How to Improve Reliability and Safety of Air Separation Units

EMERSON

Industrial gases are an important feedstock for many process manufacturers

Here are practical tips for plants using an on-site air separation unit to processes these gases.

Many industrial processes require various gases in large volumes as feed-stocks and for ancillary applications (Figure 1). Large chemical and petrochemical complexes are the largest segment of the market at 25%. These plants and facilities use oxygen, nitrogen and argon for multiple purposes throughout the plant. Oil producers and terminals often fill the head space of storage tanks with nitrogen to reduce the risk of fire. A steel mill with a basic oxygen furnace can consume many tons of oxygen when converting iron to steel, contributing to the metals and materials market segment of 15%.

These gases are captured from the air we breathe by separating its atmospheric mix into its various components, with up to six gases recoverable on a practical basis.

While there are several mechanisms able to accomplish these separations, most are only practical on a small scale. When gas volumes measured in tons are required, the only commercial-scale process is cryogenic distillation, where air is liquefied and then separated by fractional distillation into its components. Nitrogen and oxygen are the primary products, but trace gases, primarily argon, can be extracted where needed.

Gold Base Chemical Production Over 800M Tons Per Year

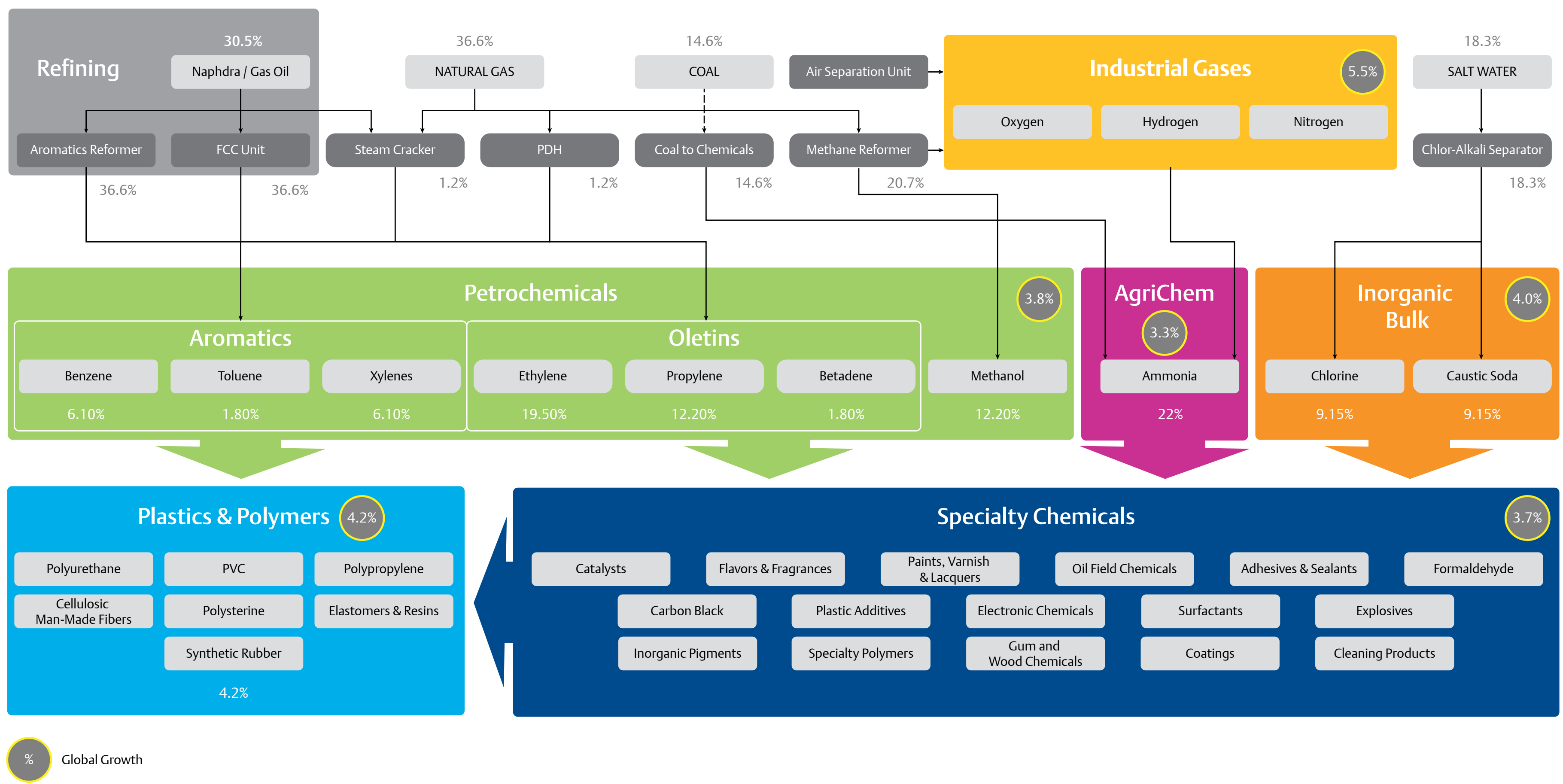


Figure 1: Industrial gases (yellow box, upper right) accounts for a major percentage of global chemical production.

A Quick Look at the Process

To start, think about the basic steps of the process (Figure 2). Air is drawn into a multi-stage compressor train, passing through inter-coolers to reduce its temperature. Once compressed, to 8 bar (115 psi) typically, the air is chilled further using a direct-contact water cooler, which also captures remaining particles. The next step is a molecular sieve to remove any hydrocarbons, carbon dioxide, and water vapor.

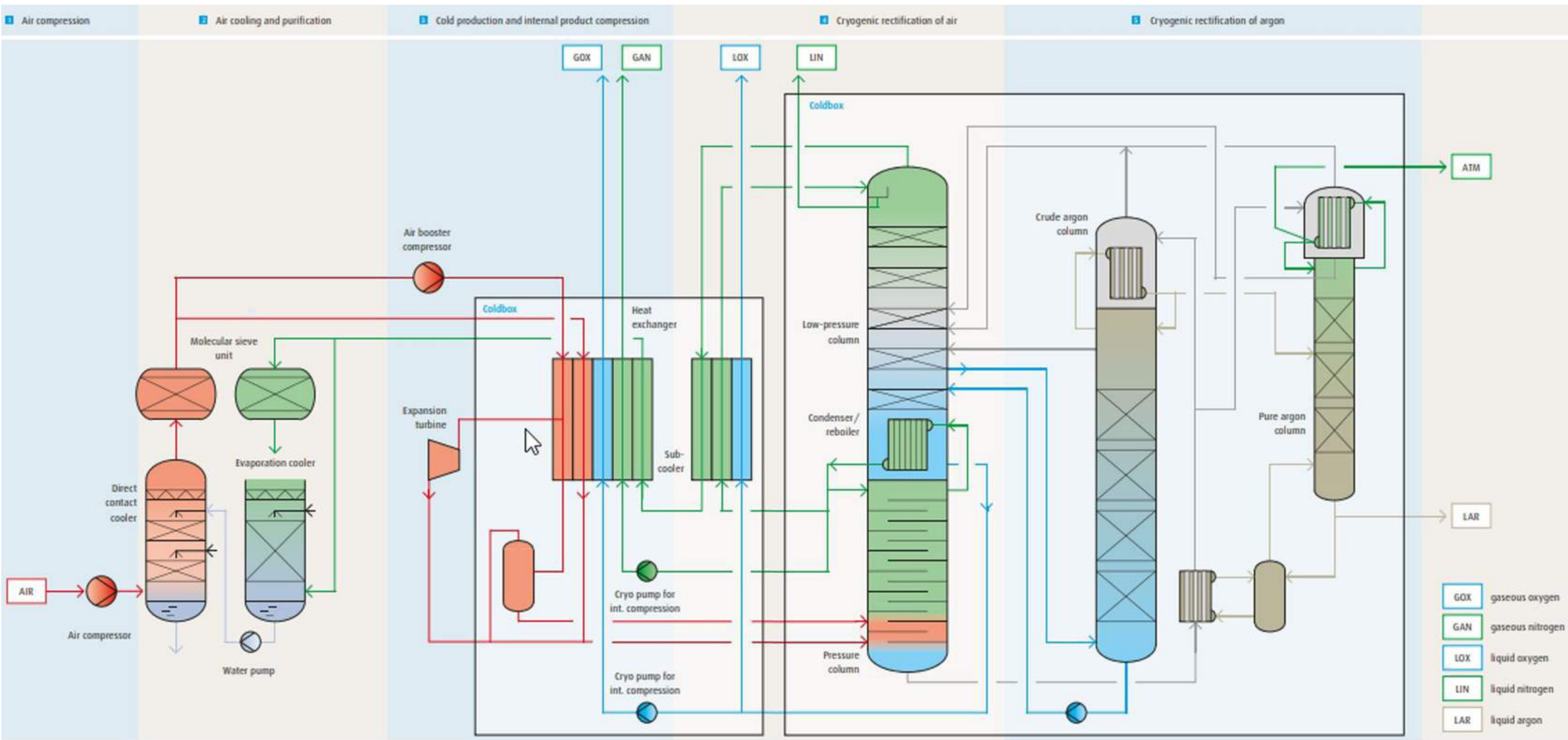


Figure 2: When converted to a liquid, air can be distilled into its components, similar to the process used to turn crude oil into end products.

The purified compressed air passes through an expansion turbine and heat exchangers to reduce the temperature to -173°C (-280°F). Now liquefied, it passes into the cold box (Figure 3), which is industry jargon for the air separation unit, a large, heavily-insulated distillation column, designed to separate the gases in spite of their very close boiling points.

Nitrogen comes out the top, oxygen out the bottom, and a third stream, rich in argon and other trace gases, comes out of the middle. This middle stream is purified further in a second column.

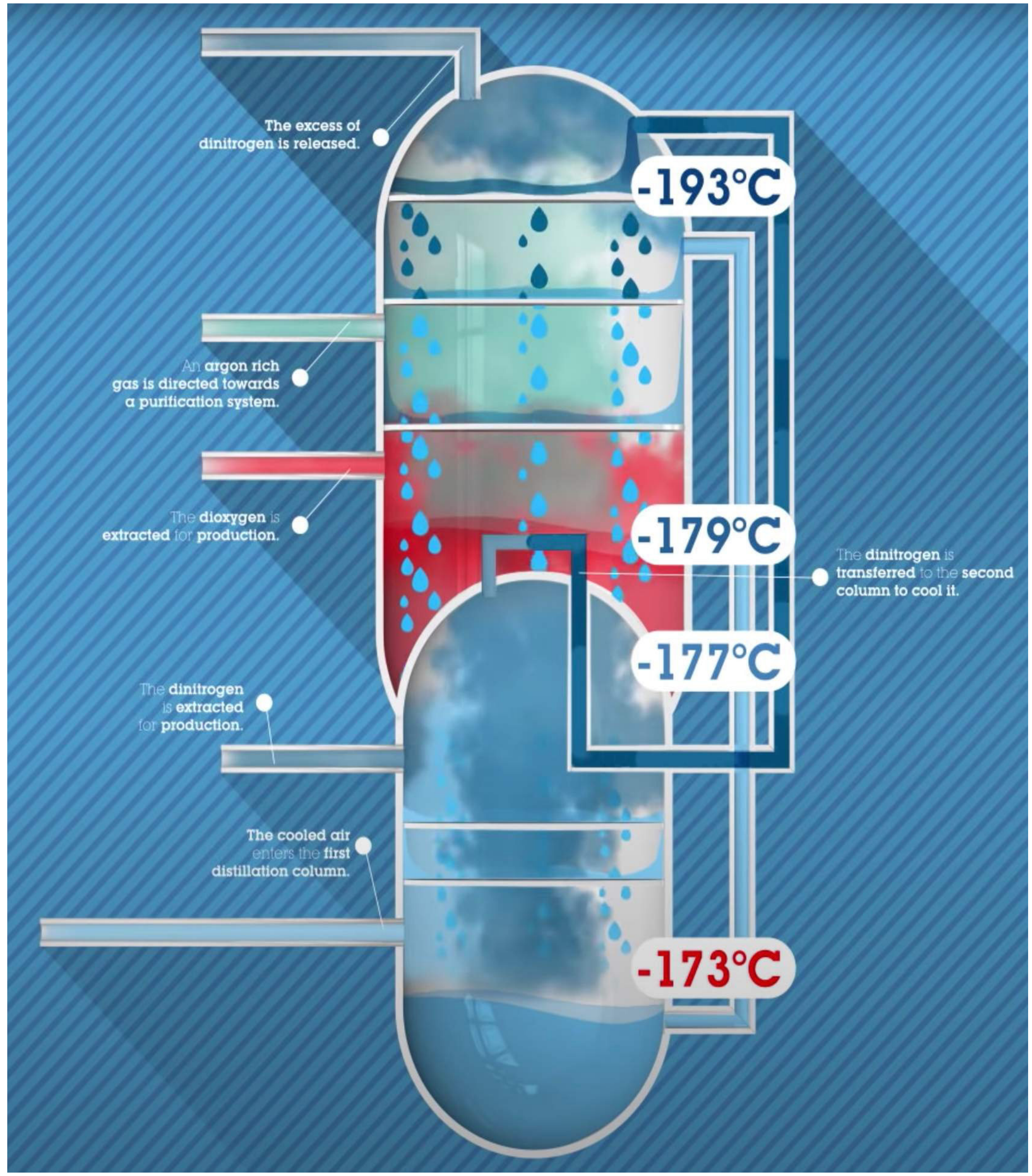


Figure 3: The cold box is the heart of an air separation unit, where gases with tightly-clustered boiling points can be separated.

Dealing with the Pain Points

In this e-book, we will concentrate on areas of concern to plants that have air separation units on site. Some may be owned by the company, while others may be installed by the supplier as a service. In any case, the same concerns apply:

- Safety
- Reliability
- Energy consumption

These areas are critical because air separation using this process is complex and costly:

- Liquefying air requires enormous compressor and refrigeration capacity, with the energy to drive it.
- Removing contaminants with membranes and molecular sieves requires regeneration.
- Cooling and removing contaminants consumes large volumes of water.
- Cryogenic temperatures pose a variety of hazards.
- Concentrations of leaking nitrogen can displace oxygen and endanger operators.
- Concentrations of leaking oxygen can accelerate combustion if given an opportunity.

Let's unpack what it all means and look at these areas one at a time.

Safety

While there are many areas in a gas separation facility where safety is a concern, the primary hazard is found in the cold box. As a powerful example of what can happen, a July 19, 2019 explosion at a plant in China's Henan Province (Figure 4) caused 15 fatalities, many more injuries, and enormous plant damage.

The consensus opinion on the cause pointed to liquid oxygen seeping out through a leak into the surrounding perlite insulation and secondary containment. The outer casing was not designed to sustain continuous localized direct cryogenic temperatures and it ruptured under the pressure, releasing liquid oxygen that created an oxygen-rich atmosphere, resulting in two explosions and fires.

Most cold box incidents are the result of leaks since metal cracking is a common side effect of cryogenic temperatures. Most installations maintain a flow of purge air within the larger enclosure to avoid the kind of buildup in the insulation just discussed.

Protecting the primary cold box and secondary separation columns calls for a variety of instruments strategically placed (figure 5) to capture data able to indicate a leak in progress:

1. The space within the cold box enclosure should be monitored for temperature in several positions along its height. These readings should be stable and reflect the production level and purge air flow at a given time. If one area begins to change significantly, it likely stems from a leak.

2. The space within the cold box enclosure should also be monitored for pressure, typically at the top and bottom given the length involved, and since the insulation can often create zones within the enclosure. Changes in readings not attributable to purge air may indicate a leak, and such changes can be compared with temperature changes to corroborate suspicions.

3. Purge air flow should be monitored since under normal conditions there is little reason for it to change. If flow goes down, it is likely caused by higher pressure in the enclosure from a leak. If flow goes up, it may indicate a leak of the enclosure itself.

4. Using a gas detector to detect a release of nitrogen isn't practical given its atmospheric presence, but it is possible to recognize when oxygen level is higher than the normal 21% found in the atmosphere. If this value, normally measured at the bottom of the cold box, shows oxygen enrichment, it strongly suggests a leak in progress. Flame detectors can monitor the spaces between the primary cold box and secondary separation columns. This is the final line of defense and will call for the most drastic countermeasures.

These instruments, working together, provide additional layers of protection for the operators, equipment, and process. They can often be installed while the unit is running, without any changes required to the process itself, or to the control system.

Where it is impractical to add such instruments using conventional cabling, a wireless solution, such as WirelessHART, can make the process far easier and less expensive. WirelessHART integrates easily with the Wi-Fi networks available in most plant environments, making deployment even easier.

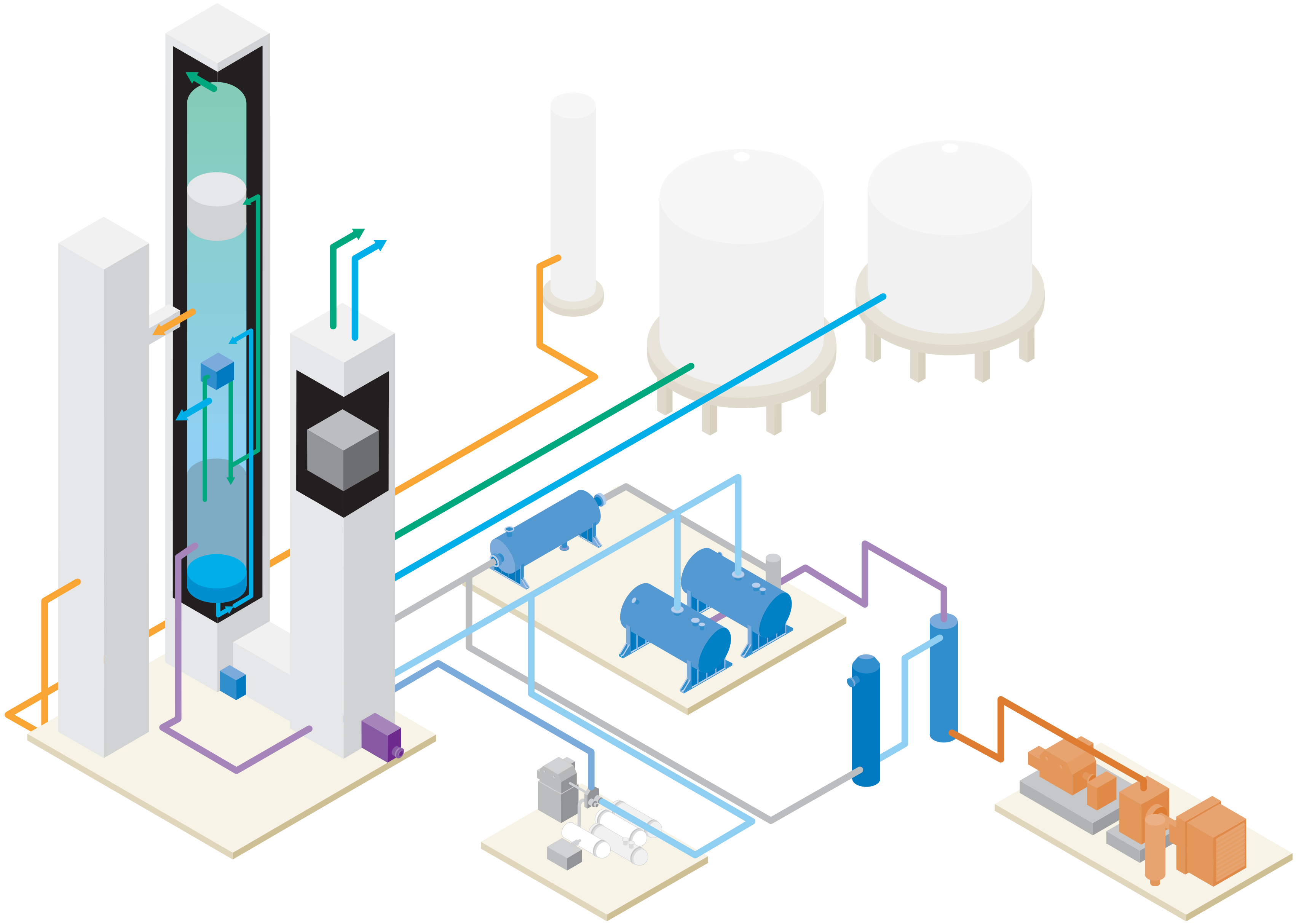


Figure 5: Monitoring instruments to support safe operation are separate from the unit's process instrumentation and automation system.

As an actual example, a western European process plant site wanted to improve safety around its cold box, so it worked with Emerson to install 14 new WirelessHART temperature instruments and 14 WirelessHART pressure instruments. These instruments are now used to monitor changes around the cold box that could indicate a leak.

Voting for safer and more reliable operation

Every air separation plant has multiple safety-instrumented functions (SIFs) which work together in a larger safety-instrumented system. These are designed to bring the unit to a safe state in the event of an upset or other incident that the main process automation system can't handle.

For example, if pressure in the air separation unit exceeds safe limits, a pressure instrument will trigger a function to shut down the process, and possibly vent some of the pressure. This SIF must work in an emergency, however, if it trips due to a malfunction when there is no actual emergency, it disrupts production and wastes money.

Such situations are usually rare, but the effects can be very costly. As a result, some plants use a two-out-of-three (2oo3) voting scheme to avoid unnecessary trips and shutdowns. Instead of a single safety instrument, three identical instruments take their measurements at the same point. This methodology can be implemented for any kind of instrument—such as those measuring pressure, temperature, flow, or other parameters.

To trip the safety function, at least two of the instruments must both report that the critical variable has crossed the threshold. Normally if there is an actual emergency, all three will show the change. However, if only a single instrument reports a problem, the system will not respond because it interprets it as an instrument malfunction.

This is a costlier approach than a single safety instrument, but in many environments the expense of an unnecessary emergency shutdown and unit restart far outweighs the additional cost. Emerson instruments simplify and reduce the cost of implementing 2oo3 voting schemes by combining measurements and safety logic into a single device (Figure 9).

With each the assemblies shown in Figure 9, three instruments are used for the 2oo3 voting scheme, and the fourth provides data required by the process automation system for real-time control. Each assembly provides SIL3 level protection in the process.

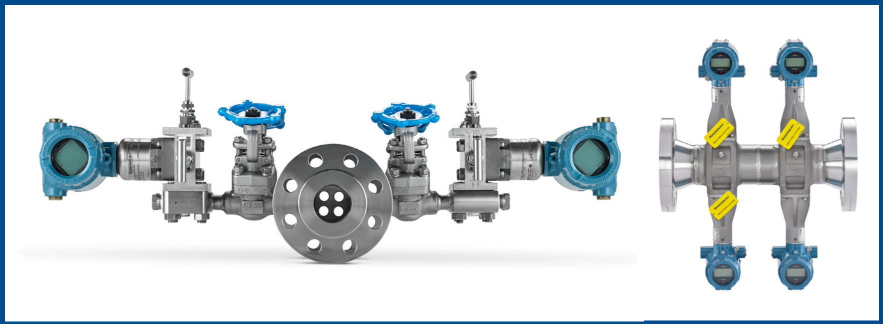


Figure 9: These differential pressure flow meter (left) and vortex flow meter (right) assemblies each uses four identical instruments.

Reliability

An air separation plant depends on an extensive fleet of compressors, refrigeration units, pumps, expansion turbines, and other rotating equipment. Many of these are so strategic that losing one can shut down the entire unit if a blown bearing or other mechanical failure causes an unexpected outage. Air separation plants have the additional challenge that these installations often must work at cryogenic temperatures, but many installations deal with normal conditions.

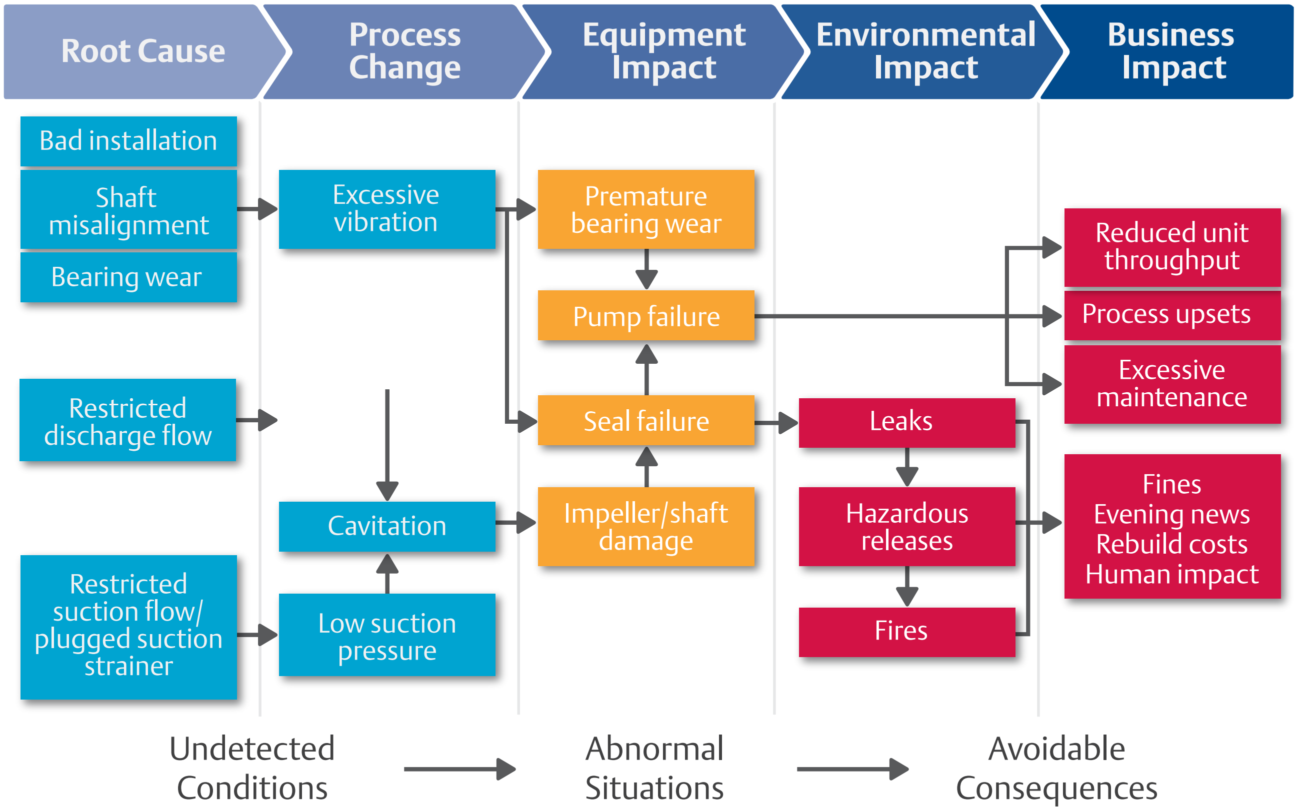


Figure 6: Pumps have characteristic problems that interfere with production. Other installations pose their own challenges.

The critical word here is unexpected outage, since these days, there should be no such thing. Very few failures come fully unannounced because most present detectable warnings well in advance. Instruments are available to identify characteristic symptoms and provide warnings to reliability teams before a failure.

Take centrifugal pumps as a case in point (Figure 6), although similar difficulties apply to compressors, turbines, etc. Pumps tend to be maintenance intensive, suffering a failure or some level of degraded operation on average every 12 months. Those in critical applications often have duplex and even triplex installations as backups, ready to switch over at a moment's notice.

Pumps and other installations can be equipped with instruments to monitor condition and performance to ensure problems are detected as soon as possible so appropriate action can be taken.

Pumps are commonly equipped with instruments (Figure 7) to monitor specific variables, such as:

- Vibration
- Bearing temperature
- Inlet/outlet pressure
- Strainer clogging
- Seal fluid pressure/level

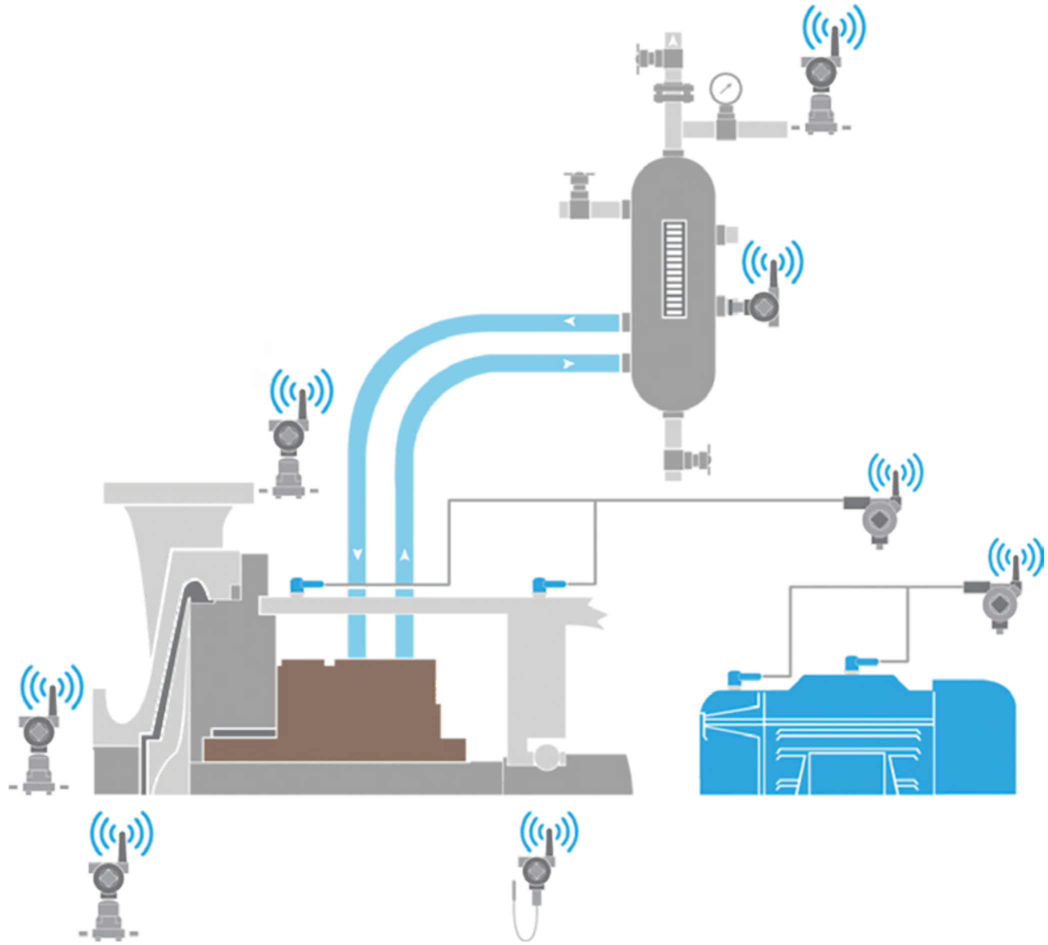


Figure 7: Adding instruments and monitoring their readings reduces the likelihood of an unexpected outage stopping the process.

In most air separation plants, very few installations have this kind of monitoring. Usually, operators on routine rounds use their eyes and ears to look for developing problems. Some may even have portable diagnostic instruments. But given the reduced number of human operators in plants these days, this means the checks are probably not as regular or as frequent as they should be.

Installing instrument on critical installations—combined with an automated monitoring platform—is a serious undertaking, but recent advancements in hardware and software make it much easier and less expensive than with traditional methods (See Diagnostic Dashboards Sidebar). The number of instruments designed for equipment monitoring capable of operating on WirelessHART networks has grown substantially, to the point that every type of instrument necessary for a full pump or other rotating installation monitoring setup is available for use with WirelessHART networks.

New analytical and dashboard apps make performance and condition monitoring more effective

Equipment monitoring has become easier thanks to a new type of software tool, which draws from concepts developed by the consumer electronics industry whereby sophisticated apps make user interactions much simpler and quicker. When provided with data from equipment condition instruments, the apps perform the data collection and analysis tasks for specific types of equipment.

For example, an app to monitor the efficiency of heat exchangers is much different than one designed for watching multiple functions on a motor/centrifugal pump skid. A user might not realize the extent of the difference since the dashboards can have a very similar look and feel, even though the internal functions have little commonality.

These software and hardware combinations provide critical information for equipment monitoring at far lower costs than traditional methods. Implementation is also much simpler because each app is designed to provide a specific function, instead of using a monolithic, general-purpose analysis platform. The results provided can be easily recognized by plant personnel, with no need for expert interpretation.

These apps can be deployed on an application-by-application basis without a commitment to a larger system, so their effectiveness and ROI can be evaluated, and the plant can move on to the next item of equipment.

Compared to traditional methods, these apps are easy to set up and test on a variety of installations. For most applications, recognizing and quantifying the payback is just as easy as the initial deployment.

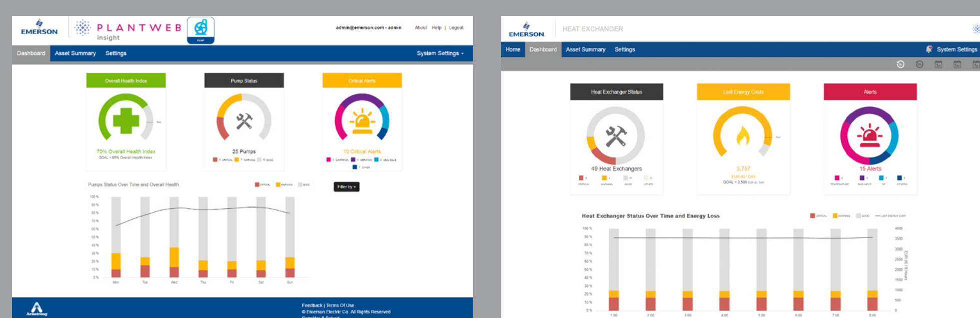


Figure: Emerson's Plantweb Insight Apps are specialized to analyze specific types of equipment, such as pumps (left) and heat exchangers (right). This minimizes the amount of configuration when setting up new applications, and greatly simplifies use during operation.

Energy Consumption

As mentioned earlier, air separation is an energy-intensive process due to the required compressor and refrigeration capacity. Equipment monitoring can help control or at least compare energy consumption for major equipment assets, but there is one additional area where an air separation plant must be watched carefully: heat exchangers. Process manufacturing plants of any size invariably have some population of heat exchangers, but air separation units have more than their share, necessary to get the compressed air temperature down as low as possible before it is fed to the expansion turbine.

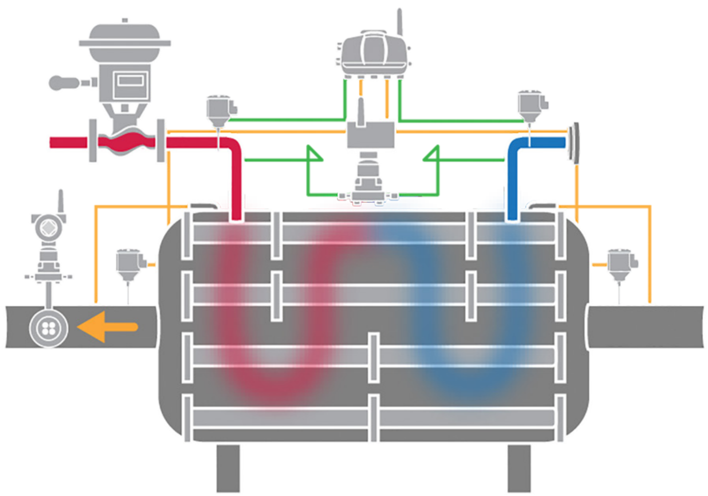


Figure 8: This representative heat exchanger shows the typical instrumentation layout, with temperature and flow instruments on both sides.

In most process manufacturing plants, heat exchanger fouling is a concern due to impurities in process fluids causing buildup and loss of efficiency. This is not the case with air separation plants since the compressed air stream carries few impurities. However, the chilled transfer fluid on the other side of the heat exchanged can carry impurities, whether it's water or some other solution. Loss of efficiency due to this condition may happen slowly, making it difficult for operators to effectively measure degradation in heat exchanger performance.

The main operating parameters (Figure 8) relate to flow rate and temperature differential for the two respective fluids, in this case, compressed air as the process fluid, and water or refrigerant as the transfer fluid. A given heat exchanger has heat transfer limitations based on the amount of surface area between the two fluids and the heat conductivity characteristics of the internal surfaces themselves.

Since these characteristics are fixed, it is possible to calculate the maximum theoretical heat transfer for a specific set of temperature differentials and flow rates. Any deviation from the calculated maximum indicates a loss of efficiency, which raises operating costs. The challenge becomes determining how far the unit is running from its maximum and if fouling might be occurring. Instrumentation can help make these critical determinations.

Ideally, it is best to have inlet and outlet temperatures measured for both the air and transfer fluid, along with flow rate for both as well. Since air flow is controlled by the unit's process automation system, this variable should already be available, however, it is valuable to measure differential pressure across both sides.

There are WirelessHART temperature transmitters capable of sending data from four instruments on one wireless signal, reporting each reading in turn. The host system sorts out the data and updates each reading individually. The differential pressure (DP) reading across the tubes uses a native WirelessHART DP instrument.

The flow meter for the transfer fluid could use any one of several measurement technologies, but some of the self-contained DP technologies are also available as native wireless and are often the best choice for this type of service.

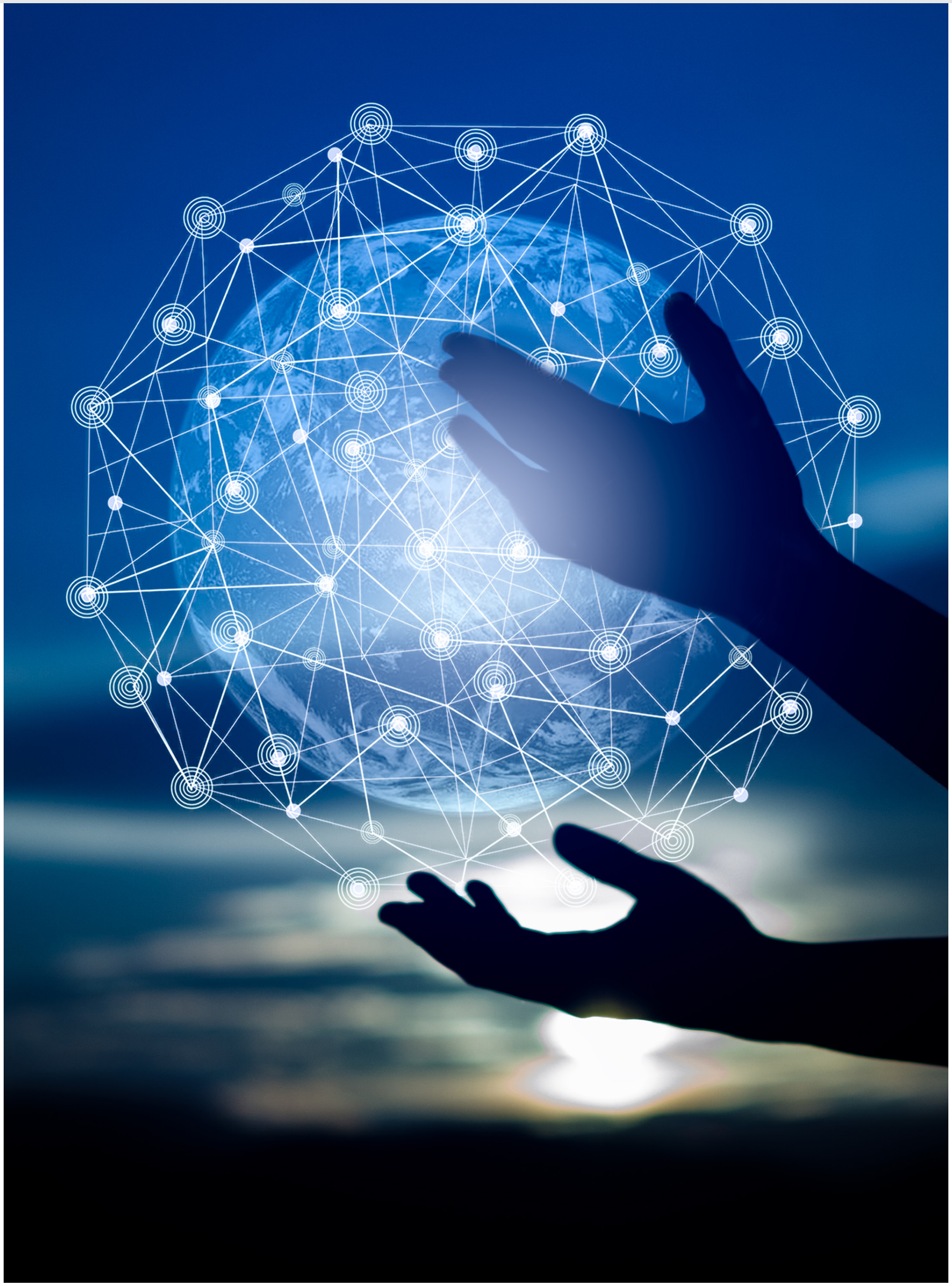
In each case, the cost and possible downtime of installing these WirelessHART instruments must be balanced against expected benefits. Experience has shown most installations can quickly deliver a viable ROI when using wireless instruments, but the case is not as clear with wired instruments due to the much higher cost for wiring.

All part of Digital Transformation

All the elements discussed so far are part of a larger digital transformation effort able to deliver improved safety and operations by:

- Improving availability, lowering maintenance costs, and reducing risk due to equipment failure
- Avoiding product contamination and loss of primary containment
- Reducing the number of safety incidents
- Lowering energy usage, reducing emission levels, and reducing overall energy costs

Emerson can help plant personnel working with air separation units achieve these goals, while increasing plant effectiveness and profitability.



Emerson Automation Solutions
Global Response Center
United States
T +1 888 889 9170
www.emerson.com

EMERSON