Assessments of Seven Refractometers for Evaluating Wildland Fire Retardants

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Introduction

Refractometers are used at airtanker bases to determine the amount of salt in a sample of fire retardant. Because salt is the active ingredient in long-term fire retardants, a refractometer can give an idea of the effectiveness of the product, assuring that the quality is maintained in the field. In addition, the density of retardant is proportional to its salt content. Knowing the density of retardant is crucial to determining the weight of an airtanker after it has been loaded. Keeping an airtanker's weight within specified limits is critical for safe operation.

This project began as a proposal submitted by the Klamath Falls airtanker base manager to the Fire and Aviation Steering Committee of the Forest Service's Technology and Development Program. The proposal requested a survey of various types of refractometers to determine if any brands or types might be easier to use than the Reichert 10440 refractometer used at the Wildland Fire Chemical Systems laboratory and at most airtanker bases.

Refractometers are used in a wide variety of applications and industries. They can help determine the amount of solids in solutions ranging from fruit (to help determine ripeness and optimal harvest time), sauces (including soy and ketchup), antifreeze, washing fluids, beer, and wine.

Highlights...

- Refractometers are used at airtanker bases to determine the amount of salt in a sample of fire retardant.
- Because salt is the active ingredient in long-term fire retardants, a refractometer can give an idea of the retardant's effectiveness.
- The density of retardant is proportional to its salt content. Knowing the density of retardant is crucial to determining the weight of an airtanker after it has been loaded.
- All but one of the seven refractometers assessed produced results that were satisfactory for use at airtanker bases.

Refraction

Refractometers work on a principle known as light refraction. An example of refraction can be seen by putting a straw at an angle in a glass of water (figure 1). The straw bends slightly. If you put another straw in a glass of water containing dissolved sugar or salt, the straw would appear to be bent even more. The scale in the refractometer allows observers to measure the angle at which the light bends in a liquid.

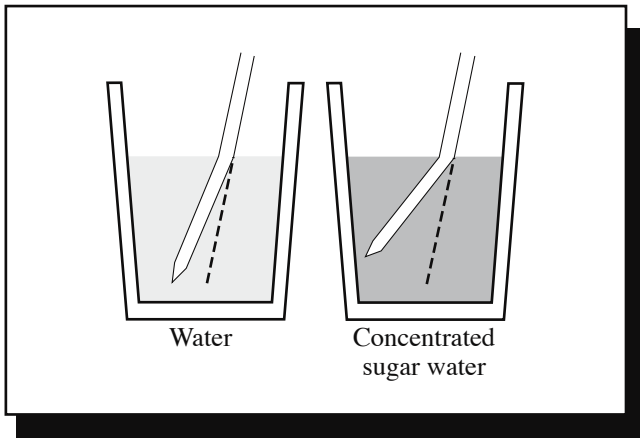


Figure 1—Because of light refraction, a straw appears bent when it is in a glass of water. If the water is replaced with concentrated sugar water, the straw appears to be bent even more.—*Illustration courtesy of ATAGO U.S.A., Inc.*

As the density of a liquid increases (such as when the salt concentration is higher in fire retardant), the liquid's refractive index (ability to bend light) increases proportionately. A refractometer puts this principle to practical use.

The hand-held refractometers found at airtanker bases use a *transparent detection system* (figure 2). A retardant sample with a lower salt content will give a larger angle of refraction (line a in figure 2). A retardant sample with a higher salt content gives a smaller angle of refraction (line b in figure 2).

Digital refractometers use a different method called a *reflection system*. This system is a bit more complicated. The explanation that follows is from the ATAGO U.S.A., Inc., Web site *http://www.atago.net/english/k-basic.html*. In figure 3, light A, entering from the lower left of the prism, is not reflected back by the boundary, but exits through the sample. Light B is reflected by the boundary face to the right, directly along the prism boundary. Light C, entering the prism at too large an angle to pass to the sample side, is totally reflected toward the lower right of the prism.

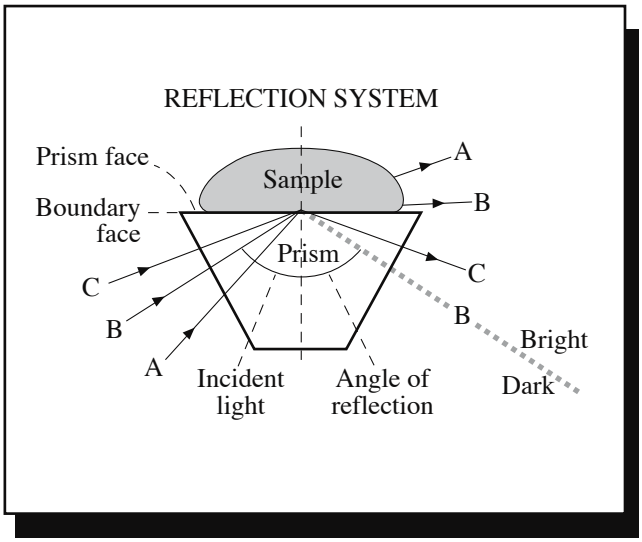


Figure 3—An illustration of the principles used in the reflective detection system of a digital refractometer.—*Illustration courtesy of ATAGO U.S.A., Inc.*

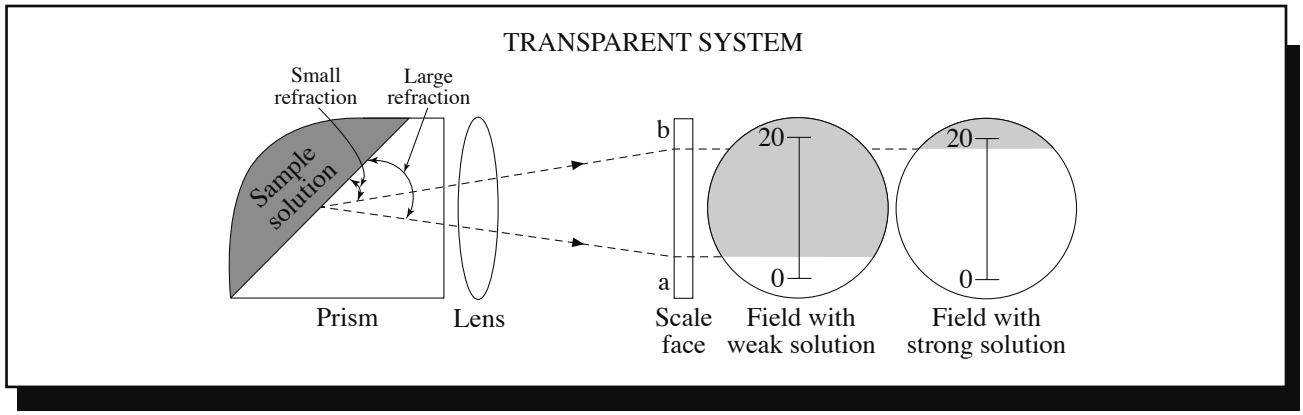


Figure 2—An illustration of the principles used in the transparent defection system of a hand-held refractometer.—*Illustration courtesy of ATAGO U.S.A., Inc.*

A boundary line is produced that divides light and dark fields on either side of the dotted line B in figure 3. Because the angle of reflection of this boundary line is proportional to the refractive index, the position of the boundary line between light and dark fields can be converted into the refractive index. (*http://www.atago.net/english/k-basic.html*)

Different Scales for Refractometers

The Reichert 10440 refractometer used in the Wildland Fire Chemicals Systems (WFCS) laboratory in Missoula, MT, and at many airtanker bases, has an arbitrary scale, with a range of 0 to 30 units. The arbitrary scale commonly is used to test industrial fluids, such as antifreeze. This scale is available in a limited number of refractometer models offered by only a few manufacturers.

The Brix scale is common in refractometers. This scale measures the grams of sugar in 100 grams of pure sucrose solution. An 18 on the Brix scale represents 18 grams of sucrose in 100 grams of a pure sucrose/water solution.

We evaluated refractometers with both types of scales. A conversion chart provided by Reichert was used to convert retardant values from the arbitrary to the Brix scales. The relationship between the two scales is nearly linear, with the Brix scale reading roughly one unit higher than the arbitrary scale. Table 1 indicates specific refractometer values for a given fire retardant in both arbitrary and Brix units. ***All printed values released by WFCS are based on the arbitrary scale***. It is critical to keep the scale in mind when reading printed material from either WFCS or the retardant companies that describe the recommended refractometer values for a particular retardant (known as refractometer targets).

Table 1—Comparison of arbitrary-scale refractometer units to Brix-scale refractometer units for different types of fire retardant. The Brix scale represents grams of sucrose in 100 grams of pure sucrose/water solution.

Retardant	Arbitrary scale (units)	Brix scale (percent)
Fire-Trol LCA–R/F	13 to 15	14 to 16.2
Fire-Trol LCG–R/F	14 to 16	15.1 to 17.3
Fire-Trol GTS–R	15 to 18.25	16.2 to 19.7
Fire-Trol 300–F	15 to 18.25	16.2 to 19.7
Phos-Chek HV–R/F	11 to 13	11.9 to 14
Phos-Chek MV–R/F	11 to 13	11.9 to 14
Phos-Chek LV–R	11 to 13	11.9 to 14
Phos-Chek LC–95A	12.75 to 14.5	13.8 to 15.7
Phos-Chek LC–95D	13.75 to 15.75	14.8 to 17
Phos-Chek D75–R/F	11.25 to 13.25	12.2 to 14.3
Phos-Chek 259–R/F	12.25 to 14.5	13.2 to 15.7
Phos-Chek G75–F/W	10.25 to 12.25	11.1 to 13.2

Assessment of Different Refractometers

Seven different refractometers were assessed (figure 4), including the Reichert 10440 used by the WFCS lab. Two of the models were digital, while the other five were standard hand-held analog models. These models

Figure 4—Hand-held refractometers are held to the eye when being used.

were selected for the assessment based mainly on their price and availability. Prices ranged from $120 to $700. The models evaluated were:

ANALOG REFRACTOMETERS		
Model	**Scale**	**Cost ($)**
ATAGO ATC–1E	Brix	250
Bellingham & Stanley Eclipse	Arbitrary	120
Leica IFT 40	Arbitrary	250
Reichert 10440	Arbitrary	Not available
Reichert Brix 35HP	Brix	250

DIGITAL REFRACTOMETERS		
Model	**Scale**	**Cost ($)**
ATAGO Pocket Pal–1	Brix	300
Misco Digital	Arbitrary	700

Some models have eyepieces that focus (ATAGO ATC–1, Bellingham & Stanley Eclipse, and Reichert Brix 35HP). All models, except the Bellingham & Stanley Eclipse, automatically compensate for temperature. The Bellingham & Stanley Eclipse includes a correction factor table to accommodate changes in temperature. The table is fairly easy to use, according to an airtanker base manager who uses the Eclipse. Additionally, all models have methods to calibrate the instrument. Digital refractometers should be calibrated daily using deionized or distilled water. Recalibration of analog refractometers should follow the manufacturer's suggestions.

Occasionally, refractometers may need to be recalibrated professionally. Tek-Net, a New Jersey company, will clean and recalibrate a refractometer for about $75 plus shipping costs. They also will let you know whether it is more cost effective to repair the refractometer than to purchase a new one.

Tek-Net
Attention: Ray Coles
1985 Swarthmore Ave.
Lakewood, NJ 08701
732–905–5530

Be sure to include your name, address, and phone number when shipping your refractometer.

Assessments

The seven refractometers were judged on their ease of use, ease of cleaning, ease of reading, and overall utility. They were compared for their accuracy and repeatability when used by the seven different evaluators. The evaluators took readings of four different concentrations of three different retardants (unthickened, low-viscosity thickened, and high-viscosity thickened retardants). Results were compared among users and also among instruments. We would expect the results from the Brix-scale refractometers to compare well with each other and the results from the arbitrary-scale refractometers to compare well with each other (accuracy). Additionally, we would expect that for any particular instrument the values obtained by different evaluators should be fairly consistent (repeatability).

The evaluators' experience in the WFCS laboratory ranged from 2 to 3 days to 15 years. Some wore glasses, some wore contact lenses, and others did not require vision correction. Because personal preferences play a large role in which refractometers users like, the aim of this evaluation is not to recommend one or two refractometers, but to discuss the advantages and disadvantages of each instrument. The Misco digital refractometer did not produce accurate or reproducible results, so the author does not recommend its purchase.

Because these instruments were tested in a laboratory, their durability in a field setting, particularly in the case of the digital refractometers, is not known.

Figure 5 compares the results from the refractometers that were assessed. Figures 6 through 12 show the different refractometers and the results of assessments by the evaluators for each of the refractometers. The captions provide additional information about the evaluators' findings.

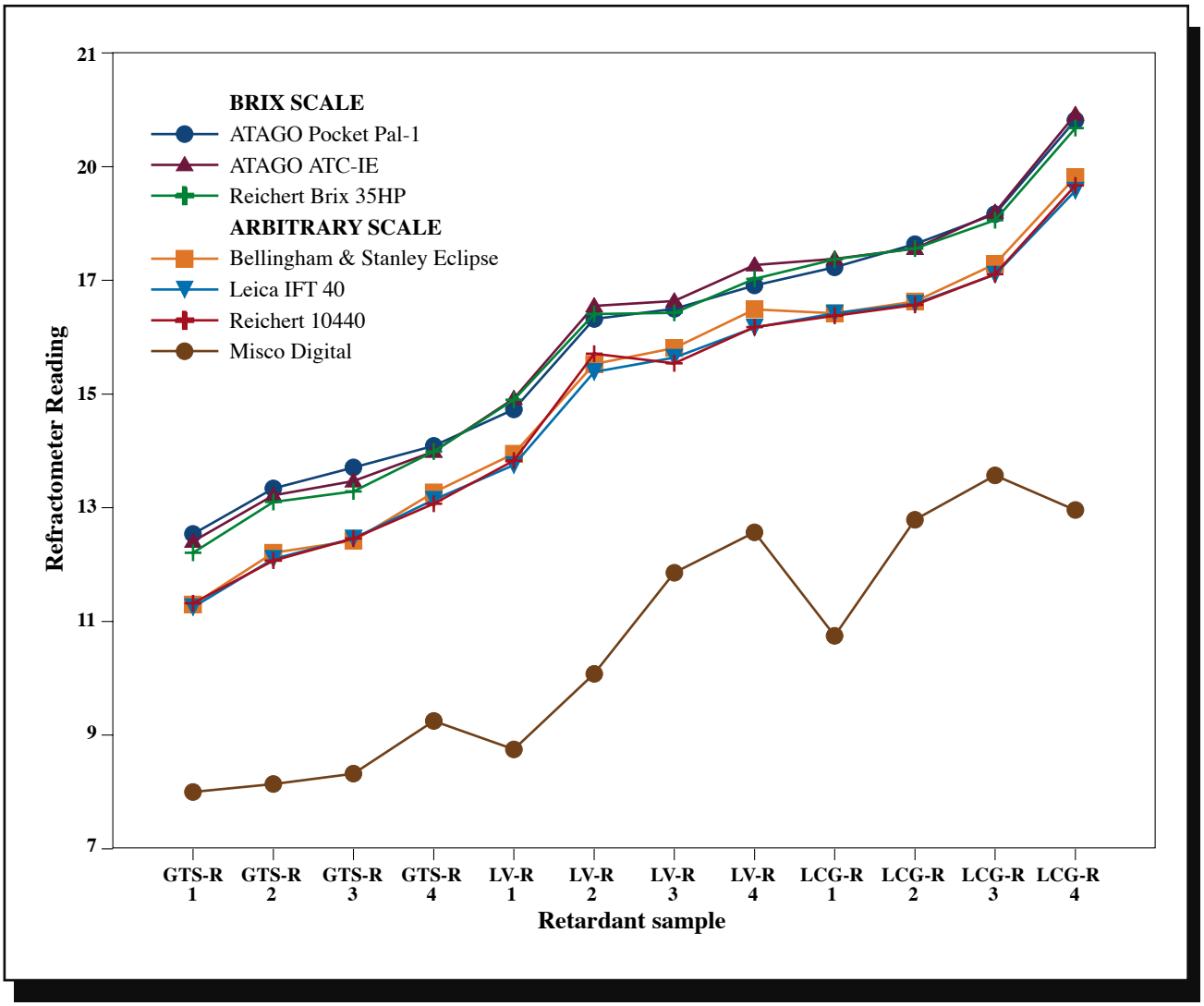
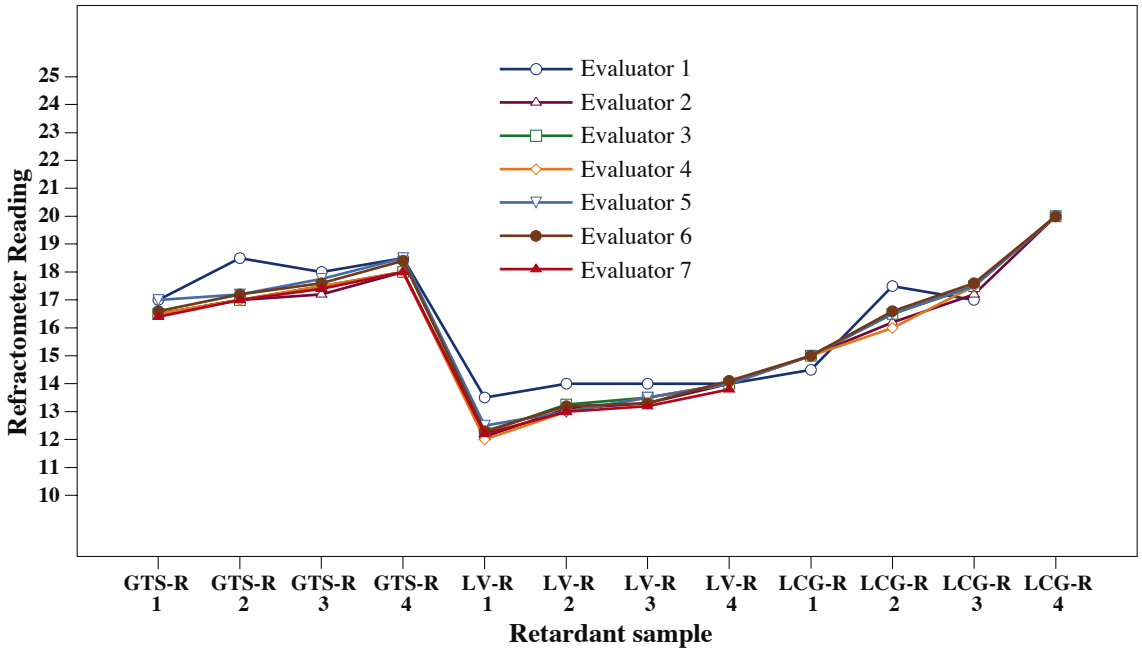


Figure 5—This graph compares the seven refractometers that were assessed. The three Brix-scale refractometers have values that are clustered above the arbitrary-scale refractometers. The Misco Digital refractometer had the lowest values. There was some question whether this refractometer truly used an arbitrary scale. Additionally, the shape of its line differs from the others, raising a question about its reliability.

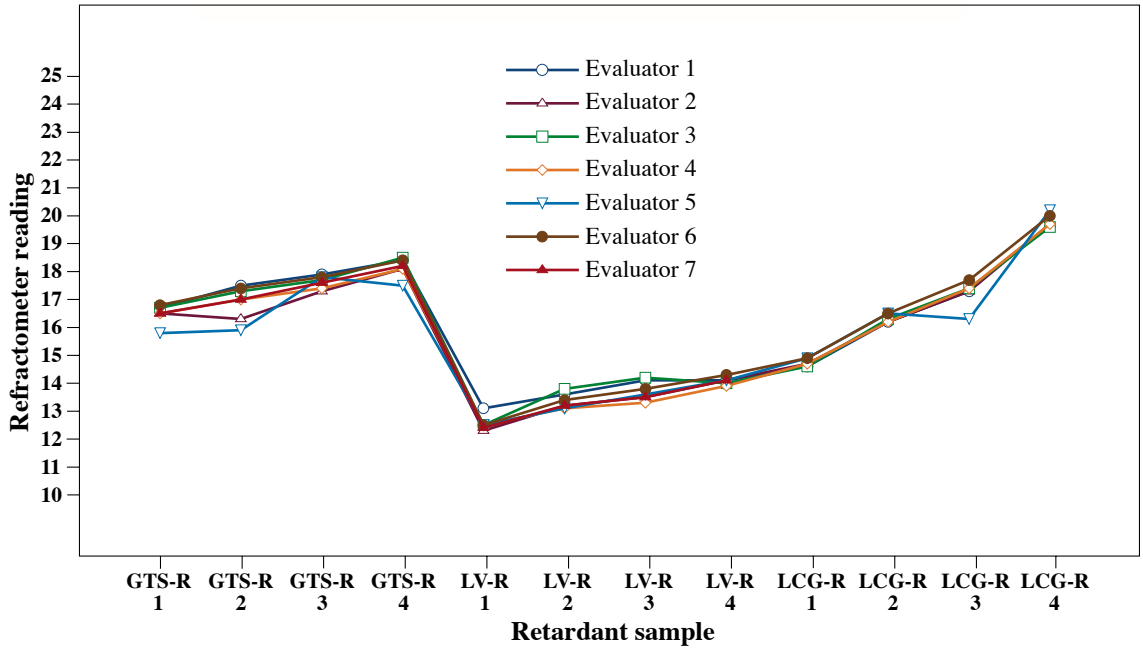
ATAGO ATC-1E

Figure 6—ATAGO ATC–1E: This refractometer was well liked by evaluators. The readings were accurate, as indicated by the closeness of the points measured by most evaluators (one evaluator read the results slightly high). The prism is steep. Unthickened retardant had a tendency to run off when some evaluators used this refractometer.



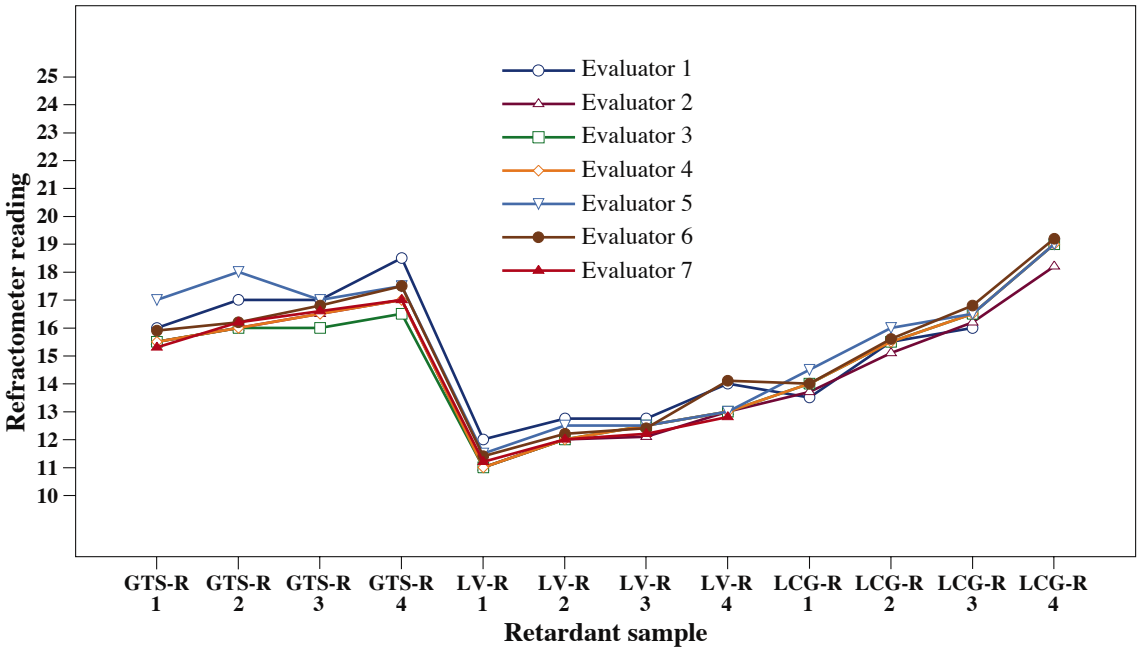
ATAGO Pocket Pal-1

Figure 7—ATAGO Pocket PAL-1: This refractometer received very high ratings from all evaluators. It is accurate and easy to read. Its durability in the field is unknown. It needs batteries and daily calibration (easy to do). It is easy to clean.



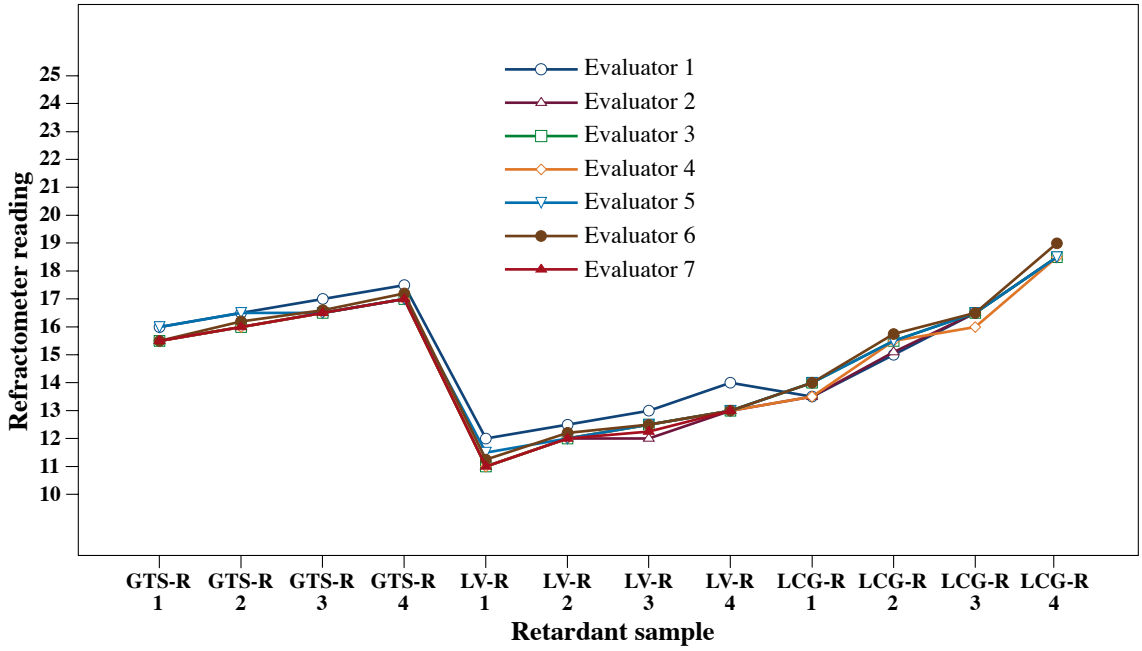
Bellingham & Stanley Eclipse

Figure 8—Bellingham & Stanley Eclipse: This refractometer does not have automatic temperature compensation. Readings were not as accurate (note the distance between the points measured by different evaluators). The scale was easy to read. This was the least expensive of the refractometers tested.



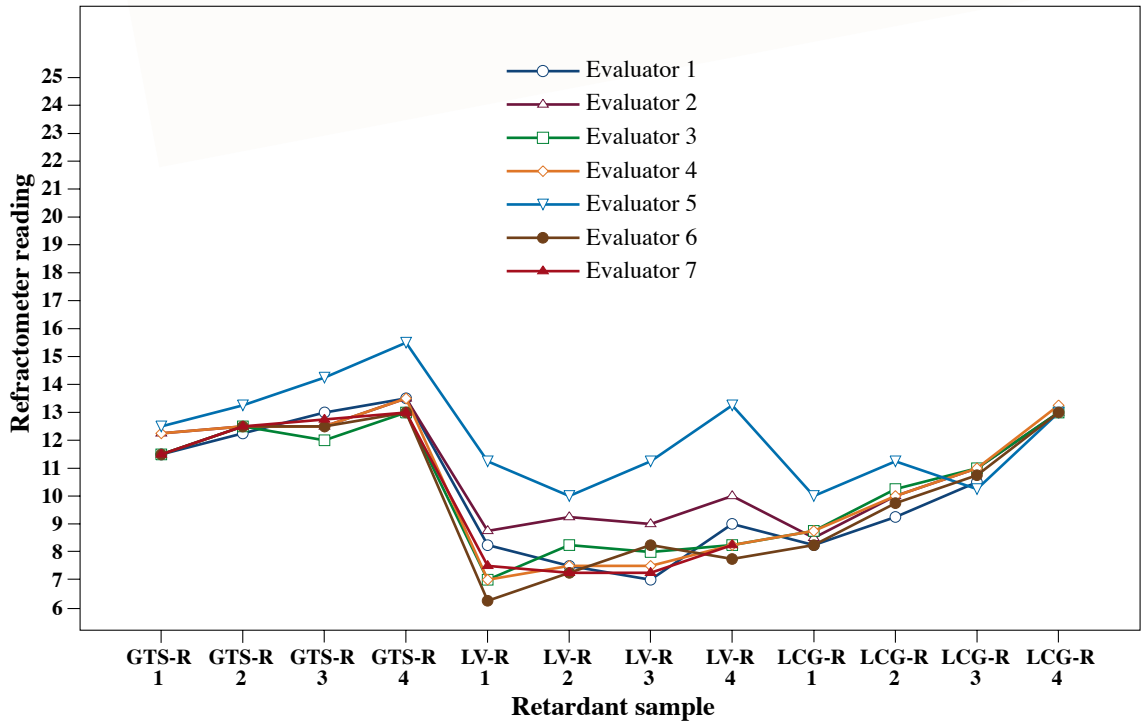
Leica IFT 40

Figure 9—Leica IFT 40: The "next generation" of the Reichert 10440. The scale is easy to read, but this refractometer appears to be less durable than the others evaluated. Evaluators provided little information about this model.



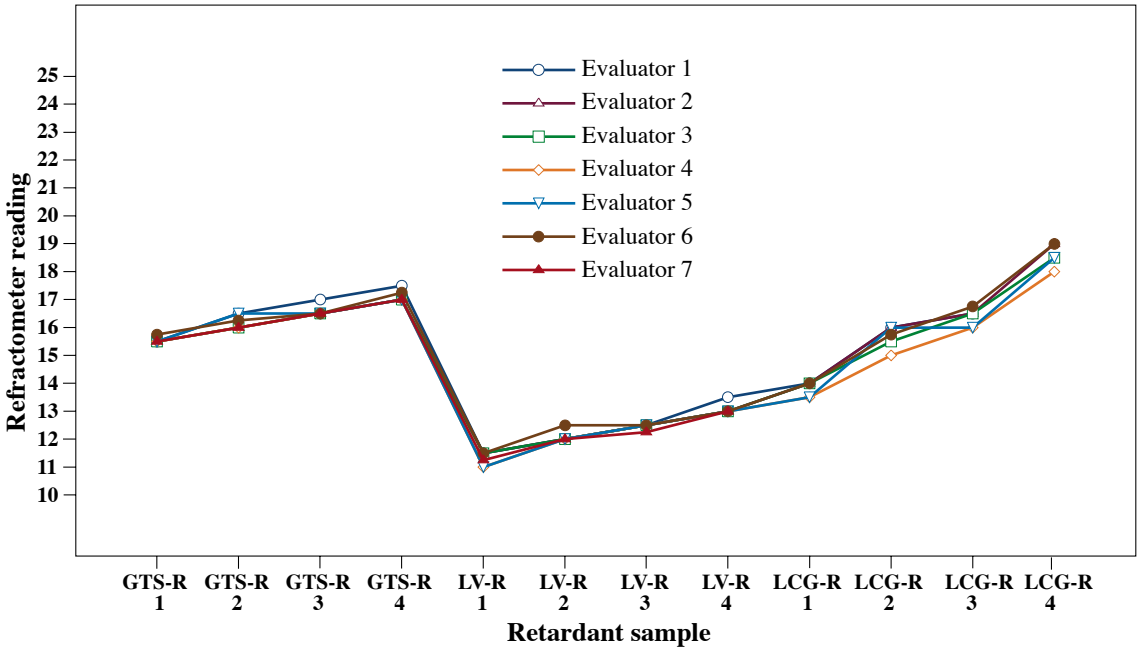
Misco Digital

Figure 10—Misco Digital: This refractometer was the least accurate with the least repeatable results of those assessed, as shown by the large discrepancies among evaluators. The display was easy to read, but the reading angle was awkward. Evaluators needed both hands to operate this refractometer rather than one hand, as was the case for the other refractometers that were assessed. A container of retardant had to be available in which to dip the tip of the refractometer (all others evaluated needed only a couple of drops of retardant), increasing cleanup time. This refractometer, the most expensive of those assessed, is the only one that the author would NOT recommend buying based on assessment results.



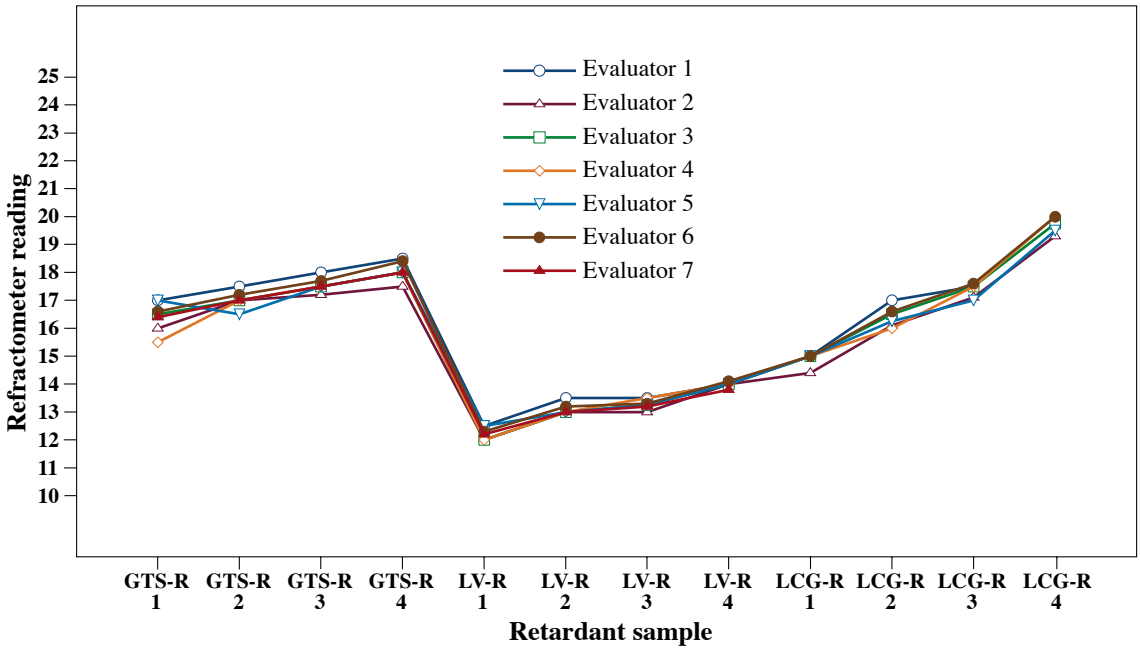
Reichert 10440

Figure 11—Reichert 10440: This model was the most difficult to read. The readings were accurate and repeatable, as indicated by the closeness of the points measured by different evaluators.



Reichert Brix 35HP

Figure 12—Reichert Brix 35HP: The clear plastic flap that covers the prism doesn't stay up, which annoyed nearly all the evaluators. The scale was fairly easy to read. The readings were accurate and repeatable, as indicated by the closeness of the points measured by different evaluators.



Ordering Information

ATAGO ATC–1E
Cole-Parmer
625 East Bunker Ct.
Vernon Hills, IL 60061
Phone: 800–323–4340
Catalog No. A–02943–31
Company's description: Refractometer with ATC, 0 to 32 percent Brix scale

ATAGO Pocket PAL–1
Cole-Parmer
625 East Bunker Ct.
Vernon Hills, IL 60061
Phone: 800–323–4340
Catalog No. A–02941–51
Company's description: Refractometer, 0 to 53 percent Brix scale

Bellingham & Stanley Eclipse
Bellingham & Stanley, Inc.
1000 Hurricane Shoals Rd.
Building D, Suite 300
Lawrenceville, GA 30043
Phone: 800–678–8573
Item No. 45–43
Company's description: Eclipse refractometer, 0 to 30 arbitrary scale

Leica IFT 40
Fisher Scientific
Phone: 800–766–7000
Catalog No. RE 10440
Company's description: Leica IFT 40 Industrial Fluid Tester refractometer

Misco Digital
Misco Products Division
3401 Virginia Rd.
Cleveland, OH 44122
Phone: 216–831–1000
Product No. DFRX (refractometer) and NRE
Company's description: Digital fiberoptic refractometer 105209, plus a nonrefundable engineering fee.
Note: You must specify the type of scale you want.

Reichert 10440
This model is no longer available commercially. The Leica IFT 40 and the Reichert Brix 35HP refractometer are both made by the same company. They are considered replacement models for the Reichert 10440.

Reichert Brix 35HP
Fisher Scientific
Phone: 800–766–7000
Catalog No. 13975114
Company's description: Leica 35HP Brix refractometer

About the Author

Shirley Zylstra is the project leader for the national interagency Lot Acceptance and Quality Assurance (LAQA) Program for the Wildland Fire Chemical Systems Program at the Missoula Technology and Development Center. She also is responsible for interagency environmental reporting for the U.S. Environmental Protection Agency's toxic release inventory of airtanker bases nationwide. After receiving her bachelor's degree at Oregon State University, Shirley served as a Peace Corps volunteer for 2 years in Togo, West Africa. She began working in the fire chemicals program in 1992. As a lab technician, she was extensively involved in developing field effectiveness tests for firefighting foams and in general laboratory testing of fire chemicals for qualification and approval. She left the program in 1997 to pursue a master's degree in environmental toxicology at Colorado State University. She returned to the program in 2000 after finishing her degree.

Library Card

Zylstra, Shirley. 2005. Assessment of seven refractometers for evaluating wildland fire retardants. Tech. Rep. 0557–2822–MTDC. Missoula, MT: U.S. Department of Agriculture Forest Service, Missoula Technology and Development Center. 16 p.

Describes an assessment of seven refractometers that could be used at airtanker bases to measure the amount of salt in a sample of fire retardant. Because salt is the active ingredient in long-term fire retardants, a refractometer can give an idea of the product's effectiveness. In addition, the density of retardant is proportional to its salt content. Knowing the density of retardant is crucial to determining the weight of an airtanker after it has been loaded. Keeping an airtanker's weight within specified limits is critical for safe operation.

The Wildland Fire Chemical Systems program at the USDA Forest Service's Missoula Technology and Development Center assessed the following refractometers: ATAGO ATC–1E, ATAGO Pocket Pal–1, Bellingham & Stanley Eclipse, Leica IFT 40, Misco Digital, Reichert 10440, and Reichert Brix 35HP. All but the Misco Digital produced results that were satisfactory for airtanker bases.

Keywords: accuracy, airtanker bases, firefighting, fire fighting, repeatability, salt, testing, wildland fire chemical systems

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For additional information about assessing refractometers, contact Shirley Zylstra at MTDC.
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E-mail: *szylstra@fs.fed.us*

Forest Service and Bureau of Land Management employees can search a more complete collection of MTDC's documents, videos, and CDs on their internal computer networks at: *http://fsweb.mtdc.wo.fs.fed.us/search/*.

Electronic copies of MTDC's documents are available on the Internet at: *http://www.fs.fed.us/t-d/* (Username: t-d, Password: t-d).