MANAGEMENT OF MANUFACTURING MACHINE COOLANT CONDITION

by

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Gratitude to my parents who gave me life and a safe environment to grow up in. I thank my wife Klara for her love and for encouraging me to pursue the MSET program and always supporting me. I appreciate Uncle Frank for mentoring my professional development. Thanks to Hadady Corp for sponsoring the research.

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LIST OF ABBREVIATIONS

AIAG	Automotive Industry Action Group
ASTM	American Society of Testing and Materials
CM	Conditions Monitoring
EP	Extreme Pressure
EPA	United States Environmental Protection Agency
LSL	Lower Specification Limit
MO	Microscopic Organism
MRF	Metal Removal Fluid
MQL	Minimum Quantity Lubrication
MWF	Metal Working Fluid
NAE	National Academy of Engineering
OEE	Overall Equipment Effectiveness
OSHA	Occupational Safety and Health Administration
PM	Preventative Maintenance
P_p	Capability Measure
P_{pk}	Capability Measure
PPM	Parts per Million
SME	Small Medium Enterprise
USL	Upper Specification Limit
WB (coolant)	Water Based (coolant)

GLOSSARY

biofilm	Biological growth on the surface of a coolant tank (Passman, 2018).
buffering	The ability of a solution to resist changes in pH (Passman & Küenzi, 2020).
carry out	Coolant clinging to surfaces such as work piece or chip conveyor is lost from the coolant tank (Foltz, 2018).
change-out	The process of removing coolant, cleaning coolant tank, and adding fresh coolant (Foltz, 2018).
charge	A fresh batch of coolant added to the tank after cleaning (Seidel & Meyer, 2019).
common cause	Cause which produces only random variation in a system (Automotive Industry Action Group [AIAG], 2005).
dry machining	Machining without the aid of coolant.
contamination	Substances contained in in-use metalworking fluids that are not part of the received fluid, such as abrasive particles, tramp oils, cleaners, dirt, metal fines (American Society of Testing and Materials [ASTM], 2018, p. 5)
Great Lakes Basin	The basin is defined primarily by hydrology. Watersheds that drain into the Great Lakes and their connecting channels are in the Great Lakes basin. (Environmental Protection Agency [EPA], 2019, The Great Lakes Basin section).
insert	General term for a carbide indexable cutting bit.
make-up fluid	A coolant and water mixture added to the tank to account for coolant losses (Zebra, 2005).
metalworking fluid	Any fluid used for the purpose of cooling or treating metal surfaces during metal removal, metal forming, or surface protection or preservation. (ASTM, 2018, p. 5)
metal removal fluid	Any fluid in the subclass of metalworking fluids used to cut, or otherwise take away material or piece of stock. (ASTM, 2018, p. 5)
neat	Undiluted solution as sold (Byers, 2017).

P_p	Capability index between groups which considers the spread of the data (AIAG, 2005).
P_{pk}	Capability index between groups which considers the spread and centering of the data (AIAG, 2005).
R^2	Linear regression – a statistical measure of linearity (AIAG, 2005).
recharge	Replace old coolant in tank with fresh coolant (Seidel & Meyer, 2019).
sessile	A form of biofilm that grows on coolant tank surfaces usually at the splash zone. Sessile are differentiated from microbes residing in the fluid. (Passman, 2018).
sigma (δ)	A measure of process control. Standard deviation of a population or a sample. (AIAG, 2005).
special cause	Variation not caused by random sources (AIAG, 2005).
tramp oil	Waste oil from lubrication and leakage which accumulates in the coolant tank (ASTM, 2018).

ABSTRACT

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Coolants used in metal chip forming processes provide two major benefits: cooling and lubrication (Foltz, 2018). Water based machine coolants now dominate the metal forming industry (Benedicto et al., 2017). Water based coolant is a suspension of Extreme Pressure (EP) oils and other chemicals in a water base (Brinksmeier et al., 2015). Coolants have life cycle concerns including health, environmental and disposal (Canter, 2017). Managing the lifecycle of the coolant is critical. Maintaining consistent levels of parameters is the key to a predictable service life for the coolant (ASTM, 2017a). The report focused on metal chip forming processes typical of a lathe or vertical machining center at Hadady Corporation, rail division. The report examined the effect of careful control of coolant concentration and fluid level upon coolant life. Coolant pH was used as a predictor of coolant life. The report was inconclusive due to measurement system uncertainties and a limited timeline for data collection. A connection between fluctuations in coolant tank level and variation in coolant concentration and pH was revealed. The importance of achieving the target concentration at coolant changeout due to the difficulty in reducing concentration in service was highlighted. The report witnessed the recovery of pH, and reduction in microorganism growth due to restoring proper coolant concentration. The use of a digital refractometer and upgrading old lathes with an oil skimmer is recommended.

Keywords: Manufacturing, Metal Chip, Forming Processes, Coolant, Refractometer

CHAPTER 1. INTRODUCTION

1.1 The Problem

Manufacturing machinery water-based coolants have life cycle concerns including health, environmental and disposal (Canter, 2017). Regarding disposal, the change out value is up four percent of production scheduled time (Canter, 2017). Water based (WB) coolant consists of 95% potable water (Brinksmeier et al., 2015). Manufacturing machinery coolant concentration changes by four percent over a week due to extreme heat (Brinksmeier et al.). Coolant condition was measured by factors including concentration, and pH value to quantify coolant life (Seidel & Meyer, 2019). Fresh water composes only three percent of the world's supply (National Academy of Engineering [NAE], n.d.). Managing WB coolant reduces water usage aligning with the Grand Engineering challenge *Provide Access to Clean Water* (NAE, n.d.).

1.1.1 Health Concerns

Manufacturing machinery coolant (coolant) affects the health of the operator thru skin contact or via breathing (Health and Safety Group, 2011). Bacteria thrive in coolant and replicate rapidly (Stear, 2005). Health problems range from dermatitis, a mild skin irritation to Legionnaires' disease (Principe et al., 2017). Coolant is subjected to contamination introductions of tramp oil, litter, and dirt all of which serve to degrade the coolant (Stear). Metal fines suspended by the tramp oil in the coolant cause skin abrasion. (ASTM, 2017b)

Excess concentration contributes to skin irritation and higher fluid cost (Byers, 2017). Figure 1.1 on page 2 shows a supplier coolant analysis report. The report illustrated elevated concentration controlled microorganism (MO) activity, but was not an economical method (ASTM, 2017b).

DuBois

COOLANT MAINTENANCE

PRODUCT NAME:	Perkool 5250	PROJECT NUMBER:	95,028
CUSTOMER NAME:	Hadady-Vector Engineering	DATE OF SAMPLE:	October 02, 2018
MANUFACTURED BY:	Perkins Products	DATE COMPLETED:	October 05, 2018
SYSTEM/MACHINE:	See Below	SALESMAN NAME:	Jim McLaughlin

SYSTEM/MACHINE:	107	112	114	202	604	606	609	610
CONC. BY ALK.:	27.0	23.3	27.0	14.4	10.2	24.9	11.3	24.0
pH:	9.57	9.56	9.5	9.56	8.97	9.78	9.06	9.13
% TRAMP OIL:	0.4% Cream	13.6% Cream	10.8% Oil	0.2	12%	0.2% Cream	1.0	0.3
C.I. RUST TEST:	None	None	None	None	None	None	None	None
TOTAL ALK. (per 100 ml):	500	431.8	500	266.3	187.8	461	208.8	443.9
CONDUCTIVITY (uhmo):	11400	10160	3430	7350	3940	1198	6900	10560
BACTERIA (per ml):	0	0	0	0	0	0	0	0
MOLD (per ml):	0	0	0	0	0	0	0	0
YEAST (per ml):	0	0	0	0	0	0	0	0
RESIDUE:	Soft, oily	Soft, oily	Soft oily	Soft, oily	Soft, oily	Soft, oily	Soft, oily	Soft, oily

Figure 1.1: Over Concentration Limits Microorganism Growth (Dubois, personal communication, October 2, 2018)

Figure 1.1 shows a period during 2018 when the mixing valve to adjust the coolant to water mixture ratio was set too rich. The concentration is indicated in the row CONC BY ALK. The concentration of all machines 107 thru 610 was over the upper specification limit of ten percent. A rich coolant mixture contains excess of all active ingredients including the biocide (Canter, 2011). High coolant concentration prohibited the growth of MO (bacteria, mold and yeast level are zero at the bottom of report excerpt). Adding biocide is a more appropriate response if inhibiting biological growth is the only goal (ASTM, 2017b).

Mist in the form of liquid or solid aerosol particles is generated during machining operations (Dasch et al., 2018). The following discussion is sourced from the Dasch et al. 2018 paper. Mist is both a health and environmental concern. Mist is a health concern when inhaled, and an environmental concern when exhausted outdoors. Indoor mist is regulated by

Occupational Safety and Health Administration (OSHA) and outdoor mist by the Environmental Protection Agency (EPA). Mist control is composed of reduction (prevention) and elimination (control) measures. Ventilation or collection control misting.

1.1.2 Environmental and Disposal

Spent coolant requires recycling or disposing by a waste handler (Lazarus, 2018). Lazarus states disposed coolant is considered a restricted substance and not permissible to be dumped into a sanitary sewer. The cost of disposal includes per gallon, trip, and manifest charges (Crystal Clean, personal communication, June 5, 2020). The total value of coolant change out is up to four percent of production scheduled time (Canter, 2017). The overall cost of coolant change-out includes not only disposal cost, but also labor and supplies to clean the coolant tank, and lost production time. Unplanned maintenance is one of the critical factors in overall equipment effectiveness (OEE) (Stroup, 2017).

1.1.3 Machining Performance

Coolant condition also affects machining performance (Feldhausen et al., 2019). Well maintained coolant yields longer cutting tool life, better surface finish and dimensional control of finished parts (Foltz, 2018). Coolant low concentration causes rust, MO, and a lack of part cleanliness (Byers, 2017).

1.2 The Impact of the Problem

Consisting of 95% potable water, coolant concentration changes by four percent over a week due to extreme heat (Brinksmeier et al., 2015). Foltz (2018) states evaporation and carry out (from chip conveyor, chips or work piece) contribute to changes in the coolant concentration. During evaporation only the water content in lost (Foltz). Foltz states evaporation increases the concentration, while carry out decreases the concentration. Premature degradation of coolant results in unplanned maintenance, and resultant production interruptions (Sachat et al., 2017). Unexpected interruptions can't be planned for and are highly disruptive.

Traditional alternatives to water based coolant include dry machining, mist application, and minimum quantity lubrication (MQL) (Dobbeler et al., 2015). Where none of the afore mentioned solutions are effective, coolant is applied. Dobbeler et al. states -especially for high-speed machining and exotic materials (nickel and titanium alloys), WB coolants are relied on. The coolants used in the latter applications have a cost premium (Benedicto et al., 2017).

1.3 How the Problem is Measured

Coolant condition was measured by factors including concentration, and pH value to quantify coolant life (Seidel & Meyer, 2019). Concentration is the basic measure for coolant but does not give an indication of health (Foltz, 2018). The pH value is the simplest indicator of coolant health (Sachat et al., 2017). Other factors such as hardness, conductivity, and microbial contamination yield additional information regarding coolant health (Brinksmeier et al., 2015). Consistent coolant life is the goal. As with other machining variables a tradeoff exists. As an example, for cutting tools productivity in the form of cutting speeds and feeds are balanced against tool life. Rather than simply maximizing coolant life, the desired goal is predictable life.

1.4 Connectivity of The Problem with The NAE Grand Challenge

Fresh water composes only three percent of the world's supply (National Academy of Engineering [NAE], n.d.). Managing machinery coolant reduces water usage aligning with the Grand Engineering challenge *Provide Access to Clean Water* (NAE, n.d.). The NAE of Engineering states 95% of water is used for reasons other than household use. To make the resultant 0.3% available for households, water use requires conservation in other areas such as farming and manufacturing (NAE).

Fresh water occurs naturally in vast repositories. The Great Lakes in the Midwest United States holds 84% of the fresh water in North America (EPA, 2019). The EPA states access to fresh water is controlled by geographic and political rules. A city must border the lake to extract water in the Great Lakes example, (Department of Natural Resources [DNR], n.d.). The Indiana DNR states to purchase water a city necessarily resides in the Great Lakes basin. Residing in the basin means surface water naturally returns to the Great Lakes. Accordingly, cities outside the Great Lakes basin do not have rights to access the water.

Water merits conservation in all aspects of the product life cycle. Ogaldez, (2012) states for metal products water is consumed in the production of steel. Ogaldez informs water is consumed by electric power generation, transportation, and conversion of the raw materials into a finished product. While electric power is the primary overall user, water content in coolant is the primary direct usage for metal chip removing processes (Ogaldez). Water is also used for flushing during cleaning of a coolant tank (Passman, 2018).

1.5 Summary Introduction

A predictable coolant life is necessary to minimize changeout costs and disruption to production resulting from premature coolant failure. Small-medium enterprises (SME) with limited resources require a coolant monitoring program with a minimum number of variables (Dobbeler et al., 2015). The fluid management program needs to consider the size, operations, and goals of the company. (Foltz, 2018). Coolant conditions were monitored to determine the critical variables and values. Guidelines for application and equipment selection were given.

The pilot study was conducted using chip forming production equipment from Hadady Rail division.

CHAPTER 2. **REVIEW OF LITERATURE**

2.1 Use of Coolant

Coolants fall under the subcategory metal removal fluids (MRF) in the group metalworking fluids (MWF) (White, 2018). End users in modern metal working seek to replace or reduce the use of costly MWF (Benedicto et al., 2017). "Due to the increased tool wear induced by high cutting temperature, in many cases cooling lubrication supply is still not expendable" (Dobbeler et al., 2015, p.1). Dobbeler et al. notes coolant is especially necessary for high-speed machining and exotic materials or high temperature resistant materials. Dobbeler et al. states lower workpiece temperature yields higher dimensional process stability.

2.1.1 Types of Coolant

The two main types of machine coolant are oil based and water based (water miscible) (Seidel & Meyer, 2019). Brinksmeier et al. (2015) states "Oil based MWF are especially used in processes which require efficient lubrication, whereas water based MWF are applied where the dissipation of heat is more important than lubrication" (p. 606).

2.1.2 The Early Uses of Coolant

The use of lubricants to decrease friction was well known since ancient times (Brinksmeier et al., 2015). McCoy (2018) explains to lower cutting forces and product better surface finish, lubricants were employed beginning in the late 1800's. McCoy states straight oils were used first for metal removal processes employing metal cutting tools run at low speeds. Extra heavy-duty applications such as broaching and thread rolling necessitate the use of straight oils (Foltz, 2018).

Heat created by cutting forces is the enemy of cutting tools (McCoy, 2018). Temperatures in the cutting zone reach 2000 degrees Fahrenheit (McCoy). Ninety percent of cutting forces are converted to heat (Dobbeler et al., 2015). According to McCoy the heat has two sources: friction between the tool/workpiece, and metal deformation. McCoy states the metal deformation energy required to shear off the chip consumes two-thirds of the power required. McCoy also states to increase cutting speed water was used for cooling beginning in the early 1900's. As a refinement carbonate of soda was added to prevent rust in a mixture called suds (McCoy).

Eventually the cooling properties of water, and the lubricating benefits of oils was combined into one product (Byers, 2017). CIMCOOL was the first commercial product offered in the mid 1940's (Byers). CIMCOOL is an emulsion, an oil mixture suspended in a water solution (Byers) also known as a soluble oil.

Early research held the view coolant provided exclusively a cooling effect in a lathe rough turning operation (Kurimoto et al., 1982). Kurimoto et al. reasoned pressure was not adequate for the coolant to penetrate into the cutting zone. Kurimoto et al. stated MWF's migrate away from the cutting zone due to temperature and surface tension. Counteracting forces include capillary force and increased wetting ability due to lower viscosity (Brinksmeier et al., 2015). The lubricating effect of coolants is undisputed today (Brinksmeier et al., 2015). The lubricating effect of the vaporized coolant forming a chemically induced thin layer between the cutter and workpiece was later proven (Byers, 2017). Kennametals (2013) cutting tools introduced a novel technology in 2013 called Beyond Blast. Kennametals states the coolant is directed into the cutting zone by routing through the cutting insert. Kennametals claims cutting tool life improvement of 300% when cutting titanium.

2.2 Tradeoffs in Water Based Coolants

Water is ideal for removing heat, and oil is best for providing lubrication (Byers, 2017). According to Brinksmeier et al., (2015), water promotes rust, and to treat the adverse side effect, a corrosion inhibitor is added. The addition of an ingredients to correct the deficiency of another has a cascading effect (Brinksmeier et al.). The original water-oil blend cumulates in a complex mixture of 20-40 different ingredients (Brinksmeier et al.). Table 2.1 summarizes tradeoffs in coolant formulation.

Table 2.1: Tradeoffs in Water Based Coolant Formulation (Brinksmeier et al., 2015)

Desired property	Solution implemented	Adverse effect
cooling	water	rust
Corrosion protection	Corrosion inhibitor	---
Lubrication	lipids	bugs
bugs	biocide	---
Oil and water	emulsion	foam
foam	Anti-foaming agent	---

Table 2.1 illustrates the "desired property" and subsequent "adverse effects" of the various "solution implemented".

2.3 Other Lubrication Strategies

Conventional alternatives to coolant include dry machining, mist, and minimum quantity lubrication (MQL) (Benedicto et al., 2017). Newer promising methods include high pressure, cryogenic, and nano (Benedicto et al.).

Nano fluids contain nano particles creating an artificial layer on top of the workpiece (Kadirgama, 2020). Kadirgama states the buffer layer reduces friction and consequently reduces cutting forces and increases tool life significantly. Kadirgama states the higher heat conductivity of nanofluids leads to better tool life and improved surface finish. Secondary benefits include reduced residual stress and microcracking of the work piece (Kadirgama). Nanofluids are more expensive per linear inch of cut but have lower overall sustainability costs (Kadirgama).

2.4 Assessing Coolant Condition

Conditions monitoring (CM) as part of a fluid management program is designed to reduce fluctuations in coolant variables (Foltz, 2018). Conditions monitoring results in cost control thru better health and machining performance (Foltz). Stear (2005) recommends at a minimum to check concentration and pH.

2.4.1 Collecting Samples

Andrew (2019) recommends coolant collection methods be consistent. The following techniques are recommended by Andrew. Bacteria samples are strategically collected from tank surfaces in the splash area where replication occurs. Collect bulk fluid samples from slightly below the coolant surface by inverting the sample bottle after stirring away tramp oil. Once submerged the sample bottle is turned right side up to collect the sample.

2.4.2 Coolant Concentration

Coolant concentration is the best indicator of overall coolant condition and cooling effect (Foltz, 2018). The percent concentration measures the amount of coolant compared to the total liquid volume. Typical values are three to ten percent for machining (Brinksmeier et al., 2015). Using an optical based refractometer, the concentration is derived from the refractometer index of the MWF (Canter, 2011). Optical refractometers operate on the principal additives in the water refract or bend a beam of light (Canter). The refractometer is read from the scale at the intersection of the light and dark areas (Wan & Liang, 2011). Concentration is also measured by the alkalinity method (Dubois, 2020).

2.4.3 Measuring pH Level

pH measures the acidity of the coolant. pH is a useful indicator, tracking well with the level of bacteria (Sachat et al., 2017). Coolant is intentionally alkaline to retard the growth of MO (Sachat et al.). The desired pH level is between 8.5 and 10 to prevent corrosion (Andrew, 2019). Paper pH measurement strips are inexpensive but lack precision to track the minute changes in pH (McGuire, 2016).

2.4.4 Water Quality

Ninety five percent of the typical coolant mix is composed of water (Foltz, 2018). Water supply quality has a impact on coolant performance (Foltz). Foltz states “Of the water analysis results, total hardness has perhaps the greatest effect on the metalworking fluid mix” (p. 317). Foltz states water hardness indicates the presence of minerals (primarily calcium and magnesium). Water hardness is measured as an equivalent amount of calcium carbonate $CaCO_3$ (Foltz). Foltz explains soft water will produce foaming, whereas excessively hard water will cause scum formation. Foltz explained 80-125 parts per million (PPM) is ideal water hardness for MWF.

Bacteria in the water source supply the feedstock for harmful bacteria colonies (Foltz, 2018). The potential decrease in service life of coolant due to water supply quality is shown for the Hadady Dyer IN plant in Figure 2.1 on page 12.

DuBois

Analytical Report

PROJECT NUMBER	DATE OF SAMPLE	DATE COMPLETED	SALESMAN
101,197	05/15/20	05/18/20	Jim McLaughlin
CUSTOMER NAME	PRODUCT NAME	MANUFACTURED BY	MACHINE
Hadady – Dyer	Water	-	-

Objective

Check the quality of the water.

Results

TEST	WATER
pH	5.8
Chlorides	40 mg/L
Hardness	120 mg/L
Bacteria	10^4
Mold	0
Yeast	0

Metal Analysis ppm

	Water		Water		Water0
Fe:	0	Ag:	0	P:	0
Cr:	0	Si:	0	Zn:	0
Pb:	0	B:	0	Mo:	0
Cu:	0	Na:	10	Ti:	0
Sn:	0	Mg:	18	K:	9
Al:	0	Ca:	19		
Ni:	1	Ba:	0		

Conclusion/Discussion

Bacteria is present in water. This may shorten life of metalworking fluids.

Figure 2.1: Water Supply Condition Effect Upon Coolant Life (Dubois, personal communication, May 15, 2020)

The bottom of report states the bacteria in water supply shortens coolant life. The Dyer 2019 annual water report did not list a bacteria level (Town of Dyer, 2020). Dyer water is sourced from Hammond Indiana (Town of Dyer). The Hammond 2019 report showed an acceptable level of bacteria. The report showed detected total coliform at 2.5 [% of the samples] with a maximum allowed level of less than five percent (Hammond Water Works, 2019).

The precise collection location for the water sample was unknown, but likely from a garden hose in the shop used to fill coolant tanks. Although deemed safe for drinking by Hammond, the quality of the Dyer water is detrimental to coolant longevity (Foltz, 2018).

2.5 Coolant Aging

Once the tank has been charged, coolant is subject to material additions and subtractions (fluid losses) throughout life (Seidel & Meyer, 2019). Seidel and Meyer define coolant aging as "all changes that occur in the metalworking fluid during the service life" (p. 426). Seidel and Meyer cite harmful additions are contaminants such as tramp oil, biological material, and debris. Fluid loses are the result of water evaporation, and fluid carry out (Brinksmeier et al., 2015). To account for evaporation, make-up fluid is added.

A coolant analysis is a useful tool for examining coolant condition. Figure 2.2 on page 14 shows an annotated coolant report conducted by Dubois.

DuBois

COOLANT MAINTENANCE

PRODUCT NAME:	Perkool 5250	**PROJECT NUMBER:**	101,528
CUSTOMER NAME:	Hadady-South Holland	**DATE OF SAMPLE:**	June 26, 2020
MANUFACTURED BY:	Dubois	**DATE COMPLETED:**	July 02, 2020
SYSTEM/MACHINE:	See Below	**SALESMAN NAME:**	Jim McLaughlin

SYSTEM/MACHINE:	Standards	304	305	397	650	651	01-001
CONC. (BY ALK.):	7.0%-10.0%	1.4	3.2	9.9	6.7	2.4	11.0
pH:	8.5 -9.5	8.22	8.76	8.84	9.03	8.37	9.14
% TRAMP OIL:	<0.2	0.1%	0.1%	0.1	0.1	0.1	0.1
C.I. RUST TEST:	None-Slight	Severe	None	None	None	Severe	None
TOTAL ALK. (per 100 ml):	>125	26.3	58.9	180.2	122.5	44.3	201.1
CONDUCTIVITY (uhmo):	<7500	2920	3760	6850	5510	4790	7450
BACTERIA (per ml):	<10^6	10^4	0	0	0	0	0
MOLD (per ml):	<10^3	0	0	0	0	0	0
YEAST (per ml):	<10^3	0	0	0	0	0	0
RESIDUE:	Soft, oily	Soft, oily	Soft, oily	Soft, oily	Soft, oily	Soft, oily	Soft, oily
SEDIMENT:	<0.2	Trace	Trace	Trace	Trace	0.1	0.1
CHLORIDES:	<350	40	60	240	160	60	280

GAS CHROMATOGRAPHIC ANALYSIS (PPM)

ALKANOLAMINE:						
RUST PREVENTIVE I:						
RUST PREVENTIVE II:						
RUST PREVENTIVE III:						
BIOCIDE:						
LUBRICITY ADDITIVE:						
FUNGICIDE:						

COMMENTS

304, 305, 651: Concentration is low. Please increase concentration to 7.0% 10.0%.
397, 650, 01-001: Suitable for continued use.

from Jim McM 09/29/20.
per email:

Jim:
Do you have a cheat sheet/ technical background to help understand the information on the reports.
Notes such as:
At levels above xx mold, need treatment, or Ph should be in the range….

Joe,
I went thru this with my chemist today in the lab and here are the specified ranges
you want to be between for maximum efficiency. If you have any questions call me.

Paint Pretreatment – Metalworking Fluids – Food C & S – Facilities Maintenance – Process Cleaning – Water Treatment
7025 West 66th Place, Bedford Park, IL 60638

Figure 2.2: Annotated Sample Coolant Report (Dubois, personal communication, July 02, 2020)

Figure 2.2, on page 14 is annotated with the recommended action level for the various categories as shown in the yellow back shaded column labeled 'Standards'. The "COMMENTS" section in the middle of the report is Dubois summary of the coolant condition and recommended action. The first line of "COMMENTS" section recommends increasing the concentration for machines 304, 305, and 651. For machine 304 the current concentration as measured by alkalinity was 1.4%, far below the target value of eight percent. Hadady requested Dubois on newer reports to add the column *Concentration by Refractomete*r for comparison to the sampling method used by Hadady. The measures CONC (concentration), pH, % TRAMP OIL, BACTERIA, MOLD, and YEAST were of particular interest for the study.

The preceding factors lead to the deterioration of the coolant (Canter, 2011). The depletion of the additives as the coolant ages is not uniform (Canter). Premature aging causes rust, microbial growth and health issues, with microbial growth being the main parameter (Brinksmeier et al., 2015). Figure 2.3 on page 16 shows the typical trends in compounds as the fluid ages. A determination is made of the critical coolant functions and then monitor the component responsible for the functions (Byers, 2017).

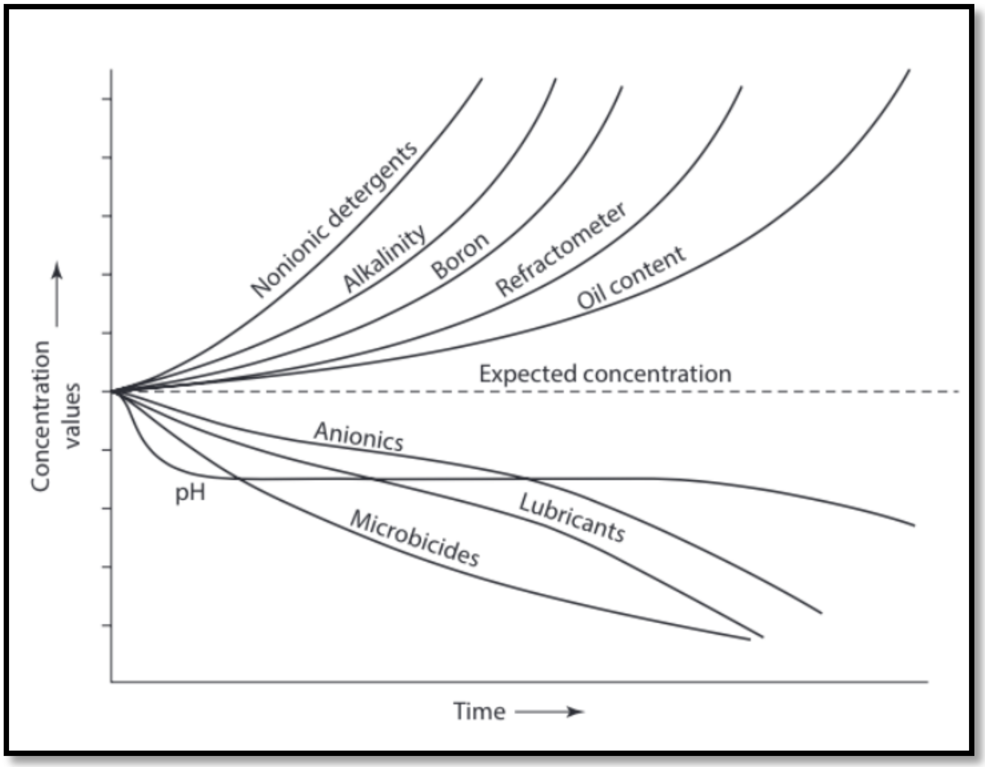


Figure 2.3: Metalworking Fluid Composition Changes Over Time (Byers, 2017, p. 211)

The graph in Figure 2.3 shows the expected concentration as a straight dotted line with zero slope. The concentration in practice is allowed to vary between the lower specification limit (LSL) and upper specification limit (USL). All other independent variables are nonlinear in shape reflecting the deterioration of the coolant versus time. The increasing refractometer curve illustrates the tendency of a handheld refractometer to overstate the concentration of a used solution (Byers, 2017).

Figure 2.3 did not specify a scale or units of measure for the horizontal Time axis. Puneeth and Ganesha Prasad (2019) indicated a duration of one week for the steep drop in the first portion of the pH curve.

2.5.1 Coolant Concentration Variation

Concentration fluctuates rapidly due to water evaporation, especially in warmer climates or during periods of high production (Brinksmeier et al., 2015). Make up fluid constitutes a water-coolant mixture to maintain the concentration within control limits (Zebra, 2005). Water evaporation leads to a buildup of hard water deposits in an effect known as the *boiler effect* (Foltz, 2018).

Refractometer reading becomes difficult to discern when the fluid is contaminated by oil as the emulsified oil blurs the reading (Zebra, 2005). Refractometer readings on used coolant are less accurate and tend to overstate the concentration level (Canter, 2011). Newer digital refractometers feature increased accuracy and are less affected by tramp oils (Canter).

2.5.2 Make Up Coolant

Coolant losses are accounted for by the addition of make-up coolant (Zebra, 2005). The addition constitutes straight water, neat coolant or a mixture of the two (Brandt, 2018). For WB coolants evaporation is the primary mechanism to consider (Lazarus, 2018). Topping off the coolant level with straight water is the simplest method and is expected to replace the water lost. As a result, the concentration levels will jump around. Figure 2.4 on page 18 illustrates the choppy appearance of coolant concentration data points when adding only water or straight coolant.

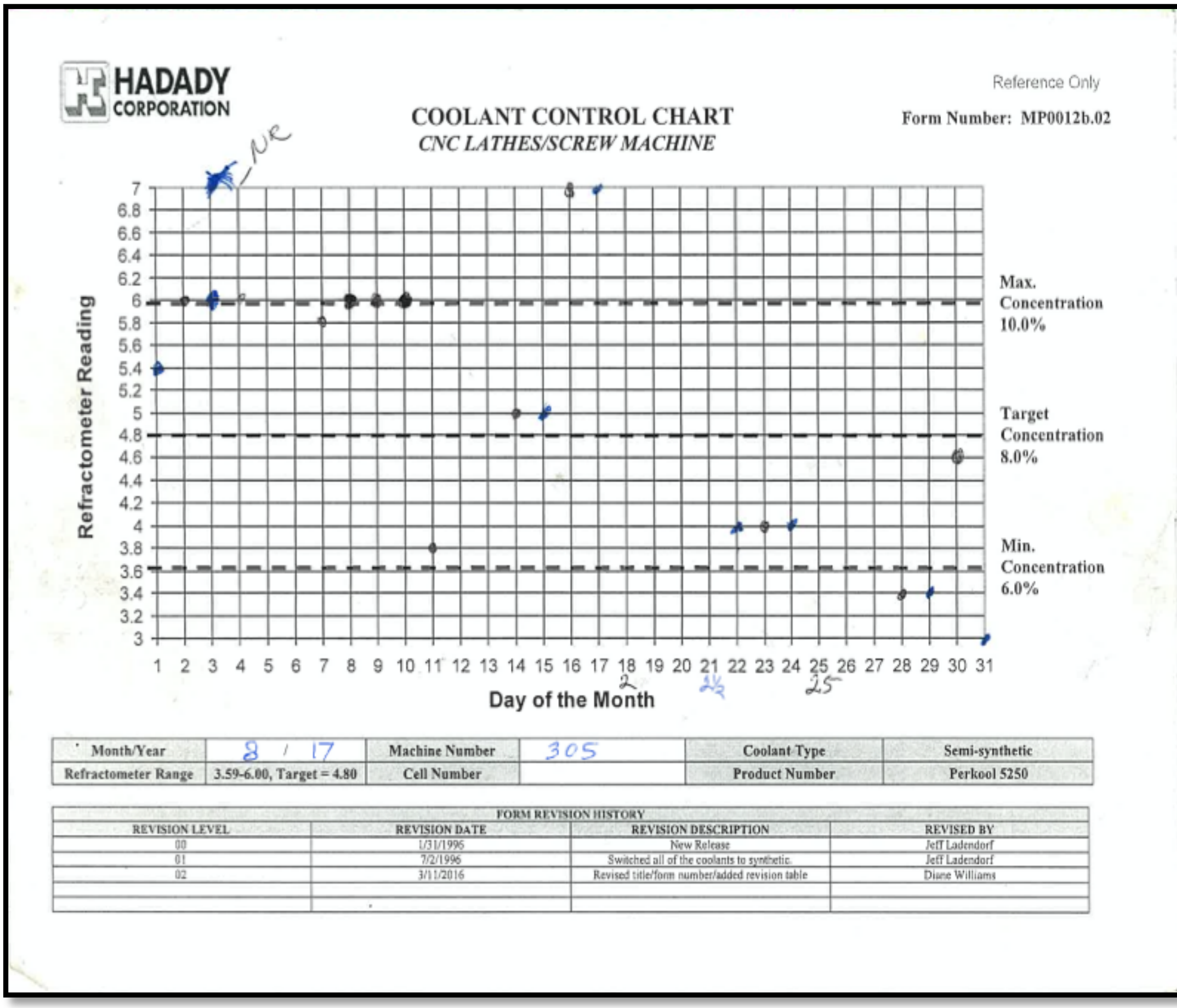


Figure 2.4: Coolant Concentration Shift Due to Addition of Straight Water (Hadady, 2017)

The concentration level in Figure 2.4 shows drastic shifts due to the water addition. The seventh through the tenth day of the month the concentration was at the upper specification limit. After the addition of water, the concentration is near the LSL on the 11th day. The process capability indices for the graph will suffer. The biocide effectiveness is degraded by the diluting effect (Canter, 2011).

The correct concentration of makeup fluid requires calculation. A sample calculation is shown in Figure 2.5 below (Zebra, 2020).

Example Known Factors
Desired Concentration: 5%
Total Sump Size, gallons: 50

Unknown Factors
Remaining Sump Concentration
Make-up Required, in gallons
Make-up Concentration Needed

1. Determine the volume of concentrate needed for the entire sump volume of 50 gallons at the desired concentration of 5%:
   Example: (.05 x 50 = 2.5 gallons of concentrate)
2. Check the concentration of the remaining sump volume with a refractometer (for this example calculation we will use 8%).
3. Figure the amount, in gallons, the remaining sump contains (in this example we will use 25 gallons). Subtract this amount from the original volume of 50 gallons:
   Example: (50 - 25 = 25 gallons)
4. Determine the volume of concentrate needed for a make-up batch if only 25 gallons are remaining in sump at 8% concentration:
   Example: (25 x .08 = 2.0 gallons of concentrate)
   Then
   (2.5 gallons of concentrate originally in entire sump)
   -2.0 gallons in remaining sump
   .5 gallons of concentrate needed for make-up
5. Determine concentration for make-up batch:
   Example: (.5 gal of conc. ÷ 25 gal fluid required = .02, or 2% conc.)

ANSWER: The sump now needs to be filled with a 25 gallon make-up batch at a concentration of 2%.

Figure 2.5: Make up Fluid Calculation of Concentration [%] and Volume [gallon] (Zebra, 2020, p.12)

Adding fluid at target concentration does not yield the correct concentration level for the tank unless already at the target (Zebra, 2020). The example in Figure 2.5 shows a sump at eight percent required the addition of two percent makeup fluid to restore the proper five percent concentration.

Computer automation of the formulas in Figure 2.5 is possible, but on the shop floor a simple graphical method is expedient. Assuming a five-gallon addition of fluid, the formulas simplified. The following graphs Figures 2.6 and 2.7 were derived and displayed on pages 20 and 21.

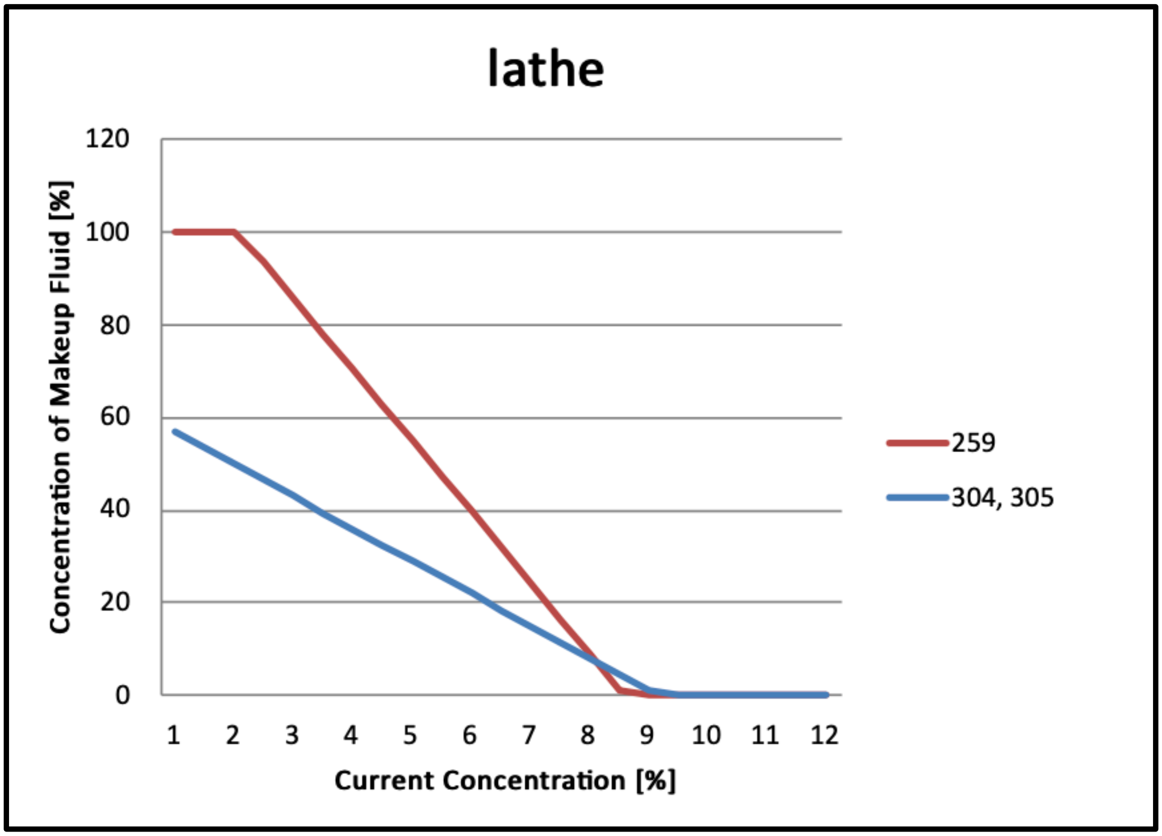


Figure 2.6: Makeup fluid Concentration for Lathes (Five Gallon Fluid Addition)

For lathe 259 (indicated by a red graph line), above a current concentration of 8.5% straight water is added. Straight coolant is added below two percent current concentration. Lathes 304, 305 (indicated by a blue graph line) never add five gallons of straight coolant due to smaller coolant tanks. The two curves for lathe 259 and 304, 305 cross each other at the target concentration of eight percent.

After taking daily refractometer readings, the current concentration is known. As an example for lathe 259, assume the current concentration is 5.5%. The curve in Figure 2.6 yields a makeup concentration of 50%. The makeup fluid would be 2.5 gallons water, and 2.5 gallons concentrate for a total of five gallons. The graph for the verticals 650 and 651 in shown in Figure 2.7 on page 21.

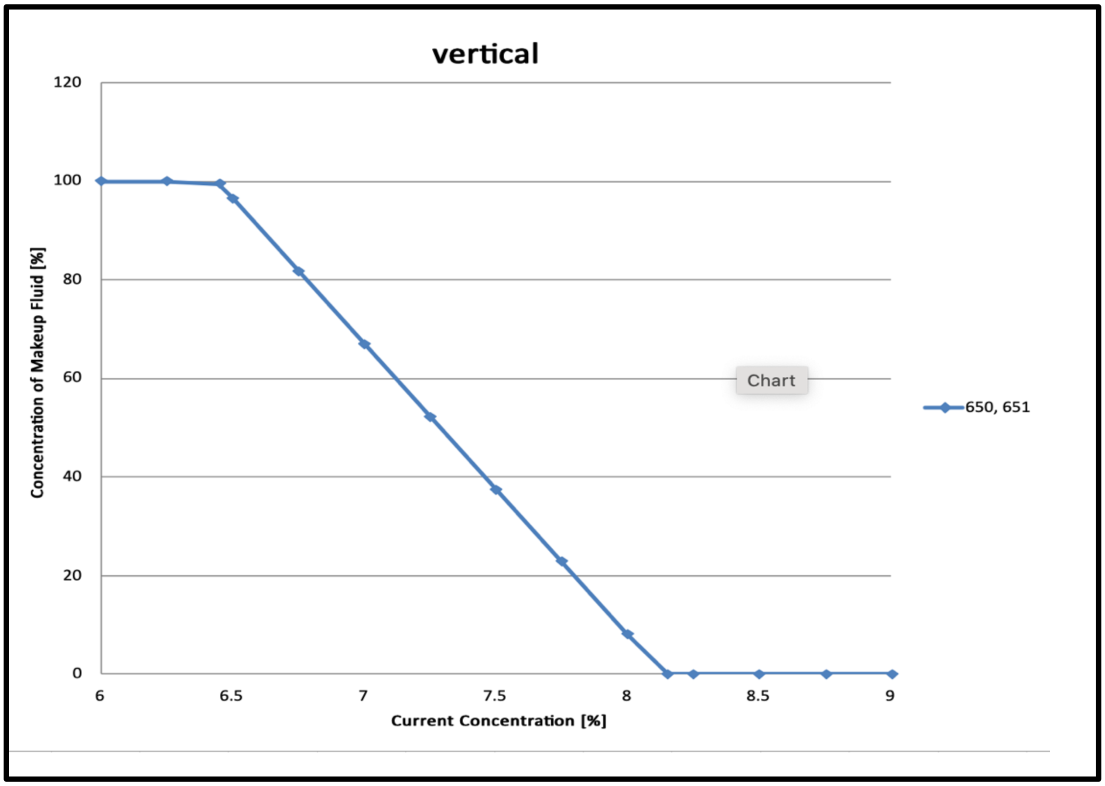


Figure 2.7: Makeup fluid Concentration for Verticals (Five Gallon Fluid Addition)

Note in Figure 2.7, an eight percent makeup fluid is only required when the sump is already at the target concentration of eight percent.

2.5.3 Microbes in the Coolant

Biodegradability is beneficial from an environmental disposal perspective, but from a fluid maintenance view microbes are detrimental (Passman, 2018). Passman states bacteria and fungus are historically the two major groups found in coolant, with bacteria being more prevalent. Bacteria flourish in WB coolants and are impossible to avoid completely even in a well-maintained sump (Brinksmeier et al., 2015). Strains of bacteria exist with a doubling rate of less than 20 minutes (Passman). The type of bacteria typically found in coolant reseed within 12 hours of a recharge (Stear, 2005). As the bacterial count increases, the pH decreases; below seven the coolant is deemed unusable (Seidel & Meyer, 2019). The decrease of pH is indicative of the acidic byproducts released by the bacteria (Sachat et al., 2017).

Coolant has bioremediation additives in the neat mix, or biocides are added tank side (ASTM, 2017b). Once the bacteria level is out of control shock treatment are unlikely to kill the entire population and is considered a temporary measure (ASTM, 2017b). The biocide chemicals are unable to penetrate the sessile biofilm deposits in the splash zones (White, 2018). Underdosing of biocides selects bacteria resistant to biocide active ingredients (ASTM, 2017b).

Measurement of MO contamination is subject to wider variation than other MWF tests (Passman, 2018). Passman states the common swab test relies on growth media to culture the bacteria. Commercially available growth media are receptive to less than ten percent of the total MO flora (Passman). Bacteria count testing timeliness is an concern; sample testing within 18 hours of gathering is recommended (Passman). Passman states bacteria culture tests have a lag issue: by the time the test results show a threshold value, the UCL is exceeded.

CHAPTER 3. **RESEARCH METHODOLOGY**

3.1 Research Methodology Overview

The research method reinforced behaviors contributing to predictable coolant life. The review of literature in Chapter two supported the idea a well maintained and controlled coolant 'takes care of itself'. The study sought to confirm which simple behaviors produce the desired effect of excellent coolant life. The experimental statement is posted below.

Cleanliness and careful control of coolant concentration yields acceptable coolant life.

Figure 3.1: Experimental Statement (Foltz, 2018)

Coolant concentration was closely monitored for the experimental group. Makeup fluid was a coolant and water mixture. The make-up fluid was at a concentration to always maintain the target coolant concentration. The make-up fluid concentration followed the methodology given in Figures 2.6 and 2.7 on pages 20 and 21 respectively.

Coolant life of six months was considered an optimal outcome for the research study and report. Coolant life of nine months would be exceptional. The two main reasons coolant is changed out prior to the scheduled preventative maintenance (PM) date is presence of bacteria or dirty appearance. Bacteria as exhibited by odors or biofilm (Passman, 2018) is the more common cause at Hadady.

A hybrid approach was used to ascertain the end of coolant life. Bacteria levels equal to or greater than 10^6 [cell/mm] was the primary measure used (Dubois, 2020). Bacteria count is a direct measure of MO level and the preferred method, but limited due to operating constraints. Bacteria count was performed by Dubois once a month. Due to the frequency of bacteria counts, a pH level less than eight was the second criteria to ascertain coolant end of life.

The third condemning criteria was a sustained objectionable smell as reported by the operator on two or more consecutive days. The coolant was kept clean by good housekeeping and skimming the tramp oil. Biocide was not used.

3.1.1 Research Environment

The research environment was production equipment of the rail division at Hadady Corp. The equipment was composed of lathes and verticals machining centers ranging from seven to 20 years old. The coolants used were supplied by Dubois Chemicals.

3.1.2 Sample Population, Participants ("N"), and Validation

The participants were three lathes and two verticals. The five participants 'N' were differentiated by recording the machine number on the bottom of the form. The machines are summarized below:

Table 3.1: Equipment Specifications (Hadady, 2020)

Description	Machine No.	Year purchased	Coolant Tank size [gallons]	Coolant	Integral coolant tank	Skimmer	Way Lube Return
lathe	259	1997	82	Dubois Pearl-Z 3421-D	yes	no	no
lathe	304	2003	40	Dubois 5250	yes	no	no
lathe	305	2003	40	Dubois 5250	yes	no	no
vertical	650	2013	300	Dubois 5250	no	yes	yes
vertical	651	2013	300	Dubois 5250	no	yes	yes

Compared to the lathes, the verticals incorporated new features including a separate coolant tank, tramp oil skimmer and way lube return. The older lathes had an integral coolant tank as part of the machine base casting. The segmented internal cavities are notorious for collecting debris in the corners (Lazarus, 2018). Lathe 259 has twice the coolant tank capacity as lathes 304 and 305 (82 versus 40 gallons respectively). Way lube return keeps the bulk of the lube oil out of the coolant tank, and skimmers remove the tramp oil (Zebra, 2005).

The independent variable was time. The dependent variable was coolant life as indicated pH level and micro-organism growth.

The sample size was daily readings (Monday thru Friday) at ten AM for two and a half consecutive months. Each daily sample (n) was recorded as a discrete data point on both the concentration and pH data collection forms.

Monthly coolant analysis was conducted on coolant samples by the supplier Dubois.

3.1.3 Statistical Measures (Quantitative and Qualitative)

A capability study was conducted on concentration as a function of time to verify the current LSL, and USL limits were obtainable in the production environment. Make up fluid was of particular interest. The addition of straight water or neat coolant is convenient but has an adverse effect upon concentration value (Brinksmeier et al., 2015). Make up coolant addition occurred daily and constituted a discontinuity in the data points. All machines use the same coolant Dubois 5250, except machine #259 which uses Pearl Z. Both products (5250 and Pearl Z) were used at a median concentration of eight percent (Hadady specification 6.8.70-9.1251). Both products had a LSL of six percent, and a USL of ten percent. Product Data sheet for the two coolants used are displayed in the Appendices A-1 and A-2 on pages 62 and 63 respectively. The MWF industry being “more geared toward comparative performance than meeting specifications” makes absolute evaluation of coolant difficult (Canter, 2018, p. 54).

Qualitative data was also collected. *Monday morning odor* is one of the first signs of MO buildup (Passman, 2018). Passman explains over the weekend with no aeration, tramp oil floating on the surface of sump restricts oxygenation. Passman states the temporary smell is caused by the release of bacteria. Khan et al., 2021 stated "As a rule of thumb, a full surface layer of oil indicates greater than two percent hydraulic (tramp) oil concentration relative to the total fluid," (p.592).

Quantitative bacteria count tests were supplemented by qualitative remarks. 'Heavy tramp oil observed' was an example of a study observations to describe coolant condition.

3.1.4 Limitations and De-limitations

The lathes 304 and 305 run identical products and are considered interchangeable. Vertical 651 runs more cast-iron products than vertical 650. Cast iron chips in the coolant accelerate the chemical breakdown of the coolant resulting in reduced lubricating ability (Zebra, 2005). The reduced lubrication although measurable in terms of performance (Feldhausen et al., 2019), was outside the scope of the study.

Coolant changeout dates for the equipment is staggered. Coolant is changed out as part of a PM program. A PM schedule date of one machine in the spring and another in the summer were possible. Seasonal effects were discounted as all data was collected during the winter while heating maintained a consistent shop temperature. Variations in the neat coolant active ingredients formulation was not considered remarkable.

The study had time constraints which affected the initial conditions and duration of data collection. A complete study spans a period of nine months. Due to time constraints to complete the research, a maximum period of two and a half months was available to collect data. The initial condition of the machines varied as shown in Figure 3.2 on page 27.

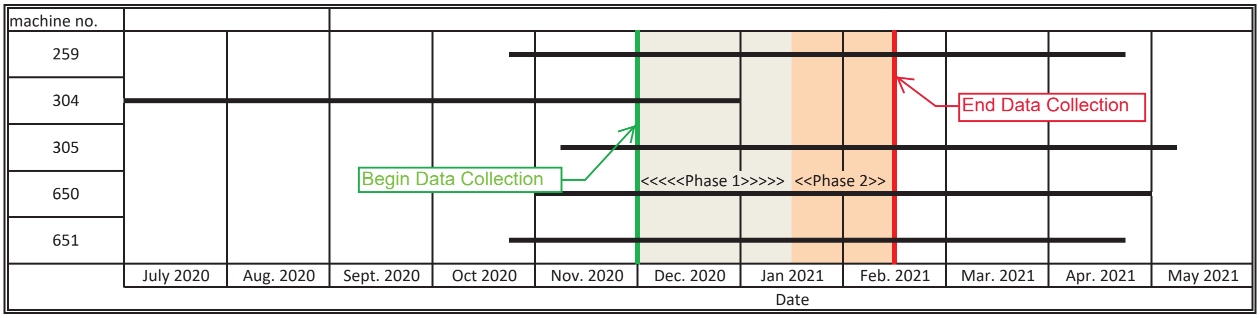


Figure 3.2: Timeline for Data Collection (Hadady, 2020)

The actual coolant lifecycle shown in Figure 3.2 for each machine, assuming a six month life span, is shown as the thick black line. Data collection began December first as shown by the green vertical line. Data collection concluded the second week of February as represented by the vertical red line. For example, machine 259 coolant was last changed in late October 2020. Thus the data collection period captured the middle third of the coolant lifecycle for lathe 259. Finishing in mid-February allowed ample time to analyze the data prior to research report submission. Prior to the start of data collection, both the experimental machine and control machine employed the current method of fluid addition. Vertical machine 650 was operated by the current method for a month before data collection began. The pH behavior immediately after changeout was monitored to minimize the effect of initial conditions.

The study had two phases as indicated in Figure 3.2. Phase one ran thru the middle of January. Phase two was a refinement of Phase one. Phase two used a zero-to-ten Brix refractometer as opposed to an 0-30 for Phase one. Phase two discarded the first reading of the coolant pH to minimize contamination from one sample to the next.

All three lathes were over 15 years old and had integral coolant tanks built into the base casting. The integral coolant tanks are notoriously difficult to keep clean (Lazarus, 2018). The preceding contributions to coolant life were discounted. A justification will be supplied in the following discussion. The life of the coolant depends upon the age, sump size, cleanliness, and other factors (Lazarus, 2018). Lazarus explains metal chips hidden under a cover harbor MO and initiate bacteria growth thus shortening the coolant life. Figure 2.3 shows on page 16 shows the pH drops quickly after change-out and then levels out. Figure 2.3 shows the pH drops quickly under actual conditions. Therefore a sharp pH drop after changeout did not correlate directly to the initial MO contamination. The experiment did not have any other measures to detect MO contamination, and thus the effect was discounted.

Passman and Küenzi (2020) explained alkalinity testing provides an earlier indication of MWF deterioration than pH. The use of buffers in coolant serves to resist changes in pH (Passman & Küenzi). The time lag in using pH data to predict coolant condition was discounted.

Hadady has other machines using coolant, in particular centerless grinders. The grinding process produces fine particles from the wheel and metal chips having significant surface area (Brinksmeier et al., 2015). Brinksmeier et al. states the particles transfer metallic-ions to the MWF causing a noticeable shift in the MWF chemistry. As a de-limitation of the study the grinders were excluded, only chip forming processes were studied. The grinders have external tanks of simple construction which makes cleaning and coolant changeout easier.

3.1.5 Control Treatment Groups

Control group was one lathe 304 and one vertical 651. The experimental group used a coolant water mix for make-up fluid. The control group continued the current method of makeup fluid using straight water or straight coolant. Biocide was not used.

3.2 Research Instruments

Research instruments included an optical refractometer in possession of the Hadady quality department. pH values were obtained using a digital pH meter. The pH meter had a 0.01

resolution as recommended by McGuire (2016) to track the subtle drift in pH. The pH meter calibration was checked daily using a solution of known pH. Observations were performed by research study author and maintenance department personnel. Data was analyzes using Minitab (Minitab, 2004), a statistical software, and Microsoft Excel (2021).

3.3 Procedures for Data Collection

Data collection was guided by the following company specifications shown below in Table 3.2.

Table 3.2: Data Collection Procedures (Hadady, n.d.)

Author	**Procedure**	**Title**
Hadady	4.8.70-9.1250	Refractometer Usage and Care
Hadady	4.8.70-9.1251	Rust Prevention & Coolant Level Reporting
Hadady	6.8.70-9.1251	Coolant Product and Mixes

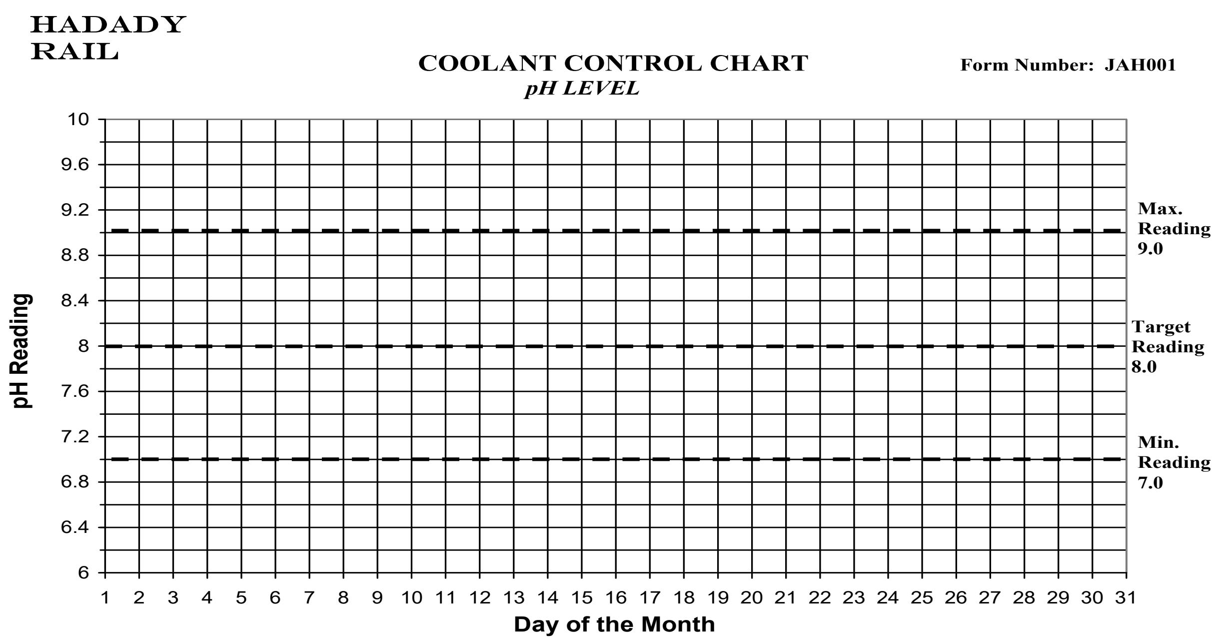
Coolant samples were collected via the turret nozzle for lathes or the coolant gun for verticals representing the coolant as delivered to the machined. The coolant sample data collection followed Hadady specification 4.8.70-9.1251. Fluid additions for the experimental group of machines 305, 259, and 650 were documented. The fluid additions were documented for amount (to the nearest half gallon) and concentration.

Hadady specification 6.8.70-9.1251 recommends a three-hour waiting period after addition of make-up fluid before readings are taken. Therefore, make-up fluid was added after the daily readings were taken.

Results were compared against monthly coolant analysis by supplier Dubois.

3.4 Presentation of Data

Graphs of concentration and pH versus time were the basis for data presentation. Data was accumulated in a monthly form. The Coolant Concentration Data Collection Form has already been introduced as Figure 2.4 on page 18. The pH collection form is shown in Figure 3.3 below. The pH meter calibration log is shown in Appendix A-3 on page 64.



Month/Year	/	Machine Number		Coolant Type	Semi-synthetic
		Cell Number		Product Number	Perkool 5250

FORM REVISION HISTORY			
REVISION LEVEL	REVISION DATE	REVISION DESCRIPTION	REVISED BY
00	10-26-20	New Release	Joe Hus

Figure 3.3: pH Level Data Collection Form (Hadady, 2020)

3.5 Return on Investment

Coolant changeout follows a bi-annual PM schedule. Recent unforeseen events have resulted in the coolant being recharged after four months. The additional cost for early changeout is estimated to be composed of the following cost contributions: coolant, labor, disposal, and lost productivity. All factors were multiplied by one-third due to the changeout occurring two months early. Calculation is shown in Figure 3.4 below.

Coolant Cost =50 gallons x \$13.40 per gallon x .10 concentration x $\frac{1}{3}$ = \$22

Labor Cost = 8 hours x \$50 per hour x $\frac{1}{3}$ = \$132

Disposal Cost = 1.5 x 50 gallons x \$1.25 per gallon x $\frac{1}{3}$ = \$31

Lost Productivity = 2 x 8 hours x \$60 lathe per hour x $\frac{1}{3}$ = \$320

Total =\$507

Notes: Disposal factor 1.5 account for rinse tank
Lost Productivity factor of 2 account for disruption

Figure 3.4: Sample Calculation for Cost Resulting From Early Change Out of Lathe Coolant

The extra cost incurred with premature coolant changeout for a lathe is approximately \$500 not including intangible costs such as health and safety. The monetary savings alone was not enough reason to justify the project. Other drivers existed to support the undertaking of the project. Hadady industrial division customers have expressed interest in rust prevention throughout all manufacturing operations using MWF. Regarding coolant, the mixed cost per gallon is the important factor for comparison costing not the neat cost per gallon (Foltz, 2018).

3.6 Research Methodology Summary

Regular additions of an adjusted mix of coolant maintain the active ingredients at an optimal level (Canter, 2011). The experimental group used a coolant and water mixture to maintain target concentration. The control group utilized the current method of adding straight water, or straight coolant if the concentration was low. pH values, outside lab testing and qualitative measures charted the progress of the study.

Three criteria were used to determine when useful coolant life had expired:

1. Bacteria counts equal to, or greater than 10^6 [cell/mm].
2. Coolant pH less than eight.
3. Sustained objectionable smell reported by the machine operator for two or more consecutive days.

The study had three significant factor which were discounted. First, machine coolant tank condition, a potential source of MO contamination was not detectable. Secondly, the time period for data collection was limited. Lastly, the initial conditions of the experiment varied. Prior to the start of data collection, both the experimental and control machine employed the current method of adding straight water or straight coolant.

CHAPTER 4. **RESULTS**

4.1 Results Objectives

Coolant concentration and pH were the primary measures recorded to track the life of the coolant. Concentration data was coarser than pH due to instrument resolution (0.2 Brix which equated to ¼ % concentration, versus 0.01 pH respectively). The experiment included two phases as detailed in Chapter 3, sub-section 1.4.

The research statement described in Chapter three, and illustrated in Figure 3.1 on page 23 is broken down into two parts:

1. Cleanliness and careful control yields consistent coolant concentration
2. Close examination of coolant yields acceptable coolant life.

The first part of the experimental statement 3.1, the input, was achieved by proper coolant housekeeping. Good housekeeping of the coolant was not quantified but employed manual skimming to minimize tramp oil. "Careful control' of the coolant was implemented by daily checks for the experimental machines. Fluid was added to the control machines as required to maintain a full tank at the target coolant concentration. 'Consistent coolant concentration' was measured by statistical control indices.

The second part of the experimental statement 3.1, the output, was tracked by an examination of the coolant pH. The machine coolant did not meet the end-of-life criteria detailed in Chapter 3, sub-section 3.6. Therefore examination of trends in pH was critical to understanding and predicting coolant life.

The input conditions required verification before reaching any conclusions on the output. Verification consisted of the experimental machine exhibiting better statistical control of the coolant concentration than the control machine.

4.1.1 Results Overview

The report examined general trends and anomalies in coolant concentration and pH in sub-section 4.2. Next, the consistency of coolant concentration was examined in sub-section 4.3. In sub-section 4.4 careful attention was given to trends in pH to predict coolant life. Sub-section 4.5 examined other factors influencing coolant life. Lastly sub-section 4.6 presented a summary of the research conclusions.

4.2 Coolant Concentration and pH Results

Figures 4.1 through 4.6 show the data for the experimental machine as blue data points. The control machines are shown as green data points. The daily readings were grouped into weekly buckets with a week beginning on Monday. The target concentration is indicated as a green centerline on the concentration graphs at eight percent. The pH of a new coolant mixture is shown as a red centerline on the pH graphs. Fluid additions were denoted for the experimental machine, where 'w' designated the addition of straight water. A fluid mixture of coolant and water at X % concentration was designated as 'fX'. Fluid additions to the control machines were not documented. Regarding events dates, the year was omitted for purposes of brevity since the data occurred within a continuous three-month span.

The concentration curve for lathes 304 and 305 is presented in Figure 4.1 on page 35. Table 3.1 on page 24 shows lathes 304 and 305 have a coolant tank capacity of 40 gallons. Also from Table 3.1 the capacity of verticals 650 and 651 is 300 gallons, over seven times the capacity of the lathes. The smaller coolant tank capacity for the lathes 304 and 305 introduced more variability in the coolant concentration and pH. Lathes 304 and 305 concentration data also highlighted the measurement uncertainty of using an optical refractometer.

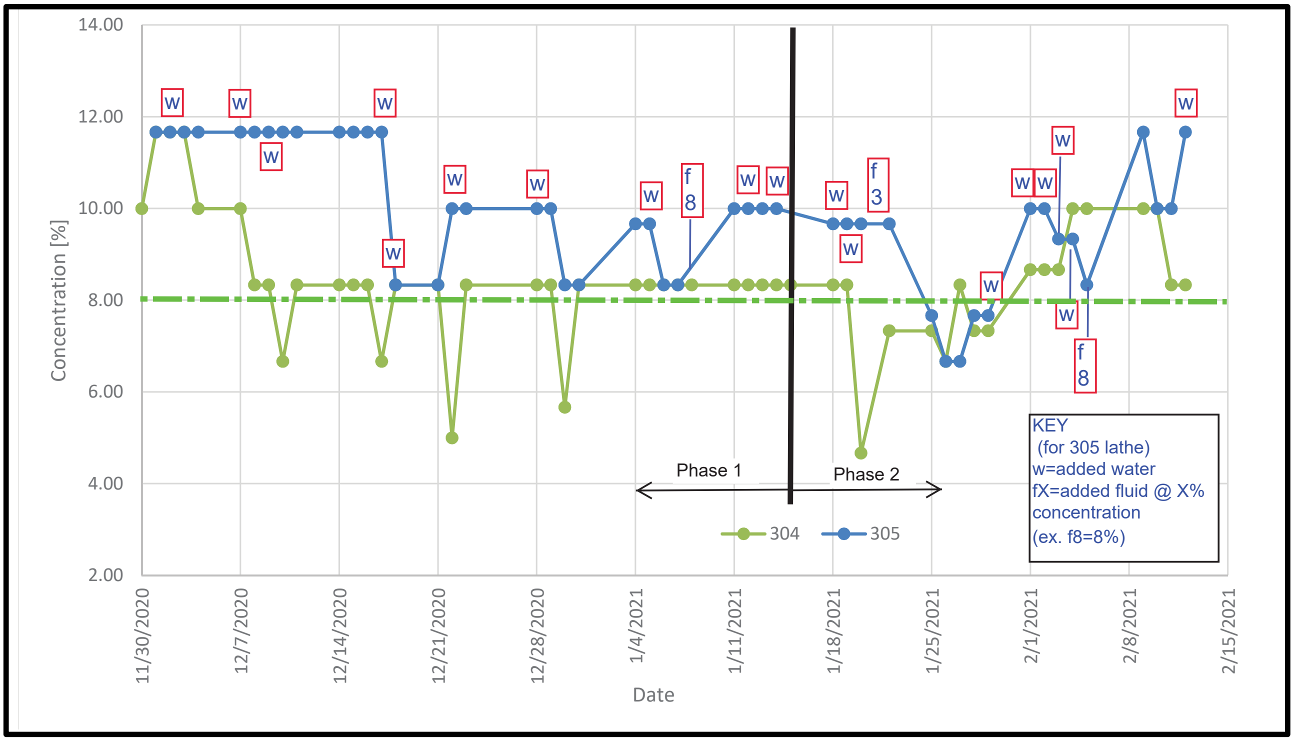


Figure 4.1: Coolant Concentration Versus Time for Lathes 304, 305

Figure 4.1 shows machine 304 exhibited periods of steady concentration and swings in concentration. The coolant concentration of lathe 304 was steady at 8.2% over an 18 day period beginning on December 31. Lathe 304 had four events in December where the concentration dipped by more than one percent and then returned to the same start value two days later. The first event began on December 9 where the concentration dipped from 8.3% to 6.7%, then returned to 8.3% amounting to 1.6%. The magnitude of the four dips varied between 1.6% and 3.3%. The four dip and recovery cycles of more than one percent were not explainable.

Machine 305 exhibited periods of steady concentration and swings in concentration. The coolant concentration of lathe 305 was steady at 11.7% over a 16 day period beginning on December first. December 22, the concentration increased from near the target level to the USL, from 8.3 to 10.0%, an amount of 1.7%. Lathe 305 had 21 total five-gallon additions of fluid over the range of the data collection dates. Lathe 305 had seven water additions in December to lower the concentration. The water addition on December first was expected to produce a decreased concentration on December second. The first four additions did not bring the concentration down. The water addition on December 17 brought the coolant concentration down by 3.4% from 11.7% to 8.3%. The formulas in Figure 2.5 on page 19, predicted a decreased concentration in the amount of one percent. The decrease in concentration of 3.4% was too large to be attributed to the addition of five gallons of water.

The four unexplainable dip and recoveries in concentration for lathe 304 had an unknown cause. The swings in concentration of 1.7 and 3.4% for lathe 305 were caused by the small coolant tank size. The swings for lathe 304 were amplified by measurement system limitations of the optical refractometer.

Figure 4.2 below shows the daily pH readings for lathes 304 and 305 where the red centerline represents the pH of a new coolant mixture at 9.3 pH.

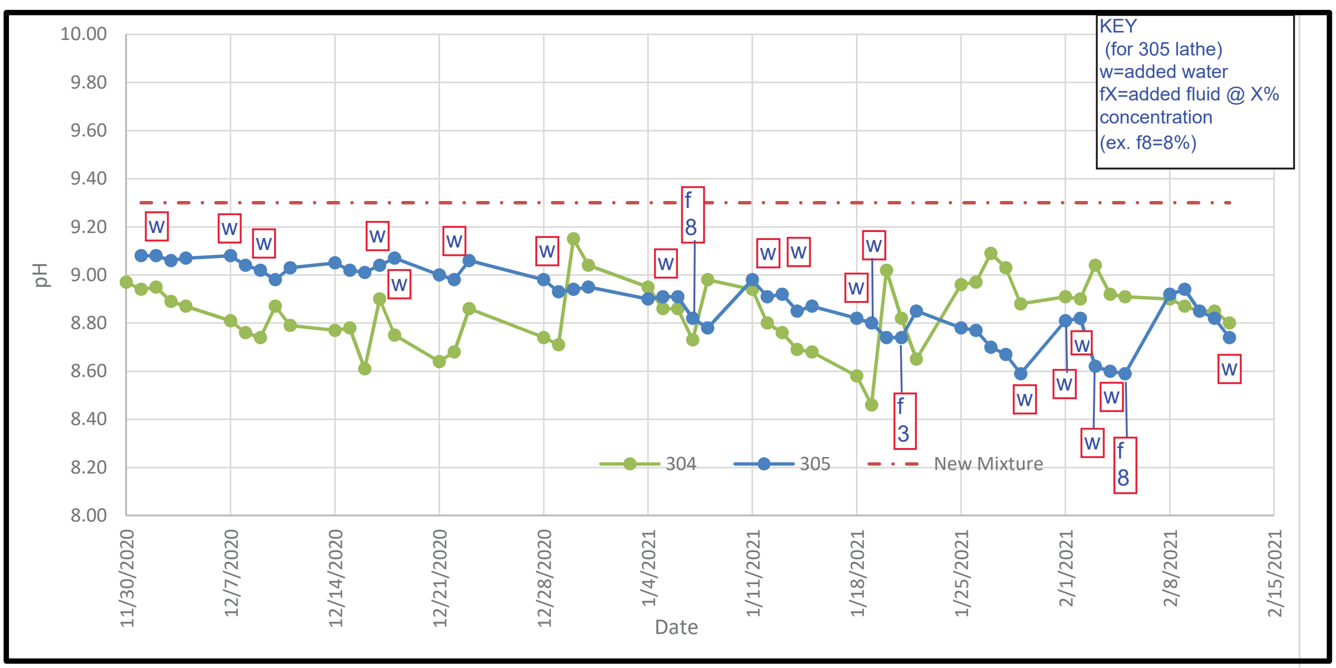


Figure 4.2: Coolant pH Versus Time for Lathes 304, 305

Figure 4.2 on page 36 shows lathe 305 started out as the upper curve reflecting a more recent coolant changeout date. Lathe 305 started out at 9.1 pH on November 30, but by December 30 had dropped below the 304 curve. December 30, the pH of machine 305 was 8.9 and the pH of 304 was 9.1.

The pH trend for lathe 305 had a general downward trend from a high of 9.08 to a low of 8.60. The pH trend for lathe 305 exhibited less variation in December than in January and February. The variation for lathe 305 was 0.15 pH in December, 0.28 pH in January, and 0.26 pH in February. The smaller variation in pH for lathe 305 in January was not explainable as no conditions for lathe 305 had changed.

Lathe 304 exhibited two pronounced stair step declines on December 30 thru January seventh, and January eight thru January 19. The first decline in pH was from 9.15 to 8.73, an amount of 0.42 pH. The second decline in pH was from 8.98 to 8.46, an amount of 0.52 pH. A steep recovery in pH was observed on January 19, increasing from 8.46 to 9.01, an amount of 0.55 pH. The recovery occurred one day after the coolant concentration increase from 4.6 to 7.3%, as shown in Figure 4.1 on page 35. The magnitude of the recovery was 2.7%. The increase in pH of 0.55, and increase in coolant concentration of 2.7% appeared connected. Correlation was not verifiable since fluid additions to the control machines were not documented.

The data collection spanned 11 weeks. The pH for lathe 304 dropped, over the Friday thru Monday weekend for the first seven weeks. The drops varied in magnitude between 0.1 pH on the weekend ending December seventh, and 0.21 pH the weekend ending December 21. The opposite trend was observed for lathe 305 on three occasions. The pH increased more than 0.2 over three weekends ending January 11, February first, and February eighth. The opposing pH trends for the lathes, decreasing for lathe 304 and increasing for lathe 305 were from an unknown cause.

The curves for the verticals 650 and 651 are presented next, with the coolant concentration curves shown in Figure 4.3 below.

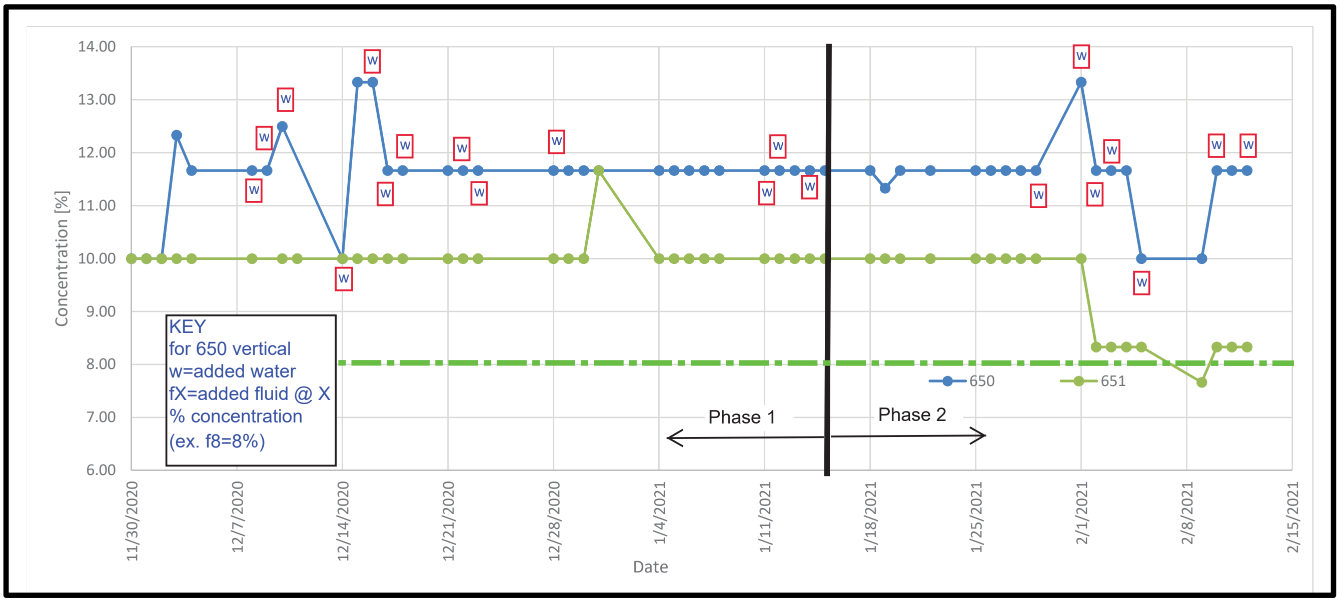


Figure 4.3: Coolant Concentration Versus Time for Verticals 650, 651

Verticals 650 and 651 exhibit elevated concentrations compared to the target rate of eight percent. Figure 4.3 shows vertical 650 as the upper curve with multiple data points at 11.8 %. Vertical 651 is the lower curve with multiple data points at ten percent. The 650 and 651vertical concentration curves were more consistent than the 304 and 305 lathe concentration from Figure 4.1 on page 35. The larger coolant tank capacity of the 650 and 651verticals had a leveling effect upon the concentration. A five-gallon fluid addition was only two percent of the total coolant tank volume for the verticals compared to 11% for the lathes.

Vertical 651 was remarkably consistent thru February first, except for a single data point on December 31. The difference was attributed to operator measurement bias, as a substitute operator took the measurement on December 31.

A total of 13 water additions for machine 650 during Phase one did not bring the concentration down from 11.8%. Once the concentration is above the USL of ten percent, lowering the concentration is difficult in practice. Evaporation, a primary source of fluid loss (Lazarus, 2018) serves to increase the concentration. Water additions made to compensate for evaporation only replaced the lost water and did not reduce the concentration. Under specification concentration level is raised by adding undiluted coolant.

The curves for verticals 650 and 651 pH level are presented in Figure 4.4 below. The nearly linear pH profiles for verticals 650 and 651 portrayed the gradual deterioration of the coolant.

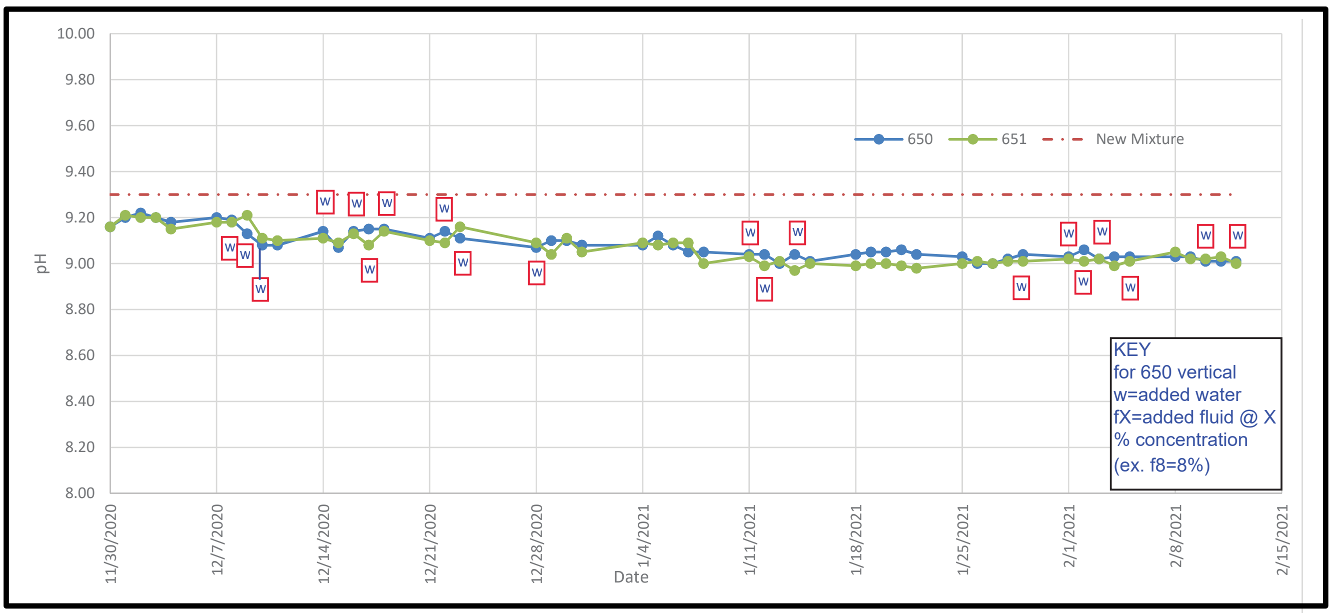


Figure 4.4: Coolant pH Versus Time for Verticals 650, 651

The pH curves for vertical 650 and 651 were smooth with a downward slope. The pH curves of machines 650 and 651were nearly coincident since the coolants were changed out only one week apart. The maximum daily difference between the two curves was 0.08 pH on December ninth. Machines 650 and 651 experienced a drop of 0.2 pH over the two and a half months of data collection. The magnitude of the drop was from a high of 9.2 to a low of 9.0 pH.

The coolant data for lathe 259 is shown below in Figure 4.5. Lathe 259 had no control machine for comparison purposes. Lathe 259 used a higher quality coolant than the other machines due to operator sensitivity.

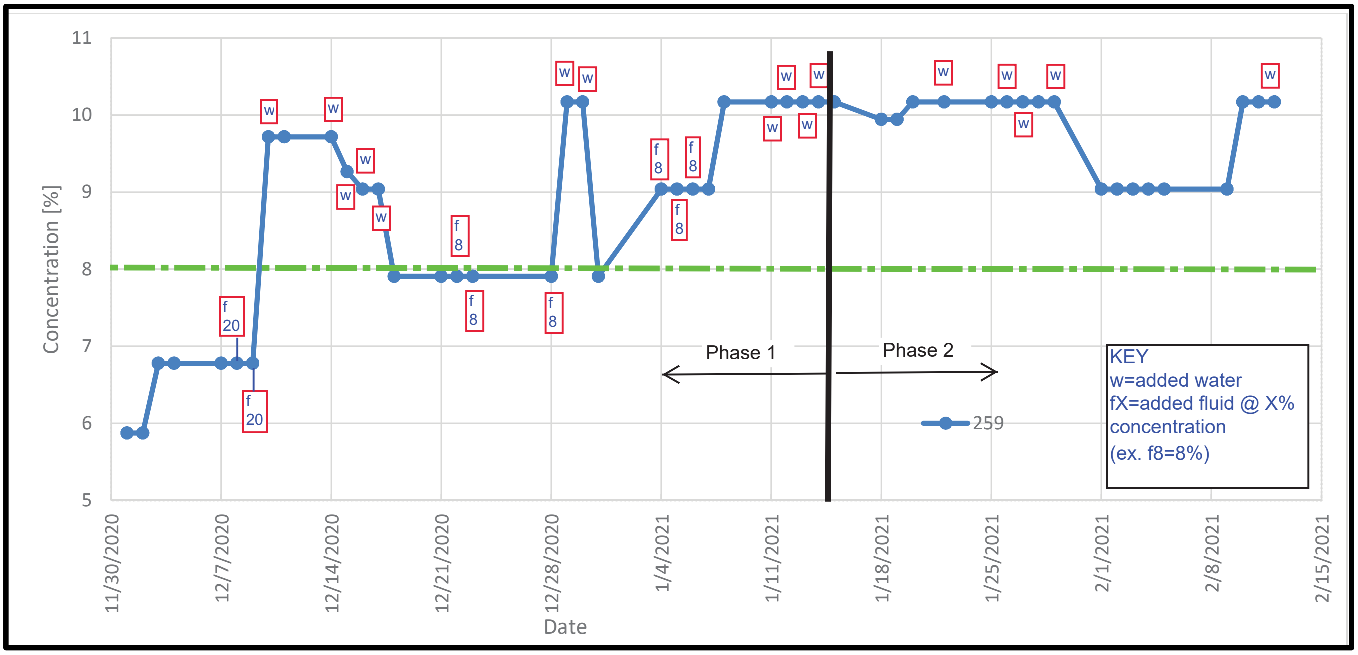


Figure 4.5: Coolant Concentration Versus Time for Lathe 259

Figures 4.5 for lathe 259 shows the variation in readings in Phase one was greater than the variation in Phase two. The range during Phase one had limiting readings of 5.8% and 10.2% for a range of 4.4%. Phase two had limits of 9.0% and 10.2% with a range of 1.2%. The difficulty associated with reading the lower resolution refractometer of Phase one explained the wider data range of 4.4% in Phase one.

The coolant concentration for lathe 259 trended upwards over the dates November 30 thru January eight from a low of 5.9% to a high of 10.2%. The upward trend was attributed to a particular event. Late November, the operator of machine 259 reported the coolant smelled bad. Prior to November 30 a refractometer was temporarily unavailable. Lacking a gauge to measure the concentration, the mixture concentration was unknown. The coolant concentration was found to be too lean when a measurement device was obtained. The coolant concentration was enriched over the period November 30 thru January sixth to bring up the concentration. The bad coolant smell had abated by December seventh.

The pH curve for lathe 259 is shown below in Figure 4.6 and exhibited a convex shape.

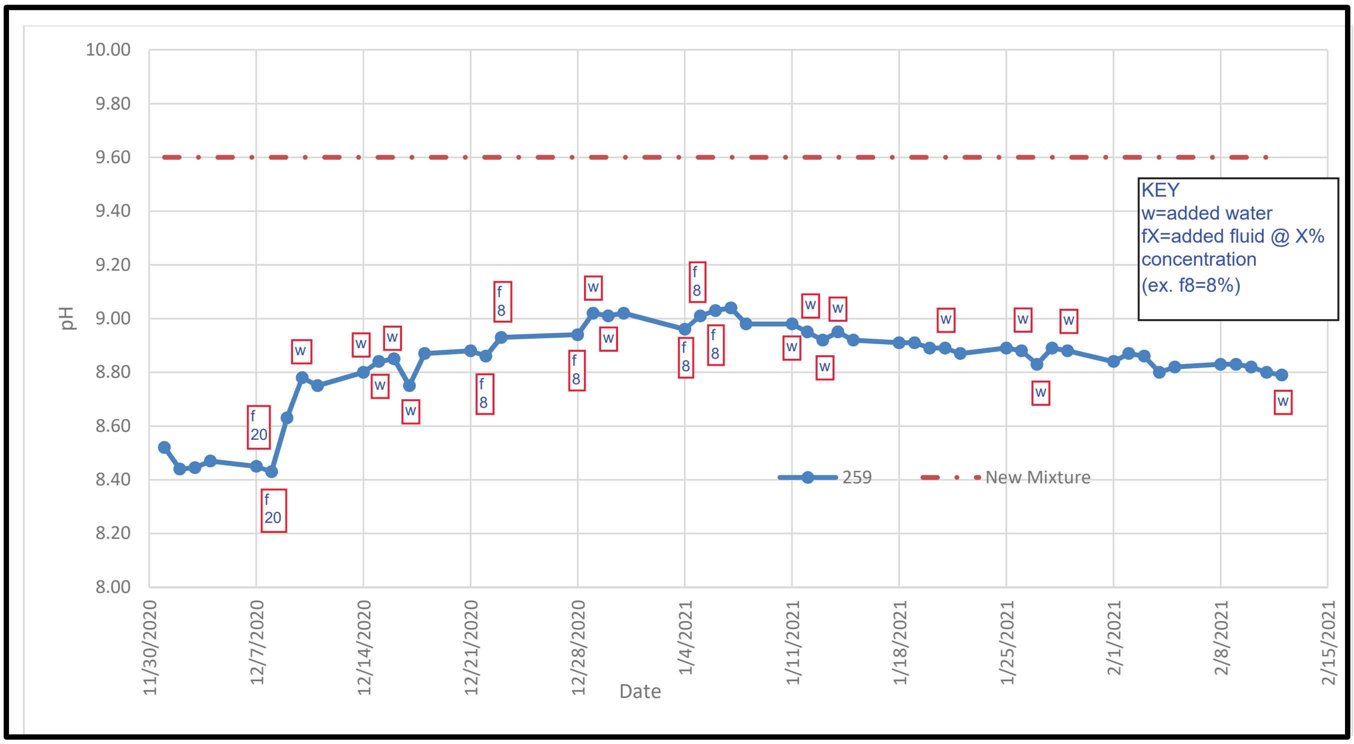


Figure 4.6: Coolant pH Versus Time for Lathe 259

Figure 4.6 shows the daily pH readings where the red centerline represents the pH of a new coolant mixture at 9.6 pH. The pH trended upwards over the dates November 30 thru January seventh. The pH value ranged from 8.44 to 9.02 pH, reflecting the enrichment of the coolant concentration. After January seventh the pH graph showed a gradual downward trend. The pH varied from a high of 9.05 to a low of 8.80 amounting to a 0.25 pH decrease. Fluid added on consecutive days December seventh and eighth at 20% concentration illustrated the ability of fluid additions to increase the pH. The pH increased 0.4 from December eighth thru December tenth, the largest two-day jump in the study for lathe 259. The coolant pH was recovering, reaching a peak of 9.05 on December 29. The 9.05 pH value was 0.55 pH away from the 9.60 value of a new mixture. Seidel and Meyer, 2019 summary of Rabenstein et al. 2009 states on page 426 “The metalworking fluid is therefore continuously subject to a combination of chemical, physical and biological effects. As a consequence, the aging processes leads to changes in metalworking fluids that are partly irreversible.” Lathe 305 began at a pH of 9.1 on November 30 as shown in Figure 4.2 on page 36. The 9.1 pH value was 0.2 below the new mixture pH of 9.3. Vertical 651 began at a pH of 9.2 on November 30 as shown in Figure 4.4 on page 39. The pH value of 9.2 was 0.1 below the new mixture pH of 9.3. The ‘partially irreversible’ aspect of the Seidel & Meyer 2019 quote is demonstrated by the wider gap between the starting (new mixture) and peak machine values in pH. Machine 259 had a wider gap compared to machine 305 and 650 (0.55 versus 0.2 and 0.1 respectively). The pH of lathe 259 never fully recovered from the conditions of initial contamination and low concentration.

4.2.1 Concentration and pH Comparison with Outside Testing

Dubois tested the coolant on January 13. The results comparing Hadady and Dubois are shown in Table 4.1 on page 43. Hadady measurements were field tests, whereas Dubois performed lab measurements.

Table 4.1: Comparison of Hadady and Dubois Coolant Measurement (Dubois, personal communication, January 13, 2021)

Machine	Hadady Concentration [%] (by Refractometer)	Dubois Concentration [%] (by Alkalinity)		Hadady pH	Dubois pH	Dubois Bacteria [cell/mm].
259	10.0	3.9		8.92	8.8	0
304	8.3	3.6		8.76	8.8	10^3
305	10.0	4.8		8.92	8.9	10^5
650	11.0	8.3		9.00	9.0	0
651	10.0	6.3		9.01	9.0	10^3

The coolant concentration readings of machines 259, 304, and 305 varied between Hadady and Dubois by a factor of two. Direct comparison wasn't appropriate since two different methods were used to analyze the concentration. The Hadady coolant readings were on the low side of the Dubois readings. Machine 259 showed the biggest variation in concentration readings with Hadady at ten percent and Dubois at 3.9%, a difference of 6.1%. The coolant samples were at least two months old when collected. Byers, 2017 explained the tendency of a handheld refractometer to overstate the concentration of a used solution.

The pH values between Hadady and Dubois compared favorably with a 0.1 pH discrepancy being typical.

The bacteria level of machine 305 was the highest of the five machines. The bacteria level for 305 had reached ten to the fifth power. The ten to the fifth power was one magnitude away from the ten to the sixth power end of coolant life criteria. Machines 259 and 650 showed no bacteria at zero cells per mm.

Next the statistics of the coolant concentration were examined. The swings in daily concentration were examined for significance in machines 304, 305, 650 and 651.

4.3 Coolant Concentration Capability

The process capability for coolant concentration was critical for showing the effectiveness of the experimental over the control method. Identical lathe 304 and 305 were compared as well as identical verticals 650 and 651. The figures used a subgroup size of one due to the limited number of data points collected. Process control (+/- three Sigma (δ)) is represented by both capability index $P_p>1.0$ and $P_{pk}>1.0$. The parameter P_p represented 'between subgroup' control and P_{pk} represented 'between subgroup' overall control (Hadady, 2012). The index P_p was important because process spread was considered more important than process centering. The data points included Phase one and two dates.

The process capability graph for lathe 304 shown in Figure 4.7 below exhibited a data spread outside the specification limits.

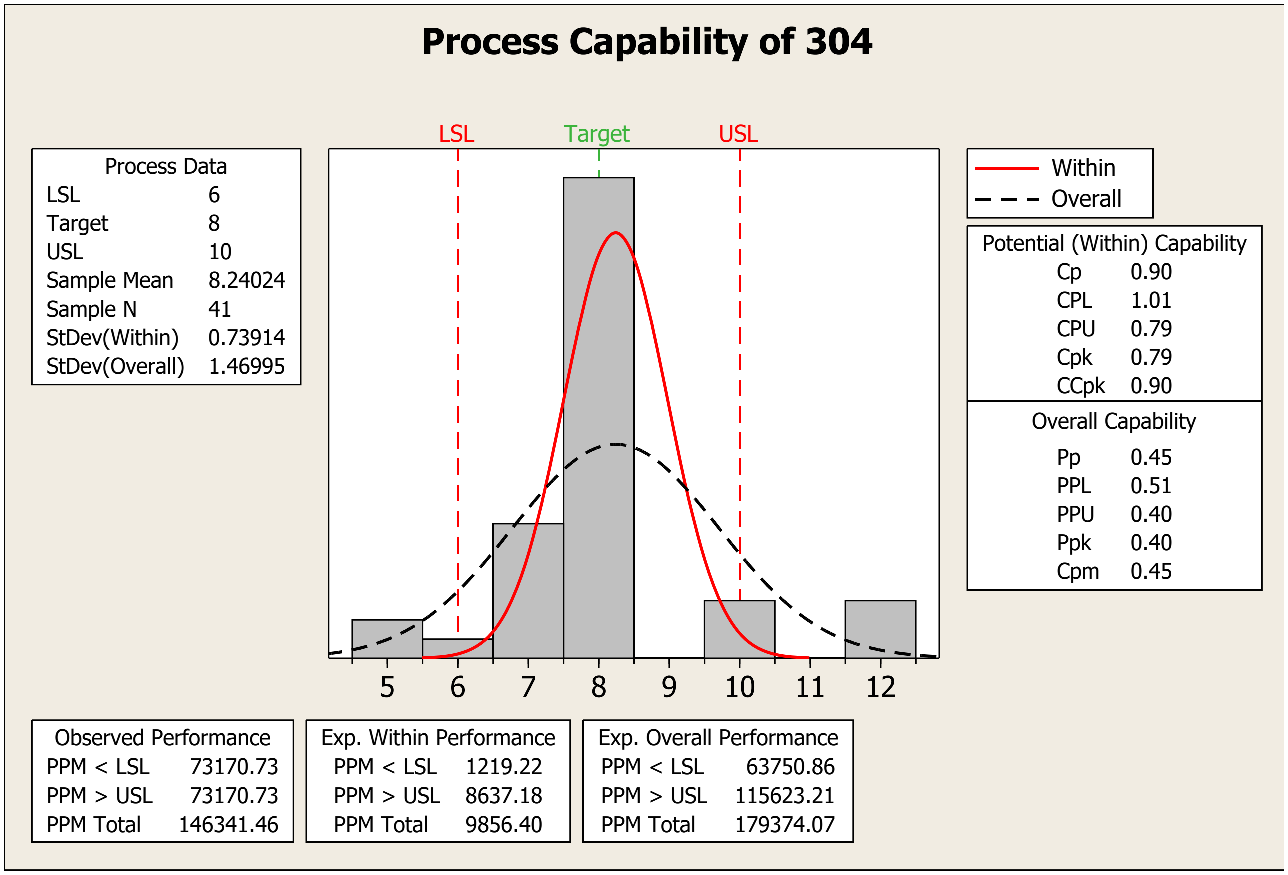


Figure 4.7: Process Capability for Coolant Concentration [%], Lathe 304

Figure 4.7 for lathe 304 had data points outside the specification limits (LSL, USL). The data points at five percent concentration were below the LSL, and the data points at 12% were above the USL. Data points outside the specification limits indicated the process was not capable (AIAG, 2005). The data was well centered on the target value of eight percent as shown by the tallest bar segment at 8.2%. Gaps in the graph exist at concentration of nine and 11%. A similar graph was created for each machine, but only summary data will be presented next.

The process capability of machines 304, 305, 650, and 651 is summarized in Table 4.2 below.

Table 4.2: Statistical Analysis of Coolant Concentration

machine	Sample Average	Standard Deviation	P_p	P_{pk}
304	8.2	1.47	0.45	0.40
305	9.9	1.65	0.40	0.00
650	11.6	0.69	0.97	-0.78
651	10.0	0.26	2.49	-0.05

Table 4.2 shows machines 304, 305, 650 and 651 had an average concentration above the target level of eight percent. Machine 304 average was the closest to the target varying by 0.2%, as reflected by the highest P_{pk} value of 0.40.

Comparing the verticals 650 and 651 to the lathes 304 and 305, the vertical's concentration had less variation than the lathes. Vertical 650 coolant concentration standard deviation was 0.69% maximum, versus a 1.47% minimum for lathe 304.

Comparing the lathes, experimental machine 305 had a bigger standard deviation (1.65 vs. 1.47) than control machine 304. Machine 305 had a lower P_p (0.40 vs. 0.45) than machine 304. The data comparing lathes 304 and 305 did not provide conclusive evidence the input conditions were met. Comparing the verticals, experimental machine 650 had a bigger standard deviation (0.69 vs. 0.26) than control machine 651. Similarly machine 650 had a lower P_p (0.97 vs. 2.49) than machine 651. The data comparing verticals 650 and 651 did not provide conclusive evidence the input conditions were met. Thus, conclusion on the output were not reliable.

Trends in the pH were examined in the next section to determine if the experimental results were promising enough to continue the research.

4.4 Investigation of Trends in pH

Time constraints for collection of data as detailed in Figure 3.2 on page 27 existed. Due to time constraints the trends in the pH value were important for predicting coolant life. Noticeable trends in the pH were investigated. Figure 2.3 on page 16, illustrated curves of selected MWF properties versus time. The pH curve has three distinct regions. As applied to lathes 304 and 305 the pH curve had the shape shown in Figure 4.8 shown below. The curves assume a coolant life of six months.

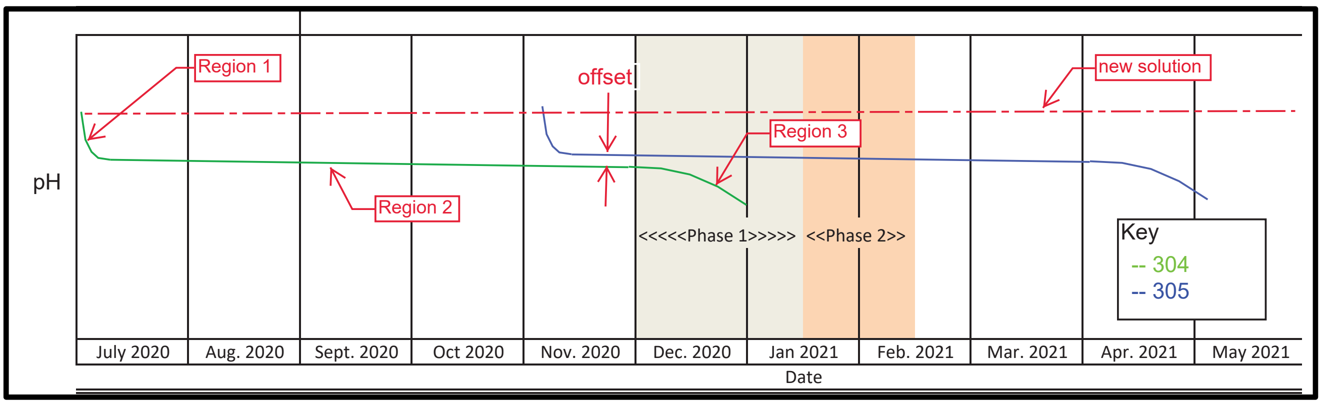


Figure 4.8: Shape of Time Versus pH Curve (Byers, 2017)

The first region (region one) shows a sharp decline in pH as the coolant is subject to residual machine contamination. Region two is nearly linear with a slight negative slope. Region two has the longest duration and coincides with the gradual degradation of the coolant. The pH begins to drop off as the coolant life is about to expire in region three.

Two conditions would indicate shortened coolant life in region two. The condition of a vertical shift between two pH curves (labeled ‘offset’ in Figure 4.8), or a steeper downward pH slope. The next section looked for the presence of either condition.

4.4.1 Linear Plot of pH Curve

A linear fit for the pH data of sub-section 4.2, is presented in Figure 4.9 below. Machines 305, 650 and 651 exhibited a linear decrease, whereas machine 304 exhibited a linear increase.

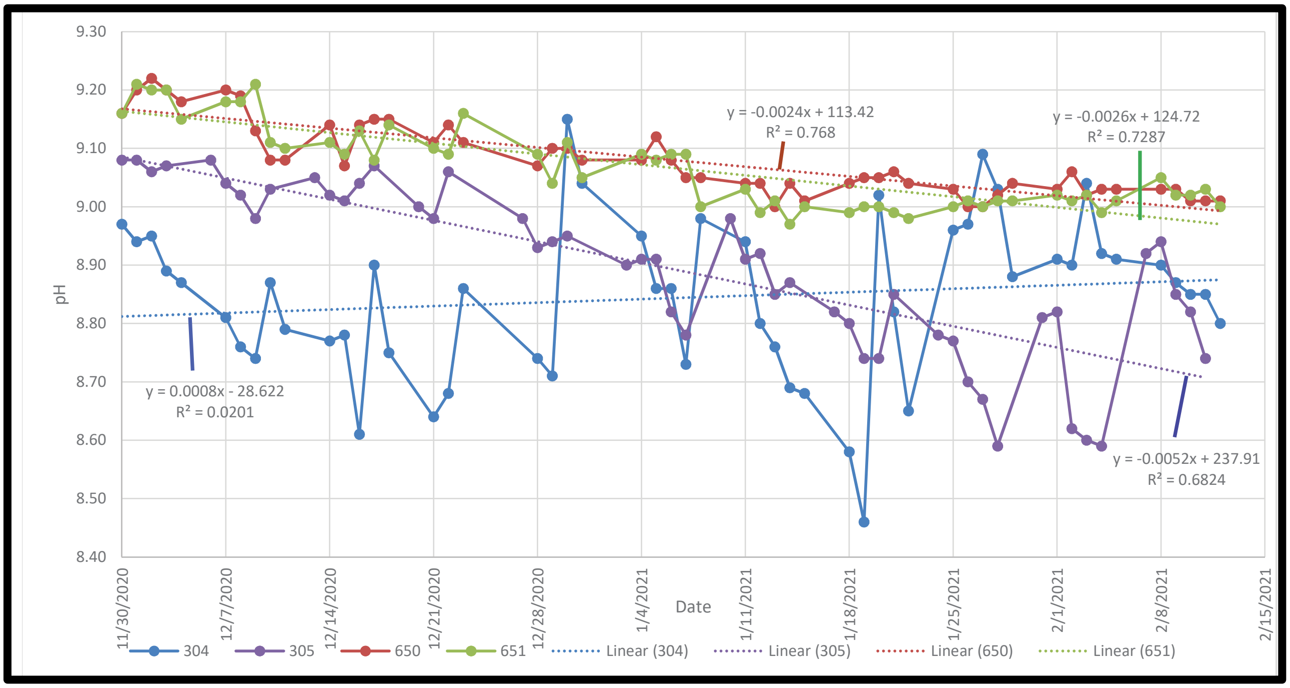


Figure 4.9: Linear Fit of pH Curve

Based upon the linear shape of the pH graphs in Figure 4.9 for machines 304, 305, 650, 651, the pH data resided in region two. Next the linear region of the pH plot will be examined.

The slope of the linear equation represents the average daily change in pH for each curve. Machine 304 exhibited a daily change of +.0008 reflecting a daily increase in pH. The machines 305, 650 and 651 exhibited a daily decrease in pH ranging from -.0024 to -.0052. The daily change for machines 304, 305, 650 and 651 were imperceptible to the pH meter which had a resolution of .01. Extrapolating the daily pH slope to a monthly figure yields +.024, -.156, -.072, and -.078 respectively for machines 304, 305, 650 and 651.

Verticals 650 and 651 had the coolant changed out only one week apart. The negative slope of the control machine 651 was steeper than the experimental machine 650 (-.0026 vs. -.0024). The .0002 daily slope difference represented an 0.03 change in pH over the over two and a half months of data collection. The 0.03 difference in slope was not statistically significant between machines 650 and 651 at a confidence level of 95%.

Regarding the lathes, the coolant in 304 was changed out five months prior to machine 305. The expected vertical shift with the 304 curve below the 305 curve was not observed. The two linear fit curves crossed on January 23, with the curve 304 crossing above the curve 305.

The experimental lathe 305 did not indicate an increase in coolant life as indicated by an offset in pH curve. The experiment vertical 650 did not indicated an increase in coolant life as indicated by the slope of the pH curve. Thus continuation of the experiment was not advised.

Whereas the experimental method did not better the coolant concentration control, the pH linearity of the coolant improved. The linear regression R^2 is listed in Figure 4.9 on page 48. The R^2 value of experimental machine 305 exceeded the control machine 304 (.682 versus .021) indicating better pH linearity. The R^2 value of experimental machine 650 slightly exceeded the control machine 651 (.768 versus .729).

4.5 Other Factors Influencing Coolant Life

Other factors impacting coolant life to be discussed include:

- water quality
- make up fluid quantity

The two preceding factors have potential adverse effect upon coolant condition. Water quality is of particular concern as stated by Foltz, 2018.

4.5.1 Water Quality

The typical water hardness in Illinois is 125-200 PPM (Foltz, 2018). A water sample for Hadady facility located in South Holland IL was collected from the garden hose used to fill machine coolant tanks. The results are summarized in Table 4.3 below.

Table 4.3 Water Sample Hadady South Holland (Dubois, personal communication, June 5, 2020)

pH	7.2
Total Hardness [PPM]	120
Bacteria [cell/mm].	10^4

The total hardness of 120 PPM was just below the Illinois typical range. The bacterial level of ten to the fourth was identical to the Dyer water sample from Figure 2.1 on page 12. The South Holland report had the same caution stated on the bottom. The caution read: “Bacteria is present in water. This may shorten life of metal working fluids”.

4.5.2 Make-up Fluid Quantity

Adding make-up fluid to restore the proper coolant level is part of daily machine maintenance. Fluid carry out from the cut metal chips is visible if the chip conveyor is run continuously. Figure 4.10 on page 51 shows coolant trailing from a leaking scrap hopper.

Figure 4.10: Coolant Loss from Carry Out

Running the chip conveyor intermittently reduces carry out but requires operator intervention and the conveyor binds if chip buildup is excessive.

The amount of make-up fluid varied depending upon machine usage, chip conveyor usage and other factors. The average daily makeup fluid is tabulated in Table 4.4 below.

Table 4.4: Average Daily Makeup Fluid Addition [Gallons per Day]

Machine	259	305	650
Makeup Fluid [Gallons per Day]	2.3	2.1	2.0

Table 4.4 shows the machines 259, 305 and 650 consumed two gallons of fluid a day. The lathes 259 and 305 consumed the same quantity of coolant as the vertical 650.

Another finding of the experiment was the realization the lathe coolant tanks have been over-filled for the last ten years. The fluid level gages on the coolant tanks were obscured by grit. Once the sight glass were visible, came the recognition the coolant tanks were overfilled by 30% coolant volume.

4.6 Results Summary

The experiment needed to first demonstrate proof of 'consistent coolant concentration' before making any conclusion on coolant life. The following points were contrary to the assertion:

- Coolant concentration data had unexplained variability on the order of the acceptable product tolerance range (USL-LSL) for lathe 305.
- Coolant pH for lathe 304 exhibited repeating linearly descending trends, an indication of special causes.
- The statistical measures for coolant concentration were worse for the experimental machines (305 and 650) than the control machines (304 and 651). The statistical measures used were standard deviation and process indices P_p and P_{pk}.

Therefore, the experimental method was not sound. To consider the worth of continuing the experiment, the preliminary results were examined in terms of pH. The preliminary results were not encouraging based upon the following points:

- In terms of slope of the pH curve, control vertical 651 exhibited accelerated degradation of coolant as compared to experimental vertical 650. The magnitude of .03 pH difference over two and a half months of data collection was not statistically significant at an 95% confidence level.
- In terms of pH curve offset, control lathe 304 did not have a pronounced negative linear offset as compared to experimental lathe 305.

Thus, justification did not exist to continue the experiment.

The experiment had several significant limitations with the potential to skew results. The first three limitation were previously identified in Chapter three, sub-section 3.6 on pages 32:

- Machine coolant tank condition, a potential source of MO contamination was not detectable.
- Two and a half month time frame for data collection was abbreviated compared to the nine months needed for a full experiment.
- The initial conditions of the experiment varied for experimental machine 305 and 650.
- Measurement system uncertainty from the use of optical refractometer for lathe 259.
- Discrepancy between HC and Dubois coolant concentration measurements as detailed in sub-section 4.2.1 on pages 42-43.
- Fluid additions to the control machines 304 and 651 were not recorded. Having not recorded data limited interpretation of coolant concentration and pH data for the control machines.

The experiment did provide useful insights:

- The lathes 304 and 305 had more variability in the coolant concentration and pH data than the verticals 650 and 651. The variability was due to smaller coolant tank capacity.
- Coolant concentration above the target level is difficult to bring down even with multiple additions of water as illustrated by machine 650.

- City water quality has an impact on coolant life as detailed in sub-section 4.5.1 on page 50.
- The average daily water consumption was found to be two gallons for all the machines as shown in Table 4.4 on page 51.
- The machine pH partially recovers from an extended period of low coolant concentration as demonstrated by lathe 259.

Summarizing the results, the research was inconclusive and will be further explained in Chapter five, Conclusions, Summary, and Recommendations.

CHAPTER 5. **SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS**

5.1 Summary

Water based coolant is pervasive in metal working process due to the useful properties of cooling and lubrication provided (Foltz, 2018). Foltz and ASTM-1497 (2017a) support the assertion careful management of machine tool coolant condition maximizes the benefits of WB coolants. The lifecycle of machine coolant has concerns including health, environmental and disposal (ASTM, 2017a). Water based coolants being composed of over 95% potable water warrants conservation. The conservation was in alignment with the Grand Engineering challenge *Provide Access to Clean Water* (NAE, n.d.). Potable water is a limited resource and extending the life of water based coolants decreased the quantity of water consumed.

Chapter two Review of Literature discussed coolant longevity best practices. The review of literature did not find any quantitative studies addressing coolant life.

The research herein focused of the benefits of carefully monitoring and maintaining coolant concentration. Daily adjustments of coolant concentration and coolant level were compared against the current reactionary method. Fluid was added only when the coolant tank level appeared low. Coolant concentration and pH data were collected for two and a half months. The results of the research were inconclusive in establishing the benefit of daily additions of the proper coolant mix. The research experimental method did not produce measurably improved control of coolant concentration. The fluid additions to the experimental machines were at a concentration tailored to retore the concentration to the target level. The inability of the fluid additions to achieve the target concentration was unexpected.

Nor did the study offer promising results in terms of coolant pH. The coolant in the experimental lathe 305 degraded at a faster rate than the experimental lathe 304 based upon pH curve offset. The coolant in the experimental vertical 650 degraded at a slower rate than the experimental vertical 651 based upon pH curve slope. The magnitude of the pH slope was not statistically significant at a 95% confidence level. The sole improvement in coolant pH came from better linearity of the pH curve for the experimental machines.

The study data contained anomalies in the coolant concentration and pH not explainable by the addition of fluid. Gage repeatability and precision, and the study timeline were limitations in the study.

5.2 Conclusions

The principal study findings expanded the body of knowledge marginally thru negative results in the area of machine tool coolant life. Instead, the study revealed instances of useful applications. The applications are of interest to machine shop operators especially with equipment over 15 years old.

The first useful instance was due to the effect of coolant tank size. Lathes 304 and 305 had smaller coolant tank capacities compared with the verticals 650 and 650. Lathes 304 and 305 saw more variability in the coolant concentration and pH than verticals 650 and 650. The finding was consistent with the research statement expressed in Figure 3.1 on page 23. The smaller coolant tank experienced greater swings in coolant level percentage due to carry out and evaporation than the verticals. Machines with fluctuating coolant fluid levels require closer monitoring to maintain the concentration at acceptable levels.

The second instance the study demonstrated was the ‘partially irreversible’ aspect of coolant properties (Seidel & Meyer, 2019). The coolant concentration of lathe 259 was found to be below the LSL, and evidence of MO growth existed at the begging of the data collection. Section 4.2 on page 41-42, showed increasing the coolant concentration to the target level resulted in a partial recovery of the coolant pH. Likewise the study illustrated the ability of proper coolant concentration to restore MO balance without the use of tank side biocides.

Coolant concentration is difficult to bring down in practice. Repeated water additions to vertical 650 as shown in Figure 4.3 on page 38 did not reduce the concentration. To achieve the target concentration a proper amount of coolant is required at fill up. Hadady specification 6.8.70-9.1251 *Coolant Product and Mixes* lists the tank capacities and required amount of coolant for each machine.

Lathe 259 used a premium coolant Dubois Pearl Z. The product data sheet in Appendix A-2 on page 63 lists the benefits. The benefits include: reduced misting and fluid carry-off, and excellent tramp oil rejection (Dubois, 2014). The reduced misting of Pearl Z was supported anecdotally by machine operator remarks. Reduced fluid carry-off was not verified by the experiment. Lathe 305 using Dubois 5250 coolant and lathe 259 using Pearl Z both consumed two gallons of makeup fluid a day per Table 4.4 on page 51. The tramp oil rejecting property of Pearl Z was noticed by the study author during manual skimming. The tramp oil skimmed easily and exhibited a sharp separation between the coolant and oil layers.

5.2.1 Threats to Validity

The research method was unsuccessful in producing improved control of coolant concentration. Maintaining a consistent coolant concentration and fluid level appeared to be a sound methodology for achieving the goal of 'consistent coolant concentration'. The study contained limitations impacting both coolant concentration and coolant pH.

A zero-to-ten optical refractometer has a stated accuracy of +/- 0.1% (Zebra, 2012). Both the study author and maintenance personnel reported difficulty reading the scale on the refractometer. The daily coolant concentration readings varied on the order of the specification bilateral tolerance. The reading varied from the target level to the USL or LSL daily. The scale randomly turned blurry and the delineation between the light and dark areas on the refractometer was not crisp. Zebra (2005) stated the refractometer was not defective, the coolant contaminated by emulsified tramp oil blurs the refractometer reading. The measurement system uncertainty from the optical refractometer was deemed the major study limitation to coolant concentration control.

The coolant concentration of machines 650 and 651 was consistently high (above USL) during data collection as shown in Figure 4.3 on page 38. Figure 1.1 on page two demonstrated the ability of elevated coolant concentration to control MO levels. The elevated coolant concentration levels potentially obscured the pH comparison of experimental machine 650 and control machine 651.

5.2.2 Interpretation of Findings

Fluid additions were not recorded for the control machines 304 and 651 to maintain the current method of coolant control. The decision to not record the make-up fluid addition was based upon the intent to adhere to the current process. Not recording the fluid additions had the unintended consequence of obscuring the cause of shifts in the coolant concentration and pH. The four dip and recoveries in concentration for lathe 304 was an example. The causes of the dips identified in section 4.2 on page 36 were not explainable.

The experiment was useful for generating baseline data. The slope of the coolant pH decline is shown in Figure 4.9 on page 48. The slope is useful for predicting the degradation of coolant pH in the liner region of Figure 4.8 on page 47. The average daily slope is also helpful to identify uncontrolled trends in coolant pH. The daily fluid consumption tabulated in Table 4.4 on page 51 is useful for scheduling the frequency of fluid additions.

5.3 Recommendations

Recommendations are based upon data collected during the operation of the experiment. The process of conducting the experiment yielded more tangible results than the quantitative analysis of the coolant concentration and pH data.

A digital refractometer has the resolution to provide feedback necessary to discern and react to coolant fluid additions. The digital refractometer is also less affected by tramp oil than the handheld optical type (Canter, 2011). The use of a zero to ten optical refractometer did not have enough repeatability to detect the daily fluid additions. The optical refractometer resulted in over or under dosing of the coolant concentration. The use of a digital refractometer in the machining environment is highly recommended.

Preparation of the research report led to the identification of two deficiencies in the Hadady quality system. The first deficiency was an error in the tank capacity of lathe 259. The tank capacity was 82 gallons, not 45 as was stated in Hadady specification 6.8.70-9.1251.01. The second deficiency was the lack of a quality department work instruction for the calibration of an optical refractometer.

Stagnant areas of a coolant tank with poor circulation are susceptible to increased MO growth (Passman, 2018). Verticals 650 and 651 had a field modification which eliminated a coolant pump from the low tank during installation. The removed pump created a dead end chamber with poor coolant circulation. A modification of the coolant tank construction allowing better circulation with the adjacent chamber is recommended for verticals 650 and 651.

A mobile skimmer is recommended to be shared between lathes 304, 305 and 259. The three lathes lacked a skimmer or lube oil collection system. The spent lube oil drains into the coolant tank. Section 4.5.2 on pages 50-52 revealed the lathe coolant tanks were being overfilled. The operator’s perception was the lathes produced less smoke with the coolant level extra high. Manual skimming had been utilized on the lathes over the last year to remove tramp oil, but was tedious and time consuming. A skimmer would effectively remove the tramp oil. A skimmer with a timer for automatic shutoff is advised.

The use of hazardous chemicals is to be minimized. Coolant treatments including sump cleaners and biocides to control MO growth are concentrated chemicals. The treatments need to be applied at manufacturer recommended levels. The tendency to apply treatments at reduced concentration levels is to be avoided. Underdosing selects bacteria resistant to the biocide active ingredients (ASTM, 2017b).

5.3.1 Future Research

The research data collected over the two and a half month span provided glimpses, especially of coolant pH. The change in pH of the non-aerated coolant tank over the weekend was of particular interest. Puneeth and Ganesha Prasad (2019) predicted a pH decrease due to the acidic byproducts of anaerobic bacteria which thrive in a static sump. The pH of lathe 304 decreased on seven consecutive weekends as expected. Contrarily, the pH of lathe 305 saw an increase in pH over three weekends. The source of the pH increase over the weekend is worth investigating since is opposes the natural degradation of coolant pH.

The pH of new coolant drops by a third of the total magnitude as shown in Region one of Figure 4.8 on page 47. The coolant loses appreciable buffering in the one week span. Puneeth and Ganesha Prasad (2019) showed the pH of new coolant in a lab environment remained steady. Reasoning the drop in pH was due to residual MO contamination of the coolant tank sparked a question. The question ‘was the magnitude of the pH drop in Region one a measure of how well the coolant tank was cleaned’? The topic warrants future investigation as a benchmark to determine when a coolant tank requires a deep cleaning (remove chip conveyor).

Summarizing, the study did not deny the benefits of conditions monitoring of manufacturing machine coolant. Conditions monitoring as part of a fluid management program is a proven method for reducing fluctuations in coolant variables (Foltz, 2018). The coolant concentration data collected were suspect, the coolant pH data collected were judged trustworthy. The coolant concentration and pH data viewed together yielded inconclusive results. Measurement system uncertainty, a two and a half months timeframe for data collection, or data collection initial conditions caused the inconclusive results. The value of the experiment was demonstrated by the ancillary findings presented in the section 5.2 conclusions and section 5.3 recommendations.

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APPENDIX A-1

Dubois Perkool 5250 Product Data Sheet (Dubois, 2015)

DuBois

Perkool 5250

Semi-Synthetic Coolant

Description

Perkool 5250 is a versatile, biostable, non-phenolic, semi-synthetic lubricant designed for a wide variety of machining applications.

Key Properties

- Easily mixes in all kinds of water and is low foaming
- Pleasing odor and light color provide good operator acceptance
- Provides exceptional cooling and rust protection
- Contains a superior lubrication package

Typical Specifications:

TEST	RESULT
Color	Clear, Yellow
Foam at 5%	Low, Quick Break
pH at 5%	9.3
Chlorine	None
Flash Point (COC)	None
Lbs per Gallon	8.3

Applications

- Grinding, milling, drilling, turning, reaming, sawing, broaching and tapping

Use Instructions / Typical Concentrations

Always Add Product To Water

Dilute to 5% to 10% concentration for most applications.

Concentration Control:

Use hand held refractometer BX-10 (0-10% BRIX)
DuBois Part # 11753225
It is always important to adjust (zero) a refractometer with plant (make-up) water prior to testing the product. Use the following Refractometer Chart to insure proper in-use concentration. If the refractometer reading is outside the chart range take the reading X 1.6 to determine the concentration.

Refractometer Chart:

CONCENTRATION	READING
2%	1.3
4%	1.5
6%	3.8
8%	5.0
10%	6.2

Material Compatibility

Perkool 5250 is safe for use on ferrous metals, but it is generally not recommended to use on copper, brass, bronze or aluminum.

Handling and Storage Instructions

DO NOT FREEZE.

Disposal

Any disposal of this product should be in compliance with all federal, state and local regulations. Please refer to the Safety Data Sheet (SDS) for instructions regarding proper disposal of this product.

Precautions

KEEP OUT OF THE REACH OF CHILDREN.
Please refer to the label and Safety Data Sheet for all warnings, recommendations for safety equipment, and other regulatory information. Copies of the Safety Data Sheet (SDS) can be ordered by calling 800-438-2647.

DuBois Corporate Office • 3630 East Kemper Road Sharonville, OH 45241-2011 • 800 438 2647
DuBois Canada • 1155 North Service Road West, Unit 11 Oakville, ON L6M 3E3 • 866 861 3603
www.duboischemicals.com

Revision:
7/6/2015

APPENDIX A-2

Dubois PEARL-Z 3421-D Product Data Sheet (Dubois, 2014)

Pearl-Z 3421D

BACTERICIDE-FREE Cutting & Grinding Fluid

Description

Pearl-Z 3421D is a premium medium oil content cutting and grinding fluid for ferrous and non-ferrous metals. It utilizes a proprietary new BACTERICIDE-FREE technology engineered to meet the varied performance demands of today's machine shops. **Pearl-Z 3421D** is engineered to reduce misting and fluid carry-off, so use cost is minimized. More importantly, resources associated with maintaining dangerous bactericides are reduced dramatically.

Key Properties

- BACTERICIDE-FREE for maximizing user safety
- Operator acceptance
- All metal safe
- Low residues making it easier to clean off parts
- Excellent tramp oil rejection
- Suitable for high pressure applications

Physical Properties

Color:	Blue Fluid
Density:	8.20 lb/gal
Flash Point:	None
Foam:	Low
Hard water stable:	Yes
pH (concentrate):	10.0
pH (5% dilution):	9.6
Chlorine:	None
Sulfur:	None

Use Instructions

ALWAYS ADD PRODUCT TO WATER!

Pearl-Z 3421D provides superior performance when used properly and will handle the toughest applications. **Pearl-Z-3421D** can be used to machine or grind any alloy offering superior corrosion protection. Dilute 5.5% to 10% for machining applications and grinding applications.

Dispensing

Pearl-Z 3421D is dispensed by pouring, pumping or educting through DuBois equipment. Contact your DuBois account representative for proper use.

Concentration Control

Use hand held refractometer BX-10 (0 TO 10% BRIX) DuBois Part# 11753225

It is always important to adjust (zero) a refractometer with plant (make-up) water prior to testing the product. The refractometer reading should be multiplied by 1.11 to determine the chemical concentration of the **Pearl-Z 3421D** working fluid. A 10% solution will have a reading of 9.0.

Product Compatibility

Pearl-Z 3421D is safe at the recommended concentrations on all common material of construction including; steel, stainless steel, aluminum, copper and brass, and common rubbers and plastics when used as directed.

Handling and Storage Instructions

DO NOT FREEZE.

Precautions

KEEP OUT OF REACH OF CHILDREN.
Please refer to the label and Material Safety Data information for all warnings, recommendations for safety equipment and other regulatory information. Copies of the Material Safety Data information can be ordered by calling 800-438-2647.

Disposal

Please refer to the Material Safety Data Sheet (MSDS) for instructions regarding proper disposal of this product. DuBois offers a complete line of wastewater treatment products. To complement our wastewater treatment products, we provide compliance consultation and testing services. Contact your DuBois account representative for more information.

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6/13/2014

APPENDIX A-3

pH Meter Calibration Log

Month and Year by:

date of month	reading before meter rezero* (2 place precision)	reading after rezero ** (2 Place precision)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
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21		
22		
23		
24		
25		
26		
27		
28		
29		
30		
31		

* must be within +/-.02 of 7 pH or need to rezero meter
** write '--' if meter rezero not required
for meter Okaton pH30 s/n T311460090, using calibrated pH=7 solution

Meter Calibration Instructions

calibrate daily before use.
may take a few reading during daily calibration before meter stabilizes (get same reading twice)

pH Sampling Instructions

competley fill 20ml cup with coolant sample,then dump out
fill cup with 5mm coolant sample
rinse probe with distilled water after use

Joe Huss 2/11/2021