LUBE-TECH

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UNDERSTANDING HOW THE TRANSMISSION FLUID RESPONDS TO DAILY OPERATIONS.

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INTRODUCTION

Oil Analysis is the key to understanding how the transmission fluid in your automatic transmission responds to daily operations. Oil analysis coupled with regularly scheduled transmission fluid and filter maintenance decreases the likelihood of experiencing downtime caused by serious transmission problems or failure.

Transmission fluid analysis makes it possible to set fluid change intervals more accurately. Operating loads, speeds, ambient temperature, number of shifts and retarder usage all have an effect on transmission fluid. Understanding these changes is critical to establishing proper fluid change intervals.

This article is intended to expand the user's knowledge of fluids and their analysis and offer guidelines on their use. Specifically, it addresses the basic characteristics and reactions of fluids, provides understanding of some standard laboratory test procedures accepted throughout the industry, and provides guidance in interpreting and using the results.

THE FUNCTIONS OF AN AUTOMATIC TRANSMISSION FLUID OPERATING ENVIRONMENT

Understanding the environment an Automatic Transmission Fluid (ATF) is subjected to is essential in discussing its function and requirements.

The environment in which an ATF is expected to operate is anything but mild. The transmission is typically placed in the same vehicle cavity as the engine and radiator and subject to whatever temperature is present. Further, the transmission cooling function is dependent on the temperature of the engine coolant for heat dissipation and any engine overheat results in transmission overheating. Airflow in this compartment is usually marginal. Dust and road contaminants are a part of this environment as well and some of it is ingested through the transmission breather. While in this environment, the transmission must transmit power from the engine to the drive axle. Consequently, the fluid in the transmission must perform a variety of functions to meet all of its requirements.

FUNCTIONS AND REQUIREMENTS

The fluid in an automatic transmission must perform many important functions beyond that of basic lubrication.

While lubrication is important, the fluid must first provide drive through the torque converter, supply logic pressure to the range control system and then supply hydraulic pressure that causes a clutch pack to engage. An engine will run, at least briefly, without its lubricating oil, but an automatic transmission will not function at all without its transmission fluid. Fluids used in automatic transmissions must perform several distinct functions. These are:

- Hydrodynamic energy transmission medium for use in the torque converter.
- Hydrostatic energy transmission medium for use in the hydraulic control logic circuits and for servo-mechanisms.
- Lubricating medium for shaft bearings, thrust bearings and involute or spur gear load surfaces.
- Sliding friction energy transmission medium for use with lubricated clutches.
- Heat transfer medium with liquid or air-cooled systems for maintenance of a suitable automatic transmission temperature range.
- Further maintain acceptable heat levels by overcoming friction between moving parts. When a layer of fluid separates two moving components, fluid friction replaces the much stronger dry friction.
- Absorb shock loads produced by variations in load and drive, engine torsional activity or vibration, shifting, and wheel slip. Even the impact caused by the meshing of gears - particularly on start-up - is softened to a large extent by the fluid trapped between the teeth of the gears.
- Improve the ability of seals to maintain hydraulic pressure by acting as a sealant.

In addition to these basic functions, other important requirements achieved through the use of additives include:

- Operate satisfactorily over a wide temperature range; i.e., provide startability and essential lubricating flow at low temperature while maintaining its lubrication qualities and fluid film thickness at high temperatures.
- Be compatible with a variety of seal materials.
- Contain or keep in suspension contaminants introduced into or generated in the transmission, and thereby maintain transmission cleanliness.
- Resist oxidation and the fluid thickening it causes. Reduce friction beyond normal lubrication through the use of friction modifiers for reduced internal wear and improved operating efficiency.
- Minimize fluid foaming which reduces fluid film thickness and clutch-apply pressure.
- Be non-corrosive towards all transmission components and furthermore, inhibit corrosion of components from other sources by forming a protective layer.

These functions and requirements constitute quite a list of demands and one might doubt the ability of any fluid to meet them all. Today's fluids are the result of years of experience and research. Lubrication scientists have developed both the refinement processes and subsequent additives to such an extent that the resultant fluids effectively address the demands placed on them.

HOW AN AUTOMATIC TRANSMISSION FLUID MEETS ITS DEMANDS

A fluid's ability to meet demands placed on it depends entirely on its physical and chemical properties, which can either be inherent or induced through the use of additives. The properties or characteristics selected for discussion are viscosity, incompressibility, and oxidation inhibition.

VISCOSITY

Viscosity is one of the most important and most evident properties of a fluid, and is defined as its resistance to flow, recognisable by its thickness.

Viscosity can be further defined, as the resistance (fluid friction) of one layer of fluid to movement, while another layer in contact with it remains fixed. This resistance increases as viscosity increases. Thus, increasing viscosity leads to decreasing energy transmission efficiency. Yet, decreasing viscosity can lead to a fluid whose resistance to flow is so low that the film boundary between mating components is actually squeezed out allowing the components to contact. Obviously, a delicate balance must be achieved and then maintained throughout operation.

Another operating difficulty with the property of viscosity is its reaction to temperature. Most fluids are more viscous at reduced temperatures and less viscous at elevated temperatures. Because of the problems associated with extreme viscosities, high or low, a distinct need exists for a fluid of a more temperature-stable viscosity resulting in the development of multi-viscous fluids. Thus, two types of fluids are produced: straight-grade fluid and multi-viscous fluid.

Most fluids become thinner at elevated temperatures but a multi-viscous fluid will thin at a reduced rate compared to straight-grade fluid. An SAE 30 weight fluid behaves as a 30 weight fluid at all temperatures while a multi-viscous fluid, i.e., SAE 15W40, behaves as an SAE 15 weight fluid at low temperatures and as an SAE 40 weight fluid at elevated temperatures.

Figure 1 illustrates the relationship of viscosity to temperature and the behavior of a straight-grade versus a multi-viscous fluid. The chart is valid between the temperatures at which the viscosities were measured (100-210°F); 38-99°C. It is customary to project the plotted data as shown.

However, some deviation from the linear (negative slope) should be expected around the cloud point of the lubricant. Cloud point refers to the temperature at which wax crystals materialize in the fluid, (0-30°F) -18 to -1°C for most transmission fluids.

The "variable" viscosity characteristic is obtained by additives called Viscosity Index (VI) Improvers. VI Improvers are best described as oil-soluble organic polymer chains that are temperature sensitive. They are tightly coiled at low

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temperatures and have little or no effect on viscosity. As temperature increases, however, these chains begin to lengthen, uncoil and interact with each other. It is their length and interaction that causes the thickening effect or viscosity increase over the inherent viscosity present in the base stock. The first number listed in a multi-grade notation is essentially the viscosity of the base stock and the second number is the grade achieved at elevated temperature by the use of VI Improvers. VI Improvers theoretically increase the viscosity at all temperatures, but it becomes considerably more pronounced as temperature increases. The amount and configuration of the VI Improver used determines the differential between the two grades.

INCOMPRESSIBILITY

The incompressibility of a fluid is a property that is often overlooked since all liquids are basically incompressible. But this property is essential. Incompressibility allows a fluid to efficiently transmit power through the torque converter and transfer pressure to the controls, clutches and lubrication points. This property is inherent and is only affected when air bubbles are introduced. Since air is compressible, a fluid contaminated with air bubbles compresses and does not transmit full pressure.

The additives used to help control air content in the fluid are referred to as anti-foam agents. These chemicals control air bubbles by reducing the surface tension of the fluid allowing the air bubbles to break through the fluid surface.

OXIDATION/CORROSION INHIBITION

Oxidation, by general definition, is the combination or chemical reaction of a substance with oxygen. The presence of water and heat accelerate the reaction. Lubricating fluids naturally coat a surface with a protective film, which displaces any oxygen or water present and thus prevents oxidation of the metals. The coating also provides protection from corrosive substances that might be present. The fluid is assisted by additives, already mentioned, additives that actually react with or plate onto metal surfaces forming a protective barrier, as well as additives that neutralize acids within the fluid. Equally important is the inherent oxidation resistance of the fluid, controlled by base stock selection, refining, and additives.

WHY AN AUTOMATIC TRANSMISSION FLUID FAILS TO MEET ITS DEMANDS

During normal operation, an ATF does react to both the environment and the demands placed on it. Oxygen, heat, wear particles, and severe usage directly affect fluid characteristics.

VISCOSITY

Viscosity is typically the first property to experience a measurable change during operation. The VI Improvers are added to improve the temperature viscosity property of the fluid. Since they are long polymer chains of high molecular weight, they are less stable chemically and susceptible to "shear." Shear is a function of time and severity of operation. It occurs when a polymer chain passes through a low clearance, high stress meshing interface (planetary gears, main-pressure pump, clutch plates, torque converter, etc.) where the chains are actually cut or sheared into smaller pieces. This shear typically begins to reduce the elevated temperature viscosity almost immediately and will continue to do so, though at a decreasing rate throughout the life of a fluid until it reaches the viscosity of the base stock. Figure 2 illustrates the viscosity change due to VI Improver shear. Straight-grade fluids do not have VI Improver additives and do not experience viscosity reductions due to shear.

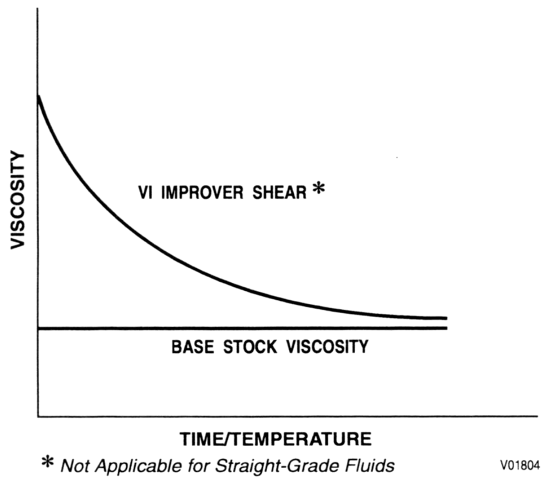

Figure 2. Viscosity Index Improver Shear

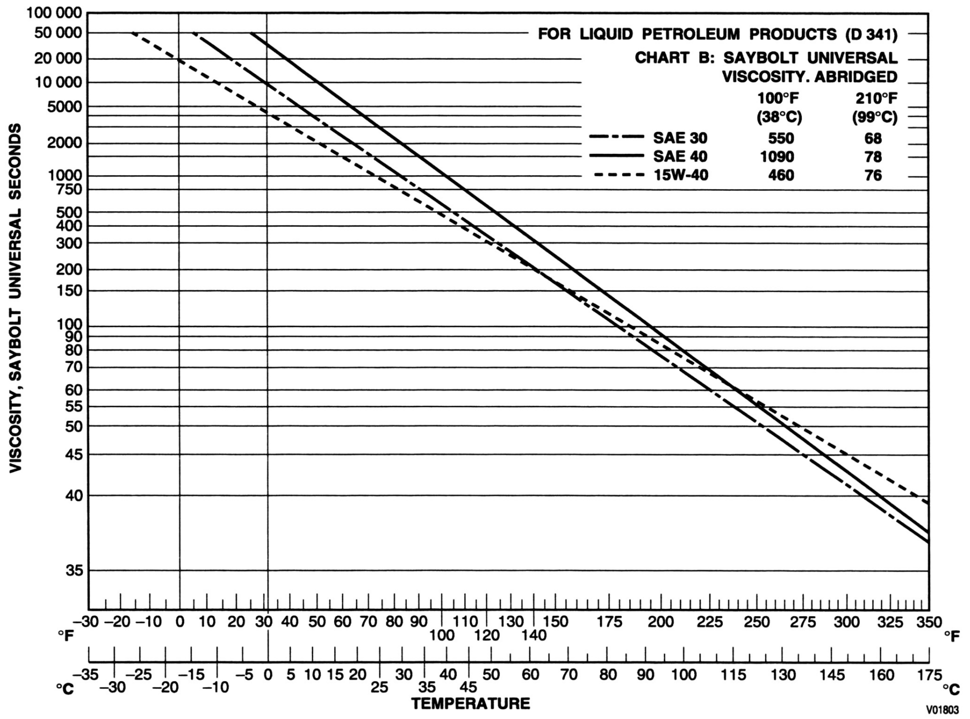

Figure 1. ASTM Standard Viscosity/Temperature Chart

OXIDATION

Oxidation is probably the single most deciding factor in limiting the functional life of a fluid.

Fluid oxidation is a chemical reaction between the fluid and oxygen much like rust is a chemical reaction between iron and oxygen. Both reactions create a product, oxidized fluid and iron oxide respectively that have little or no ability to perform the original function.

The speed of the reaction depends on several environmental conditions: air mix, temperature, time, and catalysts. Oxidation literally means "a reaction with oxygen." It follows that increased exposure to air provides increased opportunity to oxidise and the presence of an air supply is the most significant contributor to oxidation. The next significant contributor to oxidation is temperature; fluid oxidation rate increases as temperature increases. It is because of both conditions that transmission overfill can be so harmful. If a transmission is overfull, the fluid level reaches the rotating parts of the transmission. This contact results in "churning" which aerates and heats the fluid, thus accelerating oxidation. The last noteworthy contributor to oxidation is the presence of catalyst metals such as iron and copper.

Oxidation has a serious and lasting effect on any petroleum product, and transmission fluid is no exception. Oxidation creates chemical changes causing acidity and solid matter to form and an increase in viscosity, all of which

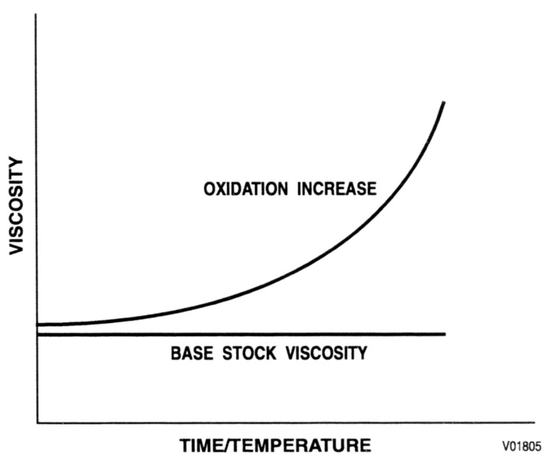

Figure 3. Viscosity Increase With Oxidation

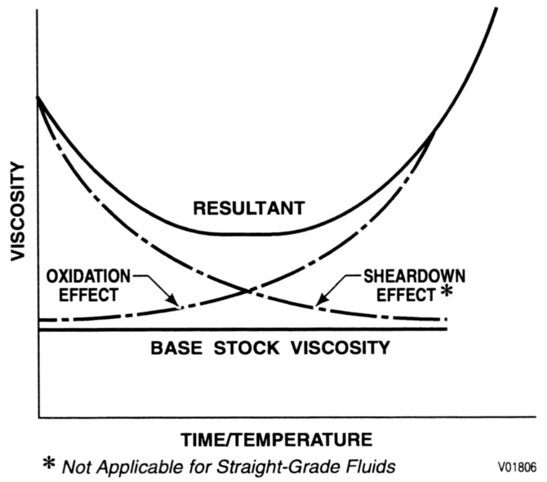

Figure 4. Resultant Viscosity

can be measured. The sludge and solid matter formed from the fluid oxidation, as well as additive oxidation or depletion and dispersant saturation, are primarily responsible for the increase in viscosity that is usually characteristic of advanced oxidation. The increase in viscosity is represented in Figure 3.

Recall that multi-viscous fluids can experience viscosity reduction due to shear. Figure 4 illustrates the resultant viscosity when both shear and oxidation are present. A straight-grade fluid would only experience oxidation.

Oxidation resistance is controlled in part by base stock selection and preparation, but additional resistance is typically needed. The additional resistance is obtained through the use of additives. Assorted additives are available to improve the oxidation resistance of a fluid. One already mentioned is an anti-foam agent intended to reduce the presence of air bubbles in a fluid. This reduces oxidation by reducing the surface contact of the fluid with air. Other additives are anti-oxidants. These additives work on a molecular scale by sacrificing themselves to the oxidation process thus limiting or controlling oxidative breakdown of the fluid. Synthetic fluids have a more stable molecular structure naturally because of their specialized, controlled manufacture or "synthesis." However, the same additive types are still used in synthetic blends to achieve maximum oxidation resistance.

CONTAMINATION

Contamination is the remaining major hindrance to fluid efficiency and can originate from a variety of sources, those most notable being oxidation, environment, and component wear. As stated, oxidation creates acidity and solid matter, both of which must be addressed to maintain fluid and transmission life. Acidity is usually addressed by introducing alkaline additives to the base stock. Fortunately, in an automatic transmission, the fluid seldom becomes very acidic unless allowed to severely oxidise. Consequently, ATF seldom contains high concentrations of alkaline additives. Nonetheless, increasing acidity in a transmission is important and should be part of a fluid analysis program.

The solid matter by-product of oxidation, if left alone, deposits onto surfaces throughout the transmission. This contaminant, as well as limited contaminants from external sources, is counteracted by detergents and dispersants. Detergents maintain surface cleanliness while dispersants keep contaminants in suspension. Contaminant suspension is necessary to provide for effective fluid changes; only those contaminants suspended in the fluid are removed during drainage. These additives are essential in maintaining cleanliness and achieving expected fluid life.

MEASUREMENT OF IMPORTANT FLUID CHARACTERISTICS AND REACTIONS

Effective analysis of fluids requires an ability to measure the various fluid characteristics. There are hundreds of different tests that can be used to evaluate lubricants, hydraulic fluids, and other oils. Often, two or three different tests can be used to measure the same characteristics. These similar tests vary in cost, accuracy, and the time required to complete each test.

In the interest of standardizing testing, the American Society for Testing and Materials, ASTM, has developed a full spectrum of tests that have been widely accepted. These standardized tests provide increased accuracy and reliability between labs. However, some variation still exists between labs.

VISCOSITY

Fluid viscosity is most often measured by ASTM Standard D445. This procedure measures the time required for a given volume of fluid to pass through a specific size orifice at a given temperature. It is typically measured at 104°F (40°C) and at 212°F (100°C). The orificed tube assembly is immersed in a liquid bath with the bath temperature maintained at each given value. This procedure is accurate within 0.5 percent.

Viscosity can also be measured by a falling ball comparator. This is a portable test that can be performed quickly on-site with reasonable accuracy. This method compares the sample fluid to a previously calibrated reference fluid. Identical balls are allowed to fall freely through the reference and sample fluids. The relative distance each ball falls is used by comparison to determine the sample fluid viscosity. The accuracy of this method varies between 1 and 5 percent, depending on user experience. Obviously, the ball may be difficult to see in dark fluids or fluids that are badly oxidized, limiting the application of this procedure.

INFRARED (IR) SCAN

An IR scan is most often obtained by differential analysis. This procedure basically measures the differential between the amount of IR light absorbed by a used fluid sample and a reference (new) sample. It involves an IR light source inside an opaque box that is directed simultaneously through the used and new fluid samples as shown in Figure 5. Pocketed cells control the

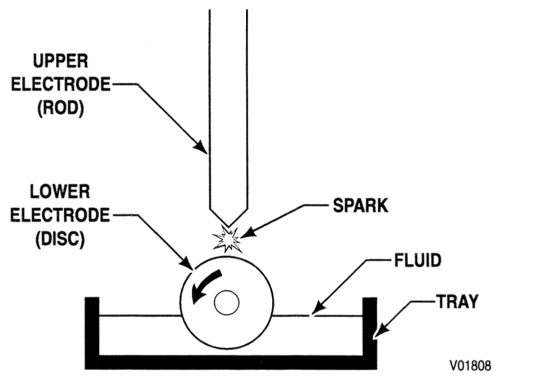

Figure 6. Spectrograph Analysis Technique

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thickness of the fluid samples. After passing through the fluid samples, the IR light is reflected through a rotating chopper and into a detector where it is analyzed. The rotating chopper alternately blocks one of the two signals so the detector is only receiving one signal at any given time. The analyzer compares the signals from the new fluid to that of the used fluid and reports the difference as absorbance units per centimeter of fluid thickness. IR light at various wavelengths (in microns) may be used and the amount of light absorbed at each wavelength can reveal information about water, glycol, minerals, organic acids (oxidation), synthetic additives, and nitrates, as shown in Table 1 below. This procedure is accurate within approximately 1/100th of an absorbance unit.

Table 1

WAVELENGTHS (MICRONS)	RESULTS/INDICATIONS
2.9	Water, Glycol
3.5*	Hydrocarbon (indicates Minerals)
5.8*	Carbonyl, Carboxylic, Organic Acids (indicates Oxidation and Synthetic Additives)
6.1	Nitrate (NO_x)
9.6	Glycol

*A major change in the ratio of the readings T 3.5 and 5.8 wavelengths indicates a significant change in the base stock (brake fluid, etc., added by mistake).

TOTAL ACID NUMBER (TAN)

Advanced oxidation will always be accompanied by the presence of acid. This acid is best measured by adding an indicator solution to a fluid sample and then adding potassium hydroxide (KOH) until the solution changes color. The acidity is expressed as the milligrams of KOH required to neutralize a gram of fluid. The standard for this procedure is ASTM Standard D974 and is accurate within 15 percent. If the fluid is too dark to use a color indicator, the change in electrical conductivity can be measured as the KOH is added. The standard for this procedure is ASTM Standard D664 and is accurate within 4 percent.

SOLIDS

Solid matter is another indication of oxidation and is simply solid particles suspended in the fluid. It is best measured by centrifuging a fluid sample at a given RPM in a tube that is narrowed and graduated at the bottom. The solids collect in the bottom and can be measured in percent by volume. The standard for this procedure is ASTM Standard D91.

WATER

Two ASTM tests, Standards D95 and D1744, are used for water content measurement. The first, Standard D95, is used for gross water contamination with the result expressed in volume percent. The water content is determined by distillation and accurate within 2 percent. The second test, Standard D1744, determines water content by reacting the sample with a karl fisher reagent and is useful for determining contamination of small amounts of water (1000 ppm). Results are expressed in parts-per-million (ppm) and accurate within 10 percent.

Part 2 of this article will be included in the next issue of LUBE.

DOES YOUR LUBRICATION PROGRAMME EMBARRASS YOU?

Recently, while perusing a book entitled "Quality Maintenance - Zero Defects Through Equipment Management" by Seiji Tsuchiya, a Japanese engineering manager and maintenance expert, I read the following line: "A breakdown that occurs because of improper lubrication is a serious embarrassment." This line, which one might easily pass over when reading, got me thinking. Why did the author use the term embarrassment? Was this simply a failure to accurately translate the book from the author's native Japanese language to English? I don't think so. I think the term was accurately translated and carefully selected. Mr. Tsuchiya recognises that most lubrication-related failures are chronic, recurring management failures, which should embarrass maintenance managers. Honour, and the avoidance of embarrassing situations carry a high priority in Japanese culture. I believe Mr. Tsuchiya chose his words carefully and strategically.

I frequently hear and read experts' reports stating that improper lubrication is responsible for between 50 to 80 percent of all mechanical and electromechanical equipment failures. When I talk to corporate or upper-level plant managers about the topic, they agree that failure to properly lubricate machines probably compromises their overall equipment effectiveness (OEE). When I am consulting at a plant site, mill or mine, I talk to plant-level engineers and technicians about their lubrication practices. They are keenly aware that these practices must be improved if reliability goals are to be met. However, progress is slow. The demand to keep up with pump, bearing, gearbox, engine and hydraulic system failures consumes all their time. They are stuck in the business-as-usual mode. There is no time to improve maintenance practices. This is embarrassing. To recognise that a chronic, recurring, controllable root cause is responsible for 50 to 80 percent of the plant's reliability problems and not address it is a management error on the highest order - plain and simple. It is the responsibility of management to replace the old business as usual with a new, more effective one that emphasises precision machinery lubrication.

Marketing and advertising experts use the acronym AIDA (Attention-Interest-Desire-Action) to refer to the process by which things get done. With respect to solving lubrication-induced equipment reliability problems, few people have reached the attention stage. Even fewer have true organisational interest. Still fewer have reached critical mass, called desire. And, I expect that there are more fingers on my right hand than companies, in North America at least, that have taken it to the action stage and truly achieved world-class lubrication excellence. Industry continues to trivialise the importance of lubrication vs. machine reliability, pay lubrication technicians bottom-dollar wages and withhold resources for training, certification and other career development activities. Moreover, if the lubrication technician exhibits promise, he or she is turned into a millwright or mechanic. This is embarrassing indeed.

Was Mr. Tsuchiya right? Is equipment failure caused by poor lubrication embarrassing? Yes, I believe he is quite correct. Failure is productive when it occurs in a new, unexplored area that produces valuable knowledge. When failure is chronic, controllable, known to management and significant in its impact, such as with lubrication-induced equipment failures, it is embarrassing and irresponsible. Audit your organisation. Is poor lubrication producing unnecessary costs? Is there a gap between the views of management and the shop floor folks with respect to the impact of poor lubrication? Are you treating lubrication casually in your organisation? Are lubrication tasks treated as a catch-as-catch-can activity? Do you lack procedures and guidelines for lubrication that enable precision and best practice? If you are answering yes to many of these simple questions, you might be headed for embarrassment yourself.

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