PALO VERDE
NUCLEAR GENERATING STATION

Mechanical Maintenance Training
Heat Exchanger Construction and Operation
Classroom Lesson

Mechanical Maintenance Training	**Date: 6/15/2010 11:19:54 AM**
LP Number: NMD40C000103	**Rev Author: GARY KEENEN**
Title: Heat Exchanger Construction and Operation	**Technical Review:** Kleinman, Dean W(Z56639) Digitally signed by Kleinman, Dean W (Z56639) DN: cn=Kleinman, Dean W(Z56639) Reason: I have reviewed this document Date: 2010.06.15 12:37:53 -07'00'
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INITIATING DOCUMENTS

Task Analysis of Tasks

REQUIRED TOPICS

None

CONTENT REFERENCES

Mark's Standard Handbook for Mechanical Engineers, Eighth edition, edited by Theodore Baumeister, McGraw Hill Book Co., 1978.

Handbook of Heat Transfer, edited by Warren M. Rohsenow & James P. Hartnett, 1973, McGraw-Hill, NY, NY.

Heat Exchangers: Design and Theory Sourcebook, edited by N.H. Afgan & E. U. Schunder, 1979, McGraw-Hill, NY, NY.

Heat Exchanger Introduction, 1993, Williams Learning Network, Rockville, Maryland

TCSAI 2740095 Include more specific info in lesson plan supporting review questions.

LESSON PLAN REVISION DATA

Jun 15, 2010 Mark Tague Incorporated TCSAI 2740095.

Tasks and Topics Covered

The following tasks are covered in Heat Exchanger Construction and Operation :

Task or Topic Number*	Task Statement
Lesson:	Heat Exchanger Construction and Operation
HXCH001	Maintain Heat Exchangers

Total task or topics: 1

TERMINAL OBJECTIVE:

1 Given a maintenance operation involving heat exchangers the Plant Mechanic will , describe the theory of operation and basic construction of heat exchangers, as demonstrated by achieving a minimum score of 80% on a written examination.

1.1 State the basic theory of heat transfer.

1.2 Define the three mechanisms of heat transfer.

1.3 List the four (4) functions performed by heat exchangers.

1.4 Classify heat exchangers by their construction.

1.5 Identify five factors which affect heat exchanger operation.

CONTENT	METHODS & ACTIVITIES
I. Motivation	Focus student attention on "What's In It For Me".
II. Pre-Job Brief	
A. Pre-job briefing on the day's activities modeling the use of the Palo Verde Standards & Expectations, Preventing Events	
B. Focus On Five (Task Preview)	
1. Familiarize worker with the scope of work, task sequence, and critical steps.	
2. Critical Steps (Terminal Objectives) Given a Maintenance activity involving Heat Exchangers (condensers, reheaters, heaters, etc.), describe the inspection, cleaning, repair and rework methods used at PVNGS, in accordance with plant procedures, manufacturer's technical manuals and standard maintenance practices, as demonstrated by achieving a minimum score of 80% on a written exam.	PVNGS Standards & Expectation book (Focus on five) Highlight the critical steps (Terminal Objectives) on the power point presentation.
3. Identify error likely situations (error traps) a. Discuss at least one specific error likely situation.	(Look at Error Precursors in S&E book)
4. Identify the Worst thing that can happen.	Apply to the setting you're in. (Lab versus Classroom)
5. Identify specific error prevention defenses to be used.	What defenses can we employ to prevent the "Worst thing that could happen"
6. Identify actions to assure proper configuration control.	This may not be applicable in every training setting.
C. Schedule	Lay out the schedule and expectations for schedule adherence
1. Length of class - One day, classroom with some lab demonstration	

CONTENT	METHODS & ACTIVITIES
2. Break policy	
a. Two Minute Drill - After lunch at a minimum	At Instructor's discretion, not to interrupt class flow.
3. Evaluation - Multiple-choice comprehensive exam at the end, on CBT	
4. Post training critique	Feedback (i.e.Class Climate)
D. Qualification	
1. Qualified to work on Heat Exchangers upon completion of this course	
III. Lesson Introduction	
A. Lesson Terminal Objective Given a maintenance operation involving heat exchangers, the Plant Mechanic will describe the theory of operation and basic construction of heat exchangers, as demonstrated by achieving a minimum score of 80% on a written examination.	Read and/or discuss the lesson objectives
B. Lesson Enabling Objectives	
EO01 State the basic theory of heat transfer.	
EO02 Define the three mechanisms of heat transfer.	
EO03 List the four (4) functions performed by heat exchangers.	
EO04 Classify heat exchangers by their construction.	
EO05 Identify five (5) factors which affect heat exchanger operation.	

TO: 1 **Given a maintenance operation involving heat exchangers the Plant Mechanic will , describe the theory of operation and basic construction of heat exchangers, as demonstrated by achieving a minimum score of 80% on a written examination.**

EO: 1.1 State the basic theory of heat transfer.

Main Idea

CONTENT **METHODS & ACTIVITIES**

I. Heat is energy in transit from one mass to another because of a temperature difference between the two.

A. Definitions needed for this course

1. Heat: a form of energy associated with the motion of atoms or molecules and transferred from a body at a higher temperature to one at a lower temperature.

2. Temperature: a measure of the ability to transfer heat.

3. Heat Exchanger: device to transfer heat from one fluid to another.

II. Principles of Heat

A. Heat energy will move from a high energy state to that of a lower energy state.

1. The process will continue until a state of equilibrium is reached.

a. Equilibrium is the energy state where the material is at the same energy level as its surroundings.

CONTENT	**METHODS & ACTIVITIES**
2. Energy will flow from a “hot” material to a “cold” material.	
a. “Hot” and “cold” refer to temperature, not the amount of heat.	
b. The process continues as long as there is a temperature difference between the materials.	
B. The mechanisms for heat transfer are:	These mechanisms are identified only here – discussed in next EO.
1. Conduction	
2. Convection	
a. Natural	
b. Forced	
3. Radiation	
a. The only method of heat transfer through a vacuum.	
C. The heat transfer processes can work separately or in conjunction with others.	
D. Heat transfer coefficient	
1. It is a property of each material. Each material has its own heat transfer coefficient.	
2. It is a measure of the material’s ability to transfer heat.	
a. The higher the value, the more heat transfers through the material.	
b. This number is not an additive property.	
3. The coefficient values will be affected by scale build-up, film boundary layers, air layers and other material interference.	

EO: 1.2 Define the three mechanisms of heat transfer.

Main Idea

CONTENT	METHODS & ACTIVITIES
I. Conduction: heat is transferred as a result of physical contact between two materials or from one part of an object to another part of the same object.	PPT Slide #15
A. The transfer is by short-range interaction of molecules and/or electrons.	
1. Heat is transferred by collisions or direct interaction.	
2. The atoms with greater thermal energy pass a part of the energy to its neighboring atoms.	
a. This process continues from atom to atom.	
B. Occurs in all solids, liquids and gases.	
C. It is the only method for heat transfer through opaque solids.	
D. If heat is to be conducted through a material there must be a temperature difference between opposite sides of the material.	PPT Slide #16
E. The heat transferred through a material slab by conduction is affected by	Describe factors that affect conduction. PPT Slide #17
1. The surface area of the material	Define: <u>Directly proportional</u> (double the value, double the heat transfer)
a. Directly proportional	
2. The temperature difference	
a. Directly proportional	

CONTENT	METHODS & ACTIVITIES
3. The time the temperature difference is maintained	
a. Directly proportional	
4. The thickness of the material	Inversely proportional (double the value, half the heat transfer)
a. Inversely proportional	
II. Convection: heat transfer in a gas or liquid by the circulation of currents from one region to another.	Define and discuss convection PPT Slide #19
A. The heat is transferred by the actual movement of the heated material	
B. This is usually the most important heat transfer process within liquids and gases.	
C. Forced convection: the heated material is moved by fans or pumps.	
D. Natural convection: arises from the change in density that takes place when a liquid is heated.	Describe natural convection
1. Gases and liquids expand when heated	
2. Heated gas or liquid is lighter than the colder liquid	
3. Colder fluid displaces the heated fluid thereby setting up convection currents.	
III. Radiation: the emission of energy in the form of electromagnetic waves.	Define and discuss radiation. PPT Slide #20
A. Consists of electromagnetic waves, which transmit energy from a source to an absorber.	
1. This energy travels in straight lines	
2. It is the primary means of heat transfer from the sun	

CONTENT	METHODS & ACTIVITIES
3. Will traverse a vacuum as well as transparent material	
4. Is of primary importance for bodies at high temperatures and for transmission across regions in which there is no material medium	
B. All bodies above absolute zero temperature radiate energy	Define <u>Absolute zero</u> - when all molecular motion ceases, about –460ºF = 0º Rankine -273º C = 0º Kelvin
C. Material subjected to radiation will:	
1. Absorb it	
2. Transmit it	
3. May reflect it	
IV. Combination of heat transfer mechanisms	
A. Conduction and convection work together in most processes	
B. Radiant heat transfer has a minor role in the processes of heat transfer in heat exchangers	
C. An example of the combination of processes is a steam radiator for heating a room.	PPT Slide #21
1. Uses all three processes	
2. Conduction	
a. Heat transfer from the steam to the outside of the radiator	

CONTENT	METHODS & ACTIVITIES
3. Convection	
a. This is the primary means of heat transfer to the room	
b. Evidence of this is by the even heat distribution	
4. Radiation	
a. Generates only a small part of heat transfer to heat the room	
b. Significant factor in your comfort at that temperature	Could compare with summer and winter 72 degree air – wall temperature makes you feel cooler in winter, warmer in summer

EO: 1.3 List the four (4) functions performed by heat exchangers.

Main Idea

CONTENT	METHODS & ACTIVITIES
I. Raise system temperature A. Heaters, for example feedwater heaters	
II. Lower system temperature A. Coolers, for example lube oil coolers	
III. Add latent heat A. Convert a liquid into a gas – vaporization B. Convert a solid into a liquid – melting	Latent heat is the energy added to cause a change in state. A pot of boiling water on a stove is an example of latent heat. The water is boiling at a temperature of 212 degrees F. The steam in the pot is also 212 degrees. The more energy you add, the more water turns to steam, but the temperature of both the water and steam remains the same.
IV. Remove latent heat A. Convert vapor/gas into a liquid condensation B. Convert a liquid into a solid – freezing	

EO: 1.4 Classify heat exchangers by their construction.

Main Idea

CONTENT	METHODS & ACTIVITIES
I. Types of heat exchangers	
A. Direct contact	PPT Slide #23
1. Heat transfer occurs with the intermixing of the fluids	
2. This is used for fluids that can be mixed together	
3. Spray type	
a. Evaporative effect creates the temperature change	
b. Latent heat of vaporization is released to the condensing fluid or visa versa	
c. Examples are:	
1) Cooling towers	
2) Pressurizer spray nozzles	
B. Closed type or indirect contact	
1. Transfer is across a containment device	
2. The heat transfer occurs through an intermediate material	
3. There is no mixing of the fluids	
4. Most common is the tube and shell type heat exchanger	Which is what this course is all about. PPT Slide #24

CONTENT	METHODS & ACTIVITIES

5. This allows the heating or cooling of fluids that do not mix or fluids that have to be maintained at a high degree of purity or to prevent contamination of other systems

II. Heat exchanger design

A. Components

1. Shell

a. Purpose

1) Provides the supporting enclosure for the heat exchanger

2) The determination of multipass or single pass may be made by the use of different head configurations for the heat exchanger

3) The area between the tube sheets of a shell and tube heat exchanger where the fluid contacts the outside of the tube is called the shell side of the heat exchanger.

b. Typical materials of construction

1) Cylinder or pipe of carbon steel or alloy steel

2) Plate of carbon steel, molybdenum, nickel, chromium, chromium nickel steels, and other alloys

2. Bonnet or head

a. The end of the heat exchanger

CONTENT	METHODS & ACTIVITIES

b. Purpose

1) Provides the entrance and exit connections for the cooling fluids

2) Slows down the fluids prior to entering the tubes to minimize erosion

3) Can be designed to establish the number of passes the cooling fluid will make in the heat exchanger

c. Typical materials of construction

1) Normally made of the same material as the shell

3. Tubesheet

a. Purpose

1) Separates the shell side from the head or end bell and seals the tubes for the separation of the two fluids

2) Provides a means of holding the tubes in the heat exchanger

a) Tubes may be packed, rolled or welded to the tube sheet

3) There are several types of tube sheets

a) Single tube sheet

b) Double tube sheet

(i) Commonly used for leak detection

CONTENT | **METHODS & ACTIVITIES**

c) Fixed tube sheet

d) Floating tube sheet

b. Typical materials of construction

1) Usually alloys of copper or iron

2) Materials will be compatible with the materials of construction of the tubes and the shell

4. Tubes

a. Provides the means for separation of fluids in the heat exchanger

b. Transfers the heat from hotter fluid to colder fluid

c. Typical materials of construction

1) Carbon and carbon moly steels

2) Copper and copper alloys

3) Nickel, monel or aluminum

4) PVNGS uses titanium tubes in the main condenser

5. Baffles

a. Used on the shell side of the heat exchanger

b. Purpose

1) Direct flow more evenly around the tube bundles for more efficient heat exchange

2) May provide support for the tubes within the tube bundle

CONTENT	METHODS & ACTIVITIES
c. Materials of construction	
1) Materials should be compatible with the materials of the shell and the tubes	
B. Thermal expansion features	PPT Slide #26
1. Expansion joints	
a. Not required on all heat exchangers	
b. Purpose	
1) Used to reduce the thermal stresses between the tube and shell of the heat exchanger	
a) Allows the tubes to expand or contract	
2. Floating Tube Sheets/Heads	PPT Slide #27
a. O-ring or packing seals the floating tube sheet	
3. U-tube Heat Exchanger	PPT Slide #28
a. Both ends of tube attached to same tubesheet	
4. This allows tubes to freely expand	
a. Thermal expansion of shell does not affect tube bundle	
5. Packed Tubes	PPT Slide #29
6. Tubes are rolled into one tube sheet	
a. Free to expand through the packed tube sheet	

CONTENT	METHODS & ACTIVITIES

C. Shell side fluid selection

1. The choice of fluid on the shell side will influence the type of heat exchanger and evaluation of the following factors should be considered.

    a. Cleanability

        1) Shell side is difficult to clean

        2) Usually the shell side has the cleaner fluid

    b. Corrosion

        1) Corrosion may require the use of expensive alloys for shell construction

        2) Corrosive fluids are usually placed in tubes to minimize the cost of an expensive shell

    c. Pressure

        1) High pressure shells are thick walled and expensive

        2) High pressure fluids are usually inside the tubes

    d. Temperature

        1) High temperatures reduce the allowable stresses in material

        2) Safety of personnel may require the insulation of the shell if there are high temperatures in the shell

        3) High temperature fluids should be inside the tubes

CONTENT	**METHODS & ACTIVITIES**
e. Hazardous or expensive fluids	
1) The most hazardous or expensive fluid should be placed on the tightest side of the heat exchanger	
2) This is usually the tube side	
f. Pressure drop	
1) If the pressure drop of a fluid is critical and must be accurately predicted, that fluid should be placed inside the tubes	
2) Fluid Characteristics inside the tube are more predictable	
3) Pressure drop inside the tube can be calculated with less error	
III. Classification of heat exchangers	
A. Shell and tube heat exchangers are usually classified by the method used for reducing thermal stresses between the tubes and the shell	
1. Fixed tube	PPT Slide #30
a. Advantages	
1) Simplest to fabricate	
2) Cheapest	
3) Shell and tube fluids are tightly held	
4) Internal leakage could only be due to leaky tube joints or perforations	

CONTENT	METHODS & ACTIVITIES
b. Disadvantages	
1) High thermal stresses between tube and shell	
a) Could loosen tube joints	
2) Difficulty of mechanical cleaning of the outside of the tubes	
a) If shell fluids are not clean or if scale deposits cannot be removed chemically a removable tube bundle may be necessary	
c. A fixed tube heat exchanger with an expansion bellows reduces thermal stresses between the tube and shell	
1) Usually limited to pressures less than 100 psi	
2. Internal floating head	PPT Slide #31
a. Advantages	
1) Eliminates shell and tube stresses	
2) Tube bundle is removable for cleaning	
3) Shell fluid is tightly held preventing external leakage	
b. Disadvantages	
1) Internal gasket on floating end may fail	
2) Severity of this problem depends on the toxicity and reactivity of the fluids	

CONTENT	METHODS & ACTIVITIES
3. U-tube bundle	PPT Slide #32
a. Advantages	
1) Removable	
2) Eliminates shell to tube stress	
3) Requires only one shell joint at the fixed end	
b. Disadvantages	
1) U-tubes are difficult to replace and clean	
B. Fluid flow	
1. Parallel flow	PPT Slide #33 & 34
a. Flow of both the cooling media and the fluid to be cooled flow in the same direction	
1) Flow velocities may not be the same	
2) If the length of the cooling tubes are long enough, the temperature differential at the exit of the heat exchanger may be small	
2. Counter flow	
a. Flow directions are opposite to each other	
b. This allows for the maximum heat transfer from one fluid to another due to maintaining a high temperature differential across the tubes	

CONTENT	**METHODS & ACTIVITIES**
3. Cross flow	PPT Slide #36 & 37
a. The fluids flow in a perpendicular path to each other	
b. This is useful in removing or adding latent heat to a system	
c. This is the method of flow in the condensers	
1) The main condensers remove latent heat from the steam and convert it into condensate	
2) Latent heat removal is a constant temperature process	
C. Number of passes	
1. Single pass	PPT Slide #37
2. Multiple pass	
IV. Construction of a shell and tube heat exchanger	
A. Tube configuration	
1. Straight tube	NOTE: Many straight tube heat exchangers have a slight upward arc in the tubes to aid in drainage.
a. Tubes are usually arranged in a bundle configuration and enclosed in a cylindrical shell	
1) Tubes can be made of various materials depending on the service of the heat exchanger	

CONTENT	METHODS & ACTIVITIES
2) Tube materials may include Admiralty metal, arsenical copper, carbon steel, stainless steel or titanium	
3) The main condenser uses tubes made of titanium	
b. Many straight-tube heat exchangers have a slight upward arc in the center to facilitate draining of the tubes	
2. U-tube	
a. A single tube makes a "U" bend and returns to the initial tube sheet	
b. Only one tube sheet is required and half the number of tubes as the amount of holes in the tube sheet	
c. The design minimizes the need for a thermal expansion joint	
d. The tubes are normally installed as a removable tube bundle for ease of cleaning and repair	
1) An exception to this is the tubes in the steam generator	
B. Tube surface and type	
1. Plain surface	
a. The surfaces are relatively smooth	
2. Extended surface	PPT Slide #38
a. Tube surface is fitted with studs, fins or rings or some other method to extend the surface area	

CONTENT	METHODS & ACTIVITIES
b. This increases the total heat transfer area available without a substantial increase in the size and weight of the heat exchanger	
3. Helical tube	PPT Slide #39
a. Spiral type tubes for a higher heat transfer surface area	
b. Design allows for a minimal consideration of an expansion joint for the tube structure	
4. Double tube	
a. Used for low pressure high temperature applications	
b. Consists of two concentric pipes or tubes in a nested tube configuration	
1) One fluid stream flows in the inner tube and the cooling fluid passes in the annular space between the tubes	
2) Usually designed for counter flow applications for highest efficiency	
3) Thermal variations for the tubes must be considered in the construction of the heat exchanger	
C. Baffle configurations	PPT Slide #40
1. Segmental	
a. Most common type	
1) Directs flow almost perpendicularly across the tubes	

CONTENT	METHODS & ACTIVITIES

2) Disadvantage is that it allows for fluid bypassing in removable tube bundle configurations

   a) A space is required to allow for the removal of the tube bundle

   b) This space will allow flow of fluid from the inlet to the outlet, thereby bypassing the tube bundle

b. Gives good heat transfer rates for the pressure drop

c. Baffles also act as tube supports

2. Strip baffles

   a. Similar to segmental baffles but can handle larger flows

   b. Uses two segments place on opposite sides of the heat exchanger

   c. A third larger center segment is placed downstream to create flow around the tube bundle

   d. Usually formed by cutting a segment from a disk

3. Disk and doughnut baffles

   a. Consists of alternately placed disks and doughnut shaped baffles

      1) Disk is usually larger than the size of the doughnut hole

   b. Fluid bypassing is not a consideration in this arrangement because of the larger area allowed for flow past the disk

CONTENT	METHODS & ACTIVITIES

c. Disadvantages of this arrangement is that tube supports will affect the flow of fluid through the heat exchanger

d. Orifice baffles

1) Consists of disks with oversize holes for the tubes to pass through

2) Fluid flows through the space between the disk and the tube

3) These baffles are rarely used

a) Least effective for heat transfer

b) Cannot be cleaned when plugged with dirt or scale

c) Do not provide support for the tubes

EO: 1.5 Identify five factors which affect heat exchanger operation.

Main Idea

CONTENT	METHODS & ACTIVITIES
I. Temperature difference	
A. This is the driving force for the heat transfer	
B. The higher the temperature difference, the faster the heat transfer rate through the material	
C. Heat transfer will continue as long as there is a temperature difference	
D. At low temperature differences there is a low rate of heat transfer	
II. Fluid film resistance	
A. Boundary layer	PPT Slide #41
1. When a fluid flows along a surface the velocity changes from zero at the surface to the maximum value in the main stream	
2. Boundary layer thickness The distance from the surface to the area where the local velocity is 99% of the main stream velocity	
3. The velocity change happens in a short distance	
a. From the edge of the material to the center of the stream	
4. The transition layer is called the boundary layer	

CONTENT	**METHODS & ACTIVITIES**

5. In the boundary layer the mixing motion of the fluid is small

    a. Heat transfer is mainly by conduction

    b. Therefore the boundary layer is a major factor in the overall heat transfer

III. Film coefficient

A. Defined as the rate of heat transfer per unit area and unit temperature drop

B. Relates the heat transfer of the piping surface to the fluid mainstream, noting its dependency on the laminar film layers

C. With forced flow (normal condition)

1. Flow is turbulent

2. Boundary layer thickness can be greatly reduced by increased fluid velocity

3. Thus the film coefficient can be greatly reduced

D. For forced flow of high viscosity fluids such as oil

1. Laminar flow may prevail

2. The boundary layer may extend to the entire flow region

E. With free or natural convection

1. Fluid motion is induced by differences in fluid specific gravity

    a. Differences in specific gravity are due to temperature differences

CONTENT **METHODS & ACTIVITIES**

F. The film coefficient for a given fluid and surface configuration depends on:

1. Specific heat of the fluids
2. Viscosity
3. Density
4. Thermal conductivity
5. Coefficient of expansion
6. Temperature difference

IV. Surface area

A. A large surface area will allow for more heat transfer

V. Fluid velocity

A. The faster the flow of fluid, the higher turnover rate of the cooling fluid

1. Turnover rate is the time required to add enough molecules to completely replace the molecules existing in a confined area
2. The actual molecules may not all be different, because some of the new ones could go first

B. Fluid velocity directly affects the boundary layer and the fluid heat transfer

SUMMARY OF MAIN PRINCIPLES

The following items are things to consider in your lesson summary. They are not mandatory. You should develop your own summary.,

Objectives Review

Review the Lesson Objectives

Topic Review

Restate the main principles or ideas covered in the lesson. Relate key points to the objectives. Use a question and answer session with the objectives.

Questions and Answers

Oral questioning

Ask questions that implement the objectives. Discuss students answers as needed to ensure the objectives are being met.

Problem Areas

Review any problem areas discovered during the oral questioning, quiz, or previous tests, if applicable. Use this opportunity to solicit final questions from the students (last chance).

Concluding Statement

If not done in the previous step, review the motivational points that apply this lesson to students needs. If applicable, end with a statement leading to the next lesson.

You may also use this opportunity to address an impending exam or practical exercise.

Should be used as a transitional function to tie the relationship of this lesson to the next lesson. Should provide a note of finality.