To Know Cleaning You Have to Know Soil—Especially Particles

By John B. Durkee, Consultant in Metal and Critical Cleaning

The title is one of my favorite (at least professionally) expressions. And it makes sense: it is, after all, why every country's military operation has an intelligence department—to know what the enemy is capable of and what they are likely to do. If one has to know where the enemy is in order to shoot at them, one may have to know what the soil is and where it is located in order to remove it.

In 2007, this column will focus on soils—greases, oils, particles, and others—and what to do about them. That soils can be so broadly characterized, chemically and physically, is what makes surface cleaning so challenging. Soils are a gift to cleaning consultants; without them, we would be out of a job!

ABOUT SOIL

More often than not, the soil we have to remove is material we added to enable something we wanted to happen. It can be a left-over amount—an excess beyond that which was needed. It can be something that was formed in the operation we enabled.

Examples are:
• Particles from a deliberate machining or polishing operation;
• and particles from wear between surfaces.

And these soils, which often are carriers of particles:
• Metalworking or heat-transfer fluids used in finishing operations;
• grease used for lubrication, either fluid or solid;
• grease applied for long-term protection;
• lubricating oils added to avoid wear;
• rust-preventive fluids;
• acid brightening chemicals;
• and spent plating solutions, etc.

IGNORANCE CAN BE BLISS

Very often, a user doesn’t have to know how to clean some unknown material from parts. Users with a TCE (trichloroethylene) degreaser probably won’t spend time doing chemical analysis of an unexpected grease found on purchased materials; they’ll just immerse a basket of the parts in boiling TCE.

The same can be true of particles on metal surfaces. A user with an aqueous cleaning bath having ultrasonic transducers probably doesn’t know or care about the chemical identity of tramp particles, how they’re bonded to the metal, or even where they are located on the surface. They’ll just immerse a basket of the parts in the water bath and turn on the ultrasonic power.

This column is about those circumstances when neither of those methods of treatments works—probably because the particle isn’t what it was or where it was expected.

PARTICLE THEORY

For a consultant, and a user, removal of particles presents the most difficult problem.

Ultrasonic (20,000 to 250,000 cycles/sec or 20 kHz to 250 kHz)—generated pressure waves are omnidirectional. They reach, generally, in all directions. A user doesn’t need a GPS to locate a particle so he can aim pressure waves at it.

But this information-free approach probably won’t succeed if particles are small. Because of their size, laws of adhesion dictate that they will be more tightly bonded to metal surfaces. Further, if these particles (submicron) are shorter than the fluid boundary layer associated with the pressure waves is tall, the waves will wash over them, leaving the particles untouched by pressure force. The limit of effectiveness is somewhere around 1 to 5 microns.

The boundary layer problem is lessened with pressure waves of higher frequency (250,000 to 1,000,000 cycles/sec). Unfortunately, these waves (called megasonic) are unidirectional. Users have to aim their transducers at the particle-laden surface in order to impact these articles with pressure waves. Megasonic waves aren’t really useful below levels around ½ to 1 micron—even if the particle’s location is known.

The problem with particles gets worse and never gets better. When particles with nano-sized dimensions must be removed (or moved), other technology that requires additional specific information must be involved. So it’s worthwhile to know how to manage and classify small particles.

PARTICLE CLASSIFICATION SCHEMES

For those trying to remove particles from surfaces, there are several types of information that are significant:
• Hardness: If the cleaning and process liquids do contain particles, their composition matters. If they’re made of talc, the surface won’t be worn. If they’re made of diamond from a polishing wheel, it’s the opposite case. (Particle hardness is characterized by the Mohs relative scale, as shown in Table I.)
• **Angularity.** Particles with low angularity, such as spheres, were probably formed intact, and their impact with finished surfaces probably doesn’t change the finish level. Particles with high angularity possess sharp or acute angles between facets, were probably formed by inter-particle collisions, and their impact does wear surfaces.

In other words, it is probably less important, in terms of surface protection, to remove round particles than angular particles. See Figure 1.

Particle composition and angularity can be jointly considered. At one extreme, spherical plastic particles, of any size and amount, may be treated with less urgency. At the other extreme, quartz particles probably compel immediate attention.

My experience is that the smallest particles—the most difficult to remove—are the most angular because they are broken fragments of larger particles, and more hard because their surface has been mechanically worked as they were formed.

• **Size and size distribution:** This information is needed to design a particle removal system. Unless process materials change, it probably needs measurement only once. So, contract this work with an outside lab.

Representative data are shown in Table II, and plotted on log-probability graph paper in Figure 2.

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**Table I: Mohs Scale of Relative Particle Hardness**

<table>
<thead>
<tr>
<th>Mohs Scale Value</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Talc</td>
</tr>
<tr>
<td>2</td>
<td>Gypsum</td>
</tr>
<tr>
<td>3</td>
<td>Calcite</td>
</tr>
<tr>
<td>4</td>
<td>Fluorite</td>
</tr>
<tr>
<td>5</td>
<td>Apatite</td>
</tr>
<tr>
<td>6</td>
<td>Feldspar</td>
</tr>
<tr>
<td>7</td>
<td>Quartz</td>
</tr>
<tr>
<td>8</td>
<td>Topaz</td>
</tr>
<tr>
<td>9</td>
<td>Corundum</td>
</tr>
<tr>
<td>10</td>
<td>Diamond</td>
</tr>
</tbody>
</table>

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**Table II: Typical Particle Size Data**

<table>
<thead>
<tr>
<th>Particle Size Range Microns</th>
<th>Min Size Micron</th>
<th>Max Size Micron</th>
<th>Particle Concentration grams/cm³</th>
<th>% of Mass in Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 to 2</td>
<td>0</td>
<td>2</td>
<td>14.5</td>
<td>0.5</td>
</tr>
<tr>
<td>2 to 4</td>
<td>2</td>
<td>4</td>
<td>7.3</td>
<td>7.8</td>
</tr>
<tr>
<td>4 to 6</td>
<td>4</td>
<td>6</td>
<td>12.4</td>
<td>14.4</td>
</tr>
<tr>
<td>6 to 8</td>
<td>6</td>
<td>8</td>
<td>29.9</td>
<td>20.1</td>
</tr>
<tr>
<td>8 to 10</td>
<td>8</td>
<td>10</td>
<td>34.2</td>
<td>50.0</td>
</tr>
<tr>
<td>10 to 12</td>
<td>10</td>
<td>12</td>
<td>14.4</td>
<td>84.1</td>
</tr>
<tr>
<td>12 to 100</td>
<td>12</td>
<td>100</td>
<td>1.4</td>
<td>98.6</td>
</tr>
</tbody>
</table>

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It’s important to note two key parameters from the distribution plot. One is the median (50% value) of particle size. In Figure 2, the value is about 8 microns. The other is the 10 or 15% cutoff point. In Figure 2, the value is about 2 to 3 microns. That difference in size is significant (see below).

• **Amount.** Mass amount data are a component of the particle size analysis in Table II.

Distribution and amount information can also be jointly considered. It will be used to select and design the particle removal process.

**SEDIMENTATION**

This is a low-cost way of separating particles from liquid. But it’s not very practical in finishing operations—except as a first stage of particle cleanup.

It’s based on a difference of density. Heavier particles settle in a lighter liquid. Simple equations govern this behavior, plotted as Figure 3.

Particles whose size is between 50 and 100 microns will settle in one to two minutes. It can be useful to remove this size particle if the volumetric liquid throughput does not
make the settling volume too large. But it's probably not
the only treatment step.

**Filtration**
Particle removal or collection may start with filtration. But it may not end there.

In metal finishing work, particles remain on surfaces as
debri from cutting or polishing operations. As a more
finely featured surface is produced by mechanical shear
forces, the produced particles are smaller and probably
more angular.

Even worse, particles degrade on contact with surfaces. Submicron-sized particles are often made from micron-
sized particles where there has been surface wear.

If the polishing is done in a liquid carrier or heat transfer
medium, some particles will be removed from the surface.
Usually that liquid is recycled through a filter. The remain-
der defines the cleaning task.

But if the filtration equipment isn't correctly sized or
operated, the particles won't be effectively removed, the
net surface contamination will increase, and the cleaning
task worsens.

Sizing of a filter is, as is the case with most things in
life, a tradeoff between quality and quantity.

As smaller particles are removed, the capacity of the fil-

ter to hold them declines as does the volumetric through-
put, and, therefore, useful life.

Example data are plotted in Figure 4.

Note the interaction between the particle size distribu-
tion information in Figure 2 and the information about
expectation for filter performance in Figure 3. The size of
the finer particles does matter. They may not be removed.

**Sub-Micron Particles**
Note in Figure 3 that if the median particle size is below
about 1 micron, filtration performance won't be satisfac-
tory. In that situation, filtration isn't the answer, and
neither are pressure waves produced by ultrasonic trans-
ducers. Probably, pressure waves produced by megasonic
transducers aren't, either.

At least five unusual and specific ways have been used to
recover submicron particles. They all involve custom engi-
neering and details are beyond the scope of this column:

- A collector fluid: This can be an emulsion or a viscous
  fluid into which the particles are chemically or electro-
  statically attracted and then collected. More angular
  particles, with more surface area for bonding, will be
easier to collect. Naturally, this (probably unusual) fluid
becomes an additional soil for cleaning operations.

- Centrifugation: This is sedimentation with centrifugal
  force providing enhancement of particle separation from
  fluid vs. gravitational force.

  But little relief should be expected with centrifugation
  of submicron particles. Figure 5 shows that a 100X
  increase of separation force has little effect in this range
  of particle sizes. Compare to Figure 3. Centrifuges excel
  at removing large chips produced by machining opera-
tions, but not surface polishing operations.

- Electrostatic precipitation (EP): Not commonly
  used in cleaning operations, there are two versions of
  this approach. Basically, EP involves charging the parti-
cles in a liquid by moving them adjacent to an element,
which "radiates" an electrostatic charge. Particles close
to the element take on this charge. When the liquid
flows near an oppositely charged (grounding) element, the particles are attracted to it.

Obviously, this can’t be done in aqueous media. And it’s not a good idea to attempt it in cleaning solvents with a low dielectric constant such as cyclohexane or paraffins. But it has been done in formulated lubricating/cutting/grinding oils.

A clever variant on this approach is to split the fluid stream into two portions. Each then passes an oppositely charged element. When the stream is recombined, the oppositely charged particles attract and agglomerate. The larger particles can then be removed from the liquid by the means described above.

- **Bubbles.** This approach is significant to those involved with surface finishing at the nano scale. To this author, it’s still empirically and not theoretically defined. The basic idea is that pressure pulsations (not necessarily produced by pressure waves) cause collapse of gas (not vaporized liquid, not water vapor) bubbles at surface imperfections. This is how nucleate boiling is done. Only here, the surface imperfection is the particle!

  So one doesn’t generally care about the size of the particle or where it’s located. The particle is removed by the mechanical force liberated when these bubbles collapse.

  Note that this approach doesn’t collect (as does a filter) submicron particles for removal from apparatus or parts, it just removes them from a surface. There is no guarantee they won’t be redeposited!

- **Prevention.** If cleaning is required, one has to know what it is that one is cleaning, then the best way to do cleaning is to eliminate the soil (particle) before it becomes a concern. Often this is practically impossible. But also often the information above which characterizes particles provides clues as to how tiny particles are formed.

  Polishing surfaces with submicron diamond grit suspended in a mix of viscous oils and fatty acid amides or with fine alumina in a water-based suspension is certain to produce a smoother surface, and submicron debris. But if the submicron particles are found to be formed in some other manner, then prevention may be possible.

**SUMMARY**

Is it possible to make a problem appear too complicated? Absolutely! But generally, more and better information about a problem makes for a more certain solution for it. Knowledge of soils is central to solution of cleaning problems.

**REFERENCES**

2. A good example is found in U.S. Patent 5,821,175 which can be an excuse to try the new Google patent server at http://www.google.com/patents. Finding specific patent information has just gotten easier!
3. As indicated in this column, manipulating nano-sized objects will be one future aspect of metal finishing work.
5. While this measurement may be made only once, that doesn’t mean it’s done with only one sample—only one analysis.
7. If the information in Table II is produced by a filtration or sieving scheme, the mass amount will be directly known. If the size and distribution information in Table II is produced by optical means (light scattering), the mass amount can be estimated from the reported number of particles and the size and distribution information.
8. The science of wear management, including management of tiny particles, is called tribology. Those engineers and scientists practicing tribology may be involved in lubrication of engines or bearings, design of prosthetics, or design of hard disks.
9. Filter media for removal of particles of submicron size can be useful. But their service life will be short, they will be easily blinded (foiled), and their removal efficiency will be low. Removal of submicron particles with pressure waves or filter media is a challenge best avoided.
10. It is commercially possible to remove particles as small as ~0.1 micron from liquids. It’s routinely done by firms that conduct medical research, make semiconductors, work for NASA, and the like. But it’s a multiple-stage process, done in a controlled environment (cleanroom), not done with low cost, and supported by a QC lab.
11. Water transmits (conducts) electrostatic charge and allows it to dissipate. Cyclohexane does not; it holds electrostatic charge because it’s not conductive. Released charge in a weak point solvent can provide ignition to a fire.

*John Durkee is the author of the book “Management of Industrial Cleaning Technology and Processes,” published by Elsevier (ISBN 0-804-48887). He is an independent consultant specializing in metal and critical cleaning. You can contact him at 122 Ridge Road West, PO Box 847, Hunt, TX 78024; 830-238-7610; (fax) 612-677-3170; or (e-mail) jdurkee@precisioncleaning.com.*