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INDEX TERMS

Cutting Fluid
Fluid Deterioration
Microbial Deterioration
Cutting Fluid Requirements

MICROBIOLOGICAL CAUSES OF CUTTING FLUID DETERIORATION

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ABSTRACT

Several aspects of the causes and prevention of the microbiological deterioration of cutting fluids are described. Reference is made to the fact that the nature of the fluid and the kind of operation in which it is involved are inherent in the longevity demonstrated by the fluid in use. Emphasis is also placed on proper maintenance, including surveillance of personnel hygiene and overall sanitation. The role of preventive maintenance is also discussed in terms of biocide function. Mention is made of several novel approaches to control of microorganisms.

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ABSTRACT

Several aspects of the causes and prevention of the microbiological deterioration of cutting fluids are described. Reference is made to the fact that the nature of the fluid and the kind of operation in which it is involved are inherent in the longevity demonstrated by the fluid in use. Emphasis is also placed on proper maintenance, including surveillance of personnel hygiene and overall sanitation. The role of preventative maintenance is also discussed in terms of biocide function. Mention is made of several novel approaches to control of microorganisms.

INTRODUCTION

The subject of this symposium is "Running Metalworking Fluids Indefinitely". It should be obvious to those attending that this is just hyperbole and is meant to get the attention of the audience. The statement could be made without contradiction that nothing lasts forever and perhaps should not. The subject of my contribution relates to the role that microorganisms play in determining how long water-soluble cutting fluids will survive in use.

If microorganisms were contained, controlled, or eliminated, how close can we get to a longevity for liquids that is asymptotic at infinity? In order to answer this question, we have to look at a related series of problems that deal with how microorganisms interact with cutting fluids.

Microbial Deterioration of Water-Based Products

A number of factors are involved in the microbial deterioration of metalworking fluids in use. Not in order of importance, the following could be considered as being contributory (Table 1).

Several of these cannot be manipulated if they indeed affect microbial activity. For example, it would not be feasible to change either the size of the system or the type of operation if this is what a plant is charged with. Other factors may involve economic considerations which preclude making changes even if microbial activity is convincingly restricted. This latter statement may be academic since restrictions imposed by EPA (Environmental Protection Agency) and OSHA (Occupational Safety and Health Act)

and availability of replacement fluids may make it necessary to reevaluate the cost involved in preventing microbial deterioration.

Microorganisms Associated with Cutting Fluid Deterioration

Although a rather extensive number of species of microorganisms have been isolated from cutting fluids and another group have demonstrated ability to grow in cutting fluids in the laboratory, on the basis of frequency of isolation, the list is rather small. (Modified from Bennett, 1972; Rossmore, et al, 1972) These organisms come from a variety of sources (Table 2) and it is fairly easy to see that poor plant sanitation, particularly in the area of house-keeping and personal worker hygiene, can contribute greatly to the accumulation of microbial contamination in the fluids. The primary microbial culprits in the actual chemical deterioration of fluids both due to their proclivity and numbers are organisms belonging to the genus Pseudomonas. The two species most commonly encountered are Pseudomonas aeruginosa and Pseudomonas oleovorans. This group has a reputation of being difficult to kill and having the broadest appetite and the least nutritional need among any group of microorganisms extant. Thus, it is extremely difficult to find a formulation that sooner or later does not become a meal to these voracious creatures. Among the things they do best are oxidations of saturated and unsaturated hydrocarbons (Schwartz, 1973; McKenna and Coon, 1970). Thus, the cutting fluid milieu is tailor-made for them.

These organisms are highly oxidative which means that they grow best under conditions of maximal aeration, reproducing approximately every 45 minutes or so under the ambient conditions in the fluid. A companion group of organisms which are not necessarily as active both due to their numbers and their more restricted appetite are the anaerobic sulfate reducers. They grow only under conditions of oxygen deprivation at a potential of about minus 300 millivolts and apparently cannot begin growth on fresh fluid but need preformed materials from aerobic bacterial growth (Isenberg and Bennett, 1959). Their major contribution to deterioration may be subjective considering the unpleasantness of hydrogen sulfide in the immediate environment and also may be a contributing factor to corrosion since they can cause this even in the absence of oxygen.

A third microbial factor to be considered and which has gained more interest recently are the fungi. (Rossmore, et al, 1972) Due to changes in operational conditions, with fluids, or biocide used, some systems become overgrown with fungi belonging primarily to two genera: Fusarium and Cephalosporium (Rossmore and Holtzman, 1974). These

organisms can grow on the ingredients in cutting fluids but appear primarily to become troublesome after there has been prior bacterial growth in the fluid (Table 3). Their major contribution to deterioration seems to be aesthetic and mechanical since it is not uncommon or improbable for islands of fungi to combine with organic debris to clog filters, flumes, and nozzles.

Causes of Deterioration

The longevity of a fluid is controlled by a number of factors, some of which I have already mentioned. These could be divided into two groups: the "use" factors and "abuse" factors.

Use Factors. In systems where the fluid has a long half-life, i.e. where the replacement rate is very low, it is conceivable that the innate characteristics of the fluid that tend to be preservative gradually wear out, making the rest of the fluid more amenable to microbial attack. There may be, in fact, an accumulation of metal ions that are solubilized during the machining operation which can contribute to the stimulation of microbial growth, the inhibition of germicidal action, and the catalytic deterioration of the fluid, the subsequent breakdown products of which are better foods for the resident microbes. During use, there is continual evaporation of water as well as carry-off of the total fluid. It is always necessary to replace the water as well as replace the concentrate used to maintain proper fluid levels. The longer a system is in use, the greater will be the effect of the addition of water containing calcium and magnesium, since this accumulation of hardness does two things: at a certain level these ions are necessary for bacterial action against hydrocarbons, but beyond that level they react with emulsifiers (e.g. Sodium Petroleum Sulfonate) to produce hard-water soaps causing emulsion separation and also react with long-chain fatty acids (e.g. oleic) in synthetics, again to produce hard-water soaps.

Abuse Factors. It may be difficult to separate "abuse" from "use" in the minds of some individuals. First and foremost, I would list plant sanitation since one of the surest causes of microbial deterioration of a new fluid is its addition to a system that has just been dumped but not cleaned (Table 4). This is the way the ancient people made bread and cheese, never cleaning out their tubs when they poured either the fresh milk or placed the fresh dough for leavening. There was always some active agent left over from yesterday's cheese or yesterday's dough to start the process going. The same thing is true of cutting fluids: if yesterday's pit was sour, the sourness doesn't leave with the fluid; it clings to the machines, to the weirs, and to the walls and flumes. Hopefully, it should not be necessary to

do cleanings too frequently but it is self delusion if the new fluid is expected to last after it is added without prior thorough cleaning of the machines and sump.

Worker hygiene is another aspect of "abuse" in which microbiology can play a part. Perhaps signs should be erected in bright colors: "No P in the pit. No lunches in the sumps. No butts in the flumes." The data are rather convincing that these serve as hors d'oeuvres for the bacteria as they prepare to attack the basic components of the fluids. These contaminants also serve sometimes to shift the balance of power in the fluids and create microbial populations that tend to be more obnoxious from an aesthetic point of view. Table 5 shows a system of 45,000 gallon capacity, milling nodular iron, and smelling like an outhouse. You will note that the total bacterial levels in the system are not only high but they contain two groups that are found in feces (Proteus and coliforms); enough said.

I would also include under the heading of "abuse" the frequent disregard for fluid concentration. Not only does a less than optimal concentration drastically affect its cutting and cooling function but in fact it may also make this fluid much more sensitive to microbial attack.

Perhaps another abuse, although not intended as such, results from the mixing of two different products in the same central system. In these instances, because of the impracticality of disposing of 50 or 60,000 gallons of the fluid type in use, the new formulation is used as make-up to gradually replace the older fluid. Without extensive testing, it may not be possible to find out at what level of use and ratio of the two fluids will there be an incompatibility and, if one does develop, what the consequences will be. In one actual system, the gradual replacement of a soluble oil with a synthetic fluid was uneventful until the ratio exceeded four parts synthetic: one part soluble oil. The remaining soluble oil became unstable and partially separated from the rest of the fluid. The oil coalesced into large black masses and became semi-solid. The fluid itself had little or no fungal count but the solidified oil had counts as high as 30,000 fungi per gram (Table 6). These results indicate that the accidental abuse of the fluid produced products that may have served as foci for the growth of fungi. The minimal fungal levels in the fluid even in the face of the suspiciously strong musty odor is indicative of what I have referred to previously (Rossmoore and Holtzman, 1974) as "the iceberg effect". Coincidentally, there was a related system which had been similarly treated but without the musty smell and fungi and without an accompanying humidity in the region below machine level where the sumps were located. High ambient humidity is the perfect condition for the initiation and continuance of

fungal growth on the flumes, sidewalls, and filters. It would seem that judicious use of exhaust fans could help reduce this problem.

The Effects of Microbial Deterioration

I have already mentioned the major effects. In summary, they can be classed under the headings: physical, chemical, and biological.

Physical Effects of Deterioration. These relate primarily to the action of the fungi which by their very nature and aggregation interfere with the physical operation of the fluid flow, machine function, and filtration, so that with extensive fungal growth the problem may almost be beyond redemption.

Chemical effects refer primarily to the reduction in lubricity resulting from the utilization of active ingredients by the organisms and also in the case of emulsions their splitting as a result of extensive bacterial growth. Extensive microbial growth is also associated with great variation in the size of the oil droplets. This is also similar to findings with hard water which also causes separation and which is also the cause of variation in droplet size.

Biological effects of microbial action relate primarily to the organoleptic interaction of the workers with their environment. Neither the rotten egg smell of Monday mornings, the outhouse smell described before, or the stale locker-room odor, are treated with any affection by tool workers. I would submit that when these conditions get out of hand, the consequences can be most serious.

Extending Cutting Fluid Life

The statement was made before that nothing lasts forever and that extending the useful life of any product depends upon a variety of factors. In systems that have minimal or short contact time with the fluid, i.e. where the make-up rate is very high, like 50% weekly (e.g. as might exist in some small 200-300 gallon machine systems), efforts made to extend product life or protect product life from microbial attack need to be minimal compared to products used in large central systems, e.g. 50,000 gallons, with make-up rate lower than 10% monthly. In both cases, it is easy to see that neither product has to last forever since there is continual addition of fresh material to make up for regular and continual losses. However, each case must be treated from a different standpoint of protection.

In a small system, where the fluid turns over rapidly,

the use of chemical biocides may not be necessary, particularly if the machines are kept clean and other good sanitary practices are maintained. The longer the fluids stay as residents of a system, the greater is the chance for microbial adaptation, growth, and the subsequent biodeterioration of fluid.

Fluids can be protected from microbial attack in a number of ways, some of which have been mentioned earlier. I would like to devote this section to discussing methods extrinsic to the properties of the cutting fluid that can be used for control of microorganisms.

1. Chemical Methods. THE USE OF BIOCIDES. Perhaps this is the most common method for controlling microbial growth in cutting fluids and their effectiveness depends upon a number of factors (Table 7). In spite of the use of what appear to be good biocides, many systems become overgrown with a variety of types of microorganisms.

This happens sometimes due to the improper and injudicious use and selection of the biocides and a lack of awareness of their shortcomings.

Solubility is an important parameter since if the biocide is to be placed in the concentrate it may have to be 20 or 30 times more soluble than in the working solution. There may also be a problem of dispersion and solubility in the working solution as well. Stability in the concentrates is an additional concern since interactions with the formulations may be more probable since the reactants are there in higher concentrations and they may be subjected to greater extremes of temperature during shipping and storage. Many biocides cannot tolerate the high ambient pH of the concentrate. Perhaps the best approach to dealing with the multiple microbial groups involved in cutting fluids would be to look for synergistic compounds. However, it is not always a wise decision to mix two compounds that are active, thinking that an additive effect will result.

As fluid longevity increases, both breakdown products of fluid and of germicides will accumulate. In many cases, it will be impossible to distinguish between the biological and chemical half-life of the active biocides but, nevertheless, this remains a concern. In addition, a number of biocides exhibit concentration effects which are not amenable to maximal efficiency in cutting fluids. In these cases, activity drops geometrically while biocide concentration is only dropped arithmetically. The effect of dosing rate in central systems, which have an extremely low make-up rate, is seen in Table 8. Notice that for well over a month the bacterial count is maintained at zero by weekly additions. When the count was allowed to rise without

weekly additions, a subsequent dose at that level had no effect. Look what happened in the final situation where less than optimal levels for fungi were used. The bacterial count was down to zero but fungi started to grow. Table 9 illustrates the concentration effect just mentioned. At 500 ppm, bacterial levels remain depressed for two weeks but at week 3 they begin to climb; whereas, at 1500 ppm, counts are maintained at zero throughout the observation period. The effects of synergism and antagonism as well as differences in activity in two different emulsions are shown in Tables 10 and 11. In these systems, Biocide A is being used to control bacteria, and Biocide B for control of fungi. In Table 10 there seems to be a genuine additive effect between A and B. Not only are both bacteria and fungi controlled, but they seem to be increasing their mutual activities. In Table 11, the reverse is true and antagonism rather than synergism is the result. I repeat the caveat mentioned earlier with regard to mixing of two different types of fluid: do not mix two different biocides without prior evaluation in a definitive system.

2. Physical Methods. THE USE OF TECHNOLOGY NOT INVOLVING CHEMICALS. Physical methods have one thing in common that is both an advantage and a disadvantage: they have no residual effect. They only are active when being applied. Therefore, the frequency of treatment may have to be on a more continual basis. Physical methods have not been generally utilized, primarily because of the need to introduce changes or additions to existing hardware. But on an experimental level, there has been ample demonstration that certain kinds of physical treatment are successful in controlling microbial growth in cutting fluids.

(a) Ionizing Radiation. In a previous publication (Rossmore and Brazin, 1969), we have shown that Cs can be used to reduce the levels of spoilage microorganisms in cutting fluids without either the development of resistant survivors or negative effects on the fluid itself.

(b) Thermopasteurization. One obvious inexpensive and safe method of controlling microorganisms to a level that reduces economic loss is the use of less than sterilizing levels of heat. The only possible drawback is the need for recooling the fluid after heat treatment. It should be possible to devise a system similar to the heat exchange units in dairies to accomplish this purpose. The adequacy of low levels of heat for prevention of spoilage in fluids has also been previously reported (Rossmore and Heinrich, 1970).

(c) Sonic Oscillation. This is a novel method of controlling microbes and it deserves a more intensive look

than has been given in the preliminary series carried out recently in my laboratory; however, we have accumulated data to show that fairly short-term treatment with sonic oscillation does reduce microbial levels and does increase emulsion stability (Table 12). One shortcoming is that there is a slight increase in temperature as the process proceeds.

There are many horizons to explore for the control of microbial deterioration of cutting fluids. New rules are being established regularly that restrict paths that can be taken. Mixtures of previously partially-successful biocides and combinations of both physical and chemical agents are worth investigation (Heinrichs and Rossmoore, 1971). These steps may be necessary in order to satisfy economic, health, and environmental requirements. This is one game in which we cannot rest on our laurels and I close with a most apt quotation from my patron saint, Louis Pasteur: "Messieurs, c'est les microbes qui auront le dernier mot!" ("Gentlemen, it is the microbes who will have the last word!")

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TABLE 1

FACTORS CONTRIBUTING TO CUTTING FLUID DETERIORATION

THE OPERATION
Type of Metal
Nature of Job
Size of Reservoir

THE FLUID
Type of Fluid
Concentration
Make-up Rate

MAINTENANCE
System Design
Sanitation Level
Residual Contamination

TABLE 2

ORGANISMS ISOLATED FROM ONE HUNDRED SAMPLES OF USED EMULSION OILS

Organism	Total Number of Times Organisms Isolated	Source	Fate
Achromobacter sp	12	W, S	D
Aerobacter aerogenes	18	W, IT	G
Aerobacter cloacae	1	W, IT	G
Bacillus cereus	7	S	D
Bacillus subtilis	3	S	D
Diplococcus pneumoniae	4	RT	D
Escherichia coli	41	IT	G
Escherichia freundii	7	IT	G
Escherichia intermedium	2	IT	G
Klebsiella pneumoniae	32	RT	G
Micrococcus citreus	1		G
Micrococcus pyogenes var. albus	5		
Micrococcus pyogenes var. aureus	17	S, IT	G
Paraclostridium intermediates	47	IT	G
Proteus mirabilis	6	IT	G
Proteus morganii	4	IT	G
Proteus sp	46	IT	G
Proteus vulgaris	57	W, S	G
Pseudomonas aeruginosa	64	W, S	G
Pseudomonas oleovorans	34	W, S	G
Pseudomonas sp	1	W, S	D
Shigella sp	1	W, S	D
Shigella madampensis (Shigella dispar)	1	IT	D
Streptococcus pyogenes, alpha hemolytic	11	RT, Sk	D
Streptococcus pyogenes, beta hemolytic	6	RT, Sk	D
Yeast	14	A, S	G
Fungi	14	S	G

Modified from Bennett, 1972
Code: D = Dies, G = Grows, S = Soil, W = Water, Sk = Skin
IT = Intestinal Tract, RT = Respiratory Tract
A = Air

TABLE 3

EFFECT OF FLUID HISTORY ON FUNGAL GROWTH

System No.	History	Fungal Fate
1	No Spoiled Fluid No Bacterial Growth	Survival, then Death
2	No Spoiled Fluid Bacterial Growth	Survival
3	Spoiled Fluid No Bacterial Growth	Growth
4	Spoiled Fluid Bacterial Growth	Survival (Growth in some Fluids)

TABLE 4

THE EFFECT OF RESIDUAL INOCULUM ON LONGEVITY OF REPLACEMENT FLUID

Preparation of System Prior to Refilling	Bacterial Counts/ml		
	3 Days	1 Week	3 Weeks
1. DUMPING ONLY	1 x 10 ⁶	35 x 10 ⁶	45 x 10 ⁶
2. DUMPING--FOLLOWED BY RINSING OF VISIBLE SURFACES	2 x 10 ⁵	4 x 10 ⁶	25 x 10 ⁶
3. DUMPING--FOLLOWED BY FILLING WITH WATER AND MACHINE CLEANSER	4 x 10 ⁴	6 x 10 ⁵	1 x 10 ⁶

System: 200 gal. individual machine
Fluid: 4% soluble oil
Operation: broaching cast iron

TABLE 5

MICROBIAL ECOLOGY OF A CENTRAL SYSTEM WITH A FECAL ODOR

Type	No. of Organisms/ml
1. Total Bacterial Count.	133 x 10 ⁶
2. <u>Proteus</u> sp	1 x 10 ⁶
3. <u>Coliform</u> sp	7.2 x 10 ⁵
4. Yeast.	1 x 10 ⁶
5. Fungi	0

Central system: 45,000 gal.
 Fluid: 3% soluble oil; 2% synthetic
 Operation: milling nodular iron

TABLE 6

ASSOCIATION OF FUNGI IN CUTTING FLUID WITH SOLID AGGREGATES

Fungal Count in Fluid 2/ml

Fungal Count in Aggregate ... 30,000/gm.

Central system: 45,000 gal.
 Fluid: 5% synthetic, trace of soluble oil
 Operation: milling nodular iron

TABLE 7

THE BIOCIDES

- SOLUBILITY
- STABILITY IN CONCENTRATES
- SYNERGISM vs. ANTAGONISM
- BIOLOGICAL vs. CHEMICAL HALF-LIFE
- CONCENTRATION EFFECT
- ANTI-MICROBIAL SPECTRUM

TABLE 8

THE EFFECT OF DOSING SCHEDULE

Machine #2--57,000 Gallons
 Soluble Oil 20-1 Machining Nodular Iron

Date	Bacteria	Dose
5-5 . . .	160 million . . .	
5-10	1,500 ppm
5-12 . . .	0	. . .
5-23 . . .	0	250 ppm
5-31 . . .	0	250 ppm
6-9 . . .	0	250 ppm
6-27 . . .	80 million . . .	
6-28	250 ppm
7-2 . . .	140 million . . .	1,000 ppm
7-5 . . .	0, but fungus!	

TABLE 9

THE EFFECT OF BIOCIDES CONCENTRATION

Soluble Oil 1-20 Laboratory Model Cast Iron

	WEEK #1		WEEK #2		WEEK #3		WEEK #4	
	Bacteria	Fungi	Bacteria	Fungi	Bacteria	Fungi	Bacteria	Fungi
CONTROL	35x10 ⁶	14x10 ⁴	105x10 ⁶	65x10 ²	77x10 ⁶	10x10 ³	1x10 ⁹	4x10 ³
500 ppm	0	35x10 ²	0	5x10 ³	3x10 ⁶	30x10 ³	30x10 ⁶	8x10 ³
1500 ppm	0	0	0	0	0	0	0	0

Replacement Rate: 10 percent weekly with germicide

TABLE 10

THE EFFECT OF BIOCIDES MIXTURES: SYNERGISM

Biocide ppm	WEEK 1		WEEK 2		WEEK 3	
	B/ml	F/ml	B/ml	F/ml	B/ml	F/ml
A 1000	0	10	6 x 10 ³	10 ³	0	10 ⁴
A 1000 + B 50	0	0	0	0	0	0
A 500	10 ⁷	2 x 10 ⁵	10 ⁶	2 x 10 ⁵	2 x 10 ⁷	10 ⁴
A 500 + B 50	0	0	0	0	0	0
A 250	10 ⁷	10 ⁶	5 x 10 ⁶	2 x 10 ⁵	10 ⁷	10 ⁵
A 250 + B 50	300	0	0	0	0	0
B 50	10 ⁶	5 x 10 ³	10 ⁶	2 x 10 ⁴	10 ⁶	0
Control	2 x 10 ⁶	0	6 x 10 ⁵	0	2 x 10 ⁶	0

B = Bacteria
F = Fungi

TABLE 11

THE EFFECT OF BIOCIDES MIXTURES: ANTAGONISM

Biocide ppm	WEEK 1		WEEK 2		WEEK 3	
	B/ml	F/ml	B/ml	F/ml	B/ml	F/ml
A 1000	0	0	0	0	0	0
A 1000 + B 50	0	0	0	15	10 ⁴	2 x 10 ⁴
A 500	0	0	0	160	0	2 x 10 ⁶
A 500 + B 50	4 x 10 ³	0	3 x 10 ⁵	160	9 x 10 ⁵	4 x 10 ³
A 250	0	0	0	0	0	10 ³
A 250 + B 50	3 x 10 ⁶	0	4 x 10 ⁷	0	3 x 10 ⁷	0
B 50	2 x 10 ⁶	0	2 x 10 ⁵	0	6 x 10 ⁵	0
Control	3 x 10 ⁶	0	5 x 10 ⁵	0	2 x 10 ⁷	0

B = Bacteria
F = Fungi

TABLE 12

EFFECT OF SONIC OSCILLATION ON BACTERIAL LEVELS IN SOLUBLE OIL

Time of Oscillation	Bacterial Count/ml		Temperature of Fluid	
	Before	After	Before	After
5 minutes	5 x 10 ⁵	5.5 x 10 ³	25°	40°
15 minutes	8.7 x 10 ⁸	2.1 x 10 ⁴	20°	45°

Oscillator: Branson model 220
Sound output - 50-55 kHz
Power output - 100W