50

A state of the art update in steam technology

The inherent characteristics of the two-phase heat transfer fluid phenomena were responsible for the almost universal use of "steam" as an intermediate heating fluid since the origin of central heating systems in buildings until the post World War II era. At that time, advances in single-phase system technology proved to outweigh evident advantages of two-phase systems, and steam application advances essentially ceased. The single-phase concept (water; a water/glycol mixture; or high-temperature low-pressure organic fluids) has predominated system design for 20 years. Many engineers today look upon steam heating systems with the same attitude as they look upon ammonia for refrigeration—only the old-timers possess the outdated skills to design such systems. Furthermore, contemporary designers feel justified by taking the position that single-phase systems are more advantageous in all respects.

Two-phase systems

If, however, one disregards available hardware and current thinking for a moment, the following theoretical characteristics of the two-phase system come to mind:

- Constant temperature heat source.
- Constant temperature heat dissipation.
- Complete isolation of multiple sources and dissipation devices, which enhances reliability.
- Thermally motivated flow.
- High heat content per unit mass flow.

In many applications, these characteristics would make a two-phase system more advantageous than a single-phase one. The next step, then, is to update our thinking on the state of the art of two-phase transfer.

A two-phase system is actually a refrigerant system. As all designers know, with the compressor off, the refrigerant condenses to its liquid phase at the lowest temperature point in the system. The system pressure will be essentially equal to the saturation pressure corresponding to the temperature at that point. The single-phase nature of these vessels results in either subcooling (liquid) or superheating (vapor). If the system design is approached with this basic analogy in mind, the state of the art starts moving forward dramatically. Consider the simple concept of controlling the heat transfer rate from a terminal device, such as a heating coil, heat exchanger, etc. Simplistically, there are two methods of reducing the heat transfer rate significantly: reduce the log mean temperature difference (LMTD), or reduce the heat transfer area.

The first method is used with face and bypass control on a heating coil. As the face dampers are closed, the mass flow of air is decreased, causing the leaving air temperature to rise, which lowers the LMTD and decreases the heat transfer rate. In the limit, heat transfer ceases only when air flow stops completely, and the coil is completely immersed in stagnant air at the steam temperature.

Another common approach to reducing the LMTD is that used extensively in standing radiator systems—the LMTD may be decreased by reducing the steam pressure. The effect of this reduction, however, has significant limitations. Reference to the steam tables and application of elementary heat transfer relationships reveal that if a device is to operate at design capacity of 5 psig, a reduction to 0 psig reduces the heating capability to 90 percent of design. A reduction to 15 in. Hg vacuum (½ in. atm) reduces the capacity to 70 percent of design. When applied to commercial piping system practices, it is difficult to sustain absolute pressures much lower than this. However, if the need were recognized, improved piping systems might be developed.

Heat transfer area reduced

If the heat transfer area is reduced, the analogy of the refrigerant system can be employed again. With low ambient (or air-cooled) head pressure control where a receiver is employed, when the head pressure tends to drop, some of the condenser heat transfer area is "flooded" with liquid. With proper design attention, this principle can be employed with steam heating load devices. As the load decreases, the heat transfer device is simply filled with liquid or condensate. The occurrence of this phenomenon without preplanning in many steam systems has caused numerous problems, ranging from frozen coils to overflowing condensate receivers.

Another method of flooding a steam condenser or heat exchanger is to partially charge it with a noncondensable gas. This approach has been employed as a problem-solving technique to prevent problems caused by liquid flooding. The hardware was quite crude: A simple vaccuum breaker on the condenser (or heating device) created an equalized pressure between the condenser and a vented condensate line, allowing the liquid water to be replaced with air. This technique, however, accelerates corrosion in the condensers and condensate systems. If the system designer were to initiate the design with this concept, very likely both problems could be prevented.

Four components of system

The four basic components of a two-phase thermal system are the source (in a steam system, the boiler or steam generator), vapor distribution (steam piping), the load or condenser (heat exchanger, heating coil, absorption refrigeration generator, etc.), and the return system. Other subsystems or components simply serve as control devices to allow successful operation with varying loads or other dynamic system responses. Return pumps, vacuum inducers, traps, control valves, etc., are not characteristic or necessary basic system components, except as they satisfy the control parameters. As an example, the so-called heat pipe is a functional two-phase thermal system. It utilizes opposite ends of the same pipe as a source and condenser, the center area as a vapor distribution system, and a wicking material as the return (using capillary action forces to motivate the liquid flow from the condenser back to the source).

Development of control and regulation devices or components must originate from a thorough understanding of the uncontrolled input—the load or condenser.

As previously discussed, on the basis of Fourier's equation, extended to steady-state flow in a heat exchanger:

$$q = \mathrm{UA}\ (\mathrm{LMTD}).$$

It was mentioned above that two elements of control were the heat exchange area and the LMTD. If one considers how either of these variables can practically be achieved with a control valve, then explores what happens when it closes, two options emerge: The area is decreased by flooding with liquid or noncondensable gases, the LMTD is decreased by reducing the steam pressure, or a combination of the two.

If a system designer selects the option(s) he desires and commences work on the system from that selection, the state of the art update starts moving forward. The solution to this problem (or methodology following the selection) inevitably leads to the return system.

Consider these examples

- *Flooding with liquid*—In past systems, if load reduction was achieved by liquid flooding, the steam trap would open, but when the pressure in the condenser was lower than the pressure in the return line, the fluid (liquid, vapor, or air) in the return line would move into the condenser rather than the liquid moving out. This process would continue until the condenser was flooded with liquid (or air from the return line).

- *Flooding with noncondensable*—The common method of achieving this was to install a vacuum breaker on the condenser such that when the pressure dropped below atmospheric, air would be drawn in through the breaker flooding some of the heat transfer surface. As the load again increased and the valve opened, the air would usually be purged into the return.
- *Reducing the steam pressure*—As mentioned above, the concept of reducing the heat transfer rate by reducing the pressure appears valid in principle; since the condenser component is at saturation conditions, reducing pressure also reduces temperature. However, the limitations in materials and methods seriously restricted the load reduction capabilities, and the result was a combination of pressure reduction and some form of flooding for load reductions below 70 percent of design.

Return piping design critical

When these characteristics are approached analytically, the conclusion which surfaces is that the key to successful design (anticipating the dynamic response phenomenon) is the design of the return piping system and the method of interconnecting the return piping system and the condenser. One finds that virtually nothing has been published in the past 35 years on condensate piping system design, except problem-solving ideas.

Although it may not have seemed obvious to many designers throughout this period, the steam trap is actually a system control device. As such, it has been incorporated into systems with little regard for its actual function, save isolating the steam side from the condensate side. When these traps opened under reduced-load conditions, the result has been far from that anticipated by the designer in many cases (or even by the trap manufacturer). The exact nature of the result depended upon the fluid in the return system into which the trap was connected.

In summary, if the advantages of two-phase thermal systems are to be realized in systems designed in the coming years, in which energy economics, maintenance, and systems reliability are becoming ever more paramount, extensive well-directed research and development in dynamic response, and yes—the lowly steam condensate system—must be addressed.