Why Use A Refractometer?

Everything You Wanted To Know About
Engine Coolant Testing

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Reichert®

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1.0 Engine Coolant/Antifreeze Testing

1.1 Hydrometer Versus Duo-Chek

Competition is fierce in the automotive services field. Service facilities face an ever increasing field of competitors, while consumers demand more and more from their service providers. Equipment suppliers must provide equipment that will perform exceptionally, at a reasonable price.

In the battle for engine coolant/antifreeze concentration and freeze point protection level testers, the hydrometer accounts for roughly 75% of all units sold. Refractometers and test strips round out the field. When service personnel are asked if they feel that their engine coolant tester is performing adequately, over 95% feel satisfied. Amazingly, 35% feel extremely satisfied! The significance of this is that three quarters of these service providers feel that their engine coolant tester must be accurate to ±5°F. Less than one-tenth of those surveyed felt that an inaccuracy of ±10°F or worse was acceptable.

The curious fact about this is that even a high precision, laboratory hydrometer (which costs over $60.00) used by a trained laboratory technician in a controlled environment, using readings which have been mathematically corrected for fluid temperature can't obtain that accuracy. According to ASTM Method D1124, the best accuracy that is achievable with a hydrometer used under these specific conditions is ±8°F. So, how can we reconcile this fact with the overwhelming feeling of satisfaction that service personnel have regarding their hydrometers. Simply, they do not realize just how inaccurate hydrometers really are!

1.2 Hydrometers and Refractometers: The Ins and Outs

- Hydrometers measure specific gravity. Specific Gravity is extremely temperature dependent. The same sample which is read at 150°F will read as having a 30°F better freeze point protection level if it is read at a temperature of 100°F. Temperature effects must be calculated.
- Hydrometers only work for Ethylene Glycol based coolant/antifreeze. Propylene Glycol cannot be read with a hydrometer due to the fact that up to 70% concentration specific gravity increases, but above 70% specific gravity decreases. A 100% solution reads identical to a 40%.
- Sampling technique is critical in hydrometer use. Air bubbles in the sample will cause inaccurate readings. The float must be kept free from the wall of the hydrometer.
- Refractometers can measure both Ethylene and Propylene glycol based coolant/antifreeze very accurately.

- Automatic Temperature Compensation is an absolute necessity for refractometers. Without it, refractometers can easily be inaccurate by more than ±16°F. With ATC, the Duo-Chek is accurate to ±1°F straight out of the box, according to ASTM Method D 3321.

There are numerous reasons why it is very difficult to obtain an accurate engine coolant concentration reading with a hydrometer, but first let us try to understand why they are so popular. Probably the most important reason for the wide spread us of these instruments is that they are very inexpensive. A hydrometer is simply a container with a weighted float device. An applicable scale is displayed either on the cylinder of the container, or on the float which correlates the specific gravity (which is measured by how much of the float remains above the fluid level) and the particular concentration of interest. There are several different styles of hydrometer, but they all work off this same principle.

Hydrometers are also popular among service mechanics because they are a visual indicator of fluid quality. When a car pulls into a service shop to have a lube job and oil change, the service shop wants to perform as many extra services as possible. Not only does it ensure the proper maintenance of the vehicle, but most of the income for these shops comes from selling customers on these extras, not on the initial service. Typically, they will check the air filter, test transmission fluid, engine coolant, and maybe even brake fluid. For the engine coolant, the technician can take a sample with the hydrometer, and show this to his customer. This gives the customer the feeling that he is informed enough to make a qualified decision of whether or not to purchase the extra service of flushing out his coolant system. An informed customer is a happy customer.

Now that we know why someone would want to use a hydrometer, let's turn our attention to why someone would not want to rely on one. For starters, hydrometers are actually far more difficult to use accurately than they appear. When you purchase a hydrometer, the instructions are very basic. Take a sample and read how many discs or balls are floating or how high a float sits in the sample, etc. Then take this number of floating discs or balls, or height of the float and refer to a chart that converts this number into the useful measure of concentration and freeze point protection. That's it! In reality, there is a lot more to it than that. Here is what they do not tell you:

Remember that a hydrometer is actually measuring the specific gravity of a solution. How it accomplishes this is to take a substance with a known specific gravity (a standard) and see if it floats in the unknown sample. If it floats, the specific gravity of the sample is greater than the specific gravity of the standard.

Disc and ball type hydrometers have discs (and balls) of increasing specific gravity. The more discs or balls that float, the higher the specific gravity of the unknown. A single float hydrometer has a float which has a weighted bottom and a hollow top. This will sink into the solution until the specific gravity of the unknown sample and the float are equivalent. The amount of the float which is submerged is an indicator of the specific gravity.

Probably the most important factor in the use of a hydrometer is the temperature relationship between the sample, the instrument, and the standard reference temperature. In order to obtain an accurate specific gravity reading it is imperative that the sample, and the instrument temperatures be at an equilibrium. Readings must be taken at a specific, stable temperature. This temperature must be noted for each reading. If this temperature differs from the standard reference temperature (which is typically 60°F, 15.56°C for most hydrometers) the specific gravity reading must be mathematically converted to its' equivalent value at the standard reference temperature.

For most substances, as temperature increases, specific gravity decreases. In other words the sample "thins out" as it is heated. This shift can be mathematically modeled. Refer to the chart "Specific Gravities of Aqueous Ethylene Glycol Solutions" at the end of this document for this temperature dependence when measuring Ethylene Glycol via specific gravity. To familiarize yourself with this type of chart, follow along with this example: A reading for a 50% ethylene glycol solution at 100°F would give a specific gravity of 1.056. This same 50% solution at 150°F would read as 1.038 specific gravity. If that hydrometer were calibrated for 100°F, it would read as 50% only if the reading was taken at a fluid/instrument temperature of 100°F. If the reading was taken at a fluid/instrument temperature of 150°F, the instrument would measure the specific gravity as 1.038 which at the instruments standard reference temperature of 100°F corresponds to 35%. The person taking the reading would think that the solution was 35% Ethylene Glycol. As a reference, the freeze point protection level for a 50% mixture is approximately -32°F. The freeze point protection level for a 35% mixture is approximately -2°F. This is a very significant error!

The chart "Specific Gravities of Aqueous Propylene Glycol Solutions" at the end of this document reveals why a hydrometer cannot be used for measuring this "environmentally friendly" type of engine coolant/antifreeze. As concentration increases to around 70%, specific gravity also increases. Above 70% however, specific gravity actually decreases with increasing concentration. For instance, at 100°F, a 100% Propylene Glycol Solution has the same specific gravity as a 45% solution! There is no way for a hydrometer to differentiate these two dramatically different concentrations.

Sampling technique is also critical in specific gravity measurement. Any air bubbles present in the sample can attach themselves to the float device and thus affect readings. For both types of hydrometer, the specific gravity of the float will be reduced if an air bubble attaches itself to the float (in other words, the buoyancy of the float will increase). An interesting test of this phenomenon is to use a hydrometer to determine the sugar concentration of a soft drink. Take a reading by simply drawing the soft drink into the hydrometer. The carbonation will form bubbles on the float/floats. Once you have taken a reading with the air bubbles, tap the hydrometer gently to dislodge these bubbles from the floats. You will see that when the bubbles are dislodged, the hydrometer will read the soft drink as seemingly more concentrated.

Another important sampling technique is to be certain that the float does not touch the walls of the container. The friction causes the float to sit lower in the sample and thus will cause the reading to appear greater than it actually is. In essence, this friction decreases the buoyancy of the float. This is more important with single float style hydrometers because their float is prone to lean into the wall. In disc and ball type hydrometers, the floats are entirely submerged and thus virtually free of friction.

Now let's look at the refractometer. Refractive index is, basically, the relative speed of light through a substance versus the speed of light through a standard, typically air. Another way to think of it is the bending of light as it passes through a substance. As light is transmitted into and through a substance, it will slow down. If that light is passed through at an angle, the substance will "bend" the light. The angle at which this light is "bent" can be measured and converted into a refractive index number which can then be converted into a % concentration number (or virtually any units which are applicable). This is exactly what a refractometer does, it simply passes light through the sample, a prism and optical system, a reticle (a printed scale), and an eyepiece. The optical system and prism capture the bent light and pass it on to the reticle and eyepiece producing a shadow line intersect on the reticle which is a visual indicator of the refractive index of the solution.

Both Ethylene Glycol and Propylene Glycol may be measured very accurately by refractive index. Both these solutions have a nearly linear relationship between concentration and refractive index. As concentration increases, refractive index increases. The following chart depicts this relationship for Ethylene Glycol.

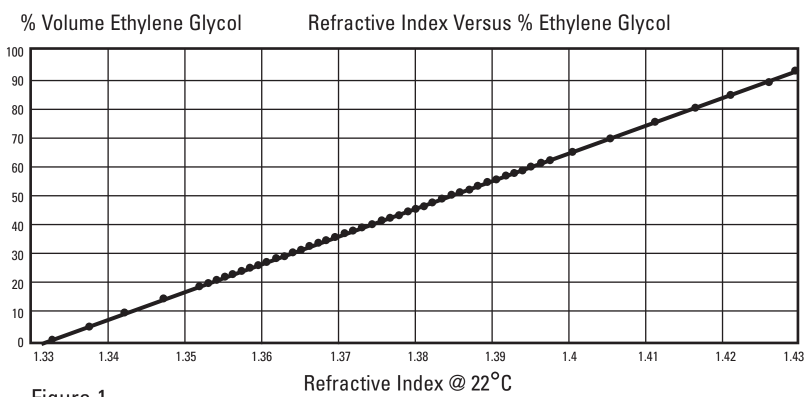

Figure 1

“Environmentally friendly” Propylene Glycol, which cannot be measured on a hydrometer, can easily be measured on a refractometer. The following graph shows the relationship between refractive index and % volume concentration for Propylene Glycol.

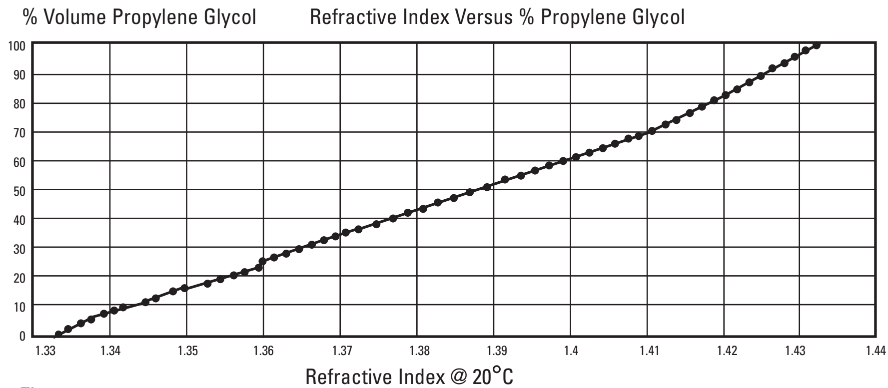

Figure 2

Sounds nice and simple. Unfortunately, refractive index is also temperature dependent. As temperature increases refractive index decreases. That is why you must also reference the temperature at which refractive index measurements are taken at or converted to. Most refractometers use the standard reference temperature of 68°F (20°C).

For refractometers, the temperature of the instrument is the critical factor. This is due to the fact that for refractive index measurements, only a drop of sample is required. The mass of this amount of sample is so small that it will almost immediately assume the temperature of the instrument. The temperature of the instrument is directly dependent upon the temperature of the environment in which it is used. If this temperature is changing fairly regularly, such as a garage with cars pulling in and out, the refractometer needs to be made of a material which will quickly equilibrate with these changes. Heavy, metal bodies act as a heat sink, therefore, lighter, polycarbonate bodies that respond more rapidly to these temperature shifts are preferred.

As an example of this temperature dependence suppose we had a 50% Propylene Glycol solution. The refractive index for this solution when measured at 68°F would be 1.38908. If this solution were to be measured at 20°F instead of the standard 68°F, the change in refractive index would be 0.006, thus the refractive index would be 1.39508. This refractive index, if not temperature corrected, would correspond to a concentration reading of 55.74% Propylene Glycol on a refractometer which is referenced at 68°F. A 50% Propylene Glycol solution will freeze at roughly -29°F, whereas a 55.74% solution will freeze at roughly-45°F. Therefore, a service technician using a non-temperature compensated refractometer under these conditions will believe he has far greater freeze point protection than he actually does.

This temperature dependence is the reason that all Reichert brand handheld refractometers currently feature “Automatic Temperature Compensation”. This feature automatically corrects all readings back to the standard of 20°C.

Thus the user need not worry about what temperature his readings are taken at. With Automatic Temperature Compensation, the Duo-Chek is accurate to ±1°F according to ASTM Method D 3321 Standard Practice for Use of The Refractometer for Determining The Freezing Point of Aqueous Engine Coolants.

1.3 Actual Test Date: The Real Deal

- Three hydrometers were tested, a floating disc type, a floating ball type, and a needle type. A Reichert Duo-Chek was also tested.
- Hydrometers were found to be inaccurate by as much as 23°F! Temperature of the fluid was an absolutely critical factor. Reading the same solution at two different temperatures gave two very different results. The Duo-Chek was off by only 2°F in the worst case. Automatic Temperature Compensation makes the difference!
- Hydrometers are harder to use accurately than expected. It is difficult to obtain enough sample, air bubbles are nearly unavoidable, and the angle the hydrometer is held at causes variations in readings. The Duo-Chek requires only a drop of sample to obtain an accurate, easy to read value.

Theory and calculation are fine, but what happens in the real world? You can test this yourself easily enough just as I did. I decided to see if I could convince some of my fellow employees to let me sample their engine coolant/antifreeze. I decided that I would test the sample both in the vehicle and then read this same sample after allowing it to cool in my office. Samples were tested with three styles of hydrometer.

The first was a floating disc type, the number of discs floating represents the freeze point protection level. It had six discs, one floating would be a freeze point protection level of +25°F, two would be +5°F, three would be -10°F, four is -25°F, five is equivalent to -34°F, and six would mean that the fluid was “not safe”. This unit was the most expensive, selling for about $10.00 at a local auto parts store. If appearance matters, it also seemed to be the most professional looking of those available.

The second was the needle type where a pointer rotates on a shaft as fluid fills the chamber. This pointer rises to a certain level dependent upon the concentration of the coolant/antifreeze and intersects a scale that is printed on the body of the hydrometer which indicates freeze point protection level. The particular unit which I purchased for about $7.00 USD was actually distributed by one of the more popular engine coolant/antifreeze producers. There were six demarcations on this instrument: +10°F, 0°F, -7°F, -20°F, -34°F, and -45°F along with their metric equivalents.

The third type was the floating ball style where the number of balls which rise to the surface is the indicator of fluid concentration. This particular model had five balls. The first ball would be equivalent to a freeze point protection level of +20°F, the second would be +5°F, the third represented -10°F, the fourth was -25°F, and the fifth meant you were safe to -40°F. This instrument also gave the corresponding boiling point protection level represented by each of these balls. This unit appeared to be, and was the cheapest of those tested. It cost approximately $3.00.

Extreme care was taken during testing to avoid any of the previously mentioned problems. There were some problems encountered, however. Unless the radiator was full to the top of the neck, I found that is was more difficult than anticipated to obtain a sample of enough volume to fill the needle type and the disc type hydrometers. I literally had to snake the hydrometer suction tube as far down into the radiator as possible to siphon off enough sample to obtain any reading. This also seemed to draw more air bubbles into the instrument. I also found that it was difficult to clear the air bubbles from the floats on the hydrometers. The reading from the needle type was also subject to the angle at which the instrument was being held. If it is not held perpendicular to the ground, the reading will fluctuate. No problems were encountered with the Duo-Chek.

Outside readings were taken after allowing the cars to sit for 30 minutes to 1 hour. It was a typically warm day here in western New York state, the temperature outside was almost 80°F. Inside readings were taken after allowing the coolant to reach room temperature of approximately 72°F. Results were as follows:

Outside Testing °F	Hydrometers Disc Type	Needle Type	Floating Ball Type	Refractometer Reichert DC70
Car #1 Actual Freeze Point -43	-25	-34	-25	-45
Car #2 Actual Freeze Point -27	-25	-20	-25	-27
Car #3 Actual Freeze Point -48	-25	-34	-40	-50
Car #4 Actual Freeze Point -44	-25	-34	-25	-45
Car #5 Actual Freeze Point -40	-25	-34	-25	-41

Figure 3

Inside Testing °F	Hydrometers Disc Type	Needle Type	Floating Ball Type	Reichert DC70
Car #1 Actual Freeze Point -43	-34	-45	-25	-45
Car #2 Actual Freeze Point -27	-34	-34	-25	-27
Car #3 Actual Freeze Point -48	-34	-45	-40	-50
Car #4 Actual Freeze Point -44	-34	-45	-25	-45
Car #5 Actual Freeze Point -40	-34	-45	-25	-41

Figure 4

Actual freeze point for these five samples was determined by two methods. The first method was a slightly modified version of ASTM Method D1177 Standard Test Method for Freezing Point of Aqueous Engine Coolants. This method is a direct measure of the freeze point curve for these type of solutions. The second method was to read the refractive index of the samples on an AR600 Automatic Refractometer. These readings were then compared to known refractive index versus concentration versus freeze point protection charts available from The Dow Chemical Company as well as numerous other Glycol processors. Both methods agreed within ±2°F.

These results reveal the deficiencies of trying to use a hydrometer to obtain an accurate measure of engine coolant/antifreeze freeze point protection level. Based upon the scale divisions of these hydrometers, the best accuracy that could be expected would be roughly ±15°F (+ 1 scale division). Temperature effects can be seen by comparing the test readings from outside to those obtained inside. Reading the same solution on the same instrument gave varying results. As expected, these results prove that as the temperature of the solutions being tested decreases, the resulting concentration reading from a hydrometer will increase. In other words, as reading temperature increases service technicians will be mislead into believing that they need to add more glycol to increase the engine coolant/antifreeze concentration level.

1.4 The Problem with Inaccuracy: The Death of a Beloved Family Member: Your Car

- What the government and truck drivers know that you don't.
- Increasing concentration to roughly 60% improves freeze point protection level. Above 70%, freeze point protection level becomes progressively worse.
- Cavitation corrosion, water pump failure, scale formation, gelation, inefficient heat transfer, boil over, freezing and cracking of hoses and engine block, solder bloom. All are problems defined by the SAE for over concentration and under concentration of engine coolant/antifreeze.
- Emissions control is impossible without the proper concentration. Catalytic converters are fickle at best.
- Over 26% of all repair costs can be directly attributed to Coolant System Maintenance Issues.

Inaccurate coolant/antifreeze concentration my actually be harmful to your engine. The United States government realizes this fact and will only use the Duo-Chek in military vehicles. Truck drivers also know the importance of maintaining their engine coolant/antifreeze concentration levels, often carrying a Duo-Chek in their tool box.

Referring to the final chart "Freezing Points of Aqueous Glycol Solutions" reveals one of the problems with increased concentration levels. As concentration is increased from 0% to roughly 60%, freeze point protection level improves. However, above 70% this protection level actually becomes worse the more concentrated the solution becomes. In this case, more is not better!

There are other problems associated with higher concentrations as well. Water pumps are designed to work with a specific viscosity of fluid. Increasing concentration increases the viscosity of the fluid, thus water pumps have to work harder, thus engines must work harder. This puts undo stress not only on your water pump and cooling system, but on the engine as well.

Another problem associated with concentrations exceeding 70% is a phenomenon known as cavitation corrosion. This is the formation of microscopic bubbles within the coolant/antifreeze as well as the action of silicate additive within the coolant/antifreeze. These bubbles and silicate particles act almost as sand paper would. They can rapidly wear away at the cylinder head, liner, head gaskets, water pump impeller, and even the radiator.

Silicate is an additive which is useful for protection of aluminum from corrosion. Nitrite and/or Molybdate which are also used as multi-metal inhibitors, are present in most fluids in very specific quantities. Increasing the concentration of Nitrite can lead to scale formation problems as well as solder bloom. Scale formation can act as an insulation thus severely affect heat transfer capability. Gelation, which also severely reduces heat transfer capacity, may result from increased levels of silicate as well as Total Dissolved Solids. Coolant/antifreeze processors recommend the exact concentration for their fluids to avoid these situations.

The Society of Automotive Engineers, Inc. (SAE) has developed a technical paper "Cavitation Corrosion Bench Test for Engine Coolants" which describes the problems associated with engine coolant/antifreeze concentration levels as well as Supplemental Coolant Additive (SCA) for Heavy Duty Engines. In this paper the Engine Manufacturers Association lists several of the problems associated with inadequate control of antifreeze and/or SCA concentrations.

Under concentration of Antifreeze/CS

1. Liner or water pump impeller cavitation.
2. General Corrosion.
3. Deposits on heat transfer surfaces.
4. Plugging of the system with corrosion products.
5. Freezing and resultant overheating and cracking of blocks, etc.

Over concentration of Antifreeze/SCA

1. Water pump seal seepage.
2. Solder bloom or solder corrosion.
3. Hose and gasket seepage.
4. Plugging of the system with precipitates or gelled additive.
5. Slush formation and resultant overheating.

This paper also contained several photographs of liners which had been pitted due to this problem. Photocopies of these are provided at the end of this document along with a schematic of this phenomenon. These reveal the problems associated with "Wet Sleeve" design engines.

Another factor to consider is that of emissions control. Catalytic converters are most effective when the air to fuel ratio is maintained at 14.7 to 1. This mixture is regulated by your car's computer. This computer uses multiple sensors to maintain this ratio. Probably the most important of which is the temperature sensor. Most cars today run around 230°, give or take 10°. Thermostats are used to regulate the minimum temperature rather than the maximum. Cooling fans regulate the high end. Maintaining this operating range puts an enormous demand on the cooling system. Heat transfer efficiency is essential, thus fluid concentration is critical in this regard.

In a second SAE paper, “Filtration of Coolants for Heavy Duty Engines”, “a 1984 poll of maintenance managers indicated that 26 percent of all diesel engine problems were associated with the cooling system”, although the author felt the true number to be as high as 40% due to the fact that cooling system problems more often cause problems which may not be attributed to this system.

Most customers expect that their service facility will protect them from these problems. One dollar spent on maintenance will save ten dollars in repairs. Service personnel have the opportunity to perform the maintenance, but once the repair is needed customers may not be willing to patronize a facility that cost them substantial amounts in repairs. The only real way for service personnel to perform effectively for their customers is to use a tool which they can rely on. The Duo-Chek is such a tool, a hydrometer is very definitely not!

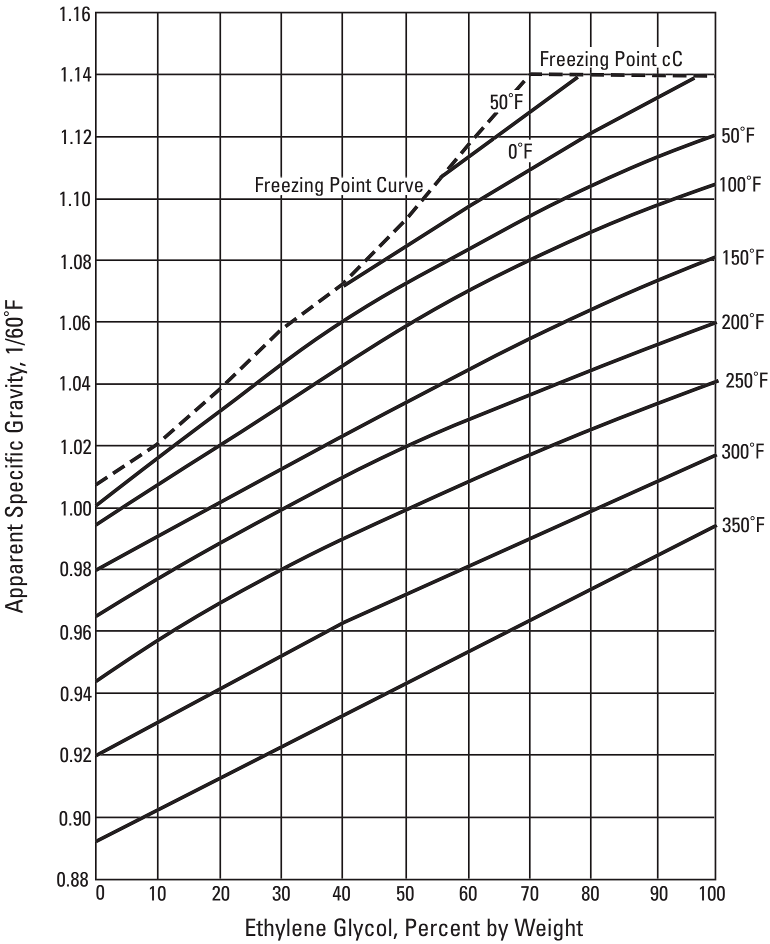

Figure 5 Specific Gravities of Aqueous Ethylene Glycol Solutions.

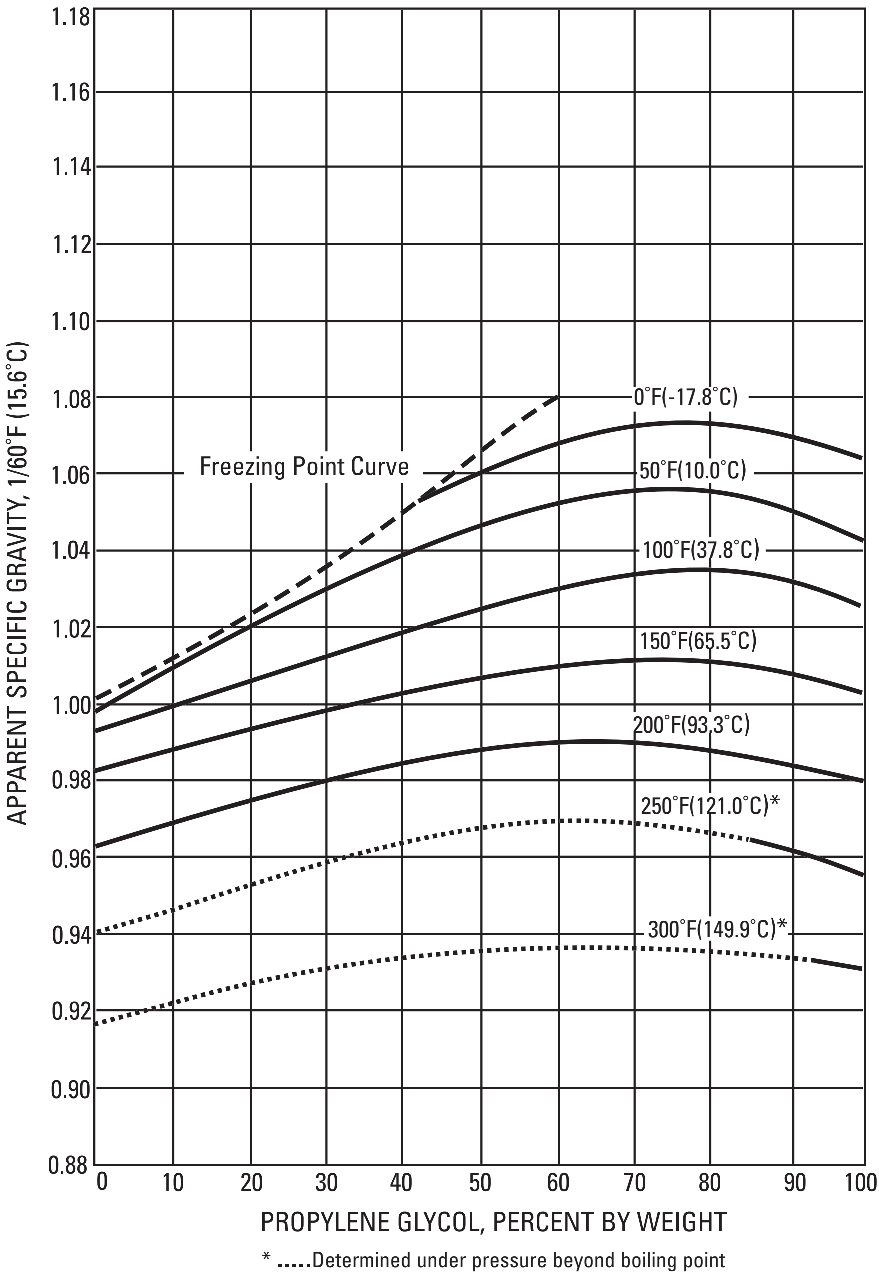

Figure 6 Specific Gravities of Aqueous Propylene Glycol Solutions.

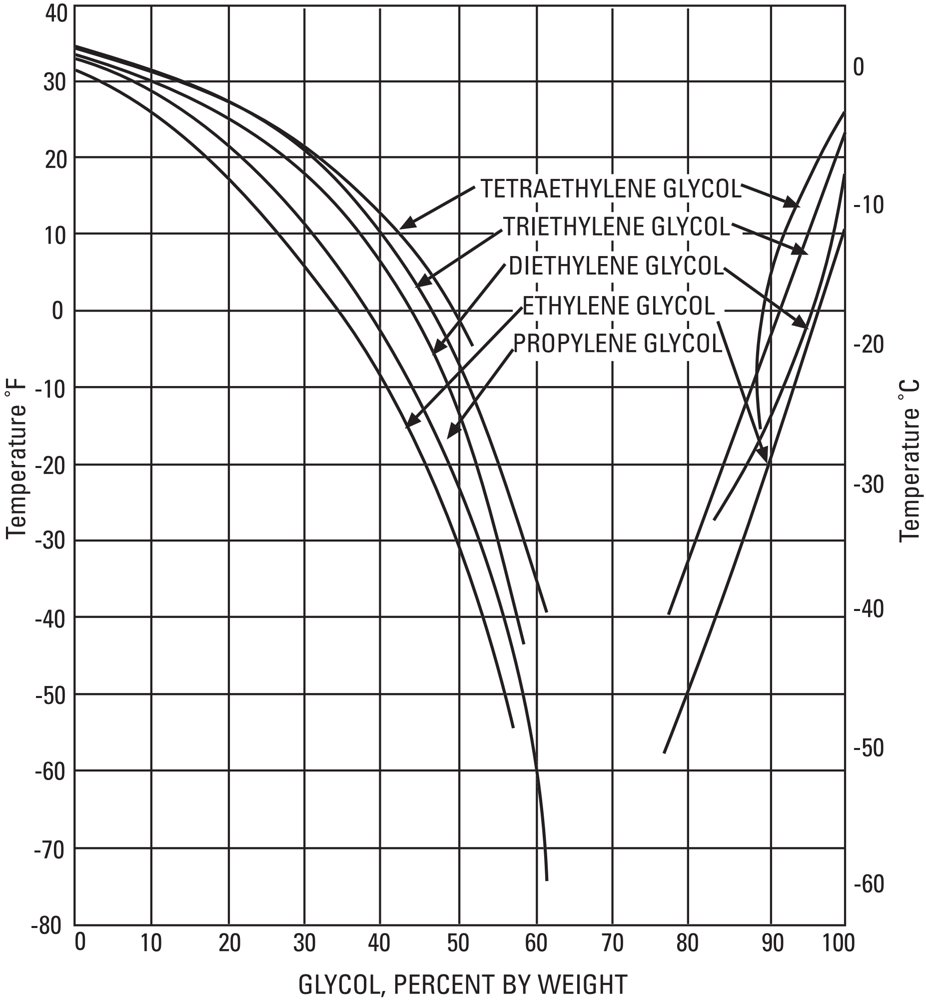

Figure 7 Freezing Points of Aqueous Glycol Solutions.

2.0 Appendix

2.1 Anatomy of a pitted Liner

Figure 7 shows a schematic cross section of an engine block and cylinder liner depicting liner pitting. When the pit penetrates the liner, the engine fails due to coolant leaking into the oil sump. An expensive in-frame overhaul is then required to repair the engine.

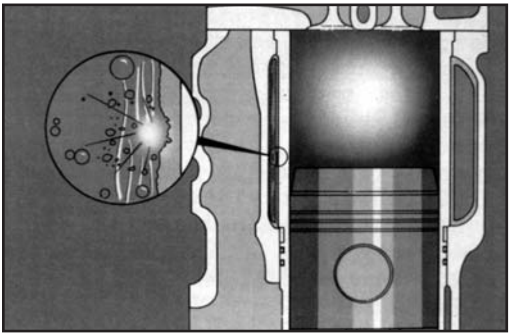

Figure 7

Figure 8 shows the thrust side of one liner taken from an engine installed in a class 8 truck. The engine failed at less than 200,000 miles due to penetration of a liner, not the one pictured. Figure 9 shows the pitting on the anti-thrust side 180 degrees from the pitting on the thrust side. Since the pitting was severe, the liner also had some pitting at 90 degrees to the thrust and anti-thrust, Figures 10 and 11.

Figure 8

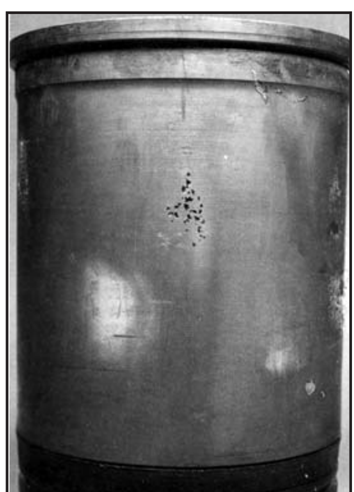

Figure 9

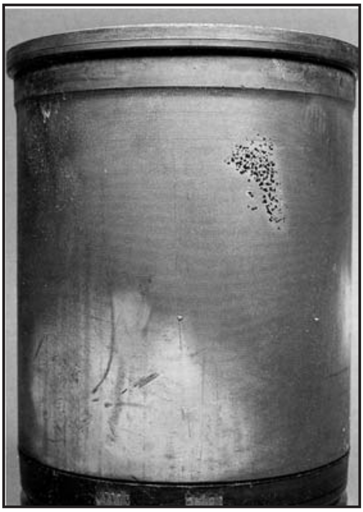

Figure 10

Figure 11

Figure 12 shows the thrust pitting area of the liner after it was cut through while Figure 13 shows the anti-thrust cross section. Note the extreme depth of the pits compared to the pit diameter. The star shaped pit circled on Figure 8 is also circled on Figure 13.

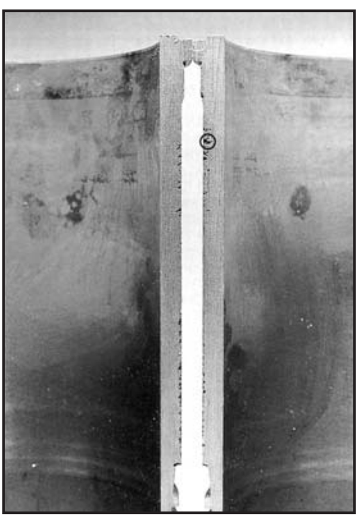

Figure 12

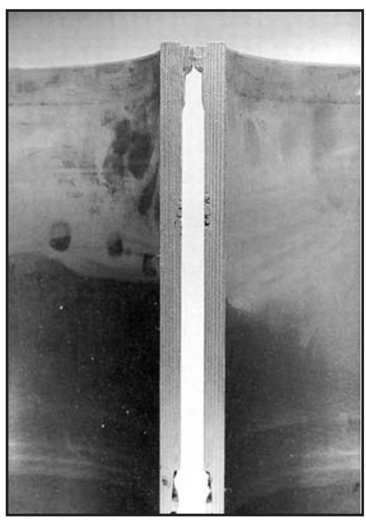

Figure 13

Due to a policy of continuous development, we reserve the right to change specifications without notice.

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