BEST PRACTICE NO. 70

INVENO ENGINEERING LLC

UNDERSTANDING STEAM PIPING NPT CONNECTIONS AND AVOIDING PREMATURE FAILURES

1. INTRODUCTION

Steam leakage plagues steam systems worldwide. The top cause of unwanted steam and condensate leaks is threaded connection failures. One steam leak can cost the plant well over $2,000 per year in energy losses—and that cost does not include all the other negatives attributed to steam and condensate leakage.

Despite their flaws, many industrial plants still use threaded connections for many reasons, often because they cost less to install than alternative methods, including welded, flanged, and tube connectors.
A high percentage of steam and condensate systems use American National Standard Pipe Thread (NPT) connections, typically for piping systems 2" and smaller.

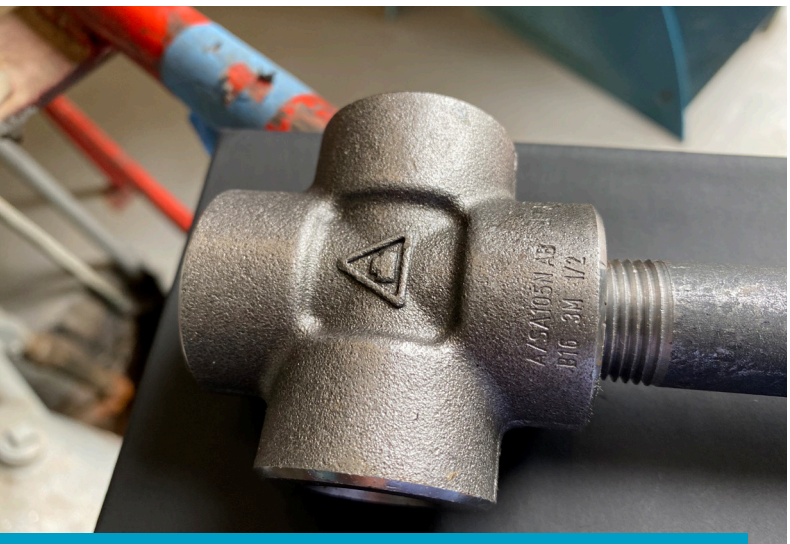

Figure 1: Typical Threaded Connection

Poor-quality threads and threaded components, limited training, and inconsistent installation standards plague the steam industry; all of these problems lead to premature failures in threaded connections, causing steam leakage and steam losses. For example, if you survey 10 different people on how to install a threaded connection, you would get 10 different answers. Inconsistent installation is one of the main problems with NPT connections that leads to premature failures. To prevent failures, plants either should have a formal, written standard procedure for installing NPT connections or use alternative connection methods.

To summarize, a main focus for designing steam and condensate systems must be preventing steam and condensate leaks, because they increase safety risks, reduce energy efficiency through energy losses, and raise maintenance costs.

2. WHY PLANTS USE NPT CONNECTIONS

When installing steam or condensate components, the plant eventually will need to remove the steam or condensate device or component for maintenance or replacement. Therefore, the system design must allow component maintenance or removal. However, it is up to the installer, design engineer, project manager, or plant management to reduce the number of NPT connections used in the system to make maintenance easier.

2.1. Personnel Installing NPT Connections

NPT connections typically are installed by a variety of plant personnel, including maintenance technicians, maintenance personnel, pipe fitters, and general work personnel. No codes govern the qualifications of a person installing NPT connections, unlike weld connections, which require a certified welder, or tube connections, which require a trained, certified person to perform the installation. It is assumed that anyone can install components using NPT connections, but the real issue is whether they can correctly install a connection that will not

suffer from premature failure and leakage.

2.1. Cost

Cost is often a factor in purchasing decisions. The cost of installing NPT connections on a new or a retrofitted project is lower than other connection methods. However, if the plant analyzes the installation cost, life expectancy, and operational cost, it will find other connection methods

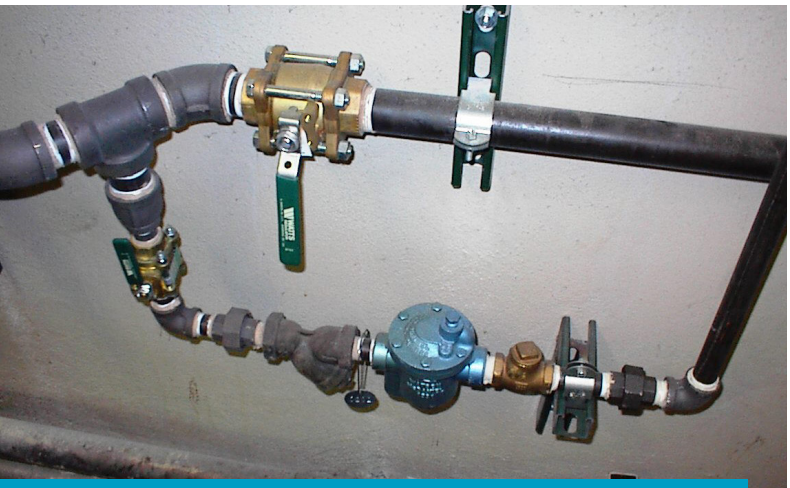

Figure 2: Over 20 Threaded Connections

preferable. Using newer technologies in steam and condensate components can reduce the requirements for connections like the steam trap universal connectors, tubing and tubing connections, and prefab assemblies. If the plant compared the time it takes to construct an installation with over 20 threaded connections to other

Figure 3: Example Steam Trap Station: 2 Tube Connections

methods of installing a steam trap station or different types of connections, then NPT would not be a feasible choice.

3. UNDERSTANDING NPT (AMERICAN NATIONAL PIPE THREAD) CONNECTIONS

NPT standards are U.S. national technical standards for screw threads used on threaded pipes and pipe fittings. The NPT standards include both tapered and straight thread series for various purposes, but for steam and condensate systems, the tapered thread is the preferred choice.

The NPT tapered design allows the male and female ends to form a seal during the proper torquing process, which compresses the male and female threads against each other to acquire the seal in a steam or condensate system. The mating of the threads is designed to do the sealing and prevent any leakage without using a sealant or lubrication materials.

Two standards that govern the majority of tapered pipe threads are the NPT and the British Standard Pipe Taper Thread (BSPT) standards. In North America, the NPT is used for more than 98% of steam and condensate applications. However, it is important that everyone is aware of differences between thread types. NPT threads have flattened peaks and valleys and are threaded at a 60° angle, while BSPT threads are rounded and threaded at a 55° angle. It is not uncommon to find BSPT threads on a job site with equipment or components imported from different countries. The two thread designs are not compatible and can lead to leakage and premature connection failures.

Tapered threads are deeper at the end of the pipe and become increasingly shallow the further they are from the end of the pipe. The taper on the pipe only allows the pipe to screw inside the fitting until it is forced to stop because of the taper. The distance the pipe can be screwed into the fitting is specified by the ANSI standard.

4. HOW THREADS ARE PRODUCED

4.1. Cold Forming

Thread rolling is a cold forming or cold metal forming

process that creates threads using precision thread rolling dies that determine which thread is manufactured. The cold forming process is different from other thread production like metal cutting, grinding, and chasing, because it does not remove any metal to create the desired thread. The advantage of this process is that no material is lost or removed from the component, resulting in stronger thread.

4.2. Thread Cutting

Thread cutting is accomplished by different methods. However, all methods remove a percentage of the pipe wall. In steam piping, plants must adhere to one of two codes, B31.1 (ASME) or B31.1 (ASME), both of which require the pipe or pipe component to be rated to the highest steam pressure and temperature in the system, which is the safety valve setting protecting the system. Therefore, removing a percentage of the pipe wall material for a thread connection might violate the code and must always be reviewed. A common practice is to use schedule 80 or a heavier wall material, which will compensate for the loss of wall material during thread-cutting procedures. However, this practice has a higher cost.

Threads are made by using a die head selected for the pipe diameter. During the cutting process, a lubricant is applied to assist in the cutting. It is important to review the pipe die for sharpness before each thread development to ensure it is capable of developing a proper thread. A test thread should always be created and checked by a thread gauge to ensure thread compliance.

5. KNOWING WHETHER THE NPT THREAD IS MEETING SPECIFICATIONS

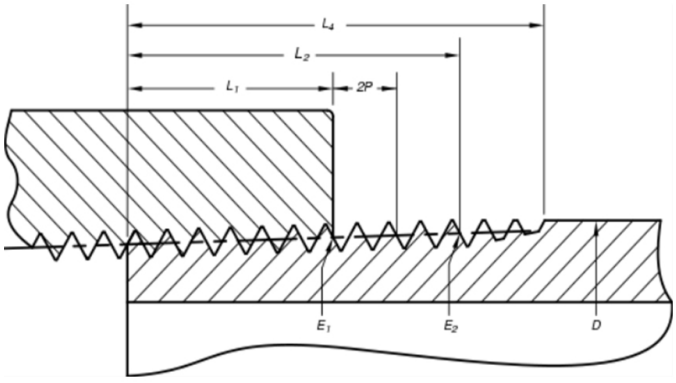

Figure 4: Hand-Tight and Effective Thread Engagement Lengths: Provided by Swagelok

5.1. Hand-Tight Engagement

Due to the taper of the thread, a pipe thread can only be threaded into a fitting a certain distance before it stops due to the mating of the threads. The NPT standard specifies this distance as the length of hand-tight engagement and uses it as a method to ensure proper thread manufacturing.

The other specified distance, effective thread, is the length of the thread that forms the seal on a conventional machined pipe thread. Installation personnel need to know the distance, or how many turns, before the threads will engage. A rule of thumb is that threads will start to engage with 1.5 turns of the threads. A torque wrench is required to make the final thread engagement to proper the tightness without overtorquing the threads and causing damage. It is critical to maintain standards to create and maintain uniform fittings for tapered pipe threads. If not, then the thread will leak, and no amount of tightening or force will eliminate the leakage.

American Society of Mechanical Engineers National Pipe Thread Taper (NPT)[7]

Nominal pipe size	Thread density	Thread pitch		Hand-tight engagement[8]			Effective thread[8]			Overall length[8]	Actual outside diameter, OD	
				Length	Turns	Diameter	Length	Turns	Diameter			
inch	$inch^{-1}$	inch	mm	inch		inch	inch		inch	inch	inch	mm
1/16	27	0.03703704	0.9407	0.1600	4.32	0.28118	0.2611	7.05	0.2875	0.3896	0.313	7.950
1/8	27	0.03703704	0.9407	0.1615	4.36	0.37360	0.2639	7.13	0.38000	0.3924	0.405	10.287
1/4	18	0.05555555	1.4111	0.2278	4.10	0.49163	0.4018	7.23	0.50250	0.5946	0.540	13.716
3/8	18	0.05555555	1.4111	0.2400	4.32	0.62701	0.4078	7.34	0.63750	0.6006	0.675	17.145
1/2	14	0.07142857	1.8143	0.3200	4.48	0.77843	0.5337	7.47	0.79178	0.7815	0.840	21.3360
3/4	14	0.07142857	1.8143	0.3390	4.75	0.98887	0.5457	7.64	1.00178	0.7935	1.050	26.6700
1	11 1/2	0.08695652	2.2087	0.4000	4.60	1.23863	0.6828	7.85	1.25631	0.9845	1.315	33.4010
1 1/4	11 1/2	0.08695652	2.2087	0.4200	4.83	1.58338	0.7068	8.13	1.60131	1.0085	1.660	42.1640
1 1/2	11 1/2	0.08695652	2.2087	0.4200	4.83	1.82234	0.7235	8.32	1.84131	1.0252	1.900	48.2600
2	11 1/2	0.08695652	2.2087	0.4360	5.01	2.29627	0.7565	8.70	2.31630	1.0582	2.375	60.3250
2 1/2	8	0.12500000	3.1750	0.6820	5.46	2.76216	1.1375	9.10	2.79063	1.5712	2.875	73.0250
3	8	0.12500000	3.1750	0.7660	6.13	3.38850	1.2000	9.60	3.41563	1.6337	3.500	88.9000

Figure 5: ASME National Pipe Thread Taper Specifications Provided by ASME

5.2. Thread Gauge, Plug, and Ring

Installation personnel must have a thread gauge, ring, and plug and to check fabricated threads and purchased threaded components. Seat and pitch gauges are conveniently combined into one simple device to easily check threads.

The thread test devices (gauge, ring, and plug) will allow installation personnel to determine whether the threads are meeting the specifications and are proper for the application.

Figure 6: Thread Gauge by Swagelok

Training is a must on how to use the thread test devices and on the specifications of the different threads.

6. NPT CONNECTIONS AND PREMATURE FAILURES

NPT connections fail prematurely in steam and condensate systems for many reasons. Plants must take all necessary steps to avoid or to severely limit the use of NPT connections. Today, many alternative connection methods will have a much longer operational life than an NPT connection, including welding, tubing, and tube connectors and carefully selected and installed flanges.

6.1. Manufacturing the NPT Threads

As previously discussed, tapered pipe threads are designed to seal between the flanks of the threads. However, manufacturing tolerances and the influx of noncertified foreign components cause a high failure or leakage with new installations.

During a quality check using a thread gauge, it is not uncommon to find that 43% or more NPT threads fail to meet specifications. All NPT threads need to be checked by a thread gauge to ensure the thread is meeting specifications.

Field NPT thread machines need to be properly maintained to ensure proper thread production. Pipe dies must be inspected, replaced, and cleaned before every operation. The plant should post a standard operating procedure (SOP) by the machine to ensure that the person operating the machine is properly producing the pipe thread. The first step is always to produce a test thread checked with a thread gauge to ensure the machine is capable of producing the proper thread. Unmaintained pipe thread machines will produce a poor thread quality, thus causing NPT connection failures.

Figure 7: Pipe Thread Machine

6.2. Lack of Proper Training

All personnel installing NPT connections need to be trained in thread design, different thread types, methods for checking threads to ensure they meet specifications, and methods for applying thread lubricant. Most installation personnel lack training and an SOP to follow, even though NPT installations are a major factor in NPT failures. Companies can provide this training in the plant, at a local training facility, or online, and it is a necessary step to ensure proper installation.

If you surveyed 20 people on how to install an NPT connection, you would probably get 20 different answers. For example, on one project investigating NPT failures, we documented 260 NPT connections using 12 different methods for the NPT connection installations. This variation in installation procedures leads to improper installation and failures.

6.3. SOPs Nonexistent for Installing Personnel

Before any steam or condensate system modification or new installation, a written SOP must be provided to the installers or provided by the contractor doing the work. A typical summary of what an SOP for NPT connection installation needs to include is as follows:

A- Quality check

1. Source of the purchase component
- **a.** Material test reports (MTRs)
- **b.** Ensure thread is NPT standard and not another international standard

2. Pipe machine
- **a.** Properly maintained
- **b.** Properly operated

B- Threads

1. Thread gauge check to determine compliance

2. Number of turns for engagement
- Understand the number of turns for the thread to engage (1½ turns for lower diameter pipe threads).

C- Sealant materials: Sealant materials are a lubricant for installation purposes, and the threads are the sealing mechanism.

1. Type of materials

2. Application procedure
- **a.** Insufficient or overapplying

3. Sufficient cure time is documented and followed during installation
- One common problem is that installation personnel do not follow the cure time instructions or do not even know about the cure times.

D- Installation

1. Misalignment

2. Overtorquing or insufficient torque
- After energizing the steam and condensate system, the torque or proper tightness needs to be rechecked.

Figure 8: Purchased NPT Nipple: Not Meeting Specifications

Figure 9: NPT Installation

E. Expansion and contraction

1. The pipe thread connections must be able to withstand the expansion and contraction of the steam and condensate during startup, operation, and shutdown.

- Review the expansion and contraction to compensate during design or installation.

6.4. Installation

To achieve a proper seal with NPT connections, a proper torque needs to be applied to the threaded connection. Undertorquing will prevent the connection from having a proper seal, while overtorquing will damage the threads and prevent a proper seal. The correct amount of torque or tightness on the NPT connections will vary depending on the diameter of the pipe, but a general starting point is that 45 lbs. of torque needs to be applied to the threaded connection. Another method that is not very uniform is the number of turns past hand/finger tight and viewing the number of threads remaining or visible.

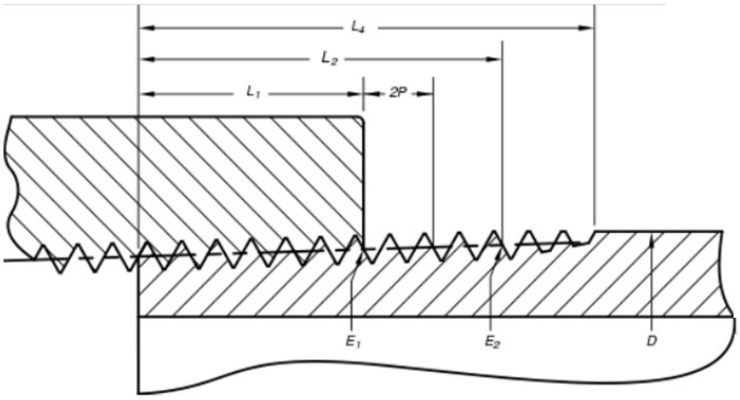

Figure 10: Hand Tight and Effective Thread Engagement Lengths

6.5. Corrosion

Steam and condensate systems will experience the effects of corrosion, such as CO2 (carbonic acid) and oxygen corrosion. Different types of corrosion will have a dramatic effect on the weakest part of steam and condensate systems: threaded pipes and threaded components. CO2 corrosion is mostly found in the condensate system, whereas oxygen corrosion is more prevalent in the steam system.

Figure 11: Thread Failure and Leakage

The corrosion will deteriorate the threads and allow steam and condensate leakage to occur, presenting a lot of negative effects in the system.

6.6. Expansion and Contraction

The steam and condensate line will experience significant expansion, depending on the steam temperature at the startup of the system, and contraction at the shutdown of the system. NPT connections must be able to absorb and compensate for the expansion or contraction and not allow any leakage. This becomes an exceedingly difficult task for a threaded connection using the metal threads for sealing. The cold installation of a threaded connection may not initially have any leakage but allow leaks after startup as the connections expand. All steam and condensate connections need to be retorqued after a startup to ensure proper sealing.

6.7. Thread Sealing/Lubrication Materials

Many thread sealing materials are available. Every manufacturer of sealing materials claims to have the best product. One thing to remember is that the sealing material is really a lubricant, because the thread does the sealing. Therefore, all necessary steps need to be taken to ensure that the plant makes or buys a high-quality thread or threaded component. A failure to review and understand all the characteristics of the thread materials will lead to thread leakage. For example, the thread lubricant materials have cure times, but a high percentage of installation personnel do not know about the cure time or fail to follow the cure times.

Another major factor is the temperature limits on the materials. As steam pressure increases, so does the steam temperature. Understanding the highest steam pressure (not operating steam pressure) and temperature in the system is critical in selecting the correct materials to be

used on threaded connections.

7. AERONAUTICAL NATIONAL PIPE TAPER (ANPT) STANDARD

The Aeronautical National Pipe Taper (ANPT) thread is similar to the NPT. The difference is that the manufacturing of the ANPT thread must be very carefully controlled for taper, diameter, and the thread form. ANPT is used in high-end technical fields but can and should be used in steam and condensate systems to prevent premature failures and leaks. When leakage cannot occur in different process systems, then the ANPT is the preferred choice.

8. CONCLUSION

All connection types (weld, tube fittings, NPT) have their pros and cons. Steam and condensate leaks cost industrial plants a lot of money in energy and maintenance and often create safety risks for plant personnel. As shown in **Figure 12**, plants should eliminate threaded connections and use welding, flanges, and tube connectors

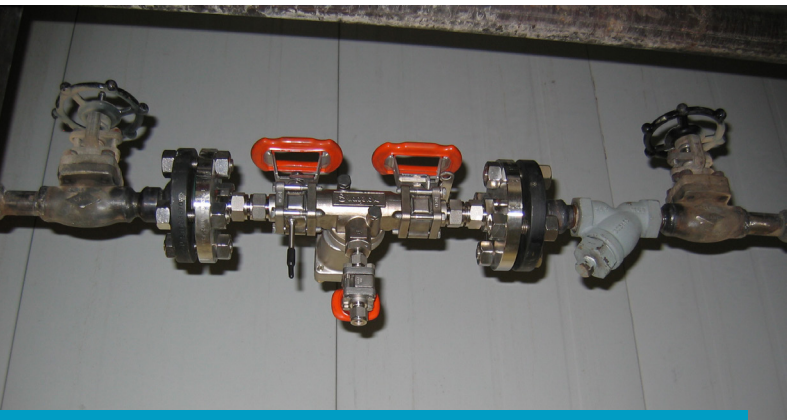

Figure 12: Using All Technologies: Welds, Flanges, and Tube Connectors

If plants spend a little effort, time, and money on the initial installation, leakage can be prevented and eliminated. What plants have done for the last 20 years is not what they should do today with the available technology.

The key to successful steam and condensate connection installations is knowledge, training, SOPs, and proper components, then leakage will not occur.