Waste Minimization and Wastewater Treatment of Metalworking Fluids

An Overview of Filtration Technology

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An Overview of Filtration Technology

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Introduction

Years ago it was common to use machine tool coolants for a short period of time then dispose of them. This did not require any elaborate means of chip removal since the coolant was not used for more than a week. As the cost of coolants increased, it became beneficial to remove the contaminants and prolong the use of the fluid. Recently, the cost of disposal and the environmental concerns have increased, so frequent disposal is no longer an economical option for even those who use small amounts of fluid. The purpose of the following discussion is to acquaint the reader with the various types of equipment available for particle removal from metalworking fluids. A brief discussion of the engineering required to design a unit that will adequately remove chips from a system will follow. The last section describes maintenance practices that should be followed to properly maintain a system once it has been installed.

The term filtration often refers to the process performed by any equipment used for the removal of solid contaminant from metalworking fluids. This usage is incorrect; filtration is the process of filtering, which differs from separation. Those devices involving separation remove the particles by virtue of their physical characteristics, for example, differences in their specific gravity. Filtration requires the use of a barrier to remove particles from the path of coolant flow. Figure 1 lists examples of both types of particle removal devices.

No discussion of filtration would be complete without a brief examination of most types of particle removal equipment. Before examining these different types, it is important to understand the difference between separation and filtration, and other terms associated with filtration.

Separation - removes the particles from the fluid using a characteristic of the materials, i.e. density or magnetism. Separators randomly remove particles. A certain size of particle removal cannot be guaranteed.

Filtration - removes particles by passing coolant through a physical barrier (septum). Filtration will remove all particles of a certain size. The filters may be rated by either an absolute or nominal scale.

Absolute - all particles of the size listed will be removed. For example, a filter with a Micron Rating of 50 would remove all particles 50 μm or greater.

Nominal - an average of the particle sizes remaining in the fluid under good operating conditions. For example, a filter with a Micron Rating of 50 would remove most particles greater than, and some particles less than 50 μm, but the average size of the particles remaining in the fluid would be 50 μm.

Micron - non-technical term used for micrometer (μm), which is the scientific unit of measurement for 0.001 millimeter (mm). Figure 2 shows the measurement in μm of known items.

Examination of the equipment required for particle removal will begin with the simplest types of equipment and progress to the more complex. This will be done by first examining separation equipment, followed by an examination of filtration equipment. This discussion will be restricted to equipment used to remove particulate from metalworking systems and will not describe any other forms of filtration. Throughout this discussion, the term "machine" will be used to refer to any type of machining or grinding center.

Separation Equipment

The simplest systems involve the use of reservoirs, or sump tanks that hold the coolant, allowing some particle settling before the coolant is returned to the machine. These sump
<table>
<thead>
<tr>
<th>Filtration</th>
<th>Coolant</th>
<th>Micrometer (um)</th>
<th>Particles (ave. size)</th>
<th>Miscellaneous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Controlled settling</td>
<td></td>
<td>1000</td>
<td></td>
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<tr>
<td></td>
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<td>800</td>
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<td>400</td>
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<tr>
<td></td>
<td></td>
<td>200</td>
<td>*Sewing needle diameter</td>
<td>Beach Sand</td>
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<tr>
<td></td>
<td></td>
<td>100</td>
<td>Machining</td>
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<tr>
<td>Magnetic Cyclone</td>
<td></td>
<td>80</td>
<td>*Razor blade thickness</td>
<td>Drizzle</td>
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<td>60</td>
<td></td>
<td>Mist</td>
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<td></td>
<td></td>
<td>40</td>
<td>*Human hair diameter</td>
<td>White light microscopy</td>
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<td></td>
<td></td>
<td>20</td>
<td>*Smallest visible particle</td>
<td>Pollens</td>
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<td></td>
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<td>10</td>
<td>Grindinng</td>
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<tr>
<td>Filters:</td>
<td></td>
<td>8</td>
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<tr>
<td>Wedge-wire</td>
<td></td>
<td>6</td>
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<tr>
<td>Rolled media</td>
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<td>Filter aid</td>
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<td>2</td>
<td>Glass-Grinding</td>
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<td>Centrifuge Cartridge</td>
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<td></td>
<td></td>
<td>0.8</td>
<td></td>
<td>Red blood cell</td>
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<td></td>
<td></td>
<td>0.6</td>
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<td>Yeasts &amp; Fungi</td>
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<td>True Solution</td>
<td></td>
<td>0.2</td>
<td>Precipitates &amp; Slum</td>
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<td></td>
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<td>0.1</td>
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<td>0.08</td>
<td>Virus</td>
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<td>0.04</td>
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Figure 2. Relative size of particles generated in metalworking processes. When examining these with a light microscope the micrometer (um) scale is used. This figure shows the relative sizes of the particles, emulsified oil droplets and areas where various particle removing equipment is effective. The sizes of various known biological objects are included as a comparison to the particle sizes (5).
Waste Minimization and Wastewater Treatment

Chapter 3

tanks generally have no automatic method of removing the chips from the tank, and they must be shovelled out. Chip removal from the tank may include a chip collecting basket that can be lifted from the tank. There are usually some chips that bypass the basket, remaining in the tank to be shovelled out. Chip removal from a poorly designed system may require that the fluid be drained from the tank and the machine shut down before the chips can be removed. The cost in lost production, whether this is due to an employee removing chips instead of making parts or shutting down the machine, dictates that an improved system be used.

One improvement on this simple sump tank is the addition of the drag chain which automates the chip removal process. The sump tank with a drag chain for chip removal is called a drag tank. This eliminates shutting down production for chip removal since the drag chain will continuously remove the chips. Adding the chain allows the tank size to increase, which enables the tank to accommodate multiple machines. Drag tanks should be constructed of steel to allow for coolant control, as components from concrete may leach into the fluid and microorganism growth can be uncontrollable. The chip drag can only remove particles that fall to the bottom. To enhance the effectiveness of a drag chain unit enhancement of settling is necessary.

An improvement to a drag tank is the addition of baffles or weirs which reduce turbulence in the tank and allow the particles to settle out. This type of system, sometimes called a separator, uses the process called controlled settling. Particles that should settle and the size of the tank needed to allow this settling can be predicted. The baffles and weirs in these units enhance particle settling, allowing two changes to the design. The first could be a reduction in tank size, compared to the drag tank, since the time required for the coolant to remain in the tank is shortened. Another change could be an increase in the number of machines supplied by one separation unit. An example of a separator is shown in Figure 3.

A separator with baffles and weirs does have some drawbacks. It requires a physical difference in the density of materials to separate the contaminant from the coolant; materials that have greater differences in density will work better in this type of system. The time required for particles greater than 15 μm to settle is a minimum of seven to ten minutes in the best systems. Removal of particles less than 15 μm is difficult with most metals because other contaminants, such as air bubbles or oil droplets, will make these chips more buoyant. The tank size can sometimes be prohibitive, since the size of the tank must increase to improve settling of smaller particles. While the baffles and weirs aid in this settling, it is still dependent on the time the coolant remains in the tank. The tank size will increase to allow the coolant to remain in it longer. Regardless of these improvements, it is still possible that particles of all sizes will remain in the coolant and large particles could still plug the line to the machine.

The most common problem with this type of equipment is that the flow through the unit is greater than the capacity for which it was designed, so the particles do not have time to settle. Also, over a period of time, coolant changes occur which may inhibit particle settling. Settling can be affected by contaminating chemicals, some of which destroy the surface tension of the coolant, while other contaminants coat the chips, making them buoyant.

Other methods of separation have been applied to coolant filtration. Most of these units require the use of a drag tank for removal of the majority of large contaminant and any fines that are collected in the device. These devices include hydrocyclones, centrifuges, magnetic separators and air flotation units.

A cyclone is a device which uses induced gravity to separate materials with a greater density from materials with a lesser density. This process was originally developed for gas/solid separation, but now has been applied to liquid/solid separation. Hydrocyclones use the velocity of the coolant as it enters the unit to produce a vortex which forces metal particles to the outer edge of the unit, while clean fluid moves towards the center of the unit. Figure 4 shows the coolant flow through a hydrocyclone. The large, dense particles are removed from the clean fluid, but those particles of equal or lesser density remain suspended.

In a system utilizing a hydrocyclone, coolant from the machine returns to a reservoir, typically a drag tank, where large particles can be removed. A pump in the reservoir sends the coolant through a nozzle tangentially aligned with the cylindrical upper portion of the cyclone. The nozzle arrangement imparts a centrifugal motion to the liquid creating a vortex. The vortex causes the particles to move toward the outer edge of the cyclone.

Figure 3 Schematic of a controlled settling separation unit. The baffles and weirs slow the coolant flow through the unit which allows the particles to settle.
The vortex at the outer edge of the cyclone has a downward descent. This pulls the particles toward the bottom of the cyclone. The coolant moves down until it reaches the apex or opening at the bottom. The opening at the bottom of the cone is not large enough to allow total release of all coolant, therefore, the liquid in the center of the cone swells upward and out the top. A portion of the coolant exits the bottom with the larger particles. This discharge is collected in a separation tank where the particles settle out and most of the coolant returns to the reservoir. The speed of the vortex can be varied by varying the velocity of the coolant as it enters the cyclone. Higher velocities enhance particle separation. The particle removal efficiency of the equipment can also be enhanced if flexible hose is used to collect and route the coolant as it leaves the top of the cyclone.

Typical system designs have a bank of cyclones piped to a common header. The piping arrangement is often perpendicular to the top discharge of the cyclone, which results in destroying the vortex of the coolant as it leaves, sending shock waves through the liquid in the cyclone. The flexible hose maintains the vortex and flow of the coolant until it enters the clean reservoir eliminating the shock waves.

One advantage of this type of system is that there are no moving components in the cyclone. This would indicate that maintenance would be slight, however, prior removal of particles large enough to plug the apex is not always adequate. This creates the need to check the apex daily to ensure it is not plugged. A second maintenance problem that exists is eroding of the apex, which increases the size of the opening and decreases the efficiency of the unit. Replacement of the worn apex is necessary to restore the efficiency of the hydrocyclone. An added advantage of the cyclone is that the forces which exist inside are conducive to emulsification, which helps to stabilize an emulsified coolant. However, this emulsification can cause tramp oils to be emulsified into the coolant.

Another type of gravity separator is the centrifuge, shown in Figures 5 and 6. While the forces used to remove particles are the same as those used in the hydrocyclone, the equipment used to create the gravity forces in the coolant inside the centrifuge differs. Unlike the cyclone, the centrifuge contains moving components. The coolant is pumped into the bowl of the centrifuge which rotates at high speeds. Periodically the bowl and operation are stopped to purge the centrifuge of accumulated particles. The centrifugal force can be the same as that produced by the hydrocyclone, but the fluid can be held at this high gravity for a longer period of time which enhances the separation.

Centrifuges are most effective when materials to be separated have great differences in density, such as glass grinding sludge and water based coolant. Unlike the hydrocyclone, the centrifuge has the ability to prevent emulsification, and to remove either tramp oils or particulate from the coolant. Centrifuges commonly used as tramp oil separators, shown in Figure 5, generate enough force that they can separate partially-emulsified oils from the coolant. The centrifuges used for tramp oil removal contain a number of coalescing discs or plates which aid in the separation of the oil and water.

In tramp oil separating centrifuges, excessive amounts of solid contaminant can plug up the discs which the auto-purge cycle cannot remove. This plugging often leads to extensive maintenance time in the removal and cleaning of the discs. Extreme care must be used when cleaning the plates, since damage or misalignment of these discs decreases the efficiency of this type of centrifuge. Addition of a pre-filter which removes all particles, except for the very large, can be very effective.
Incoming Coolant

Processed Coolant

Figure 6. Schematic of a centrifuge used for particle separation. The coolant is pumped into the spinning bowl. Spinning the bowl forces the particulate toward the outer edge. The particulate stays in the bowl while the fluid passes out the bottom.

Figure 6

fine contaminant, in the coolant line prior to the centrifuge prevents this plug-up from occurring.

The design of the centrifuge used to remove solid contaminant from liquid, shown in Figure 6, does not contain the coalescing plates, because the solids adhere to the plates and are not easily removed from the equipment. Equipment designed without these plates allow the dirt to be separated without "plugging" the centrifuge. These centrifuges have a very slow particle removal rate, and are often misapplied to systems which contain too much contaminant. Another method of particle removal is necessary, prior to the centrifuge, in order to remove the excess contaminant. These centrifuges do require a scraping device to remove solid contaminant from the bowl. Problems develop if the scraping mechanism inside the bowl fails.

Flotation, a process that incorporates the reverse of settling, is sometimes used to separate contaminants from fluids. This can be effective for the removal of contaminants less dense than the fluid, since these would naturally float. For particles that are not lighter than water, the creation of air bubbles that adhere to them will give them buoyancy and cause them to float. The particles must then be removed from the surface of the fluid tank instead of the bottom as in the drag tank.

The particles that need to be removed from the coolant are usually more dense, therefore air must be introduced. To date, the biggest problem has been to devise a method to generate air bubbles capable of attaching to all particles. The device used to generate the bubbles must be controllable so that the amount of foam produced can be controlled. The first units agitated the coolant to generate the foam. Newer models use pressurized air to saturate the coolant, then allow the air to dissipate at near zero pressure, forming finer air bubbles. This type of process has been used in waste treatment areas for numerous years, and is referred to as dissolved air flotation. A schematic of a dissolved air flotation unit is seen in Figure 7.

Another type of separator, the magnetic filter, can be extremely efficient in removing ferrous material. Particle removal is dependent on particles falling into the magnetic field, being pulled to the magnet, and removed from the coolant. If particles remain away from this field they will not be removed by the magnet. A high flow rate through the separator is one factor that will prohibit contact between the particle and the magnetic field. These units are usually designed with a large clean reservoir where the particles that are missed by the magnet can settle out. These particles must be removed manually since there is usually no other sludge removing device present in the system. One design used for magnetic separation is shown in Figure 8.

Figure 7

Filtration Equipment

The next step in the progression of particle removal equipment is the addition of a barrier through which the coolant must pass to strip out contaminants. The addition of the barrier changes what might have been a separation device
into a filtration device. A barrier will stop particles of a certain size: the absolute rating. To improve the absolute rating of a filter, a change in the barrier must take place.

The principle of filtration depends initially upon a barrier stopping particles larger than the barrier openings. As these larger particles build up on the barrier, the size of the opening decreases, preventing smaller particles from passing through. This effectively removes particles of a much smaller size than the original barrier size; the nominal rating of the filter. Essentially a barrier starts out as a strainer, and, as particles collect on the barrier, "filtration" or removal of smaller particles occurs. The types of barriers used may be permanent or disposable depending on the requirements of the system. Examples of barriers are listed in Table 1.

Filtration equipment can be divided into vacuum or pressure filters. Numerous designs of each type of filter exist, some with and some without media or precoat. Both types of filters are effective when applied properly. Most units are designed with a clean reservoir. This clean reservoir must be designed so particles that pass through that would normally be stopped by a chip cake. For most systems, under normal operating conditions, the amount of time during which this chip passing occurs is short.

The geometry of chips will determine the degree of clarity achieved in any type of filter, since the thickness and density of the chip cake determines the size of the fines removed. A tightly packed chip cake will remove smaller particles while loosely packed chips allow the fines to pass through.

As mentioned previously, numerous types of vacuum filters exist. Two of the most common vacuum filters are rolled media (paper) filters and wedge-wire filters. An example of the rolled media filter is shown in Figure 9. The roll of media is the barrier which lays in the bottom of the tank, supported by a perforated plate or a wedge-wire screen. When the vacuum has reached a point where indexing is necessary, the conveyors move. The conveyors, which rest on top of

<table>
<thead>
<tr>
<th>Barrier</th>
<th>Method of Differentiation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wedge-wire</td>
<td>Slot size; Permanent</td>
</tr>
<tr>
<td>Rolled media</td>
<td>Weight per square yard; Disposable</td>
</tr>
<tr>
<td>Pre-coat</td>
<td>Fiber or granual size based on sieve tests; Disposable</td>
</tr>
<tr>
<td>Cartridges/bags</td>
<td>Openings in barrier; May be nominal or absolute um rating; Disposable</td>
</tr>
</tbody>
</table>

Table 1. Common barriers used in pressure and vacuum filters. The characteristics used to identify and differentiate each group are listed.

to coolant flow. This resistance to flow can be measured as vacuum, if it is measured between the barrier and the pump.

The vacuum builds until a preset point is reached, then the filter automatically indexes. An index is the process used to remove the chip cake that has formed, opening a small portion of the barrier which re-establishes the proper flow rate. This may involve rotating the wedge-wire cylinder, moving the drag chain with or without media below, or shaking off the precoat. Up to ten percent of the filter’s surface area is opened during the index. The area opened during an index begins to reestablish the chip cake when flow through that area is restored.

A longer duration between indexes enhances the performance of the filter. When the chip cake is removed, that area of the barrier returns to the conditions that existed prior to cake formation. The area contains large openings which allow particles to pass through that would normally be stopped by a chip cake. For most systems, under normal operating conditions, the amount of time during which this chip passing occurs is short.

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<table>
<thead>
<tr>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower initial cost</td>
<td>1. on-going media cost</td>
</tr>
<tr>
<td>2. contaminant can be permanently</td>
<td>2. in larger systems rolled media may tear</td>
</tr>
<tr>
<td>removed from the system when</td>
<td>taken out with the contaminated</td>
</tr>
<tr>
<td>paper</td>
<td>paper</td>
</tr>
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</table>

Table 2. Advantages and disadvantages of using Rolled Media Vacuum Filters.

As the chips begin to accumulate on the surface of the barrier a chip cake is formed. It is this chip cake that aids in the filtration process by stripping out smaller particles. As this chip cake builds on the barrier so does the resistance
A loose precoat can be added to both rolled media and wedge-wire systems to enhance the filtration. Because the use of precoat may reduce flow rates, this must be engineered into the system prior to building the filter, or it will not be able to supply the proper amount of coolant to the machines. It is possible to add the precoat on the weekend while production is off to “clean-up” a system. Consult with
Figure 10. Schematic of a vacuum filter using wedge-wire cylinders as the filter barrier. The cylinders may also be suspended vertically in the tank. Conveyors move below the cylinders to remove the contaminant that settles out of the fluid.
After the coolant passes through the barrier it may pass into a separator to remove the large particles. The pump forces the vacuum from the clean reservoir from which the coolant is supplied. These systems are designed to index from differences in pressure. A differential pressure switch measures the difference in the pressure of the coolant entering the pressure chamber to the pressure after the chamber. When this difference exceeds a predetermined amount, the filter requires indexing. Indexing varies from unit to unit, some require the change to a new pressure chamber and manual removal of the barriers. For example, cartridge cans are usually designed with two cans in parallel arrangement to allow for this type of changing. The index may also involve moving a piece of a plastic belt through the unit.

There are many different types of pressure filters. Some use permanent and others use disposable media. These systems may be added to vacuum filters to give a final polishing effect or they may be used independently. Pressure filtration is affected by the geometry of the chips just as vacuum filtration is.

If the chips are coarse, the cake is not as dense and the fine particles get through. The applications that require the use of a pressure filter generally have finer chips, therefore the geometry of the chips is more uniform from system to system. In systems where removal of larger particles occurs before the pressure filter, the chips are very fine, so any cake that is formed is very dense. Usually there are not enough chips in these systems to build a chip cake, and particle removal is dependent on barrier opening size.

Table 3 describes expected clarity of the various types of pressure filters that will be described below.

Cartridge and bag filters are similar in design and will be treated as one group of pressure filters. Cartridges and bags are held inside a canister that the coolant is pumped through. The bags usually operate with the flow going from the inside out and the cartridges operate with the flow passing from the outside in. Whichever method used, the coolant is pumped through the filter which removes the particles. Cartridge or bag filters, by their design, are not capable of removing large quantities of particles. Large amounts of contaminants require frequent manual removal and replacement of the cartridges or bags. These are best used as polish filters, which are add-ons to other particle removing equipment. The purpose of the polish filter is to remove fine contaminant from a percentage of the coolant, reducing the residual contaminant level in all the coolant.

There are many types of cartridges and bags, and many different micron ratings. The type of bag or cartridge applied to the system depends on the prior method of filtration. A separator, which allows many chips to pass through, would require the use of a filter capable of removing more

<table>
<thead>
<tr>
<th>Advantage</th>
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</thead>
<tbody>
<tr>
<td>1. permanent barriers can be added</td>
<td>1. initial cost may be high</td>
</tr>
<tr>
<td>2. movement of conveyors does not affect the filter index in systems</td>
<td>2. contaminant that will not settle remains suspended in the tank</td>
</tr>
<tr>
<td>3. ability to examine cylindrically designed filter barrier without draining tank</td>
<td></td>
</tr>
<tr>
<td>4. may add precoat to remove fine contaminants during weekend shutdown</td>
<td></td>
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Table 3. Advantages and disadvantages of using wedge-wire vacuum filters

Table 4. Expected size of the contaminant, measured in micrometers (µm) remaining in the fluid after vacuum filtration. The amount of particulate, in parts per million (ppm), is expected to be 15 to 20 ppm for each category containing the um rating. The effectiveness of a vacuum filter is dependent on the particles in the fluid forming a chip cake.

The systems are the most complex types of filters that exist.

As the chips pass through the barrier a cake forms. Much like the vacuum filter, as this chip cake builds, the resistance to flow also builds. This resistance to flow increases the pressure required to pump coolant through the barrier. These systems are designed to index from differences in pressure. A differential pressure switch measures the difference in the pressure of the coolant entering the pressure chamber to the pressure after the chamber. When this difference exceeds a predetermined amount, the filter requires indexing. Indexing varies from unit to unit, some require the change to a new pressure chamber and manual removal of the barriers. For example, cartridge cans are usually designed with two cans in parallel arrangement to allow for this type of changing. The index may also involve moving a piece of a plastic belt through the unit.

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<td>4. may add precoat to remove fine contaminants during weekend shutdown</td>
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</table>
Table 5. Expected contaminant remaining in the fluid after pressure filtration. The values in this Table represent the size of the largest particle present in the coolant after it has been filtered. There is no mention of the amount of the contaminant of this size, or smaller, that may remain in the fluid. Pressure filters are generally rated based on their absolute rating.

<table>
<thead>
<tr>
<th>Filter</th>
<th>Suspended Solids</th>
<th>Basis of Clarity</th>
<th>Testing Method(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat-bed</td>
<td>Varies from 2 µm to 40 µm*</td>
<td>Weight of rolled media, which determines opening size.</td>
<td>Measuring suspended solids from known operating systems.</td>
</tr>
<tr>
<td>Pressure Tube</td>
<td>1 µm to 5 µm</td>
<td>Thickness and type of pre-cast used and integrity of tube.</td>
<td>Measuring suspended solids from known operating systems.</td>
</tr>
<tr>
<td>Cartridge Bag</td>
<td>Varies, depends on manufacturer and rating.</td>
<td>Ongoing in the barrier. The bag may be in a mesh rating.</td>
<td>Nominal - 95% to 98% removal of particles of rated size. Absolute - largest particle able to pass through the barrier. Multi-pass - slurry of contaminant is passed through a barrier, analysis for suspended particles in samples taken before and after the barrier gives the B-ratio. Particles before B = Particles after</td>
</tr>
</tbody>
</table>

* Flat-bed filter efficiency will be affected by the media that is used. The rating given is a guaranteed value for the largest particle capable of passing through the media. The average size and amount of contaminant lower than the rated value is not mentioned.

Table 5

particles. A bag filter may be applied to this system since it can hold larger quantities of chips than a cartridge, and the particles will be removed when it is lifted out of the canister. A vacuum filter which removes particles with greater efficiency than a separator may be used prior to a cartridge system. The size of the cartridge is dependent on the amount of chips remaining, the size of these chips, amount of flow through the cartridge, and the clarity required.

Other pressure filter designs include flat-bed filters and pressure tube filters. Flat-bed filters consist of a pressure chamber on top of a filter bed. A barrier is placed on top of a support grid. The barrier may be a disposable rolled media or a permanent plastic belting. The top of the pressure chamber closes down on the barrier and "seals" around the edges. The fluid is pumped into the chamber from a reservoir, is and forced through the septum to separate the solids from the coolant. As the pressure differential reaches the pre-set point the unit indexes, removing the contaminant from the surface of the filter barrier. The chamber is drained and the top raises, the barrier is moved through the chamber and is replaced by a clean section of the barrier.

Tube filters consist of long cylindrical tubes suspended in a pressure chamber. A precoat, usually diatomaceous earth (DE), is slurried and pumped onto the tubes first. After the precoat is in place the unit begins to process coolant. The coolant with chips is pumped into the chamber and through the tubes, removing the metal particles. The coolant then
proceeds onto a clean reservoir. The chips are removed until the pressure difference indicates time for an index.

During an index, the unit stops processing coolant, the coolant in the chamber and the DE with chips are flushed into a wash-down tank. This tank could be a vacuum filter or a settling tank where the DE and solids are removed. The wash-down tank has until the next wash-down to allow the particles to separate and get the coolant out of the tank. The system is usually designed with a pair of pressure chambers so that another can continue to supply clean fluid to the machines, or with a large enough clean reservoir to provide coolant through the cleaning cycle.

The advantages and disadvantages of pressure filters are listed in Table 6. This table compares pressure filters to vacuum filters, instead of different types of pressure filters. Generally there is little competition between types of pressure filters. Each type has an appropriate use and competition becomes a sales problem for vendors of the different brands. The tube and flat-bed filters compete with rolled media and wedge-wire vacuum filters in numerous applications, therefore considering the advantage of pressure to vacuum filtration is important. Item 3 in the Advantages column requires some discussion. Fluids which are difficult to vacuum filter are those high in viscosity and those that are at elevated temperatures. Vacuum filtration will cause these to vaporize thus starving the pump. Viscous and hot fluids can be forced through the pressure filters without forming vapors. The other items listed in Table 6 are self-explanatory.

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. better chip removal than with vacuum filters</td>
<td>1. system design is more complex</td>
</tr>
<tr>
<td>2. the coolant is more easily pumped through the cake than it is pulled through</td>
<td>2. dirty coolant is pumped through the media</td>
</tr>
<tr>
<td>3. ability to pressure filter solutions</td>
<td></td>
</tr>
<tr>
<td>which vacuum filter are unable to filter</td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Advantages and disadvantages of using pressure filters.

The variations of equipment design, numerous options, and the particular needs for the system make it a challenge to select the proper filter or filter supplier. In order to ensure that the system being used meets expectations, the selection of a filter supplier is a critical factor. Expertise in the area of filtration, and the availability of technical support are as important to the selection as is good filter hardware. The filter supplier selected should have numerous system designs from which to choose and be able to demonstrate the performance of systems that are in production. It is important to understand limitations of the equipment, which may only be apparent while operating during production, so that the equipment will be purchased and applied properly.

The first issue to be addressed is whether to use a central filter system or an individual filter on each machine. A central system usually uses in-ground trenches and a discharge piping network to tie multiple machines to one filter. This means that there will only be one filter system to maintain.

Individual filters, one per machine, do not require elaborate trenching and piping networks, but each filter does need to be maintained. Even if these multiple machines use the same fluid, the cost of maintaining smaller individual filters will soon exceed the cost of a central system.

While it is not recommended, systems for individual machines can be standardized. The use of a standard filter does reduce the initial purchase cost, although this initial cost should not be the sole criteria used in selecting a filter. When not applied properly these units may not perform as expected, resulting in additional costs to correct the situation. Careful examination of the filter system and study of existing filters will indicate when individual systems must be customized. Central systems, due to their uniqueness, must be engineered specifically for the job.

The engineering of a central filtration system can be very complex. There are no easy reference texts on system designs. Engineering filtration systems is an art, which like any art form requires years of practice to perfect. The actual design, engineering, construction, and method of operation should be left to the filter supplier, since this is where their expertise will surface. The information supplied by the purchaser will be used in engineering of a system specific to the job requiring the filter. Some of the information required to design a filtration system includes type of coolant, level of cleanliness needed in the coolant, size and amount of chips to be removed, type of metal, and total flow of the system.

Selection of the proper filter system is dependent on the particles to be removed, and more important, the amount of chips that can remain in the fluid after filtration has taken place. The cleanliness of the filtered coolant you request will more greatly affect the size and cost of the system than any other single parameter. All filter systems allow some chips to remain in the fluid. The size and amount of these
Chapter 3 Waste Minimization and Wastewater Treatment

chips varies with the different types of filters. The size or amount of chips that remain in the filtered coolant can be reduced by using multiple filtering processes. As an example, a vacuum filter could be used to remove the bulk of the large particles and then a cartridge filter could be used to remove those particles that pass through the first filter. Care must be used in applying this arrangement to a system to prevent the excessive cost of "over-filtering" all of the coolant. Of those particles less than 30 um, it is not known, accurately, what size is detrimental to any particular machining or grinding application. However, there is much speculation about which particle sizes are detrimental. Study continues today to determine the relationship of coolant cleanliness and part finish, tool life, etc.

Care must be used in determining where the coolant needs to be very clean and where simply straining out the larger particles is adequate. At times it is effective to isolate certain station(s) in a multiple station machining line to receive cleaner fluid than the rest of the line. This will eliminate the need of filtering all the coolant to the high degree of clarity required by the isolated station(s). The vacuum filter followed by the cartridge arrangement described previously might be applied to this situation. The coolant from the cartridge filter may be piped directly to a machine station to provide exceptionally clean fluid to that process. It can be circulated back to the vacuum filter as a by-pass cleaning cycle. The net result of this type of arrangement is to lower the dirt content in a percentage of the fluid thereby increasing the total cleanliness of the system, and, at the same time, to provide very clean fluid to a critical area if needed.

The metal to be worked in the filter system can be an important factor in its design. Common metals, typically seen in metalworking systems, can be divided into three major groups: aluminum, cast iron and steel. Systems to remove glass grinding, titanium, cobalt and tungsten carbide particles are also occasionally required. Each group has particular characteristics that affect particle removal. For example, aluminum machining chips will usually be larger with some curvature, while cast iron machining chips are smaller with less curvature since the cast iron is brittle. Generally, the large aluminum chips are easier to filter out than the cast iron. If the particles are easy to remove the filter unit is less complex.

The three major metal groups can be divided into multiple groups based on other characteristics, such as elemental composition or hardness. Changes in elemental composition can have adverse effects on the filtration process if the change causes the formation of interstitial solutions. An example of this change would be a change in the carbon content in cast iron. At low levels, carbon dissolves into the iron but does not bind, forming the solutions. It can readily move from the iron structure, thereby passing into the coolant during the cut. At higher levels the carbon is unable to move and the formation of interstitial compounds occurs. This carbon is bound in the iron and, during production, remains with the chip. The unbound carbon is much smaller than a cast iron chip, and cannot be filtered out, causing the coolant to become dark in color.

Elemental composition, as well as physical conditions such as heat treating and "working" of the metal, will change its hardness. The hardness of metal can change the shape of the chip produced since softer metals are generally not as brittle. Chips from malleable materials curl and resist breaking apart. As the hardness increases, the metal becomes less malleable so these chips may not curl and may break into small chips.

As mentioned previously the geometry of the chips is one factor that will determine the degree of clarity a filter will attain. The type of chip that is formed in a machining operation is an important design parameter of a filter system. If the hardness of the metal changes after start-up, the filter effectiveness may change. When other metals or new materials (such as composites) are used, testing should be done to determine the chip geometry and the effectiveness of different types of filters. This testing may not be possible initially, but continuing to work with the filter supplier long after the original purchase should be an option the supplier gives.

The type of cutting being done also affects the filter system design. Machining, where a metal cutting tool removes metal, produces different chips than grinding, where a non-metallic material removes the metal. For the purpose of this discussion, metal removed by a machining process will be referred to as chips, and metal removed by grinding will be referred to as swarf. There are numerous machining cuts and each produces chips of different geometry. Fast speeds and shallow depth of cut produce smaller chips while slower speeds and deeper cuts produce longer, larger chips.

The geometry of the part will also affect the chip produced. Small surfaces usually generate smaller chips while large surfaces have more area of contact at any given time, producing larger chips. This is also true of grinding systems. In ID (internal diameter of a part) grinding, the wheel is in contact with the part longer, producing longer swarf than for OD (outer diameter of a part) grinding. Sampling and analyzing a similar system will show the type of chips to be expected and the most effective method of filtration.

Flow rate through the filter is the next criteria used to design systems. Proper flow rate (in gallons per minute per square foot of filter area) will vary depending on the method of filtration chosen, and is critical for clean fluid. The flow rate in a filter is limited by the speed at which the coolant should pass through the barrier. Each barrier has an ideal flow rate for types of chips and conditions. See Table 7 for a listing of typical flow rates for vacuum filters. In vacuum systems that have the barrier suspended in the tank, the flow rate must be great enough to pull the chips onto the barrier. The flow rate affects sizing of the filter tank, since the tank has to be large enough to accommodate the filter area required for proper flow rate.
Tank sizing is a critical factor in filtration design. The first item that determines the size is the retention time. Retention time is the amount of time each gallon of coolant is held in the tank before it returns to the distribution piping to be cycled through the system again. Sizing of the tank generally requires that most vacuum filters allow a three minute to ten minute retention time, as opposed to gravity separators which require ten to 30 minutes to allow for particle settling. This allows some particles to settle, and prevents the fluid turbulence from washing the chip cake off of the filter barrier. Retention time is not critical in pressure filter reservoirs when settling is not important.

Total flow, the amount of material to be removed, and floor space available for the filter are three other factors that determine the size of the filter tank. The total flow, or gallons required by the machines and flushing, is one factor that determines how large the reservoir must be. Any filter that requires settling of the chips or swarf has to be large enough to allow the chips to settle. The tanks must also be large enough to hold the draw down, which is the coolant needed to fill the header and throughing, that is in transit when the filter is running. Essentially, the filter tank(s) must hold enough fluid to cover the filter barrier, provide enough retention time and keep machines and flushing supplied at all times.

The amount of stock removed from each part and the number of parts run per hour affect the size and design of the filter. If a large amount of stock is removed, the filter has to be designed to remove the heavy chip load. The conveyor must be heavy duty, as well as the chain drive and gear reducer. In rolled media filters the addition of a primary conveyor to remove the bulk of the chips before the filtration process may be needed. If the removal of these chips is not done through the use of a primary conveyor, the rolled media filter may not be the filter of choice, since the filter conveyor motion is related to the chip cake formation. To remove the bulk of the chips the filter conveyor would need to run often, removing the paper media before a good chip cake was established and before the disposal was necessary.

If less contaminant is present, the conveyors do not have to be as heavy, but a precoat or thicker media might be used since there would be fewer chips to form the chip cake. The use of precoat increases the size of most tanks since the flow rate through the barrier must decrease, and the filter area must increase. The use of a cartridge or bag filter as the sole system may be feasible in certain situations where very small chip loads exist, and when conveyors are not needed to remove any contaminant.

The size of a tank is often limited by the floor space available. When floor space is limited, and the filter size is decreased to fit, the filter may not have adequate retention time or filter area and it will not operate as efficiently or cost effectively. By determining the filtration needed before the majority of the engineering has been done on a machine line, proper planning can take place to avoid a space shortage. One major emphasis of research and development for filters is in the reduction of floor space required for the tank. Newer filter designs will require a minimum of floor space.

In part, the success of a filter system is dependent on the pump(s) used. The pumps move the coolant from the filter and fill the distribution piping network which supplies the machines. The pumping capacity must be large enough to supply machine and flushing requirements while maintaining the proper coolant pressure for the machining process. The filter supplier should be able to select the proper size and number of pumps, and work with the customer to select the pump manufacturer and basic design.

Each pump is rated to pump a certain amount of coolant efficiently at a specified pressure. The pump is capable of pumping more or less coolant, but at reduced efficiency; therefore it is desirable to operate the pump at its rated capacity. The higher capacity is often detrimental to the filter system clarity. If the pump is pumping more coolant it must draw the coolant through the filter at a rate faster than design rate. This forces through some contaminant that would normally be stopped by the filter barrier through. When no other method is used to regulate the pressure in the distribution piping, pumping the designed amount of coolant through the pump will provide the correct coolant pressure at the machine.

The piping network that distributes the coolant to the machines may be designed by the filtration supplier or by plant personnel. Critical areas to be engineered are the size and length of the piping required to supply the correct volume and pressure of coolant to the machines. The correct volume includes the amount of coolant required to flood the part for cooling and lubrication, rinse chips away from the part, and flush the trench system. Pressure of the coolant is very critical in lines that contain tooling through which coolant passes. In all machines the pressure must be great enough to wash chips off of the part but not too great.
that it splashes and over sprays. Pressure losses that occur along the line must be considered so that the coolant which reaches the last stage of a line is at the proper volume and pressure. Careful planning between machine builder, coolant supplier and filter supplier is needed to provide proper coolant distribution to the machine(s).

The trench system is the last area of engineering to be discussed. This is as critical as the first two and is usually designed by filter suppliers, because of their knowledge in the design of the trenches. The trench system must be designed to carry all particles to the filter, regardless of the distance. A trench which allows particles to drop from the flow, before they reach the filter, is poorly designed since these chips create dams that can interrupt the passage of all chips. Coolant and chip movement through the trench system may be by gravity only, or by gravity and coolant velocity.

All trenches require that the proper slope be designed into the system for chip passage. The slope for gravity return must be steeper, therefore the filter level must be lower than for a similar system without gravity return. Velocity trenches can be designed with less slope, since the passage of particles is enhanced by adding flush nozzles to move coolant carrying chips in the trench. The flow through the trench system is critical and specific to the chips generated, as seen in Table 8.

The metals not listed in this table may require testing to design the proper flow rate, or if they are similar to one listed, that flow rate may be used. Some experimentation and flow rate changes can be made in the field, after trench installation. Either type of trench system should be designed to eliminate as much turbulence as possible to minimize misting and foaming of the coolant.

If after the system has been designed, installed and is operating at its peak efficiency, it is determined that critical particles cannot be removed, certain filter parameters may be changed. Care must be used in determining which parameters can be changed and when these changes are not appropriate. For example, it is believed that the thickness of the rolled media can easily be changed to remove fine particles. This is true, unless the change in thickness is too great, because the system still has to be designed to allow for changes in flow, (i.e. one-ounce paper will allow coolant to pass through faster than two-ounce paper). The addition of other types of filtration equipment, or the separation of certain stages in a line for the addition of an identical filter, may be a possibility. Changes to a unit already in existence require extended evaluation of the engineering that went into the initial design, and examination of options that may be advantageous to the system. Selection of a reliable filter partner and careful engineering prior to building the filter can diminish the need to reevaluate the system design after it has been installed, thus saving time and money.

### Maintaining a Filter System

Once a filter has been installed it must be maintained to operate properly. There are three major areas that should be examined: hardware maintenance, replacement of consumable media, and coolant control. A filter system in which these areas are controlled should operate reliably for many years.

Preventative maintenance (PM) of the individual filter components is necessary to prevent the occurrence of major mechanical failures. Most PM programs include: examining and replacing worn components; cleaning and checking for proper operation of the pneumatic or electrical components; and lubricating certain sub-components of the filter, per the manufacturer's recommendations. Setting up a procedure to properly maintain the components will prevent the need for disaster maintenance (stopping production to fix the filter). The filter manufacturer should be able to provide recommended PM schedules to follow, as well as information on wear and replacement parts.

Filter maintenance also includes maintaining the filter as a single unit designed to operate within certain parameters. Regardless of the filter used, it has been engineered and designed to remove particles for a specific job. Careful control to maintain the proper filter operation is imperative to clean fluid. A frequent operational problem in filters is flowing more coolant through the unit than it was designed to accommodate. Flow through the filter barrier is limited. If the flow is increased, the filter senses a restriction and attempts to compensate for it by indexing. Increasing the flow through vacuum or pressure filters will decrease the time between indexes, thereby increasing the contaminant that migrates through the filter septum.

Consumable media is the barrier on which certain filter systems rely, and its replacement is necessary for proper operation. The expected consumption of the media may be predicted prior to the purchase of the equipment, although this will be an estimate. Initially the filter should be checked.
often, to determine when replacement is needed. After the filter has been operating, with production at 100%, a pattern of use should develop that will predict when the media needs to be replaced. This should eliminate operating the filter without media.

The coolant is the next area that must be maintained for peak performance of the system. While coolant representatives, tool engineers and plant personnel are most interested in the lubricity and cooling properties of the fluid, for the filter supplier the fluid must be "filterable" to be of any use. In other words the coolant must be maintained in a condition that enables it to pass through the filter barrier at the rate designed or the filter cannot operate properly. The fluid in the filter can be the most difficult item to control. Slight contamination of the coolant, after a period of time, may affect the performance of the filter. Chemical changes in the coolant, either natural or engineered, can also cause adverse effects on the filter. Monitoring the coolant daily is necessary to ensure that no major changes have occurred. Following the advice of the coolant supplier for proper fluid maintenance practices, and keeping records of additions that were made, will help prevent serious problems.

Control of the fluid involves the control of coolant components and contaminants. The components of the coolant must be measured to determine if they are being removed, while the amount of contaminants must be measured to determine how much is entering the system. Several important checks should be incorporated into a coolant PM program. The method used to measure each item will vary, due to coolant supplier preferences. Duplicating the methods recommended and used by the supplier may prevent discrepancies in the results. Table 9 lists the checks that may be performed and a schedule to follow. The checks, which measure conditions that change in the coolant and detrimentally affect the filter, will be described below to aid in understanding the effect on the system.

Extraneous or "tramp" oil is a contaminant that should be controlled in a filter system. Tramp oils may enter into the coolant from leaks in hydraulic components of the machine, from lubrication of the ways on a transfer machine, or from spills that occur as oil is added to the reservoirs for either of these items. Terms used to described the tramp oil as it exists in the coolant are "free," "partially emulsified" and "totally emulsified." Normally free oil does not cause filter problems. However, if it stays suspended in the coolant, it will cover the filter barrier restricting the coolant flow. Free oil may cause stagnation in the coolant when the filter is idle. Partially emulsified tramp oil, also called interface or rag, will cause filter problems as its concentration increases. It always stays suspended but does not cover the barrier unless its concentration is high. Totally emulsified tramp oil does not usually cause filter problems unless the amount is excessively high. The amount of oil that becomes emulsified varies with the coolant. To control tramp oil, the amount that enters must be controlled. There are few devices that will remove tramp oils once they have entered the filter.

Levels of neat product or "concentrate" in the coolant solution must be controlled to allow the filter to operate properly. Some components may be depleted causing filter problems, such as the rust inhibitor, the biocide and the lubrication package. The rust inhibitor preventsrusting of components in the tank, such as the conveyor systems. Also, if particulate in the filter tank rusts, the permanent barriers may become plugged with corroded particles that cannot be removed. Biocide or fungicide concentration may be depleted in a system, allowing biological organisms to grow. The "overgrowth" of biological organisms can be extremely detrimental to the filter operation, since most organisms that grow in coolant systems have a slimy coating. The organisms with their slimy coating build on the surface of the filter barrier and do not allow coolant to pass through. Depletion of the lubricity in the coolant will create problems with the moving components submersed in coolant which depend on this lubrication.

Because measurement of each of the components from the concentrate is very time consuming, often only one parameter is chosen to be measured. When the concentration is checked, the parameter measured should be a critical component of the coolant. Examples of "critical" components are surfactants, emulsifiers, lubricity agents, or rust inhibitors. A depletion of one of these components could indicate an overall depletion of the components mentioned above and the need for adjustment. The easiest and best way to replenish these components is to add the "balanced" product which will restore every component, even those that are not measured. If excessive additions of concentrate are called for, it may be advantageous to measure one of the other components. This will determine the validity of the initial test results, and may prevent unneeded use of concentrate.

Another check that should be performed is to measure the amount of solid contaminant remaining in the coolant after passing through the filter. This can be used to detect filter malfunctions; early detection of these can prevent major problems. It can also be used to check for different types of contaminant, such as metallic or non-metallic. If much of the contaminant is a non-metallic, crystalline precipitate, the underlying cause should be determined and corrected, because an excessive amount of the precipitate can induce filter problems. Grinding systems are notorious for the

<table>
<thead>
<tr>
<th>DAILY CHECKS</th>
<th>WEEKLY CHECKS</th>
<th>RANDOM CHECKS - as needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>water level (make-up)</td>
<td>biological growth</td>
<td>- rust</td>
</tr>
<tr>
<td>tramp oil</td>
<td>dirt load</td>
<td>- foam</td>
</tr>
<tr>
<td>concentration</td>
<td>filterability</td>
<td>- settling/surface tension</td>
</tr>
<tr>
<td>total oil</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 9. Checks that should be performed as part of coolant maintenance.
amount of wheel grit present. If this grit, which can cause finish problems, is passing through the filter it will be identified through this check.

Coolant foaming is a detriment if it is due to improper surface tension, resulting in the foam remaining on the fluid surface for an unacceptable period of time. Defoamers may be added to change the surface tension and reduce the amount of foam. However, if too much is added, it may not mix well and will remain suspended in the coolant until it is deposited on the barrier. On a permanent barrier the defoamer cover will not allow the coolant to pass through, while on disposable barriers it will be removed from the system. The coolant supplier should be able to recommend the proper defoamer and amount to use.

Other components and conditions may be checked periodically to determine if the fluid is performing adequately in the filter. These checks include filterability, settling and surface tension. The purpose of the filterability measurement is to prove that the coolant is able to pass through the barrier restrictions; the coolant must be able to pass through the barrier or the system will not work. The settling capability of a coolant is an important factor in those units that require chip settling. These systems may not function properly or as efficiently if settling characteristics change. The surface tension of a fluid can change the foaming and settling characteristics, causing conditions discussed earlier. Each component of the filter system is affected by changes that occur in any of the other components, whether these occur suddenly or over a long period of time.

While most manufacturing plants control the expected changes by controlling the three maintenance areas discussed above, unexpected changes will sometimes occur. Careful observation of the system is required to identify unexpected changes, and a quick response to the observed change is necessary to maintain the system.

**Conclusion**

The many filter system variations and options that are available have been discussed throughout this paper. In each area, technical experts can help guide the buyer through the necessary steps to acquire the proper equipment. Care should be taken in selecting these manufacturers to ensure receiving a quality product and satisfactory service.

**Bibliography**

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Henry Filters, Inc. is a leading supplier of standard, individually engineered, central coolant filtration systems used primarily by the metalworking industry. Individual, stand-alone filter systems are also designed for applications not requiring large, central systems. In addition to its headquarters in OH, Henry Filters has an office in Litchfield, England, allowing it to market worldwide.