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High pressure leak prevention – improved performance and reliability from anaerobic thread sealing compounds

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Abstract

Anaerobic thread sealing compounds have been available for many years and proven to be highly effective when used in a wide variety of standard pipe joints – especially when used in conjunction with tapered thread forms. This paper describes recent improvements in process reliability by developing improved performance on oiled surfaces and resistance to thermal cycling at elevated temperatures. Data is also presented demonstrating sealing capability in excess of 20,000 psi (138 MPa) after 1 hour room temperature cure.

Introduction

Transport of fluid media is an important part in many aspects of our lives and is an essential part in many technologies and industrial processes. Whether it is drinking water or natural gas travelling to our homes, power transmission from hydraulic/pneumatic systems or in heat transfer systems, many pipe or hose connections are made. Moving these fluids from one place to another effectively passing through connections without leaks has always presented a challenge to the system designer.

This paper reviews the traditional sealing methods and describes the general advantages of anaerobic adhesives. Data is presented showing the performance of anaerobic sealants in high pressure systems (>10,000psi) and describes recent developments to improve the reliability on oily surfaces and thermal cycling at elevated temperatures.

Thread Types and Traditional Sealing Methods

Predominantly today, three types of threaded connections exist defined by the thread geometry

1. ***Taper to Taper:*** Tapered threads on both the male and female components (NPT)1 create mechanical interference which forces the roots and crests of the threads into one another.

	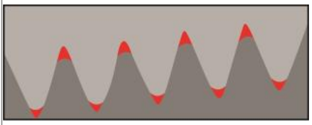
National Pipe Thread Taper (NPT)	Threads require sealant to fill voids at roots/crests.

Figure 1a: Taper-Taper Pipe Thread Form

2. ***Taper to Parallel:*** Tapered diameter male thread meets a constant diameter female thread (BSPT). The effect of increasing interference during assembly is the same as in a taper to taper connection however on a taper to straight connection this occurs only across a small portion of the leading female threads.

	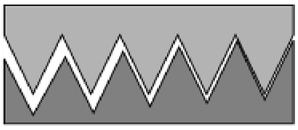
British Standard Pipe Taper (BSPT)	Threads are pressed into each other – in theory sealing by metallic closure

Figure 1b: Taper-Parallel Pipe Thread Form

3. ***Straight to Straight (or Parallel to Parallel):*** This configuration does not provide a seal in the threads. The axial load that is created upon tightening is used to compress an o-ring or gasket to prevent leaking.

	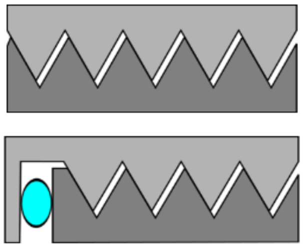
British Standard Pipe Parallel (BSPP)	ISO 228-1 requires and additional sealing element, e.g. O-ring

Figure 1c: Parallel - Parallel Pipe Thread Form

For both connection types 1(a) and 1(b), the interference caused by the thread geometry is supposed to create a seal by metal to metal contact within the threads. However, as a result of surface imperfections or manufacturing tolerances, this rarely occurs in the real world – especially at higher pressures. Traditionally therefore these pipe connections are used in combination with a sealing paste or tape to fill any remaining voids or surface imperfections. The most common approaches are described below;

1. ***Pipe sealing puttys:*** Non-curing materials (such as mineral puttys) were originally used to seal tapered threads. At higher pressures however, these sealants were often extruded out of the joint. This led to the development of solvent-based pastes which are still used for threaded joints in industrial and household applications. Solvent-based pastes fill the voids of threads and are not as easily pressed out by fluid pressures. However over time the solvent will eventually evaporate away causing shrinkage, cracking and risk of subsequent leakage.

2. ***Hemp-based fibre**:* In straight to taper connections, hemp has been used to seal pipes and threads for many years – offering a low-cost solution even against steam pressures and temperatures. However Hemp has limited chemical resistance and by forcing solid materials into the threadform creates additional radial stresses that may crack the connection

3. ***PTFE (plumber's) Tape:*** Probably the most widely used sealing solution for tapered joints. PTFE has excellent chemical resistance and is generally easy to apply. Its high lubricity allows for increased thread engagement for the same

tightening force but pipe fitters must be aware that overtightening can stress the connections beyond their design limits. The compressible nature of the tape also means that backing-off of the thread for adjustments to align a pipe with a union or elbow is not possible. Finally the high lubricity can make the fittings susceptible to loosening – especially under applications involving thermal cycling or high vibration.

4. ***Hydraulic & Pneumatic Systems:*** In these systems, plumber's tape is not recommended. The reason for this is that during assembly, the tape is prone to shredding. These small pieces can often cause contamination and block ports of control systems. Many systems have filters to pick up large particles or contaminates like this but if used at a connection downstream from the filter the system is not protected. With this concern, many hydraulic connections don't actually use a sealant at all. Hydraulic and pneumatic systems will use dry seals like flare fittings as well as o-ring compression fittings. In a flare fitting, two machined surfaces flared at an angle (37° for JIC or SAE 45°) are drawn together by a straight threaded coupler nut. This compresses the two flared surfaces to create a metal to metal seal. For o-ring compression fittings, the assembly of straight threads creates an axial load that will compress an o-ring onto the face of a female fitting. Generally, these fittings work reliably if assembled properly but leaks are not uncommon. This is especially true during maintenance operations and if the fittings are re-used.

Use of Anaerobic Thread sealants

Anaerobic adhesives and sealants are reactive polymers that cure rapidly to a thermoset plastic when in contact with metal surfaces in the absence of air. Close-fitting metal threads create near-perfect curing conditions and therefore these materials make ideal thread sealing compounds overcoming many of the limitations of traditional sealing methods. As they are applied to the threads in a liquid state, they have the ability to fill any void or imperfection that exists between the mating threads. When confined between the metal threads, there is insufficient oxygen to keep the material stable in its liquid state – rapid polymerization then creates a thermoset plastic that provides a mechanical bond between the two components. Since the sealing performance is not dependant on compression between the threads the assembly can be initially aligned to any orientation and any excess material that is squeezed out of the joint can be wiped away as the oxygen will forever prevent it from hardeneing. This means the joint has a clean apperance and provides resistance to vibrational loosening, temperatures as high as 200°C and pressures up to the burst pressure rating of most systems. The chemical resistance is also excellent and is generally considered compatible with a fluid unless it is a strong acid, strong base or oxygen/oxidizing agent. The physical properties of the anaerobic thread sealant can be tailored to specific product profiles so they are suitable for various applications.

Anaerobic thread sealants designed for taper to taper connections (such as NPT threads used predominately in North America) are often formulated with high lubricity which prevents galling of the threads and allows full thread engagement. The final cure strength is typically low to allow easy disassembly but it also resists vibration. As long as the product has not begun to cure the assembly can also be adjusted for alignment during installation.

In most of the other regions of the world fittings conforming to the ISO 7/1 standard (BSPT, DIN 2999, EN 10226-1, JIS B0203) are most common. These connections used taper to parallel thread geometries and compared to the anaerobic thread sealants for NPT fittings, these products require more strength due to the smaller contact area and faster cure since the product has to polymerize across a greater gap at the leading male thread.

Besides the fittings types, products often have a tailored viscosity. Small or fine threaded connections require a thin product that is more easily applied and flows into the smaller geometries. Larger fittings require a thixotropic product that will not slump or sag when applied to the thread but when shear force is applied during assembly will still thin out and fill the voids and imperfections. The products can also be tailored to meet certain industry approvals such as potable drinking water certifications as well as oil and gas certifications.

Anaerobic thread sealants have been created and are successfully used to maintain hydraulic systems using parallel to parallel connections. The base monomer used in any anaerobics products is soluble in hydraulic oil however, these formulas do not contain any filler particles greater than 3 microns in size. This means that if any uncured material ends up in a hydraulic line, it will not foul or clog control systems or filters. Many of the reliability issues encountered with flare fittings is that the mating flares can often be scratched during handling or be overtightened. During maintenance, where more often than not the fitting does not get replaced, an anaerobic thread sealant can be applied to the flared surfaces. This will fill the imperfections and perform as a gasket to ensure reliability. For o-ring compression fittings, leaks can be caused by compression setting of the o-ring, the o-ring drying up due to lack of lubrication or damage to the o-ring or sealing face. An anaerobic sealant for hydraulic systems can be used as an additional measure to ensure improved reliability.

Sealant Type		Hemp & Paste	Pumbers Tape	Anaerobic
Description		Hemp & Sealing Paste	Thin PTFE tape	curing liquid
Requirments	Fills voids		Creates sealing barrier	
	Media resistance	No chemicals		
	Ease of use Application time	2-step process	Needs accurate positioning	
	No contamination of fluid		Risk of debris	
	Re-adjustability Positioning	45° turn-back	Never turn back	Before cure
	Instant Seal			Low presure
Add-On	Support of geometrical integrity of threads	No	Risk of over torquing	Yes (locking function)

Table 1: Features of Principle sealing methods

Mechanical and Environmental resistance of anaerobic thread sealants

One of the key benefits of using anaerobics to seal threads is their ability to provide an adhesive bond between the pipe components in order to resist mechanical forces which may otherwise result in loosening and leakage.

Traditional sealing systems rely upon compression between mating faces in order to maintain sealing integrity. Friction between the thread faces is required to overcome any relative movement which can be induced by dynamic loads resulting from thermal expansion, pressure cycling or vibration. Ironically sealing systems like PTFE tape reduce the friction between threads in order to allow greater compression of the tape into surface imperfections – but the low friction can mean these fittings are more susceptible to vibrational loosening under dynamic loads.

Liquid anaerobic thread sealants completely fill all of the voids between threads and cure to a rigid material thus preventing any relative movement even during excessive vibration. The adhesive bond strength, which can be tailored to meet the requirements of different thread geometries, provides further resistance to any torsional loading whilst still allowing easy disassembly with conventional hand-tools.

		% of initial strength		
Environment	**°C**	**100h**	**500h**	**1000h**
Motor oil (MIL-L-46152)	22	100	100	100
Gasoline	22	90	80	80
Brake fluid	22	90	90	80
Ethanol	22	85	85	85
Acetone	22	75	70	60
1,1,1 Trichloroethane	22	90	90	85
Water/glycol 50/50	87	100	75	75
E85 Ethanol fuel	22	-	85	130
B100 Bio-Diesel	22	-	105	90
Diesel Exhaust Fluid (DEF)	22	-	130	120

Table 2: Chemical resistance data for Loctite 567[2] anaerobic thread sealant after ageing for 1,000 hours

Resistance to chemical media is an important requirement for any pipe sealant material and anaerobic materials provide excellent resistance to both chemical and thermal degradation. Table 2 shows results of relative loosening torque of threaded assemblies after exposure to various chemical media at 100, 500 and 1,000 hours exposure.

Recent Advances in Performance of Anaerobic Thread sealants

Tolerance to oil-based surface contamination

The hydrostatic tests described above demonstrate the high performance capability of anaerobic thread sealants when used under controlled laboratory conditions and at standard operating temperatures. Under these conditions care is taken to ensure all surfaces are clean and free from contamination in order to ensure consistent and comparable results. Whilst good surface cleaning is always recommended for any adhesive or sealant to achieve optimum performance it is also recognised that in many instances – especially during repair or maintenance procedures - it is not always possible to replicate laboratory conditions.

This concern has led to the development of products that show improved tolerance to surface contaminants – especially oils, corrosion inhibitors and cleaner residues. The following data shows the improvement break torque on threaded assemblies using two different common thread sealing grades:

Loctite 567(2) is a low strength anaerobic grade with high lubricity which is particularly suited for applications on taper-taper (NPT) and stainless steel threads
Loctite 577(3) is a fast curing, medium strength anaerobic sealant which is ideal for use on taper-parallel threads (BSPT) where thread gaps are usually larger and higher strength is required

Test Methods

Black oxide coated mild steel nuts and bolts (M10) were initially degreased using a solvent-based cleaner. The parts were then exposed to surface contaminants in a controlled manner. Various commercially available solvent-based oils and water-based oil emulsions were applied to achieve a surface contamination of 2-6 g/cm^2 corresponding to a light to medium level of oil contamination. The parts were then assembled using anaerobic thread sealant and allowed to reach full cure at room temperature. The resulting break torque (unseated) was then measured in accordance with ISO 10964.

Results and Discussion

Table 3 shows a summary of the breakaway torques for different oil types using thread sealing grades before and after formulation changes.

Contamination @ 2-6 g/cm^2	Loctite 577		Loctite 567	
	Original	Upgrade	Original	Upgrade
Aqueous oil emulsion	4 Nm	15 Nm	2 Nm	7.2 Nm
Engine/Motor oil	3 Nm	5 Nm	1 Nm	3 Nm
Solvent-based oil	7.5 Nm	13 Nm	3 Nm	5 Nm

Table 3: Breakaway torque (Nm) showing improved Tolerance to light-medium oil contamination on threaded assemblies(6)

Whilst it will always remain the case that optimum performance of an adhesive will be achieved by the removal of any surface contamination these results show that light to medium levels of surface oil can be accommodated and still achieve good surface adhesion. This improved oil tolerance means that the use of these grades can provide a more reliable seal even under non-ideal conditions – offering improved resistance to stresses caused by vibration or thermal expansion and contraction.

Improvements in High Temperature performance

The thermal resistance of anaerobic adhesives is an important requirement in many industrial applications – especially those involving steam or other high temperature process fluids. Traditionally the hydrocarbon polymers which form the backbone of anaerobic systems have limited the long-term operating temperatures to around 150^{o}C – beyond which a reduction in elasticity makes them less able to resist the movement caused by thermal cycling or pressure variations. However recent developments have focused on developing resin systems which retain flexibility and adhesion even after long-term aging which allow the operating envelope to be extended.

Test Methods

EN 751-1 is a standardized test to determine the sealing capability of curing compounds. The test involves 3 separate elements; soundness, hot water resistance and temperature cycling. Each test is carried out in succession on the same assembled parts.

Results and Discussion

The improved resistance to thermal cycling provides further confidence that anaerobic materials can be used in a broad range of sealing applications and provide long-term reliability at elevated temperatures.

Test Detail (EN 751-1)	**Loctite 577 (Original)**	**Loctite 577 (Upgrade)**
Soundness Test	☑ Pass	☑ Pass
Hot Water Resistance	☑ Pass	☑ Pass
Temperature Cycling **150ºC**	☑ Pass	☑ Pass
Temperature Cycling **180ºC**	☒ Fail	☑ Pass

Table 4
EN 751-1 Testing showing improved Thermal Cycling of Anaerobic thread sealants

Hydrostatic pressure testing of Anaerobic Thread sealants

In order to validate the performance of anaerobic thread sealants on taper-taper (NPT) threads used in oil and gas installations a series of hydrostatic pressure tests were carried out using selected Loctite products on fittings from various manufacturers.

Test Methods:

A range of NPT stainless steel fittings with sizes from ¼“ to ½“ were assembled using anaerobic sealants applied in accordance with manufacturer‘s instructions[1]. The maximum pressure rating of the selected fittings ranged from 10,000 – 20,000 psi and different Loctite thread sealants were selected to match the thread diameters;

Loctite 577[3] is a thixotropic thread sealant suitable for larger diameter fittings (up to 3“ diameter) and coarse threads. It is designed for use in taper-parallel fittings and has medium strength with fast cure on copper-based alloys or non-stainless steel or iron fitings.

Loctite 542[4] is a low viscosity thread sealant suitable for fine threads commonly found in hydraulic systems. It has medium strength allowing easy disassembly after full cure.

Loctite 7649[5] is a solvent-based activator used to accelerate the cure of anaerobic sealants when used on passive metal surfaces such as stainless steel. It is sprayed onto the threads and allowed to dry (1-2 minutes) prior to application of the liquid thread sealant. It remains active on the parts for up to 30 days after application..

Hydrostatic pressure tests up to the maximum pressure rating for each assembly were conducted 1 hour and 24 hours after assembly. See Table 5 for a description of components and pressure ratings.

Description	Pressure Rating (psi)
1/2" NPT (f) - 1/4" Med. Press. (m)	20,000
1/2" NPT (m)-(m) Nipple	10,000
1/2" NPT Union	10,000
1/4"NPT (f) - 1/2"NPT (m) Nipple	10,000
1/4" NPT (m) - 1/4" Med. Press. (m) Nipple	10,000
3/8" Med. Press (f) - 1/2" NPT (m) Nipple	15,000
1/2" NPT (f) - 3/8" NPT (f) Union	15,000
3/8" NPT (m) - 3/8" NPT (f) Nipple	15,000
3/8" NPT (f) - 1/4" NPT (f) Union	15,000
3/8" NPT (m) - 3/8" Hi. Press. (m) Nipple	15,000
3/8" NPT (m) - 3/8" Med. Press (m) Nipple	15,000

Table 5: Fitting geometries used for Hydrostatic pressure tests

Figure 3: Set up for hydrostatic pressure test showing various pipe fittings/sizes

Results and Discussion

Table 6 shows the maximum sealing performance in excess of 20,00 psi can be achieved within 1 hour when used in conjunction with an appropriate activator. It can be seen that for lower viscosity products (Loctite 542) which is designed for use on fine-pitch threads – more time is required to reach adequate strength before exposure to extreme high pressures.

Sealant	NPT Fitting Size (max. Pressure rating)	Maximum Sealing Pressure (psi)	
		After 1 hour	After 24 hours
Loctite 542[a]	Up to 3/8“ (15,000 psi)	Not cured	15,000
Loctite 577[a]	Up to 1/2“ (20,000 psi)	>20,000[b]	>20,000[b]

a: Used with Loctite 7649 activator   b: No failure – test stopped

Table 6: Results of Hydrostatic Pressure tests on Stainless steel fittings after 1 hour and 24 hour cure[(6)]

Conclusions

Since their introduction more than 40 years ago, anaerobic thread sealants have offered real technical advantages over traditional thread sealing methods and have helped engineers reduce process costs and eliminate downtime in industrial machinery caused by leaking pipe connections.
More recently, developments in anaerobic polymer technology have continued to extend the range of applications available by providing improved adhesion on oil-contaminated surfaces and resistance to long-term thermal cycling at 180ºC. Tests have demonstrated that static pressure resistance in excess of 20,000 psi is achievable within 1 hour of application on a range of NPT pipe fittings.

These developments illustrate the ability of anaerobic thread sealants to meet the increased efficiency and dependability demanded in today's industrial manufacturing and maintenance operations.

References

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