Broaden Your Knowledge about Condensate Pot

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Introduction

Steam condensate recovery is an essential requirement for enhancing the overall performance, reducing the operation cost and having trouble free operation of steam–heated shell and tube heat exchangers. Energy consciousness and environmental awareness have transformed condensate from an inexpensive byproduct of steam distribution to a valuable resource that can substantially reduce operating costs. From plant operation point of view, effective condensate removal guarantees smooth operation, no hammering and reduced corrosion as well.

This note briefly reviews the various options used in steam condensate recovery system and focuses on the condensate pot's design and operational considerations.

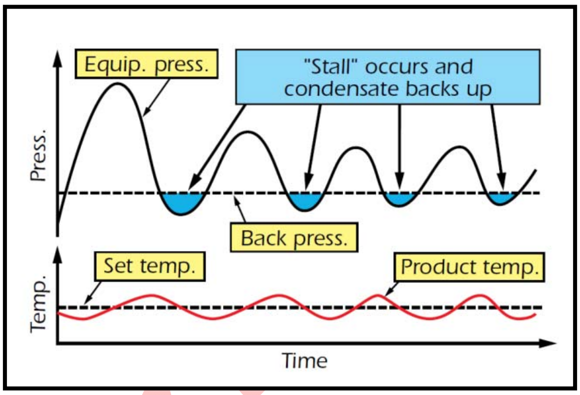

Figure 1 – Effect of Heat Exchanger Flooding

Importance of Condensate Recovery

Successful removal of condensate is a key factor in preventing stall, a phenomena that is often observed during operation of steam-heated heat exchangers. In short, stall prevents condensate from being discharged from the heating equipment. It occurs when the steam pressure in heating equipment drops below condensate header pressure causing condensate reverse flow and flooding heat exchanger with condensate.

During normal operation, the supply of steam (controlled by pressure of flow control valve) ensures that the pressure inside the heat exchanger is high enough to efficiently drain the condensate to the condensate header. However, when the demand for steam is reduced, steam control valve starts closing to match the heating requirement. This will reduce the pressure in heat exchanger and this may be too low to enable efficient discharge of steam condensate. If the heat exchanger pressure drops to condensate header pressure or below, condensate then backs up in the heat exchanger, and the equipment becomes condensate logged. This condition is known as stall. When condensate is backed up inside the equipment the product temperature falls. The control system compensates by opening the steam control valve again. Steam pressure increases and when it becomes greater than condensate pressure, condensate is pushed out of the system, and the cycle begins again.

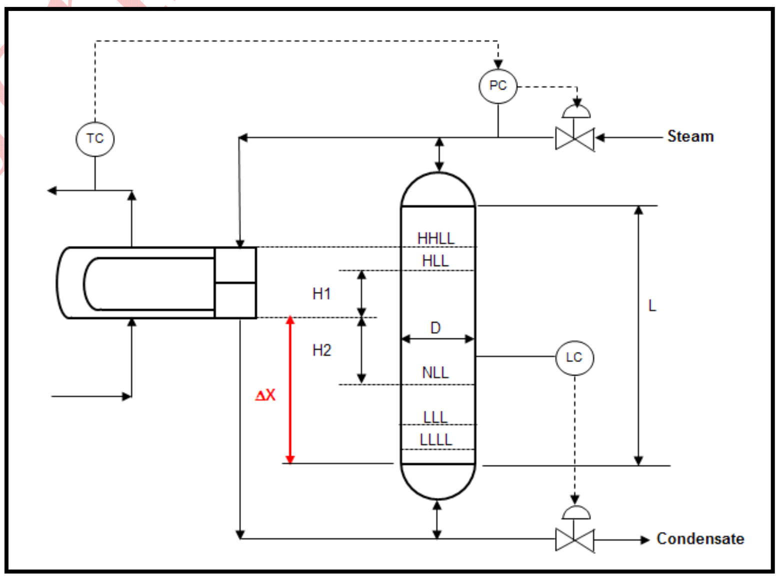

Figure 2 – Process Control via Steam Temperature Manipulation

This results in:

- **Process Temperature Swing;** as the stall cycle repeats, the steam pressure in the equipment varies above and below the backpressure causing product temperature and quality to fluctuate.
- **Water Hammer Damage;** water hammer can occur when backed-up condensate re-evaporates, or as the incoming hotter steam comes in contact with cooler backed-up condensate and is instantly condensed.
- **Tube Corrosion and Damage;** backed-up condensate in the equipment can form carbonic acid, which results in tube corrosion. Equipment temperature fluctuations can cause thermal shock and fatigue damage to the tubes.

Correct design of condensate recovery system including proper selection of condensate recovery device, equipment sizing and using right control system configuration will help to prevent these problems.

Process Control Strategies

There are two mechanisms for controlling heat transfer rate (U A ΔT). The first mechanism is to change heat transfer rate by changing the steam temperature (ΔT). With a control valve on steam supply, changing the valve position affects the heating fluid pressure and its corresponding temperature, which affects the heat transfer rate. When this mechanism is used along with steam trap or condensate pot with level control, heat exchanger is subject to back flooding and associated problems mentioned in previous section.

The second mechanism is to change the heat transfer area (A). With a control valve on condensate return (Figures 2 or 3), manipulating the valve position affects the effective heat transfer area of the exchanger. The effective area for heat transfer is the heat transfer surface exposed to steam; the submerged surface area has little contribution to the total heat transfer rate. With this configuration, heat exchanger tubes are intentionally flooded to control the process temperature. Heat exchangers are usually designed with limited area overdesign (typically 10%), therefore slight flooding should be enough for control purpose. Further flooding is required when heat exchanger is clean or in turn down condition. Heat exchangers with substantial area overdesign will suffer from flooding side effects during normal operation.

Condensate Recovery Devices

In any steam distribution system in a process plant, the condensate requires some means to guarantee continuous drainage of condensate. The most common means are:

- Steam Trap
- Condensate Pot
- Condensate Pump
- Pump Trap

Steam Trap: Steam traps are widely employed to drain condensate and vent non-condensable gases from heat exchangers. Because of the internal mechanism, steam traps drain liquid once it is condensed and keeps all heat exchanger area available for heat transfer.

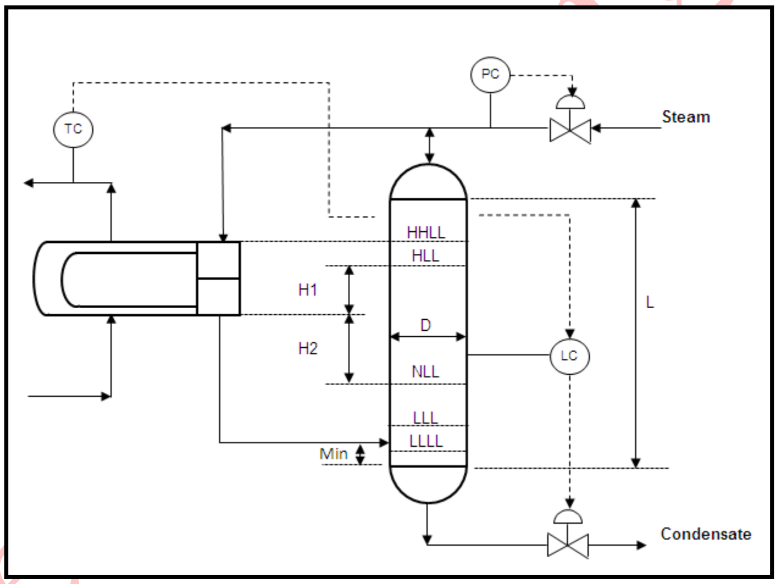

Figure 3 - Process Control via Heat Transfer Area Manipulation

Condensate Pot: The condensate level in the collection pot can be controlled using independent level controller or temperature-level cascade controller. The level controller version incorporates a modulating steam valve for process side temperature control (Figure 2), whereas the temperature-level cascade controller system uses a constant pressure steam valve and varies the exposed heat exchanger surface area by flooding the vessel with condensate (Figure 3). While both options provide process temperature control, neither is without potential performance and equipment integrity problems.

Condensate Pump: Using conventional centrifugal or positive displacement pumps with a condensate receiver at suction can be an option where other alternatives are ruled out.

Pump Trap: Incorporating a mechanically actuated pumping device driven by air, other gas, or steam, called a pump trap, is another alternative (Figure 4). This approach allows the heat exchanger to operate at its lowest possible pressure while maintaining a consistent outlet process temperature profile minimizes energy consumption. Complete, effective removal of condensate under all operating conditions allows a heat exchanger to operate with minimum corrosion on the tube bundle, assuring its structural integrity by lessening the potential for destructive water hammer. Compared to conventional pumps, pump traps can often lead to significant capital cost savings, by reducing the skirt height required for exchangers or reboilers, sometimes to as little as 4 ft.

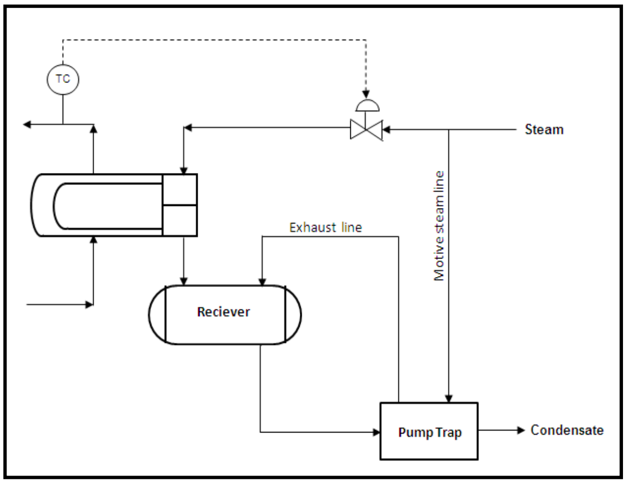

Figure 4 – Pump Trap Piping Arrangement

Table-1 represents the advantage and disadvantage of various condensate recovery devices.

Table 1- Condensate Recovery Device Comparison

Device	Advantage	Disadvantage
Steam trap	1- Inexpensive 2- Simple installation with minimum piping and instrumentation	1- Needs periodical maintenance to prevent failure causing steam break-through and steam hammering 2- Allows condensate to back up and flood the heat exchanger causing loss of thermal performance, corrosion and water hammer
Condensate pot with independent level control	1- Manual adjustment of heat exchanger surface area to match with actual thermal requirements	1- Costlier than steam trap with more piping and instrumentation devices 2- Same as item 2 in steam trap 3- Needs operator intervention to change level control set point with respect to heating requirement
Condensate pot with level control cascaded with process temperature	1- Automatic adjustment of heat exchanger surface area to match with actual thermal requirements 2- Prevents unintentional flooding as condensate pot pressure is kept always above condensate header pressure	1- Same as item 1 in condensate pot with independent level control 2- Since heating equipment flooding is required for process control reasons, corrosion still exists.
Condensate Pump	1- No flooding as it will send the condensate even with heat exchanger working at a pressure lower than condensate header 2- No tube corrosion and water hammer and thermal shock	1- Costlier than condensate pot 2- NPSHA requirement may dictate highly elevated heat exchanger at suction 3- Rotating machines need more maintenance due to seal, bearing and impeller damage
Pump Trap	1- Same as item 1 in condensate pump 2- Same as item 2 in condensate pump 3- Needs substantially lower static head at suction (NPSHA) to operate compared to condensate pump	1- Same as item 1 in condensate pump

Condensate Pot Sizing

Sizing of pot is has a close relation to heat exchanger thermal rating and hydraulic calculations.

Step 1- Calculate the condensate pot diameter; $A = Q\ T_1 / S$

Where

$T_1 = 1 - 1.5$ minutes

$S = H_1 + H_2$ (min 300mm)

Neglecting the pressure drop of piping and heat exchanger during turn down condition, the height of liquid in condensate pot required to achieve proper process control can be estimated using below relation. Due to this assumption, the liquid level in the pot will be slightly lower than H_1.

$H_1 = (1 - \text{Turndown Percentage}/100) * C$

For horizontal heat exchanger, C = tube bundle diameter

For vertical heat exchanger, C = tube bundle length

$H_2 = (\Delta P\ \text{piping} + \Delta P\ \text{heat exchanger}) / (\rho_L\ g)$

Piping include steam line from vapor balancing line connection to heat exchanger inlet nozzle and condensate outlet line from heat exchanger outlet nozzle to pot inlet nozzle or liquid balancing line connection.

The calculated (not allowable) pressure drop of steam side of heat exchanger at designed flow and fouled condition is used for this calculation. Since steam side is categorized as condensing service, steam side pressure drop should not be negligible.

Calculated diameter can be rounded up to the next nominal pipe internal diameter if it is going to be constructed from pipe. In order to have adequate mechanical strength, minimum supporting problems and proper nozzle opening on condensate pot, it is recommended no to use pot with diameter less than 500mm.

Step 2- Calculate the condensate pot length;

$L = C + H_2 + H_3 + H_4 + H_5 + H_6$

Where

$H_3 = Q\ T_2 / A$

T_2 = 1 minute Providing 1 minute between NLL and LLL will ensure that steam won't blow into condensate system because of level control action, process or steam fluctuations, causing steam hammering.

If there is low-low level trip, H_4 = 200 mm (100 mm min) otherwise $H_4 = 0$

To accommodate level instrument tapping, H_5 = 300 mm.

The condensate pot level is not expected to exceed H_1 in any operating condition (ranged from turndown to design condition, clean to fouled heat exchanger) as long as condensate is flowing and everything is under control. In view of this, setting the pot top TL with top of the heat exchanger tube sheet should be enough for operational and troubleshooting purposes (H_6 = 0). However, the most conservative approach may be is to provide H_6 of 300 mm.

ABBREVIATION	
A	Condensate pot area
C	Heat exchanger characteristic dimension
d	Condensate line internal diameter, m
D	Condensate pot diameter
L	Condensate pot length
g	Acceleration of gravity, 9.81 m/sec^2
H_1	Distance between heat exchanger bottom to flooded level in pot
H_2	Distance between bottom of tube bundle to pot NLL
H_3	Distance between pot NLL to LLL
H_4	Distance between pot LLL to LLLL
H_5	Distance between pot LLLL to bottom TL
H_6	Distance between top of heat exchanger tube bundle to pot top TL
LLL	Low liquid level in pot
LLLL	Low-low liquid level in pot
NLL	Normal liquid level in pot
HLL	High liquid level in pot
HHLL	High-high liquid level in pot
Q	Condensate volumetric flow rate
S	Condensate level span
T	Hold up time
TL	Tangent line
V	Fluid velocity, m/sec
ΔP	Pressure drop
ΔX	Differential head between heat exchanger
ρ	Fluid density

Design Details

- **P&ID Representation**

One of the main inputs from pot sizing calculations to P&D is the static head difference between heat exchanger bottom and condensate pot bottom TL which can be calculated as follow.

$\Delta X = H_2 + H_3 + H_4 + H_5$

- **Condensate Line Size**

Adequately sized condensate line should ensure:

1) Minimum pressure drop which reduces the differential static head between heat exchanger and pot TLs. This is important to reduce the size of pot and heat exchanger elevation from grade.
2) Self venting flow in the heat exchanger condensate outlet line. Presence of gas bubbles in the outlet condensate will reduce the density of liquid and cause liquid to expand and fill the heat exchanger. In this case, though condensate pot level is accurately controlled, but system is exposed to detrimental effects of flooding. In summary, for pipe equal and larger than 1" handling a fluid with viscosity less than 100cp, vapor bubbles can freely rise if liquid velocity is maintained less than the velocity calculated from below equation:

$$V = 0.31\sqrt{g\,d\left(\frac{\rho_L - \rho_g}{\rho_L}\right)}$$

Where ρ_L and ρ_g are condensate and steam densities respectively.

- **Vapor Balancing Line**

The purpose of vapor balancing line, as its name implies, is to equalize the pressure of condensate pot with heating equipment, prevent vapor blanketing the condensate pot and minimize the static head difference between liquid level in the heat exchanger and corresponding level in pot (H_2).

Vapor balancing line is not going to pass any specific flow rate; hence any size between 1" to 3" would be enough for this purpose.

- **Condensate Line Piping Arrangement**

Since heat exchanger flooding may create sub-cooled condensate, it is recommended to locate the condensate inlet close to pot bottom TL so that sub-cooled condensate exits out of the bottom of the pot without reaching the liquid surface (NLL) as shown in Figure 3. With adequately sized pressure balancing line, pot liquid surface is kept hot, and the pot pressure will remain at vapor pressure of hot liquid. As long as the liquid in the upper part of the pot is not agitated and does not contact the sub-cooled condensate, the flow of steam through a typically 1" equalizing line is sufficient to compensate system heat losses to ambient and heat transfer from hot surface to the sub-cooled condensate.

Another alternative is to connect the heat exchanger condensate line to the pot condensate outlet line as depicted in Figure 2. This arrangement may result in slightly longer pipe, higher pressure drop and subsequently bigger H_2.

Contact

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