Hydrochloric acid, better known as muriatic acid, has been used in the metal cleaning industry for years. Inhibited hydrochloric acid is used as a metal descaler prior to galvanizing. This material is also commonly used as a masonry cleaner and as an etching agent for concrete. It can, however, pose health and safety risks as well as environmental risks.

Using citric acid instead of muriatic acid to prepare concrete substrates for coating and lining applications offers a safe, effective, and environmentally friendly alternative. The process, however, is not widely used. This article discusses the advantages and limitations of using citric acid and provides some sample production rates of citric acid cleaning versus mechanical and abrasive blasting methods used to prepare concrete for coating applications.

The Chemistry of Citric Acid

Some have referred to the citric acid cleaning process as cleaning with orange juice. However, synthetically produced citric acid is an industrial strength chemical compound called 2-hydroxy-1,2,3 propanetricarboxylic acid (Fig. 1). It is a hydroxy tribasic organic acid.

Though not commonly known, the organic acid cleaning process is older than cleaning with mineral acids such as hydrochloric acid.
as muriatic acid. In fact, the term “pickling” of steel was derived from the early use of acetic acid (vinegar) for removing rust from steel.1

Food grade citric acid is produced as a primary food additive. Most soft drinks contain citric acid, which gives the drink the fruit acid “bite.” Citric acid is found in most living organisms and at low levels in nature.2 In soil, citrate is a chelating agent that promotes the necessary absorption of metals through the root system of plants.

Laboratory studies were performed to evaluate the biodegradability (measured in Swisher columns) of citric acid.2 In these tests, 90% of the citric acid was degraded, even in concentrations of 3,300 parts per million (ppm [0.03%]). The studies also demonstrated that both citrates and metal chelates degraded in short time periods under laboratory conditions (in 24 hours) and in the natural environment.

Concrete Chemistry
Concrete is made by combining cement, sand, gravel, and water.3 Cement is primarily made of finely ground lime (CaO), silicates, and silica (SiO2). Water promotes several chemical reactions (hydration and hydrolysis) that occur with the silicates to produce an initial set. The actual curing process, however, that converts the lime and calcium silicate to calcium hydroxide (Ca(OH)2) takes place over a longer time period. Calcium carbonate (CaCO3) is also formed from reactions with atmospheric carbon dioxide (CO2). The net result is a solid alkaline colloidal matrix.

Because of the chemical nature of citric acid, it has the ability to chemically react with the alkaline components of the concrete matrix to form calcium citrate. The chemical reaction of citric acid with the top layer of calcium hydroxide creates the etching of the concrete surface. The degree of etch is controlled by the strength of the citric acid, dwell time, agitation, and temperature of the substrate. As long as there is excess acid present, the calcium citrate will remain soluble. As the acid is consumed or neutralized, the solubility decreases, and the calcium citrate precipitates out as a solid.

Adhesion Tests after Using Citric Acid
Table 1 lists adhesion test results based on two different test applications of citric acid compared to other mechanical and abrasive blasting techniques. Pull-off strengths were tested according to ASTM D4541 (Standard Test Method for Pull-off Strength of Coatings Using Portable Adhesion Testers). Fixed-alignment pull-off adhesion testers were used. The coating tested was an epoxy. As can be seen from the test results, citric acid cleaning provides an acceptable surface over which to apply a high-performance coating or lining system.
A recommended cleaning procedure based on an actual procedure using citric acid in the field can be found in the box.

Production Rate Demonstrations

Two adjacent concrete floor surfaces in a plant were selected to demonstrate the effectiveness and cleaning rates of citric acid cleaning versus automatic blast cleaning. Each surface was approximately 200 sq ft (18 sq m) and had vertical surfaces to simulate adjacent walls or pedestals.

The first area was prepared using an automatic, self-propelled, reclaimable wheel blast machine (Fig. 2). The unit prepared an area 20 in. (50 cm) wide. The machine requires a 480-volt, three-phase electrical power source. For this test, steel shot was selected. Alternative abrasives or mixes may also be used. The machine was equipped with a remote dust collector. The dust collector can be as much as 100 ft (30 m) away from the blast head. Cleaning of this area was done by using power tools. In this test, approximately 10 lb (5 kg) of shot was used. The cleaning rate was determined to be 375 sq ft (34 sq m) per hour (not including the hand cleaned area along the edge, adjacent to the wall) using a two-worker crew (~190 sq ft [17 sq m] per worker-hour). The substrate was then suitable for coating.

The second test area was cleaned using a citric acid solution at 25% by weight in water. To keep the substrate wet during the acid cleaning operation, enough solution was prepared to cover the substrate to a thickness of 1¼8 in. (125 mils). Remembering that 1 gal. (3.8 L) of liquid will cover 1,604 sq ft (144 sq m) at 1 mil (25 micrometers) in thickness, the amount of solution can be calculated as follows.

\[
200 \text{ ft}^2 \text{ of surface area} \div (1,604 \text{ mil ft}^2/\text{gal.} \div 125 \text{ mils}) = 15 \text{ gal.}
\]

weight = 15 gal. of water x 8.34 lb/gal.

= 15 x 8.34

= 125 lb

A 25% solution of citric acid would therefore require 125 lb x 0.25 = 31.25 lb of dry acetic acid or roughly 30 lb. Since precision solutions are not required, all measurements are acceptable to the nearest pound (kg) or gallon (L).

The solution remained on the surface for 20 minutes, the required minimum cleaning time. During this step, two workers used stiff bristle brooms to constantly agitate the solution. After 20 minutes, the pH of the solution was determined using litmus paper. Any excess acid can be neutralized by using sodium hydroxide (NaOH), trisodium phosphate, or potash (potassium carbonate). For this test, sodium hydroxide was used, but potash is much safer because it is not as aggressive as sodium hydroxide. Once the pH of the sodium hydroxide was determined to be between 6 and 9 (to ensure that the residual acid is neutralized), the solution was rinsed from the concrete using large amounts of fresh water (Fig. 3). The spent solution was disposed of in the drainage system, where it was processed through the plant’s water treatment facility. The entire process took approximately 45 minutes. The cleaning rate was determined to be 265 sq ft (24 sq m) per hour, using a two-worker crew (~130 sq ft [12 sq m] per worker-hour).

The entire surface including the area adjacent to the walls was cleaned. No supplemental surface preparation

### Recommended Citric Acid Cleaning Procedure

1. Check for concrete curing compounds. If present, select an alternate cleaning procedure.
2. Always use proper personal safety equipment (rubber boots, rubber apron, rubber gloves, and an acid respirator).
3. Clean the concrete using a solution of trisodium phosphate or detergent solution to remove heavy dirt, oil, and grease. Flush the surface with water.
4. Prepare a 20 to 25% solution by weight of citric acid. Some manufacturers sell 50% solutions of an industrial grade acid that is less expensive.
5. Cover the substrate to a depth of approximately 1/8 in. (125 mils).
6. Continuously agitate the solution using stiff bristle brooms.
7. After 20 minutes, check the pH of the solution. If the pH is less than 6, add sufficient caustic to bring the pH to between 6 and 9.
8. Rinse the surface using large quantities of fresh water. Do not allow the calcium citrate to dry on the surface. This will result in difficulty when removing and possible recleaning.
9. Allow the surface to dry and apply the specified coating material.
10. Dispose of spent solution in accordance with local regulations.
was required (because the acid cleaning process does not leave any untreated areas), and the surface was acceptable for coating application.

If the spent citric acid cleaning solution cannot be disposed of in a drainage system and processed through the normal water treatment process, the solution can be treated as recommended by the supplier of the citric acid prior to disposal in a non-toxic waste disposal area.

**Benefits and Limitations to Using Citric Acid**

The advantages of using citric acid to prepare concrete surfaces for coating and lining applications are listed below.

- Citric acid is safer to use than muriatic acid, which is the standard of the industry.
- Citric acid is biodegradable (includes disposal of cleaning residue). Abrasive blasting debris generally is not.
- An acceptable substrate is produced for coating application—a medium to coarse finish as required by ASTM D4260 (Standard Practice for Acid Etching Concrete).
- No dust is generated by citric acid cleaning compared to abrasive blasting or power tool cleaning.
- Less personal protective equipment (rubber boots, rubber apron, rubber gloves, and an acid respirator) is required compared to abrasive blasting.
- Protection requirements for equipment in the area are lower when citric acid cleaning is used compared to abrasive blasting.
- Citric acid cleans hard-to-reach areas such as those close to walls and under equipment.

Some disadvantages of using citric acid are listed below.

- Cleaning with citric acid is an unfamiliar process so training is required for workers to perform it properly.
- The material cost of citric acid is more expensive than muriatic acid.
- Some locations (job sites) may require collection and disposal of the spent citric acid solution at a municipal waste site.
- Citric acid cleaning requires large volumes of water to remove the insoluble calcium citrate compared to muriatic acid.
- Citric acid has a slower reaction time than muriatic acid—3 to 5 minutes for muriatic versus 20 minutes for citric acid at 75 F (24 C).
- The substrate must be completely dry before a coating can be applied.
- Citric acid cleaning is not suitable for walls or overhead substrates.
- It cannot be used to remove concrete curing membranes.
- Surface temperature must be above 60 F (16 C)—higher temperatures result in faster cleaning rates.
- Cleaning rates per person hour are much less than for a wheel blast machine.

**Conclusion**

Citric acid cleaning of horizontal concrete surfaces is an effective and safe procedure.

For example, it has been used as an effective cleaning preparation technique on concrete floors for coating in critical areas of nuclear power plants. The South Texas Nuclear Generating Station, Comanche Peak, and Grand Gulf have all used citric acid etching as the primary floor preparation technique. Increased use and experience should further increase the effectiveness, efficiency, and safety of the citric acid cleaning process.

The effectiveness of citric acid as a concrete cleaning and etching material can be increased by formulating proprietary solutions specifically designed to etch concrete. One such modification in effectiveness could be the addition of an acid-compatible wetting agent to improve wetting of the concrete. Another could be the addition of a buffering agent such as ammonium hydroxide or triethanol amine. Foaming agents could be added to increase the effectiveness on vertical surfaces. In addition, the cost of commercially available standard solutions of citric acid (50% by weight) may decrease.

**References**

2. Pfizer Chemicals Division Information Sheet No. 2030, Environmental Impact of Citrates.
4. ASTM D4260, Standard Practice for Acid Etching Concrete (West Conshohocken, PA: ASTM).

**Also Consulted**

SSPC-SP 13/NACE No. 6, Surface Preparation of Concrete (Pittsburgh, PA: SSPC; Houston, TX: NACE International).

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