Industrial Technologies Program
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A BestPractices Steam Technical Brief

Industrial Steam System Heat-Transfer Solutions

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Introduction

This Best Practices Steam Technical Brief provides an overview of considerations for selecting the best heat-transfer solution for various applications. Many steam heat-transfer applications are available in the industrial world. This brief presents a basic tutorial of the elements of an effective heat-transfer equipment selection process, including:

- Overview
- Getting the Correct Information
- Codes and Specifications
- Operational and Maintenance Considerations
- Installation Guidelines
- Conclusions and Recommended Actions

Overview

Neglecting to use basic fundamentals, and failing to establish appropriate specifications for selecting the correct heat-transfer solution, can lead to premature failure or non-performing heat-transfer.

This brief focuses on numerous industrial heat-transfer applications in various locations and industries, concentrating especially on the Industries of the Future. The most prevalent industrial heat-transfer issues include:

- Incorrect steam pressures
- Code violations
- Water hammer
- Poor temperature control
- Premature failures
- Dirt buildup
- Improper trap selections
- Condensate backpressure problems, including overhead condensate returns.

Properly selecting heat-transfer components will prevent these issues. Therefore, this brief addresses selection and design criteria.

Getting the Correct Information

One of the most frequent comments from manufacturers about selecting the correct heat-transfer unit is lack of specific requirements for the application. For example, when selecting the correct steam pressure, the end user does not normally know the steam supply pressure at the exact point where the heat-transfer equipment is going to be installed. Often an end user does not know all or any of the parameters that are required to come up with the proper heat-transfer. Many times, when a heat exchanger has failed, the end user will simply purchase a duplicate replacement without doing root-cause analysis.

Commonly, little consideration is given to design, selection, longevity, performance, or failure when selecting the correct heat-transfer unit. For example, the maximum and minimum flows, and the normal operating conditions of the heat-transfer unit are overlooked. Consideration of all components that are going to be selected in process applications is important. The end user needs to give the control-valve manufacturer the correct minimum, maximum, and normal flow requirements for the process application. The importance of giving manufacturers complete information is also true when selecting steam traps and other related steam equipment. Therefore, in every heat-transfer process application, certain criteria must be provided to manufacturer staff to help them size and select the correct heat-exchange equipment. The following information should be determined and provided to manufacturers for proper sizing and selection of heat-transfer equipment and associated components.

Process Conditions:

- Process fluid or vapor
  - Maximum flow
  - Minimum flow
  - Normal
- Process pressure
  - Design pressure
  - Maximum allowable pressure drop
- Inlet temperature
- Outlet temperature
- Specific heat
- Specific gravity
- Viscosity
- Foul factor.

Steam Conditions:

- Steam pressure, temperature (upstream of control valve)
  - Design pressure
  - Maximum pressure
  - Minimum pressure
  - Normal operating pressure
- Steam pressure, temperature (downstream of control valve)
  - Design pressure
  - Maximum pressure
  - Minimum pressure
  - Normal operating pressure
- Steam flow
  - Design flow
  - Maximum flow
  - Minimum flow
  - Normal operating flow
- Condensate-return flow
  - Design flow
  - Maximum flow
  - Minimum flow
  - Normal operating flow.

Codes and Specifications

Tubular Exchanger Manufacturer Association (TEMA)— TEMA is an organization of many different manufacturers of heat-transfer equipment that have pioneered the research and development of heat exchangers for more than fifty-five years. TEMA specifications provide valuable guidelines for the selection and application of heat-transfer equipment.

A heat-transfer unit designed to meet TEMA requirements will have selection and sizing information documented and provided to the end user. This information includes:

- Materials
- Heat-transfer area
- British thermal units (Btu) required
- Pressure drop
- Flow rates
- Fouling factors
- Pressure ratings
- Temperature ratings.

Heat-transfer units that are not designed to meet TEMA specifications typically will have only pricing provided, leaving the end user without any performance or construction information. Unfortunately, this is the standard in the industry.

If the end user can specify a TEMA designation, the suppliers of heat-transfer equipment will follow the TEMA guidelines. In most applications, it benefits the user to specify a TEMA designation. Designations, which apply to the different process applications, can be TEMA C, TEMA R, etc. Visit the TEMA Web site and contact information at *www.tema.org* for more information.

American Society of Mechanical Engineers (ASME)—ASME has established a set of rules, called the ASME Code, for the construction of boilers, pressure vessels, and nuclear components. The rules apply to safe design and construction. Some heat-transfer units are required to be ASME-code stamped and others are not. Generally, all units can be specified and constructed to ASME standards. A shell-and-tube heat exchanger operating more than 15 pounds per square inch gauge (psig) must have an ASME-code stamp. The standard in the industry is to ASME-code stamp all heat-transfer units whenever practical; commonly, industry stamps items such as plate coils, plate-and-frame, steam coils, and shell-and-tube heat-transfer units.

A steam coil operating at 100 psig does not need to be code stamped, but must have a pressure and temperature-rating label. Steam coils and unit heaters should be labeled for either 150 psig or 250 psig operating-steam pressures, together with the corresponding operating temperature limits. For more information regarding code stamps, contact ASME at *www.asme.org*.

Software Systems—Several software programs are used specifically for the design of the most common types of heat-transfer components. Manufacturers and larger consumers of heat-transfer equipment typically use these software systems.

Heat-Transfer Equipment—Great flexibility exists in designing a heat-transfer system. Different applications can use many different types and variations of heat-transfer equipment. The major types of heat-transfer equipment are:

- Plate Coil
- Plate-and-Frame
- Spiral Heat Exchanger
- Bare Tube
- Finned Tube
- Shell-and-Tube.

Heat-transfer units can be made of many different materials, depending on the needs and requirements of the process. Each type of unit has criteria for proper application and design. In the selection process, understanding both the advantages and disadvantages of each type of heat-transfer unit is equally important. One type of heat-transfer unit will work well in one application, but may perform badly in another.

Operational and Maintenance Considerations

Maintenance and Servicing Considerations—A heat-transfer unit's arrangements are designed to include the maximum heat-transfer area possible. Design and layout must also permit access to the heat-transfer area for cleaning as required by process conditions. For example, a heat-exchange application that requires constant cleaning should use a single-pass shell-and-tube heat exchanger or plate-and-frame unit that can be easily cleaned, either chemically or mechanically.

Economic Considerations in Heat Exchanger Selection—With all the different types of heat-transfer units available, selecting a unit can have economic implications. For example, several different heat-transfer options exist for low steam pressure. A plate-and-frame heat exchanger will have a lower initial cost than a shell-and-tube design; both designs will perform to meet the process specifications. However, when the steam pressure increases to 100 pounds per square inch gauge (psig), the selection of heat-transfer equipment is limited to a shell-and-tube unit because the design is able to withstand the high steam pressure and temperature. A plate-and-frame unit will have a lower temperature and pressure rating because of the rating of the gasket materials.

Higher steam pressure can result in decreased required heat-transfer surface area, because of a higher temperature differential between the steam and process.

Pressure drops permitted by the system affect heat-exchanger size. The highest allowable pressure drop results in savings in heat-exchanger surface area. As important as the pressure drop limitations are on the process side, understanding pressure drops on the steam side are also crucial when selecting the external components of the heat-transfer unit.

Space Restrictions Affect Heat Exchanger Costs—If a shell-and-tube heat-transfer unit design must change to conform to a length or height restriction for an installation area, it will typically be more expensive to make the unit.

A shell-and-tube heat exchanger is more cost effective to manufacture when designed with a long- and small-diameter shell, but the tube bundle typically must be removed for repair. Therefore, to accommodate for the removal of the bundle, the overall space for installation requirements is double the length of the shell. A shell-and-tube unit can also be made shorter, with multiple passes or bends, but this design type is difficult to clean.

The end user must consider all variables of the heat-transfer design for installation.

Construction Materials—The construction materials used in heat exchangers depend on the fluids, vapors, temperatures, and pressures in the system. A balance of initial cost against the expected life and maintenance requirements of the unit must be done to provide the best unit for the application. Individual components, or the entire unit, can be made of any material, such as stainless steel, copper-nickel, copper, Alloy 20, or other special alloys. Selection of materials involves careful consideration of these factors:

- Initial cost
- Longevity
- Maintenance
- Performance
- Corrosion resistance.

All units should be evaluated on a ten-year operation basis, including:

- Initial cost
- Maintenance cost
- Down-time losses caused by failure or performance loss
- Replacement cost if unit fails.

Heat-transfer equipment can be made to last one year, five years, ten years, or more, depending on the selection of materials and installation versus the cost.

Heat-Transfer Equipment Rating versus Expected Loads—A properly designed heat exchanger will handle its rated load under its specified conditions. In certain cases, additional heat-transfer area must be added to account for a fouling factor. This essentially means that some products or vapors will foul the heat-transfer area, thus reducing performance or even shutting down the process. End users can specify a fouling factor. This fouling factor adds more heat-transfer area to the unit and allows the heat-transfer unit to continue to meet performance standards with fouling on the heat-transfer surface. The fouling factor is typically a modest additional cost compared to the value it can provide to the process operation. Not all manufacturers include fouling considerations in their designs. Assuming an optimistically low fouling factor does not achieve savings, even if it seems to make a heat exchanger more cost effective. Later on, difficulties with reduced capacity, low process yields, frequent shutdown for cleaning, and extra maintenance can quickly counterbalance the savings that an unrealistic fouling factor may gain.

Fundamental Heat-Transfer—Heat-transfer design for process applications requires complicated calculations. Some calculations involve elaborate theoretical work, and some entail multitudes of separate computations.

Steam Pressure Selection—Select the lowest steam pressure possible to meet performance specifications, while also considering economic issues. Care should be taken in selecting the correct steam pressure, because a higher-than-required steam pressure can cause control problems, require additional safety equipment, and result in different materials of construction.

Saturated Steam versus Superheat—The typical steam process applications require 100% steam quality at saturated-steam conditions; 100% steam quality is steam with no minute droplets of condensate entrained in the vapor. The addition of any superheated steam to a heat-transfer process can cause performance problems, if the original design did not accommodate the superheated condition of the steam. Further, superheated steam temperatures may require material changes to handle the pressure and temperature of the steam.

Condensate Drainage—In designing heat-transfer units, condensate drainage is done by gravity or by pressure differential. Heat-transfer equipment should be installed to promote gravity drainage with no vertical lift before or after steam traps; this is crucial in any application that has a modulating steam-control valve. With these applications, care should be taken to prevent backpressure on the drain devices (steam trap or control valve). Backpressure on the drain devices causes numerous premature failures and performance problems, leading condensate to accumulate in the heat-transfer unit. This will result in water hammer and poor temperature control. Poor condensate drainage can also result in corrosion problems for the heat-transfer unit.

Insulation—Insulate all heat-transfer-exposed surface areas. Please refer to the DOE Best Practices Steam Tip Sheet on insulation for further details on payback and material selection (*http://www.oit.doe.gov/bestpractices/steam/*).

Installation—Probably one of the biggest issues in reliability of heat-transfer is the proper installation of the heat-transfer equipment. The sizing and length of pipe from the control valve outlet to the inlet nozzle on the heat-transfer unit is crucial. A minimum of 10 pipe diameters from the control valve to the inlet connection of the heat-transfer is required.

Condensate drainage must have sufficient pipe length, typically 18 inches vertical, at the outlet nozzle of the heat-transfer unit, and a horizontal length of pipe of no more than 8 inches to the steam-trap inlet. An additional 18 inches of vertical drop from the steam trap outlet to the condensate receiver tank inlet is required.

If the heat-transfer unit has a steam-supply modulating control valve, all condensate drains must flow by gravity to a collection tank or pumping system to pump the condensate back to the boiler area.

To ensure proper control of any of the heat-transfer, preventing backpressure or vertical lifts in the condensate piping is essential.

Air Venting/Vacuum Breakers—All heat-transfer components, whether shell-and-tube, plate-and-frame, or any other type, require vacuum breakers and air-venting mechanisms. Air is an insulator and will increase start-up times and affect process-operating temperatures if it is not eliminated. Vacuum breakers protect heat-exchange equipment when a system is shut down, by not allowing vacuum to occur and hold condensate in the heat-transfer equipment. Therefore, all heat-transfer devices should generally have an air vent and vacuum breaker installed at points designated by the heat-transfer manufacturer. The normal locations are close to the steam inlet or on the top portion of the heat-transfer unit.

Installation Guidelines:

Improper installation will cause:

- Premature failure of all components
  - Heat-exchanger equipment
  - Steam traps
  - Control valves
  - Piping
- Poor control
- Water hammer.

To properly install heat-transfer equipment, follow the checklist, below.

✔ Install a condensate-drip pocket with a steam trap in front of the steam control valve.

✔ Use ball valves with locking handles for all piping sizes of less than or equal to 2 inches in diameter. This provides the best lockout/tagout safety procedure. Be sure to check with your compliance officer to ensure compliance with any company, local, state, or federal regulations concerning lockout/tagout procedures.

✔ Install a strainer in front of the control valve.

✔ Control-valve selection is influenced by required turndown capabilities:
- Cage control = 40 to 1 turndown with the highest degree of controllability
- Globe control valve = 30 to 1 turndown
- Regulating valve = 20 to 1 turndown.

✔ Install pressure gauges before and after the control valve.

✔ Control-valve outlet piping must be increased to be equal to or larger than the inlet connection to the heat-transfer unit. The control valve should be located at least 10 pipe diameters away from the heat-transfer unit with the expanded piping.

✔ Install a vacuum breaker and air vent on the heat-transfer unit or the steam-supply inlet.

✔ Condensate drainage pipe should have a vertical drop-leg (condensate outlet of heat exchanger) of at least 18 inches or more from the heat-transfer unit.

✔ The horizontal distance from the vertical drop-leg to the steam trap should never be more than 8 inches. Any length more than 8 inches can lead to steam locking.

✔ For condensate capacities of 8,000 pounds per hour (lb/h) or less, use a steam trap.

✔ For condensate capacities of 8,000 lb/h or greater, use a control valve with a level controller.

✔ Install a test valve or a visual sight glass after the steam trap for visual indication of performance.

✔ **Never take a rise** in the condensate line after the condensate drain device if there is a modulating control valve off the inlet of the heat-transfer unit. Condensate discharge piping rising after a drain device is one of the most significant causes of premature failure of heat-transfer equipment. If gravity drainage is not achievable, then a pumping steam trap or liquid mover must be installed to accommodate the lifting of condensate.

Conclusions and Recommended Actions

Four factors impact the performance, longevity, and maintenance requirements for heat-transfer and related components:

- Initial knowledge and documentation of all the operating parameters. Without correct operating parameters and application information, proper sizing and selection of heat-transfer equipment is impossible, and all aspects of performance will be compromised. For successful heat-transfer design, the plant must make detailed operating and application information available. If the plant does not have this capability, many engineering firms can assist in gathering this important information.

- Codes and design specifications. Specifying a TEMA designation and an ASME pressure and temperature requirement will enhance all heat-transfer selections.

- Installation of heat-transfer. Following appropriate installation recommendations can eliminate most premature failures and greatly enhance the performance and efficiency of the heat-transfer.

- Always evaluate the selections in terms of a ten-year operational period, considering all factors.

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America. By investing in technology breakthroughs today, our nation can look forward to a more resilient economy and secure future.

Far-reaching technology changes will be essential to America's energy future. Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies that will:

- Conserve energy in the residential, commercial, industrial, government, and transportation sectors
- Increase and diversify energy supply, with a focus on renewable domestic sources
- Upgrade our national energy infrastructure
- Facilitate the emergence of hydrogen technologies as a vital new "energy carrier."

The Opportunities

Biomass Program
Using domestic, plant-derived resources to meet our fuel, power, and chemical needs

Building Technologies Program
Homes, schools, and businesses that use less energy, cost less to operate, and ultimately, generate as much power as they use

Distributed Energy & Electric Reliability Program
A more reliable energy infrastructure and reduced need for new power plants

Federal Energy Management Program
Leading by example, saving energy and taxpayer dollars in federal facilities

FreedomCAR & Vehicle Technologies Program
Less dependence on foreign oil, and eventual transition to an emisions-free, petroleum-free vehicle

Geothermal Technologies Program
Tapping the earth's energy to meet our heat and power needs

Hydrogen, Fuel Cells & Infrastructure Technologies Program
Paving the way toward a hydrogen economy and net-zero carbon energy future

Industrial Technologies Program
Boosting the productivity and competitiveness of U.S. industry through improvements in energy and environmental performance

Solar Energy Technology Program
Utilizing the sun's natural energy to generate electricity and provide water and space heating

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