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Journal of the International Institute for Conservation – Canadian Group (J. IIC-CG), Volume 16.
Now the Journal of the Canadian Association for Conservation (J. CAC).

J.CAC is a peer reviewed journal published annually by the Canadian Association for Conservation of Cultural Property (CAC), 207 Bank Street, Suite 419, Ottawa, Ontario K2P 2N2, Canada; Tel.: (613) 231-3977; Fax: (613) 231-4406; E-mail: coordinator@cac-accr.com; Web site: http://www.cac-accr.ca/.

Journal de l'Institute international pour la conservation – Groupe canadien (J. IIC-GC), Volume 16.
Maintenant le Journal de l'Association canadienne pour la conservation et la restauration (J. ACCR).

Le J.ACCR est un journal révisé par des pairs qui est publié annuellement par l'Association canadienne pour la conservation et la restauration des biens culturels (ACCR), 207, rue Bank, bureau 419, Ottawa (Ontario) K2P 2N2, Canada; Téléphone : (613) 231-3977; Télécopieur : (613) 231-4406; Adresse électronique : coordinator@cac-accr.com; Site Web : http://www.cac-accr.ca.

The Treatment of Rusted Machinery in Preparation for Surface Coatings

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Manuscript received November 1991; revised manuscript received December 1992.

This paper reviews various field-tested methods for cleaning machinery and treating surface rust as preparation for display. The treatments combine the use of traditional conservation methods with commercial and industrial materials and techniques. These can be adapted and applied successfully on a small scale to meet the requirements of conservation-restoration projects. Cleaning techniques such as pressure washing, grease and oil removal, emulsion cleaning and immersion cleaning are discussed. The author also presents information on rust removal including rust convertors, mechanical removal, grinding, abrasive blasting and chemical removal when the removal of rust is necessary prior to applying a surface coating.

Cet article passe en revue diverses méthodes éprouvées de nettoyage et de traitement de la rouille telles qu'appliquées à des machines qui seront exposées. Les traitements font appel aux méthodes conventionnelles de restauration et aux techniques et matériaux commerciaux et industriels. Ils peuvent être adaptés et appliqués avec succès à petite échelle afin de répondre aux exigences des projets de conservation-restauration. L'article traite de plusieurs méthodes de nettoyage, comme le lavage au jet d'eau sous pression, l'enlèvement de la graisse et de l'huile, le nettoyage par émulsion et par immersion. L'auteur donne aussi des renseignements sur les méthodes employées pour enlever la rouille lorsque cette opération doit être effectuée avant qu'un revêtement ne soit appliqué. Parmi ces méthodes, on retrouve l'utilisation de convertisseurs de rouille, l'enlèvement mécanique, le ponçage, le sablage et l'enlèvement par voie chimique.

Introduction

The conservation of machinery amounts to a discretionary combination of preventative maintenance and restoration. The maintenance aspect is straightforward, practical and time-tested. It was developed during the second half of the nineteenth and the first decades of the twentieth centuries to ensure the well-being of machinery in the off-season storage periods of its working life. Formulated over many years through a process of careful observation and trial and error experimenting, the established rules of machinery maintenance — as found in the operating manuals of this era — are surprisingly compatible with today's museum standards of artifact preservation.

The restoration aspect of machinery conservation is a much more recent and controversial phenomenon. Ideally, since machines are legitimate artifacts, their treatment should be governed by the same ethical considerations one would afford any artifact. Machines — in particular those machines intended for outdoor use — are coated artifacts. That is, they have been given a protective surface coating during manufacture in order to protect their constituent materials from the elements and from extensive mechanical wear and handling. Unlike domestic coated artifacts, however, most machines have been subjected to years of exposure and operation outdoors, and this has an enormous impact on the condition in which they come into our care. Intact original coats of paint on machinery more than forty years old are extremely rare, while coatings in very good or mint original condition are almost unheard of. To make matters worse, after a hard working life outdoors, many machines are simply abandoned to rust away and do not find their way into museums until their historical value is appreciated, often several decades later. Whatever paint survives to represent the artifact's state of last use may have been further subjected to fifty years or more of exposure to the elements. This of course has left next to nothing of the original coat of paint on many machines: more than 20% would be unusual, and even that 20% will be severely oxidized, faded and cracked.

In keeping with accepted conservation practices, even incomplete and deteriorated original coats of paint on machinery should be saved whenever possible. In theory, surface losses can be touched up or inpainted with removeable materials such as acrylic paints or pigmented waxes. In practice, however, this course may not always be practical. Often a machine will feature large expanses of sheet metal which were originally painted one solid colour, usually with a very smooth high-gloss finish. Inpainting up to 80% of such an area may not meet the practical and aesthetic demands of curators, programmers and the public. Yet one can rarely leave the machine as it exists, *i.e.*, without some degree of repainting. On display, the rust-dominated surfaces will tell very little about a machine's history or working life, apart from its years of neglect. Nor can such deteriorated objects be returned to their condition of last use with any honesty: regrettably, that state is lost forever.

This being the case, the conservator who is entrusted with the treatment and care of machinery collections may eventually have to come to terms with recoating these artifacts as a prerequisite for display. This can prove to be quite challenging, since the conservation literature and training courses on the subject are very few and far between. There is really only one recourse, and that is to enter the foreign realm of industrial and commercial processes: processes developed over many years by corrosion engineers and paint chemists for large-scale cleaning and derusting operations. Armed with his or her knowledge and training in traditional conservation, an acute awareness of health and safety practices and a reasonably open mind, the conservator should be able to borrow and evaluate industrial and commercial techniques and materials with confidence and adapt them to the project at hand: a project which by conservation standards is relatively large, but by industrial and commercial standards is infinitesimally small.

Protective coatings will usually be in one of two forms: paint or a synthetic lubricant in the form of oil or grease. Both types of coating require a clean substrate for aesthetic reasons and to ensure their long-term effectiveness in preserving the underlying metal. The purpose of surface preparation is to remove all of the surface contaminants which could interfere with the application and stability of the protective coatings. These include dirt, oil/grease, old paint, rust and mill scale. The contaminants are usually found in this order, working from the outermost layer down to the bare metal substrate. They are generally removed in a similar sequence. All of these contaminants can interfere with the keying of new paint or oil to the metal substrate; they can shield the metal from coming into contact with the inhibitors of a paint primer; and they can harbour soluble, hygroscopic salts such as sulphates and chlorides which can promote corrosion.

The initial stages of preparation discussed below (cleaning and degreasing) are applicable to most treatments of machinery regardless of the projected final goal. Paint systems generally require an additional preparatory stage (rust removal) in order to be effective, particularly when the artifact will be stationed and/or operated outdoors.

Cleaning Techniques

As with most conservation treatments, the first step after initial documentation is one of surface cleaning. In the context of machinery collections, this will usually involve the removal of the most common and outermost accretion: dirt or soil.

Where it is not mixed together with oil or hardened grease, surface dirt can normally be removed in situ by the standard conservation method of dry cleaning with vacuum and brush. Hardened mud will require a certain amount of mechanical loosening with hand tools, such as scrapers and spatulas. These should be made of a material softer than steel, for example, wood or plastic, as these will minimize the possibility of damaging the underlying surfaces. Presoaking the accretions with warm water will greatly facilitate the cleaning process.

Localized wet cleaning should follow, using an appropriate quantity of warm water and detergent (preferably a 5% solution of sodium dodecyl sulphate in water) combined with the judicious use of soft stencil or scrub brushes and the scraping tools mentioned above.

Pressure Washing

It is tempting to carry out the initial cleaning of an industrial artifact with industrial cleaning equipment, that is to say, with a portable pressure washer. Originally developed in the 1930s for cleaning locomotives, these machines have evolved into a sophisticated industry standard for cleaning trucks and heavy equipment. Running on a 220 V power supply or either a gasoline or diesel engine, they are capable of instantly delivering tap water at a rate of 7 litres per minute (3.5 Imperial gallons/minute) at variable pressure up to 18,000 kPa (2600 psi), which is enough to remove almost any type of soil accretions, especially if a pre-soaking stage is involved. More expensive models of pressure washers feature a built-in heating coil which runs on heating oil, natural gas or kerosene. These machines are capable of delivering the same rate of pressurized water, but heated anywhere from 30° to 95° C, or as steam at up to 150° C at about 6200 kPa (900 psi), all within a matter of about 15 minutes. A large number of commercially prepared detergents can be introduced into the water supply to increase the cleaning efficiency of the system, and dozens of accessories, such as rotary brushes, are also available. The major manufacturers of pressure washers are K.E.W. (Denmark), Hotsy Corporation and L.& A. Products, Ltd. (both U.S.). Prices are in the $5000 to $8000 range.

The main appeal of pressure washing is the lack of physical effort it requires. All that is involved is directing the spray lance and walking around the machine being cleaned. But the convenience comes at a high price in terms of the many disadvantages of the system. The greatest problem is the lack of control one has over the water being sprayed. It will find its way into every conceivable nook and cranny in the machine, including electrical parts (*e.g.*, generators, starting motors) and unless it is carefully blown out of every recess with pressurized air right away, it will lead to further rusting. This is especially true of heated water and its vapour; steam, of course, will infiltrate the same areas and condense into tiny droplets which, like morning dew, are much more corrosive than a continuous sheet of water, because they create many distinct anodic and cathodic areas on the surface of the metal (Diamant 1971, pp. 31-32). If the pressure washer is used indoors, as it must be in wintertime, it will saturate the surrounding air with moisture for a long time unless very efficient ventilation is available. It may seem redundant to worry about the additional corrosion of a rust-covered relic, but many artifacts are composites of steel and organic materials — wood, textiles, leather and paper, to name a few — and these will suffer from exposure to excessive moisture.

Lack of ventilation will also promote flash rusting on any ferrous tools and equipment in the vicinity, and it will saturate and cockle any paper documentation and reference material as well. If the water is heated near the boiling-point, billowing clouds of obscuring steam will be generated until one is literally working blind in a fog.

Other problems associated with pressure washing include the tendency of the mud-laden spray to be deflected by the innumerable different angles presented by the typical machine, all too often right back onto the operator and any walls in the vicinity. A protective face shield, rubber boots and a full-length rubber apron are essential apparel in this operation. In addition, loose components on the artifact pose a novel problem in that they may be detached by water at a pressure of 18,000 kPa and carried some distance at an unexpected velocity; a definite threat to the well-being of workers and artifacts. Finally, one should keep in mind that the 7 litres of water per minute and the mud it dislodges has to go *somewhere*, usually into the sewage system, so proper indoor drainage is a must in the form of a large floor sump which can be dredged periodically.

An alternative to the excesses of pressure washing is to organize the cleaning process into two separate stages: a localized cleaning stage *during* disassembly; and a second stage concentrating on the artifact's component parts *after* disassembly. The first cleaning stage should concentrate on threaded fasteners, that is, the nuts, bolts and cap screws holding the machine together. This preliminary local cleaning operation gives a sense of control and finesse to a restoration project. For while one can say with some certainty that a machine can not be efficiently cleaned without disassembly, it is also true that one can not disassemble a machine efficiently without a certain degree of cleaning first. Cleaning the exposed parts of fasteners and their environs makes subsequent close-up photography during disassembly much more effective, providing an invaluable record when reassembly begins. It also enables the conservator to use penetrating oil and heat more effectively when loosening stubborn fasteners, and it encourages the use of the proper tools for the job. Wrenches and screwdrivers which provide an exact fit on a cleaned part will do far less damage to the metal being torqued than close or approximately fitting tools. In the process, the tools will stay cleaner. This will encourage their being treated with respect by other users, while clean tools will be more than welcome during the final reassembly of the cleaned parts.

Admittedly, this is an almost surgical approach to cleaning and disassembly. It is time-consuming and labour-intensive, so be warned: it will try the patience of most non-conservators and it may be difficult or impossible to convince them of its merits.

Grease and Oil Removal

In many cases, the dirt on a machine will be mixed together with accumulations of oil and hardened grease. This demands a more elaborate cleaning operation than simply brushing, loosening and vacuuming. The accretions can be virtually melted off by using a pressure washer running in the steam range, but as discussed above, a high price will be paid in terms of the attendant inconveniences. In this instance, the hot liquified grease will drip off the machine and coalesce as sticky globules all over the floor — and often the walls — of the entire work area. It is much better to remove as much of the accretions as possible by mechanical methods. The bulk of the grease can be removed by scraping. As with the removal of hardened mud, only tools made of soft material such as plastic or wood should be used in this operation because most metals, particularly those making up the fasteners, are quite soft and very easily damaged by sharp steel edges.

Even more important than this is the fact that grease accumulations, which have a tendency to build up in the vicinity of fasteners, very often cover the only original traces of paint and varnish left on a machine. In many instances, as with the axle skeins of wagons and carriages, the grease may have been laid down within the first few weeks of the vehicle's working life and it may never have been removed. The grease may have served as a protective barrier for eighty years or more, so it should be removed with great care. Wooden tongue depressors are ideal implements for this task. They are strong, flexible and comfortable to hold, and both ends can be cut to a point or angle on a band saw in seconds, or shaped with a scalpel. The wood can also be dampened with solvents (see below) in order to soften up the accretions. For cleaning small, intricate areas like hexagonal nuts and screw heads, Fisherbrand Tongue Depressors are highly recommended. They are advertised as being splinter-free, straight-grained smooth white birch. They sell for about $.06 each.

Once the greater part of the grease has been removed mechanically, one will have to resort to chemical methods to finish the job. The options are fairly limited when dealing with fasteners *in situ*. Swabbing with solvents qualifies as the *traditional* conservation technique for dissolving and removing hydrocarbon contaminants like mineral oil. The solvents commonly used by conservators include acetone, ethanol and mineral spirits. They pose no threat to the underlying metal nor do they involve the use of rust-promoting water. In most cases these solvents will be very effective. Acetone and ethanol do tend to evaporate fairly quickly, however, so frequent reapplication is necessary, which adds to the cost and labour of the treatment. Petroleum-based solvents such as mineral spirits evaporate less quickly, but they leave a thin oily deposit behind. This will have to be removed in turn with a small amount of detergent solution or acetone. The effect of the various solvents on original paint and varnish underneath the grease should be determined by testing and monitored closely. Denatured ethanol, in particular, will dissolve many shellac-based varnishes, while acetone will attack almost any type of coating. If, during testing, any colour appears on a cotton swab, one should resort to the use of mineral spirits or a detergent solution. All of the solvents mentioned here are flammable and their toxic fumes can cause problems, so proper ventilation and safety precautions are a high priority.

Emulsion Cleaning

Many commercial products known as *degreasers* are available which may prove to be more effective and economical to use than straight solvents. They are, in technical terms, *emulsion cleaning* solutions consisting of a hydrocarbon solvent dispersed in an aqueous medium, combined with an emulsifying agent, surfactants, chelating agents and often alkaline salts. On being applied to the contaminated area, these chemicals dissolve and emulsify the oil film so that it can be rinsed away with water. They are used either undiluted for heavy duty cleaning, or diluted up to a ratio of 1:8 parts with water for light cleaning. In general, these products can only be purchased from a manufacturer's regional distributor, rather than off the shelf at a hardware store. The prices, especially for large quantities, are much more reasonable with this system. Technical advice, which most conservators can critically evaluate, is readily available from the company's sales representative, and Material Safety Data Sheets (MSDSs) must be supplied with each purchase. Two examples of commercial degreasers are Cantol's Tech 736 or the more powerful Grease-Off. Both rely on xylene as their grease-cutting solvent, and because this solvent tends to evaporate, proper ventilation during application is very important. As well, both solutions are quite alkaline, so prolonged contact with aluminum and zinc alloys (*e.g.*, brass) is to be avoided.

Recently, more pleasant "biodegradable, non-toxic, non-caustic" degreasers have appeared on the market, relying on *d-limonene* as their main solvent and wetting agent. Limonene is a natural terpene extracted from the peels of citrus fruits (lemons, oranges, *etc.*). It is touted as being non-hazardous to human health and the environment to the extent that it is finding its way into many hand cleaners, such as Loctite Corp.'s Fast Orange Natural Citrus Hand Cleaner. As with most degreasers, a limonene-based cleaner can be used undiluted or mixed with water up to a ratio of 1:40 for light cleaning. One such commercially available brand, formulated from 100% organic ingredients, is All Natural Cleaner Degreaser made by Rust-Oleum, available as a liquid concentrate or an aerosol spray. In undiluted strength — the recommended dip tank solution — it cuts through grease almost as effectively as the more common petroleum-based solvents, yet it poses no threat to aluminum or copper alloys and it emits a fragrant smell of oranges rather than toxic fumes. A similar product is United Chemical Company's Citra Solve, which unfortunately combines *d-limonene* with an almost equal quantity of ethylene glycol monobutyl ether, also known as butyl cellosolve. The latter ingredient renders the product much more toxic than Rust-Oleum's formula. In addition, both products are highly flammable, so they should be used with care.

A new product from the Mirachem Corp. of Tempe, Arizona, called Mirachem 100, appears to combine the best of all possible worlds. Mirachem 100 is listed as being a biodegradable, industrial strength Cleaner/Degreaser Concentrate. The manufacturer also claims that it is non-caustic, water-soluble, sewer disposable, non-flammable, non-corrosive, non-fuming and tested non-toxic to OSHA and EPA standards. All of these claims are documented in the product's Material Safety Data Sheet. Surprisingly, Mirachem 100 also works extremely well on removing very tough grease—at least as well as Tech 736, but without the nauseating xylene fumes of the latter. The only disadvantages of the product are its moderately unpleasant smell and its relatively high cost ($30.00/L).

Immersion Cleaning

Once a machine component has been removed, it can be thoroughly cleaned from all angles. Pressure washing and steam cleaning can be used on very heavy and/or large components; lightweight parts will have to be secured in place to counteract the water pressure. As discussed above, the many disadvantages of this system make it largely unappealing. Mechanical removal of dirt and heavy grease accumulations with hand tools still ranks as the best preliminary cleaning operation.

Thorough cleaning inevitably requires the total immersion of the object in a cleaning solution for as long as necessary, followed by a clean rinse or pressure wash. Immersion allows the cleaning solution to come into prolonged contact with otherwise inaccessible and intricate areas of the artifact. A number of options are available for removing grease, oil and, in some cases, old paint. As with cleaning fasteners *in situ*, they include solvent cleaning and emulsion cleaning. A third possibility is alkaline cleaning. Many factors have to be taken into account in choosing the most appropriate system, particularly in terms of safety and cost. As a rule, one should design the cleaning operation around the single largest component to be cleaned. This can be a complex assemblage of over a hundred smaller parts held together by permanent fasteners (*e.g.*, rivets), such as an early lugged tractor wheel, or a simple structure like an automobile frame. The dimensions of the assembly will give one an idea of the size of immersion tank one will need to build or purchase, as well as the quantity — and therefore, the cost — of the necessary cleaning solution. On this note, it should be pointed out that total immersion of a component is much more effective and easier to carry out than partial immersions in a small bath; for example, sequentially rotating the rim of a wheel in a shallow semi-cylindrical trough of cleaning solution.

Immersion solvent cleaning ranks as the poorest of the three systems. On a large scale, it is prohibitively expensive, while the attendant fumes are both toxic and flammable. The solvent bath quickly becomes contaminated in the cleaning process, so that a film of oily contaminants is redeposited on the piece as it is withdrawn from the bath. Thorough cleaning will thus require a sequence of reimmersions in progressively cleaner solvent baths and a final spray of pure solvent. None of the solvents commonly used in conservation — acetone, ethanol, toluene, xylene, mineral spirits, *etc.* — is of any practical use here.

Industry tends to shun the use of these solvents because of their high cost and flammability. When solvent cleaning is unavoidable, most industries prefer to use nonflammable halogenated solvents such as 1,1,1-trichloroethane, methylene chloride and perchloroethylene in hot vapour form in a closed *vapour degreasing* system. These are extremely effective degreasing systems in which the solvent vapours condense on the cold work pieces, dissolve the contaminants, and drip down into a reservoir. The closed system allows the solvents to be recovered and reused in purified form many times, through a distillation process. The construction and operation of a system such as this would be impractical and unnecessary for most conservation programs.

Immersion in a bath of commercial degreaser/emulsion cleaner at room temperature is a system worth serious consideration up to a certain volume, beyond which the cost becomes too great. For while the manufacturers allege that the concentrated cleaners can be diluted up to a ratio of 1:8 or more with water, in restoration applications the effectiveness of the solution decreases dramatically with a dilution as low as 1:1. For immersion purposes, emulsion cleaners should be used full strength and in a closed vessel. A sealed chamber will prevent the excessive loss by evaporation of solvent — the most active and expensive ingredient of the cleaner — and this will maintain the cleaning strength of the solution for repeated reuse. In a closed system, a form of room temperature vapour degreasing comes into effect in the area of the chamber above the liquid phase. This is beneficial when total immersion of a component can not be achieved. The trapped vapours will initiate the cleaning process on any part of the artifact which is not immersed. As with almost every type of immersion cleaning, any amount of solution or object movement, *i.e.*, agitation, will facilitate the cleaning process by swirling away the outermost, emulsified contaminants and exposing fresh layers to the solution. Agitation can be applied in the form of air bubbled through the solution, a small recirculating pump or, in the case of very small immersion tanks, any kind of rocking or lateral motion applied by hand. Alternatively, the piece being cleaned can be removed from the solution at intervals and either brushed or hosed down before being reimmersed.

Once removed from the bath, the cleaned piece should be thoroughly rinsed with water before any further cleaning or derusting operations take place. This is one of the few occasions in the cleaning operation when a pressure washer is almost indispensable. But again, it is necessary to anchor light-weight pieces, and proper safety apparel must be worn. Generally, the rinse should take place just before the next cleaning stage in order to minimize further rusting of the cleaned piece. If an extended period of time is anticipated between steps, however, the piece can be left unrinsed to air dry without risk of corrosion, since the emulsion film affords a certain degree of rust protection to the underlying metal.

A cleaner like Cantol's Tech 736 works extremely well for immersion cleaning, as the xylene rapidly dissolves grease as well as paint. Both can be rinsed away after as little as 15 minutes of immersion. Mirachem 100, by contrast, has very little effect on paint, although this may be a desirable trait in some applications.

All of the products discussed here should be disposed of in a responsible manner. Even the most environmentally-friendly product becomes far from benign once it has been contaminated with oils, lead-based paint and so on.

By comparison with solvents and degreasers, alkaline cleaning is the most economical and efficient system and, with the exception of the degreaser Mirachem 100, it is the only one which is non-flammable. Alkaline cleaning involves a 5-10% solution of NaOH and alkaline salts, non-ionic surfactants and chelating agents to break down and disperse fatty compounds and mineral oils. In industry, immersion treatment is carried out with the solution heated to at least 50°C and with agitation imparted by means of convection currents in the solution, or a recirculating pump coupled to the immersion tank. Immersion is followed by a thorough rinsing. Hot alkaline immersion cleaning is every bit as effective as a powerful solvent-based emulsion cleaner in removing every last trace of dirt, carbon, grease and old paint, and the solution is still effective after many cleaning operations. As one might expect, it does have its disadvantages. For one thing, it is highly alkaline, so the solution should not come into prolonged contact with aluminum, zinc, tin or lead alloys. These turn up very often in many different forms: bronze bushings, galvanized sheet steel, soldered or brazed joints, babbitted bearings and flywheel balance weights.

The dissolving action of strong alkaline solutions on old paint is worth keeping in mind during the cleaning process, since it can serve as a kind of investigative tool for uncovering traces of original paint. This is particularly useful when the artifact has been overpainted several times with thick coats of modern alkyd enamel paints. The hot solution will remove the coats of paint in the reverse order of their application, eventually exposing the remains of the original paint scheme underneath. An immersion in the hot solution for as little as 60 seconds may prove sufficient for removing each coat. The process can be stopped at any stage by removing the artifact from the solution and rinsing it gently but thoroughly in warm water. The entire process must be carefully monitored to prevent the eventual dissolution of all remaining paint.

Perhaps the most serious drawback to using alkaline cleaning is the fact that the solution is only effective when it is heated. Depending on the volume of solution being used, this can require massive amounts of expensive energy in terms of electricity or fossil fuels. And, as the heat of the solution rises, so do the highly caustic vapours. The immersion tank must have a removable, sealable cover, and a powerful fume extraction and ventilation system is absolutely essential.

Alkaline cleaners are usually purchased as Hot Tank Cleaners in powdered form, requiring only the addition of water. It is possible to make up your own alkaline cleaning solution with lab grade chemicals, but the cost will be extremely high for large quantities of NaOH alone. The purity of lab grade reagents is not necessary for this type of treatment. Any commercial hot tank cleaning compound, such as Dynadet, made by Oakite Products, Inc., or Cantol's Martex will do the job at a fraction of the cost. The average concentration is about 60 grams of powder per litre of water (8 oz./gallon).

As with emulsion cleaning, alkaline immersion cleaning must be followed with a clean rinse to remove the residual cleaning solution and the emulsified/saponified contaminants. This is best accomplished in the form of a warm water spray, again using a pressure washer with adequate protective wear. As with emulsion cleaners, rinsing can be delayed since the alkaline solution will prevent the formation of rust as the metal dries and beyond.

Dealing with Rust

At this stage of the preparation process, the cleaned artifact component should reveal at least one of three types of surface: brown rust, silvery grey (exposed) metal, and/or a thin, compact layer of blue-grey mill scale resembling a matt coat of paint. The mill scale is an oxidation layer formed during the cooling stage of the metal's manufacture. It is worth documenting photographically before it is removed or covered over. If light mill scale is the only oxidation product present on an otherwise sound piece of steel, and if the layer has not been disrupted by corrosion, then it can be left intact to continue its function of protecting the bare metal substrate under the coats of primer and paint or oil/grease. If rust is present, and one is intent on recreating a smooth, glossy finish with new paint, then one will have to choose between one of two courses before priming and painting can commence. The two options are rust conversion and rust removal.

Rust converters

Conservators are familiar with the process of rust conversion in the form of heated tannic acid applications. This is appropriate for rough archaeological pieces which will not be painted. It may not be particularly well suited as a base for primer and enamel because of the powdery nature of the residue left on the surface. This residue tends to become mixed into the overlying paint, causing discolouration, and the powder may interfere with the keying of the paint to the metal's surface. Very little research has been conducted on this subject by the conservation profession. At any rate, the application process as currently practised is unpleasant even on a small scale in terms of staining and the disagreeable smell. As well, tannic acid is currently a suspected carcinogen, which makes the treatments even less appealing.

Industry has exploited the beneficial properties of tannic acid in the form of commercial rust converters. These are relatively new products which may be of some use in restoration projects. They convert light to moderate surface rust into a more stable blue-green to black coloured form, apparently a tannate, so that removal of the corrosion layer is unnecessary. In fact, the effectiveness of the product depends on a large proportion of the rust being left intact. Only dirt, oil and loose rust need to be wire-brushed and rinsed away before the solution can be painted on. In addition to chemically converting the rust, the solution protects the metal surface from the environment by forming a polymer coating. The dried polymer coating is said to be an effective primer — as well as top coat — by itself, making priming and painting optional.

Commercially available rust converters include Rust-Oleum's Rust Reformer, touted as being, "a combination primer and topcoat that chemically transforms rust into a long lasting protective barrier with one coat." The coating itself is described as a "water based vinyl acrylic copolymer." The hazardous ingredients of Rust Reformer include 1% diethylene glycol methyl ether (solvent/plasticizer) and 1% tannic acid. Both are bound up in an acrylic emulsion, so the health risk involved in using this product is presumably very low. A similar product is Cantol's Stop Rust!, described as a one-step water-based conversion treatment that combines with rust to form a "hard black polymer that offers a long lasting protection as a weather-proof coating or as a superior under-coating." Both products are rated as nonflammable, nonhazardous substances, essentially only eye and skin irritants.

The major selling point of rust converters is convenience, that is, a purported lack of effort required during application. This is unmistakable in the sales literature for Stop Rust!. It is heralded as being "easy-to-use . . . [with] minimal preparation required . . . It is not necessary to use expensive labor and time consuming methods." Rust-Oleum's sales literature introduces the product as a labour-saving coating, "dedicated to saving you time and money. You need only minimal surface preparation . . . get more work done faster at lower expense." A more revealing statement follows: "Use Rust Reformer whenever circumstances limit surface preparation, time won't permit use of a multi-coat coating system or when budget constraints won't allow application of a high performance coating system." This seems to imply that if and when a job can not be done properly, one can always resort to the use of a rust reformer as a kind of quick and dirty short-cut.

The problem with rust converters is that their application is far from being entirely labour-free. Essentially, the more surface preparation one carries out in terms of removing dirt, grease, paint and soluble salts, the better the adhesion and performance of the conversion coating. Only one preparatory operation — rust removal — is eliminated. The proper application of a rust converter requires as much surface preparation as any other approach. In terms of manual labour, it will probably require more than the others, a fact which will generate disappointment and resentment among workers who have high expectations of a "labour-saving" product. As a consequence, the surfaces will almost certainly be prepared inadequately and the final coating will be below standard. On the other hand, if thorough preparation is carried out by a series of immersion treatments, there will be little reason to resort to the use of a rust converter. Complete rust removal can be accomplished in a few additional steps.

This is not to say that rust converters have no conceivable use in restoration projects. They do indeed merit a place in the conservator's palette of techniques and materials. Exactly when they should be used will have to be determined by the circumstances of the project and the nature of the desired finish. Generally speaking, if there is enough rust present to warrant the use of a rust converter, the resulting finish will not be a smooth one, since the substrate will be relatively rough. Moreover, the surface texture will be streaky if the solution is brushed on, as it will be in many cases. The hard polymer coating is very difficult to sand to smoothness, and cutting down the high surface points will create breaks in the coating, thereby negating its protective function unless several additional coats are applied. In the long run, very little labour will be saved.

If a conversion coating is left unpainted, it will appear as a glossy black or dark brown finish. There are some circumstances where this may be desirable, particularly if the original artifact was not painted and a grey metal surface would be inappropriate or impossible to achieve for display. This situation arises with late nineteenth and early twentieth century wagons and carriages. Most are composites of wood with iron fittings, the latter being rivetted or nailed in place. The tires, for example, consist of flat iron bands closely fitted to the wooden felloes of the wheels. They are difficult to remove and they should not be painted along with the wood, so they must be treated in place. In any case, a coated rusty surface is much more pleasant to handle and easier to clean than an uncoated powdery one.

Mechanical Rust Removal

As mentioned above, the alternative to rust conversion is rust removal. Rust can be removed in one of two ways: mechanically or chemically. Each approach has its advantages and disadvantages; again, the choice of one over the other is largely discretionary. Regardless of what methods follow, the precleaning of the metal by the processes outlined earlier will make the task much more effective and a little more pleasant.

The mechanical cleaning methods familiar to all conservators include the use of small air abrasive blasting cabinets, hand-held abrasive materials and picking tools, *viz*, steel wool, glass-bristle brushes, pin vices and dental picks. A few domestic electrical tools, such as the architect's eraser, the Dremel tool and the engraving tool have been adopted by conservators as well. The abrasive techniques are of very limited use in treating large machines because of the enormous surface areas involved. Picking tools, on the other hand, can be useful in digging rust out of very deep pits and crevices.

Grinding/Sanding

In industry, rust removal is accomplished mechanically by power brushing, power sanding/grinding and abrasive blasting. The first two methods involve the use of either electric or pneumatic hand-held power tools. A power drill fitted with an epoxy-silicon or carbide disc or a rotary stainless steel brush (disc or cup shape) is the least expensive version of this system. A pneumatic angle sander equipped with a padded abrasive disc is more expensive but it will prove to be more durable as well as cheaper and safer to operate. A typical angle sander, like Chicago Pneumatic's CP-869 Model A, reaches a speed of 5000 RPM at 620 kPa (90 psi).

There is nothing particularly elegant or innovative about these power tools. They simply accelerate the basic operations of manual wire brushing and sanding into very rapid actions with a lot of accompanying noise, heat, and airborne dust and corrosion products. Their use in conservation is definitely limited. The size and shape of the abrasive discs or wire wheels — typically 10 to 18 cm in diameter — make it almost impossible to reach into intricate or concave areas without damaging the surrounding areas. And the high speeds of rotation, the harsh abrasive action involved, and the obstructed view of the surface being abraded, all limit the amount of control one has over the cutting action on the metal substrate. Deep scoring or swirl marks covering a metal surface are a sure sign that an angle sander has been used with excessive zeal by a careless or inexperienced operator. Repairing this kind of damage necessitates further grinding/sanding or the use of body filler.

Abrasive Blasting

Abrasive blasting merits serious consideration as a rust-removing technique. Industrial blasting dates back to the 1890s in the form of outdoor sand-blasting of structural steel, a very harsh—and, it turns out, unhealthy—operation. During the past two decades it has evolved into a remarkably versatile and sophisticated system, and the safety equipment, if used intelligently, can eliminate the serious health hazards involved in the process. Abrasive particles are available in a large number of hardnesses, sizes and materials, from superhard steel shot and glass beads to soft organics like corn cobs, ground-up walnut shells and, most recently, plastic pellets. The propellant can be air, water or centrifugal force, and the effect of the blast can be varied with pressure, distance and angle of application. Thus, blasting can be tailored to suit almost any rust removal task. There is no longer any excuse for damaging metal by blasting. The damage inflicted by old-style sand-blasting — *i.e.*, warped or buckled sheet steel panels and "shot-peened" or severely pitted surfaces on overblasted structural iron — should not discourage one from considering this technique in its modern form.

Conservators are most familiar with abrasive blasting in the context of a small, totally enclosed blasting cabinet, as mentioned earlier. This is ideal for small objects. Problems arise, however, when one attempts to blast objects which are too big to fit into a blasting cabinet. This is a situation certain to arise in the restoration of anything larger than a small stationary gas engine. The next largest blasting apparatus is a portable blasting pot with a compressor and air dryer. With this approach, instead of just inserting gloved hands into a blasting cabinet, the operator is in effect completely immersed in the blasting environment, whether it is a room inside a building or an area outdoors such as a parking lot. This approach has serious disadvantages. For one thing, a protective, life-support system is absolutely essential. This involves much more than a dust mask and goggles. The minimum requirement is a full hood or helmet breathing apparatus coupled to a clean, dry air supply. Protective boots, gauntlets and coveralls are also indispensable. In summertime, which is the only time this cumbersome gear can be used outdoors, operator discomfort from the heat can be alleviated with an air conditioning attachment.

The purchase of this equipment can add up to a substantial investment. The blasting medium itself, especially in the form of non-recoverable glass or plastic beads, adds considerably to the cost. Before one commits oneself to this course, one should give serious thought to the expense and the many troubling disadvantages involved with the system. For apart from safety considerations, blasting also presents a problem in terms of its very effectiveness. Metal which has been blasted to the "white metal" state will begin to oxidize within seconds of being blasted, so that the priming stage must follow immediately after. This urgency creates its own problems, since freshly blasted metal is never clean enough for painting. The fine dust and blasting debris in the form of spent abrasives and pulverized corrosion products must be removed first. Much can be blown off with compressed air, but thorough surface cleaning and the removal of debris from cracks and crevices will require a careful brushing and vacuuming operation, all performed in a race against the formation of surface rust.

These are only the first of several major problems which can arise when one chooses blasting as a rust removal operation. One should be aware of how dirty the blasting operation really is. The cloud of airborne blasting media, corrosion products and lead-based paint one creates does not simply vanish. Indoors, the fine dust will infiltrate and settle in places one would not imagine possible, including the bearings of exhaust fans which will be ruined in a short time. Outdoors, the lightest particles will be carried downwind for a distance of several blocks, posing a health hazard to any passersby in the vicinity and coating every object along the way with a fine layer of dust. One should make every effort to distance the operation from parked cars and HVAC air intakes.

Wet blasting, which makes use of a slurry of water and glass beads fed through a pressure washer—to name one combination—is sometimes presented as being less messy and less hazardous than dry systems. In truth, the amount of airborne dust is greatly reduced, but this does not make the air safe enough to breathe without protection. Moreover, the spent abrasive will still have to be vacuumed up after the operation, and the use of water as a vehicle entails all the disadvantages discussed above in connection with using a pressure washer. A wet-blasting system using a solution of corrosion inhibitors, like chromates, will indeed prevent flash rusting, but the toxic nature of the slurry will call for even more elaborate safety equipment, and so higher costs and closer supervision.

The weather is another factor worth mentioning with respect to outdoor dry blasting. Not just cold, winter conditions, but even a cool summer morning will chill the metal being blasted. When it is brought indoors, the exposed surfaces will be covered with condensation and flash rusting will commence within seconds.

If one is absolutely set on blasting, and cost is no obstacle, the best solution to all of these problems is the purchase of a fully-enclosed, self-contained blast room. The Empire Abrasive Equipment Corporation of Langhorne, Pennsylvania, offers 33 different models of Standard Blast Rooms as well as custom-built rooms. The average dimensions are 2.4 m (width) by 3.0 m (length) by 2.4 m (height). All rooms feature a media recovery system built into the floor, a dust collector, protected lighting, full-width doors, ventilation system and air conditioned operator's hood. This system is prohibitively expensive for most museum budgets (about $80,000 to $100,000 including installation). It is only worth considering if one is planning on doing a great deal of blasting in the future.

For most museums, the expense and inconvenience of even a portable blasting pot system make abrasive blasting an unappealing proposition. Moreover, in any form, blasting has its limitations. For while it is good for cleaning large, simple objects, it is much less effective in removing rust from barely accessible surface areas like deep recesses, cracks and crevices which catch and retain the abrasive particles, forming a shield against further blast action. Unless they are completely removed, these lodged particles will later interfere with painting, slowly trickling out with each movement of the artifact. Movable assemblies which can not be disassembled, such as sprocket chains and various hinged parts, will be almost impossible to clean after blasting. The grit which remains will eventually be coated with oil or grease and it will act as an internal abrasive in the assembly for many years.

The alternative to mechanical rust removal is the use of chemical methods.

Chemical Rust Removal

In conservation work, the commonly-used chemicals can be classed into three groups: *solvents, alkalies* and *acids*. In terms of rust removal, solvents can be eliminated from the start as being totally ineffective. Alkalies are largely ineffective in removing rust as well, except in an electrolytic bath, which is too expensive for the treatment of large objects, or in a molten salt bath ($NaOH$ at 525^oC), which requires very elaborate safety equipment and very high heating costs.

This leaves acids as the only viable chemical treatment for rust removal. Acids have been widely used for rust removal for much of the twentieth century, generally in the form of a 15% (volume concentrated acid/volume water) aqueous pickling solution for immersion treatments. Pickling is fast, effective, inexpensive and non-labour-intensive. The process is simple: the rusted object is totally immersed in a bath of acid which is usually heated and subjected to some form of agitation and aeration. Immersion is followed by thorough rinsing and passivation. The acid is prevented from destroying the base metal by the inclusion of one or more organic inhibitors, or more precisely, *restrainers*, which slow down the reaction of the acid with the exposed metal while the neighbouring rust is removed.

In industrial applications, acid pickling is designed to be fast and inexpensive, and it is carried out with a minimal amount of human intervention, so that health and safety factors are not overriding concerns. Very aggressive inorganic acids are the most popular. They include sulphuric, hydrochloric and nitric acid. Even in low concentrations, these are much too dangerous for conservation use, which normally demands a high degree of human intervention and a very deliberate work pace.

This does not preclude the entire inorganic acid family, however. As it turns out, *phosphoric acid* is a very effective rust remover and it poses only a minor health risk. It is not used to the same extent as the other acids by industry for two sound business reasons: i) it is much more expensive to buy, which is a legitimate concern when one is dealing with hundreds of thousands of litres; and ii) it is much slower-acting, which means slower production and a corresponding loss in profits. Slowness, of course, is a relative term. Conservation treatments can tolerate hours or days where business can only allow seconds. Thus "slow" by industry standards often means that an operation takes more than a few minutes to complete. Neither the cost nor the slow reactivity of phosphoric acid are of much consequence in the context of conservation treatments. The concentrated acid (85%) sells for about $3.35/L, and one litre will yield about 6.7 L of solution when diluted to 15% in water. The slow reactivity of H_3PO_4 works to our advantage as well, in that it makes the derusting process more controllable.

Perhaps the best characteristic of phosphoric acid is that it is many times safer to use than any of the others. Phosphoric acid is commonly classified as a food additive when it is sold in bulk. It is also an important component in plant fertilizer: a metric ton of manure is said to contain 2.1 kg of H_3PO_4 (5 lbs./ton). In the food industry, it is generally obtained as a clear colourless syrup in 34 kg (approx. 25 L) polyethylene carboys. Small quantities are routinely added to soft drinks, particularly colas, presumably to add a distinct tang to the beverage. The derusting ability of the acid was at one time demonstrated in elementary school science projects by the prolonged immersion of rusty nails in a glass of cola.

The safety precautions for handling phosphoric acid are no more stringent than for most solvents. Rubber gloves, goggles and a rubber apron are recommended as precautions against splashing. If skin contact does occur, even with concentrated acid, it will only amount to a minor irritation which can be rinsed away with water. The vapours of a dilute solution at room temperature will prove irritating and harmful if inhaled deeply for extended periods, so naturally this is to be avoided. A respirator and/or fume extractor are not essential, but they are a good investment.

Phosphoric acid has other advantageous properties as well. Its etching effect on exposed metal is considered to be mild at the very worst, and this effect can be lessened even further by adding a restrainer. Bear in mind that a rust-covered surface — which is what this treatment is intended for — is already irreversibly etched by corrosion. A final advantage is that phosphoric acid leaves a grey, iron phosphate deposit on the metal surface. This is said to act as both a mild corrosion inhibitor and an excellent base for the adhesion of paint or oil due to its porosity.

As a result of its many advantageous properties, phosphoric acid has found its way into dozens of commercial products: not just the rust converters discussed earlier, but rust removers and wash primers/metal conditioners as well. Almost all of these work on the same principle. Some examples are: Motomaster (Canadian Tire) Liquid Rust Remover, which claims to eliminate sanding, scraping and wirebrushing and to leave "a protective coating while permitting paint to adhere properly." Jenolite Rust and Blue Remover and Rust Preventer Jelly is a gelatinous version of the same formula. United Chemical Company Manufacturers' Metal Prep, containing 28% phosphoric acid and 5% methanol among its ingredients, is recommended for preparing metal work for painting, as it "ensures paint adhesion and more durable finishes." Mirachem Corporation's version, called Mirachem 250 Biodegradable Rust and Scale Remover Concentrate, contains 15% phosphoric acid, while Cantol's BT- 49 Acidic Metal Conditioner contains an unspecified concentration of H_3PO_4 in n-butyl alcohol.

Industry has capitalized on the phosphate forming reaction of the acid and steel in an operation known as Footner's *Duplex Process*, which dates back to 1937. In this process, rusted steel is treated by immersion in 5% sulphuric acid at 60^oC for 15 to 20 minutes, followed by a wash-water rinse at 60^oC and finally, a dip in a 2% phosphoric acid bath containing 0.3 to 0.5% iron filings at 85^oC for 3 to 5 minutes. No rinse follows this last immersion. The heated metal dries quickly by evaporation and paint is applied while the surface is still fairly warm (Evans 1961, p. 405; Speller 1951, p. 329). Footner's process has an antecedent in a British process from 1907, the *Costlett Process*, which involved only one step: the immersion of the metal in dilute phosphoric acid with iron filings added (Speller 1951, p. 327).

The use of inhibitors in a phosphoric acid derusting solution is not as important as it is with the more aggressive acids such as sulphuric and hydrochloric acids. Little has been written on the subject specific to phosphoric acid. Butyl and isopropyl alcohol are sometimes recommended (Schreir 1979, *12*, p. 12). Dozens of organic substances can be used, as listed in Uhlig's text (Uhlig 1966, p. 910-911, Table 1), including alcohols, aldehydes, sulphides and amines. These have all been assessed in relation to H_2SO_4 solutions, but as Uhlig states, "In general, for steel the same inhibitors are effective, although not to the same degree, for sulphuric, hydrochloric or for phosphoric acids" (Uhlig 1966, p. 914).

It should be noted at this point that while phosphoric acid pickling leaves something of a phosphate coating, it is not in the same league as "phosphating" (or "phosphatizing"), a process developed by the Parker Rust-Proofing Co. of Detroit in the early 1920's, and still the mainstay of metal preparation in modern industry. Parker's trade-names include Parkerizing and Bonderizing. Other patented processes along the same lines have included Coslettizing and Walterising. Phosphating involves the use of zinc, manganese or iron salts in a dilute phosphoric acid bath at an elevated temperature. The goal is to produce an adherent, corrosion-resistant coating on steel which is already absolutely clean and rust-free; post-treatment usually involves a rinse or dip in chromic acid. Phosphating is a very involved process, requiring strict control of solution temperature, concentration, and pH as well as other variables, most of them still closely-guarded trade secrets (Speller 1951, p. 327-328). Many of the companies selling these compounds will provide the services of a chemist in setting up and monitoring the process. For the moment it is too complicated for our purposes, and the scale of our operations is too small to be of any interest to the business world.

One commercial product on the market, called Oxi Solv, claims to deposit a zinc phosphate coating on metal which it derusts in an undiluted immersion process. The solution contains zinc phosphate and phosphoric acid. One can easily be misled by the term "non-corrosive" among the "environmentally friendly" nomenclature of the label. It does not say "non-acidic," which it certainly is, with a pH of 1.0. Oxi Solv works fairly well as a deruster, and it does indeed leave a whitish-grey coating at room temperature. The solution is to be used at full strength and it is marginally reusable. At approximately \$10.00 a litre, it is of use only for very small operations.

A simple derusting operation with H_3PO_4 at room temperature has been used for various restoration projects at the Saskatchewan Western Development Museum since the autumn of 1988. An 8% aqueous solution is used rather than the standard strength pickling bath (15%) for the sake of economy and to lessen even further any chances of etching. A small amount of sodium dodecyl sulphate is added as a wetting agent. The size of equipment and the amount of solution required are determined by the components of greatest volume which have to be treated. In one instance, these were the drive wheels of a gasoline tractor, six feet in diameter and two feet in width. Because of the complex nature of these wheels (with up to 300 parts each, many of them rivetted), disassembly was not an option. Immersion required a tank capable of holding at least 2273 litres (500 gallons) of solution.

Much practical knowledge has been gained during these operations. For example, finding an existing container large enough for this scale of operation can be challenging. The best material is stainless steel, which is very expensive and difficult to modify. Many other suitable materials can be found listed in such publications as Schweitzer's *Corrosion Resistance Tables: Metals, Plastics, Nonmetallics, and Rubbers* (Schweitzer 1986).

In some cases, it may be possible to build an immersion tank from lumber lined with several layers of polyethylene sheet. A few words of advice are in order here. The lateral pressure exerted by a fluid against the bottom of the container walls increases tremendously with depth, particularly beyond the one metre range (the reason dam walls are so thick at their base), so build the structure accordingly. Also, polyethylene sheet is very easily torn or punctured by any sharp metal edges with which it comes into contact. The object should be suspended in the solution from above or placed on a stainless steel rack, the latter either suspended or resting on supports without sharp corners. In any event, one must be prepared for the possibility of leakage or a major spill.

In terms of the treatment itself, the derusting action of the acid appears to vary greatly with the depth of the solution: the deeper the solution, the slower the derusting process. A large object will be derusted in diminishing degrees from the top down. This may be related to the amount of air in the solution, since aeration has been observed to increase the effectiveness of pickling baths in industry (Speller 1951, p. 302). Presumably aeration, like agitation, removes the build-up of a passivating layer of hydrogen gas from the surface of the metal which would otherwise impede the action of the acid solution. There are two simple ways to equalize the derusting action over the entire surface of the object. One can aerate the solution by bubbling air into the bottom of the immersion tank with a small air pump, or one can invert the object in the bath when the upper areas are clean.

The aggressiveness of the acid, incidentally, is most intense where the air concentration is the highest, that is, at the actual interface of the surface of the liquid and the air. It is important to avoid partial immersion of an object in the bath, as severe pitting may occur at the acid-air boundary.

The effect of the dilute acid solution on traces of original paint is quite fascinating. Like hot caustic solutions, phosphoric acid can serve as a type of investigative process during the derusting operation. Unlike alkaline solutions, however, acid leaves any paint more or less untouched while it reduces the surrounding rust. The result of this is that traces of paint on a rusted artifact — and here, "traces" means almost microscopic and previously unsuspected flecks — can be revealed and dramatically highlighted for documentation purposes. The brown areas of rust will change to a medium grey finish which will provide a striking contrast to paint traces. This will not work, however, if one uses as hot caustic bath for cleaning before acid derusting commences, since the hot caustic solution will dissolve most paints. The acid bath should not be agitated or aerated in this case, as too much motion may loosen and dislodge the paint. If the treatment is carefully monitored, the results can be well worth the effort. Prolonged immersion will eventually soften and loosen the paint, causing it to fall off. After photographing the paint, one has a choice of finishing the treatment by re-immersing the artifact in either the acid or caustic solution or preserving the partially cleaned piece for study purposes. This may consist of a water rinse followed by air drying and the application of microcrystalline wax or an acrylic lacquer like Acryloid B-72.

Once an object has been derusted by a phosphoric acid immersion treatment, it should be thoroughly rinsed to remove any residues of solvents, loosened rust and excess acid. A cold pressure-wash followed by a rinse or immersion in demineralized water is an effective method. Unfortunately, a minor problem arises here: after the final rinse, the cleaned metal is susceptible to light flash-rusting unless it is passivated in some fashion. This is usually accomplished with an acidulated rinse of 2% phosphoric acid in water heated to 85° C (see Footner's process above). An alternative is 2% phosphoric acid in a dehydrating vehicle, like isopropanol, at room temperature. Because the Footner approach again raises the problem of heating costs, a dehydrating solution may be preferable. A commercial version of a passivating solution is Du Pont's 244S Kwik-Wipe Metal Stabilizer for Steel, "designed to stabilize freshly sanded steel." According to the product's MSDS, it contains (by weight) 80-90% isopropanol and 0-1% phosphoric acid. Blue colouring also appears to be an ingredient. The directions for use instruct one to apply the liquid liberally with a clean cloth and allow it to dry at least 5 minutes before priming. The label cautions that Kwik-Wipe is *not* designed to remove visible rust.

At $14.08/L, Kwik-Wipe is much too expensive to consider for immersion passivating, especially since the solution will gradually be contaminated with water from the recently rinsed metal components, to the point where it is no longer effective. Spraying the solution onto the pieces with a portable hand-pumped spray tank is an alternative method. It will result in a complete loss of solution by evaporation, but a relatively small amount will be used overall. The cost can be reduced further by making the solution in-house, with a small quantity (1-2%) of concentrated phosphoric acid in isopropanol (99% v/w). This system has been used at the Western Development Museum with very satisfactory results. A respirator, goggles and maximum ventilation are essential safety precautions.

The passivating rinse does not have to follow derusting right away, provided the water rinse stage which normally follows pickling is omitted. Objects taken out of the acid bath and allowed to air dry without a water rinse do not flash rust in a relatively dry environment for several weeks, or even months in some cases. Thus the rinsing and passivating stages can be delayed almost indefinitely, *e.g.*, until the proper equipment and supplies are ready. This seems to indicate that the thin iron phosphate deposit on the metal affords some protection against corrosion, but not enough to withstand a thorough water rinse followed by air drying. It should be pointed out that no phosphate coating is meant to be exposed directly to the elements, even for a short period. Rather, it is intended to serve as a corrosion-inhibiting base for paints or lubricating oil.

The passivated, dried components should be primed, oiled or waxed within 48 hours to lessen the chance of rusting. All cleaned parts should be handled with gloves before being coated to avoid contamination.

Conclusion

The removal of dirt, grease and rust from large metal artifacts is invariably an unpleasant task. As such, it will never hold much appeal for conservators, particularly those who are intimidated by machinery and the seemingly rash practices of restoration crews. On the other hand, the treatment of these artifacts requires and merits the careful and methodical approach for which conservation is noted.

The materials and techniques discussed here can be utilized creatively in any number of combinations. For example, the sequence of operations can include alkaline cleaning followed by plastic media blasting and finish with phosphoric acid-isopropanol passivation. Alternatively, one might begin with pressure-washing followed by emulsion immersion cleaning and acid conversion. There is no virtue in limiting oneself to a narrow, dogmatic approach. Every artifact is unique in its own way, and the conservator now has a diverse repertoire of treatments from which to choose. Hopefully this paper will encourage conservators to play a greater role in the preservation of our long-neglected industrial heritage.

Materials

(All listed prices are approximations in Canadian funds. Taxes are not included.)

All Natural Cleaner Degreaser® (Product No. 3599): distributed by Rust-Oleum (Canada) Limited, 590 Supertest Road, Downsview, Ontario, M3J 2M5. Available in one U.S. quart (.95 L) containers for $18.82

Angle Sander, Model"A" CP-869: Chicago Pneumatic, Auto-Tool Division, Nashville, Tennessee 37209. Approx. $307.00

Blast rooms & blast pots: Empire Abrasive Equipment Corporation, 2101 West Cabot Blvd., Langhorne, Pennsylvania, 19047

Citra Solve, organic degreaser/cleaner: available from United Chemical Company, a division of Sherritt Gordon Ltd., 6424-42nd St. S.E., Calgary, Alberta. T2C 2V1. Available in cases of four 4 L containers @ $59.37/case ($3.71/L)

Dynadet®, hot tank cleaning compound: manufactured by Oakite Products of Canada, Ltd. 115 East Drive, Bramalea, Ontario, L6T 1B7. Available in 227 kg or 91 kg barrels @ $5.25/kg.

Fast Orange Citrus Hand Cleaner®: manufactured by Loctite

Canada Inc., 270 Britannia Road East, Mississauga, Ontario, L4Z 1S6. Available in 225 ml, 400 ml and 3.5 L containers. Prices vary from \$6.00 to \$12.00/L

Fisherbrand® Tongue Depressors (Cat. No. 01-346): Fisher Scientific, 112 Colonnade Road, Nepean, Ontario, K2E 7L6. Available by the case (12 boxes of 100) for \$74.86

Grease Off®, heavy duty solvent emulsion cleaner: Cantol Ltd. Available in 27 L pails @ \$4.95/L

Hotsy® pressure washer: manufactured by The Hotsy Corporation, 21 Inverness Way East, Englewood, Colorado.

Isopropanol (99%): Available from most chemical supply companies. A major supplier is Harcros Chemicals Canada Inc, 777 Supertest Road, Downsview, Ontario, M3J 2M5. Available in 18 kg (approx. 28 L) pails @ \$1.25/L

K.E.W.® pressure washer: imported and distributed by Acton Agency, 2409 Canoe Ave., Coquitlam, B.C., V3K 6A9

244S Kwik-Wipe®, metal stabilizer for steel: manufactured by Du Pont Canada Inc., Finishes Division, Mississauga, Ontario. Available in one U.S. quart (.946 L) containers for \$14.08

L.& A.® pressure washer: manufactured by L. & A. Products, Inc., 2112 Old Highway 8, St. Paul, Minnesota, 55112.

Martex®, hot soak tank cleaner: manufactured by Cantol Ltd. Available in quantities of 90 kg and 250 kg @ \$4.50/kg

Metal Prep, metal conditioner: United Chemical Co. Available in 20 L pails @ \$1.68/L

Mirachem 100®, emulsion cleaner-degreaser: Mirachem Corporation, 2107 East Fifth St., Tempe, Arizona. Canadian Agent: CPM International, #300, 5241 Calgary Trail, Edmonton, Alberta., T6H 5G8. Available in one U.S. gallon (3.79 L) containers for \$28.15, or five U.S. gallon containers for \$122.95 (\$6.48/L)

Mirachem 250®, rust and scale remover: Mirachem Corp. Available in one U.S. gallon containers for \$30.10 or five gallons for \$135.40

Motomaster (Canadian Tire) Liquid Rust Remover (No. 47-7923-2): available from Canadian Tire Corporation, Ltd., Toronto, Ontario. M4P 2V8

Jenolite Rust & Blue Remover and Rust Preventer Jelly: manufactured by Jenolite, England for High-Tech Specialty Lubricants, 815 Kipling Ave.,Toronto, Ontario. M8Z 5G8

Oxi Solv®, rust remover plus phosphate: distributed by Oxi Solv Chemicals Inc., 31018 Peardonville Rd., Abbotsford, B.C., V2S 5W6. Available in 600 ml, 3.78 L and 20 L containers, at approx. \$10.50/L

Phosphoric acid (85%): Available in Food Grade purity from most chemical supply companies. Available in 34 kg (approx. 25 L) carboys @ \$3.35/L

Rust Reformer®, rust converter: Rust-Oleum (Canada) Ltd. Available in one U.S. gallon (3.79 L) containers for \$75.60 (\$19.89/L)

Stop Rust!®, rust converter: Cantol Ltd. Available in 12 L containers @ \$21.66/L

Tech 736®, heavy duty multi-purpose cleaner and degreaser: Cantol Ltd., 199 Steelcase Road West, Markham, Ontario, L3R 2M4. Available in 27 L pails @ \$6.70/L

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