Flexible Cooling

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Liquid nitrogen can provide improved process flexibility to meet the rapidly changing demands of a challenging economy.

One of the realities of doing business that many manufacturers will face for the foreseeable future is reduced access to capital. Forecasting demand growth to justify capital expenditures is challenging when input costs and other factors can change dramatically in a short amount of time. (The recent run-up and subsequent decline in energy and commodity prices represent one example.) To address this situation, more flexible processes should be used where practical so that overall operations can be more easily ramped up or down as needed.

One way to introduce more flexibility into an existing process is by using liquefied atmospheric gases such as liquid nitrogen (LIN) in process cooling. This option is attractive because significant capital outlay often is not needed to achieve additional process flexibility. When higher demand creates a need for more cooling, cryogenic fluids can be used to increase capacity. And when the demand declines, there is little additional capital equipment that must sit idle.

Several key properties of nitrogen make it particularly well-suited to process cooling applications. As a refrigerant, liquid nitrogen can cool materials to extremely low temperatures — a characteristic that can be critical in some applications. LIN is inert and does not change the chemical properties of the material being cooled. When warmed, LIN converts to gaseous nitrogen, which can be removed easily and completely from most products without leaving any residue. Additionally, LIN has a high amount of heat capacity and therefore can be used in a range of industrial applications.

Different industries have taken advantage of some or all of the properties of LIN to achieve manufacturing objectives within their operations. In the food industry, for instance, the susceptibility of many products to thermal degradation has led to the development of numerous applications where LIN is used either as the primary refrigerant in the process or as a supplemental source of refrigeration. Also, grinding and powder generation processes use cryogenic liquids to remove heat added from frictional forces in grinding, pumping and conveying equipment.

Thermodynamics of Process Cooling

Adequate cooling capacity is a frequent bottleneck in many processing and manufacturing plants. The amount of heat removed from a process stream \( Q \) is a function of the stream properties and the temperature change, as shown in the equation:

\[
Q = m \times C_p \times (T_1 - T_2)
\]

where \( m \) is the mass of the product sample in kilograms (kg); \( C_p \) is the specific heat of the stream in \( \text{kJ/kg-°C} \); and \( T_1 \) and \( T_2 \) are the temperatures before and after the process in °C. The starting temperature \( T_1 \) typically is determined by upstream processing conditions such as the furnace temperature for a heat treating process or the ambient temperature for a food harvesting process.

The final temperature \( T_2 \) typically is based on the downstream needs such as the optimal temperature for increasing shelf life and quality for a fresh food product.

This analysis assumes that the specific heat is constant over the particular temperature range and that the product temperature does not vary internally. When these assumptions cannot be satisfied, a more accurate technique for measuring the amount of heat dissipated in a sample is to measure the change in enthalpy directly using a calorimetric technique. A differential scanning calorimeter (DSC) is one such device, but it can be complex to operate and requires some specialized skills to use correctly.

Another useful technique is based on measuring the amount of heat needed to lower the temperature of a sample to the boiling point of LIN at atmospheric pressure. When a sample is introduced into a dewar of LIN, the mass of LIN evaporated is directly related to the starting temperature, heat capacity (i.e., internal energy) and mass of the sample. Comparing the ratio of LIN evaporated to the sample mass for the two conditions tested provides a measure of the change in enthalpy (\( DH \)) when multiplied by the heat of vaporization of LIN at atmospheric pressure (\( H_v \) is 198 kJ/kg), as shown in this equation:

\[
DH = Hv \times \left( \frac{m_{LIN evaporated}}{m_{sample}} \right)
\]

Because heat cannot be lost or destroyed, an equal amount of heat must be added to or removed from the process system in a corresponding process stream. In most cases, the transfer of heat (or cooling) will be less than 100 percent efficient due to any number of deficiencies in the processing equipment; therefore, usually more cooling than what is theoretically needed is provided. A thorough analysis of the process can be used to identify where potential improvements can be made to enhance the overall efficiency of the heat transfer step.

With the required amount of cooling calculated from the two equations shown, the necessary amount of cryogen can be estimated based on its latent and sensible heats. The exhaust temperature of the nitrogen gas often can be estimated from previous experience or measured experimentally. Well-designed process cooling equipment will capture the maximum available refrigeration consistent with all other process constraints. By determining the ratio of LIN needed to achieve the...
desired degree of cooling (i.e., kg LIN/kg product), a plant then can use the appropriate variable to estimate the anticipated operating costs for LIN in the process. In most cases, the overall cost of cryogenic cooling can be determined by the amount of liquid nitrogen consumed.

**Cryogenic Cooling**

LIN has several advantages when used for process cooling. Because it is inert and relatively easy to separate from solid or liquid product streams, LIN often can be added directly into many processes. In many cases, LIN can be used without a requirement for additional processing equipment such as heat exchangers or mixers. Table 1 lists some processing applications where LIN has been used successfully to provide cooling.

The range of equipment where cryogenic cooling can be applied depends on several key attributes. From a safety perspective, it must be possible to isolate the process stream from the building environment and vent the gas to a safe location. Because nitrogen gas is a simple asphyxiant, adequate oxygen must be available at all times. Provision must be made for the substantial expansion of LIN when it is transformed into the gaseous state. Processing equipment must be constructed of appropriate materials designed to operate at the extremes of temperatures possible when working with cryogens. Finally, the process to be cooled must have adequate engineering systems and insulation to protect operating personnel from the hazards of cryogenic burns (tissue damage) that can occur from cold process equipment. An industrial gas supplier or appropriate agency should be consulted prior to implementing a cryogenic cooling process.

In addition to these safety constraints, it usually is necessary to demonstrate that contact with LIN will not cause any material changes in the product being processed. Though nitrogen is inert under typical processing conditions, it can be soluble in some process streams and cause undesirable changes such as excessive bulking in the physical properties of some products. Similarly, the process must have a provision for venting of the nitrogen. In many cases, venting can be handled adequately within the existing process. An example would be the use of a cyclone and baghouse for the separation or classification of powders. In other cases, simple dilution of the nitrogen stream might be adequate.

LIN-based cooling typically is more expensive on a per-BTU basis than other coolants such as water and air. Because LIN is used as a stoichiometric refrigerant and is not recovered in most processes, it also can have a higher operating cost than other approaches. However, for applications that require direct-contact cooling or the ability to cool to low temperatures without leaving residue on the cooled material, the additional expense is a justifiable trade-off. The enhanced process flexibility provided by LIN is yet another reason to consider this cooling method. Lower-cost cooling methods such as air or water chilling often can be combined with LIN cooling to create a more economical process.

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