Inspection of Shell and Tube Heat Exchangers

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Inspection of Shell and Tube Heat Exchangers

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Sarajevo 2023

Inspection Responsibility

TEMA G-2 Inspection

G-2.1 MANUFACTURER'S INSPECTION

Inspection and testing of units will be provided by the manufacturer unless otherwise specified. The manufacturer shall carry out the inspections required by the Code, customer specifications, and also inspections required by state and local codes when the purchaser specifies the plant location.

G-2.2 PURCHASER'S INSPECTION

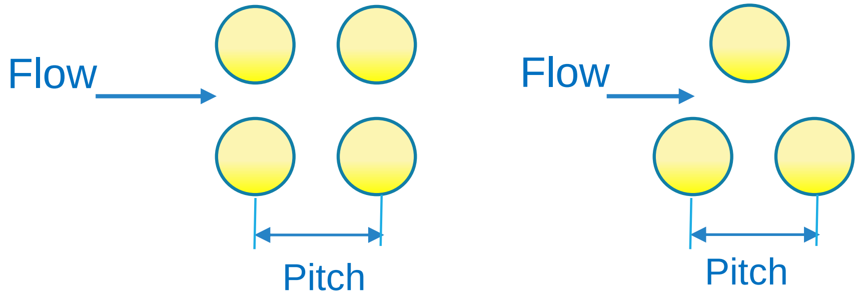
The purchaser shall have the right to make inspections during fabrication and to witness any tests when he has so requested. Advance notification shall be given as agreed between the manufacturer and the purchaser. Inspection by the purchaser shall not relieve the manufacturer of his responsibilities. Any additional tests required by the purchaser, above those already agreed to, will be to the purchaser's account. Cost for remedial work as a result of these additional tests will also be to the purchaser's account.

NDE for Heat Exchanger Bundles

Non-Destructive Testing is used extensively for the condition monitoring and remaining life estimates of heat exchanger tubing.

The tube pitch is typically a minimum of 1.25 times the tube outer diameter which usually limits external inspection access to the accessible outer tubes of a tube bundle. Subsequently, inspection of the remaining heat exchanger tubes is limited to internal tube inspection

Shell and tube exchanger tubing is inspected primarily using two different NDE techniques, electromagnetic and ultrasonic.



NDE for Heat Exchanger Bundles

ASME PCC 2 Article 312

Eddy Current Examination [ET]	Remote Field Eddy Current [RFET]	Partial Saturation Eddy Current [PSET]	Magnetic Flux Leakage [MFL]	Ultrasonic systems designed to measure tube wall thickness
Generally selected for inspection of nonferromagnetic tubes, or those that are slightly magnetic. Note that the sensitivity of this method decreases for the U-bend portion of U-tube bundles.	Generally used for inspection of ferromagnetic tubes. Its sensitivity and accuracy may be less than desired or required and will require a higher number of tubes to be inspected. It is a quicker method than ultrasonic methods	Can locate and size cracks in ferromagnetic tubes. It might not be sensitive to O.D. defects.	May also be selected for inspection of ferromagnetic tubes. However, sensitivity of this method can be poor for carbon steel tubes, and might only be best at determining the overall condition of the tube, not determining individual defect location	may be used for HE, where damage may be localized, or for validation of other NDE results. These ultrasonic examination systems are particularly suited for CS tubes due to the lack of sensitivity of other NDE methods One type of system is the Internal Rotary Ultrasonic Inspection (IRIS) system. IRIS is an accurate NDE to detect and size I.D. and O.D. metal loss Another type of system is Shear Wave IRIS (SWIRIS) and this can be effective for detecting I.D. and O.D. cracks. Both IRIS and SWIRIS require clean tubes

NDE for Heat Exchanger Bundles

Common tubing NDE methods for straight shell and tube heat exchanger

- Multi-Frequency Eddy Current Testing (MFECT ECT)
- Segmented Eddy Current Array (ECA)
- Remote Field Eddy Current (RFT)
- Partial Saturation Eddy Current (PSET)
- Full Saturation Eddy Current (FSET)
- Magnetic Flux Leakage Testing (MFL)
- Magnetic Flux Leakage Array Testing (MFA)
- Near Field Testing (NFT)
- Near Field Testing Array (NFA)
- Internal Rotary Inspection System (IRIS)
- Acoustic Pulse Reflectometry (APR)
- Tube end calliper

New API Under Development

API RP586

on NDE Techniques

Preparation for tube bundle for ID Tube Inspection

Tube cleanliness can have a significant impact on the performance and probability of detection of some NDE methods. The IRIS technique generally provides the most accurate data however it requires rigorous cleaning. Electromagnetic technique accuracy decreases exponentially with tube fouling

Tube Probe Fill Factor

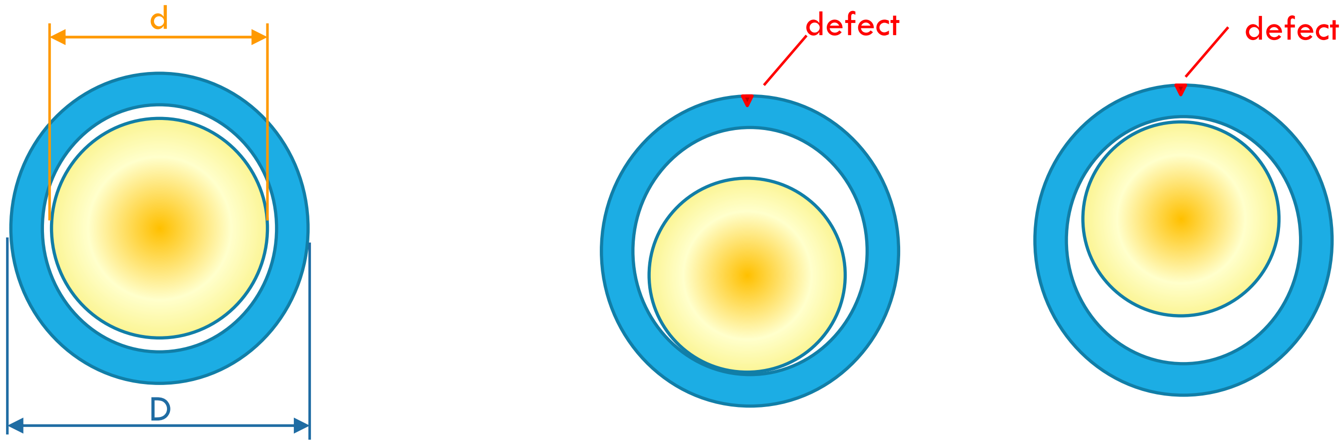
FF is as measure of the magnetic coupling between the coil and tube surface. Distance between probe coil and defect has effect on signal forming, causing problems with sizing of indication

The fill factor is calculated by

$$FF = \frac{PD^2}{TD^2} X100$$

PD=outside probe diameter   TD= tube inside diameter

A large fill factor (e.g. 85%) is desirable for optimal NDE performance (70% for RFT/RFA)



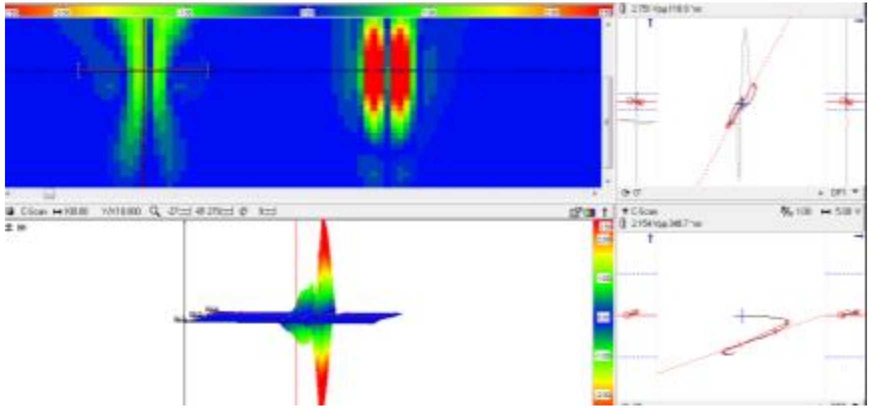
$$FF = \frac{d^2}{D^2}$$

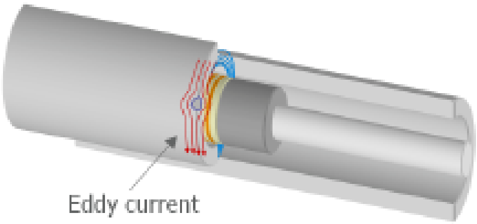
Eddy Current Inspection (ECT)

Eddy Current Testing (ECT): Non-destructive testing method in which eddy current flow is induced in the material under examination (inside surface of he tube).

An alternating current is applied to an exciting coil generating a magnetic current. This induced current is then monitored by either the exciting coil or a separate pickup coil for changes.

Conventional eddy current examination can be performed in either the differential or absolute modes. The differential mode detects small discontinuities such as pitting and cracking, whereas the absolute mode detects localized or gradual wall loss.





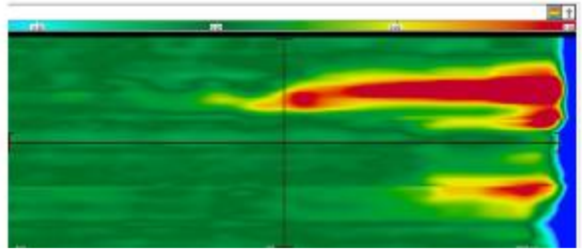
Eddy Current Inspection (ECT) – Cont’

The magnetic permeability of ferromagnetic materials severely limits the depth of penetration of induced eddy currents.

Saturated and partial saturated Eddy current testing for magnetic materials to suppress the magnetic characteristics of permeability.

Different techniques available and based on materials, configurations and thickness; proper techniques to be selected

- ET for nonferromagnetic heat exchanger tubes
- ET for coated ferromagnetic materials



Partial Saturated and Full Saturated Eddy Current Testing

Partial Saturated Eddy Current Testing : Nondestructive partial saturation eddy current (using with rare earth magnets) examination method Principles This inspection is applicable to partially ferromagnetic materials such as nickel alloy or ferritic austenitic and thin ferromagnetic materials such as ferritic chromium molybdenum stainless steel.

Full Saturated Eddy Current Testing : Full saturation eddy current (FS-ECT) uses a conventional eddy current coil and a magnet. The magnetic field of the magnet saturates the material. Once saturated the relative permeability of the material drops to one. The strength of the magnets used for saturation is very critical in this technique. Weaker magnets will not saturate the material and will produce a high signal to noise ratio. The application of a full saturation eddy current technique depends on the permeability of the material, tube thickness and diameter.

Eddy Current Inspection (ECT) – Capabilities and Limitations

Capabilities

1. Inspection speed up to approximately 24 inches per second
2. Distinguishes between ID and OD flaws
3. Good reliability and accuracy of test results
4. Can detect gradual wall thinning and localized flaws
5. U-bend tubes can be inspected with some radius limitation
6. Permanent records can be obtained on test results
7. By using MFECT techniques, flaws under the support plates (baffles) can be found and evaluated accurately.
8. Can detect axial cracks

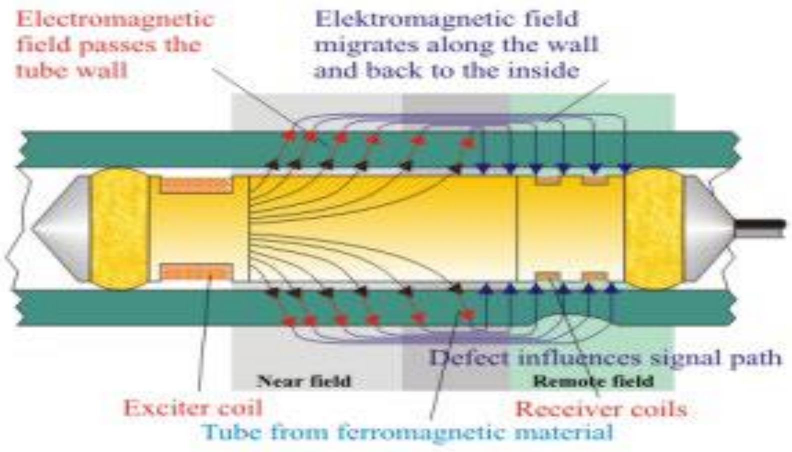
Limitations

1. Limited to only non-magnetic tube material.
2. Requires a frequency mix to inspect tubing beneath a tube sheet or baffle.
3. Does not detect circumferential cracks
4. Application is limited to 3-inch tube sizes and 0.125 wall thickness. Larger diameter and thicker wall materials could be inspected with specialized equipment.
5. Test instrumentation, systems and software packages could be very expensive.
6. Requires high inspection skills for data analysis and evaluation.
7. Discontinuities adjacent to end sheets are difficult to detect.

Remote Field Eddy Current Testing (RFT)

Remote Field Eddy Current Testing: is quite distinct from standard eddy current testing in three of its main characteristics

- RFT operates at frequencies typically below 1KHz; whereas, eddy current operates above 1KHz
- RFT can penetrate through thin-wall carbon steel heat exchanger and boiler tubes because of its low frequency operation
- RFT is a pitch-catch method; whereas a sending coil transmits an electromagnetic field to a nearby receiving coil. The resulting impedance measurement indirectly measures wall thickness.
- The RFT field passes right through the heat exchanger or boiler tube wall and far side defects are equally well detected



Remote Field Eddy Current Testing (RFT)

Capabilities

1. Internal and external corrosion pits and under-deposit corrosion
2. Internal and external erosion
3. General wall loss
4. Creep damage such as thermal fatigue cracking (if orientated perpendicular to the resultant field)
5. Baffle wear and tube-tube fretting
6. Hydrogen damage and water treatment chemical-induced damage
7. Steam impingement erosion
8. Cracking in tube wall (if orientated perpendicular to the resultant field) and sometimes in membranes (with special probes)

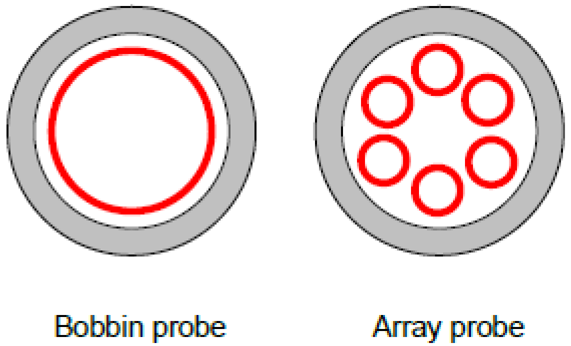
Limitations

1. Scanning speed is typically about half that of eddy current technique (6-12 inches per second, but could be slower based on the operating frequency.
2. Threshold of detection is typically 20% for local wall loss and 10% for general thinning
3. Accuracy is quoted at +/-15% of actual wall-loss
4. RFT has limited sensitivity and accuracy at baffle plates because the plates prevent the field from traveling on the outside of the tube.
5. Although RFT is easier to understand than ECT, there has been a lack of formal training and certification until recently. This has led to the technique being quite operator-dependent. ASNT has recently added RFT to its family of electromagnetic test techniques and there are now Codes and standards governing its use.

Segmented Eddy Current Array (ECA)

Segmented Eddy Current Array (ECA): ECA tubing probes are designed to inspect non-ferromagnetic tubing. Instead of coils wound around a bobbin, the ECA uses a series of smaller pancake shaped coils that are set in various array configurations according to design.

Eddy Current Array Probe



ECA Probe design

Segmented Eddy Current Array (ECA)

Capabilities

1. Inspection speed up to approximately 24 inches per second
2. Distinguishes between ID and OD flaws
3. Can detect tube flaws beneath tube sheets or baffles without a frequency mix
4. Reliability and accuracy of test results
5. Can detect gradual wall thinning and localized flaws
6. U-bend tubes can be inspected with some radius limitation
7. Permanent records can be obtained on test results

Limitations

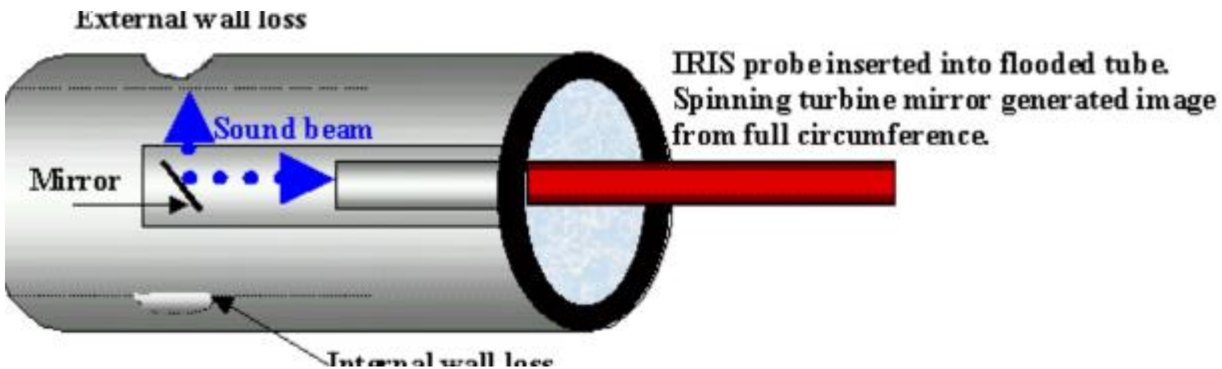
1. Limited to only non-magnetic tube material.
2. Application is limited to 3 inch tube sizes and 0.125 wall thickness. Larger diameter and thicker wall materials could be inspected with specialized equipment.
3. Requires high inspection skills for data analysis and evaluation.
4. Tubes must be cleaned.

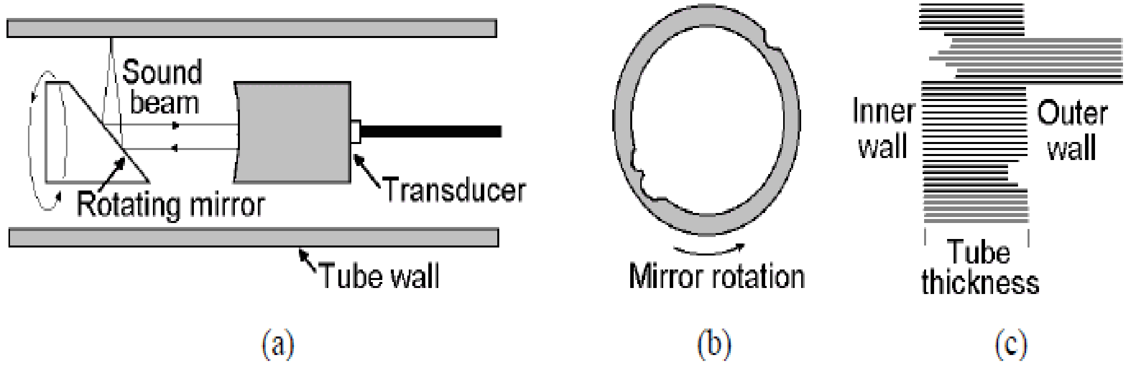
Internal Rotary Inspection System (IRIS)

IRIS: is an Ultrasonic system used for inspection and measurement of wall thickness of heat exchanger tubes

In the IRIS system, the ultrasonic transducer is contained in a test head which fits into and is centred in the heat exchanger tube, flooded with water for ultrasound transmission.

The ultrasonic pulses are emitted and reflected off a rotating mirror into the tube wall and back again to the transducer via the same path.





Internal Rotary Inspection System (IRIS) – Cont'

Capabilities

1. 100% tube inspections converge (end to end).
2. Wall loss and pit detectability's accuracy and sizing plus or minus 0.002 inch.
3. Can examine both ferromagnetic and non-ferromagnetic tubes.
4. Distinguishes ID from OD flaws and at support plates
5. Can inspect tube sizes up to 4.0 inches (or larger with specialized equipment) with wall thickness up to 0.25 inches.
6. Final reports with applicable software can be generated instantly.
7. Permanent records can be obtained on test results.

Limitations

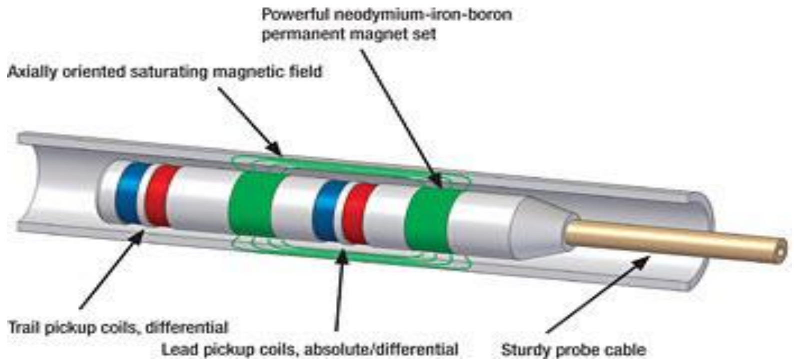
1. Coupling medium (water) is always needed.
2. Tubes must be thoroughly cleaned.
3. ID surface corrosion and deposits can significantly reduce test sensitivity due to the absorption and scattering of sound waves.
4. Test speed is approximately 3-4 inches/second. 12 inches per second high-performance equipment. Some systems cannot record the entire tube length due to computer processing and file buffer size limitations.
5. Requires high inspection skills for data analysis and evaluation.
6. Cannot detect cracking, small diameter pitting or through wall holes.

Magnetic Flux Leakage (MFL)

A magnetic flux leakage (MFL) probe utilizes a powerful magnet to magnetize the material under examination (i.e. Carbon Steel). If defects are present (corrosion or material loss), the magnetic field “leaks” from the material. MFL probes incorporate magnetic detector(s) where it can detect the leakage field.

Typically three sensors are used to measure the flux leakage received. The “Lead Differential Coil” is used to detect ID/OD sharp indications. The “Absolute Coil” is part of the “Lead Coil” and is used to detect ID/OD gradual defects. The “Trail Differential Coil” is placed outside the magnetic field to detect the “residual” flux leakage left behind by ID sharp indications.

By comparing the information between all three coils, a defect orientation (ID or OD) can be established



Magnetic Flux Leakage (MFL)

Capabilities

1. Distinguishes ID from OD flaws.
2. Can inspect ferromagnetic tubes from 0.75 to 3.5 inches in diameter and 0.120 inches wall thickness.
3. Permanent records can be obtained on test results.
4. Instrumentation can withstand adverse field conditions.
5. Inspection speeds of up to 24 inches/second.
6. Can detect flaws under support plates as well as flaws adjacent to end sheets.
7. Circumferential cracking may be detected with array-type MFL coils.

Limitations

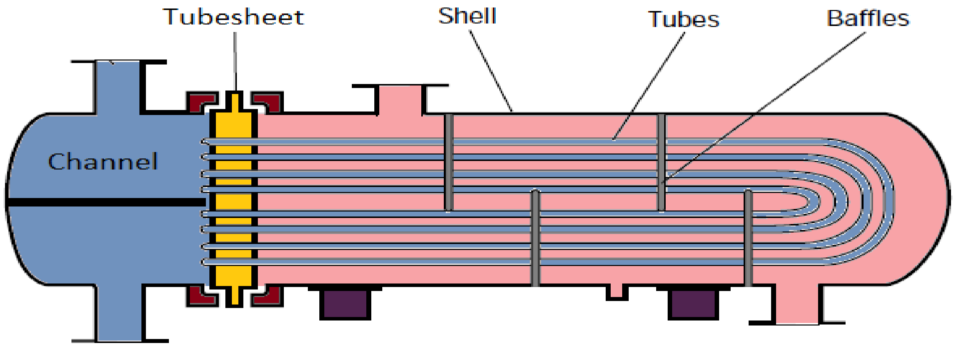
1. Detectability is limited to flaws 20% and greater.
2. Large magnets that are difficult to move.
3. Very sensitive to inspection speed. Accuracy of test results can fluctuate with probe speed.
4. Poor sensitivity to tubing flaws beneath tube sheets
5. Tubes must be cleaned. Scale or deposit can fill a flaw which will make it difficult to qualify its depth.
6. Requires high inspection skills for data analysis and evaluation.
7. Longitudinal or axial flaws cannot be detected.
8. Difficult to accurately size discontinuities
9. Cannot inspect U-bend tubes.

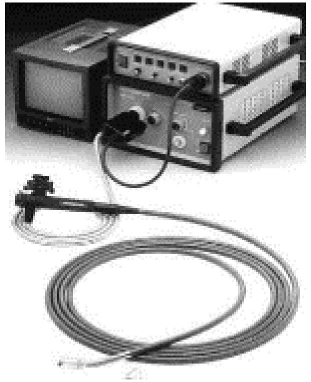
U Bend Tubing Inspection

U-bend tubing can be inspected by remote visual inspection (RVI)

Each of the straight tube NDE methods can partially inspect the straight sections of the U-tube. The U-bend itself is not inspectable by these techniques unless a special probe configuration is used.

Special probes may be found in the multi-Frequency Eddy Current, Partial saturation EC, and RFT single exciter coil categories. Acoustic Pulse Reflectometry can detect blockage >15% of the tube diameter or through wall holes in U-bends regardless of type of tubing material.





Tube and Callipers

Many tubing NDE methods have difficulty inspecting tube ends within the tube sheets due to end-effects and tube sheet interference. Mechanical gauging of the tube ends is performed to detect ID tube end erosion. A common gauge for this purpose is an internal three point expanding dial calliper.

Elliott's Tube Hole Gauges make it easy to accurately measure tube IDs and tube sheet holes found in vessels.

- Tube Size: 0.375″ to 2.000″ (9.5 – 50.8mm) OD

Capabilities	Limitations
1. Direct mechanical measurements	1. Limited measurement distance into the tube
2. Tube sizes from 0.375” to 2.00” (9.5 - 50.8 mm)	2. Measurements may be affected by tube deposits
3. Easy to calibrate	3. Relatively slow production

Examination of Tube-to-Tubehseet Joint (TTS)

a) Visual Examination

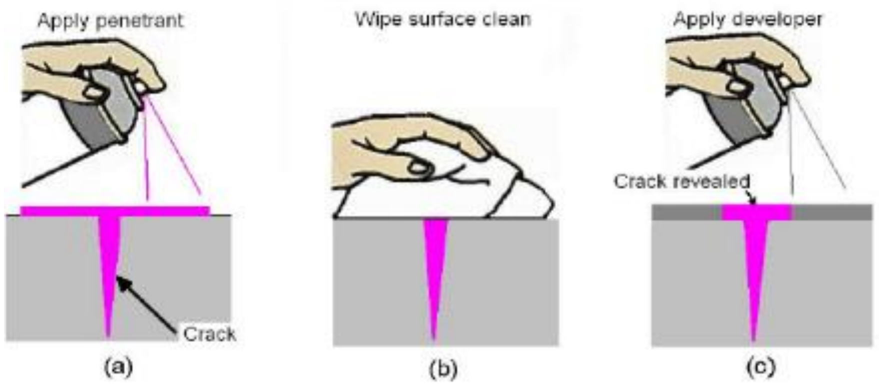
b) Surface examination by PT

c) Volumetric examination by UT

d) In situ replica examination

e) Helium leak test

f) Hydrotest



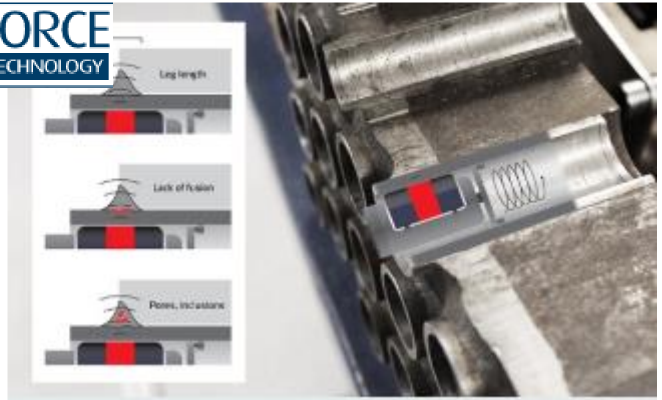
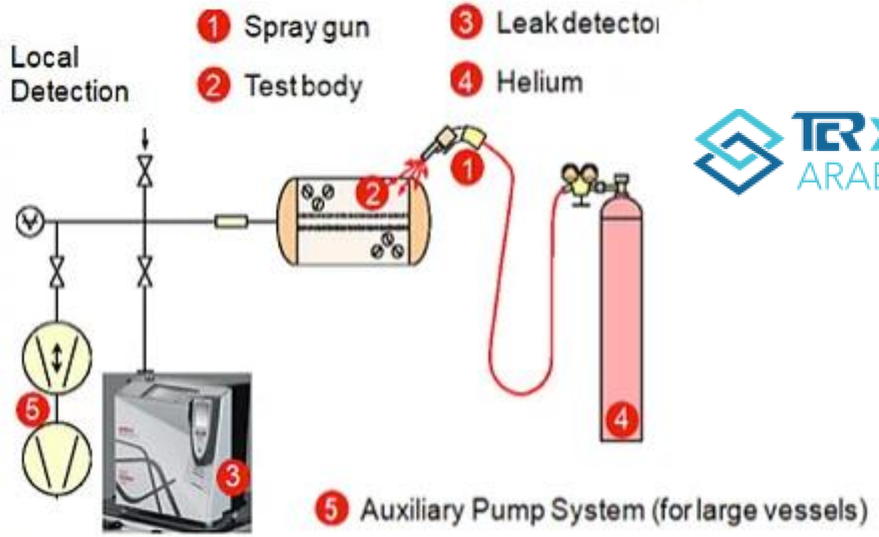


Image showing the typical failures in tube-to-tube sheet welds.



NDT Method Suitability

Material / Technique	ECT / ECA	FSECT	IRIS	RFT	MFL	PSEC
Non-Ferromagnetic Tube	2	4	1	4	4	4
Low Ferromagnetic Tube	3	1	1	1	3	2
Ferromagnetic Tube	4	3	1	1	1	2

Examples of non ferromagnetic tubes: Admiralty brass, 300 series stainless steels, Cu-Ni, Hastelloys, etc
Examples of Low ferromagnetic tubes: Monel, 2205 Duplex stainless steel, 2207 Super Duplex stainless steel, etc.
Examples of Ferromagnetic tubes: Carbons steels, Nickle Alloys

Suitability Rank
1 Preferred
2 Applicable
3 Less Applicable
4 Not applicable

ECT : Eddy Current Testing
ECA : Eddy Current Array
FSECT: Full Saturation Eddy Current Testing
IRIS: Internally Rotating Inspection System
RFT: Remote Filed Testing
MFL: Magnetic Flux Leakaghe
PSEC: Partial Saturation Eddy Current

NDT Method Flaw Detection Capability

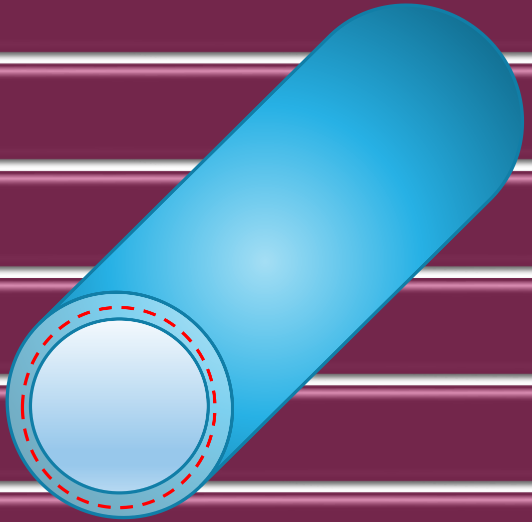
Defect / Technique	ECT / ECA	FSECT	IRIS	RFT	MFL	PSEC
ID General Wall Loss	B	B	A	B	B	B
OD General Wall Loss	B	B	A	B	B	B
ID Pitting	B	B	C	B	B	C
OD Pitting	B	B	B	C	C	C
ID Grooving	A	A	A	A	A	A
ID Erosion	B	B	A	A	A	B
OD Erosion / Impingement	B	B	A	A	A	C
Cracking (Axial)	A	A	D	A	A	B
Cracking (Circ)	C	C	D	A	A	C
Metallurgical changes (De-allyoing, hydriding)	B	B	D	A	A	C

Suitability Rank
A Highly Effective
B Effective
C Less Effective
D Not Effective

ECT : Eddy Current Testing
ECA : Eddy Current Array
FSECT: Full Saturation Eddy Current Testing
IRIS: Internally Rotating Inspection System
RFT: Remote Filed Testing
MFL: Magnetic Flux Leakaghe
PSEC: Partial Saturation Eddy Current

Acceptable Loss and Tube Replacement

- Impact on the efficiency and other operational characteristics of the heat exchanger due to the potential reduction of heat transfer area.
- Duration in service
- Time to next planned outage
- Criticality of the exchanger (process safety or to operation)
- Suspected damage mechanism
- Historical failure rate (increasing or decreasing)
- Potential consequence of tube failure
- Accuracy and effectiveness of the inception technique(s)

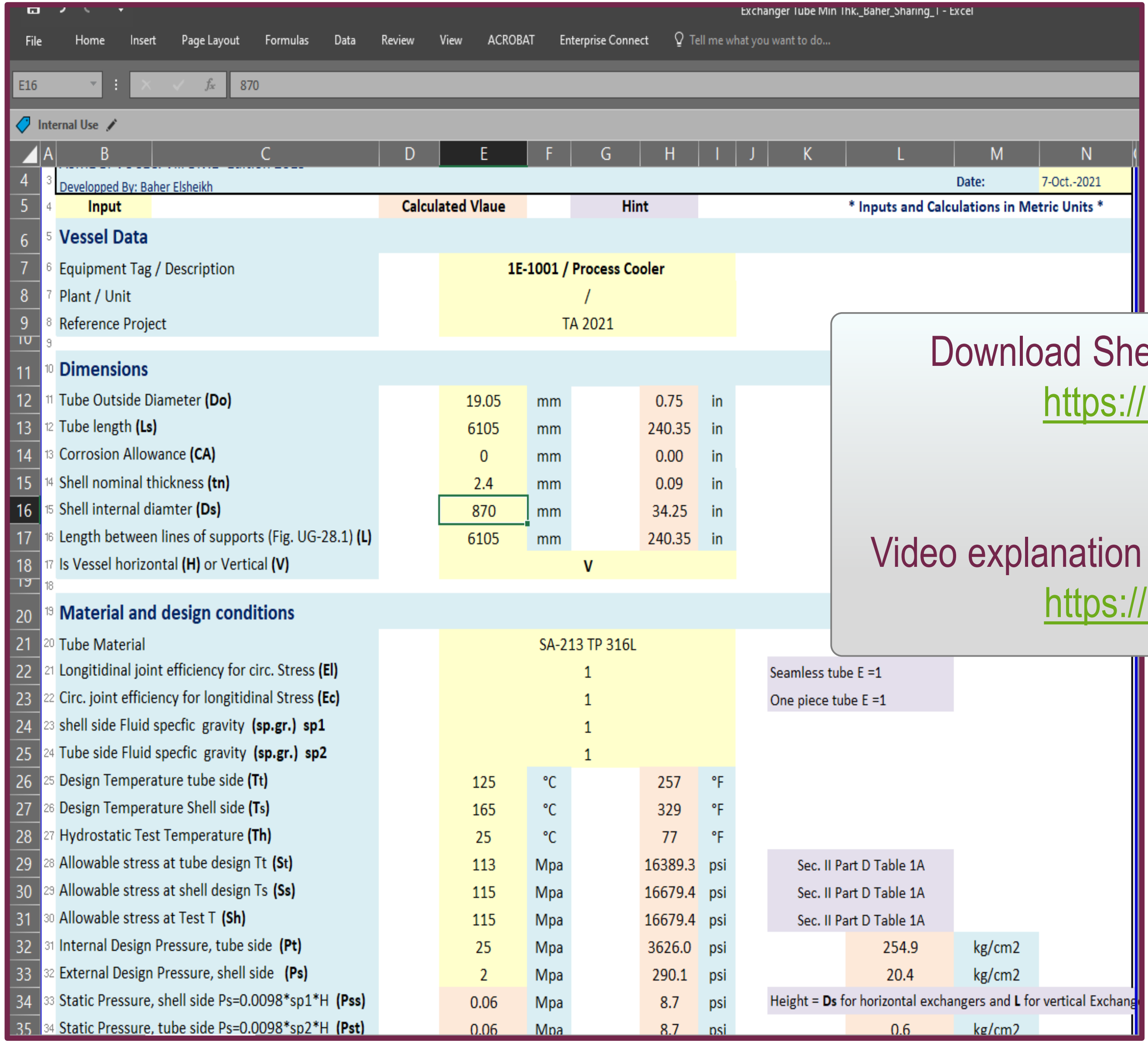


For critical exchangers:

ASME PCC-2

- Total replacement of tube bundle where 40% loss or more of nominal thickness
- Tube or bundle replacement where 20%to 40% wall loss

Calculations of Tube Minimum Required Thickness



Exchanger Tube Min Thk_Baher_Sharing_1 - Excel

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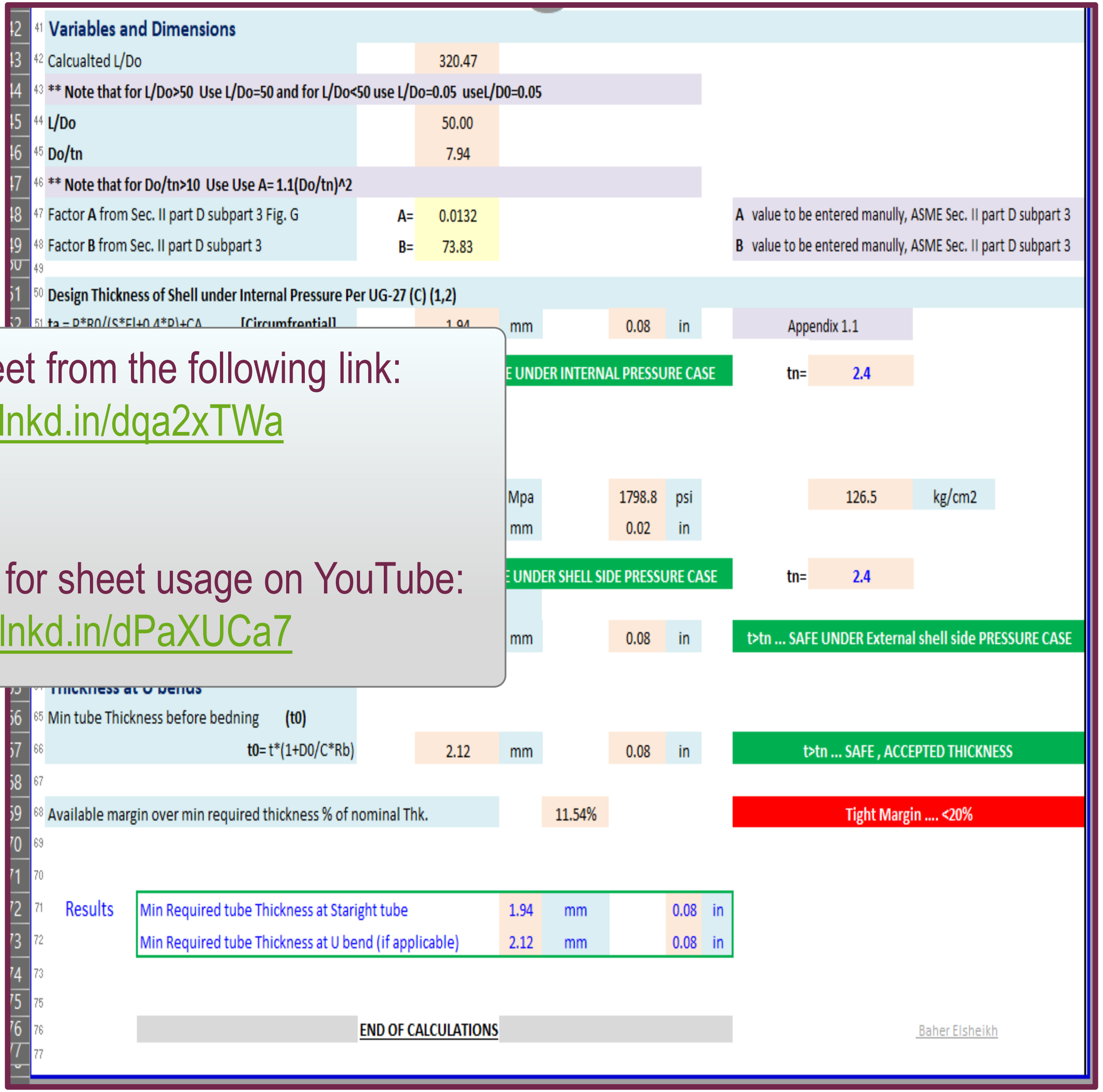
Internal Use

Developped By: Baher Elsheikh — Date: 7-Oct.-2021

Input	Calculated Vlaue				Hint
					* Inputs and Calculations in Metric Units *
Vessel Data					
Equipment Tag / Description	1E-1001 / Process Cooler				
Plant / Unit	/				
Reference Project	TA 2021				
Dimensions					
Tube Outside Diameter **(Do)**	19.05	mm	0.75	in	
Tube length **(Ls)**	6105	mm	240.35	in	
Corrosion Allowance **(CA)**	0	mm	0.00	in	
Shell nominal thickness **(tn)**	2.4	mm	0.09	in	
Shell internal diamter **(Ds)**	870	mm	34.25	in	
Length between lines of supports (Fig. UG-28.1) **(L)**	6105	mm	240.35	in	
Is Vessel horizontal **(H)** or Vertical **(V)**	V				
Material and design conditions					
Tube Material	SA-213 TP 316L				
Longitidinal joint efficiency for circ. Stress **(El)**	1				Seamless tube E =1
Circ. joint efficiency for longitidinal Stress **(Ec)**	1				One piece tube E =1
shell side Fluid specfic gravity **(sp.gr.) sp1**	1				
Tube side Fluid specfic gravity **(sp.gr.) sp2**	1				
Design Temperature tube side **(Tt)**	125	°C	257	°F	
Design Temperature Shell side **(Ts)**	165	°C	329	°F	
Hydrostatic Test Temperature **(Th)**	25	°C	77	°F	
Allowable stress at tube design Tt **(St)**	113	Mpa	16389.3	psi	Sec. II Part D Table 1A
Allowable stress at shell design Ts **(Ss)**	115	Mpa	16679.4	psi	Sec. II Part D Table 1A
Allowable stress at Test T **(Sh)**	115	Mpa	16679.4	psi	Sec. II Part D Table 1A
Internal Design Pressure, tube side **(Pt)**	25	Mpa	3626.0	psi	254.9 kg/cm2
External Design Pressure, shell side **(Ps)**	2	Mpa	290.1	psi	20.4 kg/cm2
Static Pressure, shell side Ps=0.0098*sp1*H **(Pss)**	0.06	Mpa	8.7	psi	Height = **Ds** for horizontal exchangers and **L** for vertical Exchang
Static Pressure, tube side Ps=0.0098*sp2*H **(Pst)**	0.06	Mpa	8.7	psi	0.6 kg/cm2



Variables and Dimensions

Calcualted L/Do		320.47			
** Note that for L/Do>50 Use L/Do=50 and for L/Do<50 use L/Do=0.05 useL/D0=0.05					
L/Do		50.00			
Do/tn		7.94			
** Note that for Do/tn>10 Use Use A= 1.1(Do/tn)^2					
Factor **A** from Sec. II part D subpart 3 Fig. G	A=	0.0132			A value to be entered manully, ASME Sec. II part D subpart 3
Factor **B** from Sec. II part D subpart 3	B=	73.83			B value to be entered manully, ASME Sec. II part D subpart 3

Design Thickness of Shell under Internal Pressure Per UG-27 (C) (1,2)

ta = P*R0/(S*El+0.4*P)+CA [Circumferential]	1.94	mm	0.08	in	Appendix 1.1
				E UNDER INTERNAL PRESSURE CASE	tn= 2.4
		Mpa	1798.8	psi	126.5 kg/cm2
		mm	0.02	in	
				E UNDER SHELL SIDE PRESSURE CASE	tn= 2.4
		mm	0.08	in	t>tn ... SAFE UNDER External shell side PRESSURE CASE

Thickness at U bends

Min tube Thickness before bedning (t0)					
t0= t*(1+D0/C*Rb)	2.12	mm	0.08	in	t>tn ... SAFE , ACCEPTED THICKNESS
Available margin over min required thickness % of nominal Thk.	11.54%				Tight Margin .... <20%

Results

Min Required tube Thickness at Staright tube	1.94	mm	0.08	in
Min Required tube Thickness at U bend (if applicable)	2.12	mm	0.08	in

END OF CALCULATIONS

Baher Elsheikh

Download Sheet from the following link:
https://lnkd.in/dqa2xTWa

Video explanation for sheet usage on YouTube:
https://lnkd.in/dPaXUCa7

Methods for Determining Minimum Number of Tubes to Inspect

312-1-1.1 Fixed Tube Count

The following minimum number of tubes inspected should be considered:

a) 50 tubes or 25% of tube total, whichever is greater, for heat exchangers with a total tube count of less than 500 tubes
b) 20% of tube total for heat exchangers with a total tube count of 500 tubes or more, up to 750 tubes
c) 15% of tube total for heat exchangers with a total tube count of 750 tubes or more, up to 1,000 tubes
d) 10% of tube total for heat exchangers with a total tube count of more than 1,000 tubes

312-1-1.2 Tube Bundle

The following areas of the tube bundle should be examined at a minimum:

a) the first three rows adjacent to the inlet nozzle and the last two rows adjacent to the exit nozzle.
b) every second tube around the perimeter of the bundle. For multipass heat exchangers, the perimeter of each pass shall be included.
c) a selection of tubes in the interior section of the bundle.
d) areas with a history of active damage mechanisms.
e) areas that have not previously been examined.
f) failure of 10% of the tubes examined shall require an additional 10% of tubes to be examined in the examined area, as per (a) through (e).

312-I-1.4 EVA

a) Use of Extreme Value Anlaysis (EVA) makes it possible to accurately assess the remaining life of large numbers of tubes using relatively minimal data.

b) EVA assessment is based on ASTM E 2283, "Standard Practice for Extreme Value Analysis of Non metallic Inclusions in Steel and Other Microstructural Features.

Inspection Effectiveness Table

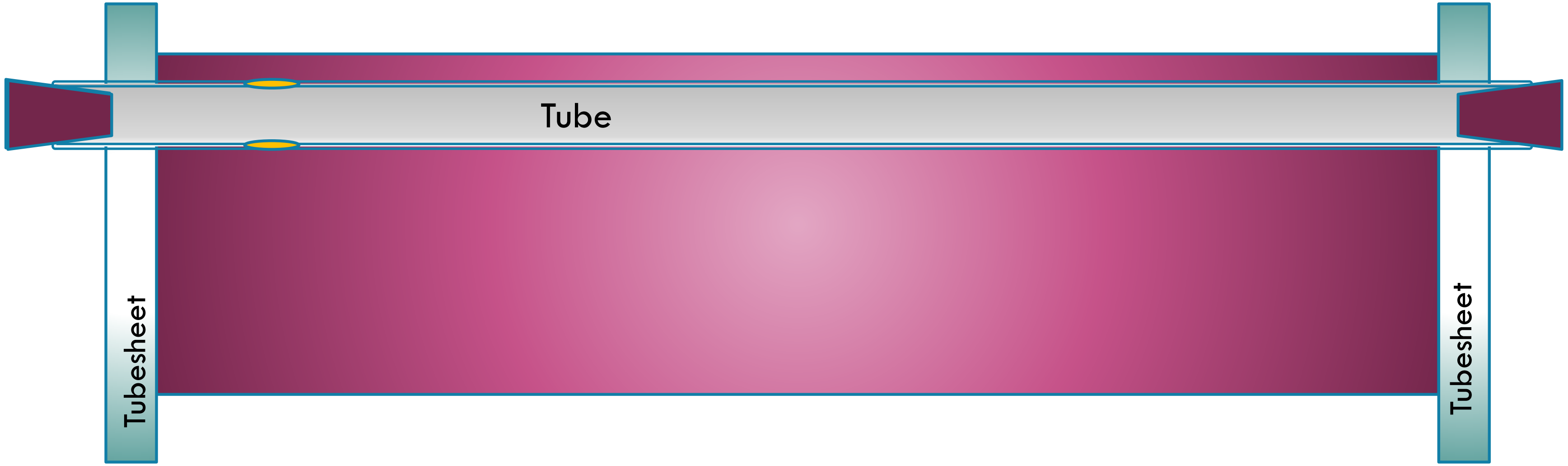
ASME PCC 2
Table 312-I-1.3-1

Table 312-I-1.3-1 Inspection Effectiveness Table

Inspection Effectiveness Category	Damage to Consider	Inspection Method	Number of Ferrous Tubes by Intrusive Inspection Methods	Number of Nonferrous Tubes by Intrusive Inspection Methods	Number of Tubes by Nonintrusive Inspection Methods
Highly effective	Wall loss [excluding MIC]	IRIS	80% to 100%	80% to 100%	Not applicable
	...	IRIS and EVA 99% CI as lower bound	20 to 30	20 to 30	...
	...	RFET or MFL	100% and pull 2 worst tubes for lab analysis	Not applicable	...
	...	ET	Not applicable	100%	...
	Cracking	SWIRIS	100%	Not applicable	...
	Cracking or MIC	ET	Not applicable	100%	...
Usually effective	Wall loss or localized and general corrosion (excluding MIC)	IRIS	60% to 80%	60% to 80%	Profile RT 50% at 0 deg and 90 deg
	...	IRIS and EVA 95% CI as lower bound	20 to 30	20 to 30	...
	...	RFET or MFL	100% and use IRIS on 2 worst tubes	Not applicable	...
	PSET	90%	Not applicable	...	...
	...	ET	Not applicable	80%	...
	Cracking	SWIRIS	80%	Not applicable	...
	...	PSET	100%	Not applicable	...
	Cracking or MIC	ET	Not applicable	80%	...
Fairly effective	Wall loss (excluding MIC)	IRIS	40% to 60%	40% to 60%	Not applicable
	...	IRIS and EVA 90% CI as lower bound	20 to 30	20 to 30	...
	...	RFET or MFL	80% and use IRIS on 2 worst tubes	Not applicable	...
	PSET	70%	Not applicable	...	...
	...	ET	Not applicable	60%	...
	Cracking	SWIRIS	60%	Not applicable	...
	...	PSET	80%	Not applicable	...
	...	RFET or MFL	100%	...	...
	Cracking or MIC	ET	Not applicable	50%	...
Poorly effective	Wall loss (excluding MIC)	IRIS	20% to 40%	20% to 40%	Not applicable
	...	IRIS and EVA 80% CI as lower bound	20 to 30	20 to 30	...
	...	RFET or MFL	60% and use IRIS on 2 worst tubes	Not applicable	...
	PSET	50%	Not applicable	...	...
	...	ET	Not applicable	40%	...
	Cracking	SWIRIS	40%	Not applicable	...
	...	PSET	60%	Not applicable	...

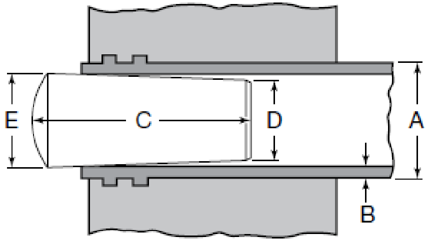
Tube Plugging – Tapper Plug

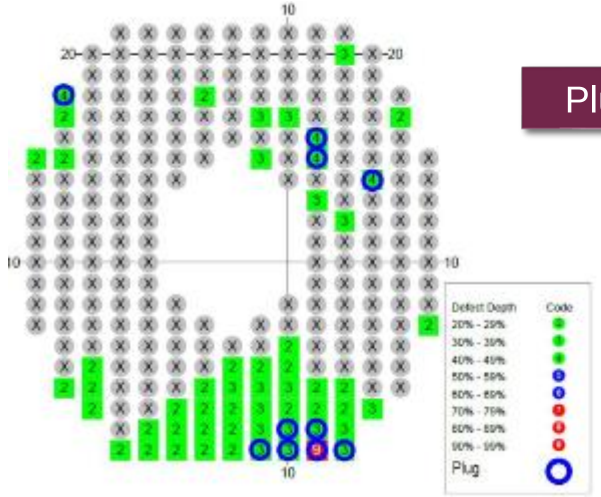
- All tubes that are plugged should be pierced to provide venting and draining to prevent possible plug blowout. Always puncture the tube before plugging



Friction Taper Plug to be used only when

- Shell side operating pressure <=1.5 Mpa
- Shell side operating temperature <=205 ^{o}C
- Tube to tubesheet are expanded not welded

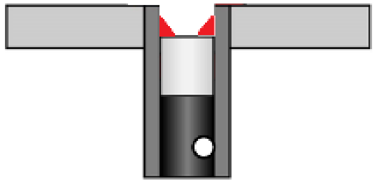


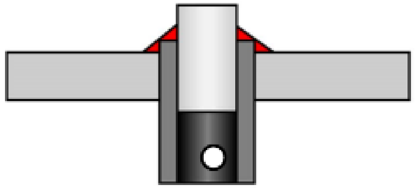


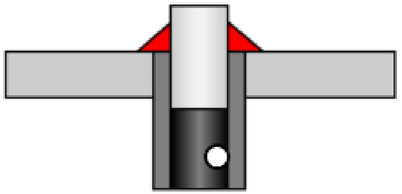
Plug Map

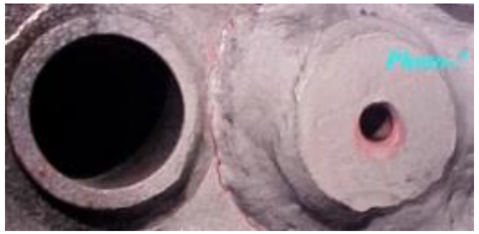
Tube Plugging – Welded Plug

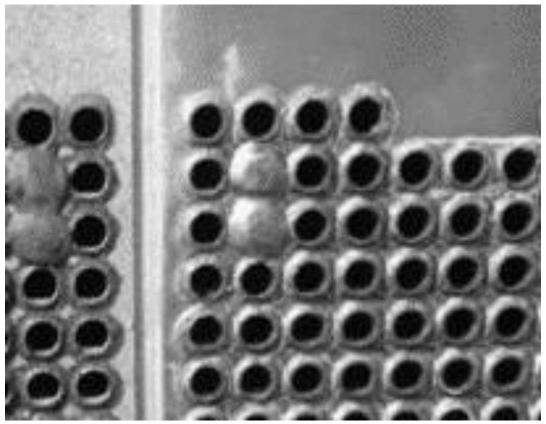
- Plugs with different shapes can be installed by welding to the tubesheet or to the inner surface of the tube
- Sometimes the plug is welded to ensure it doesn't leak or blow out and turn into a projectile.
- When it is welded, the plug should have a material test report.
- The welding must be done in accordance with approved WPS, with care of requirements of Dehydrogenration (if applicable) PWHT … etc.
- Mock-up to be prepared to ensure proper application and qualifications of the welders
- Plug map shall be prepared to record number of location of plugged tubes





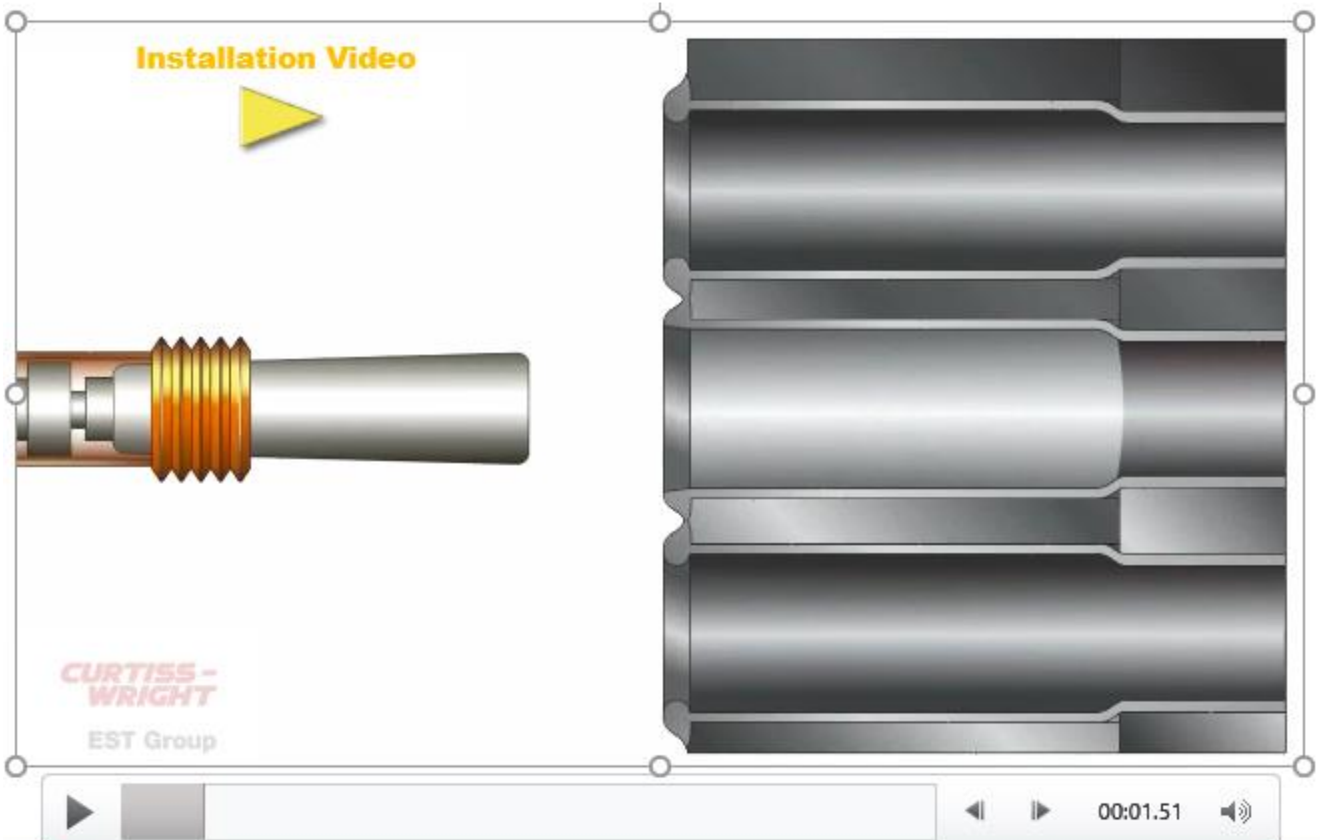


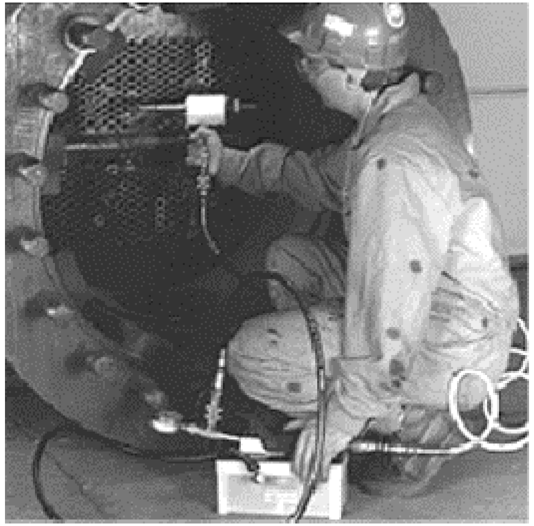




Tube Plugging – Mechanical Plug

- Mechanical plugs should be considered in situations where friction fit tapered plugs are not appropriate for the pressure and/or temperature of service or other technical / environmental conditions.
- Mechanical plugs are typically installed by a pneumatic or hydraulic system. Other styles of plugs may be considered for higher pressures.





Tube Plugging – TEMA NOTES

TEMA E-4.8 PLUGGING OF TUBES

- In U-tube heat exchangers, and other exchangers of special design, it may not be feasible to remove and replace defective tubes. Defective tubes may be plugged using commercially available tapered plugs with ferrules or tapered only plugs which may or may not be seal welded.

- Excessive tube plugging may result in reduced thermal performance, higher pressure drop, and/or mechanical damage. It is the user's responsibility to remove plugs and neutralize the bundle prior to sending it to a shop for repairs.