ExxonMobil Chemical

Heat Exchanger Tube Plugging Guidelines

TABLE OF CONTENTS

Technology Owner - Matt Findlay, Lead Mechanical Specialist
Document Author - Matt Findlay

Date of Issue - See Revision History

First review for validation: 11/08/02
Comments incorporated and reissued for validation: 24/01/03

1.0 SCOPE

The purpose of this practice is to provide guidelines for the safe plugging of corroded or leaking tubes in shell and tube exchangers, air fin exchangers and tubular reactors where immediate tube replacement is not practical. The guidelines are also suitable for plugging tubesheet holes after tubes have been removed. In some circumstances it may be possible to sleeve damaged tubes as an alternative to plugging. For additional information on this option contact core engineering.

2.0 INTRODUCTION

The maintenance plugging of tubular exchangers or reactors can result in significant personal safety concerns as a result of a tube plug being ejected at high velocity during a post repair hydrostatic test. Plug failure during operation will also impact the mechanical reliability of the equipment and result in additional maintenance and lost opportunity costs. In addition failure to vent or cut plugged tubes in an appropriate manner can lead to subsequent equipment damage.

The purpose of this document is to consolidate affiliate feedback and lessons learned on various aspects of tube plugging and to present this as a Best Practice in order to assist affiliates in minimizing safety and reliability issues as a result of tube plugging. The information in this practice was originally obtained via the Fixed Equipment Network discussion group and has been documented in the lessons learned section of the KBS.

Tube plugging results in four effects per tube pass which should be considered in terms of process efficiency and potential EDD's.

1) Reduces the effective heat transfer surface in proportion to the change in tube numbers.
2) Increases the tube side velocity in proportion to the change in tube numbers.
3) Increases the tube side pressure drop in proportion to the square of the change in tube numbers.
4) Increases the tube side heat transfer film coefficient. (This does not compensate for the loss of heat transfer area).

The practice recognizes and endorses various types of plugs, which are classified into two general categories.

a) Hammered plugs: which may or may not be seal welded.
b) Engineered plugs: typically these are expanding plugs and are commercially available. These can be installed by a contractor or by maintenance personnel.

3.0 PLUG TYPES

Hammered Plugs: This type of plug can take the form of a Solid Tapered Plug, Counterbored Tapered Plug, or Two Piece Plugs. All are driven into a tube with a hammer.

Solid Tapered Plug: A Standard Tapered Plug is a metallic plug, of compatible metallurgy to the tube to be plugged, with an approximate 2 percent taper. The plug is manually hammered home and the axial movement is typically around 10 mm (0.4 in) for a 2 percent taper on a 19 mm (3/4") diameter plug. The contact is roughly a point load. The plug may be provided with a tapped blind hole in the outer end to facilitate installation and removal. e.g. into an air fin header box.

Counterbored Tapered Plug: A counterbored Tapered Plug is the same as the Standard Tapered Plug, but with the plug counter bored to about half length, or around 10 mm (0.4 in) below the final surface of the tubesheet when hammered home. This provides some flexibility on the wall of the plug and reduces the point contact loads on the tube and stress in the tubesheet ligaments. The plug wall thickness is typically similar to the uncorroded tube thickness.

Two Piece Plug: This plug consists of an outer ring which has no taper on the outside diameter, but a tapered bore and an inner pin with a matching tapered OD. The outside diameter of the ring is custom made and machined to give a snug push fit into the tube, is typically about 50 - 60 mm (2 - 2-1/2") long, and has a shoulder equal to the tube thickness and tube OD. This stops it being driven into the tube, however it is good practice to grind the tube end flush with the tubesheet prior to inserting this type of plug. The minimum wall thickness of the outer ring is typically 2 mm (0.080 in). The inner diameter of the outer ring and the outer diameter of the inner pin have matched 1-% tapers. The wider diameter is at the tube sheet face. The inner pin is hammered into the outer sleeve just like a solid taper plug. The advantage of this type is that there is no relative movement or damage between the plug and the tube, and the seating load between the plug and tube is more uniform over its entire length.

Engineered Plug: An Engineered plug is a serrated or grooved expanding two piece plug, which is designed with an "engineered" pull that correctly expands the plug by applying a specific load or movement. Satisfactory experience has been obtained with two types of expanding plug, which are illustrated in attachment 1:

a) Expansion Seal Technologies' "Pop A Plug" and b) Furmanite's expanding plug.

The Pop A Plug snaps off a shaft at a set load and the Furmanite plug is set by torquing a nut. Both these plugs are expanded from the back side of the tube sheet, therefore additional shell side pressure tends to increase the plug seating load, rather than reduce it, as occurs in a hammered plug. The attached Pop A Plug data sheet illustrates the considerations and information required prior to using these types of plugs.

The serrated profile of the Pop A Plug makes it a good choice for dirty tubes where the serrations can bite through scale and achieve a seal. The Pop A Plug can also be used in conjunction with a hammered plug to seal a thick tubesheet. In this case the Pop A Plug is applied to the back of the tubesheet and a hammered plug to the front. The Pop A Plug can also be installed at the rear end of a bundle allowing plugging of remote locations.

4.0 PLUG SELECTION

The selection of plug type may be risk based and or driven by factors such as time available for repair, cost of plugging, tube/tubesheet metallurgy or condition of tube/tubesheet. Table 1 and the notes below provide some guidance in selecting a suitable plug type.

1) Hammered plugs can be of three generic types. 1) Solid taper, 2) Counterbored taper or 3) Two piece taper. Plug types 1) and 2) typically have a 2% taper and type 3) typically would have a 1% matching taper between the mating parts - taper expressed as change in radius over length. Typically plugs have a length of 50 - 60 mm (2 - 2-1/2").

2) Plugs should be of a similar metallurgy to the tube being plugged in order to have compatibility of mechanical properties, thermal expansion and corrosion resistance. For seal welding compatibility between tubes, tubesheets and plugs needs to be considered.

3) The plug type should take account of the corroded surface condition of the tube to be plugged, its ability to be seal welded and the condition and strength of adjacent tubes and surrounding tubesheet ligaments. e.g. a hammered plug resulting in high point contact may damage tubesheet ligaments or disturb adjacent tubes in damaged or brittle situations. Any tapered plug will also result in a crevice between the tube ID and the plug. The crevice will normally be exposed to the shell side process conditions.

4) Seal welding is recommended for all hammered plugs made from carbon steel, stainless steel, monel and other easily weldable materials used in equipment with a shell side flange rating greater than ASME B16.5, Class 150#. Seal welding may be waived where there is concern that welding may create additional problems for adjacent tubes, where the welding is impractical or where the risks arising from a plug blow out have been fully considered and appropriate actions taken.

Although consideration may be given to brazing brass and copper-nickel plugs this is often not practical. Admiralty and Cu-Ni can we welded with Ni base fillers like Inco Weld A or Inco 182.

Some care may be required with the application of a welded plug in a rolled only tubesheet due to possible deformations at adjacent tubes arising from the process of inserting the plug and/or the heat of welding. This situation may justify waiving seal welding in lower risk situations and the use of a two piece plug, but in higher risk situations the use of engineered plugs is recommended.

If a hammered plug is not seal welded for any reason the risk of plug blow out during hydrotest must be understood and mitigated by suitable safety procedures.

If hammered plugs are used in services with shell side flange ratings of 600# or greater per ASME B 16.5, then strength welding to the tube and tubesheet wall is required. To achieve this the tube should be cut back 6 - 12 mm behind the tubesheet face and the plug welded to the tube end and the tubesheet hole by a two pass process.

Seal or strength welding is not required for engineered plugs, and these are considered a practical alternative in cases where welding is desired but impractical.

5) Expanding (engineered) plugs should be considered for higher risk applications, or applications where seal welding is desired but not practical. These type of plugs require more detailed pre planning and QA checks to ensure the correct size plug is selected relative to the actual tube ID, surface condition, joint detail and tubesheet thickness. Two acceptable types of engineered plugs are illustrated in attachment 1.

6) In some cases, it may be desired to extract the leaking tube. e.g if the tube surface is badly corroded or vibration is a concern. In this case plugs can be installed directly in the holes on both tubesheets or within a short sleeve of compatible tube inserted into the tubesheet hole. The tube piece used as the sleeve should be longer than the tubesheet thickness, extending both sides of the tube sheet and is first rolled and expanded, followed by plugging. This process protects the tubesheet hole from damage and is useful if the tube will eventually be replaced. If a tube insert is not used an alternative would be to use a countered bored or two piece plug or an engineered plug.

5.0 TUBE HOLING / CUTTING:

1) When plugging tubes, the tube must be either holed or cut. This is necessary to prevent pressure build up within the plugged tube as a result of gas diffusion or blocked-in fluid expansion, or to minimize differential expansion stresses between the plugged tubes and adjacent unplugged tubes. The latter problem can arise where the plugged tube will assume the shell side temperature while the unplugged tubes will be at operating temperature somewhere between the shell and tube side temperatures. If a tube is already holed by virtue of a leak, and cutting is not necessary, then additional; holing may not be necessary. Long air fins are a particular example where cutting is typically required. As a guide, consideration should be given to cutting tubes if the mean metal temperature difference between

the plugged and unplugged tubes exceeds 28c (50F). Special tools are available to properly perform internal tubing cutting.

2) To provide maximum venting, U-tubes should be cut or drilled to vent them at the upper end (high point), and exchanger tubes in fouling service should be cut at both ends.

3) Additional considerations may be required if a cluster of adjacent tubes are to be plugged and cut, as this may reduce the support of the tubesheet provided by the staying action of the tubes. Such cases are not uncommon. As a guide, an engineering review is recommended if nine or more adjacent tubes are involved on a fixed tubesheet design, or if the shell or tube side of the exchanger has a pressure/temperature rating of ASME B 16.5 600# or greater.

4) When tubes are cut, consideration needs to be given to the possibility of the cut tube vibrating in service and damaging adjacent tubes. Where this is a concern, complete removal of the tube is the best approach. If this is not possible internal support by bridging the cut can be achieved using an extended solid taper plug. The extended inner end of the plug should be untapered and should have a diameter that achieves a snug push fit inside the tube. The installed plug must be seal welded. This type of action may be required for high velocity shell side vapor phase conditions.

6.0 PROCEDURES FOR TUBE PLUGGING

1. Identify the exact locations of tubes in the exchanger which require plugging. Leaking tubes should be clearly marked at both ends.
2. Determine the tube size, the type of tube/tubesheet joint and tube material.
3. Select the plug type and material to be used with the help of table 1 and the notes of sections 3 & 4.
4. Clean and descale the tube end ID.
5. Determine whether the tube needs to be cut or holed using the guidance of section 5 and internally perforate all tubes before installing the plugs. If for any reason, the tubes are not perforated or cut, this should be documented for future reference, and to provide essential safety information to maintenance crews who may have to remove the plug in the future.
6. Determine whether there is a concern for vibration damage from a cut tube using the guidance of section 5.
7. Determine whether the plug needs to be welded or brazed using the guidance of section 4 and review and approve the welding procedures to be used. If welding or brazing is not to be applied, conduct a task risk assessment to review the hydrotest and inspection plan.
8. Fit the plug. In the case of hammered plugs, judge the amount of axial plug movement required by hammering against the suggestions in section 3.
9. Conduct a leak test. (Caution: See Section 7.0, "Tube Plugging Safety Considerations" prior to proceeding with this step). For shell and tube exchangers and tubular reactors where the shell pressure is the higher, then a single test is

adequate. If the tube side pressure is highest, a second tubeside test may be required. Since a plug could at some time be subject to a full hydrostatic test, the test pressure should generally be 150% of design pressure, however there may be cases where an alternative test pressure is appropriate. Appendix 2 contains a summary of considerations and practices taken from the FEEN mechanical archive and may be used in selecting an appropriate test pressure and/or closure leak test pressure.

10. Document the location of all plugged tubes and the status of holing or cutting on a suitable sketch or tubesheet drawing.

7.0 TUBE PLUGGING SAFETY CONSIDERATIONS

1. The principal safety concern with plugging tubes is a plug blowing out at high velocity, particularly during the post plugging hydrotest. Since all plugged tubes should be holed or cut, exchangers with high pressure on the shell side pose a more significant risk.
2. Plugs should never be hammered while the exchanger is under pressure.
3. All leaking tubes should be cut or drilled positively behind the tube sheet to vent off any pressure buildup.
4. Plugs should be seal welded, or an engineered plug should be used to reduce the risk of plug blowouts.
5. Personnel should never stand in front of the tube sheets while the exchanger tube bundle is under pressure. Inspection should only take place after the test pressure is reduced to a predetermined safe pressure (e.g. design pressure). All inspection must be done from the side, at a safe distance, during the hydrotest.
6. Consideration should be given to placing a substantial safety shield or barrier in front of exposed exchanger tubesheets during pressure testing to contain a potential high velocity plug, should it be dislodged. Such a shield or barrier should be mandatory in the case of unwelded hammered plugs.
7. Caution is required if the tube is perforated and filled with flammable material in service, as the bundle may not be gas free, and therefore could be dangerous to work on.
8. Prior to removing a plug, the inspection records should be consulted to confirm that the tube was perforated. If any doubt exists, assume that it has not been perforated. If it is suspected that a plugged tube was not perforated, or that the tube may have become pressurized, then the precautions suggested below are required during plug removal. If the plug is seal welded, the weld integrity should be confirmed using Dye Penetrant then the plug may be drilled to relieve any pressure present before attempting to remove it. If the plug is not welded, no attempt should be made to remove it, until a thorough method statement has been developed and this has had an appropriate safety and risk review.

Table 1

Plug Type Selection Guidance

Criteria	Solid Taper Plug	Counterbored Tapered Plug	Two Piece Plug	Engineered Plug
Shell side flange rating <= 150# and plug not welded. (Note 1)	✓	✓	✓	✓
Concern for mechanical damage to adjacent tubes, stress corrosion cracking of tubesheet or crevice corrosion due to driving in tapered plugs.			✓ Notes 1, 2	✓
Concern for welding induced damage to adjacent tubes or rolled only tubes.		✓ Notes 1, 3	✓ Notes 1, 2	✓
Shell side flange rating > 150# and plug seal welded.	✓ Note 4	✓ Note 4		
Shell side flange rating > 150# and plug not welded.				✓ Note 1
Shell side flange rating => 600# and plug strength welded to tube and tubesheet by two pass process.	✓			✓ Note 1

Notes

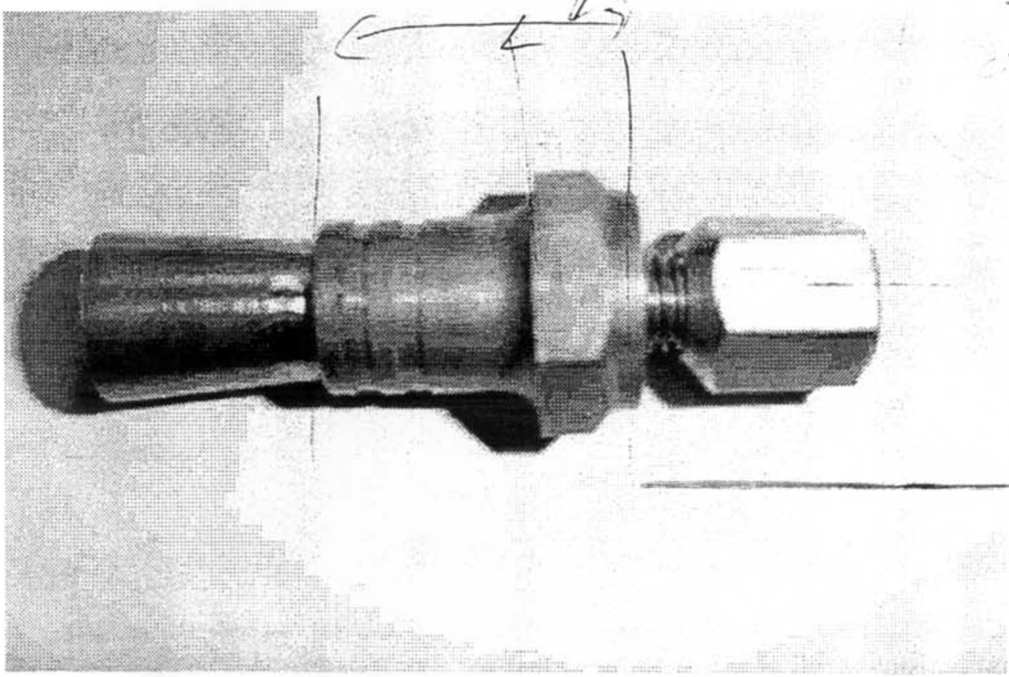
1) A task based risk assessment should be conducted to ensure adequate safety precautions are in place to avoid injury or damage due to a potential plug blow out during hydrotest, or subsequent plug removal.
2) If shell side pressure rating greater than ASME B 16.5 150#, weld pin to ring.
3) Do not use if shell side pressure rating greater than ASME B 16.5 150#
4) Strength welding required for shell side pressure rating of ASME B 16.5 600# and above.
5) The plug should be of a similar metallurgy to the tube.

Attachment 1

a) POP A PLUG - Typical data sheet.

"Pop A Plug Spec Sheet.pdf"

b) FURMANUTE PLUG - Photograph



Attachment 2

Summary of leak testing practices and considerations

- The "89 EEEL 925 - MASCOM Heat Exchanger Maintenance Manual" provides a summary of common maintenance practices The following guidance is provided:

  If there has been no weld repairs to the pressure parts of the exchanger, or no loss of metal thickness which requires proving by a strength test, then maintenance pressure testing can be confined to a leak test of the tube / tubesheet joints of the bundle. Shell side testing for leak testing of flanged joints is not considered necessary unless there have been in-service leakage problems."

  Tube bundles in good, uncorroded condition - test tubeside to 1.5 x operating pressure [1)]
  Tube bundles with corrosion or have been repaired or tubes plugged - tubeside full hydro as per original test. Tube bundles which failed either of the above two tests -- test at full hydro after repairs made.

  1) A common alternative hydrostatic leak test is 1.1 x design pressure.

- Hydrotest pressure may not always correspond to 150% of design pressure. Test pressure for vessels built to codes other than ASME 8 Div 1 or Div 1 post 1998 may have a different test basis. The original test basis should normally be adopted.

- The membrane stress arising from hydrotest should be limited to 90% of the specified minimum yield strength, except in cases where a specific Fitness for Service assessment has been conducted.

- In cases where equipment thickness has been reduced due to corrosion, or where continued operation is contingent upon a Fitness for Service assessment, the test pressure may have to be based on the MAWP or other documented failure basis. This basis should consider the corroded condition at the end of the anticipated run length.

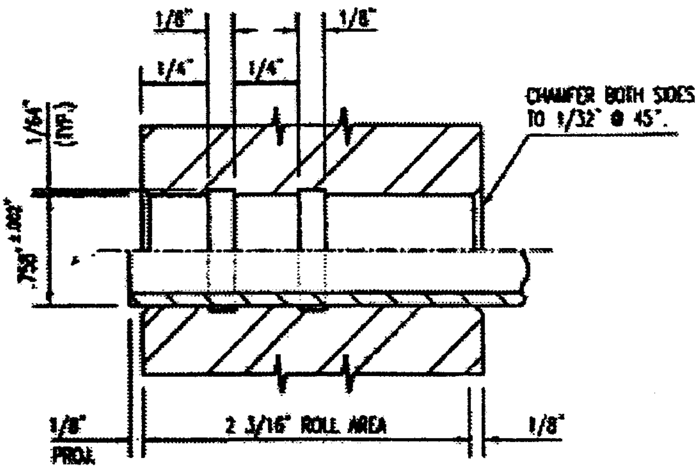
HDPE E-4228A TUBE PLUGGING

Note: All data taken below for exhanger came from vendor drawings.
Manufacturer: Dunn Heat Exchangers, Inc.
Tube Size: 3/4" O.D. X 0.083" (A.W.) X 14'18' - 0" LG.
Tube Material: SA-249-TP316
Tube Inside Diameter: ~ 0.584"

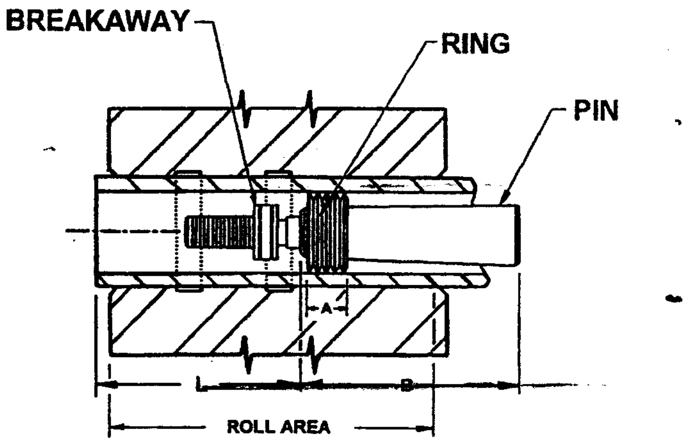
Pop-A-Plug Size Purchased: V-555-S-CPI
Pop-A-Plug Rated Tube I.D. Size Range: 0.556" to 0.620"
Tube Seal Welding: No
Distance from Face of Tube Sheet to Roll Area behind Grooves = 3/4"
Distance from Exposed End of Tube to Roll Area behind Grooves = 7/8" (See sketch below.)
Length the Pop-A-Plug Seating Area In The Tube = 1-7/16"
Length of Pop-A-Plug RING "A" = ~5/16"
Length of Pop-A-Plug PIN "B" = 1.4"

IMPORTANT REQUIREMENTS

1. BEFORE EACH TUBE IS CUT, use the "GO-NO GO" gauge to check the tube inside diameter ON EACH END to ensure that it is within the correct diameter range for the purchased Pop-A-Plug to properly to seal. Tube rolling will thin out the wall diameter by ~ 10% and increase the I.D. In this case the I.D. could be ~ 0.601", still within the acceptable range for sealing.
2. Cut tubes ONLY ON THE FLOATING END of the exchanger bundle. The cutting tool should be adjusted to make the cut in the tube approximately 5" in from the outside face of the floating tube sheet.
3. Cut each tube completely 360° all the way around.
4. Remove and account for all loose shavings from the exchanger bundle.
5. Record the exact locations of all tubes cut and plugged.



TUBE HOLE GROOVING DETAIL
HDPE E-4228A



TOOLING

A carbon steel sleeve should be made, that will slip over the end of the installation tool to properly position the Pop-A-Plug inside of the tube behind the last groove.

Recommended Insertion Distance "L" of Pop-A-Plug

Distance "L", measured to the end of the Pop-A-Plug, on the Breakaway side, to the exposed end of tube, should be between 1" to 1-1/4".

Confirmed with Mr. Ted Topakas of EST Group, Inc., Phone #215-513-4300.