Quenching the thirst for optimisation

Vinai Misra, Woodward, USA, explains how to improve quench control for refrigeration compressors.
Refrigeration quench systems are often used to separate heavier hydrocarbon liquids from compressed gas streams or for cooling compressed gas streams in the processing of natural gas liquids (NGLs), liquefied petroleum gas (LPG) and LNG, as well as in the production of ethylene, propylene, and ammonia liquefaction.

Because of the complexity and variability of these processes, a compressor’s refrigerant, if utilised, is typically injected and controlled manually by experienced operators when starting, stopping, and changing process levels. Injecting refrigerant too soon, too late, or too much or too little can have a huge and detrimental impact on process stability and, of course, the quality of the final product.

With their understanding of the interactions between a typical refrigerant process and the compressor train, Woodward’s engineers successfully developed and implemented an automatic quench control algorithm. This algorithm anticipates and adapts to changing process conditions, resulting in increased process stability, reduced startup and commissioning times, increased system reliability (fewer trip events), and simplified unit operation.

**Basics of quench systems**

Typical quench systems inject liquid refrigerant into a refrigerant compressor’s recycle line to provide cooling of the recycle line through the anti-surge valves (ASVs). Depending on system design, the quench liquid may be injected directly at the discharge of the ASV, upstream of the stage suction scrubber (see Figure 1), or directly at the stage suction knock-out (KO) drum. Whenever the ASV opens during startup, shutdown or normal operation, the
quench controller is designed to inject liquid refrigerant as a way of cooling the hot gas recycle path that is normally set directly by a process temperature controller. This controller action is referred to as ‘direct acting’, (i.e. positive error) resulting in an increase of injected refrigerant for an increase in recycled gas.

A typical closed-loop propane/propylene quench refrigerant system is shown in Figure 1.

**The importance of quench temperature control**

Whenever a compressor’s suction pressure is experiencing transient variations or the compressor is being operated outside its normal design conditions, adjustment of the quench temperature setpoint is required to ensure process stability and product quality. This setpoint variation can lead to one of two undesirable conditions:

- **Over-quenching**, where the setpoint is significantly below the dew point curve (Figure 2), which may result in:
  - High liquid level in the KO drum eventually leading to a unit trip event.
  - Liquid particles being pulled into the compressor’s inlet eventually leading to mechanical damage.
- **Under-quenching**, where the setpoint is significantly above the dew point curve, resulting in:
  - High compressor inlet temperatures leading to a compressor trip event on high-high discharge temperature, and a compromised compressor stage ratio.

Poor quench control can greatly exacerbate the startup and loading of a closed-loop refrigerant system. System startup pressures and temperatures may be somewhat different from designed operating conditions and the impact of these differences on the overall system is often ignored during initial system design.

Some of the common issues associated with trying to manually control refrigerant injection during process startups include the following:

- Tripping the compressor due to exceeding the compressor’s discharge temperature high limit.
- Tripping the compressor due to exceeding the suction KO drum’s high liquid level.
- Compressor overloading.

**Compressor startup-related issues**

A typical challenge during a process startup is successfully balancing process gas pressures, temperatures and related drum levels, without exceeding the equipment’s trip settings or overstressing the system. Before starting a compressor, quench refrigerant injection level is typically set to ensure a balance between the ambient process temperatures, process pressures, and drum levels. At this point, the compressor is not cooling the process gas, the chillers are not loaded, and the recycle valves are partially open, maintaining a safety margin from the compressor’s surge line.

During the compressor startup process, the partially opened recycle valves cause the refrigerant to be continually compressed and recycled, resulting in a rise in refrigerant temperature (see Figure 1) until the equipment’s high-temperature limit is exceeded and the compressor is tripped. To prevent this type of overheating action and resulting system trips, a quench system is often used to inject liquid refrigerant into the hot recycle gas path.

When high-pressure liquid refrigerant is mixed with low-pressure hot recycle gas, the refrigerant partially evaporates or ‘flashes’, thus increasing the vapour pressure and reducing the inlet gas temperature. The evaporation rate of the quenching liquid and the resulting cooling effect strictly depend on the recycle flow rate. Once this ‘flash’ limit is reached, an equilibrium recycle condition through the main condenser is established and the system is considered to reach its stable/equilibrium state.

In this state, a system limitation is that the temperature cannot be lowered more than a predefined level based on the ASV downstream pressure. This is due to the tight relation between pressure and dew point temperature as shown by the dew point curve of Figure 2. A related issue is that at this state if the quench controller’s setpoint is set lower than the corresponding dew point, the quench controller will then begin increasing the liquid refrigerant being injected until the amount of liquid in the gas path is too great and it cannot be flashed. Correspondingly, this excess liquid fills the suction scrubbers, which can often lead to high scrubber level trip events.

Once an equilibrium state is reached, many operators put the quench control into a manual operating mode to prevent trip events. However, manual control
tends to limit the system’s ability to make changes to injection levels based on process changes.

Woodward’s control algorithm prevents excess liquid level formation in the scrubbers. It lets the temperature control setpoint be adjusted automatically with the inlet pressure based on the refrigerant’s dew point. This allows the system to reach and maintain flash point equilibrium even with changing process conditions.

Prime mover related issues

Achieving successful compressor startups also depends on the compressor’s prime mover (turbine or motor) sizing and performance. Variations of boundary conditions (e.g. loop starting pressure and steam header pressure) can complicate and compromise unit startup. Because it adds mass flow to the compressor’s inlet, the quench system can greatly impact the load and performance of the prime mover. To reduce this prime-mover-loading effect during compressor startups, operators often manually manipulate the quench valves to improve starting times. However, this action then limits the effectiveness of the quench system during this critical startup process and its ability to maintain the overall discharge temperature below a safe limit.

Because of the interactions between the overall process and the compressor train, there is a lot to consider during a process and compressor startup. Woodward’s field-proven control algorithms monitor these interactions and automatically compensate for them within set limits, greatly simplifying process and compressor startups.

Loading related issues

During the loading phase of a refrigerant compressor, operators often must address the occurrence of numerous trip events. Once started, the compressor is typically loaded by enabling the system’s suction pressure controller, which then varies compressor speed or throttle valve position to load the compressor and maintain the target suction pressure. During this loading phase, if the quench controller is not properly managed, a large decrease in suction pressure often results in a high KO drum level trip (due to over quenching). It can also result in high inlet temperature, compromising the performance of successive compressor stages. The advantage of Woodward’s quench control algorithm is that it anticipates and compensates for system changes during the loading phase. By automatically adjusting the controller’s target setpoint, the algorithm eliminates typical system loading issues.

Standard quench valve control limitations

Because of the many different controllers within a typical refrigeration compressor process and their interactions, many plant operators will switch these controllers to a manual mode during system startup. That includes manual operation of the quench.

Although this may appear to the operator to simplify system startup, manual quench valve control can often result in longer and more complicated system starts.

There are several shortcomings of the standard control of quench systems, including the following:

- Any manipulation of multiple quench valves, ranging from two to four valves, can trigger the anti-surge controllers to respond – and that in turn requires additional quench valve adjustment. This continuous adjustment makes it extremely difficult for the operator to ensure a smooth compressor startup.

- Compressor stage recycle flow is affected by the level of refrigerant injected in the recycle path. If too much liquid is injected during startup, this action may result in forcing the compressor stage towards a surge limit line.
Even when the operator can successfully manually keep the suction scrubber levels within safe limits, the amount of quenching may still not be optimum. This may result in a compressor overload condition eventually tripping the unit due to an over-motor current condition.

Designed to optimise quench levels during both compressor startup and shutdown phases, Woodward’s quench control algorithm virtually eliminates the need for operator intervention.

**Shared stage-to-stage quench control**

For a typical gas compressor, the maximum compressor discharge temperature level determines the minimum required total quenching level during initial startup. However, the amount of recycle path quenching at each stage can vary based on process operating conditions, complicating control. To ensure that the maximum compressor discharge temperature level is not reached, Woodward’s quench control algorithm for each stage utilises a shared control architecture allowing all the stage quench controllers to function together and protect the compressor and process. This approach also acts as a permanent discharge temperature limiter to safely protect the compressor during possible hazardous operations by using a shared control logic across the quench temperature control valves (TCVs).

Since the quench system is meant to cool down the hot ASV recycle gases, there is a tight relationship between the ASV control and the TCV control. The Woodward algorithm involves de-coupling the ASVs and TCVs, variable suction temperature setpoint control, discharge temperature limiting, startup assistance, and anti-surge transient assistance. By coordinating control of ASVs and quench control valves, the algorithm ensures safe and optimal operations during transients – without the need for manual intervention.

This approach yields benefits such as:

- Avoiding unnecessary trips due to prime mover overload.
- Avoiding high discharge temperature trips due to compressor discharge pressure and quench level misbalance.
- Avoiding suction scrubber high level trips due to the excessive injection of cooling refrigerant.
- Avoiding pulling liquids into the compressor which could damage the compressor.

**Automatic quench control optimises compressor functionality**

An advanced automatic quench control algorithm is now in operation on multiple compressors and processes throughout the world. The algorithm automatically optimises quench refrigerant injection by adapting to changing compressor and process conditions during all phases of operation. This type of adaptive control algorithm has been proven in multiple sites to increase process stability, reduce startup and commissioning times, increase system reliability (fewer trip events), and simplify unit operation. **LNG**