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Technical Bulletin

Demystifying the use of Refractometers for Metalworking Fluids

Abstract

It is no secret that concentration control is essential to maximizing the life and usefulness of metalworking fluids. Proper concentration can maximize feed and speed rates, reduce surface finish problems, and reduce tool wear and skin problems.

Refractometers are indisputably the best method available for accurately maintaining proper coolant concentrations. It is the purpose of this technical bulletin to demystify the use of the refractometer.

This bulletin will help you get the most out of your existing refractometer with respect to measuring emulsions, issues effecting precision, temperature effects, proper measurement scale selection and correction factors, and tramp oil contamination.

Introduction

Demands for high-quality and tight tolerances are nothing new, but achieving them at the lowest possible cost certainly makes a company more competitive. Key to improving part quality and maintaining tolerance is the elimination of process variation. This usually takes the form of identifying and controlling variables that effect process stability. One often overlooked area, metalworking fluids, is a great place to concentrate attention and the payoff can be enormous.

With so much to be gained by metalworking fluid maintenance and control, it is astonishing that so many companies do not have a formal process in place to collect data and monitor them. The benefits of properly controlling metalworking fluids are numerous (see Fig. 1).

REDUCING:	LEADS TO:
Coolant Use, Cost & Disposal	Saving Money
Fluid Concentration Problems	Higher Feed & Speed Rates, Less Tool Wear
Dermatitis	Better Working Conditions
Machine Downtime	Better Productivity
Part & Process Variation	Better Quality & Saving Money
Waste and Rework	Better Quality & Saving Money
Part Corrosion	Better Part Finish, Quality, Savings
Rancid Fluids	Better Working Conditions
Messy Cleanups	Better Productivity

Fig. 1

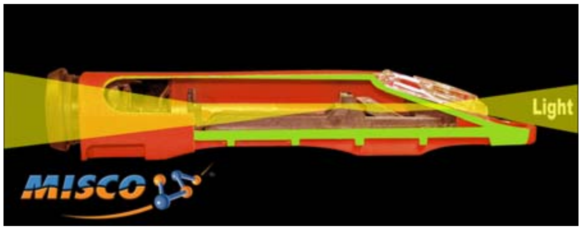
Concentration is the easiest part of a process to monitor and yet it is often the most neglected. A refractometer is an optical instrument used to measure fluid properties and, when used correctly, can help eliminate concentration as a source of variation before problems begin. Refractometers can perform a measurement in just seconds and can be used by anyone on the shop floor with very little training. Although they have been used successfully for decades to monitor and control the concentration of metalworking fluids, their use is often misunderstood.

"When you can measure what you are speaking about and express it in numbers, you know something about it, but when you cannot express it in numbers, your knowledge is a meager and unsatisfactory kind"
Lord Kelvin (1824 -1907)

Refractometers

Refractometers very accurately measure the speed of light as it passes through a solution. The more concentrated the solution the slower light will travel as it passes through it. The traditional handheld analog refractometers and the new digital handheld refractometers are two primary types of field instruments used to measure metalworking fluids.

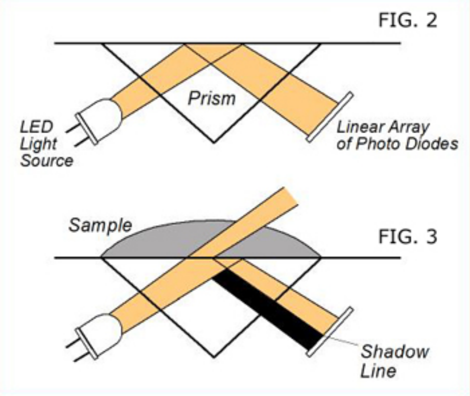
The first is the tried and true traditional analog refractometer. Simply place a few drops of fluid under the flapper, point it at a light, and look through it. The reading is taken at the point a shadowline crosses the tiny internal scale.



Digital instruments work similarly but contain their own light-source and display the measurement on a digital LCD readout. At the heart of the digital instrument is a linear array of photodiodes, much like the CCD array in a digital camera, where the shadowline is imaged and read (see Fig. 2 & 3).

FIG. 2

FIG. 3



The linear array in a digital refractometer can discern changes in the position of the shadowline with much better resolution than the human eye. Generally, the more elements in the linear array the more accurate the refractometer will likely be and the better it will be at reading emulsions. Digital instruments are also usually more accurate than analog instruments because they remove the subjectivity inherent in determining where the shadowline crosses the scale, as is the case with an analog refractometer. This is especially true of emulsions.

Range, Resolution, Precision, & Unit of Measure

Refractometers are classified according to their range, resolution, precision, and unit of measure (the scale). Resolution is the smallest unit of measure that the refractometer is capable of displaying or the smallest readable scale division and precision is the ability of an instrument to give repeatable measurements.

Independent of the type of instrument used, the actual reading is defined by a scale that equates refractive index to a particular unit of measure. Think of a thermometer; Fahrenheit and Celsius are two different units of measure that can be used to describe the same temperature. On a metalworking refractometer the unit of measure may be Brix or it may be measured in completely arbitrary units.

Brix is a measure of sugar concentration and you may ask; what does sugar have to do with metalworking fluids? Brix refractometers were first developed for measuring sugar concentration and many decades later where adopted for use measuring metalworking fluids. One common misconception is that Brix is always a direct reading of the percent concentration of a metalworking fluid. However, since Brix is a measure of sugar; it is only coincidental if there happens to be a direct 1:1 relationship between a Brix reading and the percent concentration of a metalworking fluid.

More often than not, a correction factor must be applied to convert the Brix reading into a useful unit of measure, such as percent concentration. This correction factor is either published by the fluid formulator or it can be determined by measuring several known concentrations and then charting it out (See Charting Concentrations, page3).

Nearly every metalworking fluid has a different relationship between concentration and Brix, so it is important to make sure that you are using the right correction factor. Once you know the factor, you simply take reading on the Brix scale and multiply the Brix reading by that factor. So, if your reading is 5 Brix and the factor is 1.5, then the concentration is 7.5%. The Brix instruments used for measuring metalworking fluids usually require a scale range of 0-10 Brix, or 0 to 30 Brix, depending on the fluid to be measured.

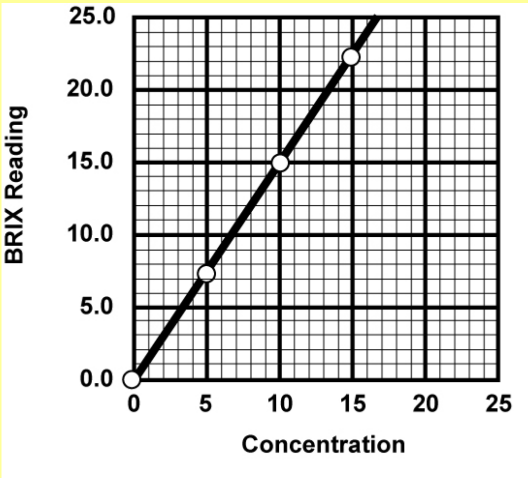
***Example:* 5 Brix x 1.5 Factor = 7.5%**

When using a correction factor, it is important to make sure that the factor is indeed for the Brix scale and not some arbitrary scale like the 10440, 10440VP, or IFT40 scale. The sheer number of metalworking fluids on the market, together with the high-cost of making a custom scale for traditional analog refractometers, made it impractical to make a direct reading scale which displayed the concentration for just one particular fluid formulation. However, in the 1970's, one such custom scale was made to measure a single fluid. This scale is known as the 10440, 10440VP, or IFT40 scale depending on the brand of refractometer.

Although this scale had a direct 1:1 relationship with just the one fluid it was designed for, the scale can be used as completely arbitrary units for all other fluids that are charted against it. The scale in these instruments has a range from 0 to 30 "arbitrary units," and at first glance appears similar to a Brix refractometer; however, the units are completely arbitrary and have no relationship to Brix units or to concentration, except for the one fluid it was initially designed for. Through the years this instrument has caused a great deal of confusion in the metalworking industry, since its arbitrary scale is often confused with the Brix scale. If one were to take a reading with this instrument, thinking that it had a Brix scale, and then apply a Brix correction factor to the reading, the result could be off by a good margin.

Charting Concentrations:

If a fluid manufacturer cannot provide you with a correction factor or a reference chart you will need to make a chart to correlate Brix readings to concentration. A separate chart must be made for each type of solution being tested. If the fluid manufacturer has provided you with a correction factor or a reference chart you will not need to do this.



Readings:

Water = 0 Brix
5% = 7.5 Brix
10% = 15 Brix
15% = 22.5 Brix

Step 1
- Mix a number of known solutions which bracket the actual concentration to be used. For example, if a 10% solution is most often used, carefully mix 5%, 10%, and 15% solutions.

Step 2
- Check zero point or Zero-Set the instrument.
- Take a Brix reading for each prepared sample with the Palm Abbe, and the sample, at or near room temperature (20°C / 68°F).
- Record the results and plot them on graph paper. Remember to add a point at 0.0 Brix for water.

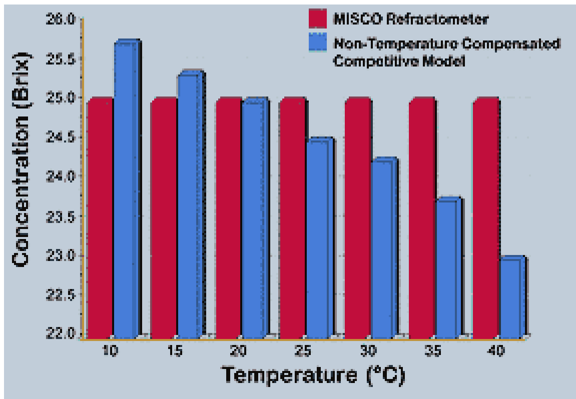
Step 3
- Draw a straight line between the plotted points along a path that best represents the center of the data. Do not be concerned if some of the points fall slightly off the line. The concentration for future measurements of the same fluid can be determined by matching the Brix value against the corresponding concentration on your graph. A separate graph must be constructed for each type of fluid used

Temperature Compensation

Since the refractive index of a fluid is related to its density, changes in density will have an increasing or decreasing effect on refractive index. Nearly all materials expand when heated (become less dense) and contract when cooled (become more dense). To counteract this uncertainty, most refractive index measurements are made at, or referenced to, a particular temperature which is usually 20 ºC (68 ºF). Because it is impractical in the field to measure the temperature of a fluid and manually apply a correction for the temperature difference, many modern handheld refractometers are equipped with automatic temperature compensation.

Some traditional handheld refractometers are temperature compensated by means of a bi-metal strip that expands or contracts depending on the temperature of the instrument. This bi-metal strip moves the optics inside the instrument to adjust for temperature variations. One drawback to this type of compensation is that the reading is compensated only in a straight line (linearly) not taking into account changes in the temperature coefficient for differing concentrations. Linear compensation is not quite as accurate as non-linear compensation, but it should provide accurate repeatable results for most water-soluble fluids measured within its temperature range. The largest amount of error in measurement will occur near the limits of the temperature compensation range and for high-fluid concentration.

Digital refractometers utilize a thermistor to accurately measure the exact temperature of the instrument. A microprocessor interprets the signal from the thermistor and applies a correction to the readings based both on the temperature difference and the percent concentration of the fluid under test.



The chart above, compares a temperature compensated refractometer (red/dark) to a non-compensated refractometer (blue/light). It is plain to see that at 20 ºC (68 ºF) they are both correct; however, as the temperature deviates from 20 ºC, there is a marked error in the non-compensated instrument. Clearly a non-temperature compensated refractometer cannot be trusted to give accurate readings.

Since most temperature-compensated refractometers used for metalworking fluids are Brix refractometers, they are compensated for aqueous (water-based) sucrose solutions. Even though the temperature coefficient of most aqueous metalworking fluids is generally close to that of sucrose, a refractometer will produce the most accurate and repeatable readings when a metalworking fluid is measured close to 20°C and for concentrations of 15% or less.

Given that the temperature coefficient of oils, hydrocarbons, and non-aqueous solutions is generally larger than that of sucrose, any non-aqueous samples should be measured as close to 20°C as possible to ensure the best precision.

The actual temperature of the sample has little bearing on the accuracy of the reading. The sample volume is usually so small, compared to the mass of the instrument, that in most cases the sample almost immediately assumes the temperature of the instrument.

For the most accurate possible results, the instrument temperature, the ambient temperature, and the fluid temperature should all be in equilibrium within the range of the instrument's temperature compensation. A general rule-of-thumb is to wait ten seconds for every 10° difference, between the sample temperature and the instrument temperature, for the temperature to stabilize.

Taking a reading of a sample with a rapidly changing temperature is a sure way to get inaccurate readings. The MISCO Palm Abbe digital refractometer has special circuitry that prevents it from displaying a reading if the temperature is rapidly changing.

Problem Readings and Fuzzy Lines

Concentrations of most clean metalworking fluids will produce relatively sharp shadowlines on traditional analog refractometers and will produce repeatable readings on most digital instruments. However, there are a number of situations where you may obtain somewhat fuzzy or altogether unreadable shadowlines, or be unable to reproduce readings on some digital handhelds.

The first thing to remember is to always keep your refractometer clean. Before you use a refractometer, inspect the measuring surface to make certain that it is clean and free of any material from a prior test. Most refractometers have common glass prisms and require wiping with a soft towel or cloth to prevent scratching the surface. The MISCO Palm Abbe uses only sapphire optics, the next hardest substance to diamond, which cannot be easily scratched.

In the case of a traditional analog refractometer, the fuzziness may be caused by a number of different things. First, make sure that there is adequate sample volume on the prism. The sample should completely cover the prism surface and be squeezed by the flapper. If the sample size is adequate sometimes you can obtain a better shadowline by opening and closing the flapper a few times and then retaking a reading.

Most Brix refractometers have a scale from 0 to 32 Brix units. However, some have a range as small as 0 to 10 Brix. These latter instruments are designed to magnify the 0 to 10 region of the Brix scale which can amplify the effect of a fuzzy shadowline. Therefore, if a fluid on a 0 to 10 instrument is too fuzzy to read, it may be more readable on an instrument with a larger range.

Tramp oil is another common cause of fuzzy readings. Typically, tramp oil floats on top of the sump fluid. However, the fluid's surface is the location where most people collect their sample when using a dipstick. No matter how hard they try, they will not be able to get a good sample from a sump containing tramp oil since they will inevitably transfer some tramp oil to the refractometer in the process. To help avoid this, it is recommended that a disposable pipette be used to take a sample from deeper in the sump, below the tramp oil layer. The pipette should be disposed of after each use to prevent cross contamination of samples.

One advantage to a digital refractometer is that it reads light reflected off the bottom of the sample, as opposed to light transmitted through the sample, as with an analog instrument. Small amounts of tramp oil in a sample placed in the well of a digital refractometer will ultimately rise to the surface and therefore will not affect the reading.

Poor shadowlines can also be attributed to some emulsions. Refractometers are ideal for measuring binary (two-part) mixtures where both components are completely miscible and form a homogeneous solution with a single uniform refractive index. An emulsion represents the complete opposite of this. An emulsion is a mixture of two or more fluids that are immiscible and non-homogenous. In the case of metalworking fluids, an emulsion consists of oil dispersed in a water phase.

A fresh clean emulsion will usually provide a relatively sharp shadowline when read on an analog refractometer. This is because emulsifiers in the solution coat each oil droplet and prevent them from coming together as a larger droplet. These initial oil droplets are relatively small compared to the wavelength of light used by the refractometer. As a result the fresh emulsion fools the refractometer into thinking the emulsion is a homogenous fluid and a sharp shadowline is projected on the scale.

Overtime, as the emulsion is used, it becomes contaminated and begins to break down. As the emulsion becomes less stable, the original tiny droplets begin to come together to form larger sized droplets. Eventually, the droplets become rather large compared to the wavelength of light and the refractometer becomes confused. The fuzzy shadowline is the result of conflicting refractive indices between, the index of the water, the index of finer emulsified oil droplets, and the index of the larger droplets. Since there is no uniform refractive index the shadowline appears fuzzy on the analog refractometer.

Some digital refractometers, like the MISCO Palm Abbe, have the uncanny ability to accurately display a reliable reading for emulsions thanks, in part, to the additional resolution provided by a linear detector array with 1,024 elements. Other digital refractometers that have arrays with only 128 elements usually experience more trouble measuring emulsions.

Calibration

Calibration is one of the central elements of any reliable measurement system. Even the best measuring instrument in the world is completely useless unless it is in calibration. Calibration is a process that establishes the relationship between the values displayed on a refractometer and the known value of a corresponding standard fluid.

Measuring device calibration is a mandatory requirement of most good quality-management systems and is required for ISO 9000 companies. The quality of all data is dependent upon maintaining the calibration of the refractometer.

One common question is; how often should a refractometer be calibrated? This is a difficult question to answer. Obviously the longer the time interval between calibrations the less the measured value can be trusted. The answer actually depends on a number of factors, including: the type of refractometer, how critical the particular process is in relation to quality or safety, the environment it is used in, how often it is used, how it is stored, and how it is cared for.

The calibration interval can be based on statistical data, manufacturers' recommendations, or on the requirements of your quality management system. A general rule-of-thumb is that the refractometer should be zero-set, or the zero-set should be verified, with water (preferably distilled water) at least once per shift. Some fluid formulators recommend zero-setting the refractometer to the actual water that is used for mixing. In any case, it is a good idea to perform the verification at an ambient temperature as close to 20°C as possible.

Periodically the upper portion of the refractometer scale (the, "Span") should be tested with a fluid of known value. NIST traceable standards are available to test different scale points. This process should be performed by trained quality control technicians. A good general rule-of-thumb is that the Span should be verified once each month. Finally, it is recommended that the refractometer be returned to the manufacturer, or sent to an accredited calibration facility, for a full traceable multipoint calibration once each year.

It is further recommended that all refractometers be marked with a unique serial number and that they should be labeled indicating the last date of calibration and the date when the next calibration is due. Never take someone's word that a refractometer is calibrated; unless you have first-hand knowledge of calibration – don't use it. An operator should not use a refractometer that is past its calibration due date.

Quality Instruments

Clearly anyone reading this document is deeply concerned with the quality of their process and the parts that they produce. Why then would anyone consider using an second-rate refractometer? The metalworking industry has been flooded with thousands of cheap Asian-made refractometers that do not have the necessary quality to be useful. Most are not temperature compensated and cannot be calibrated at any point other than water.

MISCO is among a handful of professional refractometer manufacturing companies worldwide that produce high-quality instruments for measuring metalworking fluids. It is in your best interest to purchase only quality name-brand instruments from MISCO or other proven and reputable manufacturers. Quality instruments are supported by the manufacturer, will last longer, and will give more accurate readings over their life span. Remember, you get what you pay for.

Mixing

The real problem with concentration control is understanding how to mix the fluid to obtain the desired concentration. Mixing errors are a common source of error in preparing and maintaining metalworking fluids. Careful attention must be paid to the manufacturers' instructions on how the fluid should be mixed. Fluid preparation and makeup should only be performed by specially trained personnel. Most fluid producers are happy to provide this training at no cost.

The process of mixing fluids can be very confusing since there are so many ways of expressing fluid concentration. Even if the concentration of a mixture is expressed as a ratio, or by percent, there is still uncertainty in what that actually means.

The concept of ratio means different things to different people. Depending on whom you ask, the ratio 10:1 could represent one part of concentrate IN ten total parts of solutions (one in ten or 10%). Or, 10:1 might represent one part concentrate TO ten parts water (11 total parts) or 9.1%; meaning a 10% solution would actually have a ratio of 9:1. The latter being the more frequently used definition for metalworking fluids.

Likewise, percent by volume can be equally confusing since it may be defined as the percent of metalworking fluid relative to the percent of water (10% metalworking fluid to 90% water), or as the percent volume of the metalworking fluid relative to the total volume of the entire solution (10% metalworking fluid to 100% of the fluid). Most will agree that the latter is the most correct definition.

The best mixing method will depend specifically on the process recommended by the fluid producer. Make sure that you carefully read the product literature for each metalworking fluid and use the method recommended by the fluid producer. This is especially important when using a refractometer to maintain a system. If in doubt, call your metalworking fluid salesperson or technical support person.

No matter how you mix it, almost every fluid formulator will agree that you should only use pure water produced by deionization or reverse osmosis. Tap water has minerals and impurities that can degrade metalworking fluid and promote bacteria and fungal growth. It is also generally agreed that when mixing you should add water first and then add the metalworking fluid. Thick of the acronym O.I.L., for "Oil-In-Last."

Conclusion

It is advantageous, to make one person or department solely responsible for concentration control. As in any business operation, if there are no controls in place, nothing will be controlled. Too often this is left to chance. Detailed records should be kept on the date the fluid was put in use, daily refractometer measurements, the addition of any additives, and any complaints concerning the fluid quality or part quality. The salesperson or technical service representative, for the fluid that you are using, is your best resource when it comes to answering questions about the fluid or helping to diagnose problems.