Temperature Measurement in Distillation Processes

Thermocouples and RTDs are both used in distillation and fractionation processes. Here's a comparison between the two sensor types, and advice on where to use each.

By Ehren Kiker, Product Marketing Manager - Pressure/Temperature, Endress+Hauser

Figure 1: Thermocouples and RTDs are used in distillation column cooling processes.

Temperature measurement is a common control parameter in distillation cooling and heating processes (Figure 1). Temperature control relates to product quality, process optimization and stability, resulting in improved plant safety and reduced process energy costs. While a seemingly simple parameter, understanding the importance of temperature measurement is critical to running a distillation column at peak efficiency.

In this article, we'll consider various cooling and heating distillation processes, how thermocouples (TCs) and resistance temperature detectors (RTDs) compare in these and other applications, and some recent advances in sensor technology.

Distillation is Cool

Distillation is a common process in many chemical and petrochemical plants. It's the process by which multi-component mixtures are separated into various products based on differing volatilities. It works by applying and removing heat, vaporizing the lower-boiling point/higher volatility components, while less volatile components remain in liquid phase.

Depending on the application and process fluid, temperature control may be used for cooling distillate to condense high volatility products into liquid phase, or heating of process fluid to vaporize the high volatility components for easier separation.

Cooling Methods

Distillate cooling is typically accomplished via several methods: fin fan cooling, refrigeration or cooling towers. The first two methods are used to cool process vapors, causing them to condense into liquids that can be recirculated for additional processing. Cooling towers are used extensively in chemical processes to cool steam and heating water and recirculate the condensate to plant utilities or reboilers where it can be reheated and used for a variety of purposes.

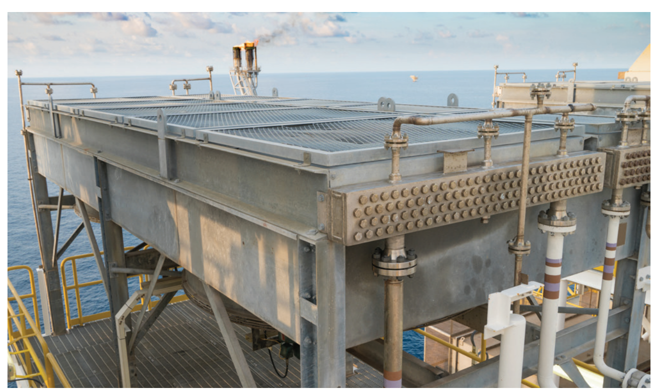

Figure 2: Fin fan heat exchanger coolers are used to cool distillates.

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Fin fan cooling (Figure 2) works by running process vapors through a tube bundle. These bundles have fins around the outside, increasing the surface area of the tube and speeding the cooling process. Large fans are used to create airflow over the tubing. Fan speed is adjusted via a variable speed motor to provide sufficient airflow to reach the desired cooling temperature while minimizing energy costs.

TC or RTD sensors measure the temperature of the process fluid. This temperature is then used as the PID process variable to control the speed of the fan motor via the variable frequency drive.

Refrigerant systems run a coolant (e.g. ammonia) though tubing. Compression and expansion create large temperature drops to cool process vapors running through the cooling area. This method is typically used in applications where extremely low cooling temperatures are needed. In the case of refrigerant cooling, temperature measurement is used to control the flow of coolant through the system. TC or RTD sensors monitor the temperature of the process fluid inside the area being cooled, adjusting the fan speed to facilitate the condensation/expansion of the coolant to provide the required cooling and regulating control valves to limit the flow of coolant.

Cooling towers are air-cooled systems that work via direct heat transfer between air and the water being cooled. In cooling towers, air and water are brought into direct contact to reduce water temperature. As the temperature of the water drops, a small amount of it evaporates, reducing the temperature of the water being circulated through the tower. Water that has been heated by other processes is pumped to the cooling tower, where it first is sprayed through nozzles to create small droplets, exposing more of the surface area of the water for maximum air-water contact. Once cooled, the water can be sent to various parts of the plant where it can be used for plant utilities or sent to boilers where steam is needed for process such as distillation columns.

TC or RTD sensors monitor the temperature of the water being cooled. A controller adjusts fan speed to facilitate evaporation of water droplets to speed the cooling process while insuring electrical energy is not wasted by running the fan faster than required. Cooling towers are widely used in chemical processing because they require no special coolants and are relatively energy efficient.

TC and RTDs are interchangeable in most cooling systems. However, RTDs have become the de facto standard in most industrial cooling processes because of more consistent repeatability.

Hot Fractions

In addition to cooling processes for distillates, heating processes are involved when handling distillates. Fractionating or distillation columns are used in chemical processes to separate mixtures into their component parts, or fractions. Fractions are based on differences in volatility (i.e., boiling point).

Distillation columns work by monitoring and controlling heating temperatures. Temperature varies vertically throughout the column, controlling the boiling point at specific heights within the column so fractions can be collected for additional processing. Process fluids inside the column are heated by process vapors coming from the reboiler. In many columns steam jackets are also used to maintain the temperature profile within the vessel.

Multiple temperature sensors are mounted in-situ to measure the temperature of the process fluid inside the column. Outputs from the sensors are used to control heating of process vapors and maintain the column's temperature profile by opening and closing control valves to inject more heated process vapors from the reboiler or steam into the steam jacketing.

As with cooling systems, RTDs have become the de facto standard for distillation columns. However, TCs are used where temperatures exceed the allowable limits of RTD sensors (> 800 C).

TCs vs RTDs

TCs and RTDs are the most common sensor types used in distillation and refining processes. In most cooling applications there is little difference between the two; however, there are some differences which can be relevant in certain applications.

TCs provide wide rangeability, with a variety of sensor types available to match to specific process conditions. TCs can measure extremely hot and extremely cold temperatures. RTDs work on the principle that as a circuit is heated the resistance across the circuit increases proportionally. While the response time of TCs compared to RTDs is relatively fast, response time differences between RTDs and TCs are irrelevant when the sensor is placed inside a thermowell—that's because response time delays introduced by the thermowell are much larger than those due to RTD and TC delays.

Thermocouples are relatively standard across manufacturers and must follow international standards. Any differences are usually manufacturer-specific and are secondary to the sensor itself (e.g., using solid MgO insulation vs. powder).

Advantages of thermocouples:

- Variety of TC types to select for appropriate temperature range
- Types available to measure extremely hot temperature ranges (e.g., furnaces) or extremely cold temperature ranges (e.g., cryogenic service)
- Fast response time compared to RTDs
- Easy to obtain from many local manufacturers

Disadvantages of thermocouples:

- Variety of TC types can make selection and stocking more difficult
- Price can vary greatly depending on TC type and materials of construction
- Measurement profile not linear and varies widely for different TC types
- Measurement accuracy and repeatability not as good as RTDs
- Quality between manufacturers can vary significantly

One consideration that should be given to temperature measurement in distillation columns with TCs is whether to use single point thermowells or multipoint measurement systems. In most distillation columns, there are at least five temperature measurements that must be made at different elevations on the column. With single point thermowell systems, each measuring point requires its own thermowell and sensor, as well as its own process connection on the column.

The advantage to this is that it means process owners can typically work with "standard" designs from TC manufacturers, which helps keep costs down and makes for quick delivery turnarounds. The disadvantage is that each process connection is a potential leak point and the risk grows with each additional measuring point added to the column.

Multipoint measuring systems (Figure 3) allow for a large number of sensors to be located at precise locations within a column, with only one process connection required in most applications. The obvious advantage to such a system is the reduction of potential leak points because there is only one process connection. The disadvantage of such systems is that they can be difficult to install in distillation columns due to the number of obstructions within the vessel.

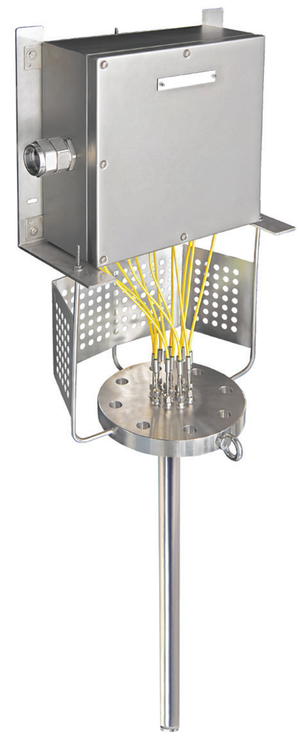

Figure 3: Endress+Hauser's MultiSens has multiple TCs that can extend as far as 100 feet from the sensor head.

Selecting RTDs

While more limited in temperature range compared to TCs, RTDs offer much greater repeatability and accuracy, and are available in models with a fast response time.

RTDs are available as three-wire and four-wire thin-film (TF) sensors, or wire-wound (WW) sensors. TF sensors are more robust and less susceptible to damage by vibration, but are limited to a narrow temperature range (0-600 C); WW sensors are capable of a wider temperature range (-200 to 800 C), but are more susceptible to vibration damage.

Four-wire sensors offer a slightly better measurement accuracy than three-wire, but in most applications the difference is not significant. In applications where dual sensors are needed for sensor backup, only three-wire sensors can be used. This is because basic RTDs consist of two wires. Both wires contribute to the overall resistance, so additional wires are needed to "compensate" the resistance of the wire from the resistance caused by heating of the sensor.

Three-wire RTDs have only one additional wire, which compensates by taking the average resistance of the two wires and assuming that resistance across each is the same. Four-wire RTDs have a dedicated compensation wire for each sensor wire, ensuring that the true resistance of each sensor wire is not included in the resistance measured by heating of the sensor. Three-wire RTDs also have the advantage of being able to be supplied as dual-sensor elements providing a built-in hot backup in case the primary sensor fails.

WW sensors are typically selected for their slightly wider temperature rangeability than TF sensors and improved vibration resistance. If excessive vibration is present, it's best to choose a vibration-resistant RTD.

Advantages of RTDs:
- Highly repeatable
- Excellent accuracy
- Can be provided with faster response times and stronger vibration resistance (manufacture specific)

Disadvantages of RTDs:
- Standard sensor can be slower to respond than TCs
- Limited temperature ranges (-200 C to 800 C)

It should also be noted that the measurement accuracy of RTDs can be greatly improved when using a transmitter and determining the sensor-specific coefficients of an equation known as Callender Van Deusen (CVD). This is known as sensor-transmitter matching, and it can greatly improve the accuracy of temperature measurement for applications where high accuracy is critical. The benefit of the CVD coefficients is that they are unique for each individual sensor, and can easily be updated in the transmitter without having to remove the transmitter for calibration with the sensor.

Summary

Good temperature measurement and control practices are critical to efficient, safe and profitable operation of distillation and fractionation processes. TCs and RTDs can be used interchangeably in cooling processes, but care must be taken at higher temperatures to select the right sensor.

About the Author

Ehren Kiker is Product Marketing Manager for pressure and temperature products at Endress+Hauser. He has more than 20 years of automation experience focusing on process measurement instrumentation.

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