

# **MACHINE and TOOL** **Blue Book**

The Magazine of Manufacturing Technology and Management

## **Controlling Coolant Contamination**

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# Controlling Coolant Contamination

**A**s industry seeks to improve the economy of plant operation, responsible managers are paying more attention to factors that affect efficient and reliable operation of their facilities. One area of attention that can pay off handsomely is the control of microbiological activity in coolant systems. Many engineers and plant operations personnel are just beginning to appreciate the effects on their machining operations caused by their plant "biosphere," which contains bacteria, fungus, mold and other contaminants.

Understanding how microbial life affects metalworking fluids helps plant managements determine how best to minimize microbial problems with confidence. Such knowledge also enables managements to more effectively evaluate the data provided by plant operators and service-company representatives.

## Effects of Microbial Growth

Fluid-transfer systems consist of pipes, valves, sumps, treatment units, towers and storage tanks used for containing and/or transporting working fluids or process fluids in an industrial operation. Excessive microbial growth causes seven principal types of problems: deterioration of working or process fluids; generation of odors; fouling of lines, valves and filters; acceleration of corrosion; poor quality and production performance; environmental deterioration, including immediate workplace; and

A look at the problems caused by microbial growth in fluid-transfer systems, the types of organisms found and the methods for evaluating contamination.

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other areas such as possible contributions to skin and/or respiratory irritation.

The deterioration of fluids is a complex process, the progress of which depends on the chemical composition of the fluid. Metalworking fluids contain a variety of organic compounds that may serve as both food and energy sources for microbes. Hydrocarbons, petroleum sulfonates, fatty acids and fatty esters, to name a few, although attacked slowly by individual types of microbes, can be degraded rapidly by consortia of microorganisms.

"Consortium" is the currently accepted term used to describe a mixed population of microbes acting as a

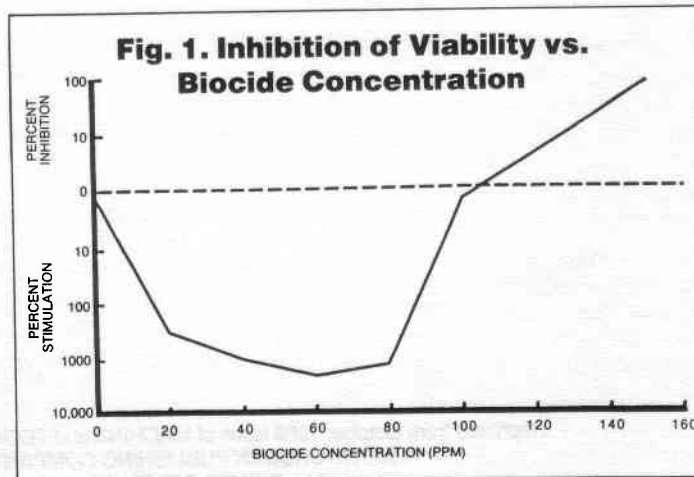
unit to carry out activities that individual members of the population cannot. These consortia can and do attack the chemicals in various additive packages such as anticorrosives and even biocides. Fig. 1 illustrates how biocides used at low doses can actually stimulate microbial growth.

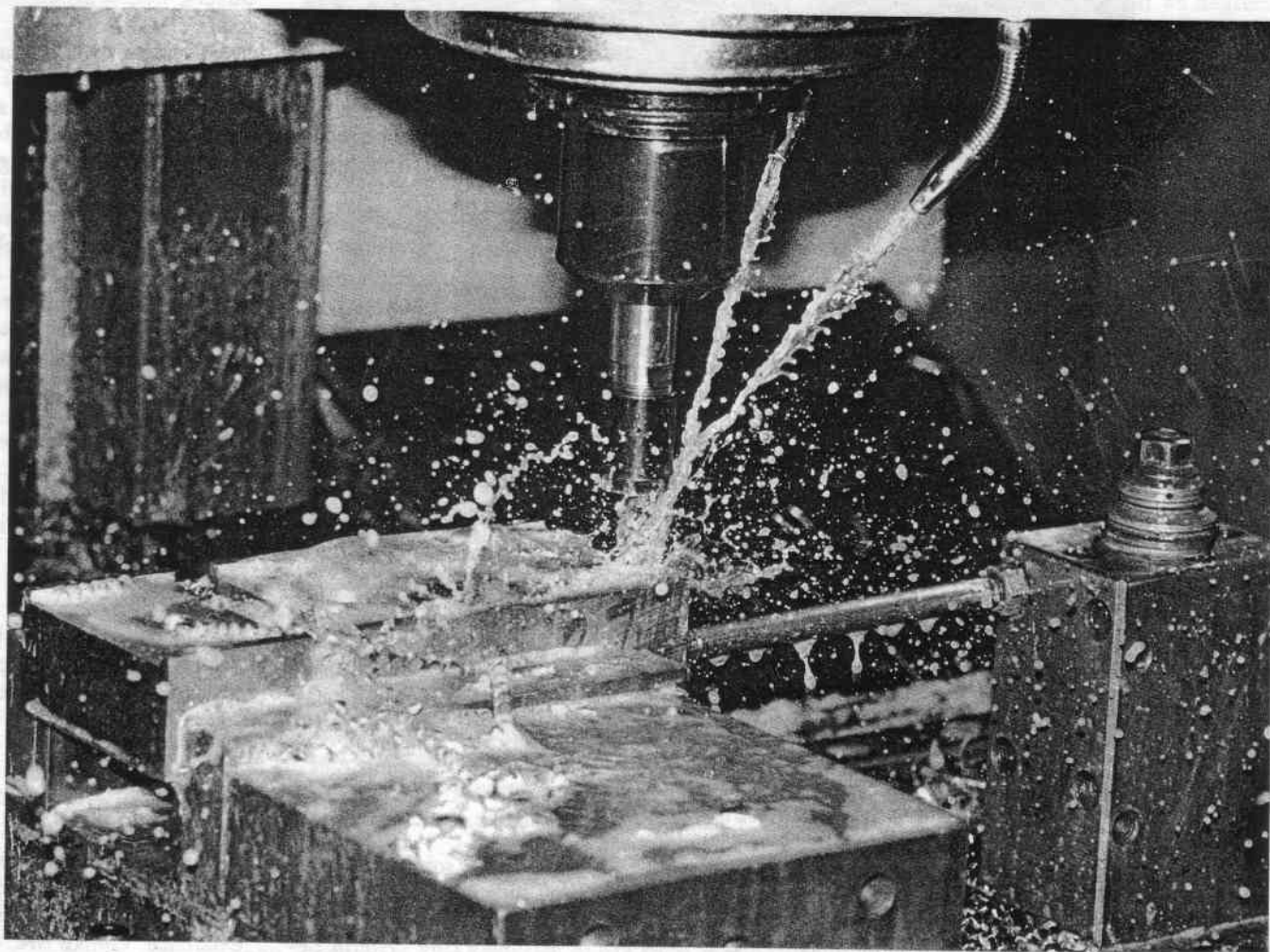
Indirect effects of microbial deterioration of working fluids include loss of pH control, lubricity, cooling properties and emulsion stability. Fluid viscosity may either decrease, as is most often the case, or increase, depending on the specific organisms and chemicals present.

Odor production is closely related to fluid deterioration since it is the result of the liberation of volatile products of microbial metabolism. A variety of odor-causing chemicals is produced, some of which are noxious, and others, such as hydrogen sulfide, are highly toxic. Adding deodorizers to sumps neither addresses the problem nor eliminates its cause.

Microorganisms tend to form films on surfaces. These films can become several millimeters thick, causing flow restrictions, preventing proper valve operation and substantially reducing filter life. Additionally, these films are good insulators and can cause significant reductions in the efficiency of heat exchangers.

Microbes living within films are often protected against biocide treatment. This is why biocides that seem to work well in bench





Metalworking fluids operate in a plant "biosphere" that contains bacteria, fungus, mold and many other contaminants.

tests are sometimes ineffective in actual plant situations. Microbes within the film, which are referred to as the "glycocalyx," are important agents of microbial corrosion.

Physically, the film forms a nonuniform barrier between the fluid and pipe or other component surface. This causes electropotential differences around certain regions of the component surface, creating microscopic galvanic cells. In addition to producing hydrogen sulfide, which is highly corrosive itself, sulfate-reducing bacteria and certain other species use the hydrogen ions that tend to accumulate at the cathode of these cells. This accelerates the galvanic reaction. Other microbes in the film produce corrosive organic acids as byproducts of their metabolism.

From a human health standpoint, the primary microbial concerns

relate to skin and perhaps respiratory irritation, discomfort and general unpleasant conditions.

#### **Types of Microorganisms Found in Metalworking Systems**

Two principal groups of microorganisms that create problems in metalworking fluids are bacteria and fungi. They can coexist in the system. Either bacteria or fungi can predominate in a system at any given time, depending upon the existing physical and chemical conditions. For example, fungi tend to have a higher temperature and lower pH tolerance than most bacteria. However, bacteria are the only organisms found at extreme temperatures or pHs.

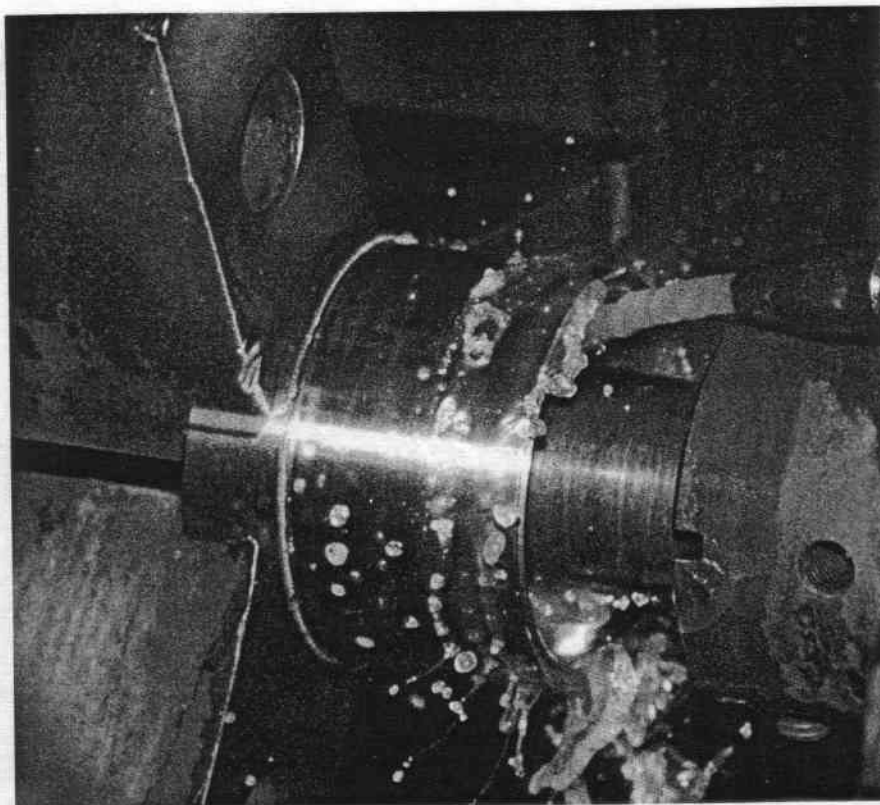
Bacteria are microscopic, single-cell organisms that differ from the rest of the biological kingdom by

their lack of an obvious internal organization. Fungi, though also microscopic, occur as either single cells or filaments. They have a cell structure similar to all higher organisms.

Fungi may occur as yeasts or molds. As yeasts, they are single-cell organisms that reproduce by budding. As molds, they form complex mazes of filaments and colorful, spore-bearing structures that give many molds their powdery appearance. A single species of fungus may exist either as a yeast or mold, depending on environmental conditions and the stage of its life cycle. Most fungi, however, exist primarily in either the yeast or mold form.

Cephalosporium is a slime- and odor-forming mold commonly recov-





Each coolant system is unique, and coolant additives should be designed specifically for each system.

ered from metalworking fluids. Fungi, like higher organisms, are generally classified by their physical appearance or morphology. Morphological descriptions are supplemented with nutritional and biochemical information.

Several approaches are applied to classification or identification of bacteria. Bacterium may change form depending on its state of well-being and may gain or lose nutritional capabilities as conditions change. The classification and identification process, therefore, dictates the use of several hundred biochemical, nutritional capabilities as conditions change.

Bacteria can be categorized roughly by their shape and ability to hold a dye known as the "Gram" stain. Gram negative rods are the predominant forms found in metalworking fluids.

Another way of classifying bacteria is based on their need for oxygen. Aerobic bacteria require oxygen in order to grow. Anaerobic bacteria cannot grow in the presence of

oxygen, although some (aerotolerant) can survive exposure to oxygen. These latter forms are of concern in metalworking systems because they tend to survive periods of aeration. A third group of bacteria, very important in industrial systems, uses the same metabolic machinery as the aerobes. As oxygen is used up, they shift gears and use the same biochemical pathways as anaerobes. These bacteria, called "facultative anaerobes," play an important role in creating an environment in which anaerobes that are present can grow.

A third way of classifying bacteria considers their metabolic capabilities: their ability to use certain compounds as nutrients, degrade them without using them as nutrients, or produce specific byproducts (such as ethanol). This approach is particularly useful in industrial situations where it is more important to know what the bacteria are doing rather than what to call them. In this scheme, bacteria are identified as sulfate reducers, hydrocarbon degraders, iron bacteria as sulfate re-

ducers, hydrocarbon degraders, iron oxidizers, etc.

Often, it doesn't matter whether the activity is the result of the action of a single species or a consortium. The consortium can be treated as though it were a single organism. This is much like dealing with your body as a whole rather than with blood cells, muscle cells and brain cells as discrete units. An industrial system that is experiencing uncontrolled microbial growth may be treated as though it were diseased, the metabolic activities being the symptoms.

If one were to list the predominant bacteria from rivers, ponds and lakes, it would be strikingly similar to a listing of bacteria most commonly recovered from metalworking fluids. This suggests that makeup water is the principal source of microbial contamination in metalworking operations. Dust particles, general, man-contributed contamination and refuse also add to microbial loadings.

### Factors Affecting Microbial Growth

Just as fire depends on air, heat and fuel for its existence, microbes have definite requirements for their existence. Unlike fire, microbes have a complex variety of requirements that are much more difficult to isolate. Nevertheless, by understanding the principal factors that affect microbial growth, metalworking plant operators can make intelligent decisions about their microbe-control programs.

The primary factor controlling microbial growth is the availability of nutrients. All microbes need sources of carbon, nitrogen, phosphorus, sulfur and energy. In metalworking fluids, these elements are readily available in some coolant chemical formulations. Though not all components of a metalworking fluid are degraded at the same rate or to the same extent, the net result is the deterioration of the fluids over various time cycles. Even biocides may serve as nutrients at low concentrations. The concentration of neat oil or synthetic chemical affects its biodegradability. Reports over the past three

ORGANISM	MINIMUM	pH OPTIMUM	MAXIMUM
PSEUDOMONAS SP.	5.6	6.6-7.0	8.0
PROTEUS SP.	4.4	6.0-7.0	8.4
AEROBACTER SP.	4.4	6.0-7.0	9.0
CLOSTRIDIUM SP.	5.0-5.8	6.0-7.6	8.5-9.0

decades have indicated that bacterial populations grow optimally in oil-water emulsions in various concentration ranges. Fungal growth appears to predominate in more concentrated fluids.

Inorganic salts also play an important role, both as nutrients and as ionic buffers. Bacteria survive longer in a balanced-salts solution than in deionized water. It has been reported that the concentration of inorganic salts, particularly those of calcium and magnesium, has a profound effect on microbial growth and coolant life. Fungi tend to prefer softer water (hardness less than 700 ppm  $\text{CaCO}_3$ ), while bacteria grow better in hard water (1000-1500 ppm  $\text{CaCO}_3$ ). Hard water interferes with the antimicrobial action of many biocides. The concentration of the principal inorganic constituents of river water is quite variable. Water hardness, for example, can vary by as much as 37.5 percent through the course of a year. Obviously, this can have a significant effect on a plant's microbe-control program.

Microorganisms grow best at neutral or slightly acidic pH. Generally, fungi grow better at moderately lower pH (4.5-5.0) than do bacteria. However, some of the iron-oxidizing grow well in 2N sulfuric acid (pH-1.0). These are called acidophilic bacteria.

Most bacteria are neutrophiles, preferring life in the 6-8.5 pH range. A few alkaliphilic bacteria grow well at pH 9-10, but these organisms do not tend to cause spoilage problems in metalworking fluids main-

tained at pH greater than or equal to 9.5. Some of the pH ranges for bacteria commonly isolated from metalworking fluids are listed in Table 1.

Alkaline solutions tend to draw carbon dioxide from the atmosphere, a process that neutralizes the solution. This reaction can lower the pH sufficiently to enable bacteria to grow. That is why alkalinity, a measure of a solution's buffering capacity, is as important a parameter to monitor as pH.

Different bacteria tolerate different temperature ranges. For example, bacteria have been isolated from icebergs and from the mouths of geysers. The bacteria most commonly recovered from metalworking

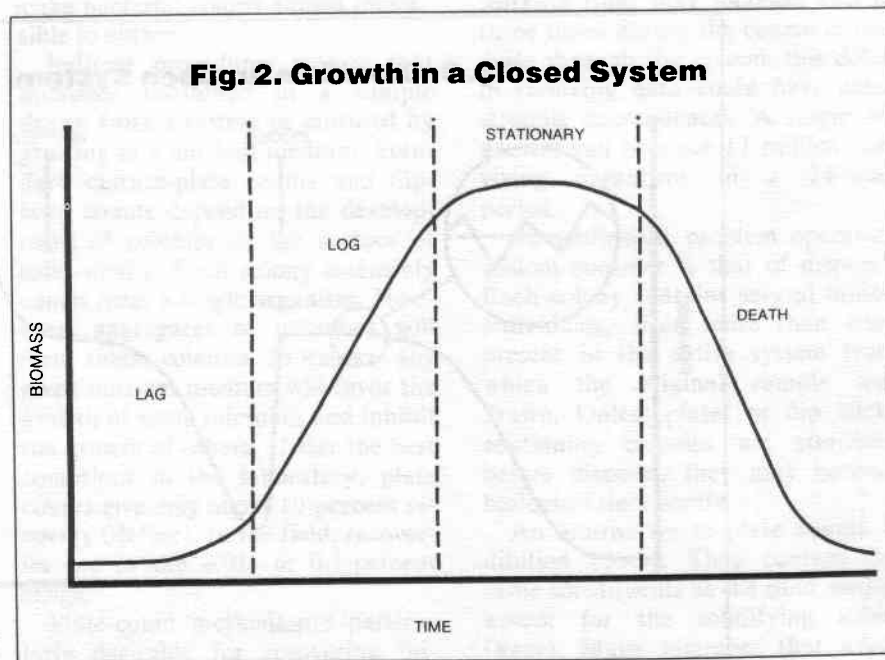
fluids can withstand exposure to temperatures up to about 45 degrees C (113 F). However, thermal treatment is usually not a viable option for controlling growth in metalworking plants.

Of the four principal factors effecting microbial growth in metalworking operations, water quality and pH are most easily controlled on site. Nutrient availability can be controlled through the careful selection of coolants, emulsions and accompanying treatment packages. Temperature control is a less practical option. Other factors such as oxygen availability and moisture content (availability of water) are important in some applications, but are not profitably controlled in metalworking operations.

#### Microbial Growth in Fluid-Transfer Systems

Fluid-transfer systems can be classified as open, closed or semiclosed. A closed system is one to which less than one percent makeup fluid is added each day. Storage tanks, hydraulic systems and closed-loop cooling systems are examples of closed systems.

In closed systems, microbial growth follows batch-culture dynamics (Fig. 2). Initially, during the lag phase, growth is not evident. Mi-



crobes are becoming acclimated and are changing their environment. The lag period is followed by a period of rapid growth accompanied by rapid nutrient depletion.

As nutrient concentrations drop below critical levels and toxic byproducts accumulate, the microbial production rate is roughly balanced by the die-off rate. This period is known as the stationary phase. Finally, as the die-off rate exceeds the growth rate, a period of population decline sets in.

In an open system, fresh nutrients are added continuously and metabolic byproducts are removed continuously. Chemical flooding for enhanced oil recovery and single-pass cooling systems are examples of this type of system. The first two stages of growth are the same as for closed systems (Fig. 3). However, once growth and death (wash-out) rates are balanced, microbial loads tend to remain constant over long periods of time. The size of the population supported in this type of system depends on the factors discussed. Changes in operating conditions will result in changes in the steady state size of the microbial population.

Most metalworking systems are semiclosed. Coolant is circulated within the system and makeup fluid

is added regularly. Microbial growth in semiclosed systems more closely resembles that in open systems than that in closed systems. However, microbial loadings tend to be more variable in the semiclosed than open systems. This variability reflects the changes in nutrient concentrations, biocide concentrations and other conditions.

In addition to the microorganisms living free in the fluid, a very important fraction of the microbial community grows in films adhering to the surfaces of fluid-transfer systems. Pioneer bacteria attach themselves to the surface and begin secreting a sticky carbohydrate substance. Other microbes and fragmentary particles and nutrients become embedded in this glycocalyx matrix, which begins to function as an immobilized bioreactor.

Consortia of microbes growing within this protective film create a special environment. Deep in the film, oxygen is soon depleted and anaerobic growth begins playing an important role in removing hydrogen ions from the metal surface over cathodic regions. The mature film is in a dynamic state, with portions of film being torn off and carried away by the fluid stream while fresh film material is being produced. Sulfate-

reducing bacteria recovered from water samples are generally bacteria that were embedded in these sloughed-off flocs of biofilm.

For many years, the importance of microorganisms in these films was unappreciated, because only a fraction of a film is active biomass. Another aspect of microbial films that has only recently been observed is their ability to protect bacteria from the action of biocides. This is a major problem with most biocide-treatment programs.

Biocides that are effective against free-living microbes may never come into contact with microbes living in the film clinging to the system surfaces. Consequently, shortly after a pulse dose, when the biocide concentration falls below toxic levels, bacteria from the film rapidly regrow in the fluid. Today, biocide manufacturers and formulators are aggressively seeking methods for making their products more effective against the microbes living within the film layers.

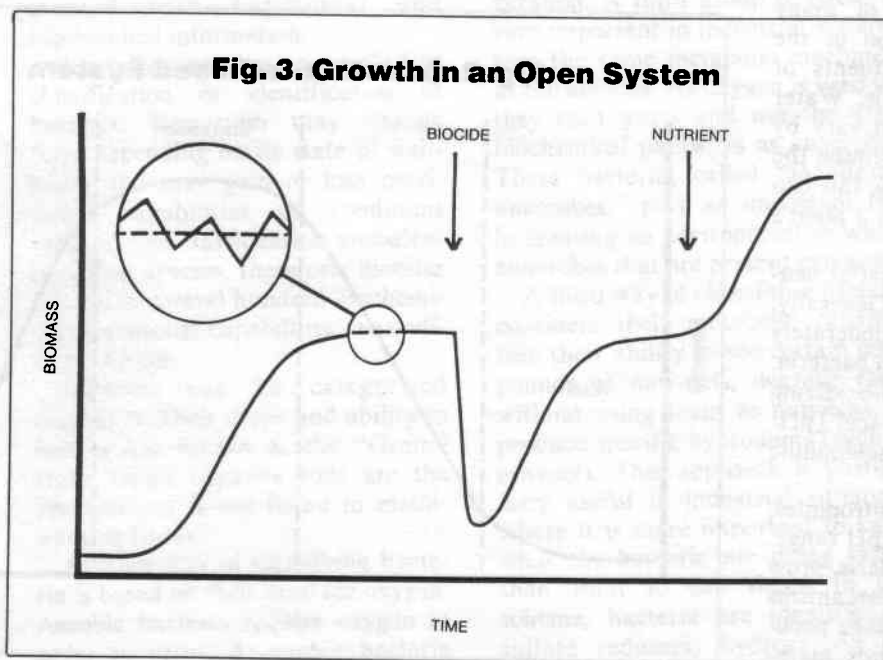
Inadequate biocide treatments may attack only part of the population, thereby reducing the competition for the survivors. Repeated treatment favors the development of resistant populations. By this procedure, biocide-resistant microbes, formerly present in relatively small numbers (before biocide treatment began), are given a competitive advantage over their sensitive neighbors. In time, the resistant community predominates over the ineffective community.

Currently, a fair amount of controversy exists over how to best circumvent this problem. In reality, the answers must be determined for each system, since each system presents a unique environment. Resist the temptation to accept standard treatments that haven't been designed specifically for your system.

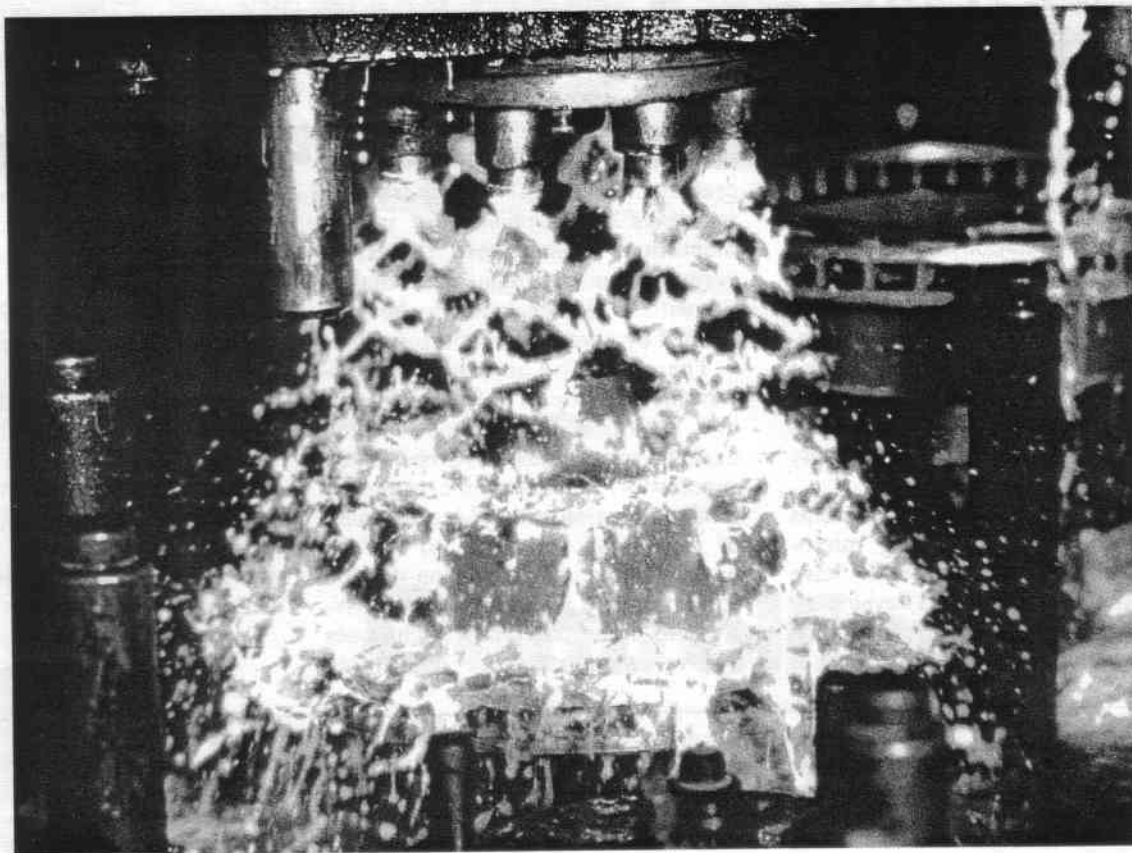
Overdosing presents its own series of problems, including costs and an uncomfortable environment for all of us.

### Measuring Microbial Contamination

Three approaches to measuring microbial contamination are deter-







Most metalworking fluid systems are semiclosed. Coolant is circulated within the system and makeup fluid is added regularly. Microbial loadings tend to be more variable in semiclosed systems than open systems.

mination of: the number of organisms present, concentrations of cell constituents and the level of microbial activity.

Direct and indirect procedures exist for determining cell numbers. Direct procedures include microscopic counts and particle counts. Although microscopic counts are relatively tedious and time-consuming, they can provide data rapidly, when equipment and trained personnel are available.

Frequently, organisms that will not grow on nutrient media can be identified under the microscope. Special staining procedures enable the technician to distinguish between live and dead cells. Other sophisticated staining procedures provide the best means of identifying or confirming the presence of certain organisms. However, these procedures are generally not applied in a plant environment. Samples must be drawn and analyzed by qualified personnel.

Particle counting is another rapid, direct method; however, it is best-

suited for clear fluids where any particles present are likely to be microbes. The electronic instrumentation for doing particle counts is expensive and the heavy inorganic particle loads in metalworking fluids make bacterial counts almost impossible to obtain.

Indirect procedures require that microbes contained in a sample drawn from a system be cultured by growing in a nutrient medium. Standard culture-plate counts and dip-stick counts depend on the development of colonies on the surface of solid media. Each colony ostensibly comes from a single organism. However, aggregates of microbes will form single colonies. Moreover, any given nutrient medium will favor the growth of some microbes and inhibit the growth of others. Under the best conditions in the laboratory, plate counts give only about 10-percent recovery (define). In the field, recoveries are in the 0.01- to 0.1-percent range.

Plate-count methods are particularly desirable for recovering mi-

crobes for further study. Dip-stick samples are easy to obtain and take little operator time, but data are not available for 24 hours to a week after the sample is collected. Since microbial populations in a metalworking fluid may increase two to three times during the course of one cycle through the system, this delay in receiving data could have catastrophic consequences. A single organism can produce 17 million surviving organisms in a 24-hour period.

An additional problem operators seldom consider is that of disposal. Each colony contains several billion individuals, often more than were present in the entire system from which the original sample was drawn. Unless plates or dip sticks containing colonies are sterilized before disposal, they may become biological time bombs.

An alternative to plate counts is dilution broths. They contain the same constituents as the solid media, except for the solidifying agent (agar). Many microbes that won't

form colonies on solid media will grow in broth media. After an appropriate incubation interval, samples are scored for the presence or absence of growth. Serial dilutions are more tedious than plate counts but give higher (probably more accurate) estimations of the size of the microbial population in the sample. The problems associated with dilution procedures are the same as those for plate counts. The key feature in both of these methods is that microorganisms must grow after having been taken out of their natural environment. Often they simply will not.

The time lag and growth problems associated with quantifying microbial contamination growth have prompted investigators to develop alternative rapid methods for estimating microbial growth. One group of

rapid-test procedures focuses on the determination of the concentration of cell constituents such as protein, enzymes, ATP, lipids, etc., in the sample. While many of these methods provide reliable estimates of microbial loadings, they also require expensive and sophisticated instrumentation. Among these, the HMB system provides comparable reliability with a test designed to be performed by nontechnical personnel.

The alternative approach is to determine the rate of different microbial activities. Radioisotope-labeled organic compounds have been used successfully to determine potential biodeterioration rates. Measurement of conversion of sulfate to sulfide, oxygen demand and carbon-dioxide formation are all examples of activity determinations. These techniques are very important for identifying

specific microbial problems and for developing procedures to control them; however, most require expertise and facilities not found in most metalworking plants.

To date, there is no single best method for measuring bacterial growth. Each procedure has advantages and disadvantages over the others. Each provides unique information. The challenge is to select a procedure that will provide the most effective, efficient and economical routine monitoring tool. That tool should quickly signal the development of problems before they become catastrophes. More comprehensive testing can then be performed as necessary to characterize the problem and institute corrective action.

**BB**