be viewed at the *Consumer Product Information Database (CPID),* CPID (whatsinproducts.com). Most are basically a mild alkaline detergent with anionic surfactants, ethanol and sodium hydroxide (for pH) as primary ingredients. Some well-known brands can have as much as 10% ethanol. But, many of the most common contain as many as 14 other ingredients including isopropyl alcohol, d-limonene (sometimes listed as lemon oil or orange citrus), fragrances, dyes, gelation additives, and glycerin or aloe for hands, and maybe nonionic surfactants. Some of these ingredients in concentrated forms are listed by various plastic material manufacturers as being incompatible with PVC. While household dish detergents are generally used at low use concentration, the combination(s) may not be compatible with vinyl records (see **CHAPTER X. DISCUSSION OF MATERIAL COMPATIBILITY:** for additional discussion), especially the critical groove side wall ridges. Additionally, these detergents if used in excessive amounts will be difficult to fully rinse, potentially leaving detrimental residue. Any use for cleaning vinyl records should be approached with caution noting the advice in Table II for those in the EU/UK that cannot easily obtain Alconox™ Liquinox™ to use a quality clear, scent-free, liquid laundry detergent.

VIII.6 **ILFORD™-ILFOTOL™:** This is a wetting agent that is water mixed with a combination of nonionic surfactant and an antibacterial inhibitor/preservative that can extend shelf-life. There are two different versions depending on the date of manufacture (manufacturers will reformulate products).

VIII.6.1 The 2015 SDS indicates 1-5% nonionic surfactant 0.014% of an antibacterial inhibitor. This version will foam if agitated/shaken aggressively.

VIII.6.1.a The nonionic surfactant by the chemical abstract system (CAS) number 68131-39-5 is likely either Stepan™ BIO-SOFT™ N25-7 or N25-9. These nonionic surfactants are similar to Dow™ Tergitol™ 15-S-7 or 15-S-9 and have similar CMC of about 50 ppm (see **CHAPTER IX. DISCUSSION OF THE FINAL CLEANERS:** for further details). The product literature lists no surface tension data, but the Stepan™ BIO-SOFT™ N25-7 or N25-9 ingredient should result in about 30 dynes/cm. Some on the internet recommend for cleaning records to mix 50-mL to 1000 mL, that could yield a nonionic surfactant concentration of as much as 0.25% which is excessive. See **CHAPTER IX. DISCUSSION OF THE FINAL CLEANERS:** for using this product at 0.1% active nonionic surfactant as a final cleaner.

VIII.6.1.b The antibacterial agent by the CAS number 55965-84-9 is widely used in many applications such as metal working fluids, circulating water systems, and paints and is a blend of methylcholoroisothiazolinone (CMIT) and methylisothiazolinone (MIT). While the biocide is dangerous in a concentrated form, the diluted biocide that is also used in cosmetics is reasonably safe as determined by this toxicological report - https://ec.europa.eu/health/scientific ... o 009.pdf, and its conclusion - "On the basis of the data submitted, the SCCS is of the opinion that the mixture of 5-chloro2-methyl-4-isothiazolin-3-one and 2-methyl-4-isothiazolin-3-one in a ratio of 3:1 does not pose a risk to the health of the consumer when used as a preservative up to a maximum authorized concentration of 0.0015 % in rinse-off cosmetic products, apart from its sensitizing potential.". The CMIT/MIT biocide (commercially sold as Kathon™ in a concentrate) is effective at very low concentrations less than 15 ppm.

VIII.6.1.c Use of ILFORD-ILFOTOL™ 2015 as a biocide for ultrasonic tanks is not valid. With only 0.014% of the biocide in the delivered product, diluting 200:1 or more would reduce the biocide concentration to less than 1 ppm making it ineffective.

VIII.6.2 The 2017 and later SDS indicates <2.5% of nonionic surfactant and <1.5% of a preservative.

VIII.6.2.a The nonionic surfactant by the CAS number: 9043-30-5 is likely GENAPOL® X 080. This nonionic surfactant is low foaming and has a CMC of 38 ppm. The product literature lists no surface tension data, but the GENAPOL® X 080 ingredient should result in about 30 dynes/cm. Some on the internet recommend for cleaning records to mix 50-mL to 1000 mL, that could yield a nonionic surfactant concentration of as much as 0.125%

which is only marginally excessive. See **CHAPTER IX. DISCUSSION OF THE FINAL CLEANERS:** for using this product at 0.075% active nonionic surfactant as a final cleaner.

VIII.6.2.b The preservative agent by the CAS number 122-99-6 should be 2-Phenoxyethanol that is widely used in many cosmetic applications. Per 2-Phenoxyethanol | C8H10O2 - PubChem (nih.gov), "According to the European Union Cosmetics Regulation (EC) n.1223/2009, phenoxyethanol is authorized as a preservative in cosmetic formulations at a maximum concentration of 1.0%. Phenoxyethanol has been classified as an antimicrobial and preservative by Health Canada."

VIII.6.3 ILFORD™ recommends use beginning at 1-part cleaner to 200 parts-water yielding the following based on the individual formulation at the maximum specified concentration.

VIII.6.3.a 2015 SDS: A nonionic-surfactant concentration as high as 0.025% which could be as much as 5X the CMC, useable as a single point of use, photographic wetting agent with some detergency. As a wetting agent with some detergency, 0.0125% equal to about 2.5X the CMC would also work.

VIII.6.3.b 2017 SDS: A nonionic-surfactant concentration as high as 0.0125% which could be as high as 4X the CMC, useable as a single point of use, photographic wetting agent with some detergency. As a wetting agent with some detergency, 0.01% equal to about 3X the CMC would also work.

VIII.6.4 Internet discussion of adding nonionic surfactant Dow™ Tergitol™ to essentially nonionic surfactant ILFORD-ILFOTOL™ to boost cleaning makes no sense, unless the ILFORD-ILFOTOL™ is diluted too much.

VIII.7 **KODAK™ PHOTO-FLO 200**: This is a wetting agent that is water mixed with a combination of 25-30% propylene glycol (i.e., anti-freeze) that acts as a solvent and as an antibacterial and antifungal agent and 5-10% nonionic surfactant. The nonionic surfactant by the CAS number 9036-19-5 is most likely Dow™ Triton™ X-114. This type of surfactant (octyl-phenol ethoxylates) is an environmental aquatic toxin and is being phased-out (see **CHAPTER IX. DISCUSSION OF THE FINAL CLEANERS:** for details). If the surfactant is Dow™ Triton™ X-114, the surface tension will be about 31 dynes/cm, the CMC will be 120 ppm, but the low 25°C/77°F cloud-point limits this product mostly to applications equivalent to room temperature.

VIII.7.1 The product literature indicates use at 1-part cleaner to 200 parts water that will yield a diluted nonionic surfactant concentration of about 0.05%, which for this nonionic surfactant is near the lowest usable concentration for its intended purpose as a single point of use, photographic wetting agent.

VIII.7.2 The propylene glycol component makes for a very stable shelf-life, and as an ingredient is very safe. For information propylene glycol is an antibacterial and antifungal agent at concentrations 25% and greater; but at less than 1% can accelerate bacteria growth. As a solvent, propylene glycol is sometimes used in cleaning agents as a stabilizer and thickener. Any use as an anti-foaming agent would be at concentrations much higher than intended for cleaning a vinyl record. I did mix equal proportions of 0.05% propylene glycol with 0.05% Dow™ Tergitol™ 15-S-9 and there was no appreciable anti-foaming action.

VIII.8 **ALCOHOLS**: Isopropyl Alcohol (IPA); also known as 2-propanol (CAS # 67-63-0) or Ethanol (CAS # 64-17-5) is often added to DIY record cleaning solutions. IPA is in every residential medicine cabinet. Ethanol or IPA can be an effective solvent, can be an effective wetting agent; are effective disinfectants at high enough concentration, and are fully miscible with water. However, they only produce an azeotrope at high concentrations (evaporate with water at the same concentration) but at low concentrations can evaporate from water. But Ethanol and IPA can be very hazardous.

Any alcohol mixture that is flammable or whose vapors can be explosive should not be used in or near an electrified record cleaning machine or ultrasonic tank that is not EXPLOSION PROOF; appropriately designed to meet National Fire Protection Agency (NFPA)-70 National Electric Code (NEC). The NFPA classifies products flammable if they have a flashpoint less than 100°F/38°C.

Do not use any alcohol with delicate lacquer or shellac records – damage will occur. Concentrated alcohols can cause stress cracking in some plastics such as Acrylic. Low concentrations <5% can be acceptable but first dilute with water.

VIII.8.1 **Toxicity Hazards of Alcohols**: Pure Ethanol is drinking alcohol and aside from the inebriating effects is very safe. But most Ethanol purchased is denatured (made undrinkable) with methanol, and methanol and IPA can be very toxic.

VIII.8.1.a Denatured Alcohol. Denatured alcohol that is purchased on-line or at a hardware store is generally ethanol (drinking alcohol) that has been denatured (made undrinkable) by generally adding methanol. However, methanol can be very toxic (absorbed through the skin) at higher concentrations. It's important to read the label and/or the SDS. There are many grades of "denatured alcohol" and the methanol content can range from relatively safe 0.5% in reagent-grade to hazardous >25% in industrial grades.

VIII.8.1.b IPA: IPA is toxic if ingested or breathed at high concentrations for extended periods. IPA ingested can seriously harm or kill with a little as 250 mL (known as the single lethal dose). IPA vapors have an Occupational Safety and Health Administration (OSHA) allowable 8-hour exposure limit of 400 ppm, but the American Conference of Governmental Industrial Hygienists (ACGIH) sets exposure limits for IPA at 200 ppm. The reported odor threshold for IPA is 22 ppm. When purchasing IPA, purchase pharmaceutical grade which is nothing more than IPA+water which is what you will find in pharmacies; or reagent grade with specification sheet from a reputable source.

VIII.8.1.c Methanol: Wood alcohol is methanol. Methanol can be very toxic; both through inhalation and skin absorption. Ingestion can be lethal or can result in blindness. Methanol vapors have an Occupational Safety and Health Administration (OSHA) and American Conference of Governmental Industrial Hygienists (ACGIH)allowable 8-hour exposure limit of 200 ppm. The reported odor threshold for methanol is between 100 and 1500 ppm.

VIII.8.2 **Fire Hazards of Alcohols**: Alcohol + water solutions can be combustible at very low concentrations (2%) and at slightly higher concentrations (as low as 7%) flammable and the vapors can be explosive. Flashpoint is the temperature that a fluid can ignite. Ethanol and IPA at 70% (and greater) are very flammable with a flashpoint of 14°C/57°F and 21°C/70°F respectively, and they burn with a blue-flame that is not immediately noticed.

VIII.8.2.a Reviewing **Figure 37** (*Astbury, G.R. & Bugand-Bugandet, J. & Grollet, E. & Stell, K.M. (2005), Flash points of aqueous solutions of flammable solvents. Institution of Chemical Engineers Symposium Series. 505-522* (7))., at 2% IPA + Water solutions are classified as combustible with a flashpoint of 65°C/149°F. At greater than ~7.5% Ethanol or 10% IPA +Water solutions are classified as flammable with a flashpoint less than 100°F/38°C.

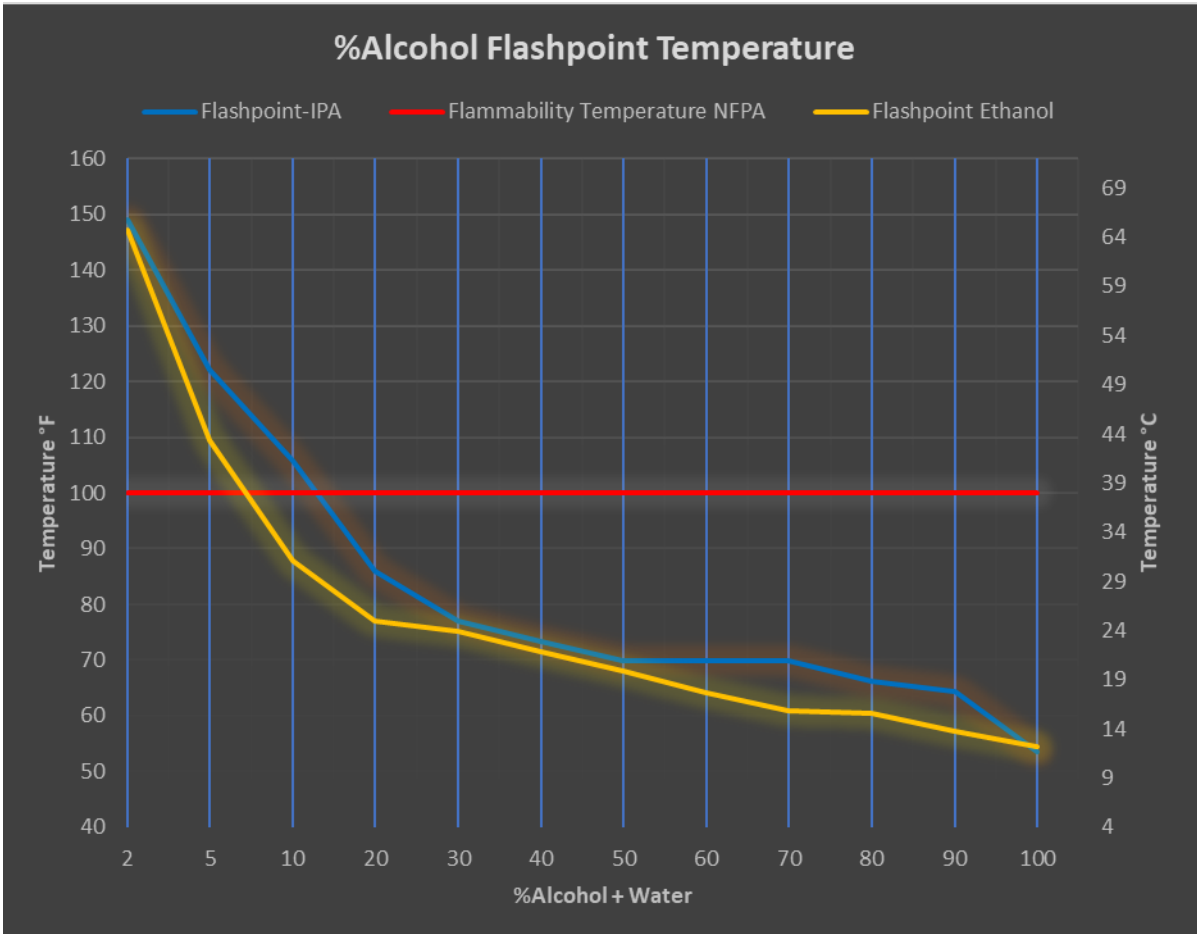


Figure 37 – Alcohol + Water Flashpoint Temperature

VIII.8.2.b Explosion limits are based on the concentration at 25°C/77°F that can explode if an ignition source is applied. At 100% IPA, the lower and upper explosive limits are 2.3 to 13.2%. But, even diluted with water, at 25% IPA + water, the lower and upper explosive limits can be 2.3 to 7.1%. Data source - *Effects of upper explosion limit for isopropyl alcohol by steam, inerting at 1 atm and 150 _C by 20-L-apparatus, Shang-Yi Shen • Jia-Chi Chen • Shang-Hao Liu, Ron-Hsin Chang, Horng-Jang Liaw, Chi-Min Shu J Therm Anal Calorim (2013) 113:1619–1624 (73).*

VIII.8.2.c For information, a cigarette is not a credible ignition source for alcohol, but an electrical arc/spark is; reference: *Geiman, Justin & Fuss, P., (2013). Investigation of cigarettes as an ignition source for Coleman fuel. Fire and Materials 2013 - 13th International Conference and Exhibition, Conference Proceedings. 759-768* (15).

VIII.8.3 The purpose of alcohol is mixed. IPA by itself it is often used as a drying agent and diluted 5% to 25% with water able to significantly reduce its boiling point (vapor-pressure) as noted **Figure 38**. However, Ethanol+water does not reduce the boiling point the same amount mostly contradicting its use as a drying agent.

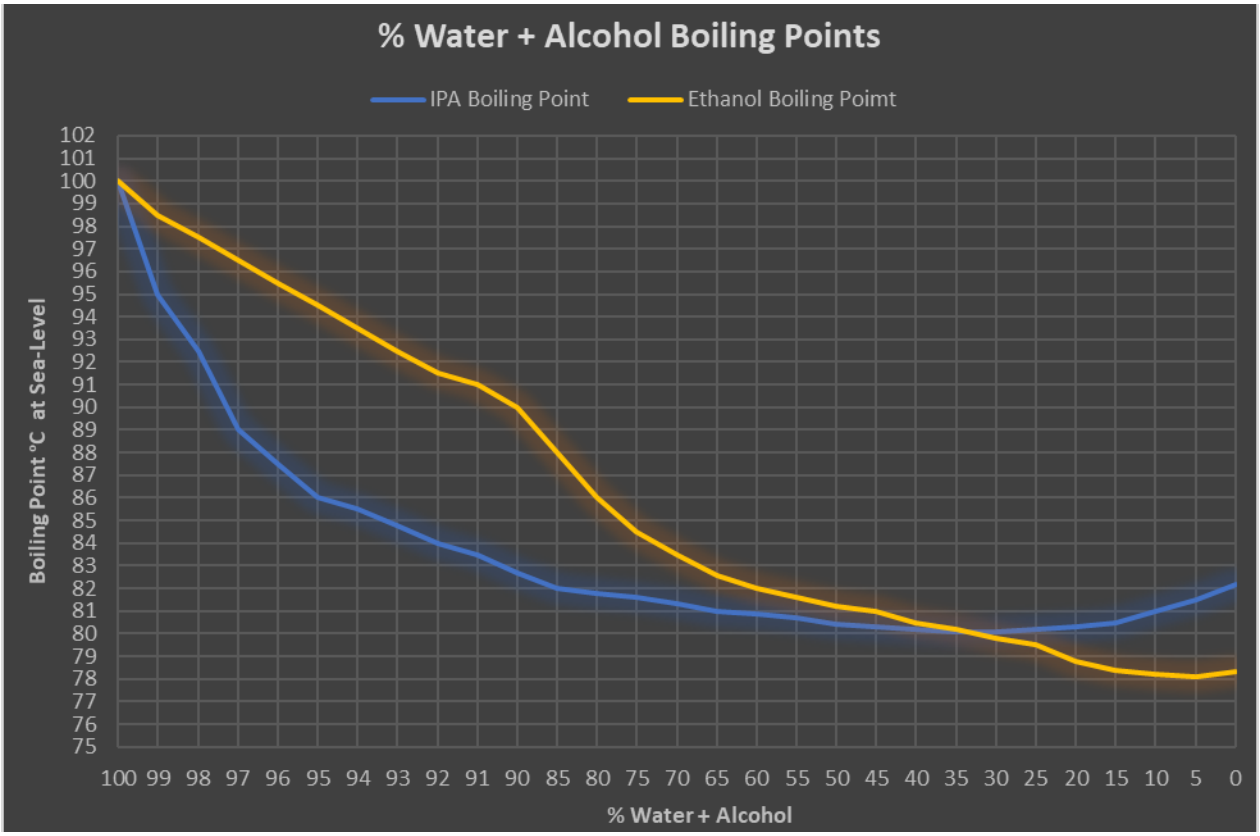


Figure 38 – Water + Alcohol Boiling Points

VIII.8.4 However, for aqueous cleaners with alcohol and surfactants, the article abstract "*The Vapor Pressures Of Ethanol-Water Solutions Of Detergents*" *by B.DFlockhart, 1960* (9) indicates that the affinity between detergent and alcohol is strong enough such that the solution boiling point is not lowered, but instead increased. This would imply that alcohol as an ingredient with detergents does not improve drying, so its use is for other purposes such as a co-solvent for other ingredients especially in concentrated forms.

VIII.8.5 **Figure 39** shows that Ethanol and IPA will reduce the water surface tension improving wetting similar to a nonionic surfactant with about 15% to 20% being the optimum concentration for a surface tension of about 34.6 to 30.5 dynes/cm respectively. Data for **Figure 39** is from "*Surface Tension of Alcohol + Water from 20 to 50°C*", *Gonzalo Vazquez, Estrella Alvarez, Jose M. Navaza, Journal of Chemical and Engineering Data. 1 May 1995 (31)*. Various forums discuss using just DIW and a few percent IPA and getting improved cleaning, especially for particulate. This result is valid because even 2.5% IPA in water can reduce the surface tension to about 60 dynes/cm, reducing the water-IPA solution contact angle with the record improving the wetting and improving the cleaning especially for fine particulate.

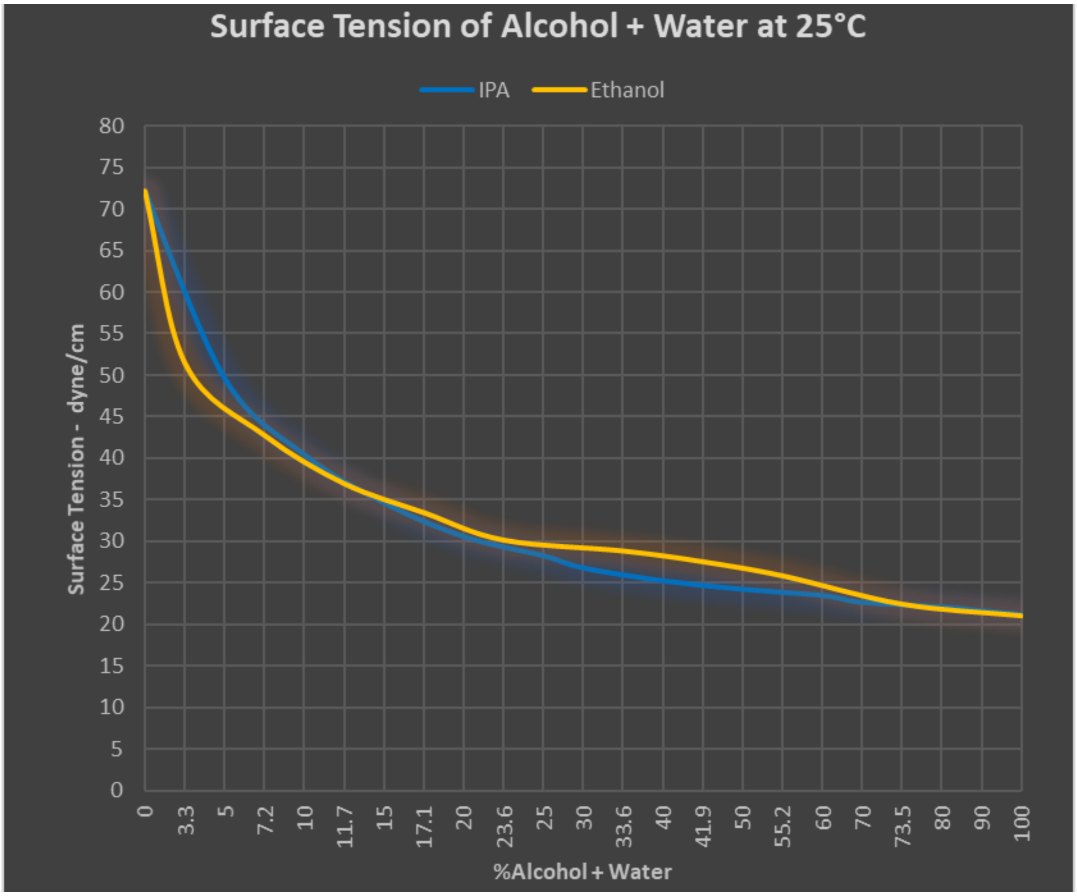


Figure 39 – Water + Alcohol Surface Tensions of at 25°C

(*adapted with permission copyright 1995, American Chemical Society*)

VIII.8.6 Ethanol or IPA at low concentrations 2.5% to 10% can assist cleaning by combining with low surface tension surfactants to improve the solubility at water-oil interfaces causing some organic soils to swell thereby allowing surfactants (in the cleaner) to lift the soil from the surface as noted **Figure 40**. This is used to good effect in **CHAPTER XIV. DISCUSSION OF ULTRASONIC CLEANING MACHINES:** for applications requiring a non-flammable, low residue formula. A solution of 2.5% IPA has shown to be complementary with very low concentrations of non-ionic surfactant added only for wetting.

Figure 40 – Organic Soil Roll-Up

VIII.8.7 When diluting various concentrations of IPA such 100%, 91% or 70% to achieve a final lower percent the following equation can be used noting that this is % by volume.

$$V_{IPA} = \frac{C_f}{C_i} V_f$$

Where:
V_{IPA} = Volume of IPA to add (mL)
C_f = Final Concentration of IPA (v/v%)
C_i = Initial Concentration of IPA (v/v%)
V_f = Final Volume of Fluid (mL)

Examples: To obtain a 2.5% IPA in 1400 mL of solution using 70% IPA = (0.025/0.70) x (1400 mL) = 50 mL.

To obtain a 2.5% IPA in 1400 mL of solution using 91% IPA = (0.025/0.91) x (1400 mL) = 39 mL.

VIII.8.8 **Alcohol Evaporative Losses:** Ethanol and IPA at low concentrations (<50%) are not azeotropes and can evaporate separately from water; and this is quite evident when reviewing the applicable vapor-liquid equilibrium diagram that when boiling shows the vapor vs the liquid concentration. At low concentrations, the alcohol vapor concentration is much higher than the liquid concentration. At higher concentrations when an azeotrope forms, the alcohol concentration in the liquid and vapor are the same. For those that may use Ethanol or IPA at low concentrations in an ultrasonic tank (use only at concentrations that are not flammable); over a period of time, the alcohol will evaporate from the water faster than the water evaporating. Unless the alcohol concentration is monitored (alcohol hydrometers are available), the concentration will drop if the tank bath life is extended.

VIII.8.9 **IPA Purity Specifications:** Quality IPA is generally manufactured in accordance with two different industry standards (known as monographs) - - United States Pharmacopeia (USP) Grade and American Chemical Society (ACS) Reagent Grade. Of the UPS-Grade, there are two (2) variations of IPA and there is also USP "rubbing alcohol" which can contain ethanol or IPA. There is also two widely used Industrial specifications *Fed-Spec TT-I-735a, Isopropyl Alcohol* (23)and *ASTM D770 (Standard Specification for Isopropyl Alcohol)*.

VIII.8.9.a In **Table VIII**, the different types of IPA and "rubbing alcohol" are listed and there can be significant differences in the purity, ingredients and the maximum allowable non-volatile residue (NVR). ACS, USP, TT-I-735a and ASTM D-770 IPA that is sold generally has much lower NVR. But store bought 70% and 91% USP Grade 'may' have high NVR depending on the manufacturer labeling and quality.

VIII.8.9.b For cleaning purposes, avoid all alcohol labeled as 'rubbing alcohol' since the denaturant and other ingredients such as perfume oils and colorants may not be listed and NVR can be very high. The safest recommendation is to purchase 91% UPS Grade or better purity from a manufacture that has a readily available SDS.

VIII.8.9.c If mixing very small quantities (i.e., 2.5%), the 91% USP grade should be fine. By the time its diluted whatever NVR it has is so diluted it's inconsequential. Assuming the worst case USP-Grade IPA NVR, a prepared 2.5% solution (0.025)(50 mg/L) = 1.25 mg/L = ~1.25 ppm. The NVR from the surfactant >50 times higher. However, if using the IPA as delivered as a wipe-solvent- i.e., no further dilution, then the quality difference 'may' be noticeable. It all depends on the quality of the product.

Table VIII
Alcohol Specifications & Purity

Alcohol Specification	Alcohol Concentration & Other Ingredients	NVR
ACS Reagent Grade IPA	>99.5%	10 mg/L
TT-I-735a Grade A	99.9% or better	20 mg/L
TT-I-735a Grade B	99.6% or better	
UPS Grade IPA	>99%	50 mg/L
	91% + DIW	
	70% + DIW	
ASTM D770	99.8% or better	50 mg/L
USP Grade Rubbing Alcohol	68.5 to 71.5% IPA, DIW & may contain perfume oils & colorant.	Clear unscented 70% rubbing alcohol may be the same as 70% UPS Grade IPA
	68.5 to 71.5% ethanol, DIW & denatonium benzoate denaturant & may contain perfume oils & colorant.	Not less than 14 mg/L
	68.5 to 71.5% ethanol, DIW & sucrose octaacetate denaturant & may contain perfume oils & colorant.	Not less than 3,560 mg/L

VIII.9 **ENZYMES.** Enzymes are biological catalysts that are generally some kind of protein. There is the "lock & key" analogy associated with enzymes and cleaning. The particular enzyme must be the right key to unlock (dissolving) the particular soil. There are four (4) basic enzymes used and how each works can be contaminant, time, concentration and surface dependent, and they have to be rinsed.

! CAUTION

The enzymes can be irritating to some individuals. Per *Guidance for the Risk Assessment of Enzyme-Containing Consumer Products (1)*, "Almost all enzymes used in consumer products are proteins which are foreign to the human immune system and can act as allergens through a Type 1 hypersensitivity mechanism following exposure, typically by inhalation.". If while handling or using an enzyme any breathing irritation or difficulty is experienced stop use immediately and seek medical attention if symptoms persist.

VIII.9.1 Proteases break down protein-based soils including blood, urine, food, feces, wine and other beverages. This is the most commonly used type enzyme in cleaners.

VIII.9.2 Amylases break down starch molecules like eggs, sugars, sauces, ice cream, gravy. This is a commonly used enzyme in cleaners.

VIII.9.3 Lipases break down fat molecules like oils and grease. This may work for fingerprints, but mineral-based such as refined/synthetic oils/greases - not so well.

VIII.9.4 Cellulases are used to soften fabric and restore color to fibers made up of cellulose material. They also remove particulate soil and reduce fabric graying and pilling. How well they actually remove particulate is unknown - literature is pretty thin, and likely surface dependent - may work on clothes, but not hard surfaces or very small particles.

VIII.10 **ANTI-STATICS**. Read any audio forum, and there will likely be some discussion of using anti-static cleaners and sprays. Fundamentally, static can be dissipated from any surface with a film of water; and the film of water does not need to be very thick. A thickness of only 20 angstroms (equal to 0.0020 microns) appears sufficient. So, if the applied fluid can uniformly wet the record, static can be dissipated. The proof of this can be extracted from the following papers:

VIII.10.1 *Static Charge Removal with IPA Solution, Tadahiro Ohmi, Seiji Sudoh, and Hiroyuki Mishima, IEEE Transactions on Semiconductor Manufacturing, Vol. I, No. 4. November 1994*. This article tested the ability of IPA+water solutions to remove charge from Teflon™ (PTFE plastic). Teflon™ per **Figure 29** is one of the most negative materials on the Triboelectric series and has a very low critical surface tension of about 19 dynes/cm. The paper demonstrated the ability of 20% IPA + water and greater % IPA to dissipate the charge from Teflon™. Less than 20% IPA + water did not. The explanation is that 20% IPA + water from **Figure 39** has a surface tension of about 30 dynes/cm and this is able to wet the Teflon™ enough to dissipate the static charge. So, any solution that will 'wet' the record can remove static charge.

VIII.10.2 *Why Three Monolayers of Moisture Are Important, Tom Green, T.J. Green Associates, LLC, Bob Lowry, Electronic Materials Consultant, September 2016 (76).* This paper shows that very thin films of water only angstroms thick that naturally condensed on a surface of mica from ambient humidity can change the mica (which is an insulator) conductivity as shown **Table IX**. For information, a single monolayer of water is 2.8 angstroms (0.00028 microns). From various ESD guidelines, and anecdotal information, a dewpoint of about 50°F to maybe 55°F appears to be the threshold where static is not generally formed on a record. At 40% humidity/77°F, the water film should be about 20 angstroms thick (0.0020 microns), and this should be sufficient to essentially make the surface conductive or at least dissipative. From **CHAPTER XI. DISCUSSION OF CLEANLINESS CRITERIA:** a water film of 0.0020 microns thickness on the record would be equal to about 0.020 mg water uniformly spread-out on one side of the record. Also, to note, is that ambient air contains enough ionic impurities such as salts, so that condensed moisture will not be pure water and should be conductive.

Table IX
Mica Conductivity from Condensed Water Film

Relative Humidity @25ºC/77ºF	Dewpoint	Ambient air water g/m^3	Conductivity measured across mica	Water Film Thickness - microns
20%	33ºF	4.8	<0.01 pico-amp	0.0010
30%	43ºF	7.1	~0.02 pico-amp	0.0016
35%	47ºF	8.2	~0.08 pico-amp	0.0018
40%	51ºF	9.6	~0.3 pico-amp	0.0020
50%	57ºF	11.9	~1.0 pico-amp	0.0025
60%	62ºF	14.2	~5.0 pico-amp	0.0030
70%	66ºF	16.3	~10 pico-amp	0.0032

VIII.10.3 Some anti-static chemicals are used to leave a thin coating that then prevents static from developing, and these chemicals are all low vapor pressure (will not easily evaporate) and are very hydroscopic (absorb water). So, the thin coating absorbs moisture from the air developing a water film on the record surface. The most efficient are quaternary ammonium compound (QAC) cationic surfactants; which are also disinfectants. Propylene glycol is also very hydroscopic as can be non-ionic surfactants, but both to a lesser degree. Most of these anti-static coatings have limitations when the ambient humidity drops below about 35%.

VIII.10.3.a One common DIY record formulation uses HEPASTAT™ 256 as the source of the QAC. There is one industrial anti-static fluid not used in any DIY record cleaners – ACL Staticide® that uses Methyl bis(2-hydroxyethyl) cocoalkyl quaternary ammonium nitrates/chlorides for the QAC at about 0.1% (1000 ppm) and specifies useable to 15% humidity.

VIII.10.3.b In the paper *Investigating the impact of cleaning treatments on polystyrene using SEM, AFM and ToF–SIMS, Anna L. Fricker, David S. McPhail, Brenda Keneghan and Boris Pretzel, Heritage Sci (2017) 5:28 (4),* nonionic surfactant BASF™ Dehypon™ LS45 and anionic surfactant Orvus™ WA Paste were used at 1% (10,000 ppm) to clean polystyrene. The polystyrene was cleaned using microfiber cloths and rinsed with demineralized water wetted cloths to remove residual surfactant. Post rinsing inspection with time-of-flight secondary ion mass spectrometry (ToF–SIMS) showed evidence of surfactant residue measured as one-monolayer which is about 9 angstroms (0.0009 microns). Realistically, this layer will exist/mix with the water layer that naturally deposits from the air. But if that surfactant was a cationic surfactant, then the high fluid film conductivity could act as a strong anti-static; any negative effects to music playback notwithstanding.

VIII.10.3.c In the paper *Record Contamination: Causes and Cure by Percy Wilson, 1965 (61)* it states: "*One thing, however, became abundantly clear during the early part of the investigation: the treatment of the record surface with any material whatsoever that leaves a deposit increases the liability to noisiness within a few months. Detergents in particular (whether anionic or cationic) will produce a battery of pitted sections of the groove in about 12 months' time. We surmised, though we have not investigated this thoroughly, that the action was not so much on the vinyl chloride as on the lead stearate or other additives that go to make up the modern disc material.".* Note: This conclusion may not apply to modern records that no longer use lead-based ingredients; see **CHAPTER X. DISCUSSION OF MATERIAL COMPATIBILITY:**. However, cleaner residue can still be audible as discussed **CHAPTER XI. DISCUSSION OF CLEANLINESS CRITERIA:**

VIII.11 **BIOCIDES:** Chemicals are used to kill and/or control microbial growth such as bacterial, spores and viruses; and they can be categorized as those that can sterilize (kill everything), disinfect (kill most) or inhibit (prevent growth). Cationic surfactants that are positively charged and used as anti-static can also be very effective disinfectants and the specific type as previously discussed is quaternary ammonium compounds (QACs). However, QACs are not completely sporicidal (kill mold spores), but simple hydrogen peroxide is sporicidal. The CMIT/MIT chemicals in ILFORD™ ILFOTOL™ are inhibitors.

CAUTION

HEPASTAT 256 in its concentrated state it is classified as being flammable, an acute toxicity oral and dermal hazard, and can cause burns to exposed skin. Once diluted, it is much safer, but as a concentrate this is an industrial product and should be handled accordingly with appropriate PPE.

VIII.11.1 **HEPASTAT™ 256**: HEPASTAT™ 256 is a concentrated antibacterial (disinfectant), anti-static, general purpose alkaline cleaner and is intended to be diluted with tap water 1/2 to 1-ounce per gallon (diluted 1-part cleaner to 125 to 250 parts water). This product is very effective as a disinfectant able to kill just about any bacteria or virus (*including COVID-19*) with appropriate contact time as specified by the manufacture. This product is used by some of the DIY cleaners, generally as an anti-static and sometimes recommended to extend ultrasonic tank bath life by inhibiting bacteria. The active ingredients are quaternary ammonium salt compounds. But, it's also a broad-based alkaline cleaner with many ingredients beyond the blend of cationic quaternary ammonium compound (QAC) surfactants including ethoxylated nonionic surfactant, ethanol, sodium metasilicate (for pH), sodium EDTA (to allow use with tap water), and fragrance.

VIII.11.1.a Note that a 9/2015 bulletin from *New York Mount Sinai Silekoff Centers for Occupation Health titled "Quaternary Ammonium Compounds in Cleaning Products: Health & Safety Information for Health Professionals*" (60) raises sufficient respiratory health concerns that use of this product or any quaternary ammonium compounds (QACs) for cleaning records should be approached with Caution with those that may have asthma or other respiratory ailments.

VIII.11.1.b Additionally, for information most quaternary ammonium compounds are classified as highly toxic to aquatic life according to the United Nations' Globally Harmonized System of Classification and Labelling of Chemicals (GHS).

VIII.11.2 **BAK50:** BAK50 is 50% concentrated benzalkonium chloride CAS No. 8001-54-5. It's a cationic surfactant blend of alkylbenzyldimethylammonium chlorides that are classified as QACs and are powerful disinfectants. It is similar to HEPASTAT™ 256 without the other nonionic surfactant and alkaline ingredients. BAK50 is readily available in small quantities and low cost in the EU/UK, but not in the USA. Laboratory grade is available in the USA at much higher cost. BAK50 is generally applied at 1-part BAK50 to 200 parts distilled/demineralized water, similar to HEPASTAT™ 256. As a concentrated product, the safety profile/hazards of BAK50 as a concentrate are the same as HEPASTAT™ 256.

VIII.11.3 **MOLD:** There are essentially two different categories - there is mildew which is the dust type and has a musty smell and is relatively easy to remove from a record using most wet cleaning processes. Then there is the fuzzy/slimy mold, generally has a more pungent odor and this is something else and can be dangerous. The EPA has guidelines for mold remediation - Mold Cleanup in Your Home | Mold | US EPA. If the record has fuzzy/slimy mold, the general recommendation is to avoid and do not try to recover unless of extraordinary value. For mildew-type mold, a full wet process such as **CHAPTER V. MANUAL CLEANING PROCESS:** is the safest since the mold should not become airborne – lots of water and lots of cleaner can be applied to 'remove' the mold. The same technique is used to 'remove' bacteria and viruses from your hands, and in the age of COVID we all know the drill – clean with soap and water for 20-seconds. If you dry brush the mold, it will become airborne and now becomes a respiratory hazard.

VIII.11.3.a If there is concern that after washing there may still be live mold spores in the record, then a solution with sporicidal action is required. Using the *Centers for Disease Control*

(CDC) Guideline for Disinfection and Sterilization in Healthcare Facilities, 2008 Update: May 2019 (13) as a guide, some observations. Common disinfectants such as alcohol and QACs (sometimes referred to as Quats) such as HEPASTAT™ 256 and BAK50 do not have very good sporicidal activity. They may inhibit growth, but not necessarily kill the spores.

VIII.11.3.b The safest sporicidal solution that should be compatible with records to kill mold spores is simple hydrogen peroxide. The one disadvantage is kill-time; 3% = 2.5-hrs while 6% = 1-hr. Sodium hypochlorite (bleach) does have very good sporicidal activity with much faster kill-time than hydrogen peroxide and should also be compatible with the record. However, specific record compositions may react differently; and the exact concentration to use is dependent on the starting concentration and household bleaches may contain other ingredients. If using hydrogen peroxide to kill mold, after soaking, lightly brush to agitate fluid and then dispose to drain. Apply tap-water rinse with brush assistance to remove all hydrogen peroxide noting that the hydrogen peroxide will mix with water almost instantly. Then continue to either general pre-clean or final clean.

VIII.11.3.c Mildew/moldy record jackets are generally disposed and replaced with blank jackets such as White Die-Cut LP Jacket (Pack of 10) (sleevecityusa.com). If not severe, the internet has a number of methods that can be tried. However, take appropriate precautions to avoid exposing yourself to airborne mold; such as perform outside and wear appropriate personnel protective equipment (PPE).

VIII.12 **ACIDS, CARBONATES & FINE PARTICLES**: Some of the fluorescing particles in **Figure 11-C** were very tightly adherent non-organic/mineral based particles. These type particles are natural to the environment; known as aerosols Lecture25.pdf (gatech.edu). While they can range from 0.002 to 100 microns, there is a significant amount between 0.5 and 1 microns and if these conglomerate (clump together) - larger particles are generated. These size and type particles can be present during the record pressing and handling (depending on the cleanliness of the pressing plant), and can essentially be pressed into the record or deposit on the record. Or, they may be from prior use of tap water for cleaning used record that was not rinsed with DIW, or dried cleaner residue. These type particles are not going to be easily removed even if just on the surface and can be a source of background hiss or staticky type noise; or accumulate on the stylus.

VIII.12.1 The paper *Adhesion and Removal of Fine Particles on Surfaces, Aerosol Science and Technology, M. B. Ranade, 1987* (46) shows for aluminum oxide particles, the force (acceleration) required to remove a 10-micron particle is 4.5 x 10^4 g's, a 1-micron particle is 4.5 x 10^6 g's and a 0.1-micron particle is 4.5 x 10^8 g's." Even an aggressive cleaning with Alconox™ Liquinox™ and brush may fail to remove these very small, but tenacious particles/debris that can 'hide' in the valleys between the groove side wall ridges.

VIII.12.2 However, acids can dissolve these types of particles (similar to cleaning a coffee pot of water residue or removing rust) or swell them enough to be removed. This is the reason for the acid-clean and acid-soak addressed in **CHAPTER V. MANUAL CLEANING PROCESS:**. However, acids are not effective against organic soils. For an acid to work, the surface must first be degreased, so that is accomplished with the pre-clean step using Alconox™ Liquinox™ as an aggressive detergent.

VIII.12.3 Alconox™ Citranox™ is recommended as the acid-cleaner that is effective, compatible (with appropriate exposure) with both the vinyl record and the final cleaner, of known ingredients from a long-established supplier, and safe with appropriate use and PPE such as gloves. Additionally, detailed technical information is readily available at Critical Cleaning Detergents & Validation | Alconox Inc.; and product is readily available to the consumer at a reasonable cost. Some general details of Alconox™ Citranox™ are provided as follows:

VIII.12.3.a The product is a combination of citric and glycolic acids (combined up to 35%) plus pH stabilizer, and anionic and nonionic surfactants for wetting and some detergency. Citric and glycolic acids are weak acids whose strength is related by their ionization potential in solution – identified as the constant pKa. The lower the pKa, the stronger the acid. Citric acid has three pKa values – 3.08, 4.74 & 5.4. Glycolic acid has one pKa value – 3.83. Acetic acid (distilled white vinegar) has one pKa value – 4.75. For reference, strong acids such as hydrochloric the pKa value is zero (0). Citric and glycolic acids are common in many household products.

VIII.12.3.b The pH stabilizer is triethanolamine (TEA), CAS # 102-71-6 with as much as 10% in the concentrate and about 0.15% when diluted for use. TEA is common in skin care products and cleaning agents, and also acts as a surfactant and an emulsifier. For skin care products its approved in the USA for "non-rinse-off" at less than 5% while EU approves at less than 2.5%. The toxicology of TEA has been extensively reviewed such as the *Cosmetic Ingredient Report (CIR) of Triethanolamine (TEA) and TEA-containing ingredients, 2011 (16)* and *Ethanol, 2,2',2''-nitrilotris-: Human health tier II assessment, 2013 (22)*. For the in-use concentration of 0.15% and combination with no adverse interacting product, the TEA in Alconox™ Citranox™ is safe for use as prescribed by **CHAPTER V. MANUAL CLEANING PROCESS:**.

VIII.12.3.c The product is concentrated with about 65% active ingredients, the remainder water. So, the recommended manual cleaning use concentration of 1.5% solution is about 1.0%/10,000 ppm active.

VIII.12.3.d The product mixes easily, and as a 1.5% solution has a pH of about 2.5, and product surface tension is about 32 dynes/cm, so it has excellent wetting capability. The product does not foam as much as Alconox™ Liquinox™ or rinse as easily.

VIII.12.3.e The Alconox™ Citranox™ is compatible with the Alconox™ Liquinox™ pre-cleaner and the Dow™ Tergitol™ 15-S-9 nonionic (or equivalent) final cleaner and is compatible with the record with appropriate limited exposure at room temperature for the few minutes when washing or 15-minutes soak (see additional details **CHAPTER X. DISCUSSION OF MATERIAL COMPATIBILITY:**)

VIII.12.3.f The product is non-flammable, is biodegradable, has no reported acute or chronic toxicity hazards, and has been widely accepted and used in many industries for many years, and product quality is very high.

VIII.12.4 If substituting Distilled White Vinegar (DWV): Distilled white vinegar is water and acetic acid (also known as ethanolic acid made from distilled grain alcohol) and the percent acetic acid should be identified as "% Acidity". Grocery store distilled white vinegar is generally 5%, but industrial grade can be as high as 30%. Note that there are many types of vinegars such as apple cider – use only "white distilled vinegar" which is the purest (little or no residue) form. The vinegar by itself will not "wet" the record and unless immersed in a bath of vinegar will bead-up on the record. Adding some nonionic surfactant (see **CHAPTER III. CLEANING SOLUTION PREPARATION:**) will allow the DWV solution to "wet" the record.

VIII.13 **DETRITUS OF UNKNOWN ORIGIN – SPOT CLEANING**: Used records can be contaminated with blobs/specs of paint and material of unknown origin such as embedded fingerprints and dried paper-pulp that will defy previously discussed aqueous pre-cleaners – detergents and acids. For this type detritus that appears to be removable (not a metal shard embedded in the record), spot cleaning with IPA solvent is the first recommendation. Name-brand Q-Tips™ with a secure cotton head and paper type shaft are recommended over off-brands that use plastic shafts. Wet the Q-Tip™ with IPA and wet the detritus and attempt to clean/rub to remove. Consider use of a wooden toothpick to assist. If successful, complete process by performing the final clean step of **CHAPTER V. MANUAL CLEANING PROCESS:** or equivalent with machines (*vacuum-RCM or UCM*). If this fails, one of the following last-ditch efforts may work.

VIII.13.1 Detergent-Enzyme Soak: Fill a sink with warm tap-water (about 90°-95°F) and add clear, fragrance-free, liquid laundry detergent. Mix well. With the RLP applied, completely submerge the record and soak for about one (1) hour. Most quality, liquid laundry detergents are a blend of surfactants, enzymes and slightly alkaline. After soak, scrub-brush surface and then rinse with tap-water/brush. If the detritus is mostly removed, perform the pre-clean/final clean process as specified **CHAPTER V. MANUAL CLEANING PROCESS:**; the acid wash is optional. Let the record air dry for about one (1) hour and recommend not playing for 24 hours to give the record time to 'recover' all physical properties that may have softened during the soak. If the detritus is not removed, complete the final clean/rinse/dry steps of **CHAPTER V. MANUAL CLEANING PROCESS:** and consider trying Zippo™ lighter fluid and/or wood-glue.

VIII.13.2 Zippo™ Lighter Fluid has been used as a short duration spot cleaner/solvent without major harm to the record. Zippo™ Lighter Fluid is a blend of light petroleum distillates (which can encompass many different chemicals) and naphtha (which can encompass many different chemicals). Because of the wide variable in actual ingredients, recommend using only name brand Zippo™. Aside from the flammability (flashpoint 20°F), it's relatively safe, no greater toxicity than IPA. But, any extended contact with the record will likely incur damage. But a few minutes exposure has been successfully used by many. Spot clean the detritus with the Zippo™ Lighter Fluid using the same procedure used with IPA. If successful, complete the cleaning by performing the pre-clean/final clean process (acid wash not required) as specified **CHAPTER V. MANUAL CLEANING PROCESS:**.

VIII.13.3 Wood-glue has been used with some success to remove small tenacious spots. Wood glue should be mostly polyvinyl acetate (the same co-polymer used in the record forumla discussed **CHAPTER X. DISCUSSION OF MATERIAL COMPATIBILITY:**) or variations thereof, and water. Depending on manufacturer and whether for interior or exterior use, wood glue can have other ingredients. The white/cream colored version should be polyvinyl acetate while the yellow version can be a modified polyvinyl acetate. The products are generally acidic with pH between 4 and 2.5. Using a quality product such as Titebond™ Original Wood Glue or Titebond™ II Premium, apply a small amount to fully cover the spot and affix a wooden stir stick so that it dries attached to the wood glue. Allow the wood glue to fully cure/dry for 24 hours. Then gently lift the wooden stick to remove/peel-off the dried wood glue and hopefully the detritus. If successful, complete the cleaning by performing the pre-clean/final clean process (acid wash not required) as specified **CHAPTER V. MANUAL CLEANING PROCESS:**.

VIII.13.4 If all attempts fail, the detritus may be a cellulose-based material - i.e., a piece of what was once paper. If a paper sleeve had been in contact with the record under pressure (record stored flat with records above), for months/years, the paper and its acids (paper sleeves are unlikely to be acid-free) can breakdown and essentially etch/embed/weld into the record. Cellulose is very difficult to dissolve. Think about dietary insoluble fiber, it travels from the mouth with all of its enzymes (proteins) to the gut with its acids and enzymes, through the intestines and is not dissolved. Use of hazardous highly caustic chemicals to possibly breakdown/dissolve this type detritus is outside the safety-use posture of this book.

VIII.13.5 However, if the detritus is above the groove or part of the groove; the detritus may be inconsequential. Some fingerprints can etch into the record surface. With a jeweler's loupe (or equivalent), does the detritus interfere with the groove or have the contour of the groove? If it's just a small spot, the record may play fine - leave it alone; any further attempt is likely to do more harm than good.

VIII.14 **DISCWASHER™** *1976 U.S. Patent 3,951,84 Phonograph Record Cleaning Composition (17)* (product availability is unknown). The Discwasher™ product along with the brush was/is a commonly used item for single point of use cleaning. The process applies liquid to the brush leading edge; wipes the record surface and then used the back-edge of the brush to dry. The patented solution composition is reviewed for historical purposes; the composition of what is currently sold is unknown.

VIII.14.1 Discwasher™ Formula: The formula is heavily centered around preventing the formation of micro-organisms (mold) in the record groove. Note: The common presence of micro-organisms in the record groove has not been validated. The record formulation is not biodegradable.

VIII.14.1.a Sodium Azide - up to 0.3%-wt. Sodium Azide was added as the biocide.

Concentrated Sodium Azide is extremely hazardous and toxic and its use in any current record cleaning hopefully has been suspended. It is used in automobile air bags – it's the explosive, nitrogen gas producing ingredient.

VIII.14.1.b Surfactant – up to 0.2%-wt. The surfactant was likely similar to if not Dow™ Triton™ X100 and is added as a wetting agent.

VIII.14.1.c Propylene Glycol – up to 0.2%-wt. Propylene Glycol was added as an emulsifier.

VIII.14.1.d Alcohol – up to 5%-wt. Alcohol was likely IPA and was added to assist with dissolving the surfactant into the water.

VIII.14.1.e Distilled Water – remaining percent.

VIII.14.2 Discwasher™ Assessment:

VIII.14.2.a The patent states: "*And more importantly, even after this process is achieved, any remaining cleaning composition in the form of a residue that remains upon the surface of the phonographic record acts as a lubricant, and even when it should dry, it leaves little or no noticeable or actionable dry weight residue that may cause irritation to the record playing surface during its movement and contact with the phonographic needle.*"

VIII.14.2.b One of the challenges with this cleaning solution is that it is essentially a wipe-cleaner. There is essentially no contact time. There is no time to dissolve/emulsify organic contaminants requiring brush pressure to do the work. But this can also force particulate deeper into the groove.

VIII.14.2.c Review of the composition indicates that the solution NVR can have as much as 7000 mg/L from the Sodium Azide (~3000 mg/L) + Surfactant (~2000 mg/L) + Propylene Glycol (2000 mg/L) = 7000 mg/L. If 0.5 mL dries on the record surface, 3.5 mg of NVR will remain. The residue will be oily and will collect dust and particulate that forms from record play and is in the surrounding environment. Use of the brush/liquid for every record play will eventually leave a build-up of what will essentially be sludge, and historical experience indicates this is what happened.

VIII.14.2.d The patent does state that the "…, the preferred formulation has been calculated to contain as little as 0.0004 grams per c.c. (same as 0.4 mg/mL) of dry components in a fluid treatment…". This is true only if the solution was manufactured at the lowest possible concentration.

VIII.15 **DIY RECORD CLEANING FORMULAS**. There are two widely used DIY record cleaning formulas with some variations thereof. One is based mostly on IPA and some nonionic surfactant; while the other is based mostly on cationic and nonionic surfactants with a small amount of IPA.

VIII.15.1 **London Jazz Collector™ (LJC)** (https://londonjazzcollector.wordpress.com/for-audiophiles/home-brew-cleaner-for-vacuum-rcms/)

VIII.15.1.a LJC Limitations: The formulator indicates that the cleaning solution is intended for vacuum record cleaning machines such as **CHAPTER XIII. DISCUSSION OF VACUUM RECORD CLEANING MACHINES:**, and does not recommend allowing to just evaporate to prevent leaving dissolved contaminants, e.g., NVR.

VIII.15.1.b LJC Formula:

- IPA - 99.9% 1:4 with DIW (250 mL/L) = 25% IPA
- ILFORD™ ILFOTOL™ (5% concentrate) 1:200 DIW (5 mL/1 L) = 0.5% (0.025% NID) = 250 ppm active nonionic surfactant
- Overall Delivery is specified as 2.5 mL of LJC Formula to each record side.

VIII.15.1.c LJC Assessment: The ILFOTOL™ concentration is about 8X the nonionic surfactant CMC so it has some detergency and should have a surface tension of about 30 dynes/cm so it should wet the record. The 25% IPA also has a low surface tension of ~28 dynes/cm. The high IPA concentration should reduce the fluid boiling point and assist with quicker evaporation. Additionally, the IPA at 25% is useful in assisting the ILFOTOL™ nonionic surfactant for soil swell/roll-up. Overall, given the small applied quantity (2.5 mL) the risk of cleaner NVR from incomplete rinsing is very low; at 2.5 mL the solution will have <1 mg NVR. Additionally, per **CHAPTER X. DISCUSSION OF MATERIAL COMPATIBILITY:** the small volume used at room temperature has no compatibility issues. But the solution is flammable with a flashpoint of ~27°C (81°F). However, the flammability risk is mitigated by the very small quantity used – only 2.5 mL per side, but larger quantities could pose a fire hazard.

Use of the **London Jazz Collector™** formula in an Ultrasonic Tank with 100's or 1000's of mL is dangerous. With an ultrasonic unit three mechanisms are now in play - the heat that speeds up evaporation; the record turning is drawing fluid out that is evaporating and the ultrasonics are agitating the fluid surface and a mist/vapor is often produced. All of this has the potential to setup the necessary conditions to develop flammable AND explosive vapors. At 100% IPA, the lower and upper explosive limits are 2.3 to 13.2%. But, even diluted with water, at 25% water-IPA, the lower and upper explosive limits are 2.3 to 7.1%. In a common domestic setting, it is very unlikely that the high ventilation turn-over rates that are required in medical and industrial settings that prevent the accumulation of flammable/explosive vapors will be used. So, the risk in a domestic setting is higher.

VIII.15.2 **Audiokarma™** (https://audiokarma.org/forums/index.php?threads/record-cleaning-developing-the-best-possible-methods.689430/page-51#post)

VIII.15.2.a Audiokarma™ Limitation: The formulator indicates that the cleaning solution is intended as a wash step using a brush "paint pad" as the applicator and then to be rinsed with DIW. The formulator indicates that the wash-step is followed with a final DIW rinse and dry with a vacuum-RCM. Furthermore, the formulator indicates success with using the cleaning solution in ultrasonic tanks at a 1:1000 dilution.

VIII.15.2.b Audiokarma™ Formula:

- HEPASTAT™-256 (~20% quats + 8% NID + 10% Na_2SiO_3/EDTA) @ 1:500 (2-mL/L) = 0.2% (yields 0.04% Quats + 0.016% NID + 0.02% Na_2SiO_3/EDTA) = 400 ppm Quats + 160 ppm NID + 200 ppm Na_2SiO_3/EDTA
- Dow™ Triton™ X100 (100% concentrated) - (2.0 mL/L) = 0.2% = 2000 ppm
- IPA 99.9% - (50 mL/L) = 5%

VIII.15.2.c Audioikarma™ Assessment:

- The formulator addresses using the HEPASTAT™-256 for its negative-charge cationic surfactant anti-static capability. However, so long as the record is fully wetted, and the Dow™ Triton™ X100 concentration at 0.2% is about 10 times its CMC will 'wet' the record, any static on the record will be dissipated/eliminated. The double rinse that is specified will likely leave very little cationic surfactant (quats) residue behind to leave any long-term anti-static coating.

- Dow ™Triton™ X100 at 0.2% is about 10X its CMC and will be a good wetting solution with good detergency. But, Triton™ X100 at 0.2% will be difficult to dissolve without the 5% IPA, and the high concentration will require careful (aggressive) DIW rinsing for complete removal. Otherwise, Dow™ Triton™ X100 is a nonionic surfactant that has been in use for >25-yrs – see **CHAPTER IX. DISCUSSION OF THE FINAL CLEANERS:** for further details.

- The IPA at 5% is useful in assisting the Dow™ Triton™ X100 nonionic surfactant to dissolve in the solution and for soil swell/roll-up. Precedence with using 5% IPA to assist with mixing the Triton™ X100 in water is discussed in the *Discwasher™ 1976 U.S. patent 3,951,84 (17)*. The IPA at 5% will have a flashpoint of 50°C/122°F. For vacuum-RCM this is very low risk. However, for ultrasonic tanks where some users are reporting temperatures as high as 45°C/113°F, the margin of safety is only 10%. Additionally, at 5% when used in an ultrasonic tank there will be some loss of cavitation intensity see **CHAPTER XIV. DISCUSSION OF ULTRASONIC CLEANING MACHINES:** for further details.

- Overall, the cleaning solution NVR is 2,760 ppm, so post rinse as specified is very important. If not rinsed, some of the NVR will dry to a powder/hard residue. The sodium metasilicate (Na_2SiO_3) if it dried on the record could form a very hard and tenacious residue similar to tap-water scale.

VIII.15.3 **VinylEngine™** (http://www.vinylengine.com/turntable_forum/viewtopic.php?f=53&t=96199&sid=3b488611de75c83db5f3364e57422bf9#p814914). Note that the "*Rushton Paul*" DIY ultrasonic cleaning formula addressed Ultrasonic Cleaning (positive-feedback.com) is very similar.

VIII.15.3.a VinylEngine™ Limitations – The formulator indicates that the cleaning solution is "useful" for ultrasonic tanks and vacuum-RCMs since it inhibits bacteria/fungus growth. The formulator further indicates the cleaning solution concentration can be increased for manual cleaning, but regardless, cleaning is always followed by two rinses with DIW.

VIII.15.3.b VinylEngine™ Formula: Very similar to **paragraph** VIII.15.2 "Audiokarma" and developed by the same author. The concentration range for HEPASTAT 256 and Triton X100 is expanded as follows:

- HEPASTAT™-256 (~20% Quats + 8% NID + 10% Na_2SiO_3/EDTA) @1:1000 to 1:500 (1-2 mL/1 L) = 0.1 to 0.2% (yields 0.04% to 0.02% Quats + 0.008% to 0.016% NID + 0.01% to 0.02% Na_2SiO_3/EDTA) = 200 to 400 ppm Quats + 80 to 160 ppm NID + 100 to 200 ppm Na_2SiO_3/EDTA

- Dow™ Triton™ X100 (100% concentrated) (1-5 mL/L) = 0.1 to 0.5% = 1000 to 5000 ppm

- IPA 99.9% (50 mL/L) = 5%

VIII.15.3.c VinylEngine™ Assessment:

- Same as **paragraph** VIII.15.2 "Audiokarma" for the applicable range.
- For the HEPASTAT™-256 used at 1:1000 in ultrasonic tanks, the cationic surfactant (quats) concentration is reduced to 200 ppm. The literature indicates that as the concentration of Quats is reduced the "kill" time for bacteria and viruses is increased. But, the 200 ppm should be adequate as a biocide inhibitor for the ultrasonic tank water volume.
- Dow ™Triton™ X100 at 0.1% is about 5 times its CMC and will be a good wetting solution with minimal detergency. But, Triton™ X100 at 0.5% is excessive at >25 times the CMC and will be difficult to dissolve without the 5% IPA, could be subject to excessive foam and the high concentration will require careful (aggressive) rinsing for complete removal such as the specified two rinses with DIW.
- The formula at its lowest concentration has an NVR of 1,380 ppm (mg/L) while the highest concentration has an NVR of 5,760 ppm (mg/L), so rinsing as the formulator specifies is necessary to ensure excessive residue is not left behind.

REMAINDER OF PAGE INTENTIONALLY BLANK

CHAPTER IX. DISCUSSION OF THE FINAL CLEANERS:

My recommendation is that a simple, single component nonionic, neutral pH surfactant at low concentration is considered the best chemistry for the manual (and machine) cleaning, final clean step. The final clean step should be performed with a cleaner that has the following properties:

- ✓ Low surface tension to effectively perform the final clean step of removing thin soil films not removed by the pre-clean step or deposited by the pre-clean step, or remaining from prior chemistry, and removing small particulate; and
- ✓ Compatible with the pre-cleaning chemistry and any prior-chemistry (such as an anti-static spray) to be effective in removing any residue left by the pre-cleaner or prior chemistry without any adverse reaction; and
- ✓ Low enough concentration to be easily and effectively rinsed, and
- ✓ Nonionic so that any residue that may be left behind will not react with any other contaminants, and
- ✓ Safe – be non-flammable and be non-toxic in use, and be materially compatible (with limited exposure) with the vinyl record (see **CHAPTER X. DISCUSSION OF MATERIAL COMPATIBILITY:** for further discussion of material compatibility).
- ✓ Stable Storage – concentrate is safe for long term storage in a sealed container in a cool (60°F/16°C - 80°F/27°C room temperature), dry, dark location. Note that most manufacturers will generally indicate that chemicals are good for about two (2) years shelf-life. There are too many variables for them to commit to durations any longer. But, properly stored, they can last much longer.

IX.1 Dow™ Tergitol™ 15-S-9 nonionic surfactant meets all desired final cleaner criterion and is readily available at reasonable cost from Talas™ (https://www.talasonline.com). Laboratory grade with a certificate of analysis (COA) is also available at much higher cost. As a nonionic surfactant it will be compatible with residue left from a prior chemistry of either anionic or cationic surfactants. The product in its diluted form is neutral pH, safe and its very high performance to concentration ratio results in a very low concentration minimizing material compatibility issues with the vinyl record and risk of NVR from incomplete rinse. The Dow™ Tergitol™ 15-S-9 product is delivered concentrated at about 100% active ingredients. **Table X** lists the performance properties of two Dow™ Tergitol™ nonionic surfactants, showing near equivalency of Dow™ Tergitol™ 15-S-9 to Dow™ Tergitol™ 15-S-7, and how they compare to the often-used for record cleaning Dow™ Triton™ X-100 nonionic surfactant. **Table X** data (unless referenced otherwise) was obtained from Dow™ literature available on the internet.

Table X
Nonionic Surfactant Performance Properties

Property	**Tergitol™ 15-S-7**	**Tergitol™ 15-S-9**	**Triton™ X-100**
Chemistry (see Note 1)	Secondary Alcohol Ethoxylates	Secondary Alcohol Ethoxylates	Octylphenol Ethoxylates
CAS Number	84133-50-6	84133-50-6	9002-93-1
Cloud Point (°C/°F) – see Note 2	37 (99)	60 (140)	66 (151)
Hydrophilic-Lipophilic Balance (HLB) – (see Note 3)	12.1	13.3	13.5
Critical Micelle Concentration (CMC) ppm at 25°C/Surface Tension dynes/cm (see Note 4)	38/28	52/30	189/33
Surfactant Micelle Size nm/microns (see Note 5)	15/0.015	9/0.009	4.4/0.0044
Specific Density at 25°C	0.910	1.006	1.065
Viscosity at 25°C cPs	51	60	240
Environmental Hazard (diluted)	No	No	Yes

Notes	**Table X Nonionic Surfactant Performance Properties**
1	The DOW™ safety data sheets will show a small amount (<3 wt%) of "poly (ethylene oxide)" as an ingredient with a CAS No. 25322-68-3. This CAS No. translates to polyethylene glycol that is compatible with PVC, and SDS's from some chemical suppliers such as Sigma-Aldrich™ will list the ingredient as polyethylene glycol. Additionally, all ethoxylated nonionic surfactants have ethylene oxide molecules as part of the chemical structure often referred to as levels or moles of ethoxylation. For the Dow™ Tergitol ™ 15-S family, the last digit is the levels/moles of ethoxylation, so Dow™ Tergitol ™ 15-S-7 has 7 moles while Dow™ Tergitol ™ 15-S-9 has 9 moles. However, ethylene oxide by itself is a gas that is not compatible with PVC, and some internet forums have incorrectly stated that Dow™ Tergitol™ is not compatible with PVC. See **CHAPTER X. DISCUSSION OF MATERIAL COMPATIBILITY:** for additional discussion of material compatibility.
2	Cloud point is the temperature when the mixture starts to phase-separate, and two phases appear, thus becoming cloudy. The cloud point is the optimum temperature for detergency, but above the cloud point the surfactant comes out of solution and detergency drops. Cloud point is generally specified at 1% and will generally increase at lower concentrations as much as 75% (*Surfactant Parameter Effects on Cleaning Efficiency (40)*).
3	The hydrophilic-lipophilic balance of a surfactant is a measure of the degree to which it is hydrophilic (water loving) or lipophilic (oil loving), and is predictive of its properties. a. < 10: Lipid-soluble (water-insoluble) b. 10: Water-soluble (lipid/oil-insoluble) c. 1 to 3: Anti-foaming agent d. 3 to 6: Water in oil emulsifier e. 7 to 9: Wetting and spreading agent f. 13 to 16: Detergent g. 8 to 16: Oil in water emulsifier

Notes	Table X Nonionic Surfactant Performance Properties
4	The critical micelle concentration (CMC) is the concentration when the surfactant achieves its lowest surface tension and at greater than CMC micelles are formed. Adding additional surfactant will not lower the surface tension any further. But, for detergency, the concentration should be at least 5 to 10 times greater than the CMC to form an adequate number of micelles. However, excessive concentration will only impede solution preparation and rinsing. For reference, the surface tension of water is ~72 dynes/cm.
5	*Source: Impact of Surface Active Ionic Liquids on the Cloud Points of Nonionic Surfactants and the Formation of Aqueous Micellar Two Phase Systems 2017 (25),* and *Temperature Dependence of Triton X-100 Micelle Size and Hydration 1994 (41)*

IX.2 Reviewing **Table X**, Dow™ Tergitol™ 15-S-9 is very similar to the Dow™ Tergitol™ 15-S-7 used by the *Library of Congress* to clean shellac records. The main difference in cloud point is inconsequential for the manual cleaning process addressed herein. However, the low cloud point of Dow™ Tergitol™ 15-S-7 could make it unsuitable for use with ultrasonic cleaning tanks because of the elevated temperatures. The higher HLB value for Dow™ Tergitol™ 15-S-9 predicts better detergency than Dow™ Tergitol™ 15-S-7. The slight difference in CMC/Surface Tension between Dow™ Tergitol™ 15-S-9 and Dow™ Tergitol™ 15-S-7 is insignificant to the performance or amount of surfactant used to prepare the NID cleaning solution.

IX.3 Dow™ Tergitol™ 15-S-9 with a CMC of 52 ppm (equal to 0.0052 wt%) at 10-times the CMC for minimum optimum concentration would be 0.052 wt% (520 ppm) - same as 520 mg/L for a water solution. With Dow™ Tergitol™ 15-S-9 specific density equal to 1.06 (and very close to water at 1.0), the approximation that 1 ppm = 1 mg/L = 0.001 mL/L is used for solution preparation purposes. Dow™ Tergitol™ 15-S-9 at a 0.1% (1000 ppm) solution specified herein is ~20 times the CMC; if used at 0.25% (2000 ppm) it would be ~50 times the CMC.

IX.4 Reviewing **Table X**, and Dow™ literature, Tergitol™ 15-S-9 is intended as a safer and more efficient replacement to Dow™ Triton™ X-100.

IX.4.1 The cloud point and HLB are very similar, but Dow™ Tergitol™ 15-S-9 has 10% lower surface tension, and this is achieved at a CMC of 52 ppm versus 189 ppm for Dow™ Triton™ X-100. This means that two-thirds less Dow™ Tergitol™ 15-S-9 can be used to achieve the same performance of Dow™ Triton™ X-100. So, while Dow™ Triton™ X-100 is often used at 0.5% (~5000 ppm) solution, Dow™ Tergitol™ can be used at 0.1% (~1000 ppm) to 0.05% (~500 ppm).

IX.4.2 Additionally, Dow™ Tergitol™ 15-S-9 is reported to have a faster dissolution rate (time to dissolve), which combined with the reduced concentration makes the NID cleaning solution preparation easier and faster. Some users of Dow™ Triton™ X-100 report that they mix Dow™ Triton™ X-100 with IPA to improve dissolution which given that users are sometimes using a 1.0% (about 10,000 ppm) solution should not be unexpected.

IX.4.3 However, Dow™ Triton™ X-100 is categorized as a nonylphenol ethoxylate (NPE) and NPE chemical compounds have aquatic toxicity and are being phased-out (ref: *EPA, Nonylphenol (NP) and Nonylphenol Ethoxylates (NPEs), 8/18/2010, Action Plan, RIN 2070-ZA09 (20)*). Dow™ Triton™ X-100 was banned for commercial use/sale in the EU/UK on 4 January 2021 unless an exemption was been authorized. Medical use is authorized through 22 December 2023.

IX.5 **Polysorbate 20 (Tween™ 20):** This is a high performance, foaming, neutral-pH nonionic surfactant. It is commonly used as an emulsifier and wetting agent in a wide range of applications including cosmetics and food additives and is readily and cheaply available. The surfactant is an ethoxylated sorbitan ester (polyoxyethylene sorbitan monolaurate) with 20 moles of ethoxylation and characteristics as specified **Table XI**. The surfactant is very safe for use, having been evaluated as a food additive by *EFSA Panel on Food Additives and Nutrient Sources added to Food (ANS), European Food Safety Authority (EFSA)(21)* and others. This surfactant is very thick/viscous and may be difficult to use, and while having a HLB higher than Tergitol™, the surface tension is much higher, making Tergitol™ 15-S-9 the preferred final cleaner. But for those that cannot easily obtain Tergitol™ 15-S-9, Polysorbate 20 is an option, and should be used at the same concentrations.

Table XI
Polysorbate 20 Nonionic Surfactant Properties

Property	**Polysorbate 20 (Tween™ 20)**
Chemistry	Ethoxylated sorbitan ester
CAS Number	9005-64-6
Cloud Point (°C/°F) at 1%	76°C/169°F
Hydrophilic-Lipophilic Balance (HLB)	16.7
Critical Micelle Concentration (CMC) ppm at 25°C/Surface Tension dynes/cm	60/~41
Specific Density at 25°C	1.1
Appearance	Clear to Yellow Viscous
Viscosity (product is viscous) Note: viscosity of water is 1 cps, and Tergitol 15-S-9 is 60 cps	~300 cps
Foam	High Stable Foam
Environmental Hazard (diluted)	No

IX.6 **ILFORD-ILFOTOL™**: Referencing the discussion in **CHAPTER VIII. DISCUSSION OF PRE-CLEANERS:**, ILFORD-ILFOTOL™ can be substituted as the final cleaner depending on formulation as follows which assumes the formation constituents are at the maximum listed. To determine the version, check to see if the bottle has a manufacture date, or if an expiration date is listed, ILFORD lists ILFOTOL as good for 3-years unopened, but 1-year opened.

IX.6.1 2015 SDS with 5% nonionic surfactant: Mix 10 to 20 mL to one-liter to yield about a 0.05 to 0.1% nonionic detergent solution that with a CMC = about 50 ppm is near equal of 0.05 to 0.1% Dow™ Tergitol™ 15-S-9 with CMC = 52 ppm.

IX.6.2 2017 SDS with 2.5% nonionic surfactant: Mix 20 to 30 mL to one-liter to yield about a 0.05 to 0.075% nonionic detergent solution that with a CMC = 38 ppm is near equal of 0.05 to 0.1% Dow™ Tergitol™ 15-S-9 with CMC = 52 ppm. Note, the 2017 SDS version uses an NPE-free nonionic surfactant with an HLB of 13 and cloud-point of 75.5°C/168°F.

IX.7 **BASF™ DEHYPON® LS 54.** This is a high performance, low foaming, neutral-pH non-ionic surfactant manufactured by BASF™ that those in the UK can purchase Dehypon – Conservation Resources (UK) Ltd (conservation-resources.co.uk). This surfactant is a fatty alcohol C12 - C14 with approximately 5 moles ethylene oxide and 5 moles of propylene oxide (CAS # 68439-51-0). This product is used for cleaning textiles by conservationist as detailed in the paper "*Detergency evaluation of non-ionic surfactant BASF™ DEHYPON® LS54 for textile conservation wet cleaning, Moe Sato & Anita Quye, Journal of the Institute of Conservation, 29 Jan 2019" (53).* The product has been successfully used in ultrasonic cleaning machines such as the Degritter™ that require a low foaming cleaning agent (see **CHAPTER XIV. DISCUSSION OF ULTRASONIC CLEANING MACHINES:**). The product details are listed **Table XII**. Given the very low CMC, for manual cleaning 0.01-0.02% would be recommended. For ultrasonic tanks with pumps that may cause foam, 0.0025 – 0.005% has shown effective – see **CHAPTER XIV. DISCUSSION OF ULTRASONIC CLEANING MACHINES:**.

Table XII
BASF™ DEHYPON® LS 54 Nonionic Surfactant Properties

Property	BASF™ DEHYPON® LS 54
Chemistry	Alcohol, ethoxylated propoxylated
CAS Number	68439-51-06
Cloud Point (°C/°F) at 1% Per ref (6) cloud point at <0.05% ~40°C/104°F.	30°C/86°F
Hydrophilic-Lipophilic Balance (HLB)	Not reported
Critical Micelle Concentration (CMC) ppm at 25°C/Surface Tension dynes/cm	10/29
Specific Density at 25°C	0.97
Appearance	Clear to Yellow Liquid
Viscosity Note: viscosity of water is 1 cps.	70 cps
Foam	Low Foam
Environmental Hazard (diluted)	No

IX.8 **TERGIKLEEN™**: Commonly used commercial product with SDS.

IX.8.1 A blend of two nonionic surfactants – Dow™ Tergitol™ 15-S-3 (not water soluble) and Tergitol™ 15-S-9 (water soluble). Tergitol™ 15-S-3 is a hydrocarbon emulsifier and in water can act as a defoaming agent. Not being soluble, Tergitol™ 15-S-3 has no CMC and does not act as a wetting agent. Tergikleen™ which does not foam has found some acceptance in the UK for use in ultrasonic tanks. The recommended use of 15-20 drops per gallon works out to about 1 mL and with 1-US gallon = 3786 mL the final overall concentration could be 1 mL/3786 mL = 0.00026 = 0.026% = to about 260 ppm.

IX.8.2 Assuming a 50:50 mix, at 130 ppm concentration, the Dow™ Tergitol™ 15-S-9 critical micelle concentration should be achieved lowering the surface tension of the water to about 30 dyne/cm but very little detergent micelle reserve is provided. Some of the Tergitol™ 15-S-9 will be used to keep the Tergitol™ 15-S-3 in solution. If too much Tergikleen™ is added (quantity unknown) the Tergitol™ 15-S-3 which exists as an emulsion will likely come out of solution.

IX.8.3 If using Tergikleen™ as a single application with no water rinse used at 15-20 drops per gallon should not leave a significant residue behind by itself. At an equivalent of about 260 ppm = 260 mg/L, and if 1 to 2 mL of solution dries on the surface = 0.26 to 0.52 mg can be left behind; and what is left behind will essentially be an oil. However, what is left behind will also contain diluted contaminants from the record and therefore the final residue likely to be higher. There are reports by experienced listeners that the residue left behind is audible and is reported as a 'veil' over the high frequency music content. For further discussion see **CHAPTER XI. DISCUSSION OF CLEANLINESS CRITERIA:** and **paragraph** XIV.7.

IX.8.4 Tergikleen™ is the same record cleaning composition specified in *The Care and Handling of Recorded Sound Materials, By Gilles St-Laurent Music Division National Library of Canada January 1996(28)*. *"The Canadian Conservation Institute (CCI) recommends the use of nonionic, ethelyne oxide condensates surfactants to clean sound recordings. The CCI does not foresee long-term problems associated with the use of nonionic surfactants such as Tergitol. Tergitol 15-S-3 is an oil soluble surfactant and 15-S-9 is a water-soluble surfactant. Combined they remove a wide range of dirt and greases and can safely be used on sound recordings. Use 0.25 part of Tergitol 15-S-3 and 0.25 parts of Tergitol 15-S-9 per 100 parts of distilled water. The recording must then be rinsed thoroughly with distilled water to eliminate any trace of detergent residue."*. However, the CCI application concentration is very high; 0.25 parts of Tergitol 15-S-3 and 0.25 parts of Tergitol 15-S-9 per 100 parts of distilled water is the same as 0.25 mL/100 mL = 0.25% = 2500 ppm of each. Tergitol™ 15-S-9 at 2500 ppm is 50 times the CMC. It is unknown whether the *Library of Canada* is still using this formula. However, if in use, it would be in a manual cleaning process similar to that used by the *US Library of Congress* (42) that uses a lot of DIW for final rinse.

CHAPTER X. DISCUSSION OF MATERIAL COMPATIBILITY:

The first priority of cleaning is to do no harm. To address this as it relates to the vinyl record requires a brief discussion of vinyl record composition and then a discussion of chemical compatibility testing.

X.1 **Record Composition**: The magazine *RCA Engineer Vol. 3, No.2. Oct.-Nov. 1957* (64)has eight (8) articles on records including history of the composition, the plating process and molding. There are a number of internet site and forum discussions of vinyl record composition such as

- https://audiokarma.org/forums/index.php?threads/record-cleaning-a-comprehensive-resource.884598/#post-13072519
- https://www.vinylengine.com/turntable_forum/viewtopic.php?t=99579

These are all consistent with what is (noting that actual formulations are highly protected) addressed by *RCA Engineer Magazine, 1976, Issue 02-03, Development of Compound for Quadradiscs, by G.A. Bogantz S.K. Khanna (71)*. The quadradisc composition was developed to provide low wear with the wide bandwidth record using the Shibata™ stylus profile as addressed **CHAPTER I. VINYL RECORD CLEANING CHALLENGES:**. The following summarizes *RCA Patent 3,960,790, June 1, 1976, DISC RECORD AND METHOD OF COMPOUNDING DISC RECORD COMPOSITION (65).* Of interest, the RCA composition "*…results in a surface that wears in a smooth manner and not in a porous granular manner as heretofore experienced.*". Also, it should be noted that RCA did state "*It is a somewhat softer formulation than we had initially expected but with well-defined and controllable elastomeric properties.*".

X.1.1 **Resin**: A 60-70% of a copolymer of vinyl chloride-vinyl acetate resin suspension or solution containing 12-16% by weight of polyvinyl acetate + 26.2-36.2% of a suspension or solution type homo polymer of vinyl chloride. These two resin ingredients should total 96.2%. Note: "*The acetate makes the resin softer and, therefore, acts as an internal plasticizer.*" (source: *RCA Engineer Magazine, 1976 Issue 10-11, Polymer Science - New Materials for Phonograph Discs, by S.K. Khanna (70)*).

X.1.2 **Heat Stabilizer**: 1.6% of a sulfur-free organotin salt containing about 16% tin. All PVC compounds when heated to their glass transition temperature (temperature at which the material becomes soft) release hydrogen chloride gas. This gas triggers a further autocatalytic degradation process, causing rapid discoloration and embrittlement of the PVC. Heat stabilizers increase the heat stability by various mechanisms, such as scavenging of released hydrogen chloride gas molecules. The type of heat stabilizer used depends on the application and required heat stability. Lead compounds were among the first stabilizers used by the PVC industry but due to health concerns, the record industry phased out lead compounds moving to mostly tin based compounds.

X.1.3 **Anti-static Agent** ~1.2%. RCA successfully developed an anti-static record process that was based on a quaternary ammonium salt (specifically, stearamidopropyldimethyl-2-

hydroxyethylammonium nitrate) that coated the resin powder so it was uniformly distributed throughout the record. The details are documented in *RCA Engineer Magazine, 1976 Issue 10-11, Anti-static Phonograph Records by G. P. Humfeld (30)*. RCA as part of the testing determined that carbon black could make the record 'conductive' to impart anti-static properties. But the quantities required then (about 13%) had too many deleterious effects to be practical.

X.1.3.a Today there are many types of anti-static additives classified as either applied externally as discussed **CHAPTER VIII. DISCUSSION OF PRE-CLEANERS:** that are temporary or are internal additives that are longer lasting. Internal quaternary ammonium salt anti-static additives migrate to the record surface where they form a micro-layer of water making the vinyl record 'dissipative' (recall definition **CHAPTER VI. MAINTAINING CLEANLINESS:**). This function is sensitive to ambient humidity and can be removed with many types of cleaning eventually depleting the reservoir of anti-static additive. Do all records have dissipative internal anti-static additives – that is unknown. What is known is that some records play quieter than others and that could be a function of the record surface roughness factor discussed further in **CHAPTER XI. DISCUSSION OF CLEANLINESS CRITERIA:**.

X.1.3.b There are various conductive carbon black pigments now available that can achieve 'dissipation' at less than 5%, and emerging graphene additives that may in the future be able to reduce the record 'conductivity' to achieve permanent anti-static without deleterious effects (source: *Anti-static PVC-graphene Composite through Plasticizer-mediated Exfoliation of Graphite, Wei, Z. B.; Zhao, Y.; Wang, C.; Kuga, S.; Huang, Y.; Wu M. Chinese Journal Polymer Science, June 2018 (81)*.)

X.1.4 **Plasticizer**: 1% of a soybean oil epoxide (ESO) provides a lower melt viscosity of the mixture, which reduces the internal friction of the mixture when it is pressed into a record and thereby improves the moldability by filling the groove with less compression force. More than 1% over-saturates the resin thereby producing oily splotches on the surface of the record, and the splotches result in noise on playback. Some of the many forum discussions on removing mold release may be actually be associated with excess plasticizer/modifier. For information, ESO is a yellowish color. So clear records if they use a plasticizer may use something different from ESO.

X.1.5 **Lubricant**: 0.4% of an esterified montan wax. The wax also acts as a mold release. When the record is removed from the press without the lubricating effect of the montan wax ester in the compound, the grooves of the record are sometimes fractured, torn, and deformed by the removal. These faults in the groove produce noise on playback. Montan wax ester at the stated percentage is compatible with the resins and is homogenized into the surface of the record at the normal pressing temperature. If more than the stated amount of the montan wax ester is used, the excess amount is not absorbed into the surface of the record. Its presence results in non-uniformity in the surface of the record, particularly as related to the friction between the stylus and the groove. This non-uniformity produces noise when the record is played. Some of the many forum discussions on removing mold release may actually be associated with excess lubricant.

X.1.6 **Pigment**: Carbon black 0.2% as a coloring pigment to get black record. For information the natural color of PVC and PVCa is clear. For translucent or colored records, the carbon black is omitted and the percent colorant/pigment adjusted as necessary for the customer. Carbon black is known as an inorganic pigment, and there are organic pigments that may be used.

X.1.7 **Fluorescence**: Viewing records under UV light can show variations in the composition and maybe pressing quality with materials fluorescing different colors; see - A summary of ultra-violet fluorescent materials relevant to Conservation - Australian Institute for the Conservation of Cultural Material (aiccm.org.au). Different pigments will view differently under UV light as indicated in **Figure 41**. Depending on the exact black pigment used, records under UV light can lightly fluoresce with a bluish or brownish type color or appear as just black where the UV light is absorbed. The three records in **Figure 41** vary left to right circa 2000, circa 1980's and circa late 1950's. Recent records appear to now be using black pigments that absorb UV light. The carnauba and paraffin waxes used as "Lubricant" and the ESO-Modifier if excessive may fluoresce with long-wave (365 nm) UV lights, and this may be the source of some of the fluorescence noted in records illustrated **CHAPTER IV. RECORD INSPECTION:**

Figure 41 – Records Inspected UV Light – Pigment Variations

X.2 **Material Compatibility Testing**. There are many PVC material compatibility tables available on the internet. However, most are for rigid-PVC associated with PVC pipe, fittings, and components, and there are often no clear time limits for exposure, and there may be limited applicability to a thin relatively flexible vinyl record. Additionally, some of the PVC material compatibility tables are conflicting especially for alcohols. However, for PVC, there is non-rigid-PVC which by *ASTM-D2287* can contain 10% copolymer/plasticizer, and there is plasticized-PVC (such as vinyl curtains and vinyl-tubing) that can contain 35% and more plasticizer. The following is a summary of quantitative material compatibility testing obtained from the internet with cleaning agents performed for non-rigid and plasticized PVC.

X.2.1 *NAVSEA Report on Aqueous Oxygen Cleaning Products and Processes, 1994 (59)* tested rigid PVC per *ASTM-D1784* and non-rigid-PVC per *ASTM-D2287* (that contains 10% copolymer or plasticizer) to a variety of cleaning agents for up to 24-hours. In general, hot demineralized water and hot inorganic alkaline solutions (pH 12.5, max) and warm neutral pH aqueous cleaners (including one that contained 2-butoxyethanol – a glycol-ether water soluble solvent) did not extract any material and only a small weight gain (<2%) occurred. However, for non-rigid PVC, one hot alkaline detergent solution diluted to 10% showed a weight-loss (1.27%) after 24-hours exposure. The hot alkaline detergent was a concentrated industrial alkaline detergent (Brulin™ 815GD) that contains 5% to 10% nonylphenol ethoxylate nonionic surfactant (CAS 9016-45-9 similar to Dow™ Tergitol™ NP) and 1% to 5% anionic surfactant. Additionally, one near-neutral detergent solution containing 2-butoxyethanol showed an excessive weight gain (>2%). As a cautionary note, 2-butoxyethanol is a respiratory hazard with an allowable exposure limit of 25 ppm, and while used in many past cleaners, is no longer a common ingredient.

X.2.2 The study *A Model Approach for Finding Cleaning Solutions for Plasticized Poly(Vinyl Chloride) Surfaces of Collections Objects by Morales muñoz, Clara & Egsgaard, Helge & Sanz-Landaluze, Jon & Dietz, Christian, 2014 (54)* focused on conservation of PVC-plastic art-works. The study tested thin (2 mm) PVC with 35% plasticizer to exposure times up to 150-seconds at ambient temperature with six (6) different solutions; water, solvents (heptane, ethanol and 1-propanol), two aqeous cleaners (5% BASF™ DEHYPON® LS45 a ethoxylated propoxylated nonionic surfactant (CAS 68439-51-0) with CMC 569 ppm and 5% Hostapon™-T described as an anionic surfactant composed of fatty acid methyl tauride with sodium salt) and a 1-mole(M) potassium hydroxide (KOH) alkaline solution. The solvents at 100% all showed plasticizer extraction, while 50% ethanol-water showed only minimal extraction after 100-seconds exposure. The 5% Hostapon T and 1M KOH aqueous solution showed no extraction and similar to the NAVSEA results, showed only a small weight gain. However, the 5% BASF™ DEHYPON® LS45 aqueous solution showed plasticizer extraction after only 50-seconds exposure and it was noted that the 5% concentration was very difficult to rinse. The paper indicates that the extacted plasticizer in the sample was unknow, but that prior analysis showed 96% diisononyl phthalate (DINP), and 4% di-2-ethylhexyl adipate (DEHA).

X.2.3 The phamplet *Hallstar™ Plasticizers for PVC* (16) tested 40% plasticized-PVC with an unspecified 1% soapy water solution. However, the Hallstar™ results for 1% soapy water, 7-days at 90°C (194°F), consistently showed weight loss for all plasticizers. These results are consist with the testing that was performed by the study *A Comparison of Plasticizers for Use in Flexible Vinyl Medical Products, April 2001 by Richard C. Adams* (38); that tested very thin (thickness 0.5-1.0 mm) 40% plasticized-PVC using an unspecified 1% soapy water solution with exposure times 24-hours and 72-hours at temperatures of 50°C, 60°C & 90°C (122°F, 140°F & 194°F). The study explanation for the weight loss by the 1% soapy water solution was that surfactant micelles can remove plasticizer that is located on the material surface. However, these studies do not specify the constituents in the 1% soapy solution which if a common household detergent can contain many ingredients including alcohol, anionic surfactants; nonionic surfactants, glycerine, colorants, perfumes, etc..

X.2.4 The paper *Kinetics Study of the Migration of Bio-Based Plasticizers in Flexible PVC*, Ching-Feng Mao and De-Bin Chan, *2012 International Conference on Life Science and Engineering IPCBEE vol.45 (2012)* tested the migration of five different plasticizers (at concentrations about 30%) from very thin flexible PVC of 1 mm under contact with polystrene sheets at 190°C for 10 min. The plasticizers tested were acetyl tributyl citrate (ATBC), di (2-ethylhexyl) phthalate (DEHP), di (2-ethylhexyl), adipate (DEHA), and epoxidized soybean oil (ESO). The PVC/ESO showed no weight loss, while the PVC/DEHP was about 2%, PVC/ATBC was about 7% weight loss and PVC/DEHA was about 12% weight loss. The stability of the ESO plasticizer, the same used in the RCA™ record composition, is noteworthy.

X.3 **Data Analysis**: Its important understand that the record composition of PVCa, PVC and pigment form a polymer while any added plasticizer acts as a solvent. How each of these can be attacked by a cleaning agent should yield different, but predictable results. When the results are contrary to what is predicted, there is reason to challenge the test data.

X.3.1 Plasticizers can migrate from polymers based on three general mechanisms 1) evaporation to the ambient – same as off-gassing; 2) extracted by being soluble with liquids in contact; and 3) transfer from one surface of another. So, extacting a plasticizer is noted by weight loss.

X.3.2 Solvent dissolution of polymers follow a well documented path. The paper *A review of polymer dissolution, Beth A. Miller-Chou, Jack L. Koenig, Prog. Polym. Sci. 28 (2003) 1223–1270* states: *"First, the solvent begins its aggression by pushing the swollen polymer substance into the solvent, and, as time progresses, a more dilute upper layer is pushed in the direction of the solvent stream. Further penetration of the solvent into the solid polymer increases the swollen surface layer until, at the end of the swelling time, a quasistationary state is reached where the transport of the macromolecules from the surface into the solution prevents a further increase of the layer."*. So, for a polymer, evidence of swell and maybe weight gain are the first evidence of attack.

X.3.3 Some polymers such as Nylon are hydroscopic and will gain weight in contact with water, but over time will release the absorbed moisture and recover. PVC is only marginally hydroscopic (1-2%), so minor weight gain after exposure to water or an aqueous surfactant solution may be associated with minor swell. The weight gain associated with aqueous surfactants noted in the NAVSEA testing may water absorption and surfactant residue. High concentration surfactant solutions – those at many times the CMC, are known to be difficult to rinse and so weight gain can be a consquence. Also, the water loving head of the surfactant is hydroscopic, and if left behind will want to absorb moisture. Nonionic surfactants are known to be weak anti-static agents. In some cases such as anti-static cationic surfactants, it's intended that a surfactant film be deposited that absorbs moisture from the air since this is how the anti-static functions.

X.3.4 The weight loss and plasticizer extraction test results with solvents, Brulin™ 815GD and 5% BASF™ DEHYPON® LS45 a nonionic surfactant can be explained. Common plasticizers used in non-rigid PVC are phthaltes and the plasticizer DINP is mainly from C9 – branched alcohol isomers. So the ability of alcohols and 5% BASF™ DEHYPON® LS45 a C12-C14 ethoxalyated alcohol non-ionic detergent to extact this plasticizer should not be unexpected. As a side note, the plasticizer DINP is part of a family of phthalate plasticizers that along with bisphenol A (BPA) have received wide attention for their toxicity concerns in plastic bottles and the ability to be extracted. Overall, it is very unlikely that record compositions include any phthalate plasticizers.

X.3.5 The ability of 1% soap solutions to extract a plastizicer from flexible PVC containing upwards of 40% plasticizer should not be unexpected. The testing was performed at high temperatures and durations with an indeterminant cleaner composition that may have contained any number of ingredients including ethanol, IPA, and likely an alcohol derived nonionic surfactant. As a side note, Hallstar™ does not manufacture ESO plasticizer, so the 1% soap solution testing does not include the ESO plasticizer used by the RCA™ patent.

X.3.6 However, none of the quantitative testing for non-rigid/flexible PVC has any real correlation to the PVCa/PVC record composition detailed in the RCA™ patent. The plasticizer in the RCA™ record composition is only 1% or less and the ESO plasticizer is not commonly used in flexible PVC because of poor mechanical properties, but is a very stable plasticizer in PVC unlikely to be extracted by any aqueous solution. Additionally, the vinyl record PVCa/PVC composition is predominantly a copolymer + homopolymer and is unlikely to be attacked by any aqueous surfactant solution. Additionally, because plasticizers migrate, if the record contained any appreciable amount, it would never last as long as it does.

X.4 **Aqueous Surfactant Cleaner Summary:** There is no data that supports that an aqueous surfactant cleaner (less any solvent such as alcohol) of mildly acidic to near neutral pH to mildly alkaline is going to harm a modern (1970's and later) PVCa/PVC record used at any application temperature that would not otherwise soften/harm the record. The greatest harm from surfactant-based cleaners is failure to rinse leaving residue that can then lead to other consequences. However, recalling **CHAPTER IV. RECORD INSPECTION:** and **paragraph** VIII.10.3.c, there is variability in the record composition especially with re-pressed (recycled) records or very early records (1950's to 1960's) that may have used lead-based heat stabilizer. Therefore, to be conservative, using the smallest chemical concentration is always prudent. From this perspective, there is no evidence that the Alconox™ Liquinox™ pre-cleaner at 1% concentration, Alconox™ Citranox™ acid at 1.5% concentration or the Dow™ Tergitol™ 15-S-9 final cleaner at 0.1% concentration for **short exposure times** at temperatures up to about 40°C (104°F) will have material compatibility issues with PVCa/PVC vinyl records, substantiated as follows.

X.4.1 The manual cleaning process specified herein (and vacuum RCM) exposes the vinyl record to the cleaning solutions at room temperature for an accumulated time of only a few minutes – 5 minutes at most. Even if used in heated ultrasonic tanks for longer durations up to about 15 minutes, the exposure time is still very short.

X.4.2 The concentrations recommended herein are all very low in comparison to those tested. The 0.1% Tergitol 15-S-9 recommended herein is 50 times less than the 5% BASF™ DEHYPON® LS45, and 10 times less the 10% alkaline detergent (Brulin™ 815GD) that when diluted would contain 0.5% to 1% nonionic surfactant. and 0.1% to 0.5% anionic surfactant.

X.4.3 The Alconox™ Liquinox™ concentrate contains two anionic surfactants combined for 12.5% to 35% and two nonionic surfactants - one an amine at 1% to 2%, the other an ethoxylated nonionic surfactant similar (by CAS No.) to Dow™ Tergitol™ 15-S-9 at 2.5% to 10%. Diluted to 0.5% to 1% as specified herein, in use the Alconox™ Liquinox™ pre-cleaner contains only a maximum of 0.1% ethoxylated nonionic detergent; a concentration no different from that specified herein for use of Dow™ Tergitol™ 15-S-9. While the sodium alkylbenzene sulfonate anionic surfactant in Alconox™ Liquinox™ is more aggressive than the mild anionic surfactant used in Hostapon™-T; diluted to 1%, in use the Alconox™ Liquinox™ anionic surfactant concentration is only 0.35% which is 14 times less than the tested 5% Hostapon™-T.

X.4.4 Other than anionic and nonionic surfactants, Alconox™ Citranox™ contains two weak organic acids; citric acid and glycolic acid and the pH stabilizer triethanolamine (TEA). These two acids are common to many household products including skin care, cleaners, and food additives. Review of material compatibility tables indicates flexible PVC is compatible with both acids at room temperature; especially at the low use concentration. Distilled white vinegar (5% acetic acid) although classified as a weak acid is also classified as a solvent and is compatible at 5%, but at higher concentrations may not be compatible and this is evaluated further in **Section** X.5. Most material compatibility tables list triethanolamine as compatible at room temperature, some show incompatible at high temperature and at least one shows incompatible at room temperature. However, the in-use concentration of 0.15% is very low (with solvency close to water – see **Table XIII**), and is safe for cosmetic products and their packaging and used at room temperature for the limited exposure time is consider safe for the record.

X.4.5 The paper *Corrosion of Lead and its Alloys, Stuart Lyon, December 2010* (74) indicates that the solubility of lead is greater in distilled water than in anionic solutions stating that "*In distilled water free from dissolved gases, corrosion is slight though significant however, the rate of corrosion is increased by the presence of oxygen.*"; and "*Lead is not generally attacked rapidly by solutions that contain anions where the lead salt is sparingly soluble and, hence, where lead can passivate by the formation of a salt film.*". The detrimental effects noted by *Record Contamination: Causes and Cure by Percy Wilson, 1965 (61)* in **paragraph** VIII.10.3.c may have been from residue left behind versus a short exposure followed by DIW rinse. Additionally, cationic surfactants have been used for anti-static record ingredients and coatings since 1960 per *Anti-Static Phonograph Records G. P. Humfeld, RCA Engineer Magazine Vol. 6, No.3. October-November, 1960 (29).* However, as previously addressed **CHAPTER VIII. DISCUSSION OF PRE-CLEANERS:**, anionic surfactants are generally not compatible/soluble with cationic surfactants, so this may have been the root cause for the observation.

X.4.6 The use of cleaning agents in ultrasonic cleaning machines (UCM) heated to the point that the record no longer has the same stiffness as room temperature should be approached with Caution especially if using a cleaning agent other than just purified water. Chemical reaction rates are proportional to temperature. The Dow™ Tergitol™ 15-S-9 final cleaner at less than 0.1% concentration and the Alconox™ Liquinox™ pre-cleaner at less than 1% concentration should be UCM compatible with vinyl records, but time and temperature need to be considered and further details and recommendations are addressed **CHAPTER XIV. DISCUSSION OF ULTRASONIC CLEANING MACHINES:**. But, use of other aqueous cleaning agents without knowing detailed constituents could present a risk and using the least amount for the shortest time prudent.

X.5 **Solvent Compatibility with Records**: Solvents can dissolve polymers, and solvents can span a wide variety of chemistries. One of the constant debates at many forums is the use of ethanol and isopropanol (IPA) alcohol solvents and their material compatibility with records. There are no definitive test results. There are some tests exposing a few records with visual observation and subsequent playback to determine change in sound. One test did analyze the alcohol for evidence of extracted components, and none where found which is predictable. But these do not duplicate the 'gold-standard' testing that RCA™ did, and are unlikely to determine the actual effect which is more likely associated with swell and causing accelerated wear of the record. In an attempt (*as futile as it may be*), to address the issue, a basic Hansen Solubility Parameter Analysis was performed.

X.5.1 *Charles M. Hansen (Ph.D)* in 1967 developed a method to predict if one material will dissolve in another. The method is based on one of foundations of chemistry that "**like dissolves like**". Hansen expanded upon the *Hildebrand* solubility parameter to establish three parameters that would characterize the forces that hold the molecule together.

$$\sqrt{(\partial d^2 + \partial p^2 + \partial h^2)} = \partial t$$

Where: ∂d = the energy from dispersion forces between molecules

∂p = the energy from dipolar intermolecular force between molecules

∂h = the energy from hydrogen bonds between molecules.

∂t = the total and is the *Hildebrand* solubility parameter that is the sum of the squares of the three *Hansen* parameters

X.5.2 For polymers, the three parameters are used to calculate a sphere with radius-R. The smaller the radius-R, generally, the smaller the number of solvents that can attack/swell/dissolve the polymer. For solvents, the three parameters are used to calculate their distance from the center of the polymer sphere D(S-P) as follows where 's' designates the applicable solvent parameter and 'p' designates the applicable polymer parameter.

$$D_{(S\text{-}P)} = [4(\partial_d s - \partial_d p)^2 + (\partial_p s - \partial_p p)^2 + (\partial_h s - \partial_h p)2]^{0.5}$$

X.5.3 D(S-P)-R = distance of the solvent from the center of the polymer solubility sphere.

- D(S-P)-R< 1; If less than the radius of interaction for the polymer, the polymer will likely be partially or completely soluble in the solvent.

- D(S-P)-R= 1; If equal to the radius of interaction for the polymer, the polymer is likely to swell and may partially dissolve in the solvent.

- D(S-P)-R> 1; If greater than the radius of interaction for the polymer, the polymer will not dissolve but depending on how close to the radius of interaction for the polymer, the solvent may cause the polymer to swell.

X.5.4 **Table XIV** show the analysis results. Remember the analysis is only a prediction, but it compares against known data, and this assumes room temperature. Heated applications such as ultrasonic tank cleaning accelerate chemical reaction rates and the results could be worse. The term "weight gain" may only apply to the side wall ridge peaks and only measurable in micro-grams (µg).

X.5.5 The first take-away is that the record PVCa/PVC composition is not that much different than PVC. But, it's important to do a stepped proportional analysis where PVCa at the allowable variation is first determined. Otherwise, doing just an analysis of the total PVC + PVA will yield solubility spheres much larger than those calculated herein making the record appear less compatible than it likely is.

X.5.6 For a quick summary, use of ethanol and IPA at 20% or less are unlikely to cause any material compatibility issues used at any temperature that will not damage/warp the record, flammability and explosion hazard notwithstanding. At higher concentrations, there is uncertainty and results will be dependent on the specific record composition; application temperature; polymer weight to solvent volume and the exposure time. However, high concentrations at higher temperatures, fire and explosion risk should preclude use. Is someone using 70% to 100% alcohol to wipe a record for a few minutes using just a few milliliters going to cause harm? It is very unlikely.

X.5.7 Soaking a record with high concentrations of alcohol solvents at room temperature for extended periods could be harmful. We do not how reversible is any swell, and we do not know the exact record composition. If reversible such as Nylon, and adequate time between cleaning and play, then little harm will occur. If, not, and the record properties are altered – likely softened or possibly hardened, in either case accelerated record wear would be expected and the high frequency side wall ridges/peaks that are the thinnest portion of the record should be the most susceptible. If they soften, the stylus will permanently bend/smear the peak and high frequency data (signal amplitude/strength) will be attenuated/lost.

Table XIII
Hansen Solubility Parameter Record Polymers & Solvents

Material	**Total ∂t**	**Dispersion ∂_d**	**Polar ∂_p**	**Hydrogen ∂_h**	**Radius R**
POLYMERS					
Polyvinyl Chloride (PVC)	21.36	18.20	7.50	8.30	3.50
Polyvinyl Acetate (PVAc)	25.66	20.93	11.27	9.66	13.71
Polyvinyl Chloride-Acetate 60% PVCa - calculated (44% PVC/16% PVA)	13.83	11.36	5.10	6.03	4.08
Polyvinyl Chloride-Acetate 70% PVCa calculated	15.46	13.07	5.70	5.97	4.22

Material	Total ∂t	Dispersion ∂_d	Polar ∂_p	Hydrogen ∂_h	Radius R
(58% PVC/12% PVA)					
Inorganic Carbon Black (CB) Pigment 250 nm	26.91	21.10	12.30	11.30	16.60
Organic Pigments (OP) Black or Red	13.00	9.80	7.70	5.00	5.20
RECORD COMPOSITIONS Per the RCA Patent (calculated parameters)					
Record 60% PVCa + 36.2%-PVC + 0.2%-CB	16.05	13.42	5.79	6.63	3.73
Record 70% PVCa + 26.2%-PVC + 0.2%-CB	16.47	13.96	5.98	6.38	3.91
SOLVENTS - Listed Total (∂t) Increasing					
VM+P Naptha (ingredients similar to Zippo™ Lighter Fluid)	15.48	15.00	2.70	2.70	NA
Epoxidized Soybean Oil (ESO) plasticizer	17.34	16.50	1.60	5.10	NA
100% Toluene	18.20	18.00	1.40	2.00	NA
100% Methyl Ethyl Ketone	19.00	16.00	9.00	5.10	NA
100% Acetone	20.00	15.50	10.40	7.00	NA
100% Acetic Acid	21.37	14.50	8.00	13.50	NA
100% IPA	23.50	15.80	6.10	16.40	NA
91% IPA/Water	25.47	15.78	6.99	18.73	NA
100% Ethanol	26.50	15.80	8.80	19.40	NA
95% Ethanol + 5% Methanol (denatured)	26.67	15.77	8.98	19.55	NA
100% Propylene Glycol	29.52	16.80	9.40	23.30	NA
70% IPA/Water	30.24	15.74	9.07	24.17	NA
30% Acetic Acid/Water (Distilled White Vinegar)	39.38	15.27	13.60	33.66	NA
20% IPA/Water	42.65	15.64	14.02	37.12	NA
0.15% Triethanolamine/Water	47.15	15.47	15.94	41.59	NA
Water	47.80	15.60	16.00	42.30	NA

Table XIV
Hansen Solubility Parameter Record & Solvents Analysis

Combination	Solvent Distance from Polymer Center D(S-P)	Polymer Radius R	D(S-P)-R	Data/Risks
PVC & Solvent - Documented Baseline Data for Comparison Tested 0.5 gm polymer in 5 mL solvent				
PVC % 100% Methyl Ethyl Ketone	3.90	3.50	0.40	Testing showed strongly swollen & sightly soluble
PVC & 100% Toluene	4.98	3.50	1.48	Testing showed swelling
PVC % 100% Acetone	5.91	3.50	2.41	Testing showed swelling
PVC & 100% Propylene Glycol	6.44	3.50	2.94	Testing showed compatible
PVC & 100% Ethanol	6.85	3.50	3.35	Testing showed compatible
PVC & 100% Acetic Acid	8.09	3.50	4.59	Testing showed compatible
LEAST SENSITIVE RECORD FORMULATION **Record 60% PVCa + 36.2%-PVC + 0.2%-CB**				
Record & VM+P Naptha	3.38	3.75	-0.37	Incompatible
Record & 100% Acetone	6.23	3.75	2.48	Likely to result in swelling
Record & 100% IPA	6.46	3.75	2.71	May result in swelling
Record & 91% IPA	6.89	3.75	3.14	Likely compatible
Record & 100% Ethanol	7.53	3.75	3.78	Likely compatible
Record & Denatured Ethanol	7.58	3.75	3.83	Very likely compatible
Record & 70% IPA	8.17	3.75	4.42	Compatible
Record & 30% Acetic Acid (Vinegar)	11.32	3.75	7.57	Compatible
Record & 20% IPA	12.16	3.75	8.41	Compatible
Record & Water	13.92	3.75	10.17	Compatible
MOST SENSITIVE RECORD FORMULATION **Record 70% PVCa + 26.2%-PVC + 0.2%-CB**				
Record & VM+P Naptha	3.38	3.91	-0.53	Incompatible
Record & 100% Acetone	5.50	3.91	1.60	Likely to cause swelling

Combination	Solvent Distance from Polymer Center D(S-P)	Polymer Radius R	D(S-P)-R	Data/Risks
Record & 100% IPA	5.80	3.91	1.89	Likely to cause swelling
Record & 91% IPA	6.25	3.91	2.34	May cause swelling
Record & 100% Ethanol	6.90	3.91	2.99	Likely compatible
Record & Denatured Ethanol	6.95	3.91	3.05	Likely compatible
Record & 70% IPA	7.60	3.91	3.70	Very likely compatible
Record & 30% Acetic Acid (Vinegar)	10.93	3.91	7.02	Compatible
Record & 20% IPA	11.72	3.91	7.82	Compatible
Record & Water	13.53	3.91	9.62	Compatible

X.6 **Closing thoughts:** Off-gas testing may be an easy, low-cost qualitative test for solvent absorption (polymer swell). IPA is not expected to extract anything; any attack should cause swell. The following procedure could be used for a qualitative test:

X.6.1. Soak a record sample in IPA for X-hrs.

X.6.2. Remove the record sample from the IPA and allow any IPA to dry/evaporate for ~15 minutes.

X.6.3. Check for odor; IPA has a very low odor threshold ~22 ppm. If there was odor, this is the first evidence that the record absorbed ‘some’ IPA.

X.6.4. If odor-free (more likely) place the sample in a sealed glass container and heat in a water bath at 95°F to 100°F for 2-4 hours.

X.6.5. Check the container air for odor. If it smells of IPA, the record likely experienced some swell; and even a small amount can have an impact.

X.6.6. Industry advances this off-gas test by placing samples in an oven filled with oil-free nitrogen and then samples with a GC/MS to get quantitative results with sensitivity to 1 ppb. But off-gas testing using just our noses can be very sensitive for what we are concerned with and eliminates the many variables associated with trying to measure and analyze weight change.

CHAPTER XI. DISCUSSION OF CLEANLINESS CRITERIA:

When cleaning any item, there is the very first question - "What is clean?", and for a record the next question should be "When is a vinyl record clean?" **CHAPTER I. VINYL RECORD CLEANING CHALLENGES:** indicated we have no practical quantitative verification method. This Chapter *attempts* to answer these questions by establishing quantitative criteria and to show that the process detailed **CHAPTER V. MANUAL CLEANING PROCESS:** can achieve a *clean vinyl record*.

XI.1 The concluding statements from **CHAPTER I. VINYL RECORD CLEANING CHALLENGES:** are that for vinyl records, a robust precision cleaning process is required to achieve desired cleanliness. In the precision cleaning industry, there are visual and quantitative cleanliness levels. The following are the visual cleanliness levels commonly used by *MIL-STD-1330D (51)*, *MIL-STD-1622B (52)* and NASA adjusted for a vinyl record.

XI.1.1 **Generally Clean (GC)**: Freedom from manufacturing residue, dirt, oil, grease, etc. The generally clean level is specified for hardware that is not sensitive to contamination and is easily cleaned or recleaned. A vinyl record that passes GC can have particles greater than 50 microns and organic contamination greater than 50 mg/ft^2 present. This level of cleanliness is insufficient for a vinyl record. The user will experience annoying noises, possible collection of 'gunk' on the stylus and the playback fidelity will likely be compromised.

XI.1.2 **Visibly Clean (VC)**: Free of all particulate and nonparticulate matter visible to the normal unaided eye or corrected vision eye with bright white light. This level is for hardware that requires removal of surface particulate and nonparticulate for operation; or hardware for which recleaning would be difficult and/or time consuming. A vinyl record that passes VC can have many particles less than ~50 microns and have organic contamination as high as 50 mg/ft^2 depending on the contaminant. This level of cleanliness is achieved with simple wet brushes but based on groove dimensions and geometry is insufficient to prevent annoying noises or an accumulation of 'gunk' on the stylus, and maximum fidelity from a vinyl record is unlikely.

XI.1.3 **Visibly Clean + Ultraviolet (VS+UV)**: Visually clean and inspected with ultraviolet light. This level is usually specified for hardware that cannot tolerate buildup of hydrocarbons between uses or operations, and is more sensitive to particulate, but is limited to only those contaminants that are visible and fluoresce. A vinyl record that passes VS+UV can have many particles less than ~25 microns and have organic contamination of 25 to 50 mg/ft^2 depending on the contaminant. Lightweight mineral oils that do not fluoresce can be non-detectable with VS at levels of 50 mg mg/ft^2. Cleanliness level VS+UV based on groove dimensions and geometry is insufficient to prevent annoying noises and to obtain maximum fidelity from a vinyl record. However, once cleanliness is established by a precision wet cleaning process, VS+UV should be suitable for maintenance of cleanliness. This concept is fundamental to *MIL-STD-1330D* (51) and *MIL-STD-1622B (52)*.

XI.2 *MIL-STD-1246C, Product Cleanliness Levels and Contamination Control Program* (50) (now superseded by commercial specification IEST-STD-1246) has been a source for defining quantitative product cleanliness levels in terms of allowable particulate and allowable non-volatile residue (NVR) for decades. Other agencies such as NASA specify similar cleanliness levels. Some of the various cleanliness levels are defined in **Table XV**. Achieving a cleanliness level of 50A in a residential setting is a challenge - but doable (as will be discussed); aided by vinyl records having the advantage of being a fairly robust, reasonably hard material that is not porous and has no inaccessible areas. The following are a few notes to **Table XV**.

XI.2.1 When specifying cleanliness requirements, the particulate level and non-volatile residue (NVR) level are specified separately, so for example a cleanliness level of 100A can be specified.

XI.2.2 Because of how particle counts are measured, *MIL-STD-1246C* (50) can show fractional counts. For the purposes of this document, and similar to how other activities specify particulate cleanliness levels, all counts are simply ranged and all counts are rounded-up. For each cleanliness level, particles smaller than the smallest specified have an allowable count that is unlimited (but silting is not allowed).

XI.2.3 The pre-clean, rinse, final clean, rinse process detailed in *MIL-STD-1330D* (51) and similar type precision processes can routinely achieve cleanliness Level 50A. While *MIL-STD-1330D* (51) uses a parts washer or ultrasonic tank for final cleaning, the use is for complex geometries, process efficiency (many parts at-once) and for cleanliness verification. The final clean step of **CHAPTER V. MANUAL CLEANING PROCESS:** is as effective for cleaning and this will be shown in **Table XVI**.

XI.2.4 A particulate Level 25 (and less) can generally only be achieved in a controlled cleanroom or equally controlled environment such as provided by a vertical air flow (laminar) bench or hood with HEPA air filters, that are readily available from a number of vendors, but at costs starting at about $3K. However, as addressed in **CHAPTER V. MANUAL CLEANING PROCESS:**, use of lower cost, portable room or desk-top HEPA air filter should establish a temporary area of very low levels of airborne particulate for those so inclined.

XI.2.5 The flat surface area of each 12-inch record (minus label area) side calculates to about 0.6-ft^2. However, the grooves and side wall ridges add surface area. Using the nominal groove dimensions from **CHAPTER I. VINYL RECORD CLEANING CHALLENGES:**, the groove side wall (triangle hypotenuse) is about 0.0016-inches so that each groove that is about 0.0022-inch wide at the top has about 0.0032-inches linear length and 0.0032”/0.0022” = 1.46 correction to the 0.6-ft^2 calculated flat surface area. Adding 10% for the side wall ridges, the actual record surface area = (0.6-ft^2 flat surface area) x (1.46 groove correction) x (1.1 side wall correction) = 0.96-ft^2. Rounding up, a 12-inch record has an actual surface area of about 1.0-ft^2. The 1-ft^2 area makes its very simple to convert NVR mg/ft^2 to film thickness.

XI.2.6 The NVR nominal film thickness (*Contamination Control Engineering Design Guidelines for the Aerospace Community, NASA Contractor Report 4740, May 1996) (55)* shown in **Table XV** assumes the contaminant is uniformly applied and has a density of 1-g/cm^3 = 62.43 lbs/ft^3 (same as freshwater); and while a 1-micron film calculates to about 9.1 mg/ft^2, for ease of use 10 mg/ft^2 equals 1-micron thickness is applied. Most water-soluble nonionic surfactants have a density very close to water, but lower density contaminants such as oil will develop larger film thickness while denser contaminants such as hard water spots develop thinner thickness as noted for **Table VII**.

Table XV
MIL-STD-1246C Particulate and NVR Cleanliness Levels

Particulate		
Level	**Particle Size microns**	**Allowable Count/ft^2**
25	≥2 <5	53
	≥5 <15	23
	≥15 <25	4
	≥25	1
50	≥5 <15	166
	≥15 <25	25
	≥25< 50	8
	≥50	1
100	≥5 <15	1785
	≥15<25	265
	≥25<50	78
	≥50 <100	11
	≥100	1

Non-Volatile Reside		
Level	**Limit**	**Nominal Film Thickness**
A/2	0.5 mg/ft^2	0.05 micron
A	1.0 mg/ft^2	0.10 micron
B	2.0 mg/ft^2	0.20 micron
E	5.0 mg/ft^2	0.50 micron
G	10.0 mg/ft^2	1.00 micron
J	25.0 mg/ft^2	2.50 micron

XI.3 **Figure 42** and **Table XVI** are a process analysis of the estimated NVR remaining from the pre-clean and final clean steps specified by the process detailed in **CHAPTER V. MANUAL CLEANING PROCESS:**. **Table XVI** is intended to show how the overall cleaning process can achieve an NVR cleanliness Level A of less than or equal to 1.0 mg/ft^2. **Table XVI** also shows that cleaning agents have more NVR than the NVR being removed, and shows why using tap-water for the pre-rinse, and rinsing after each cleaning agent application is acceptable**. Table XVI** has been formatted to allow easy conversion to a spreadsheet allowing users to adjust initial record NVR and chemistry to see results. **Table XVI** was developed as follows:

XI.3.1 An initial heavy soil load of 25 milligrams (that would include particulate) is used and should not be considered unrealistic for a dirty record.

XI.3.2 For the purposes of water, equivalent TDS-ppm converted to milligrams from **Table VI** was used for NVR, while the cleaner concentration in ppm converted to milligrams was used for NVR. For ease of analysis, all ppm is assumed equal to mg/L, so TDS of 200 ppm = 200 mg/L. All solutions are then corrected for the amount of solution applied or allowed to dry = (solution mL/1000).

XI.3.3 There are some assumptions since the cleaners will release and contain contaminates removed from the record surface. The amount of cleaning solution on the record is about 25 mL based on a simple test that measured the amount applied to a record. The NVR removed from the record is equally distributed in the 25 mL of cleaning solution. Each cleaning step is assumed to be 90% efficient for how it is applied. The final-cleaner would not be 90% efficient in removing an initial heavy soil load because of the small amount (about 25 mL) of cleaner and type of cleaner used. **Table XVI** should show that the high concentration pre-cleaner and acid-cleaner are doing the heavy-lifting, removing the bulk of the soil, while the lower concentration final cleaner does the final polish. However, it is important to note that because of the limited amount of cleaning solution used (~25 mL), exceptionally dirty records can exhaust the chemistry which is why **CHAPTER V. MANUAL CLEANING PROCESS:** recommends using two (2) pre-clean steps for these records.

XI.3.4 The effectiveness of the rinse under essentially unlimited, flowing tap-water may achieve better than specified, but to be conservative is assumed at 95% for this analysis and is shown in the Item 8 calculation.

XI.3.5 The lower efficiency of 85% for the final spray rinse is intended to account for the limited amount of DIW used and application inefficiency and is shown in the Item 10 calculation.

XI.3.6 To determine the NVR contamination level (mg/ft^2), the assumption (by simple measured test) is that 5-mL of post rinse water-solution dries on the surface, and the resulting NVR in milligrams is distributed across the record that was previously calculated to be about 1.0 ft^2 minus the label. This is calculated in Items 8 and 10.

XI.3.7 The final NVR on the record after each cleaning step is the sum of NVR not removed plus the NVR left from the cleaner/rinse and this shown in Item 12. However, the worst case is that the NVR is only in the groove so Item 14 shows that equivalent recalling that the groove is about 40% of the total record surface.

XI.3.8 Items 13 & 15 converts Items 12 & 14 to the film thickness.

XI.3.9 Pursuant to **Table XVI** and **Figure 42**, the NVR cleanliness goal of **Table XV** Level A (1.0 mg/ft^2) should be easily achievable, and NVR Level A/2 likely.

Figure 42 – Record NVR Following Precision Aqueous Cleaning Process

Table XVI
Remaining NVR Analysis After Pre-Clean, Acid-Clean & Final Clean

Item	Description	Pre-Clean Step	Acid-Wash Step	Final Clean Step
1	Initial record NVR • Acid-Clean Step NVR is from Pre-Clean Item 11. • Final Clean Step NVR is from Acid-Clean Item 11.	25 mg	2.5 mg	1.4 mg
2	5-mL water on record NVR after Pre-Rinse with tap-water [(assumes 200 ppm TDS) x (0.005)]	1 mg	NA	NA
3	Record NVR left from cleaning • Acid-Clean Step NVR is from Pre-Clean Item 8. • Final Clean Step NVR is from Acid-Clean Item 8.	NA	2.1 mg	1.1 mg
4	Cleaner NVR from 25 mL application [(cleaner ppm/40)]	125 mg	250.0 mg	25.0 mg
5	Estimated NVR removed from record at 90% cleaner efficiency [(Item 1) x (0.90)]	22.5 mg	2.3 mg	1.2 mg
6	Total cleaner solution NVR before rinse (sum of items 2:5)	148.5 mg	254.4 mg	27.3 mg
7	Tap-water rinse NVR (unlimited volume) (assumes 200 ppm TDS)	200.0 mg	200.0 mg	200.0 mg
8	5-mL water on record NVR after 95% effective rinse with flowing tap-water [(item 6) x (0.05) +(item 7)] x (0.005)	1.0 mg	1.1 mg	1.0 mg
9	Purified water rinse NVR (2.5 ppm from **Table VI**)	NA	NA	2.5 mg
10	5-mL water on record NVR after 85% effective rinse with spray purified water [(item 8 x 0.15) +(Item 9)] x (0.005)	NA	NA	0.01 mg
11	Record NVR still remaining after cleaning • For Pre-Clean and Acid-Clean sum of (Item 1 x 0.1) + Item 8. • For Final-Clean sum of (Item 1 x 0.1) + Item 10	3.5 mg	1.4 mg	0.13 mg

Item	Description	Pre-Clean Step	Acid-Wash Step	Final Clean Step
12	Best-case Equivalent total surface NVR contamination level • Pre-clean = sum of items 8 + 11; acid clean = sum of Items 8 + 11 • Final-clean = sum of Items 10 + 11.	**3.5 mg/ft²**	**1.4 mg/ft²**	**0.13 mg/ft²**
13	Best-case: Equivalent film thickness from Item 12 (Item 12) x (1 mg/ft²/0.01 micron)	**0.4 microns**	**0.2 microns**	**0.02 microns**
14	Worst-case: Equivalent surface contamination level assuming Item 12 is only in the groove that is 40% of the record total surface. (Item 12/0.4)	**9.0 mg/ft²**	**3.5 mg/ft²**	**0.33 mg/ft²**
15	Worst-case: Equivalent film thickness assuming Item 12 is only in the groove (Item 13) x (1 mg/ft²/0.01 micron)	**0.9 microns**	**0.4 microns**	**0.04 microns**

XI.4 **What Detritus is Audible**? Having discussed what is clean, and what a reasonable cleaning process can achieve, the existential question remains – is what can be achieved using reasonable chemistry and methods good enough for a record? Audio forum reports from users using ultrasonic cleaning machines (UCM) without rinsing, indicate that by analysis of the bath cleaning concentration, cleaner (surfactant) residue equal to much greater than 150 mg/L (150 ppm) can be left behind and many report stylus residues, and those with critical listening skills hear distortion noted as "veiling of the music". This begs the question; how large do imperfections need to be before they are audible?

XI.4.1 While **CHAPTER I. VINYL RECORD CLEANING CHALLENGES:** summarized the groove dimensions and geometry, very little detail was provided. The details of the groove geometry and the dynamic relationship of the stylus to that geometry can be affected by the record cleanliness. The lateral and vertical displacement defines the signal amplitude/output. The record spinning at ~33.333 revolutions per minute (rpm) = 0.56 revolutions per second (rps); the linear (tangential) velocity will vary from 51 cm/sec (20 inches/sec) at the outer-most groove to 20 cm/sec (7.9 inches/sec) at the inner-most groove. **Figure 43** shows simplistically the groove modulation wavelength (ridge to ridge distance) to reproduce various frequencies between the outer and inner-most grooves for 12-inch, 33.333 rpm and 45 rpm records. At the highest frequency the values can be as small as 10 microns for a 33.333 rpm record at the inner groove.

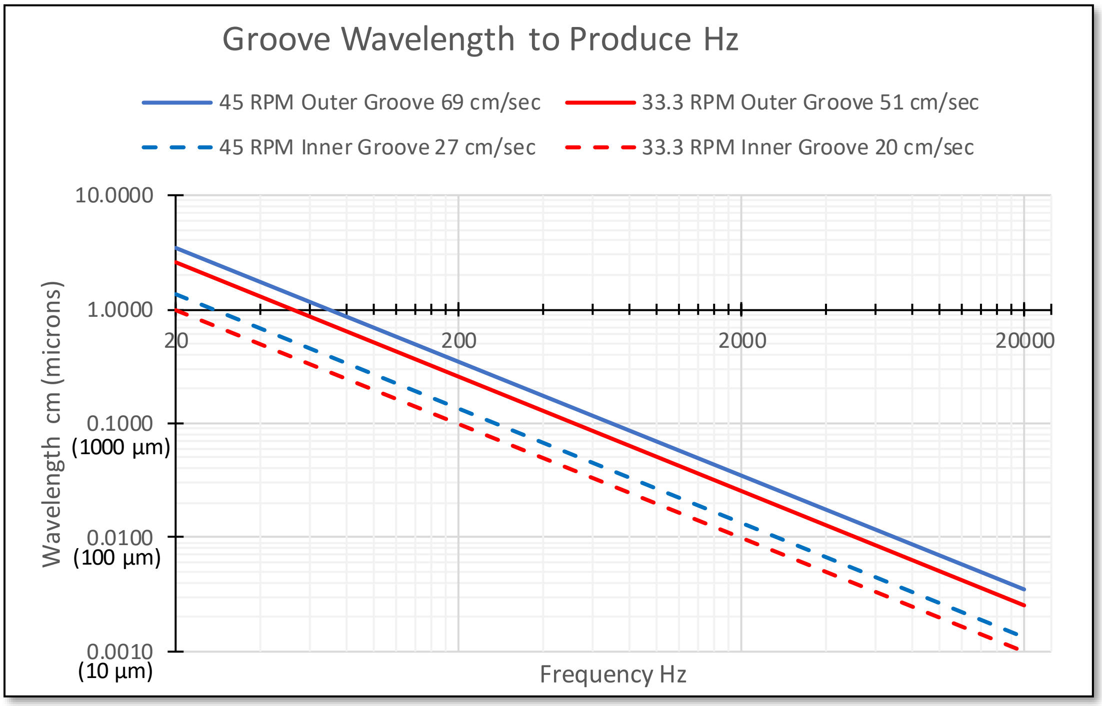


Figure 43 – Record Groove Wavelength to Produce Hz

XI.4.2 The stylus as it moves laterally and vertically is displaced, and displacement over time equals velocity and from velocity comes acceleration and all of this is combined to be the modulation amplitude – the stylus motion that produces an audible signal. Fundamentally, during a silent, unmodulated groove, the stylus is not moving in relation to the record that is moving underneath it. The modulations cause the stylus to move up and down (vertically) and side to side (laterally). The recording industry uses groove-stylus velocity as a measure of signal output. Groove-stylus velocity, acceleration and amplitude can be calculated as follows (equation source: *Disc Phonograph Records by Dr. A. M. Max, RCA Engineer Magazine 1966-08-09 (1)*).

$$V = A2\pi f$$

$$a = \frac{A4\pi^2 f^2}{g}$$

$$A = \frac{V}{2\pi f}$$

Where:
V = Velocity (cm/sec)
a = Acceleration (g's)
A = Amplitude (cm)
f = Frequency (Hz)
g = Acceleration constant = 981 cm/sec/sec

XI.4.3 There are three limiting factors when recording records, the stylus velocity, stylus acceleration and stylus radius. The amplitude equation above is usable for frequencies greater than 1000 Hz since at lower frequencies the amplitudes would be unreasonably large and because of this, the *Recording Industry Association of America® (RIAA)* recording curve attenuates the lower frequencies. Acceleration becomes limiting as the frequency increases as shown **Figure 44** and to correct recording engineers will often adjust the recording signal to limit acceleration to about 2000-g's (depending on the cutting head limitations) along with the RIAA® recording curve that amplifies high frequencies.

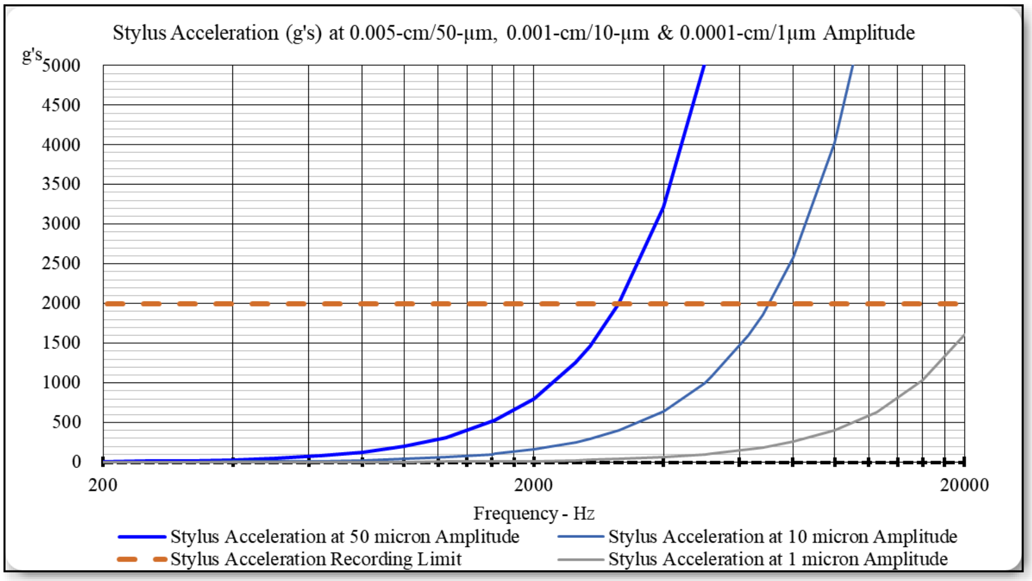


Figure 44 – Stylus Acceleration

XI.4.4 **Figure 45** shows the RIAA™ recording curve, the peak groove-stylus velocity at a maximum recording amplitude of 0.005 cm/50 microns at the inner and outer grooves (per the equations in **paragraph** XI.4.2) and examples of the effect of stylus tip radius limiting the groove velocity. A radius of 0.0004 cm/4-µm would be similar to a Shibata type stylus shape while the 0.0007 cm/7-µm radius would be similar to an elliptical type stylus.

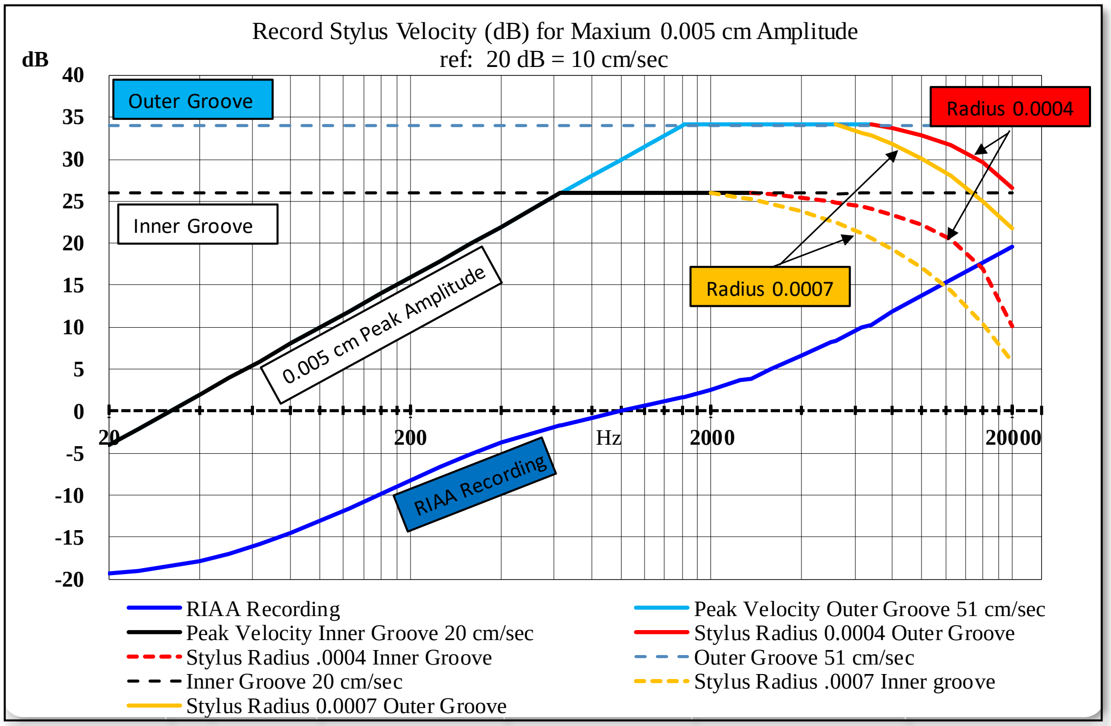


Figure 45 – Record Groove Velocity

XI.4.5 Graphs presenting groove velocity, amplitude and stylus radii can also be found in *STEREOPHILE Chart File No. 8 Record Groove Parameters, J. Gordon Holt, The Stereophile Magazine Vol.1 No. 8, August 1964 (38)* and "*Disc cutting in theory, Hugh Finnimore, Studio Sound and Broadcast Engineering, July 1975" (35).* The following is provided to better understand **Figure 45**.

XI.4.5.a The maximum amplitude is generally associated with how wide the groove can be before cutting into the groove next to it. Recalling **Figure 43**, as the frequency increases and as the stylus tracks closer to the inner groove, the stylus has less time to travel from rest to the modulation peak amplitude and therefore higher (peak) velocities occur. The practical limit of peak velocity occurs when the peak velocity of the modulation equals the linear (tangential) velocity of the groove (the speed at which the record passes the stylus). Exceed peak velocity and the "*…groove swings become so sharp that the stylus tends to ride up over them instead of traveling around them. (38)*"

XI.4.5.b Groove modulations produce sine-waves and these have curves with a radius defined by the square of the linear (tangential) velocity divided by the stylus acceleration (**paragraph** XI.4.2**)** The (tip) radius of the stylus is tracing these curves. At higher frequencies, the radius of the sine-wave curve decrease. If the radius of the sine-wave curves becomes less than the stylus tip radius, the stylus will be unable to trace the modulations and "…*the stylus loses its ability to follow the modulations accurately and tends to "gloss over them (38)*" leading to loss of signal output and distortion. A conical stylus that can have a tip radius of 0.0018-cm (not shown **Figure 45**) has difficulty in tracking high frequency peak velocities and amplitudes.

XI.4.6 Why are we concerned with these groove and stylus details? While the recording industry is often focused on the maximum peak velocity that can be recorded, from a precision clean perspective the opposite is of interest; and understanding the very small modulations and large accelerations involved provides insight to how small amounts of contamination can have an impact. The higher frequencies appear to be the most sensitive. Reviewing **Figure 44**, in order to limit stylus acceleration, the amplitude at the higher frequencies may be very small on the order of 1 micron with values as small as 0.1 micron reported (*An LP Primer, Robert Harley The Absolute Sound June/July 2007 (68))*. Reviewing **Figure 45**, technically, the area under the peak velocity lines can have recorded music, but the lowest groove velocities may only be used for records with a large dynamic range. Shure™ did a survey of the groove velocity of records that was reported in the paper *Design Considerations of the Vl5 Type IV Phonograph Cartridge, L. R. Happ* (43) *delivered at a 1978 technical seminar on phonograph cartridges.* The majority of records were recorded at 6 dB (2 cm/sec) and greater.

XI.4.7 **Table XVII** analyzes the lower expected groove velocities where the amplitudes can be very small and then calculates the corresponding amplitudes. The 0.1 cm/sec (-20 db) is listed as a reference for a silent, unmodulated groove. Some observations from **Table XVII** include that thin soil films can especially at the higher frequencies contribute to the reported "veiling of the music" and small particulate can deflect the stylus sufficient to cause an audible response as follows:

XI.4.7.a Any particle on the record has kinetic energy = 1/2 its mass times the record linear velocity squared. The stylus is essentially stationary, so when the particle 'crashes' into the stylus, some of energy may breakup/move the particle but some energy is transferred to the stylus displacing the stylus. This analysis is the same as a car hitting a stationary object. So, the same weight particle in the outer groove will have $[(51 \text{ cm/sec}) / (20 \text{ cm/sec})]^2$ = 6.5X more kinetic energy than the same particle in the inner groove.

XI.4.7.b For a simple example, a particle in the outer groove crashing into the stylus causes the stylus to displace 2.5 microns. If the system sees this as a low frequency signal (<1kHz) then the RIAA playback equalization is going to amplify the signal and a large audible response occurs. Assuming all things being equal, the same particle in the inner groove may only cause the stylus to displace (2.5/6.5) = 0.4 microns; and if the systems see this as a high frequency (>1kHz) then the RIAA playback equalization is going to attenuate the signal and a small audible response may occur. So, the location of the particle can be a significant factor.

Table XVII
Record Groove Velocity vs Frequency & Amplitude

Frequency Hz	Amplitude in Microns at Groove Velocity					
	0.1 cm/sec -20 dB	0.5 cm/sec -6 dB	1.0 cm/sec 0.0 dB	2.0 cm/sec 6 dB	3.0 cm/sec 9.5 dB	4.0 cm/sec 12 dB
1250	0.127	0.637	1.273	2.546	3.820	5.093
1600	0.099	0.497	0.995	1.989	2.984	3.979
2000	0.080	0.398	0.796	1.592	2.387	3.183
2500	0.064	0.318	0.637	1.273	1.910	2.546
3150	0.051	0.253	0.505	1.011	1.516	2.021
4000	0.040	0.199	0.398	0.796	1.194	1.592
5000	0.032	0.159	0.318	0.637	0.955	1.273
6300	0.025	0.126	0.253	0.505	0.758	1.011
8000	0.020	0.099	0.199	0.398	0.597	0.796
10000	0.016	0.080	0.159	0.318	0.477	0.637
12500	0.013	0.064	0.127	0.255	0.382	0.509
16000	0.010	0.050	0.099	0.199	0.298	0.398
20000	0.008	0.040	0.080	0.159	0.239	0.318

XI.5 **Figure 46** graphs **Table XVII** (except 0.1 cm/sec) and adds 8-cm/sec (18 dB) and 16 cm/sec (24 dB) groove velocity. It shows while anything below 25 microns will not be visible, gross contamination of 50 and 100 mg/ft^2 that develops a 5.0-to-10-micron film thickness is enough to fill-in most of the high frequency (>1000 Hz) side wall ridges (amplitude) and partially fill the groove. The 5.0 to 10 microns film thickness is an extreme amount of NVR that may be associated with an "exceptionally dirty" record. Smaller film thicknesses especially if associated with hard mineral residue from tap-water is unlikely to be uniform so should be audible as transient noise (clicks, pops, etc.,) and can cause accelerated wear of the record and the stylus. Softer residue such as surfactants can be uniform and can be displaced into the side wall ridges and effect or reduce the recorded surface amplitude which is alluded to in the paper *Record Contamination: Causes and Cure by Percy Wilson, 1965 (61)* when it discusses in generalities loss of high-notes by some contaminants that can also foul the stylus.

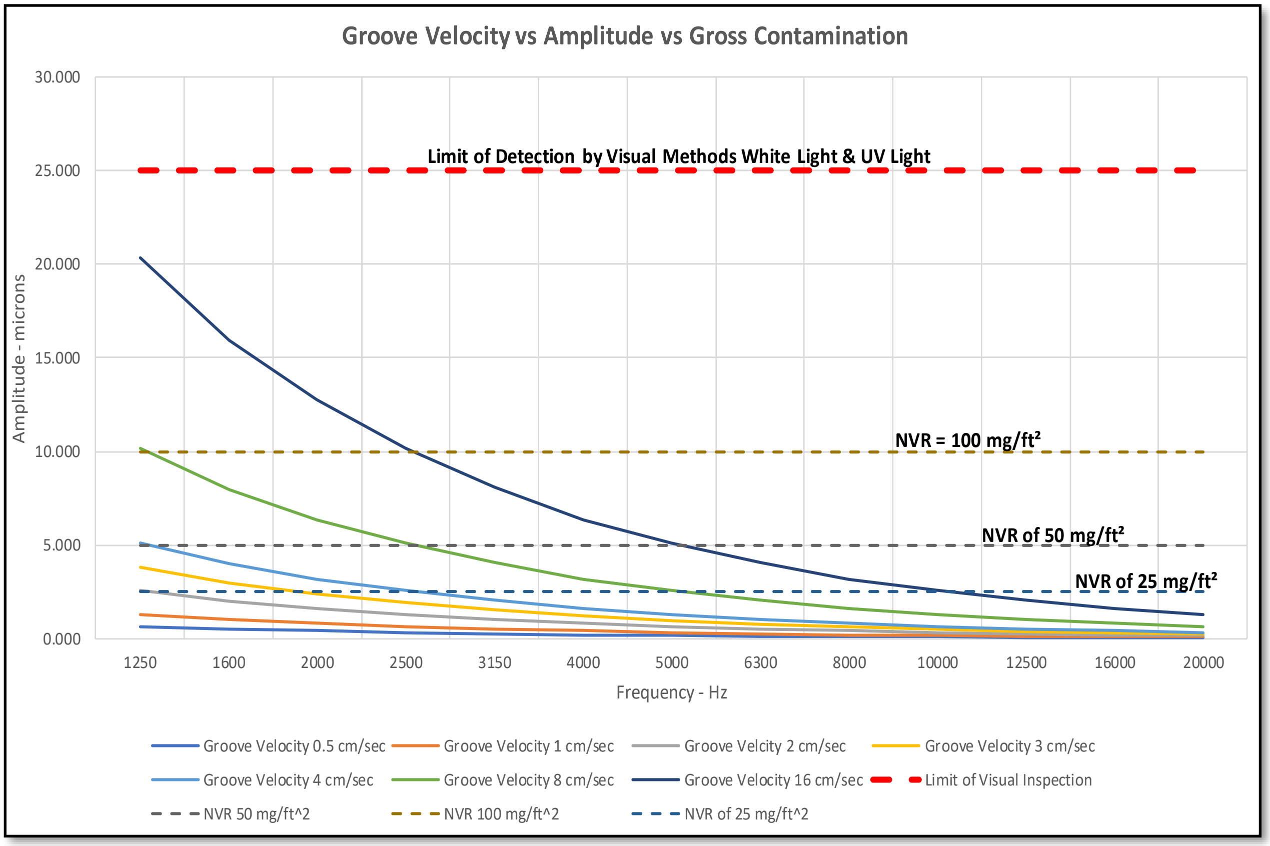


Figure 46 – Groove Velocity vs Amplitude vs Gross Contamination

XI.6 **Figure 47** focuses the data to show the overall cleaning process of **Table XVI** with groove velocity data from **Table XVII** into the zone of precision cleaning where the amplitude is less than 2.5 microns and where there can still be a lot of music. This is likely the area that experienced listeners report ability to hear loss of high frequency detail; the detail that allows the listener to hear into the instrument and into the soundstage. A surfactant film thicknesses (from NVR) less than 0.5 microns (left as a result of no-rinse or insufficient rinse) can still cover a wide range of frequencies.

XI.6.1 From **paragraph** XI.4.7.a there is an objective rationale for how “small” particulate effects the sound. But, how does residue – NVR - effect the sound? There are a number of possibilities. First, what we do know is that thick residue will cause debris/residue to form on the stylus as the record drags the stylus through the debris/residue, and records subsequently cleaned often are audibly improved indicating that the stylus will not clean a record of residue; record and stylus wear notwithstanding. We should agree that any residue that alters the natural surface finish of the record, that alters the friction factor, that increases the mass of the stylus, that alters the interface between stylus and the record may affect how and what the stylus traces. The residue can be viscous (liquid-like) or non-viscous (dry flakes/powder) and each can affect the surface differently.

XI.6.1.a Given the high accelerations that the stylus experiences, residue (mass) that collects on the stylus will cause a resultant force (force = mass x acceleration) that can affect the stylus ability to trace the groove. A viscous residue on the record groove may damp the stylus reducing the modulation reducing the signal output. It may cause vibrations if the stylus experiences variable-drag or causes the liquid to cavitate under the extreme pressure of the stylus which in either case, the background noise floor may increase obscuring high frequency detail.

XI.6.1.b If the residue coats only the side-wall ridge valley, then the stylus may not deflect/trace the full peak-to valley height and high frequency detail can be attenuated/lost. Recalling the DIY cleaners from **CHAPTER VIII. DISCUSSION OF PRE-CLEANERS:**, some are over 1000 mg/L (1 mg/ml) and if 3 mL was allowed to dry, the resultant NVR could be 3 mg/ft^2 with a resultant film thickness greater than 0.3 microns which by **Table XVII** & **Figure 47** should be audible.

XI.6.1.c A non-viscous residue may increase the surface roughness noting that the silent groove if at -20db (**Table XVII**) is very near the record baseline surface roughness (0.01 micron) causing the background noise floor to increase potentially obscuring high frequency detail, record and stylus wear notwithstanding.

XI.6.2 **Figure 47** shows that Level A = 1 mg/ft^2 should not interfere with most if any music; except for high frequency 0.5 cm/sec (-6 db) and therefore should be an acceptable NVR criterion for general record cleanliness. However, the preceding discussion of the NVR film has assumed it is uniform on the record. Instead, a more variable distribution is possible. Applying a simple Gaussian (normal) distribution for a nominal NVR of 1 mg/ft^2 = 0.1-microns, the actual film thickness could realistically vary from as low as 0.04-microns to as thick as 0.2-microns. So, depending on the individual record dynamic range, even Level A = 1 mg/ft^2 may be insufficient for very experienced or sensitive listeners.

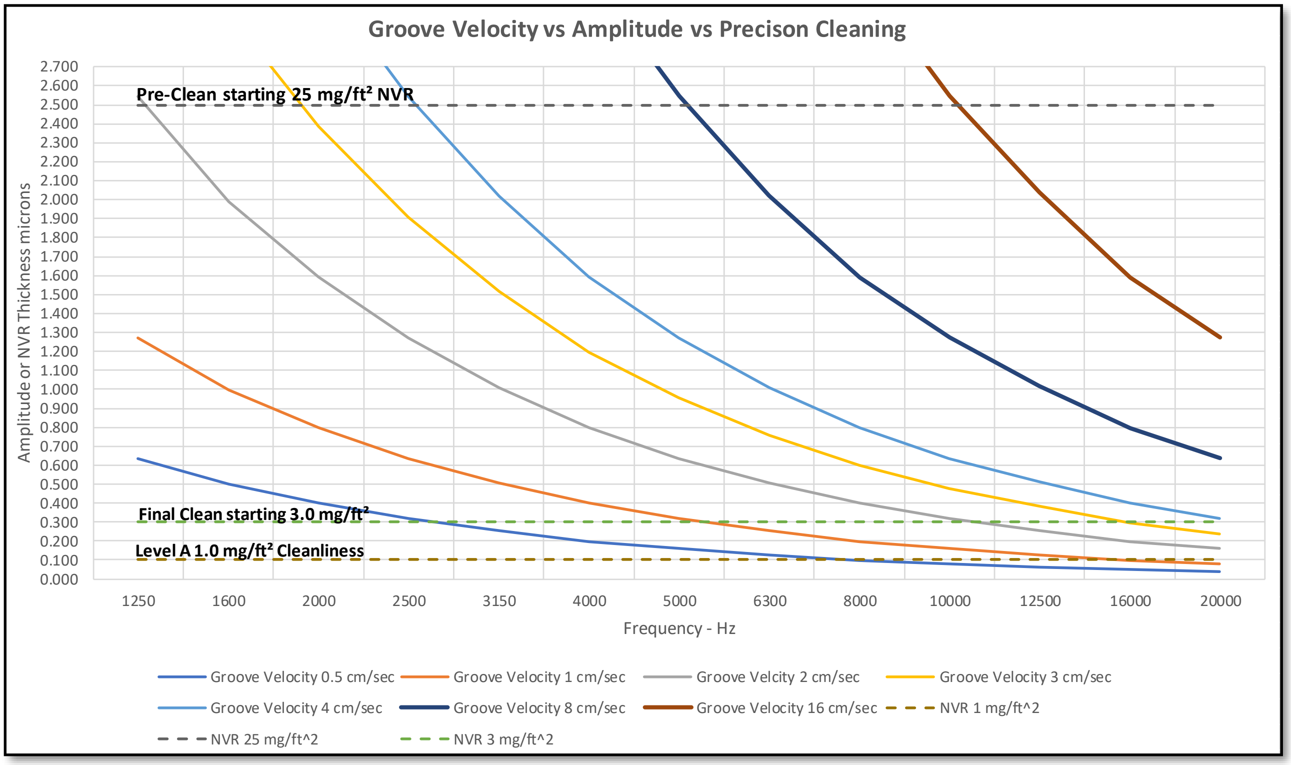


Figure 47 – Groove Velocity vs Amplitude vs Contamination Levels

CONCLUSION

Based on the vinyl record groove dimensions, geometry, and velocities and what is achievable, that for overall good playback fidelity, a *MIL-STD-1246C* cleanliness Level 50A should be the minimum goal. If Level 50A is achieved it should provide margin for uncertainty and the natural degradation that will occur during use but mitigated if reasonable practices to maintain cleanliness are used.

XI.7 **Concluding Thoughts**: Will cleanliness better than Level 50A improve playback fidelity? As previously stated, depending on the record dynamic range, even Level A = 1 mg/ft^2 (=0.1-micron) may be insufficient if the soil is not uniformly distributed on the record. However, the worst-case NVR from **Table XVI** showed 0.33 mg/ft^2 (about 0.04-micron thickness) as being achievable.

XI.7.1 My own experience implies that achieving the lowest level of any residue may be beneficial. Improved playback quality – better detail – less distortion has been noted during the dry winter months. Similar improvement was not noted with my digital sources. The only quantifiable variable was ambient relative humidity had decreased from the mid-50's to the lower 30's/upper 20's percent (humidifier not used). Per **CHAPTER VI. MAINTAINING CLEANLINESS:**, my platter and mat are grounded as specified, and I had no static issues even with carpet and socks. The lower humidity will by **Table IX** result in a thinner moisture film, but the film theoretically is less than the record surface roughness as shown **Figure 48**. But the moisture film may only be enough to fill-in the surface roughness.

XI.7.2 Recent discussion on some audio forums with subjective (listening) tests of various surfactant concentrations for ultrasonic cleaning without rinsing (details in **paragraph XIV.7**) imply that >0.03-micron cleaner residue 'may' be the threshold for audible effects. **Table XVIII** evaluates at various cleaner concentrations the film thickness if a given volume is allowed to dry without rinsing. Note that the residue thickness is assumed to be uniform across the record which may or may not be the case. Red blocked data all exceeds the Level A NVR cleanliness criteria. Yellow and orange data could be the threshold of being audible by experienced listeners.

Table XVIII
Residue Thickness from Cleaner Residue

Cleaner Concentration		Residue Thickness microns after X mL of Cleaner Allowed to Dry on a Record (1 mg/ft^2 = 0.1 micron)				
%	**mg/L**	**0.25 mL**	**0.50 mL**	**1.00 mL**	**2.00 mL**	**3.00 mL**
0.005%	50	0.001	0.003	0.005	0.010	0.015
0.01%	100	0.003	0.005	0.010	0.020	0.030
0.02%	200	0.005	0.010	0.020	0.040	0.060
0.03%	300	0.008	0.015	0.030	0.060	0.090
0.04%	400	0.010	0.020	0.040	0.080	0.120
0.08%	800	0.020	0.040	0.080	0.160	0.240
0.120	1200	0.030	0.060	0.120	0.240	0.360
0.240	2400	0.060	0.120	0.240	0.480	0.720
0.480	4800	0.120	0.240	0.480	0.960	1.440

XI.7.3 There are audio enthusiasts with very high-resolution systems in acoustically engineered rooms that can reveal details not otherwise achievable. For these individuals, the best achievable cleanliness level may yield acoustic benefits. Some people have very sensitive hearing and likewise can benefit from the best achievable cleanliness level. Consider what is written page 16 – of *UIUC Physics 406 Acoustical Physics of Music ©Professor Steven Errede, Department of Physics, University of Illinois at Urbana-Champaign, Illinois 2002 - 2017. The Human Ear —— Hearing, Sound Intensity and Loudness Levels (78) "The time-averaged, or RMS sound intensity threshold of hearing (@ f = 1 KHz) is: ~ $2.5x10^{-12}$ RMS Watts/m^2 = 2.5 RMS pico-Watts/m^2.* ***Individual people may hear better/worse than the average person, and so threshold of hearing from one person to another can vary as much as 1/10 or 10X this!!!****".*

XI.7.4 Completing the full pre-clean/acid-clean/final clean procedure detailed **CHAPTER V. MANUAL CLEANING PROCESS:**, or its equivalent with a with vacuum-RCM pre-clean followed by ultrasonic cleaning/rinsing while drying under a HEPA air hood (or temporary area of near equivalence) should repeatably obtain a cleanliness level better than Level 50A. There are audio enthusiasts already using similar processes with local HEPA air filtering; some investing many thousands of dollars and all reporting exceptional results.

XI.7.5 **Figure 48** shows the best possible cleanliness that can be achieved with certain limits as boundaries. The lowest is the water film at about 0.003 microns that forms from the air at 55°F dewpoint from **Table IX** . The best level of cleanliness is the inherent background noise of the vinyl record material that is a function of the material surface roughness which by the paper *"Disc cutting in theory, Hugh Finnimore, Studio Sound and Broadcast Engineering, July 1975" (35)* has an equivalent amplitude of 0.01 micron (*this is better than a #8 Super Mirror Finish/Non-Directional Mirror Finish used to produce/polish stainless steel mirror*). Achieving a Level-A/2 NVR cleanliness of 0.5 mg/ft^2 (0.05-micron layer equivalent) 'should' have some benefit in lowering the background noise floor for the silent track, but noting the very limited audio frequencies that may be affected at 0.5 cm/sec (-6 dB) and above. But, if a simple Gaussian (normal) distribution is applied to a nominal NVR of 0.5 mg/ft^2 = 0.05-microns, the actual film thickness could realistically vary from as low as 0.003-microns to as high as 0.11-microns. There is a cleanliness Level-A/5 (0.2 mg/ft^2 = 0.02 microns), but much lower and you are now approaching the surface roughness of the record and mostly below any recorded frequency/amplitude except for the silent track. It is possible to get the record the too clean. Some very small amount of benign residue 'may' actually be beneficial since it may fill-in the surface roughness yielding a lower background noise floor.

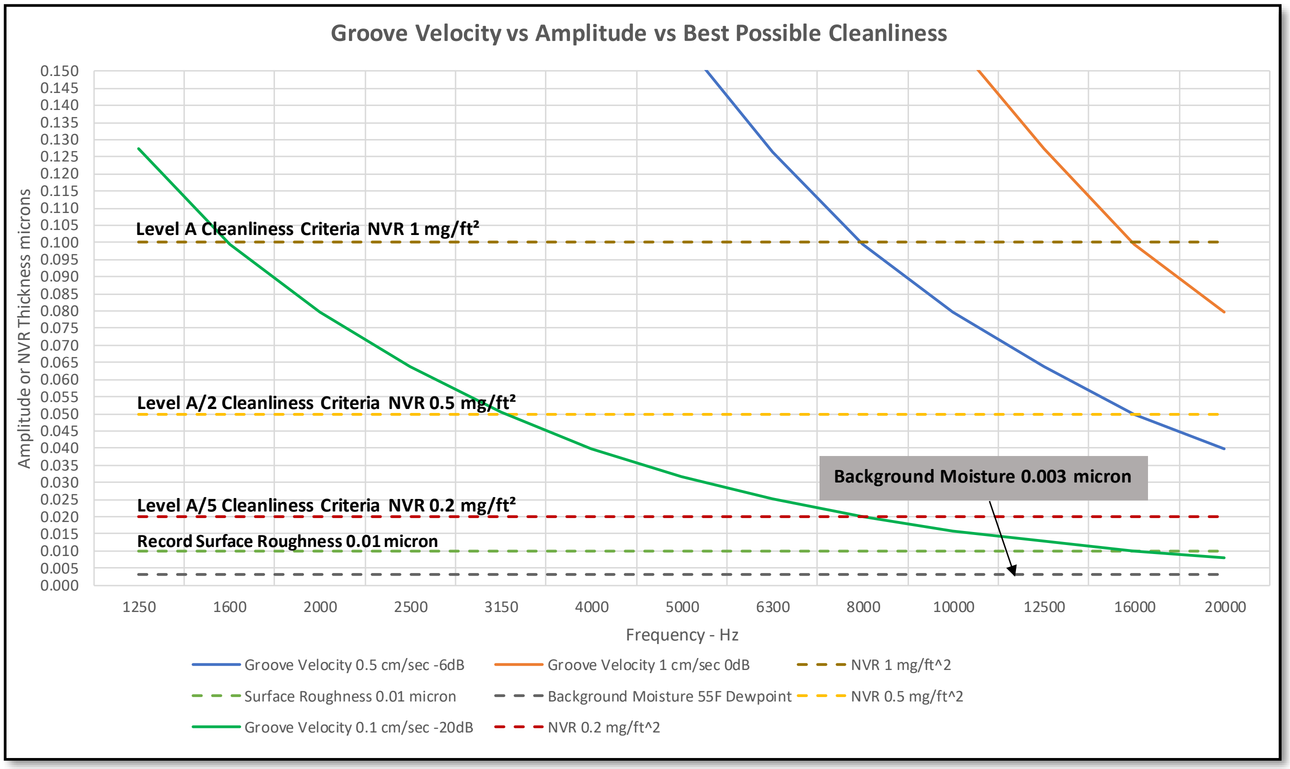


Figure 48 – Groove Velocity vs Amplitude vs Best Possible Cleanliness

XI.7.6 Caveat: The audio community is not bound to any predetermined cleanliness criteria such as particle level 50 or NVR Level A or A/2. These are being used only as industry benchmarks. The audio community can adopt any cleanliness criteria it wishes. But, as the final concluding thought for justifying precision cleaning and achieving a high level of cleanliness I refer back to what was written in the **FORWARD**, "…it is my observation, that to effectively clean a vinyl record a precision cleaning process is required, and what lies within the grooves of a vinyl record may just now be fully realized.".

REMAINDER OF PAGE INTENTIONALLY BLANK

CHAPTER XII. DISCUSSION OF THE CLEANING PROCESS:

Disclaimer: There has been no microscopic analysis to verify the following discussion. The cleaning process detailed in **CHAPTER V. MANUAL CLEANING PROCESS:** and its applicable chemistry have its roots in verified precision cleaning processes such as *MIL-STD-1330D (51).* However, actual use of the cleaning process specified herein with new and older/used contaminated/noisy records has yielded excellent results.

- Records cleaned by the process show no evidence of appreciable stylus debris viewed with white & UV light. An occasional fiber dropping from the atmosphere has been noted but easily removed. Records that were graded "generally clean" (including new records), still benefited from the pre-clean step yielding reduced surface (and overall background) noise that also yielded improved fidelity. The often-used comparison is the clarity of a glass window. The pre-clean/final-clean left the glass free of any film/haze as if the glass was removed.

- Records that still had surface noise following the cleaning process detailed in the Second Edition, benefited from the new acid-clean step or the new acid soak step detailed **CHAPTER V. MANUAL CLEANING PROCESS:**. As addressed **CHAPTER IV. RECORD INSPECTION:** for some new records, the noise abated after a few plays which is not uncommon, and as discussed initial plays effectively burnish the record surface removing microscopic burrs left from pressing. However, records that after the three (3) clean process of pre-clean, acid-clean, final-clean and the acid-soak still had residual noise or distortion without any visible detritus, these are classified as having non-recoverable physical damage. Is it possible that residual noise could be caused by deeply embedded debris that 'may' be removed with a heated ultrasonic cleaning machine discussed **CHAPTER XIV. DISCUSSION OF ULTRASONIC CLEANING MACHINES:**? At this point it's unlikely. The incorporation of the acid chemistry does manually what ultrasonics can do with power.

XII.1 The U.S. Navy, NASA and many others developed in the early 1990's as a result of eliminating ozone depleting chlorofluorocarbon (CFC) solvents, precision aqueous cleaning procedures that were all based on the foundation of pre-clean, rinse, final-clean, rinse, dry. This process is the basis of the component cleaning process specified *MIL-STD-1330D* and *MIL-STD-1622B* (*source: NAVSEA Report on Aqueous Oxygen Cleaning Products and Processes, 1994*) (59). The pre-clean step is intended to degrease, followed by a rinse, while the final-clean is intended to remove mostly invisible very fine films (including those that may be left by the pre-cleaner) and particulate, followed by a final rinse. The concept of pre-clean, final clean and final rinse is the essence of some record cleaning systems such as the Mobile Fidelity™ trio of cleaning products – Super Record Wash™, One Cleaning Solution™ and Pure Record Rinse™. However, one caveat is that the vinyl record is a fairly robust material that is applicable to a pre-clean/final clean process. Delicate materials such as a lacquer records or conservation art must be approached with Caution otherwise item damage can occur.

XII.2 The record label protector (VinyStack™ or Groovemaster™) illustrated in **CHAPTER V. MANUAL CLEANING PROCESS:** and used by the *Library of Congress (42))* allows the record to be exposed to flowing water without concern for damaging the record label. The handle/knob design of record label protectors provides ease of use and prevents handling the record surface.

XII.3 The U.S. Navy determined during the development of its *MIL-STD-1330D*, Aqueous Oxygen Cleaning Process in the early 1990's (*source: NAVSEA Report on Aqueous Oxygen Cleaning Products and Processes, 1994*) (59) that fluid agitation was critical to any water-based cleaning process, and that for pipe cleaning a minimum fluid velocity of 3 feet per second with goal of 6 feet per second was required. Additionally, for optimum performance, flushing forwards and backwards was also required for systems that had any irregular geometries. Fluid motion past a sharp irregularity would mostly bypass the backward side. The U.S. Navy also determined that the Reynolds number for turbulent flow was not the deciding factor; it was the shear force developed by the fluid velocity on the surface being cleaned. The use of water dropping from a faucet and flowing across the record surface for the first rinse to remove loose debris, the second rinse to remove the pre-cleaner and its debris, the third rinse to remove the acid cleaner and its debris and the fourth rinse to remove the final cleaner and its debris should approximate a near equivalent shear force. This will allow the rinse water assisted with the Record Doctor™ Clean Sweep Brush to penetrate the record grooves to remove/flush-away the cleaning solutions, debris released by the cleaning solutions, and finally any remaining very small loosened particulate.

XII.4 The Record Doctor™ Clean Sweep Brush with clusters of 0.05 milli-meter (0.002") wide Nylon bristles (260,000 bristles total) or the OSAGE™ Nylon record brush with 0.004" wide Nylon bristles should not deeply penetrate the record groove. Additionally, Nylon absorbs water and softens during use (but returns to original properties once dry). Furthermore, the bristle width is near equal to the top width of the record groove and when combined with the low surface tension of the Alconox™ Liquinox™, Alconox™ Citranox™ and Dow™ Tergitol™ cleaning solutions form a hydraulic wedge to force the cleaner deep into the groove. The back-and-forth brushing action then develops the fluid agitation (a combination of shear force & cavitation) necessary to deeply scrub/clean/flush the groove. But, since a new Record Doctor™ Clean Sweep Brush (or OSAGE™ brush) does not deeply penetrate the groove, there will be very little risk of record harm. Additionally, use of the Nylon brush 'wet' mitigates developing static that could occur if used 'dry' because of the strong triboelectric effect (recall **Figure 29**) that would occur between the positively charged Nylon and the negatively charged record. Note that a brush that has been used 'dry' may over time develop Nylon bristles with a chiseled or elliptical tip that could deeply penetrate the groove.

XII.5 Other Bush Details: The Osage™ brush and one version of the Statis™ brush have white nylon bristles. Off-white is the natural color of nylon. Black is produced by adding a permanent pigment. Performance wise, there is no difference. Additionally, Stasis™ is now offering a record brush with bristles tapered to 10-microns. At, 10-microns, this brush will deeply penetrate the groove. Finely tapered bristles are advertised for some toothbrushes. The problem with the fine taper is how robust will they be and is it beneficial to get deep into the groove? If the bristle is too soft then it will not move the fluid as well, and it's the fluid chemistry and motion that is doing most of the cleaning. If the bristle is too stiff, then the tips will facture and the pieces are now in the groove. So, the jury is out on whether the 10-micron tapered bristle is going to be beneficial, and whether the brush will last as long as the current 50-micron version.

XII.6 The two-step final rinse that first uses tap water to remove the Dow™ Tergitol™ NID cleaning solution and then uses Purified (distilled/demineralized) water to remove the tap-water mimics the steps used for many precision aqueous cleaning processes using a console similar to **Figure 49**. Following final cleaning with chemistry, a two-step cascading (filtered & demineralized) two-tank rinse is generally used. The first final rinse (often an ultrasonic tank) uses Purified-water to remove residual final cleaner, while a second final rinse (cascading into the first rinse) is performed with Pure-water to remove the Purified-water and any contaminants and achieve final cleanliness free of residue. So, depending on the required cleanliness level, the first final rinse is generally one step less quality than the second final rinse.

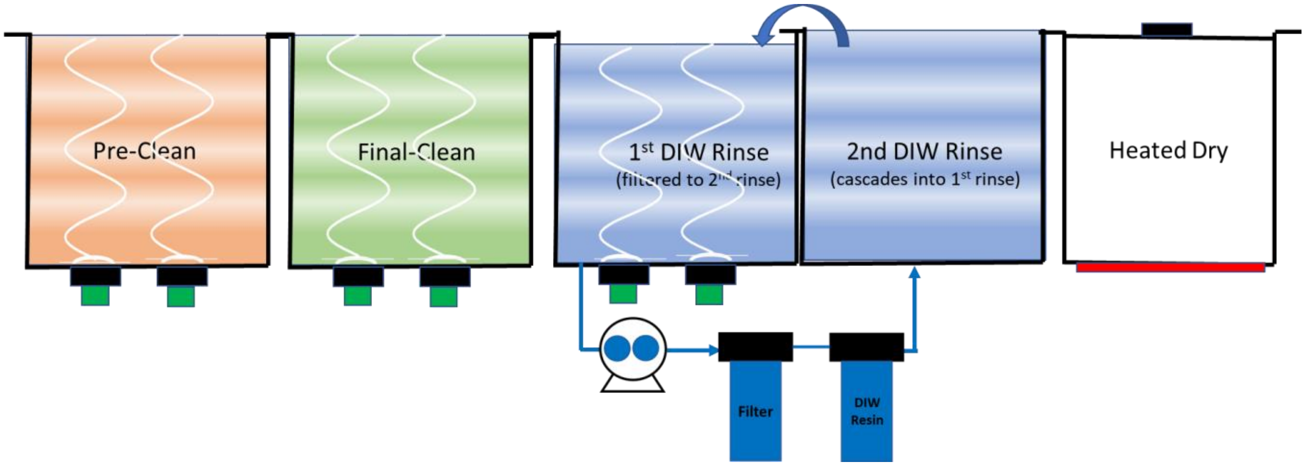


Figure 49 – Industrial Precision Ultrasonic Cleaning Console

XII.7 Rinsing is crucial and so is not physically handling the item being cleaned. Absent the record label protector with handle/knob and the four (4) rinse steps in **CHAPTER V. MANUAL CLEANING PROCESS:,** the probability of achieving particulate cleanliness Level 50 is low. The paper *Rudimentary Cleaning Compared to Level 300A Christina Y. Piña Arpin, Joel Stoltzfus, 2012* (15) showed how a very simple cleaning process (less rigorous than **CHAPTER V. MANUAL CLEANING PROCESS:**) was able to achieve NVR cleanliness Level A. However, cleaning that required the operator to handle the item being cleaned (including a 6” x 6” x 0.25” thick aluminum disc) could barely achieve NASA particulate cleanliness Level 300 (0 particles > 300 microns; 3 particles from 250 to 300 microns; 93 particles from 100 to 250 microns; and no limit on particles < 100 microns; no silting allowed). The take-away is that removing organic contamination is easy, removing particles is the challenge. Some items to consider.

XII.8 As previously indicated **paragraph** VI.12 there is an entire science on the removal of particles from surfaces. Summarizing; the smaller the particle the more difficult it is to remove from the surface, and consequently attempting to achieve particle cleanliness of Level 50 is not simple. The paper *Adhesion and Removal of Fine Particles on Surfaces, Aerosol Science and Technology, M. B. Ranade, 1987 (46)* shows for aluminum oxide particles, the force (acceleration) required to remove a 10-micron particle is 4.5 x 10^4 g's, a 1-micron particle is 4.5 x 10^6 g's and a 0.1-micron particle is 4.5 x 10^8 g's. A simple brush or wipe is not going to get the smallest particles/debris that can 'hide' in the valleys between the groove side wall ridges. As fluid flows past a surface, a boundary layer is developed and depending on its thickness (upwards of 5 microns) it will essentially shield any particles within it. So, agitation as previously addressed is critical in reducing the boundary layer to expose the surface with its particles to the cleaning fluid and the fluid velocity (shear force) that can remove them. Particles that are not removed, may still be removed using an acid.

XII.9 The NVR of the cleaner will likely be greater than the NVR being removed from the record, so rinsing away the cleaner is critical. Surfactants (lipophilic tail) essentially bond to the surface of the vinyl record, so absent an effective water rinse, some surfactant (invisible to the naked eye) will likely be left behind as noted **Table XVIII** and will be discussed **paragraph** XII.10. The common water-break test that was discussed **CHAPTER VIII. DISCUSSION OF PRE-CLEANERS:** is not applicable to a record because the record critical surface tension as shown **Figure 36** is less than water. A thin film of surfactant with oil-loving tail-down and water-loving head-up can cause sheeting/wetting. So, for a record, the final spray DIW rinse should show water beading-up as indicated **Figure 23**, but this may only indicate the record surface and not what is in the groove. If an excessive quantity of NVR is left behind, as addressed **CHAPTER XI. DISCUSSION OF CLEANLINESS CRITERIA:** it may be noted as dulling of sound from the record, or a build-up of 'gunk' on the cartridge needle/stylus.

XII.10 To emphasize the ability of surfactants to bond to surfaces, the following examples are provided. The lessons learned is avoid excessive concentrations of cleaning agents – using too much will do more harm than not using enough.

XII.10.1 During the implementation of *MIL-STD-1330D*, a manufacturer was experiencing frequent failure of the final clean step. Final cleaning was with a clear, alkaline, non-foaming solution filtered to 0.5 micron (absolute) that as part of cleanliness verification a sample was taken and checked for foam. If the final cleaner foamed, it indicated that the rinse step after pre-cleaning was not successful, and pre-cleaner was being carried over to the final clean step – contaminating the final cleaner. The final clean step was intended to only remove very fine particulate and thin non-foaming mineral-based films. The pre-clean step was using a commercial cleaning agent diluted per the vendor application notes to 10% (10:1) followed by a Purified-water ultrasonic rinse. To pass through the final clean step without it foaming, the pre-cleaner dilution had to be changed to 2% (50:1).

XII.10.2 In the presentation BASF™ *Compatibility of Nonionic Surfactants with Membrane Materials and their Cleaning Performance, Dr. Arend J. Kingma, Sepawa Nordic 2014,* various non-ionic surfactants were used to clean small silicon wafers or glass plates coated with polyethersulfone and polyamide-12 (Nylon) to test for residue. Each wafer was dipped for 10 minutes in a 0.025% (250 ppm) surfactant solution, rinsed with water and dried. Although not specified, the fragility of the wafers could have prevented an aggressive rinse step. The testing was to show that membrane filters could be cleaned with nonionic surfactants without leaving excessive residue.

XII.10.2.a Most nonionic surfactants such as Dow™ Triton™ X100 left a uniform residue of about 0.1 mg/ft^2. BASF™ DEHYPON® LS 54 was tested with Nylon, and the residue thickness was 0.15 mg/ft^2. But, some low-foaming nonionic surfactants (none as recommended for use in this document) that are not very soluble with water showed residues levels 5X higher that would equal 0.5 mg/ft^2 (0.05-micron thickness). The concern here being formulations using anti-foaming agents such as insoluble Dow™ Tergitol™ 15-S-3 that are likely to leave residue that may be audible.

XII.10.2.b One item to note is that polyethersulfone and polyamide-12 are hydrophilic and will absorb water; so, some baseline weight could have been associated with moisture. Additionally, when rinsing, the 0.025% concentration would have benefited those surfactants with higher CMCs such as Dow ™ Triton™ X100 which with a CMC of 189-ppm would have been used at <2X the CMC while BASF™ DEHYPON® LS 54 with a 10 ppm CMC would have been used at 25X the CMC.

XII.11 The drying process with first using the lint-free PVA sponge and then the very fine/soft Kinetronics™ anti-static microfiber cloth is intended to mostly wick the moisture from the surface. Like the rinse process it's a 2-step process first removing the bulk moisture with the lint-free PVA high absorbency sponge then near completely dry with a thin mostly lint-free, anti-static cloth. Leaving a very thin moisture film on the record prevents developing any static charge. Overall, this improves the drying time to just a few minutes, and since it is performed with very little pressure, the drying material should not penetrate the groove minimizing depositing small particulate or any chance for record harm.

XII.12 The final few minutes of drying in a still air environment minimizes fine lint/particulate or ambient volatile organics depositing on the record. Use of forced air drying without HEPA filtration risks contaminating the record surface/grooves with airborne lint and particulate.

XII.13 **Reality Check**: A review of *MIL-HDBK-407* (49) would indicate that the level of background contamination in a commercial or residual environment and that produced by the human (*the Peanuts™ character Pig-Pen™ is not too far off*) can be smaller than the record groove detailed in **CHAPTER I. VINYL RECORD CLEANING CHALLENGES:**. Attempting to achieve a **Table XV** particulate cleanliness Level 50 even in the most basic *Fed-Std-209* (24) Class 100,000 cleanroom (100,000 particles >0.5 microns/ft^3 of air, and 700 particles >5 microns/ft^3) can be a challenge, let alone in a mostly uncontrolled commercial or residential environment. However, larger particles will deposit/fall from the air exponentially faster than smaller particles. Once the record is spinning it develops its own air current which should 'shield' the record from all but the largest particles depositing. Paraphrasing the article – *Airborne particle deposition in cleanrooms: Relationship between deposition rate and airborne concentration* (82)"...particle settling rate, the rate of surface accumulation is proportional to the airborne concentration which is differentiated by the particle size, the exposure time, and the orientation of the surface relative to the air flow. Surfaces parallel to the average direction of flow and at right angles to gravity sustain the lowest particle accumulation.". Figure 4 of the article shows the Deposition Velocity for the very small particulate <5 um is very slow, but the large particles >25 um is much faster. Placing a turntable under an air register is not prudent.

XII.14 However, the cleaning process in **CHAPTER V. MANUAL CLEANING PROCESS:** is performed mostly wet with liberal use of flowing water. During this wet-time, the record is essentially protected from the ambient environment. It is only during the final drying process that the record is at risk and the record mostly aligned vertically during the limited drying time minimizes the risk from airborne contaminants. Additionally, if the local area where the record is being clean is cleaned of visible particulate to a visual cleanliness level of VS+UV (white light & blacklight) then a temporary clean area can be established. Adding a room or desk-top HEPA air filter as addressed **CHAPTER V. MANUAL CLEANING PROCESS:** should maintain the background airborne contamination low. Combine these elements with the cleaning process likely being performed in a residential kitchen that is manufactured of mostly hard, non-shedding surfaces, and the goal of achieving a **Table XV** initial cleanliness Level 50A should be possible.

XII.15 **Life Cycle Cost**: The manual cleaning process detailed **CHAPTER V. MANUAL CLEANING PROCESS:** has a very low life cycle cost, with cost of cleaner solutions and distilled water less than $0.05 per record. Very little cleaner is used per record.

XII.15.1 One quart of Alconox™ Liquinox™ used at 1% will prepare about 100 liters of solution and using only about 50 mL per record can clean 2,000 records.

XII.15.2 One quart of Alconox™ Citranox™ used at 1.5% will prepare about 64 liters of solution and using only about 50 mL per record can clean 1,280 records.

XII.15.3 One pint of Dow™ Tergitol™ 15-S-9 used at 0.1% will prepare about 500 liters of solution, and using only about 50 mL per record, can clean 10,000 records.

XII.15.4 Very little distilled water is used per record.

XII.15.5 The PVA sponge and drying cloths are only used to remove distilled water so there should be no need to wash. The sponge is just squeezed-out and stored wet, and the cloth(s) are just hang-to-dry and shake before use. The PVA sponge lasts about 6-12 months while the Kinetronics™ Tiger Cloth should last many years.

XII.15.6 Other equipment such as the RLP, brush, and spray-bottles are not subject to any appreciable wear. If using disposable nitrile gloves that can cost about $0.20/each, these will be the highest cost item. If you buy the next larger size, they can be reused a number of times.

XII.16 The final chapters of this book will discuss machine assisted cleaning methods: vacuum record cleaning machines (RCM) and ultrasonic cleaning machines (UCM). It's important to consider that machines are generally developed for two primary reasons – reduce labor and improve process efficiency. Process efficiency can mean faster (higher throughput) and/or higher probability of achieving quality or achieving a quality that manual labor cannot produce. Manual cleaning in the appropriate environment with appropriate controls can achieve impressive levels of cleanliness, but the labor, skill, time and probability of success generally make it impractical for manufacturing environments. But for the home audio enthusiast, depending on your attention to details, adopting machine assisted cleaning may or may not yield a cleaner record. However, the ease of use and convenience provided by machines can be very enticing and cannot be denied.

REMAINDER OF PAGE INTENTIONALLY BLANK

CHAPTER XIII. DISCUSSION OF VACUUM RECORD CLEANING MACHINES:

One machine-assisted vinyl record cleaning process that has been in use for decades is the vacuum record cleaning machine (RCM). There are a variety of self-contained vacuum-RCMs available from many vendors such as Record Doctor™, VPI™ (see **Figure 50**), Clearaudio™, Nessie Vinylmaster®, Nitty Gritty™ and Keith-Monks™ (see **Figure 51**) and Loricraft™ with costs that vary from as little as $200 to over $4,000 with a wide range of construction and features. **Table XIX** presents some major design features than can be found with vacuum-RCMs with the cost proportional to the features provided. There are lower cost vacuum-RCMs that provide a mount for the record with a top-mounted vacuum pickup tube that connects to a user provided separate stand-alone wet/dry vacuum cleaner such as the Squeaky Clean - Squeaky Clean Vinyl Record Care and the VinylBug - VinylBug Vinyl Record Vacuum Cleaning Machine.

Table XIX
Self-Contained Vacuum-RCM Features

Feature	Variations	Notes
Vacuum Location	Bottom	Nitty Gritty™ & Record Doctor™ are examples of this design. They tend to be physically compact less than the dimensions of the record and inherently simple. Cleaning solution and rinse water cannot be sequentially applied while vacuuming. Some Nitty Gritty™ users report cleaning the record off the unit and then using it to dry the record.
	Top	Clearaudio™, VPI™, Keith Monks™ & Loricraft™ are examples of this design. Their dimensions are similar to that of the record. They have the benefit that cleaning solution and rinse water can be manually applied sequentially while vacuuming.
	Top & Bottom	Clearaudio™ Double Matrix Professional Sonic is an example of this type design where vacuum is applied both top and bottom.
Air Vacuum Source	Blower	Clearaudio™, Nitty Gritty™, Record Doctor™ & the VPI™ MW-1 Cyclone shown **Figure 50** are examples. Blower designs will vacuum across the entire radius of the record. This design uses lots of air flow with very little vacuum (a few inches of water). The use of a blower is the most common and are the noisiest. Some units such as the VPI™ are legendary for their service life with many exceeding 20-years.
	Pump	Keith Monks™ & Loricraft™ are examples of this design shown **Figure 51**. A groove point-nozzle is used with a vacuum pump. The vacuum pump draws much less air than a blower but draws a relatively low vacuum of about 20" Hg. These designs are therefore much quieter and generally more expensive than blower designs.
Method of Rotation	Manual	Nitty Gritty™ & Record Doctor™ are examples of this design. This design is the least expensive.

Feature	Variations	Notes
	Motorized	Clearaudio™, VPI™, Keith Monks™ & Loricraft™ are all examples of this design. A motor is used to rotate the record and higher cost units will have a reversible function to improve cleaning example shown **Figure 50**. The Keith Monks™ & Loricraft™ units with the point-source vacuum nozzle spin at a faster speed than those with the blower vacuum source and users report they cannot soak a record without fluid flinging off the record.
Cleaning	Manual	Clearaudio™, Nitty Gritty™, Record Doctor™ & VPI™ are examples. The user applies cleaner and rinse water manually.
	Semi-Auto	Clearaudio™, Keith Monks™ & Loricraft™ are examples. The unit has a semi-auto cleaner dispensing system. Depending on platter speed, the user may or may not have much opportunity to manually work the fluid while it is rotating.
	Fully Auto	Clearaudio™ Double Matrix Professional Sonic is an example of this type. The user mounts the record and the unit will clean and dry automatically without any further user interaction.

Figure 50 – VPI™ MW-1 Cyclone Vacuum-RCM
(image by permission of VPI™)

Figure 51 – Keith Monks™ Vacuum-RCM
(image by permission of The Vinyl Press™)

Disclaimer: I do not own a vacuum RCM, and therefore no performance comparison has been made between the manual cleaning process of **CHAPTER V. MANUAL CLEANING PROCESS:** and vacuum-RCM. However, since the first edition of this paper, I have assisted a number of people using vacuum-RCMs with the successful use of Alconox™ Liquinox™ as the pre-cleaner and Dow™ Tergitol™ 15-S-9 or BASF™ DEHYPON® LS 54 as the final cleaner; and the lessons learned are discussed herein.

Be advised that some vacuum-RCM manufacturers may void the warranty if not used with their approved chemistry and this should be made clear in their literature. The formulas addressed in this chapter should not be harmful with vacuum RCMs and have been used with Loricraft™ and VPI™ units. However, some specialized units may be very sensitive to any foam, in which case, use the manufacturers supplied cleaning agent.

XIII.1 A key difference between the manual cleaning procedure of **CHAPTER V. MANUAL CLEANING PROCESS:** and vacuum-RCM, is the difference in cleaner concentration/ volume and rinse water volume that can be used. The manual clean procedure of **CHAPTER V. MANUAL CLEANING PROCESS:** has almost no limits. Any excess cleaner just drips off into a sink and there is a near infinite source of tap-water for initial rinsing. In comparison, vacuum-RCM have inherent design limits to the amount of cleaning agent and rinse water that can be applied otherwise the unit can be flooded and damaged. Additionally, because of limits with the amount of rinse water that can be applied, lower cleaner concentrations are preferred to control foam and get better rinse efficiency.

XIII.2 There are many vacuum-RCM cleaning products advertised as essentially pre-cleaners, and there are reports of excellent results with vacuum-RCM. I make no assessment and refer readers to the manufacturers and various audio forums for best practices and recommendations. Vacuum-RCMs that provide forward and reverse rotation will provide the best performance for similar reasons addressed **CHAPTER XI. DISCUSSION OF CLEANLINESS CRITERIA:** for forward/backward flushing. The use of enzymes as pre-cleaners is offered by some manufacturers and these have the benefit of being able to essentially dissolve applicable contaminants by simple soaking using little volume – whereas surfactants perform best when very wet and assisted with agitation.

XIII.3 If using vacuum-RCM for a pre-clean step, and if using the same brush for pre and final clean, rinse the record brush separately before any follow-on step to ensure pre-cleaner is not on the brush. In this instance first rinsing with tap water to remove the cleaner and then a quick spray with DIW or dip in a bowl filled with DIW can work.

! CAUTION

Do not use acids with vacuum-RCM. The blowers and vacuum pumps use metals that can be corroded and damaged by acids.

XIII.4 The following pre-clean/rinse/final clean/rinse/dry process using the Alconox™ Liquinox™, Dow™ Tergitol™ 15-S-9, BASF™ DEHYPON® LS 54 or ILFORD™ ILFOTOL™ (see **paragraph IX.6 for use**) chemistry has been successfully used by persons with vacuum-RCMs such as the VPI™ models and the Loricraft™ PRC-4. For records that are not exceptionally dirty, the pre-clean process can be deleted. The process mimics the process in **CHAPTER V. MANUAL CLEANING PROCESS:** except it substitutes a vacuum-RCM and reduces the CLEANER and NID concentration to minimize foam and improve rinse efficiency.

XIII.4.1 Pre-clean exceptionally dirty records with Alconox™ Liquinox™ at 0.5% (5 mL/L) - vacuum but do not fully dry. Depending on the record condition, two pre-clean steps may be required. Although the Alconox™ Liquinox™ will foam, most of the foam is collected in the brush as noted **Figure 17.**

XIII.4.2 Rinse pre-cleaner with DIW - vacuum, but do not fully dry.

XIII.4.3 Final clean with Dow™ Tergitol 15-S-9 at 0.05% (0.5 mL/L) or BASF™ DEHYPON® LS 54 at 0.025% (0.25 ml/L)- vacuum and do not fully dry. There will be some foam as noted **Figure 21**, but most of the foam will be in the brush.

XIII.4.4 Rinse final cleaner with DIW - vacuum and fully dry. When drying be careful of drying too long that can cause static to form.

XIII.5 A possible concept for vacuum RCM is to design a record label protector such as the Groovemaster™ that could couple to the vacuum-RCM with a magnetic coupling (and a hexagonal shaft to avoid rotational slip) to allow moving the record from the manual cleaning procedure specified **CHAPTER V. MANUAL CLEANING PROCESS:** directly to the vacuum RCM for drying.

XIII.6 A final thought on the subject of vacuum-RCM is drying. As previously addressed **CHAPTER XI. DISCUSSION OF CLEANLINESS CRITERIA:**, the normal residential environment contains thousands of invisible small particles per cubic-foot of air. The UV blacklight specified **Table I** if purchased would show an amazing amount of particulate on all surfaces. The high velocity air used by blower designs as part of the drying process draws unfiltered air across the record surface. The vacuum-RCM wet-brushes/pads should collect a lot of the airborne particles. But, if the cleaner(s) have not been fully rinsed and the invisible particles are collected by the surfactant residue – essentially a sludge will form. As a concept for those vacuum-RCMs with lids such as the VPI™ models (example **Figure 50**), modify the lid to add a replaceable fine particulate air filter such as the 3M® Filtrete™ Healthy Living Air Filters (MERV ratings 12 to 14) that have dimensions as small as 12”x12”. The large filter area would minimize pressure drop, and this could allow quick drying (with lid closed) with filtered air to prevent drawing-in and depositing airborne lint and particulate. Air filters that rated in Minimum Efficiency Reporting Values (MERVs) will have performance as specified **Table XX** that was obtained from the Environmental Protection Agency (EPA) (19).

Table XX
Air Filter Ratings

MERV Rating	Average Particle Size Microns	Filter Efficiency
1-4	3.0 - 10.0	Less than 20%
6	3.0 - 10.0	49.9%
8	3.0 - 10.0	84.9%
10	1.0 - 3.0 3.0 - 10.0	50% to 64.9% 85% or greater
12	1.0 - 3.0 3.0 - 10.0	80% to 89.9% 90% or greater
14	0.3 - 1.0 1.0 - 3.0	75% to 84% 90% or greater
16	0.3 - 1.0	75% or greater

NOTE: High efficiency particulate air [filter] - HEPA; is a type of pleated mechanical air filter. As officially defined by the U.S. Dept. of Energy, this type of air filter can theoretically remove at least 99.97% of dust, pollen, mold, bacteria, and any airborne particles with a size of 0.3 microns (µm).

CHAPTER XIV. DISCUSSION OF ULTRASONIC CLEANING MACHINES:

One power-assisted vinyl record cleaning process that is gaining wider acceptance and is the source of many audio forum discussions is ultrasonic cleaning machines (UCM). A UCM can be assembled by the user as a DIY or semi-automated and fully automated products are now available from a variety of vendors.

Disclaimer: I do not own a UCM, and therefore no performance comparison can be made between the manual cleaning process of **CHAPTER V. MANUAL CLEANING PROCESS:** and UCM. The following discussion is provided based on my experience with UCMs used for industrial precision aqueous cleaning, and since the first edition of this paper, I have assisted a number of people using UCMs with the successful use of Dow™ Tergitol™ 15-S-9 and other final cleaners; as well as UCM bath recycling, and the lessons learned are discussed in this chaper.

XIV.1 Ultrasonic cleaning has been used for decades. The precision cleaning processes detailed by *MIL-STD-1330D* and *MIL-STD-1622B* address UCMs cleaning. However, recalling **CHAPTER I. VINYL RECORD CLEANING CHALLENGES:** and **CHAPTER XI. DISCUSSION OF CLEANLINESS CRITERIA:**, the particle cleanliness level for a vinyl record needs to address less than 5 microns. This presents a unique challenge since UCM operating frequency will influence cleaning effectiveness. The book *Particle Adhesion and Removal 2015* (62), has a large section on nothing but ultrasonic cleaning. The following is a quick summary of ultrasonic cleaning:

XIV.1.1 The basic principle is that ultrasonic sinusoidal sound waves can produce bubbles that will grow until they collapse and the associated event is termed 'cavitation' as illustrated **Figure 52**. Over a period of milliseconds, as a result of the positive and negative acoustic pressure cycles, cavitation bubbles form, expand (termed rarefication), compress, expand, compress and then expand enough that they then implode. This process repeats and the implosions releases energy and localized agitation producing the scrubbing action for cleaning. The energy associated with cavitation is known by any motor boat owner who has experienced propeller pitting/wear from cavitation, and the same phenomenon can be experienced with centrifugal pumps.

XIV.1.2 For ultrasonics there is a minimum power (wattage) necessary to produce cavitation and this power is associated with the sound pressure amplitude. The higher the frequency, the more power is required. The minimum power required at 40 kHz is reported between 0.3 and 0.5 W/cm^2 (per transducer radiating surface). As the UCM tank volume increases, less power, measured as W/gal, w/L or W/cm^3 is required to maintain cavitation throughout the tank. A very small 0.5-gal/1.9-L 40-kHz tank may require 125 W/gal (33 W/L) while a 12.75-L/3.4-gal 40-kHz tank may only require 80 W/gal (21 W/L); noting that as the ultrasonic kHz increases so does the power required for cavitation. There is a limit to increasing power above which no additional benefit is obtained.

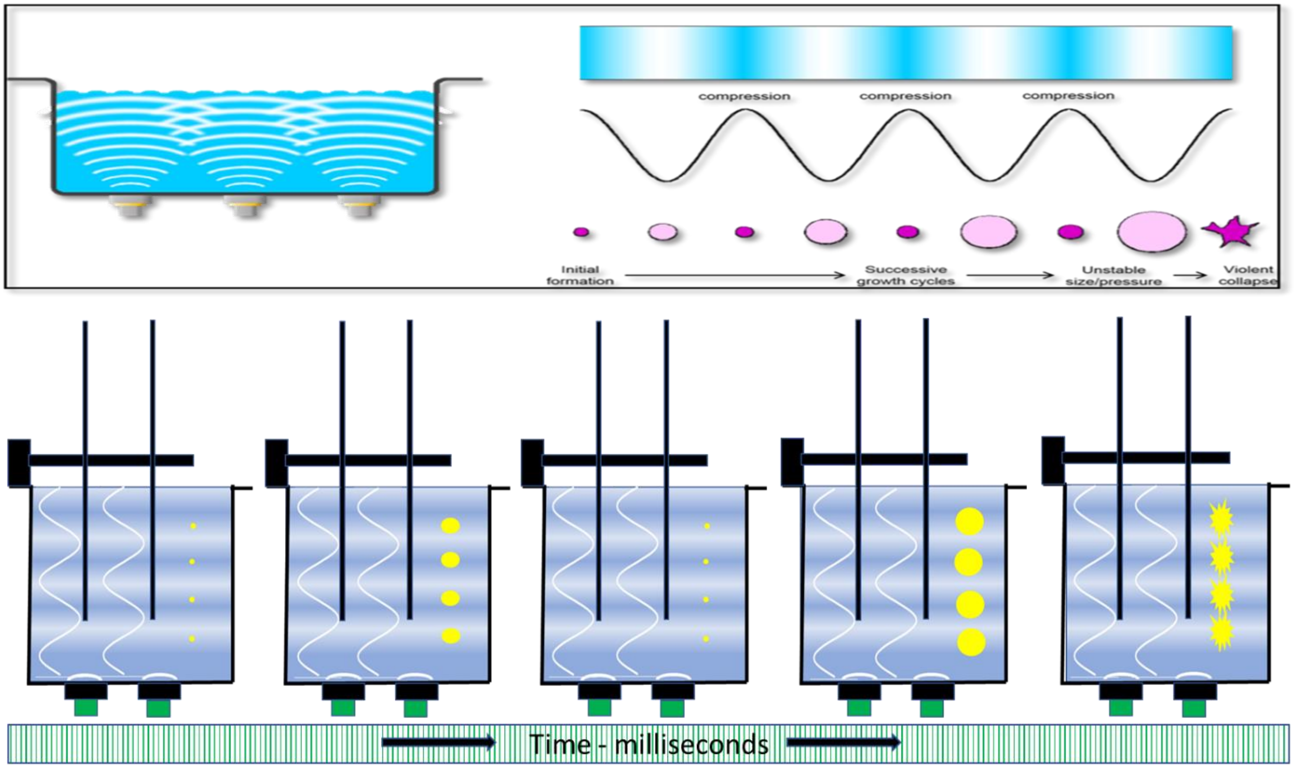


Figure 52 – Fundamentals of Ultrasonic Cavitation
(Image from NASA and Author)

XIV.1.3 The following compares the kHz and W/L for some commonly available or in-use (*KL Audio is discontinued*) UCM. The Degritter™ is a powerful UCM with four (4) 75-W transducers, two per side, but it is also 120-kHz and requires more W/L. The KL Audio™ appears as a very high powered UCM, but its volume is relatively small. The Elmasonic™ UCM at 37 kHz with its large volume is a powerful unit. Note: The quality of construction; how secure are the transducers to the metal tank, and the quality of the metal tank can affect the usable power. So, two UCM of the same size and power, can yield very different cavitation intensities, ergo different cleaning performance.

- Elmasonic™ P120H 37/80 kHz, 12-L and 300-W = (300)/12) = 25W/L

- Sharpertek™ Model XPS360-6L-D 40 kHz, 6-L and 180-W = (180/6) = 30 W/L

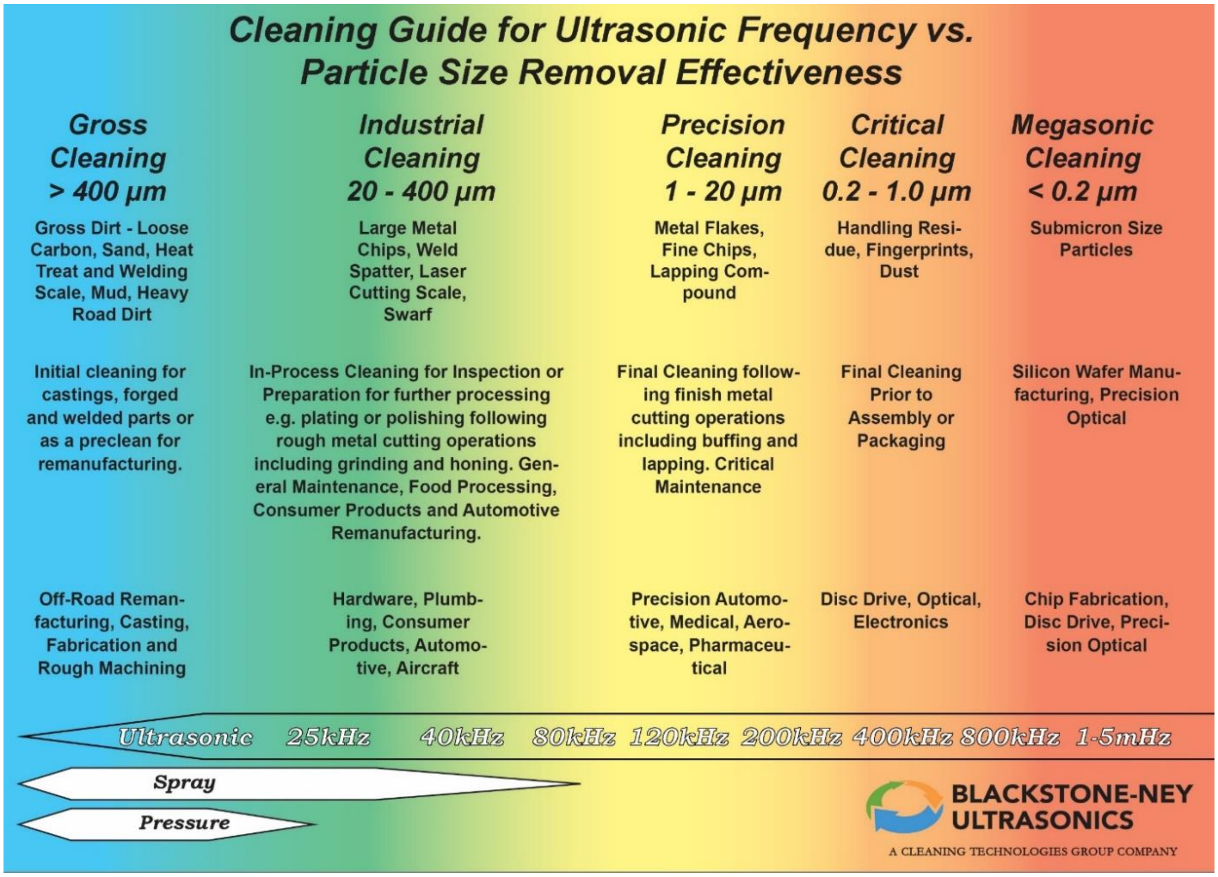
- KL Audio™ Model KD-CLN-LP200 40 kHz, 2.5-L, 200-W = (200/2.4) = 83 W/L

- Degritter™ 120 kHz, 1.4-L and 300-W = (300/1.4) = 214 W/L

XIV.1.4 The lower the ultrasonic frequency, the larger the bubble that is created. A 25 kHz UCM will produce bubbles about 125 microns diameter while 40 kHz UCM will produce bubbles about 75 microns diameter. These are not going to get into the record groove. A 120 kHz UCM will produce bubbles about 20 microns (and more of them) and these can get into the groove. But the larger bubble can produce more energy when it collapses/implodes (cavitation) so there is fluid agitation around the collapsing event that can provide cleaning. How violently the bubble collapse is determined by the amount of power provided by the ultrasonic transducers. A low power 40 kHz unit may be safe for soft metal such as jewelry, while a 40 kHz high power unit may not. The smaller bubble produced by a 120 kHz UCM by its size is limited to how violent it can collapse. A high powered 120 kHz unit has less potential for damage than a high powered 40 kHz. As the frequency increases well above 250 kHz, cavitation pretty much disappears replaced by 'acoustic streaming'. The fluid velocity produced by the acoustic streaming is what then does the cleaning; and the target velocities are not much different than those developed for pipe/tube flushing addressed **CHAPTER XI. DISCUSSION OF CLEANLINESS CRITERIA:**.

XIV.1.5 Further complicating the effectiveness of ultrasonics is the fluid boundary layer. The fluid flow at the record (or any) surface develops a static layer that is separate from the bulk fluid that is moving. The boundary layer thickness is dependent on the ultrasonic frequency (high kHz = thinner boundary layer), acoustic energy, and fluid properties (viscosity & density). To get the most effective cleaning, the cleaning process has to penetrate the boundary layer to remove the soil and particles that are contained within it. This concept is also applicable to pipe flushing and was addressed **CHAPTER XI. DISCUSSION OF CLEANLINESS CRITERIA:**. At 40-kHz, the boundary layer can be as thick as 5 microns, while at 120-kHz, the boundary layer can be as thick as 2 microns.

XIV.1.6 So, fundamentally, following the logic, lower frequency units (40 kHz) are good for larger soil surfaces and particles while higher frequency units (80-132 kHz) are better at removing smaller particles as illustrated **Figure 53**. There are UCMs that provide dual frequencies. The Elma™ (https://www.elma-ultrasonic.com/en/, Elmasonic P-series laboratory grade, tabletop, ultrasonic units have a micro-processor controlled dual frequency that can produce 37-kHz or 80-kHz. Zenith™ (www.zenith-ultrasonics.com) manufacturers industrial ultrasonic systems including benchtop units with a patented dual frequency design (called Crossfire™) that uses separate transducers to simultaneously produce 40-kHz and 80-kHz.



Cleaning Guide for Ultrasonic Frequency vs. Particle Size Removal Effectiveness

Gross Cleaning > 400 µm	Industrial Cleaning 20 - 400 µm	Precision Cleaning 1 - 20 µm	Critical Cleaning 0.2 - 1.0 µm	Megasonic Cleaning < 0.2 µm
Gross Dirt - Loose Carbon, Sand, Heat Treat and Welding Scale, Mud, Heavy Road Dirt	Large Metal Chips, Weld Spatter, Laser Cutting Scale, Swarf	Metal Flakes, Fine Chips, Lapping Compound	Handling Residue, Fingerprints, Dust	Submicron Size Particles
Initial cleaning for castings, forged and welded parts or as a preclean for remanufacturing.	In-Process Cleaning for Inspection or Preparation for further processing e.g. plating or polishing following rough metal cutting operations including grinding and honing. General Maintenance, Food Processing, Consumer Products and Automotive Remanufacturing.	Final Cleaning following finish metal cutting operations including buffing and lapping. Critical Maintenance	Final Cleaning Prior to Assembly or Packaging	Silicon Wafer Manufacturing, Precision Optical
Off-Road Remanufacturing, Casting, Fabrication and Rough Machining	Hardware, Plumbing, Consumer Products, Automotive, Aircraft	Precision Automotive, Medical, Aerospace, Pharmaceutical	Disc Drive, Optical, Electronics	Chip Fabrication, Disc Drive, Precision Optical

Figure 53 - UT Tank Frequency Cleaning Guide
(Image courtesy of Blackstone-Ney Ultrasonics™)

XIV.1.7 **Standing Waves**: In a traditional UCM with bottom firing transducers, the acoustic waves that are propagating upward through the liquid will reflect downward from the fluid surface. When reflected downward the acoustic waves will combine with the upward acoustic wave and the subsequent wave can be constructive(amplifying) if in-phase or destructive (attenuated) if out of phase. Ultimately areas/layers of higher acoustic energy/cavitation (standing waves) will form and there will be areas/layers of lower acoustic energy/cavitation. The standing waves tend to layer at a distance 1/2 of the wavelength with **Table XXI** showing the wavelengths and resultant standing wave of common UCMs frequencies; highlighted blue. The spacing of the standing wave is relative to themselves. Their position in the tank relative to a fixed point is dependent on the reflected surface – is it hard or soft; water height and other factors such as the type of transducer and water temperature. Based on an article by the late John Fuchs [Ultrasonics - Near Field and BEYOND! - CTG Technical Blog (ctgclean.com)](#), the first standing wave reflected from a hard surface (such as a tank metal wall) is about 1/2 the wavelength, while the first standing wave reflected from a soft surface (such as the water surface) is about 1/4 the wavelength. So, for UCMs with bottom firing transducers and the Degritter™ with side firing transducers into the record (soft surface), the location of the first standing wave relative to the water surface or record could be as close as 1/4 wavelength. Subsequent standing waves will be spaced about 1/2 wavelength apart.

Table XXI
Ultrasonic Tank Wavelength & Standing Waves

Frequency (kHz)	Distilled Water 20°C/68°F (speed of sound 1,483 m/sec)		Distilled Water 40°C/104°F (speed of sound 1,529 m/sec)	
	Wavelength (mm)	Standing Wave (1/2 wavelength) (mm)	Wavelength (mm)	Standing Wave (1/2 wavelength) (mm)
33	44.9	22.5	46.3	23.2
35	42.4	21.2	43.7	21.8
37	40.1	20.0	41.3	20.7
38	39.0	19.5	40.2	20.1
40	37.1	18.5	38.2	19.1
42	35.3	17.7	36.4	18.2
78	19.0	9.5	19.6	9.8
80	18.5	9.3	19.1	9.6
82	18.1	9.0	18.6	9.3
118	12.6	6.3	13.0	6.5
120	12.4	6.2	12.7	6.4
122	12.2	6.1	12.5	6.3

XIV.1.8 **Sweep Frequency**: Many ultrasonic tanks advertise a "sweep frequency" function. The "sweep frequency" function essentially modulates the main ultrasonic frequency about +/- 1 to 2 kHz with results shown **Table XXI**. The intent of "sweep frequency" is to minimize narrow standing waves that will form in the tank when using a fixed frequency which is valuable for cleaning parts that are layered static in a UCM. Sweep frequency tends to equalize the cavitation intensity throughout the tank. But the record(s) is rotating and standing waves may be beneficial since the record is exposed to a scrubbing type action as the record alternately moves from areas of lower cavitation intensity to areas of higher cavitation intensity.

XIV.1.9 **Tank Water Height**. For bottom firing UCM, the height of water above the transducers can affect the cavitation intensity. In the paper *Observations of water cavitation intensity under practical ultrasonic cleaning conditions, Bogdan Niemczewski, Tele- and Radio Research Institute, ul. Ratuszowa 11, 03-450 Warsaw, Poland, 18 November 2005 (12),* the cavitation intensity in an industrial 8-gallon UCM at two power levels (560W & 920W) and ten (10) different water levels (155 mm to 200 mm) was tested. The results relative to the maximum cavitation intensity recorded are shown in **Figure 54**. **Figure 54** clearly shows the effect of power on cavitation intensity. The effect of water height which can affect standing waves is evident. There is discussion that for the maximum cavitation intensity the water height should be whole multiples of 1/2 the wavelength and the data in **Figure 54** is suggestive of that.

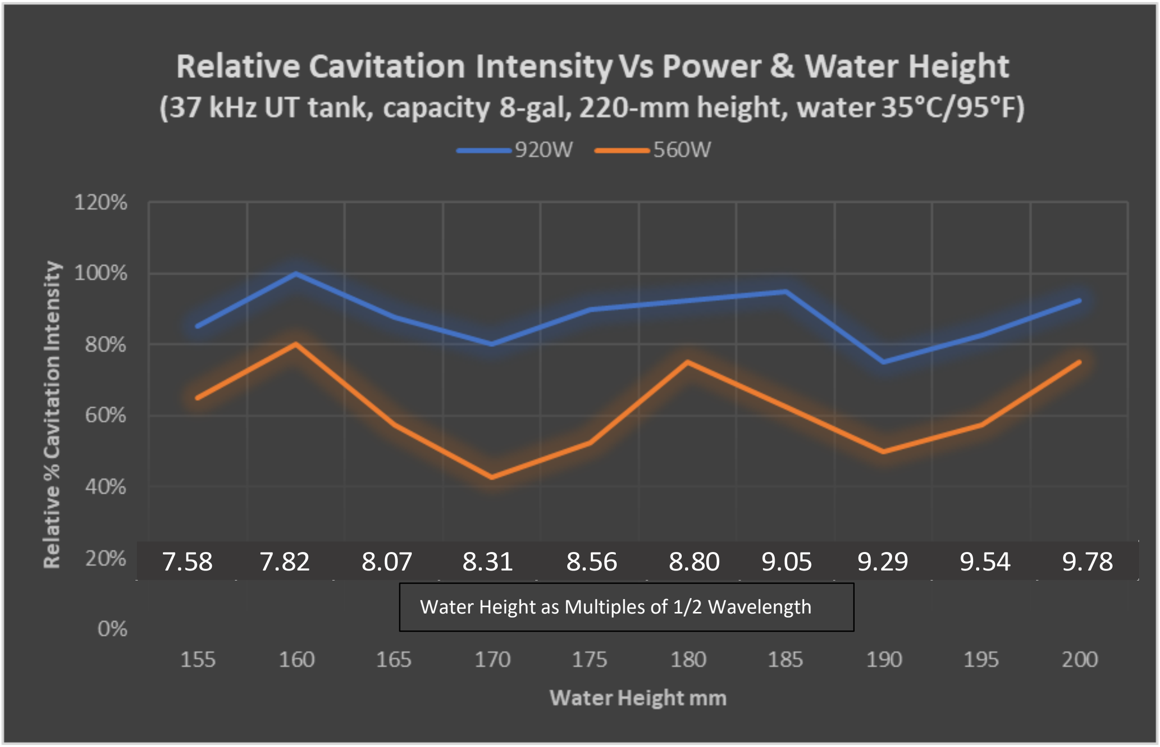


Figure 54 – Relative Cavitation Intensity vs Power & Water Height

XIV.2 Beyond the mechanics of ultrasonics, the fluid being sonicated has a profound effect on the cavitation energy and the overall cleaning efficiency. From the book *Particle Adhesion and Removal 2015* (62), and the paper *Parametric Study for High-Frequency, High-Intensity Ultrasonics in Removal of Sub-Micron Particles, Vetrimurugan, J. Michael Goodson, and Terry Lim, International Journal of Chemical Engineering and Applications, Vol. 6, No. 1, February 2015 (80),* the following are some of the variables with the fluid.

XIV.2.1 **Dissolved Gases & Degas**: Fluids exposed to air will absorb air and the solubility of air in water is inversely proportional with temperature and can decrease by about 25% between 20°C/68°F and 40°C/104°F. Air that is dissolved in the fluid will interfere with cavitation. As the cavitation bubble forms, the dissolved air in the fluid migrates into the cavitation bubble preventing maximum cavitation intensity when the cavitation bubble collapses. The degas process operates the ultrasonics with a tank of fresh liquid to remove some or most of the dissolved air. Degas efficiency is dependent on frequency, power and volume. Low frequency 40-kHz and less can take 30 minutes or more to fully degas a large tank, while 80 kHz and greater can accomplish degas in as little as 5 minutes. During the degas process, bubbles may be seen rising in the fluid; the fluid may go from cloudy to clear; there may be a change in sound; and the surface can change to smooth with just a slight rippling effect caused by the ultrasonics.

XIV.2.2 **Temperature**: For water, beyond about 40°C/104°F, the cavitation intensity can decrease. But, for lower kHz (60-kHz) cleaning efficiency can increase by about 10% up to about 60°C/140°F. However, for higher frequency (120-kHz) units, cleaning efficiency peaks at 40°C/104°F and then decreases rapidly. These temperatures are provided for reference only; the recommended temperature for record cleaning is about 35°C/95°F.

XIV.2.2.a Temperature can improve the cleaning efficiency, but for a record the mechanism may get the benefit of a thermal property called the coefficient of linear expansion (CLE) and in English units is referred to as in/in/°F. For PVC, the CLE is about 0.000032-in/in/°F; and this can also be expressed as 0.81 microns/in/°F. If the record heats from ambient (25°C/77°F) to 35°C/95°F, the record will expand by (0.81 microns/in)(18°F) = 14.5 microns/in. With a 12-inch diameter record, the record could expand in diameter by (14.5 microns/in)(12-in) = 174 microns = 0.007-in. This will not be seen, but expanding the record this much 'may' loosen tightly adherent detritus & particles. Note: metals do not expand anywhere near this amount. The CLE for aluminum is about 1/3 that of PVC, while stainless steel is about 1/4.

XIV.2.2.b Exposing the record to excessive temperatures that can cause temporary warpage is not recommended. Records while remarkably robust, are sensitive to heat. When the record warps from heat, it begins to pass what is known as the glass transition temperature; the record gets soft. Once the record is over about 55°C (131°F) it begins to release hydrogen chloride gas. The record has stabilizers to scavenge the gas during the heated pressing process and there will be some stabilizer reserve left. But once the stabilizer is exhausted the surface will harden, embrittle and micro-cracks form. At this point, the record does not stand a chance against that diamond stylus. It's suspected that records that contain repressed material are more susceptible to heat degradation (with maybe a lower allowable temperature) because they may not have as much stabilizer reserve.

XIV.2.3 **Flow Rate**: For recirculated/filtered tanks operated during ultrasonic cleaning, the optimum flow rate is about 25% of the tank volume. A flow rate equal to 50% of the tank volume is acceptable, but for lower frequency UCM (<~120 kHz) any greater and the cavitation intensity can decrease quickly. Higher frequency UCM such as 120 kHz are not as sensitive to the flow rate in the tank. The root-cause is believed (80) to be the difference in the size and time it takes for the cavitation bubble form. At low frequencies (25 kHz), the time for the cavitation bubble to form is 3-4 times longer than higher frequencies (>120 kHz). Since the record(s) as it rotates through the bath will develop flow, for lower frequency UCM there can be rotation limits and this is discussed further in **paragraph** XIV.5.3.

XIV.2.4 **Surface Tension & Vapor Pressure**: As the fluid surface tension drops less power is required to develop cavitation, and more cavitation bubbles are developed, but with less cavitation intensity, but cleaning efficiency increases. As vapor pressure (boiling point) drops, such as when using a solvent, the cavitation intensity can drop if the fluid density decreases. The density of the fluid affects the cavitation intensity. A denser fluid (such as water) is essentially stiffer and allows a higher pressure to develop in the cavitation bubble which upon implosion releases more energy. So, there is a trade-off with the chemistry of the fluid. But chemistry can bring a host of other problems if not careful, such as fire and explosion hazards if using flammable solvents (i.e., alcohol), and residue if using high concentrations of surfactants

XIV.3 The following is some guidance that has been used for ultrasonic cleaning beyond the basics such as degassing and were sourced from *MIL-STD-1330D (51)*, *NASA LPR 1740.5F, Procedures for Cleaning of Systems and Equipment for Oxygen Service, 2015* (57) and *Ultrasonic cleaning: an historical perspective Mason, T.J. 2016 (45)*.

XIV.3.1 *(MIL-STD-1330D) Generator power per radiated surface of at least 3 watts/in^2. The power per radiated surface area can be determined by dividing the total generator power by the surface area of tank bottom or side where the generator transducers are located.*

XIV.3.2 *(MIL-STD-1330D) When cleaning non-metallic/elastomeric parts limit duration to 10 minutes; but not less than 5-minutes.* The general industry guidance for all materials is 2-10 minutes. A maximum time of 20 minutes is addressed, but generally as indicating that the process has a weakness in one of the parameters such as the cleaning agent, ultrasonic power or ultrasonic frequency.

XIV.3.3 *(NASA) The sum of the parts cross-sectional area should not exceed 75% of the tank cross-sectional area*. The tank cross-sectional area is associated with the surface where the transducers are mounted. For bottom mounted transducers, the cross-sectional area is the tank length x width, and the record shows only its width x thickness (12" x ~0.1"). For side mounted transducers, the cross-sectional area is the tank height x length and the record shows its width x height (about 0.67 ft^2/record) for a much larger cross-section. This suggests why stacks of multiple records "can" be cleaned with a UCM with bottom mounted transducers, but with some loss of efficiency.

XIV.3.4 *(NASA) For most effective cleaning, total parts weight should not exceed 0.351 kg/Kw of generator power, even though a slightly higher weigh to Kw ratio can be accommodated*. If an ultrasonic tank has only 200 W power, then by this direction the total weight should not exceed 70 grams which would be only about 40% of a 180-gram record which is not much more than one record in an ultrasonic tank. The implication is that when cleaning a stack of multiple records there is likely some compromise.

XIV.3.5 *(NASA) Parts positioning, important in most cleaning operations, is doubly important in ultrasonic cleaning. If possible, critical areas to be cleaned should face the transducer(s).* This is intuitive except consider that Industry often cleans complex shapes with inaccessible areas; whereas the record in comparison is a relatively simple shape with no inaccessible surfaces. Note that for high powered, lower kHz UCM such as 40 kHz, records should be placed at least 1/2 wavelength from the transducer surface to avoid damage. The area closest to the transducers tends to have the most intense cavitation and a high-powered low kHz UCM could damage by erosion the record in this zone.

XIV.3.6 *(NASA) Non-rigid plastics absorb ultrasonic energy and can produce a shadowing effect.* This can be an issue when cleaning many records at once such as the stacked capability of the VinylStack™ Ultra Sonic Spin (**Figure 55**) or the Kuzma™ RD Kit (**Figure 57**) and other similar commercially sold units. Shadowing will depend on where the ultrasonic transducers are located. Vinyl records whose low-density material is about 22 g/in^3 (compared to 127 g/in^3 for stainless steel) will absorb ultrasonic energy. The current record spacing guidance appears based on various qualitative observations. There are ways to evaluate UCM performance based on testing for cavitation. There is the qualitative aluminum-foil test for cavitation, but it has limitations and the reader is directed to https://techblog.ctgclean.com/ search "aluminum foil" for information. There is the SonoCheck™ Healthmark Industries - Cleaning Verification - SonoCheck that is used to qualitatively verify cavitation intensity (*suitability for stacked record cleaning unknown*). There are quantitative ultrasonic cavitation meters such as https://sonicmeter.com/. However, the cost of ultrasonic cavitation meters makes purchase by an individual for one time use impractical.

XIV.3.7 **Record Spacing**: When cleaning a stack of records that uses a UCM with bottom firing transducers, there is discussion on the internet that records should be spaced not closer than the UCM wavelength (see **Table XXI**). The details and derivations are inconclusive. The wave-length which is dependent on the transducer frequency would be measured parallel to the record surface. But the amplitude which is a function of power would be measured perpendicular to the record surface; and this is illustrated **Figure 52**. Will spacing records too close impede the maximum amplitude – unknown. Industry commonly uses 25 kHz (wavelength 61.2 mm in 40°C/104°F DIW) for gross-metal cleaning; and does not space parts 2.5" apart; noting that ultrasonic waves will pass through metal. However, spacing records too close could affect the amplitude of the ultrasonic wave since the associated acoustic energy/pressure could be lost to the record (as heating). Additionally, for lower kHz UCM, cleaning too many records at a time can result in significant reduction in cavitation intensity because of flow rate affect (see **paragraph** XIV.5). So, spacing the records about equal to the wavelength should help to maximize cavitation intensity while prevent over-loading the UCM (from record mass, surface area and flow rate) and therefore is probably good practice. This is especially true for the lower kHz UCM (such as 35-40 kHz) that are more susceptible to flow rate interference.

XIV.4 Readers are directed to *Ultrasonic Cleaning Fundamental Theory and Application, F. John Fuchs, Blackstone Ultrasonics, 1995* (39) and the book *Particle Adhesion and Removal 2015* (62) for additional information on ultrasonic cleaning fundamentals. For information, *John Fuchs* (who sadly passed away Jan-2021) had a blog at https://techblog.ctgclean.com/, that has extensive information on ultrasonic cleaning. The study of cavitation energy is on-going, as is its relationship to the fluid being sonicated and the item geometry and particle soil tenacity (for want of a better term). As addressed **CHAPTER X. DISCUSSION OF MATERIAL COMPATIBILITY:**, one of the foundations of chemistry is that "**Like dissolves Like**". Unfortunately, as addressed in the **FOREWORD**, a single safe high-density solvent to handle the wide variety of soils does not exist, so experiments with different chemistry, fluid parameters and UCM designs continue. Additionally, as addressed **CHAPTER XII. DISCUSSION OF THE CLEANING PROCESS:** there is an entire science on just particle removal. Otherwise, testing has shown that for vinyl record cleaning with UCM, a balance of process, equipment and cleaning solution are required to get the best results.

XIV.5 **Record Rotation Speed**. The record needs to be in contact with the fluid and ultrasonics long enough to be cleaned. Accumulated time may not be the same as continuous contact time. Contact time is necessary to clean some soils that are essentially removed layer-by-layer and this will depend on the bath chemistry. The UCM is going to heat up during use if by nothing more than the heating caused by the ultrasonic power. Because of the heat, if using a relatively high cleaner concentration, time may have to be limited so that no part of the vinyl record is in continuous contact with the cleaner for greater than about 5-10 minutes because of material compatibility (ref: **CHAPTER X. DISCUSSION OF MATERIAL COMPATIBILITY:**). If using only DIW, then extended contact time is generally required for the process to be effective. The following are some options for rotating speed.

XIV.5.1 If using a low-residue bath (low concentration cleaner with low NVR), where there is no concern for cleaning solution drying in-place, a very slow rotation speed is an option. Targeting that the record will have a continuous exposure time of about 2-3 minutes, and with only about 33% of the record exposed at any time, a single rotation time of about 6-9 minutes (0.17 to 0.11 rpm) could be an option as could doubling the time 12-18 minutes (two complete rotations) to ensure equal exposure. NOTE – for high powered low kHz UCM such as 40 kHz with bottom firing transducers, a very slow rotation does risk damage from possible erosion if the record bottom rotates very slowly near (1/2 to 3/4 wavelength) the transducers. In this case, a minimum rotation time of about 0.5 rpm is suggested.

XIV.5.2 If using a high-residue bath (high concentration cleaner with high NVR), where there will be a post-rinse, the rotation speed can be faster since there is more chemistry, but it also needs to be faster to prevent cleaner drying in-place. In this circumstance, the record will have an intermittent exposure and the rotation time should be adjusted to obtain an equal number of rotations (i.e., no fractions) but at an accumulated time of 5-10 minutes. Calculate the time = (number of rotations)/(rpm) so for examples (5 rotations)/(0.6 rpm) = 8.333 = 8 min 20-sec; while (4 rotations)/(0.4 rpm) = 10 min.

XIV.5.3 Record rotating speed can be too fast. Recalling **paragraph** XIV.2.3, if the rotating speed develops a flow rate equal to 1/2 the tank volume per minute, cavitation intensity will decrease and maximum benefit of ultrasonics will not be obtained. What is the rpm threshold? That would depend on the number of records (the stack) being cleaned simultaneously and the tank volume. However, a very simplified analysis shows that as a record moves 1-rpm through the fluid it moves about 1.0-liter of fluid with it. The calculation is as follows:

XIV.5.3.a Assume 0.333% of the record is in contact with the fluid and recalling (**paragraph** XI.2.5) the record (minus label) per side is 1-ft^2, so at any time 0.67-ft^2 are in contact with the fluid.

XIV.5.3.b Assume that as the record rotates, it will agitate a film of fluid 0.25-inch thick on each side. Therefore, as the record rotates, the volume of water that is agitated = (0.67-ft^2)(144-in^2/ft^2)(0.5-in) = 48.25-in^3 = 0.8 mL.

XIV.5.3.c However, the faster the rotation, the more fluid is moved because of drag, so a 25% factor is applied for uncertainty to yield a simple thumb-rule that the rotating record is agitating/moving 1 liter of fluid; and a rotating speed of 1-rpm = 1-lpm.

XIV.5.3.d Example: The Kuzma™ RD Kit is often used with the Elmasonic™ P 120-H ultrasonic tank (see **Figure 56** and **Figure 57**)that has a volume of 12.75 liters. If cleaning 10 records at a time, and using the thumb-rule 1 rpm = 1 lpm, the maximum speed for 50% tank flow is (12.75L)(0.5)/(10 records)(1 lpm/rpm) = 0.64 rpm which is right at the maximum speed (0.6 rpm) of the Kuzma™ RD Kit. So, the derivation and use of the thumb-rule 1 rpm = 1 lpm appears valid for this application noting the Elmasonic™ P 120-H is a very well manufactured unit with a lot of power about 100 watts/gallon.

XIV.5.3.e However, if the ultrasonic tank is being filtered, then the flow rate of the pump has to added to the flow generated by the record rotating and the final equation is as follows:

$$Rrpm = \frac{(V)(0.5 - [Q/V])}{(N)(K)}$$

Where: Q = pump flow rate (lpm)
K = thumb-rule 1 lpm/rpm
N = number of records
R*rpm* = maximum record rpm
V = tank volume (L)

Examples:

- Single record in a 6.5-L tank, with 2.8 lpm pumped filtration. (6.5-L)(0.5-[2.8/6.5])/(1 record)(1 lpm/rpm) = 0.5 rpm

- Three records in a 6.5-L tank, with no pumped filtration. (6.5-L)(0.5-[0/6.5])/(3 records)(1 lpm/rpm) = 1.0 rpm
- Three records in a 12.7-L tank, with 2.8 lpm pumped filtration. (12.7-L)(0.5-[2.8/12.7])/(3 records)(1 lpm/rpm) = 1.1 rpm (*close enough to 1 rpm*)

XIV.5.3.f In cases where the pump should not be operated, then there are two options to operate the filter between record cleaning cycles. One option is to install a large recirculating pump to reduce the tank 1/2-life (see **paragraph** XIV.15.3) or install a holding tank to do batch filtration (see **paragraph** XIV.15.5). Batch filtration is 100% efficient and much faster.

XIV.5.4 There are a number of record spinners available. The VinylStack™ Ultra Sonic Spin – Record Cleaning Kit that could clean up to 4 records at a time with a convenient magnetic clamp design, and a rotation speed variable from 1.5 to 7 rpm illustrated **Figure 55** is no longer available (no assertion as to the correct spacing of the records is inferred). The ultrasonic tank in **Figure 55** is manufactured in the USA by Sharpertek™ Sharpertek Ultrasonic Cleaners, Medical Cleaners, Vapor Degreasers, Pressure Deburr, Ultrasonic Horns, and Ultrasonic Welders. Sharpertek™ does sell Model XPS360-6L-D that is an economical 40-kHz 6L, 180W UCM with side drain and appropriate tank inside dimensions for record cleaning 11.75"L × 6"W × 6"H. Its USA assembled and serviced with a 2-year warranty.

Figure 55 - VinylStack™ Ultra Sonic Spin
(By permission VinylStack™)

XIV.5.5 Other lower cost spinners are available – search Amazon™; Walmart™ and eBay™. However, most stack the records too close – which is easily corrected with plastic spacer(s), but they often spin at too high a speed. If the motor is 12VDC, there are now low cost variable VDC power supplies that can be used to slow the rpm such as Amazon.com: JOVNO Universal Power Supply 3V-12V 5A 60W Adjustable AC/DC Adapter 100~240V AC to DC 3V 5V 6V 8V 9V 12V with LED Display and 14 Plugs 1 Reverse Polarity Converter Cable for LED Strips Motors Speaks : Everything Else. No assertion is made to the quality or reliability of these variable VDC power sources.

XIV.5.6 A source for a very high-quality record stack/spinner is the Kuzma™ RD Kit that can stack up to 10 records at a time and rotates at 0.4-0.6 rpm - RD Ultrasonic Record Cleaning kit - Kuzma Professional Turntables, Tonearms and Accessories. **Figure 57** and **Figure 56** illustrate a UCM filtered clean/rinse system using the Kuzma™ RD spinner and an Elmasonic™ P120H dual frequency 37/80-kHz UCM for cleaning and an Elmasonic™ S120H single frequency UCM 37-kHz for rinse. The clean tank filter system is the "high-option" listed **Table XXIV**. Not shown is a radiator to keep the Elamsonic™ P120H temperature <100°F to allow serial processing of records. The Elamsonic™ P120H is a powerful 12-L UCM with 300W effective ultrasonic power and 1320W peak ultrasonic power along with a high power pulse operation. This system is pretty much state of the art for high throughput, precision cleaning of records for best achievable cleanliness.

Figure 56 – Elmasonic™ UCM Filtered Clean/Rinse System & Kuzma™ Spinner

(*By permission @dminches Steve Hoffman Forum™*)

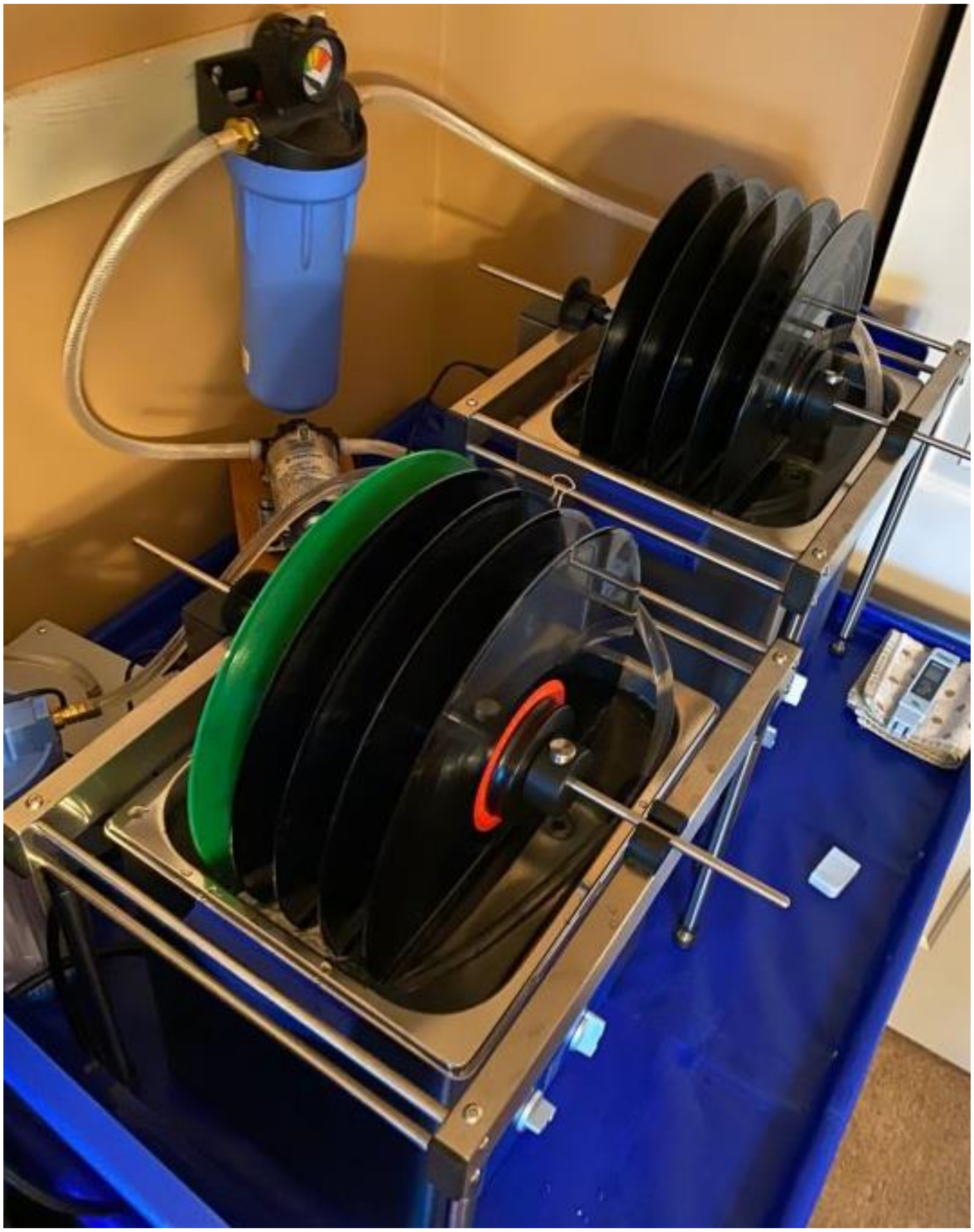


Figure 57 – Elmasonic™ UCM Filtered Clean/Rinse System & Kuzma™ RD Spinner w/Records

(*By permission @dminches Steve Hoffman Forum™*)

XIV.6 **UCM Chemistry**: If cleaning only new or relatively clean records - i.e., mostly particulate, there should be no need for a lot of chemistry. The amount of chemistry is based on whether a final rinse will be used. If using only a single UCM for final clean without separate rinse, such as the Degritter™ Record cleaning machine that is easy to use - Degritter or the Audio Desk Systeme™ Vinyl Cleaner PRO then there is comprise between convenience and ease of use, and cleaning efficiency and minimizing cleaner residue. Recall that **Table XVIII** shows the cleaner residue film thickness that can remain on the record and subjectively >0.03

microns 'may' be the threshold for hearing the effects. If not using the manufactures supplied cleaning agent, the DIY goal is to get the lowest surface tension (such as Dow™ Tergitol™ 15-S-9 at 0.01%) and maybe some detergency (1.5 to 2 times the CMC) if foam is not excessive plus a little IPA (2.5%) to help with soil-swell/roll-up recalling **Figure 40** but still be within safe guidelines for flammability. Otherwise, the following are some additional considerations when using a single UCM for cleaning:

INFORMATION

Be advised that record specific UCM manufacturers may void the warranty if not used with approved chemistry and this should be made clear in their literature. The chemistry and formulas addressed in this chapter should not be harmful with these units except for those sensitive to foam which is addressed. However, if in doubt, use the manufacturers supplied cleaning agent.

CAUTION

UCMs should not be used with any flammable liquids unless explosion proof in accordance NFPA 70 NEC, and recall from **Figure 37** that IPA at about 10% is considered flammable by the NFPA, and at about 7% can still produce explosive vapors. Any use of alcohol in a UCM should not exceed 2.5% to avoid any fire and explosion hazard noting that some UCM users are operating as high as 45°C/113°F; evaporative losses of alcohols from water and the need to monitor notwithstanding.

CAUTION

IPA can cause stress cracking of some plastics such as Acrylic at relatively low concentrations. When preparing IPA solutions add IPA to water.

INFORMATION

If using alcohol in an open ultrasonic tank, recall paragraph VIII.8.8 Alcohol Evaporative Losses. Unless the tank is refreshed frequently, the alcohol concentration is going to decrease faster than the evaporative water losses. For extended tank operation with alcohol, monitoring with an alcohol specific (ethanol or IPA) hydrometer is required if the benefits of the alcohol are to continuously realized.

INFORMATION

Industrial ultrasonic tanks can be designed to use acids, and acids are commonly used to clean and brighten brass, but any filtration system will need careful consideration. For record cleaning, there is no benefit of the acid. The ultrasonics/cavitation are supposed to clean the very fine/small particulate that the acid would clean in a manual cleaning procedure.

XIV.6.1 The large cleaner volume to record surface ratio avoids the chemistry being quickly exhausted by the record NVR (recalling how surfactants work from **CHAPTER VIII. DISCUSSION OF PRE-CLEANERS:**) and by drag-out. But the low concentration may not provide much bath life, and aside from observing sheeting on the record or maybe a 'shake test' to test for surfactant foam there is no easy quantitative method to measure nonionic solution concentration.

XIV.6.2 Anytime multiple record batches are exposed to the same bath, there is the question of whether the last item (record) is cleaned as well as the first. Using a single bath-charge for cleaning many records will present challenges as oil and particulate build-up in the tank and chemistry is depleted. Also; if use extends for many weeks, bacteria may form. For those with large record collections or those who process a lot of records, purchasing a system to produce DIW can significantly improve access to and reduce the cost of purified-water as discussed **CHAPTER VII. DISCUSSION OF WATER QUALITY:** If there is a source of readily available cheap purified water, then the bath can be dumped more frequently and the need to add filters/pumps etc. to recycle and extend the UCM bath life can be eliminated. Otherwise, for the DIY's pumped filter systems are addressed later in this chapter beginning **paragraph** XIV.14.

XIV.6.3 The use of a dual frequency UCM that can produce about 35-40-kHz followed by about 80-kHz such as the Elma™ Elmasonic™ P-series or the Zenith™ Crossfire may get the best cleaning from a single-UCM. The article Ultrasonics | Applying Multiple Frequencies for Maximum Benefit (ctgclean.com) by (*the late*) *John Fuchs* discusses not only the benefits of multiple frequencies but also the possible need for multiple cycles of multiple frequencies.

XIV.7 **Degritter™ UCM**: The following summarizes some test results of various chemistries with the Degritter™ UCM that were addressed at the Steve Hoffman Forum™ Degritter Users | Steve Hoffman Music Forums. The Degritter™ because of how it filters the tank with essentially a surface skimmer; how it pumps-down the tank for drying; pumps-down the reservoir for cleaning; and primes on start-up is sensitive to pump cavitation and producing foam so nonionic surfactants that can foam are used at very low concentrations mostly just for 'wetting'. As a general note, the manufacturer supplied cleaning agent is low foam, and users report that for dirty records' multiple cleaning cycles – as many as 3 had improved results.

XIV.7.1 Tergikleen™ at a solution concentration of about 260 ppm (1 mL/1-US-gal) left a residue that was audible and noted as a "veiling" of the music. However, the product produced no foam as expected because of the Dow™ Tergitol™ 15-S-3 which is also a defoaming agent (see **paragraph** IX.8 for further details).

XIV.7.2 ILFORD™ ILFOTOL™ at a solution concentration of 0.125% (actual non-ionic surfactant concentration about 62 ppm) with 2.5% IPA. This solution did not leave an audible residue but was problematic because of excessive foam after the first cycle. The exact version of the ILFORD™ ILFOTOL™ used is unknown.

XIV.7.3 BASF™ DEHYPON® LS 54 at a solution concentration of about 50 ppm (0.0050%) did not leave an audible residue and did not produce excessive foam. Note that BASF™ DEHYPON® LS 54 at 0.0150% with 2.5% IPA did foam excessively. The 2.5% IPA does lower the solution boiling point/increasing the solution vapor pressure that would increase the risk of pump cavitation.

XIV.7.4 Dow™ Tergitol™ 15-S-9 at a solution concentration of about 150 ppm (0.0150%) and 2.5% IPA did not initially produce foam, but after successive cleaning cycles began producing foam. Reducing the Dow™ Tergitol™ 15-S-9 to a concentration of about 80 ppm (0.008%) and 2.5% IPA significantly reduced foaming and still showed excellent wetting.

XIV.7.5 The Degritter™ tank volume is only about 1400 mL. The surfactant concentrations previously stated were being obtained by ‘drops’ of surfactant whose volume can be variable. When working with very small concentrations in small volumes such as this, it is better to prepare a diluted concentration of say 1% (10 mL/L) and then proportion from that. The equation shown **paragraph** VIII.8.7 is useable. As an example, to obtain 0.008% Dow™ Tergitol™ 15-S-9 using a 1% solution; add = (0.00008/0.010) x (1400 mL) = 11 mL. Additionally, the sequence of adding nonionic surfactant +IPA to water makes a difference. If you take a small glass container (150-200 mL) and just fill with tap-water, and do the following experiment the following will be observed:

XIV.7.5.a If IPA (2.5% equivalent) is added first and then add the non-ionic surfactant the surfactant does not immediately break-up, it sinks as a solid drop(s). It will go into solution but it needs to be agitated. As it’s agitated, the drop of surfactant break-ups and 'slowly' goes into solution.

XIV.7.5.b If 1-drop of non-ionic surfactant is added first, the drop immediately breaks-up and with some agitation quickly goes into solution.

XIV.7.5.c If adding chemicals individually to the Degritter™ tank that could be a problem. At the very least, add the surfactant as a pre-diluted solution. Otherwise, prepare a gallon of prepared cleaning solution and then fill the tank from that.

XIV.8 **Pre-Clean/Final-Clean Process with UCM**: If the record is exceptionally dirty, such as trying to resurrect a Goodwill® or flea market find, attempting to use a single ultrasonic tank to clean presents a number of challenges because of the variety and concentration of contaminants. Lower UCM frequency and/or more aggressive chemistry is preferred. The record must first be degreased to remove any oil/grease film, otherwise, the underlying or trapped particulate may not be removed. The user has a number of options, but as previously discussed, standard industrial guidance used by nearly every precision aqueous cleaning procedure is pre-clean (degrease/remove visible contaminants), rinse, final-clean (polish), rinse, dry. Additionally, if the goal is extending the bath life of a unit like the Degritter™ or to achieve the best cleanliness, there are a number of options to use UCM as part of a pre-clean/final clean process and these are addressed in the following paragraphs. In all cases, a separate UCM will be used for the final clean step.

XIV.9 **Step 1: Pre-Clean:** A variety of pre-clean methods are listed **Table XXII**. Any number of methods can be combined. Methods 1 and 3 have the benefit that the cleaner is removed/rinsed after use minimizing carry-over to the final clean step. A number of people indicate that they use Method 3 vacuum-RCM for the first pre-clean, albeit many of these people first owned a vacuum-RCM before adding a UCM. Some people whose goal is the cleanest possible record and who have the space and financial resources may use Method 3 vacuum-RCM for the first pre-clean and then use Method 4 UCM as the second pre-clean or rinse.

Table XXII
Pre-Clean Methods

Method	Chemistry	Effectiveness	Labor	Cost	Life Cycle $	Safety
1. Manual Brush	Alcohol solvent	Dependent on chemistry, brush & operator technique	High	Low	Solvent	Fire
2. Manual Brush	Aqueous		High	Low	Cleaner & Water	Safe
3. Vacuum-RCM	Aqueous		Medium	Medium to High	Cleaner, Water, & Parts; some can last 20 yrs	Noise
4. UCM	Aqueous	Dependent on chemistry & equipment design	Low	Medium to High	Cleaner, Water, Filters, Parts. Low-cost units can fail in <2-yrs	Noise

XIV.9.1 Pre-clean method 1 using IPA and brush is a common addressed item on the many audio forums; and a popular brush is the one that comes with the Audio Technica™ AT-6012 kit. The IPA is applied to the brush bristles or to the record directly.

XIV.9.2 Pre-clean method 2 can be any of the many manual aqueous methods available such as:

XIV.9.2.a One of the many record cleaning brushes and aqueous cleaner kits such as the Audio Technica™ AT-6012 kit or the Discwasher™ Vinyl Record Cleaning System. However, cleaner NVR will likely be carried-over to the final clean step reducing the final clean UCM bath life and the actual performance of these brushes and associated cleaners are debatable as previously discussed **paragraphs** VI.1 and VI.2.

XIV.9.2.b Many people pre-clean with the Spin-Clean® record washer Spin-Clean Record Washers - Shop the Official Spin-Clean Store (or equivalent). These manual spin type bath units have the benefit of not using a large bath so its economical to frequently replace the bath. Using a second unit for rinsing only is an option. An inexpensive method that can be used to filter/recycle cleaning fluid is to use a coffee filter. They are generally good for about 10-15 microns filtration which is not bad and a pour-over coffee maker such as Amazon.com: Melitta 640616 Coffee Maker, 52 oz, Glass Carafe : Home & Kitchen is inexpensive and large enough to filter the volume of the Spin-Clean® record washer.

XIV.9.2.c Or, perform only the pre-clean/rinse step from **CHAPTER V. MANUAL CLEANING PROCESS:** which will minimize cleaner carry-over. If final clean is with the Degritter™ UCM, recommend performing the final-clean/rinse step to avoid carry-over of any high foaming pre-cleaner.

XIV.9.3 Pre-clean method 3 would be similar to **CHAPTER XIII. DISCUSSION OF VACUUM RECORD CLEANING MACHINES:**.

XIV.9.4 Pre-clean method 4. The assumption is that a UCM used for pre-clean will be without post rinsing. This requires balancing the cleaner concentration to minimize the carry-over/drag-out to the final clean UCM. Otherwise, the bath life of the final clean UCM will be shortened, and there are not many cost-effective options to remove excess surfactant with filters. The UCM for pre-cleaning should be a lower frequency 35-40 kHz unit to remove tenacious soil films and large particles. Be advised, that the lower cost 35-40 kHz units can be very noisy and hearing protection may be warranted. The following are some options for chemistry. For those with IPA, the information in **paragraph** XIV.7.5 applies.

- Alconox Liquinox at 0.25 to 0.50%
- Tergitol 15-S-9 at 0.025 to 0.05%
- Tergitol 15-S-9 at 0.025 to 0.05%% + 2.5% IPA
- ILFORD ILFOTOL at 0.25 to 0.50%
- ILFORD ILFOTOL at 0.25 to 0.50% + 2.5% IPA
- BASF™ DEHYPON® LS 54 at 0.025 to 0.05%
- BASF™ DEHYPON® LS 54 at 0.025 to 0.05% + 2.5% IPA

XIV.10 **Step 2 - Final Clean:** Assuming no rinse after final clean with a DIY UCM, similar chemistry discussed for the Degritter™ can be used, but since there should be less risk of foam, slightly higher concentrations can be used. Exposure time should be similar to the pre-clean-UCM so that no part of the vinyl record is in contact with the final-cleaner for greater than 5 minutes. Assuming an exposure time of 2-3 minutes, with only 33% of the record exposed at any time, a total rotation time of about 6-9 minutes would be recommended subject to record rotation previously discussed **paragraph** XIV.5 . The following are a couple of options for DIY-UCM chemistry. In all cases the goal is to obtain the best wetting and maybe some micelle formation but not more than about 5X the CMC to minimize the cleaner MVR. If using a Degritter™, or equivalent, use the chemistry previously addressed **paragraph** XIV.7; and those with IPA the information in **paragraph** XIV.7.5 applies.

- DIW only
- DIW + 2.5% IPA
- Tergitol 15-S-9 at 0.0075 to 0.015%
- Tergitol 15-S-9 at 0.0075 to 0.015% + 2.5% IPA
- ILFORD ILFOTOL at 0.125 to 0.25%
- ILFORD ILFOTOL at 0.125 to 0.25%+ 2.5% IPA. (Note: This solution is similar to what was used by tima's DIY RCM | What's Best Audio and Video Forum. The Best High End Audio Forum on the planet! (whatsbestforum.com))
- BASF™ DEHYPON® LS 54 at 0.005 to 0.01%
- BASF™ DEHYPON® LS 54 at 0.005 to 0.01% + 2.5% IPA.

XIV.11 **Step 3 - Rinse**: If using the surfactants listed **paragraph** XIV.10 at the minimum concentration, rinsing is optional; some users are satisfied with the results. However, for best results, if using surfactant chemistry and not filtering, at least lightly rinse the record(s) with spray or wash bottle filled with purified water – effluent can just drain into the UCM tank or a separate tray before drying. Otherwise, for best -achievable cleaning, separate rinse equipment such as a container/tub of DIW, a second ultrasonic tank for DIW rinse-only (see **Figure 57** and **Figure 56**) or using a vacuum-RCM for rinse/dry are options that many have used to good effect.

XIV.12 **Step 4 - Dry:** There are a number of methods/options for drying discussed as follows, and this assumes a Degritter™ or similar UCM that has a drying feature is not used.

XIV.12.1 If cleaning stacks of records as shown **Figure 55** and **Figure 57**, most people are leaving the stack assembled and allowed to air-dry in or on a rack. Placing a HEPA filter in the area will minimize ambient particles depositing on the records while drying.

XIV.12.2 If using Method 3, vacuum-RCM as the pre-clean step, the record(s) can be (rinsed and) dried with the vacuum-RCM.

XIV.12.3 If using fans to dry, unless very fine air filters (see **CHAPTER VII. DISCUSSION OF WATER QUALITY: Table VII**) are installed there is risk of depositing very fine, invisible ambient particulate on the record. Simple expandable air filter socks can be of value. But, if using very fine air filters, small 120VAC/60Hz axial fans that are restricted to about 3600 rpm may not develop enough fan static pressure to overcome the resistance of a small fine air filter. However, small high speed 24VDC axial fans are available that can produce as much as 5X the fan static pressure of a 120VAC/60Hz axial fan, the higher noise notwithstanding. These 24VDC fans often are variable using a 0-10VDC signal for speed control.

XIV.13 **Cleanliness Verification**: UCM cleaning does present the opportunity to implement a form of cleanliness verification as part of the final-clean step **paragraph** XIV.10.

XIV.13.1 The final cleaner chemistry **paragraph** XIV.10 is nonionic; including the IPA. Bath ionic purity – TDS, can be easily monitored. There are many inexpensive TDS meters available, but resolution and full-scale accuracy at the lowest scale can yield inaccurate results. TDS meters such as the HM COM-100 (http://hmdigital.com/product/com-100/) can at the lowest range measure with a 0.1 ppm resolution recalling from **Table VI** that new purified water should measure <2.5 ppm TDS. However, in-use, allowing the TDS to increase to 10 ppm; same as Navy Grade B water specified in **Table VI**, should yield acceptable results as implied **Table VII**.

XIV.13.2 To check for particulate, obtain about 50 mL sample of the UCM bath water in a clean glass container, and place a piece of white and then black paper behind the container and inspect for visible particulate or turbidity. There should not be any visible particulate and unless very turbid (and this will take some experience), at this point the process has done all it can do. If the sample is very turbid, refresh the tank (or allow time to filter) and reclean. Alternatively, compare the sample to known sample of unused cleaning solution.

XIV.13.3 If using only DIW or DIW + 2.5% IPA, obtain about a 50-100 mL sample of the UCM bath water in a clean clear container. Cap, shake and verify no stable foam - this will verify that there is no foaming pre-cleaner that may have carried-over from the pre-clean step. If final-clean is using any of the surfactants, some foam will develop and this 'shake-test' is not applicable.

XIV.13.4 Note - if you are constantly having to reclean, the pre-clean step needs to be adjusted. It may be the chemistry, the chemistry concentration, the bath life, exposure time, record loading, or the tank Hz and watts. But an occasional (not frequent) reclean generally indicates an efficient process. If you never have to reclean, chances are you doing more than 'required', but that is not necessarily bad.

XIV.14 **Filtration Systems**: For any UCM there is the option to extend bath life (and improve cleaning consistency) by installing a pumped filtration system. Without a filter system or frequent bath refresh, the bath will accumulate all manner of detritus in-use, so that the last record cleaned is unlikely to be as clean as the first record. Depending on the bath chemistry there are three basic types of filters that can be used – particulate (commonly called sediment), activated carbon and ion-exchange (demineralizer). If the UCM will use only DIW or DIW + IPA, all three filter-types are usable. Activated carbon and ion-exchange have limitations with surfactants. If a low concentration of Dow™ Tergitol™ 15-S-9 (0.01 to 0.05%) nonionic surfactant is used to reduce surface tension then only a sediment filter is recommended. To control biologics, instead of chemistry, absolute sediment filters <0.3 micron are effective as discussed **paragraph** XIV.19.2 as is compact UV sterilization that is discussed **paragraph** XIV.23. The following paragraphs discuss design considerations associated with pumped filtration systems.

XIV.15 **Pumped Filtration**: Pumped filtration is performed either by single tank recirculation as illustrated **Figure 57** and **Figure 58** which is the most common method, or tank-to-tank batch processing illustrated **Figure 59**, **Figure 60**, and **Figure 61**. There are advantages and disadvantages to each. **Table XXIII** shows a comparison between the two-types of filtration systems assuming a UCM of 2-gallons capacity. Generally, recirculation is simpler and cheaper; while batch is faster, more efficient, but more complicated and expensive.

Table XXIII
Batch vs Recirculation Filtration

Parameter	Batch Filtration	Recirculation Filtration
UCM Tank capacity	2-gal	2-gal
Batch Tank Capacity	2.5-gal	Not applicable
Pump Capacity	1.0 gpm	0.5 gpm
Valves	Yes	None required
UCM Drain (pump) Down Time	2 minutes	Not applicable
Filtration Efficiency	100%	97% (five half-lives)
UCM Refill Time	2 minutes	Not applicable
Total Filtration Time	~5 minutes	14 minutes
Cost & Complexity	$$$/##	$$/#
Risk of Foam	Moderate depending on pump	Low

XIV.15.1 **Figure 58** illustrates a recirculating filter system. The optional aluminum radiator is used for applications that have a high throughput. The radiator removes the heat generated by the ultrasonics.

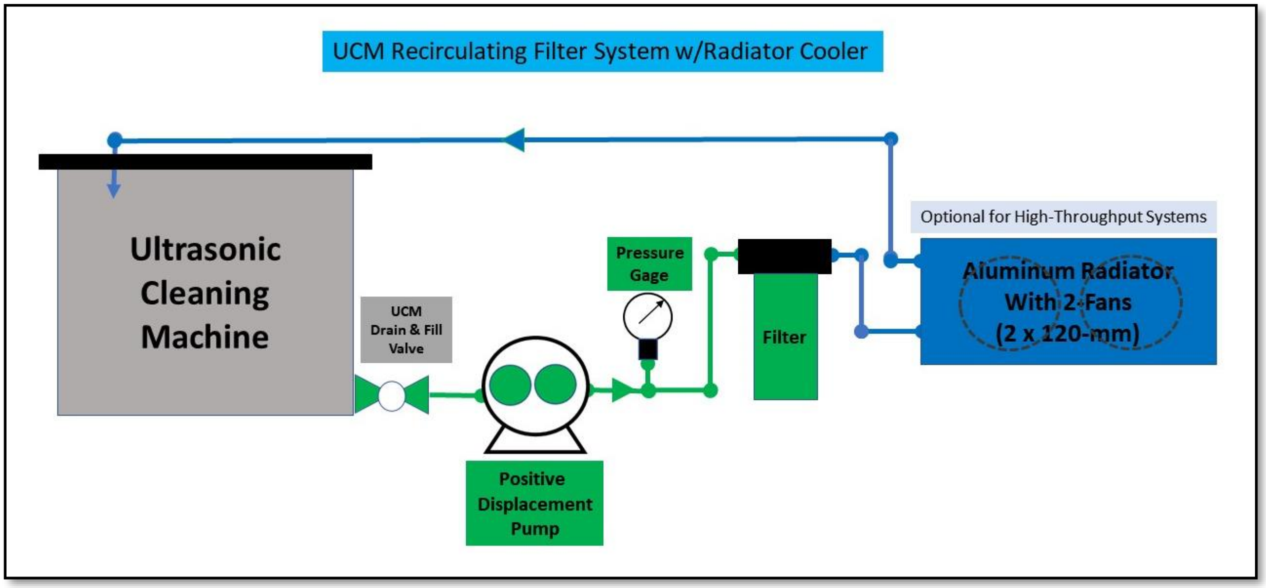


Figure 58 – UCM Recirculating Filter System w/Radiator Cooler

XIV.15.2 **Cooling Radiators**: Ultimately most ultrasonic power is converted to heat and the water will heat. To determine the approximate heating rate, the following equation converts the tank power (watts) to BTU/min, converts tank volume (gals) to water weight (lbs), and applies the specific heat capacity (water = 1 BTU/lbm-°F) so that (BTU/min)/[(water lbs)(BTU/Lbm-°F) = °F/min.

$$°F/min = \frac{0.057\ x\ P}{(8.33\ x\ V)(C_p)}$$

Where: P = UCM power (watts)
V = UCM volume (gals)
C_p = specific heat capacity assumed to be 1 BTU/lbm-°F
0.057 = converts watts to BTU/min
8.33 = converts gal to lbm

Examples:

- The Degritter™ UCM with 300-W and 1.4-L (0.57-gal) can heat the fluid about (0.057)(300)/(8.33)(0.57)(1) = 5.5°F/min.

- A 6.5-L (1.59-gal) ultrasonic tank with 180-W power can heat the fluid about (0.057)(180)/(8.33)(1.72)(1) = 0.7°F/min.

- A 12-L (3.17-gal) ultrasonic tank with 300-W power can heat the fluid about (0.057)(300)/(8.33)(3.17)(1) = 0.7°F/min.

XIV.15.2.a Gaming computers use radiators for cooling, and the fluid they use is corrosion inhibited allowing use of copper radiators. However, copper is not compatible with DIW, it corrodes and TDS in the UCM will increase. For UCM cooling, aluminum or stainless-steel radiators are required and a positive displacement pump XIV.16 is recommended to accommodate the radiator water-side pressure drop.

XIV.15.2.b Koolance™ Heat Exchangers (koolance.com) makes two economical aluminum radiators; a 1x120-mm 18-FPI Aluminum Part No. HX-422 and a 2x120-mm 18-FPI Aluminum, Part No. HX-720 Radiator, 2x120mm 18-FPI Aluminum (koolance.com) . The 2x120-mm HX-720 has been used with an Elmasonic™ P120H and was able to keep the tank temperature less than 40°C/104°F with no appreciable change in TDS. If using the Koolance™ radiator the -Rotary Elbow Barb Fitting for ID 10mm (3/8in), G 1/4 BSPP (koolance.com) which are nickel over brass are recommended. The Koolance™ products all have cut-sheets; the 2x120-mm 18-FPI Aluminum, Part No. HX-720 is available here: radiator-2-fan-120mm-18-fpi-aluminum (koolance.com).

XIV.15.2.c The 120-mm 12VDC fans are standard size with many options available. However, since the fans will be powered from a separate 12VDC power supply, a 2 x 3/4-Pin PC Fan Power Adapter Y Splitter Cable such as Amazon.com: CRJ Electronics DC Power Supply Plug to 2 x 3/4-Pin PC Fan Power Adapter Y Splitter Cable : Electronics is convenient for hook-up. Installing fans to draw air through the radiator will avoid the fan heat being added to the radiator.

XIV.15.2.d Beyond the economical Koolance™ aluminum radiator, Boyd™ Tube Fin Heat Exchangers | Boyd Corporation manufactures industrial stainless steel tube radiators, but the cost is >10X higher.

XIV.15.2.e The radiator cooling capacity is a function of five variables: surface area, water inlet temperature and flow rate, and air inlet temperature and flow rate. Radiators with detailed cut/data sheets such as that by Koolance™ 2x120-mm 18-FPI Aluminum, Part No. HX-720 radiator-2-fan-120mm-18-fpi-aluminum (koolance.com) will show the requisite data.

XIV.15.2.f The required radiator capacity is based on the UCM power rating. If the pump can operate continuously, then the radiator cooling capacity (watts) is selected equal to about the UCM power rating; some UCM power/heating is lost to ambient. If the pump is only operated intermittently; i.e., 10 minutes between batches, then the radiator cooling capacity is selected based on cooling down the fluid sufficient for the next batch. The analysis for intermittent use exceeds the scope of this book.

XIV.15.3 Recirculated pump-filtration systems follow an efficiency model that defines the time it takes to filter 50% of the tank, and is calculated as follows:

$$t^{1/2} = \frac{0.693\ x\ V}{Q}$$

Where: $t^{½}$ = time to filter 50% of the tank
0.693 = half-life exponential decay constant
V = UCM tank capacity (gal or liters)
Q = pump flow rate (gpm or lpm)

Example: A 2-gallon tank with 0.5 gpm recirculation pump would take 2.77 minutes to filter 50% of the tank. Five half-lives $(1.0 - 0.5^5)(100)$ will filter 96.875 percent of the total UCM tank. So, it will take about 14 minutes for 97% of the tank fluid to be filtered.

XIV.15.4 As previously stated, **paragraph** XIV.2.3, excessive fluid agitation can diminish the cavitation/cleaning effect of a UCM. If a high flow rate recirculation pump is used, consider energizing only between cleaning cycles to recycle the UCM bath as previously stated **paragraph** XIV.5.3.f.

XIV.15.5 Batch filtration is 100% efficient but requires a second tank. Batch filtration can use any size pump. However, pump selection can affect risk of foaming. During pump-down from the ultrasonic tank to the holding tank, or during pump-down of the holding tank to the ultrasonic tank, at the end of the evolution the pump suction will be very low causing centrifugal pumps to cavitate possibly foam. On start-up as the centrifugal pump primes again cavitation and foam may develop. Positive displacement pumps are generally more forgiving and some can run dry without damage and self-prime. **Figure 59** illustrates the easiest way to implement a batch filtration process using two (2) pumps.

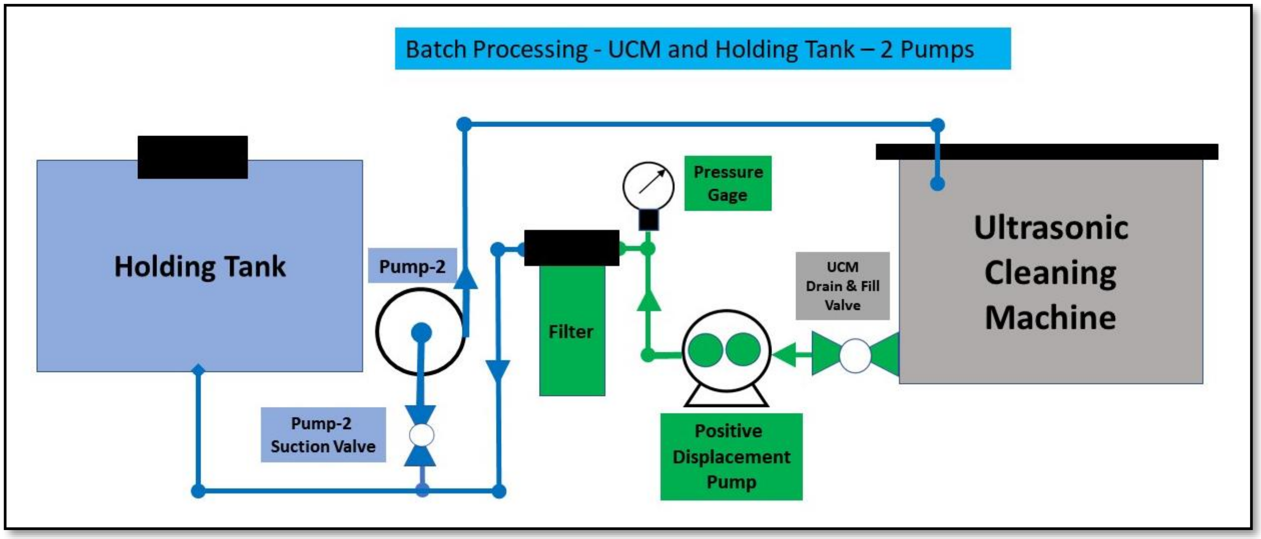


Figure 59 – Batch Processing UCM and Holding Tank – 2 Pumps

XIV.15.5.a For DIY using a 2-gallon ultrasonic tank, the ‘holding’ tank could be a 2.5 Gallon Natural Molded Polyethylene Tank with Lid & 1/2" FNPT Fitting - 12" L x 8" W x 10" H; https://www.usplastic.com/,).

XIV.15.5.b Batch filtration with two 3-way valves and one pump as illustrated in **Figure 60** and **Figure 61** can transfer water from the UCM to the batch tank and then transfer water from the batch tank back to the UCM. The plumbing and valve sourcing can get complicated and there is little cost saving from using a two-pump arrangement. The water can be filtered to or from the batch tank depending on how it is plumbed – **Figure 61** shows the arrangement for filtering from the holding tank.

CAUTION

Improper alignment of valves can lead to dead-heading a pump. Positive displacement pumps can develop pressures high enough to fail a plastic filter housing and clamp-fittings, and should be ordered with a high-pressure shutoff or provided with an over pressure relief valve.

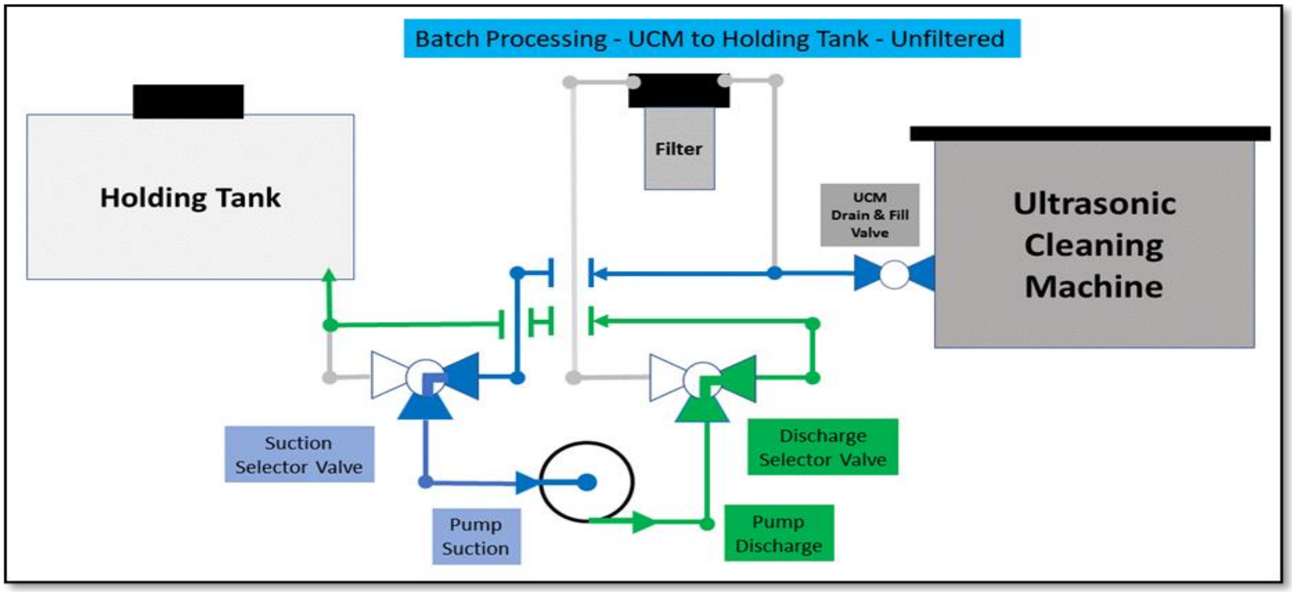


Figure 60 – Batch Processing – UCM to Holding Tank – Unfiltered

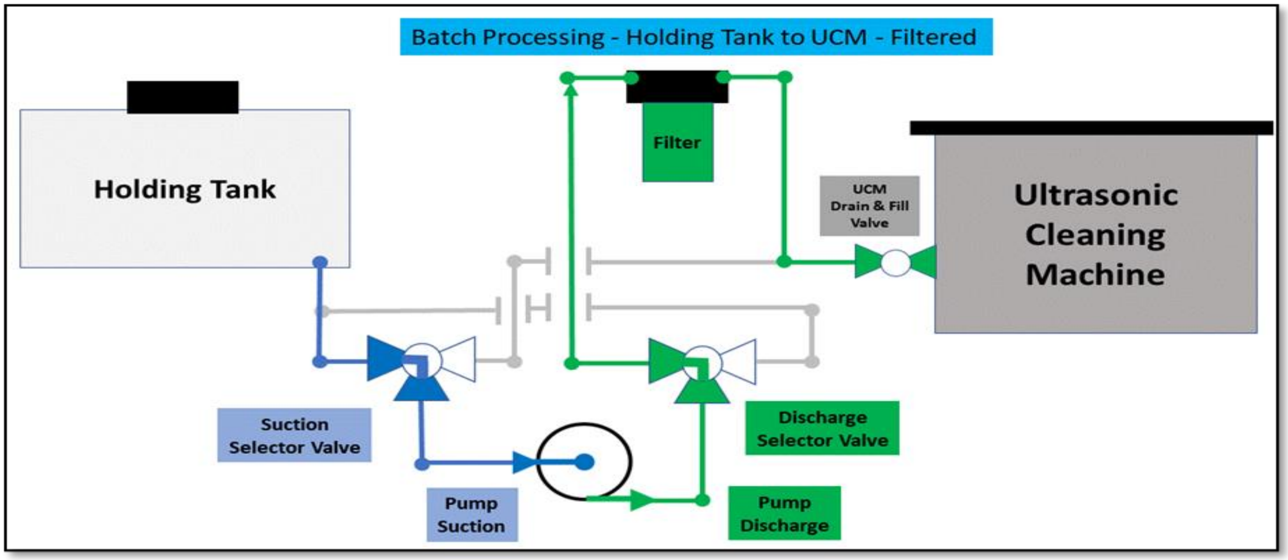


Figure 61 – Batch Processing – Holding Tank to UCM – Filtered

XIV.16 **Pumps:** The challenge with a recirculation pump is a low flow pump with enough pump head to over-come the pressure drop caused by the filter as it loads with soil. As a general note, the filtration media is located at the pump discharge where the pump discharge head is greatest to overcome the differential pressure that the filter will develop as it loads with particulate. Placing a fine, micron-rated filter at the pump suction will result in excessive pressure drop and the pump will lose suction causing it to cavitate; the technical term is loss of net positive suction head (NPSH). For pump protection from large debris all that is required is a simple strainer and these are readily available such as Shurflo™ Model 255-313 strainer. However, cleaning records is not expected to introduce large debris that could damage a pump so use of a pump suction strainer is optional.

XIV.16.1 **Centrifugal Pumps**: The most common pump design is the centrifugal pump, and low-cost units with mechanical seals are readily available. Mechanical seals can leak when operated with a low surface tension fluid such as a water + Dow™ Tergitol™ 15-S-9 mix. Alternant centrifugal pumps with magnetic couplings to the motor (also known as magnetic drive) can eliminate the shaft seal to prevent leakage. Centrifugal pumps follow a pump curve vs flow rate that generally drops significantly as pump discharge head increases; and this is complicated by small 120VAC centrifugal pumps being speed limited to 3600 rpm.

XIV.16.1.a. A common centrifugal pump that was used by some DIY UCM is the 120VAC Little Giant™ 1-AA-OM Series. This pump is rated 2 gpm at 1-ft (0.43 psi) head, and 0-gpm at 7-ft (3.01 psi). This pump is not really suitable for filtration since it will “dead-head” at 0 gpm long before any micron rated filter is actually loaded with soil.

XIV.16.1.b. In comparison, the small centrifugal pump BLDC-Pump Model DC40-1250 is 12VDC so it can operate at higher rpm, and this pump is rated 2.2 gpm at 1-ft (0.43 psi) head, and 0-gpm at 17-ft (7.4 psi). This pump will require a separate desktop style 120VAC/12VDC power source rated at not less than 18 watts such as the Mean Well™ Model GST18A12 or 25W Model GST25A12. Note: The BLDC-Pump Model DC40-1250 hose barbs are not robust and can be collapsed if a hose clamp is excessively tightened.

XIV.16.1.c. The representative pump curves for these two centrifugal pumps are shown in **Figure 62**.

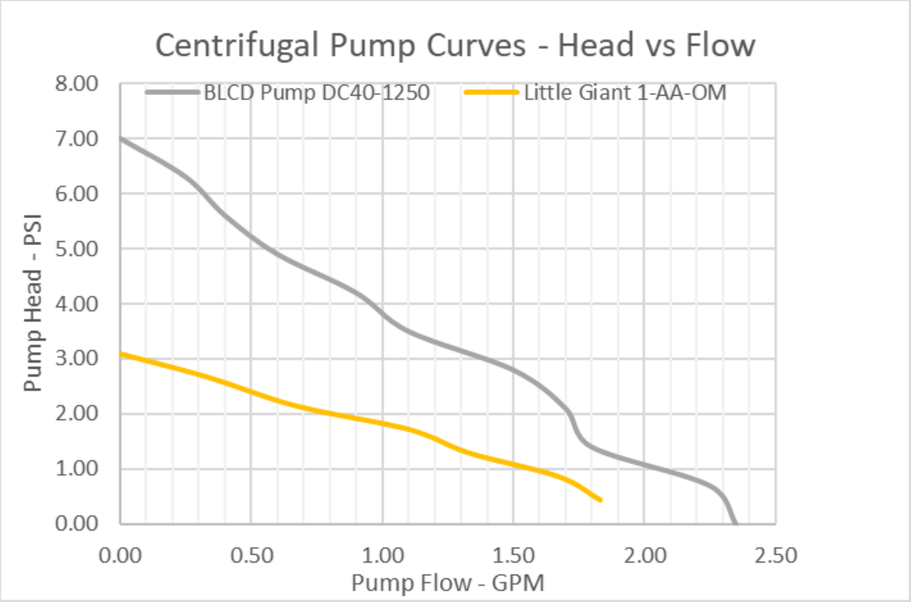


Figure 62 – Centrifugal Pump Curves

XIV.16.2 **Positive Displacement Pumps**: There are low flow, high head positive displacement diaphragm pumps well suited for UCM filtration systems, two readily available examples from SHURflo™ (Shurflo | Brands | Pentair) are listed below and the representative pump curves are shown **Figure 63**. Positive displacement pump flow rate generally varies very little with pump discharge head. Diaphragm pumps are preferred for fine filtration since they are available in compact, low flow, and high discharge pressure designs. Positive displacement pumps are also perfect for batch filtration since they can run dry and with good suction lift do not require priming providing easy installation and use. However, as previously stated, diaphragm pumps can develop pressures high enough to require over pressure protection and these are provided as a 'demand switch".

XIV.16.2.a SHURflo™ Model 8020-513-236 is 115VAC supplied with 3-prong grounded plug and is rated 1.27 gpm at 10 psi head and 1.05 gpm at 30 psi head and comes with a 60-psi overpressure shutoff (demand switch). This pump is self-priming to 10-ft and has 3/8"-18 NPT Female ports. The use of separate tube fittings is a benefit since any damage to the fitting from overtightening a hose clamp is easily corrected and parts are available to rebuild this pump. A grounded outlet with ON/OFF switch (and some with integrated circuit breaker) such as *BindMaster™ 3-Prong Grounded On/Off Switch* or *Philips Grounded Outlet Extender, On/Off Power Switch with Integrated Circuit Breaker, 3 Prong* is a convenient way to add a switch for the pump.

XIV.16.2.b SHURflo™ Model SLV10-AA48 is 12VDC rated at 0.73 gpm at 10 psi head and 0.49 gpm at 30 psi head(max) and comes with a 40-psi overpressure shutoff (demand switch); manual on/off switch and a 2-pin connector. The Model SLV10-AA40 is the same pump without a 2-pin connector. This pump is self-priming to 2.5-ft and is supplied with 3/8-inch barb connectors. This pump will require a separate desktop style 120VAC/12VDC power source rated at not less than 40 watts such as the Mean Well™ Model GST40A12 or 60W GST60A12. This pump's low flow makes its suitable for smaller volume tanks. Do not over-tighten hose clamps to fittings otherwise they can be damaged.

XIV.16.2.c There is a recent, lower price knock-off to the SHURflo™ Model SLV10-AA48. It's the SEAFLO™ 21-Series 12VDC positive displacement pump, 3/8" hose connections, 1-GPM 35 PSI shutoff, 2-Pin SAE connector/leads. This knock-off pump is not the same as the SHURflo™, but its cost is low enough that it would make sense to buy instead of the 12VDC centrifugal BLDC-Pump Model DC40-1250.

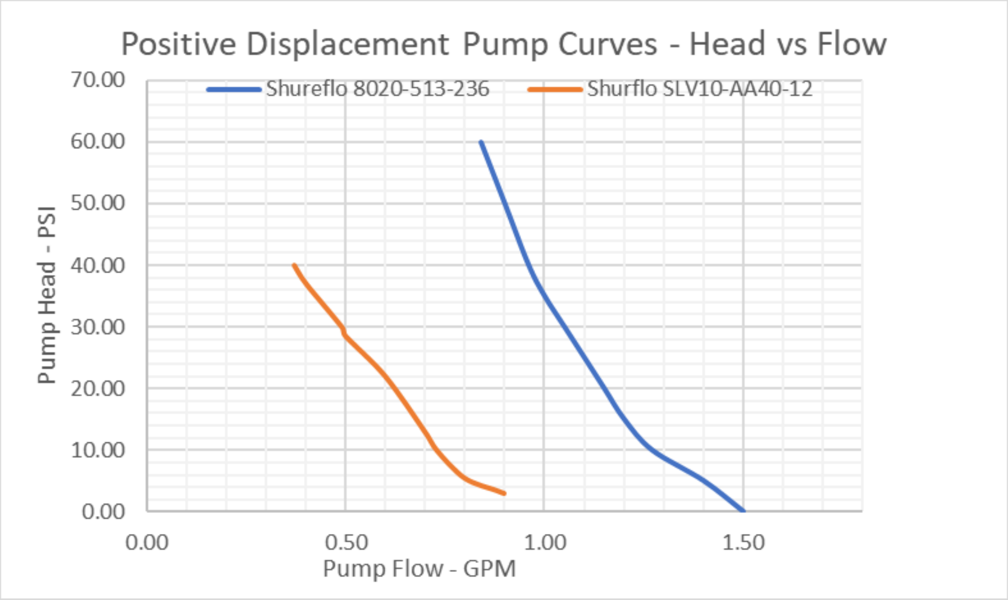


Figure 63 – Positive Displacement Pump Curves

XIV.16.3 All centrifugal pumps will likely need to be located level with the base or beneath the UCM to ensure adequate pump suction head also known as net positive suction head (NPSH). Positive displacement pumps that have much higher suction lift can be mounted above the tank – the height depending on the pump suction lift rating. However, when the pump is turned-off; make sure the tank has enough volume to collect the fluid drain-back without overflowing.

XIV.16.4 **VDC Power Supplies**: Many of the small pumps as previously addressed are 12VDC. For the DIY UCM, most will use a desk-top type switching power supply (similar to those used for laptops). It's important that a quality 12VDC power supply be purchased such as those manufactured by Mean Well™ and one that is rated well above the pump-motor rating. On motor startup, there is an initial current inrush and if the power supply is not large enough, the pump will start and then shutdown as the power supply overcurrent protection (OCP) initiates and then start again as the OCP automatically resets, and this ON-OFF-ON-OFF cycle will repeat until you turn the pump OFF. Additionally, there is the option to power the positive displacement pumps from a larger variable VDC power source. In this case, reducing the voltage to the pump motor will reduce the motor speed and reduce the pump flow rate. However, the pump discharge pressure will not be reduced since this is based on the current (amps) the motor can draw. This option has been successfully used with a SHURflo™ Model 8000-543-136 (performance similar to the 115VAC SHURflo Model 8020-513-236) and it allows reducing the pump flow low enough to allow continuous filtration with small tanks.

XIV.17 **Filter Housings**: Common point-of-use filter housing are those designed for 2.5-inch diameter x about 10-inch-long filter cartridges. There are many vendor/models available, however very few low-cost plastic housings have a built-in differential pressure gauge (or equivalent) that can monitor filter soil loading. There is a Pentek™ 3G 10" standard housing (part # 150574) with 3/4" inlet/outlet, with an integral bracket and meter mount cap that is used with part #143549 that is a differential pressure indicator that mounts to the filter cap and monitors filter soil loading/fouling. Otherwise, operating a UCM until the bath solution is cloudy can leave excessive NVR on the record unless some form of additional final rinse is added. Items to note:

XIV.17.1 Opaque filter housings will have a higher-pressure rating than clear housings and are less prone to cracking.

XIV.17.2 There are 5-inch filter housings, but these small housings have very limited filter cartridge options.

XIV.17.3 Filter housing have a specific cartridge end cap design –the commonly used Pentek™ filter housing generally specify "double open ended" – DOE.

XIV.18 **Filter Cartridges**: Filters are rated absolute or nominal. Absolute rated filters will generally remove not less than 99.5% of all particles greater than the rating. Industry standard nominally rated filters will generally remove about 80% of all particles greater than the rating, and generally have a 95% efficiency for particles about 5X the nominal rating. But some nominal rated filters can have nominal efficiency as low as 30% and the 95% efficiency can be as much as 50X the nominal rating. For absolute and nominal rated filters, the vendor should provide a filter efficiency chart that shows the filter performance.

XIV.19 **Sediment Filters**: In general, thermally bonded polypropylene particulate/sediment depth filters are preferred for their overall compatibility, superior soil holding and low pressure drop performance, and are generally rated to at least 120°F (49°C) operation. For the precision cleaning of vinyl records, a 1-micron nominal rated filter is the largest recommended; a 0.2-micron absolute filter optimum. When ordering filters make sure the end-caps are compatible with the filter housing. The Pentek™ 3G filter housing specified **paragraph** XIV.17 uses double-open-ended (DOE) cartridges.

XIV.19.1 A suitable 1-micron nominal example is the Hydronix® Model SDC-25-1010 (or equal) that DOE and at 1-micron is 80% efficient and at 5-microns is about 96.5% efficient. The 2.5” x 9-7/8” filter has a very low pressure drop of 0.6 psi at 5 gpm for a new 10-inch cartridge, has a maximum temperature rating of 145°F (63°C), has a recommended replacement at 21.75 psid and is generally available for less than $10 from many sources. This filter does come in a 2.5” x 4-7/8” size.

XIV.19.2 A much finer filter that is readily available is the Flow-Max™ FPP-0.2-975-DOE that is a pleated polypropylene 2.5” x 9-3/4” filter rated 0.2 micron absolute. The initial pressure drop is about 1.5 psi at 1.5 gpm for a new 10-inch cartridge; has a maximum temperature rating of 175°F (70°C); collapse pressure of 130 psid, and the recommended replacement pressure drop is 35 psid. As a general note, filters absolute rated less than 0.3 micron can remove bacteria.

XIV.19.3 For information, high throughput processes will often install a pre-filter such as a 1-micron nominal to extend the life of expensive very fine (i.e., 0.2 micron absolute) filters. However, the added pre-filter does increase the water flow pressure drop that can impact the pump selection if a centrifugal design, but the positive displacement pumps listed **paragraph** XIV.16.2 would be able to accommodate. Note that at the time of this paper version, a readily available 10-inch 1-micron absolute filter cartridge could not be identified for easy purchase. There are models Hydronix® and Flow-Max™ listed, but none are readily available for consumer purchase.

XIV.20 **Activated Carbon**: There are 10-inch activated carbon block cartridges such as Pentek™ CBC that are rated 1-micron absolute and flow rated 3.7 psi pressure drop at 1 gpm. These filters could be an alternative to polypropylene particulate filters for water only since they can remove some surfactants. But these type carbon filters have limited soil holding. Particulate and debris can foul the carbon block and the high-pressure drop at low flow may make pump selection difficult and expensive making them mostly impractical.

XIV.21 **Demineralizers/Deionizers**: Purified water left exposed to the ambient (such as a UCM tank) will absorb air and carbon dioxide and form carbonic acid leading to a mild acidification with a pH of about 5-6. Additionally, contaminants from the record may be ionic further degrading the water purity increasing the TDS and risk of NVR. For how a deionizer works – see **paragraph** VII.5.

XIV.21.1 There are 10-inch mixed-bed ion exchange demineralizer cartridges such as Crystal Quest part #CQE-RC-04011 but these are generally rated for only about 0.5-gpm, and most will have particulate rating near 5-microns nominal, requiring a separate particulate filter be installed downstream.

XIV.21.2 Most ion exchange deionizers/demineralizers are limited to 100°F (38°C) operation. This limits continuous operation to unheated UCM cleaning. For heated UCM cleaning, batch filtration or recirculated filtration between heated UCM cleaning cycles could be used. Like carbon filters, these are for water only since they can remove or be fouled by surfactants.

XIV.22 **Pressure Gauge**: As the sediment filters loads, the resistance to flow will cause inlet pressure to increased and consequently the pressure-drop across the filter to increase. Most high-performance sediment filters previously addressed can operate between 20 and 35 psid with most having an even higher psid before they collapse. Centrifugal pumps will dead-head (no flow) before most filters fully load. But positive displacement pumps have enough pressure capability to function with higher pressure. Therefore, when using a positive displacement pump, it's advisable to monitor pressure to obtain good filter life and protect the filter from collapse if that is a risk.

XIV.22.1 The previously mentioned Pentek™ 3G 10" standard housing (part # 150574) has the option for part #143549 that is a differential pressure indicator and is illustrated **Figure 56**.

XIV.22.2 Alternately, since the outlet pressure is the UCM tank that is essentially at 0 psig (or slightly higher if a radiator is installed), a filter inlet pressure gauge (as indicated **Figure 58**) is a reasonable indication of filter differential pressure. In this case, a standard 0-60 psig, Stainless Steel 1/8" NPT 1.5" face dial, glycerin filled pressure gauge with 1/8" to 3/8" NPT adapter is recommended. A stainless-steel tee pipe fitting, 3/8" x 3/8" x 3/8" NPT female pipe fitting can then be used (with 3/8" NPT plastic hose bards) to install in the tubing. A glycerin filled pressure gauge is recommended to damp the pulsations normal with positive displacement pumps.

XIV.23 **UV Sterilization**: If operating tank baths for many weeks/month, biologic control of algae and bacteria, small ultraviolet disinfection units such as Polaris Scientific UV Residential Archives - Polaris (polarisuv.com) UAV-1C and VIQUA™ VIQUA Home Page - VIQUA UV-1 could be an option and would avoid any need for chemical micro-biological inhibitors. These would be plumbed downstream of the sediment filter, and are very low power 10-14W. Operationally they are rated for 9000 hours, but indicate limited to 104°F (40°C). Note that these units are rated for sterilization which is more demanding than disinfection. UV disinfection is commonly used for large (i.e., 100-gal) aquarium tanks, but these appear designed for lower operating pressures. If installed, energize w/o ultrasonics and just operate periodically (try once/week and adjust as necessary) with pumping only for enough time to disinfect/filter >95% of tank and then secure. No reason to operate when cleaning records which would extend UV bulb life, but having not used these devices, experience may show otherwise.

XIV.24 **UCM Pump-Filter Parts List**: **Table XXIV** provides three cost-options for installing a DIY recirculating UCM pump-filter system (see **Figure 58**) w/o the radiator (see **paragraph** XIV.15.2) or inlet pump strainer (see **paragraph** XIV.16). Prices are estimates at the date of the last edition of this book. Specific items can be located by copying the part description and searching the internet. Many of the small parts are available from Amazon™. The pumps and filter elements are generally available elsewhere.

Note: After assembly of a new pump/filter system, operate at 30°C/86°F to 40°C/104°F for 1-2 hours (w/o records or ultrasonics) to clean the new system. If the fluid becomes cloudy or TDS is out of specification (>10 ppm), refresh the fluid and repeat until the fluid remains clear and TDS is <5 ppm. The system is now ready for record cleaning.

Table XXIV
UCM Pump-Filter System Parts List

Ultrasonic Tank Pump-Filter Systems						
Item	**High Option**	**Est. Cost**	**Medium Option**	**Est. Cost**	**Low Option**	**Est. Cost**
Pump	Shurflo™ Model 8020-513-236 (115VAC) Positive Displacement pump, 1.4-gpm, 60 psi shutoff with 3-prong grounded plug	$155	Shurflo™ Model SLV10-AA48 (12VDC) Positive Displacement pump, 3/8" hose connections, 1-gpm, 40 psi shutoff with On/Off Switch & 2 Pin SAE connector/leads	$65	SEAFLO™ 21-Series 12VDC Positive Displacement pump, 3/8" hose connections, 1-GPM 35 PSI shutoff, 2-Pin SAE connector/Leads	$35
Pump Hose Barbs	x2 Hose Barb 3/8" NPT x 3/8" Barb — nylon or plastic not metal per Shurflo™	$8	NA	$0	NA	$0
Pump Power Supply	NA	$0	MEAN WELL™ GST60A12-P1J 12V 5 Amp 60W Regulated Switching Table Top Power	$22	MEAN WELL™ GST60A12-P1J 12V 5 Amp 60W Regulated Switching Table Top Power	$22
Pump Power Supply Wiring Adapter	NA	$0	SAE Plug to DC 5.5mm x 2.1mm Female 14AWG 2ft/60cm Adapter Cable with SAE Polarity Reverse Adapter	$9	SAE Plug to DC 5.5mm x 2.1mm Female 14AWG 2ft/60cm Adapter Cable with SAE Polarity Reverse Adapter	$9

Ultrasonic Tank Pump-Filter Systems						
Item	**High Option**	**Est. Cost**	**Medium Option**	**Est. Cost**	**Low Option**	**Est. Cost**
On/Off Switch for Power Supply:	NA	$0	BindMaster™ 3-Prong Grounded On/Off Switch or Philips Grounded Outlet Extender, On/Off Power Switch with Integrated Circuit Breaker, 3 Prong	$7	BindMaster™ 3-Prong Grounded On/Off Switch or Philips Grounded Outlet Extender, On/Off Power Switch with Integrated Circuit Breaker, 3 Prong	$7
On/Off Switch for Pump:	BindMaster™ 3-Prong Grounded On/Off Switch	$7	Optional: SAE Connector Waterproof Inline 12-Volt Power Switch	$20	Optional: SAE Connector Waterproof Inline 12-Volt Power Switch	$20
Filter Canister	Pentek™ 150574 10" 3G Standard Filter Housing Black/Blue MM IB w/ PR - 3/4" FPT	$40	Pentek™ 150546 3G-Standard 10" Filter Housing - 3/4" FPT	$25	Pentek™ 150546 3G-Standard 10" Filter Housing - 3/4" FPT	$25
Filter Canister Hose Barbs	x2 plastic/nylon Hose Barb ¾" NPT x 3/8” Barb	$15	x2 plastic/nylon Hose Barb ¾" NPT x 3/8” Barb	$15	x2 plastic/nylon Hose Barb ¾" NPT x 3/8” Barb	$15
Filter Canister Wrench	Pentek™ SW-2	$6	Pentek™ SW-2	$6	Pentek™ SW-2	$6
Filter	FlowMax™ HP (Watts) 2.5" x 9.75" FPP-0.2-975-DOE 0.2-micron absolute	$50	FlowMax™ HP (Watts) 2.5" x 9.75" FPP-1-975-DOE 0.2-micron absolute	$40	FlowMax™ FM-0.35-975 2-1/2” x 9-3/4” Pleated Filter, 0.35-micron nominal	$16
Filter Canister Pressure Monitor	Differential Pressure Gauge: Pentek™ 143549 (Green (clean) 0-6 psid; Yellow (change) 6-9 psid; Red (dirty) 9-12 psid). In use, operate until filter reaches 11-12 psid. No reason to change at 6-9 psid.	$53	1X-0~60Psi Stainless Steel 1/8" NPT 1.5" FACE DIAL. Glycerin Filled Fuel Pressure Gauge with 3/8" NPT adapter ~$15. 1X-Stainless Steel Tee Pipe Fittings, 3/8" x 3/8" x 3/8" NPT Female Pipe Fitting ~$10 2X-plastic/nylon Hose Barb ¾" NPT x 3/8” Barb ~$15	$40	NA – Monitor pump motor housing temperature. When hot >120°F, replace the filter.	$0

Ultrasonic Tank Pump-Filter Systems						
Item	**High Option**	**Est. Cost**	**Medium Option**	**Est. Cost**	**Low Option**	**Est. Cost**
Tubing	3/8” ID Heavy Duty Reinforced Vinyl Tubing, BPA Free and Non-Toxic — 10 ft	$20	3/8” ID Heavy Duty Reinforced Vinyl Tubing, BPA Free and Non-Toxic — 10 ft	$20	3/8” ID Heavy Duty Reinforced Vinyl Tubing, BPA Free and Non-Toxic — 10 ft	$20
Hose Clamps	5X 3/8" to 7/8" Diameter Stainless Hose Clamp	$14	7X 3/8" to 7/8" Diameter Stainless Hose Clamp	$14	7X 3/8" to 7/8" Diameter Stainless Hose Clamp	$14
UT Tank Drain Hose Barb	Example (verify tank drain valve) - 1X 3/4" NPT x 3/8" barb	$8	Example (verify tank drain valve) - 1X 3/4" NPT x 3/8" barb	$8	Example (verify tank drain valve) - 1X 3/4" NPT x 3/8" barb	$8
Total Est. Cost		**$376**		**$291**		**$197**

REMAINDER OF PAGE INTENTIONALLY BLANK

APPENDIX A - LIST OF REFERENCES

The following documents and sources are referenced in this document and are available in the Public Domain or for purchase at the noted internet addresses. Hyperlinks are provided only to secure sites (https://).

(1) *American Cleaning Institute, Guidance for the Risk Assessment of Enzyme-Containing Consumer Products, 2019, ACIConsumerEnzymeProductRiskAssessmentGuide.pdf (cleaninginstitute.org)*

(2) *Dr. A. M. Max, Disc Phonograph Records, Max, RCA Engineer Magazine 1966-08-09, 1966-08-09.pdf (worldradiohistory.com)*

(3) *Dr. Arend J. Kingma,* BASF™ *Compatibility of Nonionic Surfactants with Membrane Materials and their Cleaning Performance, Sepawa Nordic 2014 Title ARIAL bold 30pt (semanticscholar.org)*

(4) *Anna L. Fricker, David S. McPhail, Brenda Keneghan and Boris Pretzel, Investigating the impact of cleaning treatments on polystyrene using SEM, AFM and ToF–SIMS, Heritage Sci (2017) 5:28 Investigating the impact of cleaning treatments on polystyrene using SEM, AFM and ToF–SIMS (springeropen.com)*

(5) *ARSC Guide to Audio Preservation, 2015, Library of Congress (https://www.clir.org/wp-content/uploads/sites/6/pub164.pdf)*

(6) *Ario Betha Juanssilfero , Fariza Akmal Abdul Mutalib, Wan Zulaikha Wan Zulkifli , Jamaliah Md. Jahim , Farah Diba Abu Bakar and Osman Hassan. Characterization of Copolymer Dehypon® LS 54 and Its Application for Aqueous Two-Phase Systems Paired with the Waxy Maize Starch for Protein Extraction January 2011, (PDF) Characterization of Copolymer Dehypon� LS 54 and Its Application for Aqueous Two-Phase Systems Paired with the Waxy Maize Starch for Protein Extraction (researchgate.net)*

(7) *Astbury, G.R. & Bugand-Bugandet, J. & Grollet, E. & Stell, K.M.. (2005), Flash Points of Aqueous Solutions of Flammable Solvents. Institution of Chemical Engineers Symposium Series. 505-522 (https://engage.aiche.org/HigherLogic/System/DownloadDocumentFile.ashx?DocumentFileKey=a48c5d29-842d-4382-88d8-4ecd176164fa&ssopc=1,)*

(8) *ASTM D1193, Standard Specification for Reagent Water (https://www.astm.org;)*

(9) *B.D. Flockhart, The Vapor Pressures of Ethanol-Water Solutions of Detergents" 1960,* The vapor pressures of ethanol-water solutions of detergents - ScienceDirect

(10) *Beth A. Miller-Chou, Jack L. Koenig, A review of polymer dissolution, Prog. Polym. Sci. 28, 2003 A review of polymer dissolution - ScienceDirect*

(11) *Bill W. Lee, David E. Orr, The Triboelectric Series, , ©2009 by AlphaLab, Inc. (https://www.alphalabinc.com/triboelectric-series;)*

(12) *Bogdan Niemczewski, Observations of water cavitation intensity under practical ultrasonic cleaning conditions, Tele- and Radio Research Institute, ul. Ratuszowa 11, 03-450 Warsaw, Poland, 18 November 2005, (PDF) Cavitation intensity of water under practical ultrasonic cleaning conditions (researchgate.net)*

(13) *CDC Guideline for Disinfection and Sterilization in Healthcare Facilities, 2008 Update: May 2019 Guideline for Disinfection and Sterilization in Healthcare Facilities, 2008 (cdc.gov)*

(14) *Charles M. Hansen, HANSEN SOLUBILITY PARAMETERS, A User's Handbook, Second Edition, CRC Press, 2007*

(15) *Christina Y. Piña Arpin, Joel Stoltzfus, Rudimentary Cleaning Compared to Level 300A, Journal of ASTM International, September, 2012, (https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120003024.pdf,)*

(16) *Cosmetic Ingredient Report (CIR) of Triethanolamine (TEA) and TEA-containing ingredients, 2011 Microsoft Word - TEA062711memo.docx (cir-safety.org)*

(17) *Discwasher™ U.S. Patent 3,951,84 Phonograph Record Cleaning Composition, 1976.*

(18) *EPA 2018 Edition of the Drinking Water Standards and Health Advisories Tables (https://www.epa.gov/sites/production/files/2018-03/documents/dwtable2018.pdf,)*

(19) *EPA, Indoor Air Quality MERV-Rating (https://www.epa.gov/indoor-air-quality-iaq/what-merv-rating-1)*

(20) *EPA, Nonylphenol (NP) and Nonylphenol Ethoxylates (NPEs), 8/18/2010, Action Plan, RIN 2070-ZA09 https://www.epa.gov/sites/production/files/2015-09/documents/rin2070-za09_np-npes_action_plan_final_2010-08-09.pdf,*

(21) *European Food Safety Authority (EFSA, EFSA Panel on Food Additives and Nutrient Sources added to Food (ANS), Scientific Opinion on the re-evaluation of polyoxyethylene sorbitan monolaurate (E 432), polyoxyethylene sorbitan monooleate (E 433), polyoxyethylene sorbitan monopalmitate (E 434), polyoxyethylene sorbitan monostearate (E 435) and polyoxyethylene sorbitan tristearate (E 436) as food additives, 10 December 2018, Scientific Opinion on the re-evaluation of polyoxyethylene sorbitan monolaurate (E 432), polyoxyethylene sorbitan monooleate (E 433), polyoxyethylene sorbitan monopalmitate (E 434), polyoxyethylene sorbitan monostearate (E 435) and polyoxyethylene sorbitan tristearate (E 436) as food additives - - 2015 - EFSA Journal - Wiley Online Library*

(22) *Ethanol, 2,2',2''-nitrilotris-: Human health tier II assessment, 2013, Ethanol, 2,2',2''-nitrilotris-_Human health tier II assessment.pdf (industrialchemicals.gov.au)*

(23) *Fed-Spec TT-I-735a, Isopropyl Alcohol, http://everyspec.com/FED_SPECS/T/TT-I-735A_NOTICE-4_56077/*

(24) *Fed-Std-209E, Airborne Particulate Cleanliness Classes In Cleanrooms and Clean Zones, http://everyspec.com/FED-STD/FED-STD-209E_21739/*

(25) *Filipa A. Vicente, Inês S. Cardoso, Tânia E. Sintra, Jesus Lemus,Eduardo F. Marques, Sónia P. M. Ventura, & João A. P. Coutinho, Impact of Surface Active Ionic Liquids on the Cloud Points of Nonionic Surfactants and the Formation of Aqueous Micellar TwoPhase Systems J. Phys. Chem. B. 2017, https://www.researchgate.net/publication/319257876_The_Impact_of_Surface_Active_Ionic_Liquids_on_the_Cloud_Points_of_Nonionic_Surfactants_and_the_Formation_of_Aqueous_Micellar_Two-Phase_Systems,*

(26) *GE-Osmonics™ Pure Water Handbook* (https://www.bigbrandwater.com/GE-Osmonics-RO-Membranes_ep_61-1.htmL,)

(27) *Geiman, Justin & Fuss, P., (2013). Investigation of cigarettes as an ignition source for Coleman fuel. Fire and Materials 2013 - 13th International Conference and Exhibition, Conference Proceedings. 759-768* (PDF) Investigation of cigarettes as an ignition source for Coleman fuel (researchgate.net)

(28) *Gilles St-Laurent Music Division National Library of Canada, The Care and Handling of Recorded Sound Materials, January 1996 The Care and Handling of Recorded Sound Materials (culturalheritage.org)*

(29) *G. P. Humfeld, Anti-Static Phonograph Records, RCA Engineer Magazine Vol. 6, No.3. October-November, 1960* 1960-10-11.pdf (worldradiohistory.com)

(30) *G. P. Humfeld, Anti-static Phonograph Records, RCA Engineer Magazine, 1976 Issue 10-11,* 1976-10-11.pdf (worldradiohistory.com)

(31) *Gonzalo Vazquez, Estrella Alvarez, Jose M. Navaza, Surface Tension of Alcohol + Water from 20 to 50°C"*, Journal of Chemical and Engineering Data. 1 May 1995, *https://pubs.acs.org/doi/abs/10.1021/je00019a016*,

(32) *Gordon Brushes®, Brush Material https://www.gordonbrush.com/brush-fill-materials.php*

(33) *Hallstar™ Plasticizers for PVC https://www.hallstar.com/webfoo/wp-content/uploads/Plasticizers-for-PVC.pdf,*

(34) *Harold D. Weiler, THE WEAR AND CARE OF RECORDS AND STYLI***,** *1954 (funded by Shure® Inc, now in the Public domain https://vinylrecordcleaningsystem.com/wp-content/uploads/2019/09/weiler-wear-and-care-of-records.pdf,)*

(35) *Hugh Finnimore, Disc cutting in theory, Studio Sound and Broadcast Engineering, July 1975 Studio-Sound-1975-07.pdf (worldradiohistory.com)*

(36) *James H. Kogen, Phonograph Reproduction 1978, Audio Magazine May 1978 Audio-1978-05.pdf (worldradiohistory.com)*

(37) *J G. Woodward, Record -Groove Wear, HiFi Stereo Review Magazine, October 1968, HiFi-Stereo-Review-1968-10.pdf (worldradiohistory.com)*

(38) *J. Gordon Holt, STEREOPHILE Chart File No. 8 Record Groove Parameters, The Stereophile Magazine Vol.1 No. 8, August 1964 Stereophile-1964-08.pdf (worldradiohistory.com)*

(39) *John Fuchs, Ultrasonic Cleaning Fundamental Theory and Application, Blackstone Ultrasonics, 1995 https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19950025362.pdf.*

(40) *Kenneth R. Monroe, Elizabeth A. Hill, Surfactant Parameter Effects On Cleaning Efficiency, Oct 1993, International CFC Alterantives Conference Surfactant Parameter Effect on Cleaning Efficiency (p2infohouse.org).*

(41) *Kiril Streletzky & George D. J. Phillies, Temperature Dependence of Triton X-100 Micelle Size and Hydration, Department of Physics, Worcester Polytechnic Institute, September 19, 1994 https://sciences.csuohio.edu/sites/csuohio.edu.sciences/files/media/physics/documents/Lang111995.pdf,*

(42) *Library of Congress Lacquer Record Cleaning Procedure https://www.nedcc.org/audio-preservation/cleaning-discs*

(43) *L. R. Happ, Design Considerations of the Vl5 Type IV Phonograph Cartridge, delivered at a 1978 technical seminar on phonograph cartridges (high-fidelity-phonograph-cartridge-technical-seminar-faq.pdf (d24z4d3zypmncx.cloudfront.net)*

(44) *Manual of Naval Preventive Medicine, Chapter 6, Water Supply Afloat https://www.med.navy.mil/directives/Pub/5010-6.pdf*

(45) *Mason, T.J., Ultrasonic cleaning: an historical perspective CURVE 2016 https://curve.coventry.ac.uk/open/file/d066157d-49ca-4d32-a575-8b07fa144040/1/Ultrasonic%20cleaning.pdf,*

(46) *M. B. Ranade (1987) Adhesion and Removal of Fine Particles on Surfaces, Aerosol Science and Technology, 7:2, 161-176, DOI: 10.1080/02786828708959155 Adhesion and Removal of Fine Particles on Surfaces: Aerosol Science and Technology: Vol 7, No 2 (tandfonline.com)*

(47) *Mike Bodell, The Finish Line for Your Phonograph Stylus…, May 23, 2019 The Finish Line for Your Phonograph Stylus… - The Vinyl Press*

(48) *MIL-HDBK-263B Electrostatic Discharge Control (ESD) Handbook for Protection of Electrical and Electronic Parts, Assemblies and Equipment, http://everyspec.com/MIL-HDBK/MIL-HDBK-0200-0299/MIL_HDBK_263B_162/*

(49) *MIL-HDBK-407 Precision Cleaning Methods and Procedures, http://everyspec.com/MIL-HDBK/MIL-HDBK-0300-0499/MIL_HDBK_407_1892/*

(50) *MIL-STD-1246C, Product Cleanliness Levels and Contamination Control Program, http://everyspec.com/MIL-STD/MIL-STD-1100-1299/MIL_STD_1246C_131/*

(51) *MIL-STD-1330D Precision Cleaning and Testing of Shipboard Oxygen, Helium, Helium-Oxygen, Nitrogen, And Hydrogen Systems, http://everyspec.com/MIL-STD/MIL-STD-1300-1399/MIL-STD-1330D(SH)_4106/*

(52) *MIL-STD-1622B Standard Practice for Cleaning of Shipboard Compressed Air Systems, http://everyspec.com/MIL-STD/MIL-STD-1600-1699/MIL_STD_1622B_1543/*

(53) *Moe Sato & Anita Quye, Detergency evaluation of non-ionic surfactant BASF™ DEHYPON® LS54 for textile conservation wet cleaning, Journal of the Institute of Conservation, 29 Jan 2019 Detergency evaluation of non-ionic surfactant Dehypon® LS54 for textile conservation wet cleaning (tandfonline.com)*

(54) *Morales muñoz, Clara & Egsgaard, Helge & Sanz-Landaluze, Jon & Dietz, Christian. (2014). A Model Approach for Finding Cleaning Solutions For Plasticized Poly(Vinyl Chloride) Surfaces of Collections Objects, Journal of the American Institute for Conservation, 53. 236-251. https://www.researchgate.net/publication/268448708_A_model_approach_for_finding_cleaning_solutions_for_plasticized_polyvinyl_chloride_surfaces_of_collections_objects,*

(55) *NASA Contractor Report 4740, Contamination Control Engineering Design Guidelines for the Aerospace Community, C. Tribble, B. Boyadjian, J. Davis, J. Half-net, and E. McCullough, Rockwell International Corporation, May 1996 (https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19960044619.pdf,)*

(56) *NASA Electrical Bonding: A Survey of Requirements, Methods, and Specifications, NASA/CR-1998-207400, Mar 1998(http://www.everyspec.com/)*

(57) *NASA LPR 1740.5F, Procedures for Cleaning of Systems and Equipment for Oxygen Service, 2015 (https://lmse.larc.nasa.gov/admin/public_docs/LPR_1740.5_ExtensionMemo.pdf,)*

(58) *NASA/TM-2011-217231, Evaluation of Brushing as a Lunar Dust Mitigation Strategy for Thermal Control Surfaces (https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20120000070.pdf,)*

(59) *NAVSEA Report on Aqueous Oxygen Cleaning Products and Processes, 1994 (https://p2infohouse.org/ref/14/13872.pdf)*

(60) *New York Mount Sinai Silekoff Centers for Occupation Health titled "Quaternary Ammonium Compounds in Cleaning Products: Health & Safety Information for Health Professionals, August 2015, (https://www.mountsinai.org/files/MSHealth/Assets/HS/Patient-Care/Service-Areas/Occupational-Medicine/QACsInfoforWorkers_18.pdf,)*

(61) *Percy Wilson, Record Contamination: Causes and Cure, by Journal of The Audio Engineering Society April 1965, Volume 13, Number 2 AES E-Library » Record Contamination: Cause and Cure*

(62) *Particle Adhesion and Removal, Editors K.L. Mittal and Ravi Ja, John Wiley & Sons, Inc, 2015 Particle Adhesion and Removal | Wiley Online Books*

(63) *Quantifying the triboelectric series, 2015 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6441076/,*

(64) *RCA Engineer Vol. 3, No.2. Oct.-Nov. 1957 1957-10-11.pdf (worldradiohistory.com)*

(65) *RCA Patent 3,960,790, June 1, 1976, DISC RECORD AND METHOD OF COMPOUNDING DISC RECORD COMPOSITION 14984095510067995538-03960790 (storage.googleapis.com)*

(66) *Returned/Overpressed Recycle Records, Tue Mar 10, 2020 2:12 pm (http://vpiforum.com/viewtopic.php?f=7&t=13498&start=40#p58611;)*

(67) *Richard C. Adams, A Comparison of Plasticizers for Use in Flexible Vinyl Medical Products, April 2001, Copyright ©2001 Medical Device & Diagnostic Industry, https://www.mddionline.com/comparison-plasticizers-use-flexible-vinyl-medical-products,*

(68) *Robert Harley, An LP Primer, The Absolute Sound June/July 2007 vinyl_tutorial (harryshifi.com)*

(69) *Robert Stockton, Do Turntable Mats Work? You Bet!, Audio Magazine June 1979 Audio-1979-06.pdf (worldradiohistory.com)*

(70) *S.K. Khanna, Polymer Science - New Materials for Phonograph Discs, RCA Engineer Magazine, 1976 Issue Oct-Nov 1976-10-11.pdf (worldradiohistory.com)*

(71) *S.K. Khanna & G.A. Bogantz, Development of Compound for Quadradiscs, RCA Engineer Magazine, 1976, Issue Feb-Mar* 1976-02-03.pdf (worldradiohistory.com)

(72) *SealezeTM SSG515AT2D Static Dissipation Brush Performance in an Operational Environment, Microsoft Word - SEALEZE_WHITE_PAPER_Final dam.doc*

(73) *Shang-Yi Shen • Jia-Chi Chen • Shang-Hao Liu, Ron-Hsin Chang, Horng-Jang Liaw, Chi-Min Shu, Effects of upper explosion limit for isopropyl alcohol by steam, inerting at 1 atm and 150 _C by 20-L-apparatus, J Therm Anal Calorim (2013) 113:1619–1624 (PDF) Effects of upper explosion limit for isopropyl alcohol by steam inerting at 1 atm and 150 °C by 20-L-apparatus (researchgate.net)*

(74) *Stuart Lyon, Corrosion of Lead and its Alloys, December 2010 (PDF) Corrosion of Lead and its Alloys (researchgate.net)*

(75) *Tadahiro Ohmi, Seiji Sudoh, and Hiroyuki Mishima, Static Charge Removal with IPA Solution, IEEE Transactions on Semiconductor Manufacturing, Vol. I, No. 4. November 1994 Static charge removal with IPA solution - IEEE Journals & Magazine*

(76) *Tom Green, Why Three Monolayers of Moisture Are Important, T.J. Green Associates, LLC, Bob Lowry, Electronic Materials Consultant, September 2016 (Why Three Monolayers Of Moisture Are Important - TJ Green Associates LLC. (tjgreenllc.com)*

(77) *Tyler J Johnson Jason S Olfert, Ross Cabot, Conor Treacy, Caner U Yurteri, Colin Dickens, John McAughey, Jonathan P.R Symonds, Transient Measurement of The Effective Particle Density Of Cigarette Smoke, Journal of Aerosol Science 87(May 2015)63–74. (PDF) Transient measurement of the effective particle density of cigarette smoke (researchgate.net)*

(78) *UIUC Physics 406 Acoustical Physics of Music ©Professor Steven Errede, Department of Physics, University of Illinois at Urbana-Champaign, Illinois 2002 - 2017. The Human Ear — Hearing, Sound Intensity and Loudness Levels, Microsoft Word - P406POM_Lect5.doc (illinois.edu)*

(79) *United Nations, Global Harmonized System of Classification and Labeling of Chemicals (GHS) Globally Harmonized System of Classification and Labelling of Chemicals (GHS) | United Nations iLibrary (un-ilibrary.org)*

(80) *Vetrimurugan, J. Michael Goodson, and Terry Lim, Parametric Study for High-Frequency, High-Intensity Ultrasonics in Removal of Sub-Micron Particles, International Journal of Chemical Engineering and Applications, Vol. 6, No. 1, February 2015 (http://ijcea.org/vol6/444-C1009.pdf)*

(81) *Wei, Z. B.; Zhao, Y.; Wang, C.; Kuga, S.; Huang, Y.; Wu, M Anti-static PVC-graphene Composite through Plasticizer-mediated Exfoliation of Graphite, Chinese Journal Polymer Science, June 2018 https://doi.org/10.1007/s10118-018-2160-5,*

(82) *W Whyte, K Agricola and M Derks, Airborne particle deposition in cleanrooms: Relationship between deposition rate and airborne concentration Clean Air and Containment Review | Issue 25 | January 2016 CACR25_FINAL_LR.pdf (gla.ac.uk)*

(83) *WHO Nutrients in Drinking Water 2005 https://www.who.int/water_sanitation_health/publications/nutrients-in-dw/en/,*

(84) *Yeon Joo Kim, Jaejun Lee, Sangwon Park, Chanho Park, Cheolmin Park and Heon-Jin Cho, Effect of the relative permittivity of oxides on the performance of triboelectric nanogenerator, RSC Adv., 2017, 7, 49368 (PDF) Effect of the relative permittivity of oxides on the performance of triboelectric nanogenerators (researchgate.net)*

REMAINDER OF PAGE INTENTIONALLY BLANK

APPENDIX B - LIST OF ABBREVIATIONS & ACRONYMS

AEL	Allowable Exposure Limit
CAS	Chemical Abstract System
CCI	Canadian Conservation Institute
CMC	Critical Micelle Concentration
DIW	Distilled/Deionized/Demineralized Water
DOE	Double Open Ended (ref: filter cartridge)
EPA	Environmental Protection Agency
ESD	Electrostatic Discharge
ESO	Epoxide Soybean Oil
GPM	Gallons per Minute
HDPE	High Density Polyethylene
HEPA	High Efficiency Particulate Air
LDPE	Low Density Polyethylene
IPA	Isopropyl Alcohol
LPM	Liters per Minute
NASA	National Aeronautics and Space Agency
NID	Non-Ionic Detergent
NPSH	Net Positive Suction Head
NTU	Nephelometric Turbidity Units
NVR	Non-Volatile Residue
OVP	Over-Voltage Protection
PPE	Personal Protective Equipment
PVA	Polyvinyl Alcohol (ref: sponge)
PVAc	Polyvinyl Acetate
PVC	Polyvinyl Chloride
PVCa	Polyvinyl Chloride-Acetate
QAC	Quaternary Ammonium Compound
RCM	Record Cleaning Machine (ref: vacuum type)
RIAA	Recording Industry Association of America®
RLP	Record Label Protector
RO	Reverse Osmosis
SDS	Safety Data Sheet
SEM	Scanning Electron Microscope
TDS	Total Dissolved Solids
TSS	Total Suspended Solids
UCM	Ultrasonic Cleaning Machine
UV	Ultraviolet
VAC	Volts Alternating Current
VDC	Volts Direct Current
VTF	Vertical Tracking Force
WHO	World Health Organization

APPENDIX C - RECORD OF CHANGES

Date	Edition	Change
2020-05-19	-	Initial paper for development and review. Review by Bill Hart of the The VinylPress™ results in a major revision of the draft.
May 2020	Rev A	Official version advanced to Revision A designating that all comments and changes have been adjudicated and incorporated and paper is approved for public release by author and Bill Hart of The VinylPress™.
March 2021	2nd	Major revision. Instead of advancing to Rev B, decision is made to title as Second Edition. Change details addressed in the book Forward were as follows: • Chapter I addresses the challenge of cleaning a vinyl record has been expanded to discuss and show examples of record wear. • Chapters II to V detail the manual cleaning procedure. Chapter II has been modified to add polyvinyl-alcohol (PVA) clean room sponge, disposable pipettes and some alternatives for those in the EU/UK. Chapter III has been modified for those in the EU/UK. Chapter IV has been expanded to show additional ultraviolet (UV) light pictures of records. Chapter V has minor modifications to address technique when cleaning, and use of the PVA sponge for drying with some revised photos for clarity. • Chapter VI addresses maintenance of cleanliness and has been extensively revised with expanded discussion of static. • Chapter VII discusses water quality and has been revised to show why water better than demineralized/distilled is not required, and addresses methods and the cost associated with home production of distilled or demineralized water. • Chapter VIII discusses pre-cleaner chemistry and has been extensively revised to address isopropyl-alcohol, anti-static and biocide solutions, and adds discussion of mold and scale, and of the more popular do-it-yourself (DIY) compositions. • Chapter IX discusses final cleaner chemistry and has been updated to include BASF™ DEHYPON® LS-54 a non-ionic surfactant available only to consumers in EU/UK, and Tergikleen™. • Chapter X discusses material compatibility and has been completely rewritten based on the details of the RCA™ record composition and a Hansen™ solubility parameter analysis. • Chapter XI addressing industry cleanliness levels and how they relate to a vinyl record has been completely written and retitled as “Discussion of Cleanliness Criteria”. An error in the table showing soil film thickness was corrected and detailed analysis of the record groove velocity and resultant amplitude has been added to justify the rationale for the recommended cleanliness criterion. • Chapter XII which discusses the overall cleaning process retains the information that was in Section XI.

Date	Edition	Change
		• Chapter XIII that now discusses vacuum record cleaning machines (RCM) has been revised to add images and a table describing the various design features and to reflect lessons learned. • Chapter XIV that now discusses ultrasonic cleaning machines (UCM) has been extensively revised adding new information on the ultrasonic cleaning process and lessons learned. • References are identified in each instance and the full citations are hyperlinked for download in the **APPENDIX C - RECORD OF CHANGES** at the end of this paper. Hyperlinks are provided only to secure (https://) sites.
January 2022	3rd	Major revision. Change details addressed in paper Forward. Book remains available for free download at the https://thevinylpress.com/

REMAINDER OF PAGE INTENTIONALLY BLANK