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Coolant Capability Study

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Department of Chemical, Biomolecular, and Corrosion Engineering

Honors Research Project

Submitted to

The Williams Honors College

The University of Akron

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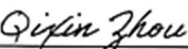


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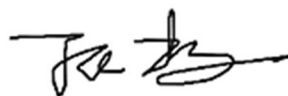
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1. EXECUTIVE SUMMARY

From this research, an investigation was done into the feasibility of integrating a biobased coolant into an already existing manufacturing operation where a heavy-duty coolant is currently being used. This was tested, alongside two semi-synthetic coolants for additional data points, to see how different base coolants would impact the performance in an intense manufacturing environment. There are set chemical characteristics and corrosion resistance properties required for option in this manufacturing operation, so testing for them would ensure the best coolant is selected. From this study it was determined that the heavy duty coolant performed the best with the ecofriendly coolant performing the worst. However, from the data collected on the ecofriendly coolant, a baseline has been recorded which can help in further selection and testing of a more ecofriendly coolant. From the chemical characteristic testing, more in depth corrosion testing was done with the heavy duty coolant to determine the concentrations of contaminants (chlorides and sulphates) before failure. From this testing a database of results can be collected and held for further reference and research as the company looks for more environmentally friendly options.

2. ABSTRACT

In manufacturing there are several factors that need to be taken into consideration, for example: feasibility, costing, and environmental impact. To produce a product through machining, a coolant is needed to maintain that cutting speed while also lubricating and protecting the tooling and product from damage. This coolant, metal working fluid, needs to work well with the composition of the product as well as other fluids it may come into contact with like honing oils, rust preventatives, and other metalworking fluids. On top of these the cost of a fluid can impact the decision as well as the impact it can have on the environment. In this work, an examination was

done on the feasibility of incorporating an ecofriendly coolant into an already existing manufacturing operation at the Timken Company. Current coolants must meet chemical characteristics and provide some corrosion resistance to the product being produced. With a new bio-based coolant an evaluation was done to see if it is compatible to be integrated into the existing process. While this specific ecofriendly coolant did not meet the chemical characteristics standard, a baseline corrosion resistance was determined and compared to current coolant. From these results, future research and selection of an ecofriendly coolant can be done that would better meet the standards and environment at the Timken Company.

3. INTRODUCTION

Metalworking fluids took time to evolve into what is used in the modern day. Beginning in the 19th century, one of the first metal working fluids was water. It was easily accessible and kept the cutter cool although it may not have provided the best lubrication to the cutting-object interface [19]. This was not a huge issue as it is today because the machines were not operating at as high speeds then as they do today. Another modification of water as a metalworking fluid was using soda water or sodium bicarbonate in water as it provided a slightly better rust inhibitor of the machine. Some other practices that have since fallen out of favor to more effective methods were using animal fats, mixing lead into animal fats, and into the mid-20th century 1, 1, 1-trichloroethane was an additive used in cutting fluids to increase efficiency. However, this was phased out as it was had ozone depleting and central nervous system depressing properties after further study [20].

Over time, four basic categories of metalworking fluids have been developed: straight (pure) oils with no dilution, soluble oils which have a high petroleum oil content (designed to dilute in water to have a milky dispersion), semi synthetics containing a low-moderate oil content with some water

and performance additives, and synthetics that contain only water and water soluble additives [10]. The last three options are normally sold as concentrates that are then diluted to the desired concentrations, ~5-10% is average. Similar product made from vegetable or synthetic oils are also available but based on the level of oil content the performance will vary comparatively to the above categories. For a visual comparison see Figure 1, displaying the differences between the four categories.

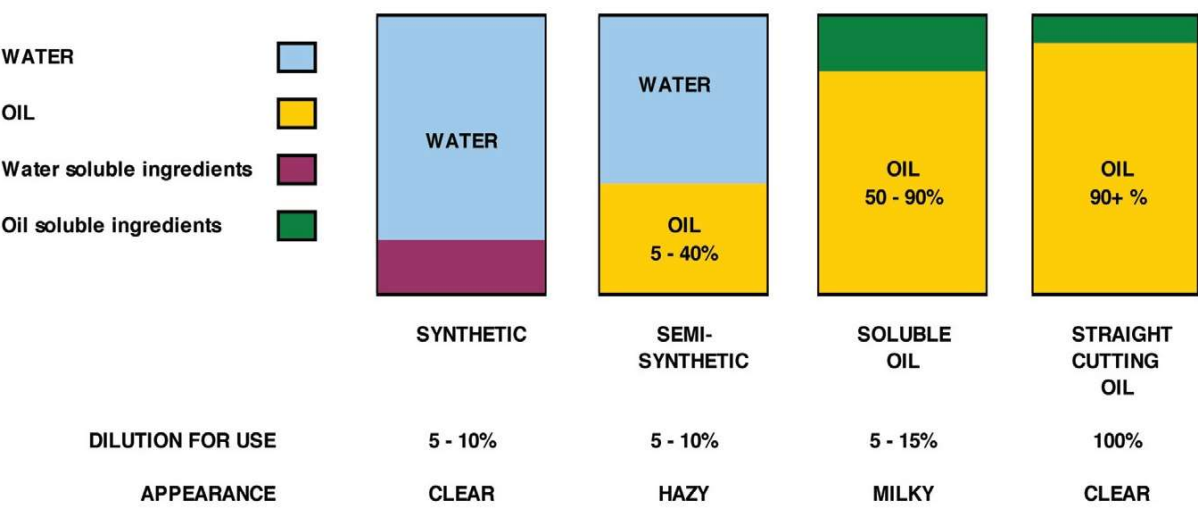


Figure 1. Visual displaying the four-metalworking fluid classifications [10].

For the synthetic, as seen in *Figure 1*, it is a clean oil as it contains pure water and known synthetics that are also soluble ingredients. It serves as an excellent heat reducer and remains unaffected by hard water [10]. Because there is no oil it experiences low to no foam and will reject any oil exposed to the fluid. One can see this as it is a transparent mixture, and any contaminant oil will float to surface and be discolored. Some disadvantages of this are due to the high-water concentration that provides little to no physical lubricity and no oily protective films post machining. These protective films normally act as a short-term rust preventative and protect the machined surface from contaminants.

For the semi synthetics, as seen in *Figure 1*, they are also a cleaner option being a majority water and offer good heat reduction. Since oil is also a part of the mixture there is the added benefits of physical lubricity and the protective film for rust control. However, with the oil, the mixture has the likelihood of foaming and can be impacted by hard water [15].

For the soluble soils, as seen in *Figure 1*, being a majority oil, they offer excellent physical lubricity, rust control from the protective film, some heat reduction, and can be easier to manage as the mixture does not evaporate off like in the synthetics. However, with the increased oil concentrations, the residue left behind can be extreme and too thick on machined parts. The mixture can be impacted by hard water, and from the high temperatures of machining, the oil mixture can cause a blue haze/mist and smoke being a safety hazard for the operator.

For the straight oils, as seen in *Figure 1*, being +90% oil, they offer some of the best lubrication and rust control for machining parts. In addition, they have the added benefits of having a longer life and being easy to manage with no water content and minimal other additive content to monitor for. With these benefits there are some costs, they can be expensive, cause excessive heat generation leading to smoke and in some cases fire hazards. They are messier than the other options being a majority oil and can leave oil mist lingering in the air. All of this requiring extra safety precautions and trainings to ensure safe operation and use.

From the advantages and disadvantages listed above, one can then apply them to applications to see when and where the different fluids would perform the best. To simplify it a bit as there are hundreds and thousands of applications, they are broken down into four groupings as seen in *Table 1*.

| | MACHINING | GRINDING |
|-----------------------|---|--|
| VERY HEAVY DUTY | Broaching Form Tapping Reaming Threading Gear Cutting | |
| HEAVY DUTY | Drilling Sawing Cut-Tapping | Creep Feed Form, Thread & Flute |
| MODERATE DUTY | Turning | Tool Room Internal Center-Type Centerless |
| LIGHT DUTY | Milling | Surface Double-Disk Rotary |

Table 1. Machining & Grinding categories ranked by severity [10].

These have been grouped by the Society of Tribologists and Lubrication Engineers for ease of definition. As seen in *Table 1*, machining requiring the most force and speed as well as generate high temperatures would require the most heavy-duty lubricant capable of keeping the cutter cool at those high speeds and intensity. Whereas, at the lighter duty machining and grinding, a cheaper or less intricate option can be utilized.

| Severity of Operation | Synthetic | Semi-Synthetic | Soluble Oil |
|-----------------------|--|---|-----------------------------|
| Light | Rust inhibitors & cleaning agents only. No lubricants. | Low oil content (5%-10%) + rust inhibitors. | |
| Moderate | Some polymeric lubricants. | High oil content (20%-30%). | High oil +/- esters & fats. |
| Heavy | High-level polymeric lubricants + phosphate ester. | High oil + EP lubricants. | High oil + EP lubricants. |

Table 2. Metalworking Fluids for the severity of operation [10]

Based on the classifications in *Table 1*, *Table 2* lists the best metalworking fluids for the severity of operation. As previously mentioned, the light operation requires less intensity in the operation and therefore will not need as intense lubrication for its operation so the synthetic for rust inhibition and cleaning is a good option. Another option being a low oil content with rust inhibitors for the semi-synthetic as the main concern for this operation would be protecting the machined parts from rust along with the machining system and keeping it clear of any debris. For the more moderate scenarios, lubrication becomes more of a necessity as the applications are getting into turning and tool-room operation-more intense operations. More oil content fluids would be the preference as they can offer better lubrication than the general synthetic, but some of the polymer lubricants would also be applicable. Then for the heavy-duty operations, the higher/highest oil level fluids would be necessary to keep up with the intensity and lubricate the machines. Making the more semi-synthetic and soluble oil fluids the preference over synthetic.

One option that some have investigated for machining is eliminating metalworking fluids altogether or limiting the amount applied. This process is known as ‘dry machining’ and the latter as ‘near-dry machining’ or ‘minimum quantity lubrication machining’ [18]. However, with the directives for implementing these methods coming primarily from the management standpoint, little to no attention is being paid to the system or physics implications this would have. In *Figure 2*, is one such example and shows the impact of tool wear and machining time with dry vs wet (metal working fluid machining). From the figure, the dry machining experienced a higher turnover of tool wear and shorter tool life/machining time [16]. Whereas the machining with fluid saw a longer life of the tool over a greater machining time.

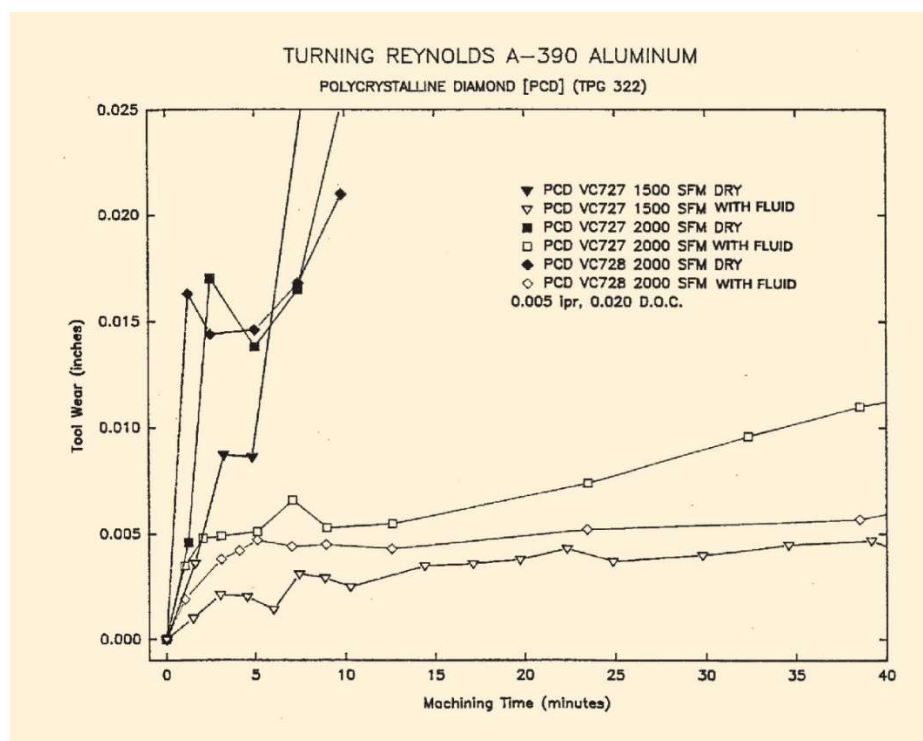


Figure 2. Graph displaying tool wear vs machining time for dry and wet machining [10].

An alternative option more prevalent today and that does not fit into the basic four categories is the biodegradable lubricant. There are three basic definitions for biodegradability from the Organization for Economic Co-operation and Development (OECD): readily biodegradable,

ultimate biodegradation (aerobic), and inherently biodegradable [21]. To be readily biodegradable the substance has had 70% removal of dissolved oxygen and carbon and 60% of theoretical oxygen demand or theoretical carbon dioxide production obtained by the respirometry test methods [see reference 21 for test methodology]. To achieve ultimate biodegradation, the test compound is 100% used up by microorganisms resulting in the production of carbon dioxide, water, mineral salts, and a new microbial cellular biomass. A substance can show inherent primary biodegradation if it exhibits biodegradation above 30% theoretical and inherent ultimate biodegradation above 70% theoretical. As companies look for ways to be more environmentally friendly, switching metalworking fluids to a biodegradable counterpart is on the docket and holding it to such standards as above ensures that the products being produced are biodegradable to a standard and not just a word printed onto the container [21].

In manufacturing, metalworking fluids have a variety of uses in the manufacturing process. When properly maintained, these fluids can provide lubrication, cooling, corrosion protection, and flush debris from the work surface [2]. Unlike other lubricating fluids, metalworking fluids will be exposed to the shop environment and will pick up contaminants. With some common contaminants in manufacturing operations being chlorides and sulfates. Because of this, it is important to understand the full capabilities of the metalworking fluid and the performance limitations before use in manufacturing environments. Trying and testing new coolants is essential to this process as it helps to identify any issues before introducing a new metalworking fluid to the manufacturing line and enables the company to find alternatives and/or make changes, as necessary.

4. EXPERIMENTAL

In order to carry out some testing to identify if a coolant will work in a specific manufacturing environment, some additional tools/equipment are necessary to have. Equipment used in the

coolant study was a humidity cabinet, oven, and pH meter. In addition, the coolants were tested on low-carbon steel Q-coupon panel following using a method in ASTM D-1748 (Standard Test Method for Rust Protection by Metal Preservatives in the Humidity Cabinet) [8]. For this specific study, the coolants will be denoted as 'coolant X' (e.g., coolant A, coolant, B, etc.) as the specific names are propriety information to the Timken Company. Coolant A is a high lubricity, long-life, and heavy-duty lubricant recommended to be used at 5-10% dilution with water in applications such as automotive, high alloy steels, and cast iron. Coolant B is a semi-synthetic metalworking fluid containing a mix of additives enhancing its machining performance and surface finish to be used at ~5% dilution. It is recommended for cast iron, low-medium alloyed steel, and high alloyed stainless steel. Coolant C is another semi-synthetic metalworking fluid which is very versatile across applications as it is robust, chlorine-free, and has been formulated to run with aerospace grade alloys/metals with the dilution of the concentrate varying from ~3-5%. Coolant D is a biobased, vegetable based, concentrate with additives (e.g., sulfur) to increase performance and make a more economical general-purpose coolant with the suggested dilution ~5-10%.

To prepare the coolant samples for testing, fresh samples of the concentrates were taken and diluted with deionized water (DI) to 5% for all coolants and the bottles were labeled with the name and dilution. To begin the testing, the sample bottles were thoroughly agitated to ensure complete mixing of the concentrate and DI water. The mixability of the concentrates was noted based on how well they went into solution. Afterwards, to evaluate for the stability of the solutions, the samples were left to sit for about a month period at room temperature and were observed to see whether they would stay in solution, fall out of solution, or if a precipitate would form. Results were recorded and images taken of any changes. To test the alkalinity of the solutions, 10ml of the

freshly prepared candidate solution put in a beaker. The pH meter was calibrated prior to testing to ensure accuracy. The pH of each solution was then taken and recorded.

To record how well the coolants will perform with other metalworking fluids in the plant environment, the tramp oil rejection test was performed along with the persistence of coolant to foam test in a similar manner to ASTM D7112-19 (Standard Test Method for Determining Stability and Compatibility of Heavy Fuel Oils and Crude Oils by Heavy Fuel Oil Stability Analyzer (Optical Detection) [9]. For each candidate, 25ml of solution was taken and placed into a 100ml separatory funnel. After adding 5.0ml of hydraulic oil to the funnel, the funnel was shaken vigorously for 1 minute. Once the minute was up, a timer started and the solutions were visually observed following ASTM D7112-19 [9]. The times it took for any foam that formed to subside and for the oil to split out of the solution were recorded for each solution.

The last test performed was the rust prevention test which was followed in a similar manner was ASTM D-1748[8]. A bare steel Q-panel was prepared for each candidate solution to be tested by sanding down each side of the panel with 400 grit sandpaper and wiping the surface clean with filtered hexane. The coupon was labeled with a Dremel tool and placed in a beaker filled with filtered hexane. Then, the beaker was placed into an ultrasonic tank and cleaned for at least 2 minutes to remove any excess debris from the surface. Once removed, a wire was strung through the panel's hole and secured. A 250ml beaker was filled with the candidate solution and the prepared Q-panel was dipped into the beaker allowing for complete coverage of the panel. Then the panel was removed and hung to dry for ~20minutes ensuring the coupon did not touch any other surface in this time. Once dry, the coupon was placed into a humidity cabinet at 48°C, 90% relative humidity (%RH) for a period of one week. Panels were checked daily to track any progression of corrosion or failure of the panels.

5. RESULTS AND DISCUSSIONS

Coolant Chemical Characteristics Testing

For the mixability and stability tests, a ranking system from 1-5 was used. With 5 performing the best and 1 the worst. The cut off point for meeting requirements to be used in a manufacturing environment is a rating of 4 because at 3, the solutions were seen to be unstable for longer periods of time and would require extra steps/equipment to be used (e.g., agitator, mixer).

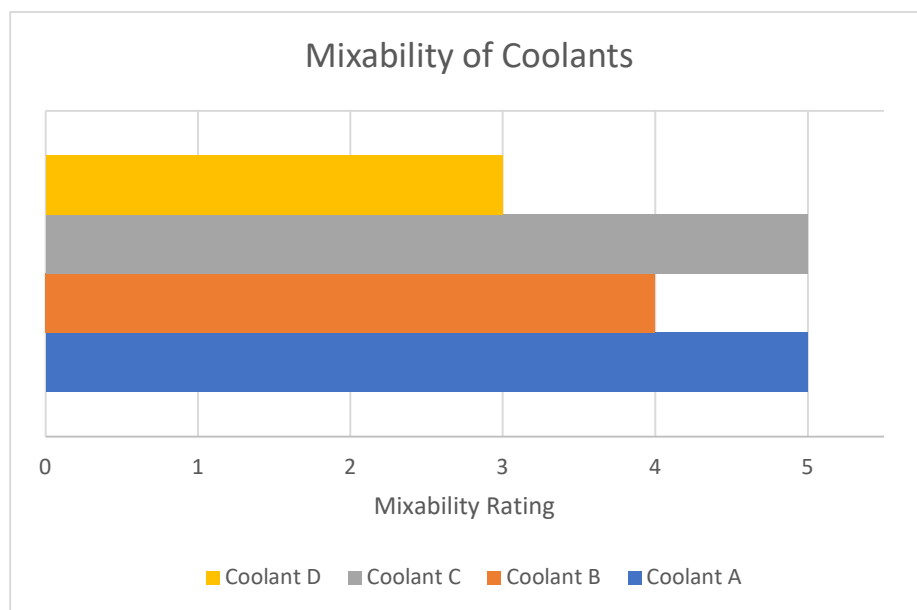


Figure 3. Mixability rating of the four coolants. Mixability of coolant D (biobased) did not meet specifications.



Figure 4. Coolant D (biobased) after mixing the 5% solution. The precipitates that formed out of the solution brought up concern of stability of the coolant.

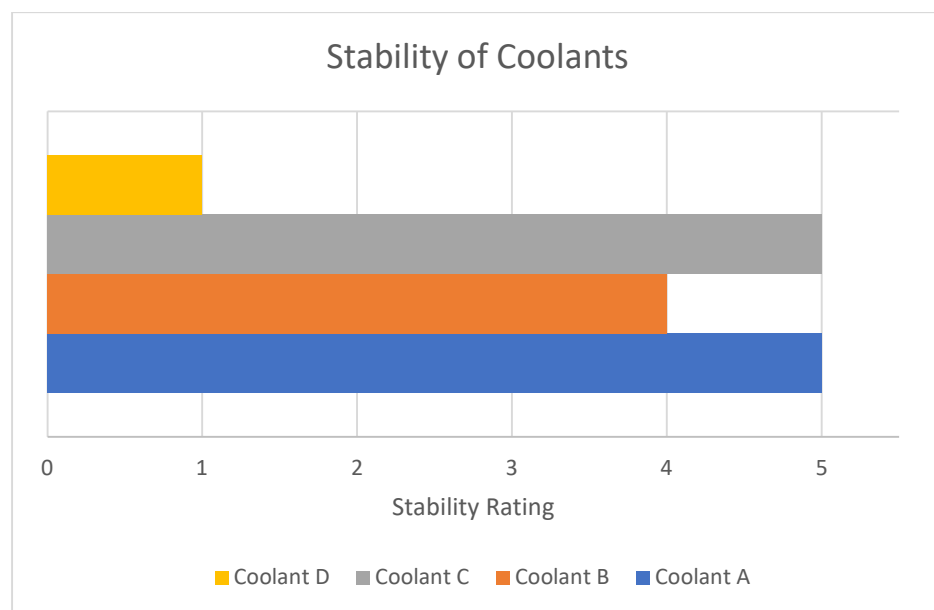


Figure 5. Stability rating of the four coolants. Coolant D (biobased) would not meet requirements for use in manufacturing environments.

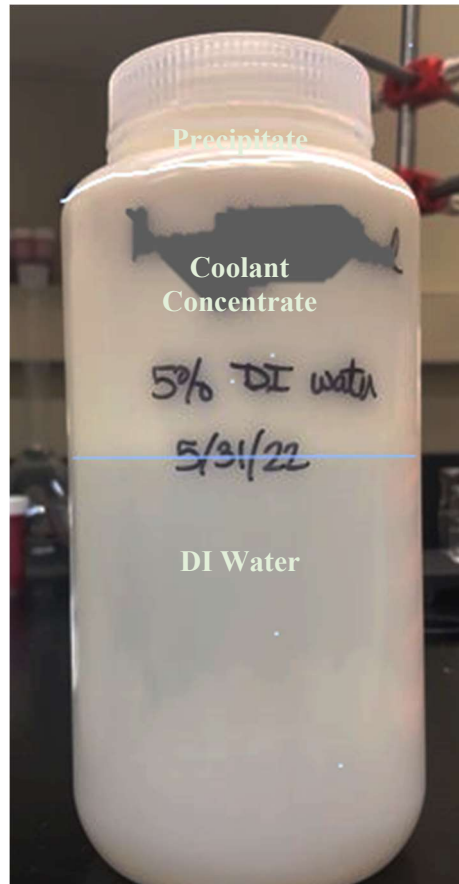


Figure 6. Coolant D stability after mixing, showed three separate layers of solution after sitting out 24 hours.

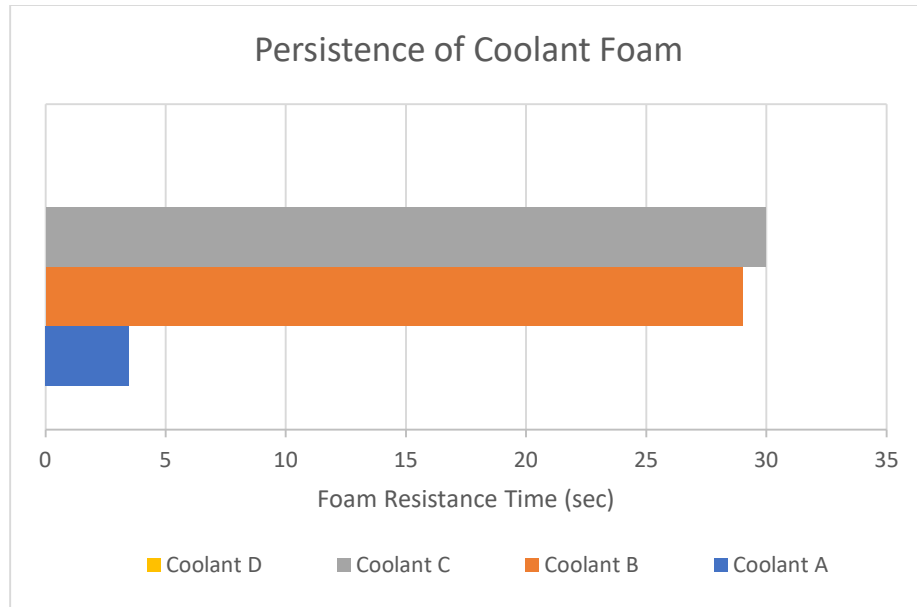


Figure 7. Persistence of Coolant Foam of the four coolants. Coolant D did not foam. Coolants C and B would require a foam inhibitor additive for use in a manufacturing environment.

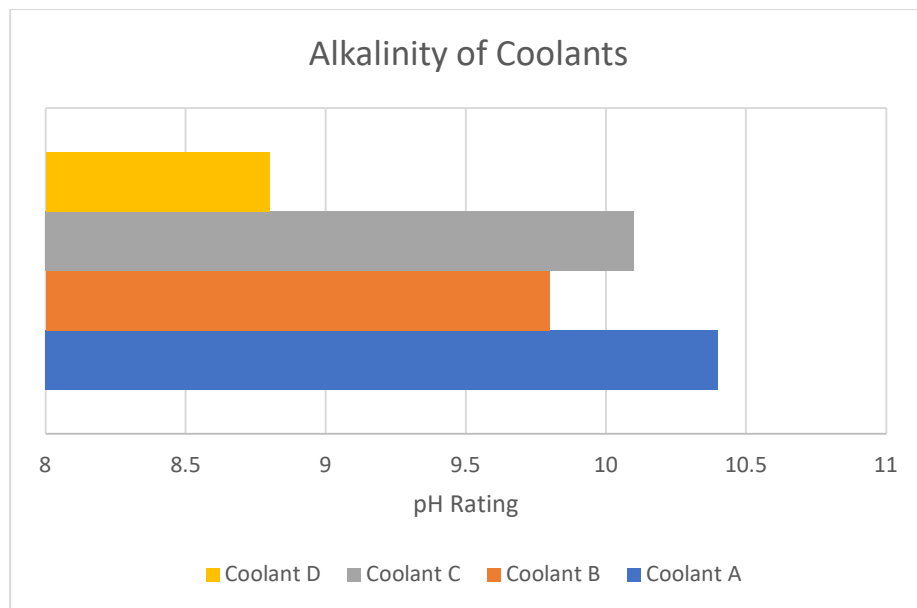


Figure 8. Alkalinity measurements of the four coolants. Coolants with a similar pH are less likely to react if there is cross contamination. The pH of Coolant D (biobased) may react with existing coolants.

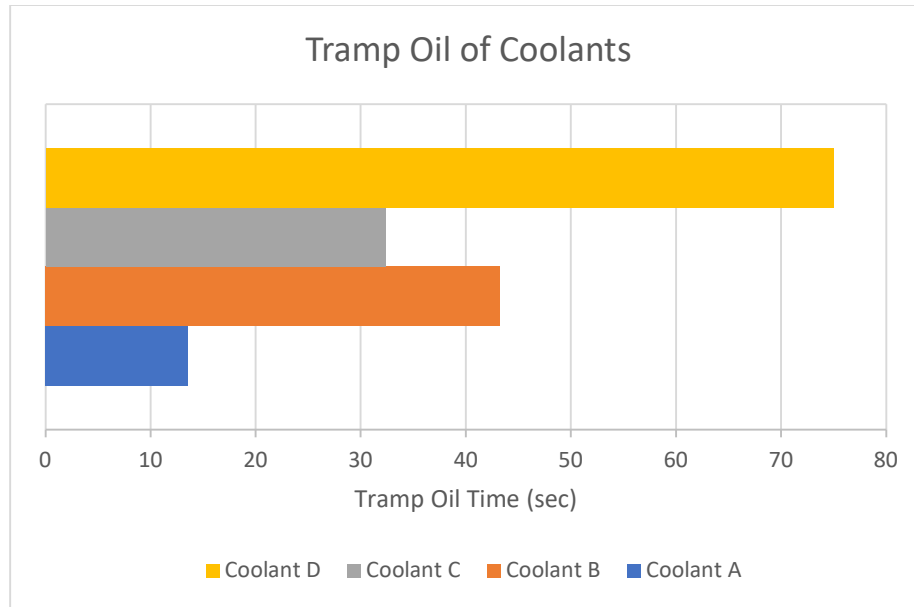


Figure 9. Tramp oil rating of the four coolants. Coolant A (heavy-duty) separates the fastest and would minimize the tramp oils changing the coolant performance.

By the performance in the tests above, coolant A (heavy-duty) was the only coolant that met all specifications and had little to no concern meeting Timken specifications for metalworking fluids. Therefore, it was chosen to be the coolant used for corrosion testing following ASTM D-1748 [8] to see how chlorides and sulfates impact the performance of coolants in corrosive environments.

Chloride Contamination Corrosion Testing

The concentrations of chloride testing were selected as 50 ppm, 100 ppm, and 150 ppm using sodium chloride (NaCl). These concentrations were chosen because in previous studies, chlorides have been found to be corrosive in the smallest of concentrations [23]. Samples were coated with the contaminated coolant and visually observed at regular intervals. Figures 10-12 show the results for 50 ppm of chloride contamination. Figures 13 and 14 show the effect of 100 ppm chloride and Figures 15 and 16 show the effect of 150 ppm chloride.



Figure 10. A steel coupon coated with coolant A (heavy-duty) containing 50ppm Cl^- showed no change after 1 day at 90% RH and 48°C.

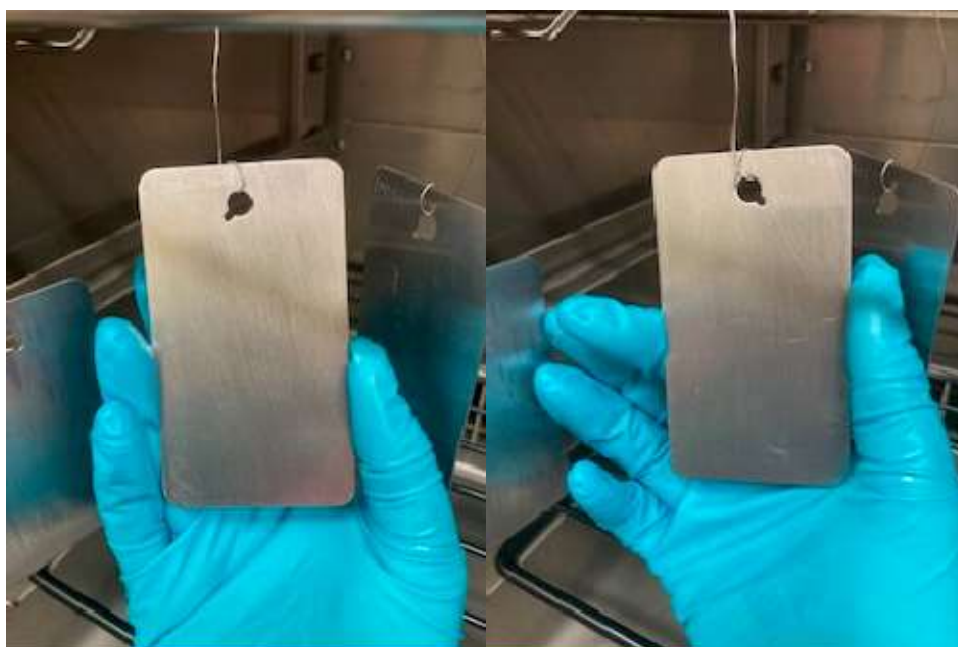


Figure 11. A steel coupon coated with coolant A (heavy-duty) containing 50ppm Cl^- showed no change after 1 week at 90% RH and 48°C.

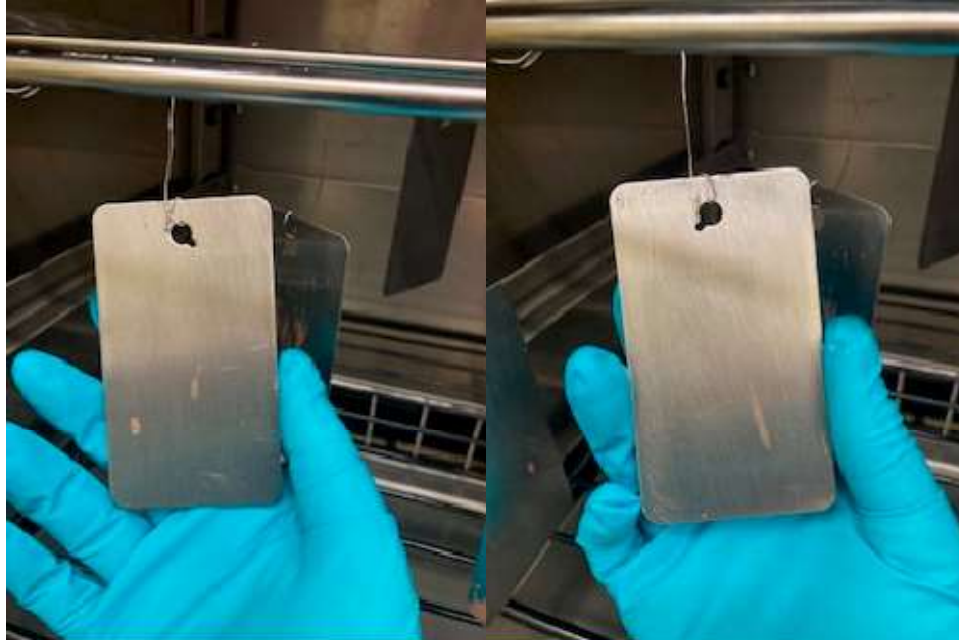


Figure 12. A steel coupon coated with coolant A (heavy-duty) containing 50ppm Cl^- showed corrosion after 2 weeks at 90% RH and 48°C.



Figure 13. A steel coupon coated with coolant A (heavy-duty) containing 100ppm Cl^- showed some corrosion after 1 week at 90% RH and 48°C.

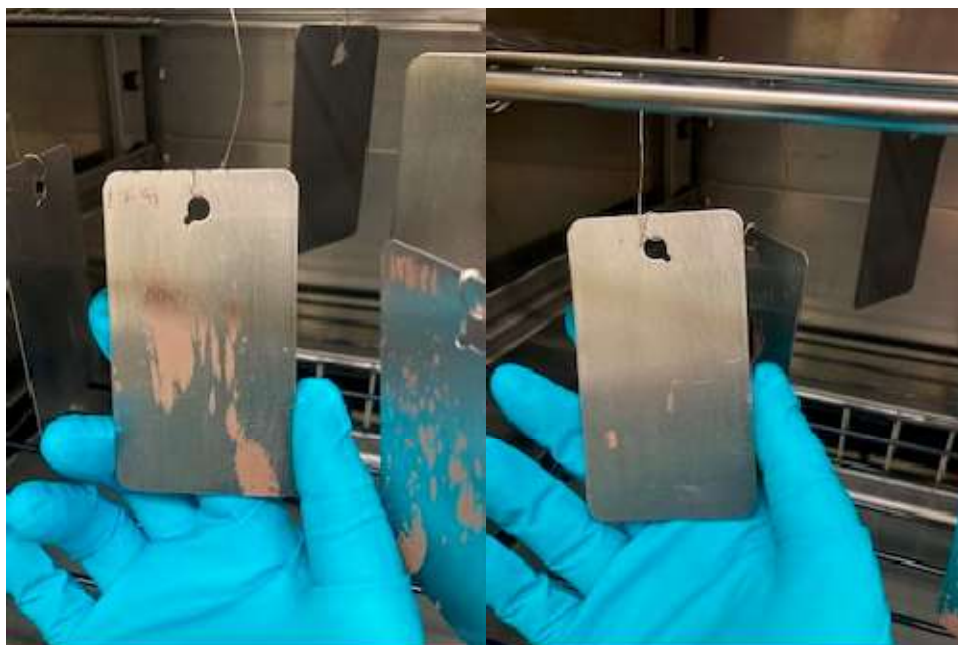


Figure 14. A steel coupon coated with coolant A (heavy-duty) containing 100ppm Cl^- showed progressively worse corrosion after 2 weeks at 90% RH and 48°C.



Figure 15. A steel coupon coated with coolant A (heavy-duty) containing 150ppm Cl^- showed some corrosion after 1 week at 90% RH and 48°C.



Figure 16. A steel coupon coated with coolant A (heavy-duty) containing 150ppm Cl^- showed severe corrosion after 2 weeks at 90% RH and 48°C.

The severity of corrosion increased with increasing chloride contamination. Based on ASTM D-1748 [8], all three coupons failed the test after 2 weeks at 90% RH and 48°C with more than six spots of corrosion on the surface of the coupon.

Sulfate Contamination Corrosion Testing

The concentrations of sulfates tested in Coolant A (heavy-duty) were selected as 100ppm, 200ppm, and 300ppm using sodium sulfate (Na_2SO_3). These concentrations were chosen as sulfates are less corrosive than chlorides and would need higher concentrations to see similar results as chlorides. In order to obtain the best results, it was decided to start at a slightly higher concentration of 100ppm and progress at increments of 100.



Figure 17. A steel coupon coated with coolant A (heavy-duty) containing 100ppm sulfate showed no change after 1 day at 90% RH and 48°C.



Figure 18. A steel coupon coated with coolant A (heavy-duty) containing 100ppm sulfate showed some corrosion after 1 week at 90% RH and 48°C.



Figure 19. A steel coupon coated with coolant A (heavy-duty) containing 100ppm sulfate showed some corrosion after 2 weeks at 90% RH and 48°C.

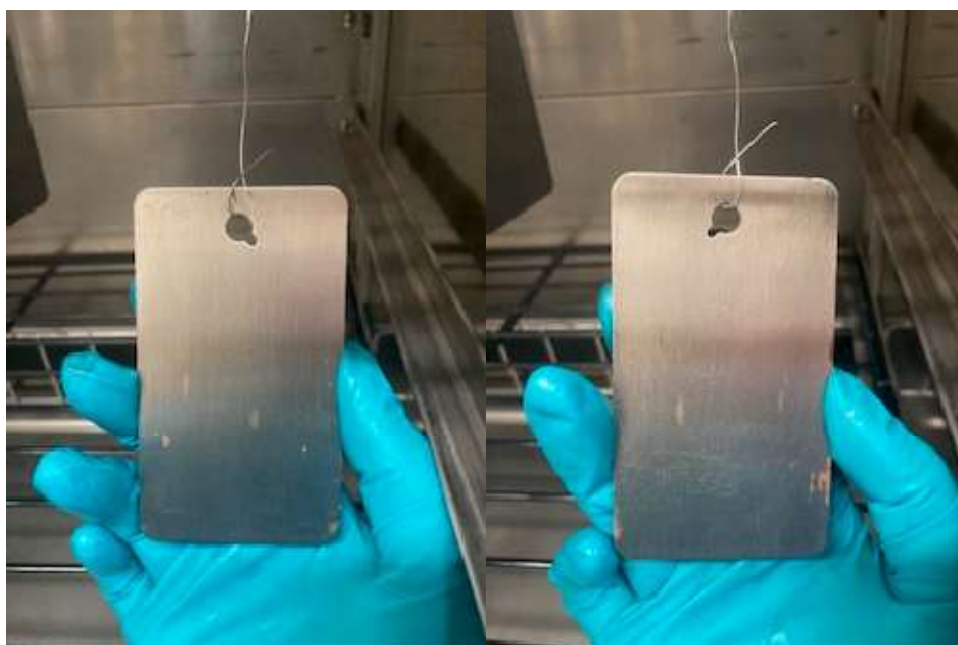


Figure 20. A steel coupon coated with coolant A (heavy-duty) containing 200ppm sulfate showed some corrosion after 1 week at 90% RH and 48°C.



Figure 21. A steel coupon coated with coolant A (heavy-duty) containing 200ppm sulfate showed progressively worse corrosion after 2 weeks at 90% RH and 48°C.



Figure 22. A steel coupon coated with coolant A (heavy-duty) containing 300ppm sulfate showed some corrosion after 1 week at 90% RH and 48°C.



Figure 23. A steel coupon coated with coolant A (heavy-duty) containing 300ppm sulfate showed severe corrosion after 2 weeks at 90% RH and 48°C.

After the two weeks at 90% RH and 48°C the coupons exposed to sulfate-contaminated coolant also experienced severe corrosion. Compared to the chloride-contaminated coupons, the progression is similar to that of the chlorides; however, it took higher concentrations of the sulfates to get these results. Looking at the 100ppm coupons between the sulfates and chlorides, the chlorides had an much more severe and spread out corrosion after the 2 week period despite being the same concentration. Which can infer that chlorides are more corrosive than sulfates are; therefore, there should be a lower tolerance for chloride contamination in manufacturing than sulfates where the concentration can be higher and have less of an impact.

6. DESIGN CONSIDERATIONS

When working with metalworking fluids, some of the larger concerns are: “What is in it?”, “How will this react with the other fluids in my facility?”, “How expensive is it?”, and, a newer one, “Is it environmentally friendly?” These are common questions that facilities look into when certifying a new fluid in their facility and coolants are no different. For coolants,

biodegradability is an important factor in determining if they are environmentally friendly. For determining if a coolant is biodegradable there are different degrees of biodegradability from readily to non-biodegradable (see

Table 3 below).

| Type of Biodegradability | % degraded | Period |
|--------------------------|-------------|-----------------------------|
| Readily Biodegradable | $\geq 60\%$ | 28 days \pm 10 day window |
| Ultimately Biodegradable | $\geq 60\%$ | 28 days |
| Inherently Biodegradable | 20-60% | ≥ 28 days |
| Non-biodegradable | $\leq 20\%$ | 28 days |

Table 3. Four types of biodegradability based on amount of MWF degraded over a 28 day period.

To determine if a fluid is more eco-friendly and biodegradable, running OECD Guidelines for Testing of Chemicals- Test No. 301: Ready Biodegradability [22] can determine what type of biodegradability the coolant has. It acts as a good marker to determine if a labeled coolant is actually fully biodegradable or if it falls somewhere different on the spectrum. Another couple of general rules to predict if a substance will be biodegradable were noted by Tyler Housel, expert from Zschimmer & Schwarz, who noted that for any specific substance any of the following rules may dominate [11]:

1. Vegetable oils (triglyceride esters) and synthetic esters are more biodegradable than pure hydrocarbons.
2. High viscosity/high molecular weight slows biodegradability.
3. More polar groups improve dispersibility.
4. Branched hydrocarbon chains reduce biodegradability.

Being able to determine if the coolant to be used is biodegradable and how the chemistry within it can limit its performance is important to best be able to dispose of it properly and have a smaller carbon footprint. However, from the testing above, there was a poorer performance from the biodegradable coolant, which is concerning when discussing switching to a more ecofriendly option. However, these tests were geared to integrating a new coolant into a system already in place with other fluids currently in use. If a new plant/facility were to be built with being more environmentally conscious in mind, the facility could be designed around the shortcomings of the biodegradable options and the performance would not? be impacted as much. This would open a good opportunity to grow the market for these newer fluids and allow the research for them to grow too. It may also lead to improving their overall performance with time.

The other concern to be looked at is the cost comparison between these different types of coolants. A limiting factor for switching to an ecofriendly coolant, is the initial cost rather than the overall cost benefit. In addition, depending on the makeup, biodegradable lubricants can impact the performance. Many initial biodegradable options were made from lower-cost vegetable oils. They performed poorly and got a bad reputation in the manufacturing industry. However, newer options have been made from synthetic hydrocarbons, which can help maintain the higher performance similar to mineral oils with the added benefit of being ecofriendly and less toxic [11].

However, in order to increase this knowledge of newer options of biodegradable lubricants and to continue the testing, cost is a large barrier, with some of the basic tests costing up to \$15,000 for a single round of testing [11]. With having additional testing costing thousands more, it has severely limited the growth of the field. Lowering the cost of this testing or increasing the funding/support from industry would help the scientific study and growth of these new biodegradable lubricants. These lubricants can have a performance and cost that match that of

mineral oils but would have the added benefits of biodegradability, lower carbon footprint, and less toxicity to the environment with spills.

7. CONCLUSIONS

From the study, it was determined that coolant A (heavy-duty) performed the best in the initial tests which justified the further corrosion testing with chlorides and sulfates. Coolant A (heavy-duty) had good mixability and stability over time showing no concerns. In addition, it performed the best out of all the coolants in the persistence to foam test and rejecting the tramp oil. From the initial corrosion tests, it would be interesting to compare coolant A to coolant C (chlorine-free semi-synthetic), which performed mediocre in the coolant chemical characteristics (or whatever you call that section) tests. Because coolant C is semi-synthetic and chlorine free, it would be interesting to see how well it would protect the steel surface when contaminated with chlorides and sulfates and exposed to a corrosive environment. The biodegradable coolant, coolant D, did not meet requirements for the tests performed. However, it was a vegetable-based coolant, not a synthetic hydrocarbon-based coolant. This result does not necessary limit other biodegradable coolants from being acceptable for use, especially those made from the recent technology of synthetic hydrocarbons mentioned previously. For future testing, it would be interesting to see how a synthetic hydrocarbon coolant would compare to the heavy-duty and semi-synthetic coolants. In addition, adding the OCED [22] test to assess and rank how biodegradable the coolants are would provide a more complete cost-benefit analysis..

8. REFERENCES

1. J. V. Rensselaar, The Growth of Biobased Metalworking Fluids (2012), STLE- Featured Article,
https://www.stle.org/Shared_Content/TLT_Articles/Featured_Articles/The_Growth_of_Biobased_Metalworking_Fluids.aspx?WebsiteKey=a70334df-8659-42fd-a3bd-be406b5b83e5
2. Dr. N McGuire, Minding the metalworking fluids (2016), STLE- TLT Feature Article,
https://www.stle.org/files/TLTArchives/2016/04_April/Feature.aspx?WebsiteKey=a70334df-8659-42fd-a3bd-be406b5b83e5
3. ASTM D2881-19, *Standard Classification for Metalworking Fluids and Related Materials*, ASTM International, West Conshohocken, PA, 2019
4. Brinksmeier, E., Meyer, D., Huesmann-Cordes, A.G. and Herrmann, C. (2015),
“Metalworking fluids—Mechanisms and performance,” CIRP Annals—Manufacturing Technology, 64 (2), pp. 605-628. DOI: 10.1016/j.cirp.2015.05.003
5. N. Carter, Development of Guidelines for Using and Maintaining Metalworking Fluids (2008), STLE- TLT Feature Article,
https://www.stle.org/files/TLTArchives/2016/04_April/Feature.aspx?WebsiteKey=a70334df-8659-42fd-a3bd-be406b5b83e5
6. ASTM D1173-07, *Standard Test Method for Foaming Properties of Surface-Active Agents*, ASTM International, West Conshohocken, PA, 2015
7. ASTM D892-18, *Standard Test Method for Foaming Characteristics of Lubricating Oils*, ASTM International, West Conshohocken, PA, 2018
8. ASTM D1748-22, *Standard Test Method for Rust Protection by Metal Preservatives in the Humidity Cabinet*, ASTM International, West Conshohocken, PA, 2022

9. ASTM D7112-19, *Standard Test Method for Determining Stability and Compatibility of Heavy Fuel Oils and Crude Oils by Heavy Fuel Oil Stability Analyzer (Optical Detection)*, ASTM International, West Conshohocken, PA, 2019
10. J. Byers, Selecting the ‘perfect’ metalworking fluid (2009), STLE- TLT Best Practices, https://www.stle.org/files/TLTArchives/2009/03_March/Best_Practices.aspx?WebsiteKey=a70334df-8659-42fd-a3bd-be406b5b83e5
11. N. Canter, Biodegradable lubricants: Working definitions, review of key applications and prospects for growth (2020), STLE- TLT Feature Article, https://www.stle.org/files/TLTArchives/2020/12_December/Feature.aspx?WebsiteKey=a70334df-8659-42fd-a3bd-be406b5b83e5
12. N. Canter, Sustainable additives: Assisting with reducing the carbon footprint of lubricants (2022), STLE- TLT Tech Beat, https://www.stle.org/files/TLTArchives/2022/09_September/Tech_Beat.aspx?WebsiteKey=a70334df-8659-42fd-a3bd-be406b5b83e5
13. N. Canter, Upgrading biodegradable lubricant performance (2009), STLE- TLT Tech Beat, https://www.stle.org/files/TLTArchives/2009/06_June/Tech_Beat_I.aspx?WebsiteKey=a70334df-8659-42fd-a3bd-be406b5b83e5
14. Sounding Board- Please share one BEST PRACTICE you use regularly in your work and state your job title (2013), STLE-TLT Sounding Board https://www.stle.org/files/TLTArchives/2013/11_November/Sounding_Board.aspx?WebsiteKey=a70334df-8659-42fd-a3bd-be406b5b83e5

15. N. Canter, Foam: Dealing with a persistent problem (2015), STLE- TLT Feature Article,
https://www.stle.org/files/TLTArchives/2015/12_December/Feature.aspx?WebsiteKey=a70334df-8659-42fd-a3bd-be406b5b83e5
16. Dr. N. Canter, The Possibilities and Limitations of Dry Machining (2009), STLE- TLT Metalworking,
https://www.stle.org/files/TLTArchives/2009/03_March/Metalworking1.aspx?WebsiteKey=a70334df-8659-42fd-a3bd-be406b5b83e5
17. Sounding Board- What is the worst and most potentially dangerous lubricant practice you ever saw? (2011), STLE-TLT Sounding Board
https://www.stle.org/files/TLTArchives/2013/11_November/Sounding_Board.aspx?WebsiteKey=a70334df-8659-42fd-a3bd-be406b5b83e5
18. Astakhov, V. (2012). Environmentally friendly near-dry machining of metals. Metalworking Fluids (Mwfs) For Cutting and Grinding, 135-200. doi: 10.1533/9780857095305.135
19. Hartness Flat Turret Lathe Manual; a Handbook for Operators.: A Handbook ... : James Hartness : Free Download, Borrow, and Streaming : Internet Archive. (2022).
<https://archive.org/details/hartnessflattur00ha>
20. 1,1,1-Trichloroethane. (2022). https://pubchem.ncbi.nlm.nih.gov/compound/1_1_1-Trichloroethane#section=Uses
21. Test No. 301: Ready Biodegradability. (2022). https://www.oecd-ilibrary.org/environment/test-no-301-ready-biodegradability_9789264070349-en

22. OECD (1992), Test No. 301: Ready Biodegradability, OECD Guidelines for the Testing of Chemicals, Section 3, OECD Publishing, Paris,
<https://doi.org/10.1787/9789264070349-en>
23. OSTI (2012), Corrosion Mechanisms in Chloride and Carbonate Salts, Sandia Report, SAND2012-7594, Sandia National Laboratories, New Mexico, chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.osti.gov/servlets/purl/10517