RESILIENT systems

Matt Thundyil, Dave Seeger and Carl Hahn, Transcend Solutions, USA, discuss how effective contamination control can help operators to maintain resilient operations in the face of the energy transition.

The hydrocarbon and chemical processing industries are being disrupted by the transition to green energy. It is intuitive that fossil fuel processors will be under social, political and investor pressure to reduce their carbon dioxide (CO$_2$) footprint, and this will affect their operating profitability. The winners emerging from this disruption will be those that have maintained operating excellence, and have adapted the fastest. As discussed in a previous article, one of the most critical factors affecting operating excellence is resilience in the face of disruptions to systems and varying feed streams to the facility.[1] When a system is not resilient, it tends to fail, and failure can often translate into reduced throughput and uptime; increased operating costs and environmental impact; and ultimately a decrease in profitability. During paradigm shifts within industries, the less resilient players lose, and the more resilient players not only survive, but often thrive.

The resilience of a system is defined as the system's capability to recover from anomalous operations, which are endemic in the process industry. Anomalous operations are often characterised as 'process upsets', and can be caused by a myriad of factors beyond the control of the facility, including variations in feedstock, weather events (cold fronts, hurricanes, heatwaves, etc), or by reliability issues in support systems (power, environmental treating, etc). Most process facilities are interconnected to maximise operating

flexibility and energy efficiency. The consequence of such interdependence is the propagation and amplification of any anomaly in the operation. Figure 1 illustrates this.

What if that propagating anomaly could be intercepted? In a resilient system, a black box that absorbs the anomaly allows the system to operate without any fluctuation caused by the anomaly. This concept is captured in Figure 2, where a black box (in the feed to the green unit) can absorb fluctuations in the feed, providing a stable feed to the green unit, and therefore to all downstream systems.

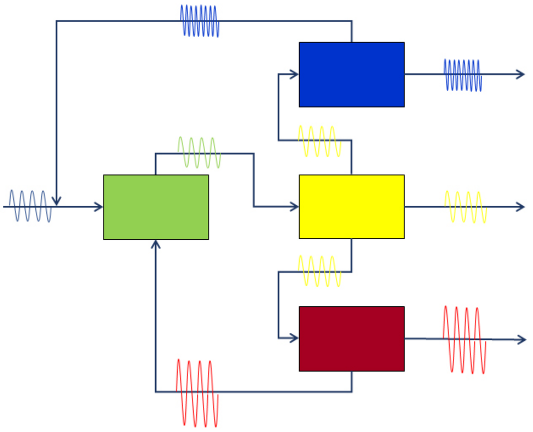

Figure 1. An anomaly in the feed to the green unit cascades to downstream units, resulting in the amplification and transmission of this anomaly into additional systems.

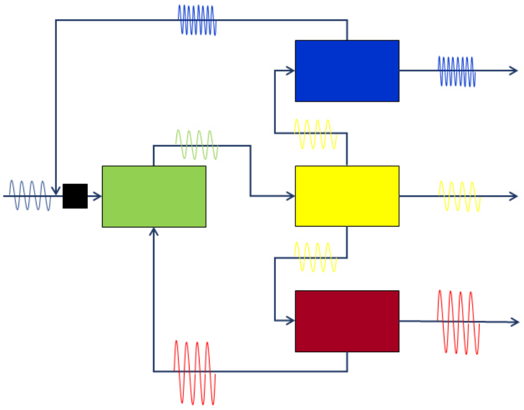

Figure 2. An anomaly in the feed to the green unit is absorbed by the black box, assuring stable feed to the downstream units.

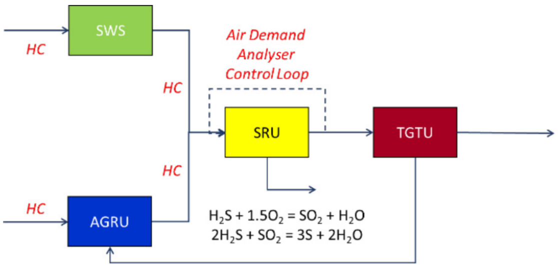

Figure 3. Generic SRU schematic.

Contamination as a process anomaly

There are many different types of anomalies that can afflict a process system. Contamination is one of them. There are a variety of ways that contamination is introduced into the system, including the following:

- Feedstock can be contaminated (sand, corrosion products, treating chemicals, immiscible liquids, etc).
- Pipelines can corrode.
- Corrosive chemicals are used or formed (chlorides, carbon dioxide, hydrogen sulfide [H_2S], sulfuric acid, caustic, etc).
- Aggressive operating conditions (high temperature, high pressure, etc).

Contamination can take a number of forms, as listed below:

- Solid particles in gases.
- Solid particles in liquids.
- Liquid droplets in gases.
- Immiscible liquid droplets in other liquids.
- Dissolved or vaporised contaminants in either liquids or gases.

Contamination can also affect a process in a variety of ways, including:

- Heat exchanger fouling.
- Catalyst or adsorbent bed fouling.
- Column foaming or fouling.
- Rotating equipment (compressor, pump) fouling and damage.
- Turbine or generator damage.
- Valve or pipe wear.

Contamination control systems are engineered into most process systems, as the impact of contamination on process instability is well accepted, even if it is not well understood. These systems take the form of filters, coalescers, separators, strainers, etc. The challenge that most plants face is that the contaminants in their systems are not effectively removed by the units that are expected to remove them. The effect of persistent contamination – and its impact on process instability, downtime, reduced throughput and increased operating cost – typically becomes accepted as the prevailing paradigm. When an entire industry is disrupted, accepting the prevailing paradigm trap is not a winning strategy. Rather, the winners are those that transcend the paradigm. Breaking the paradigm often involves asking 'would we face these issues if the system was clean?' This simple question points operators in the direction of the root cause, and its solution. Thundyil et al have recently illustrated that operational excellence through effective contamination control is possible without significant capital expenditure, if operators know precisely where to look.[2]

Example one: heat exchanger fouling

Heat exchanger fouling is often caused by contamination in process streams. The consequent loss of heat transfer frequently results in the additional energy being expended to overcome the loss in heat transfer coefficient. In some cases, the lost heat transfer cannot be overcome, and the consequence is a direct loss in production. Many cryogenic heat exchangers operate in complex, interconnected, energy-integrated services where any loss in heat transfer results in a loss in recovery. In the hydrocarbon processing market today, the most common examples of cryogenic exchanger fouling are in NGL recovery facilities, and LNG production facilities.

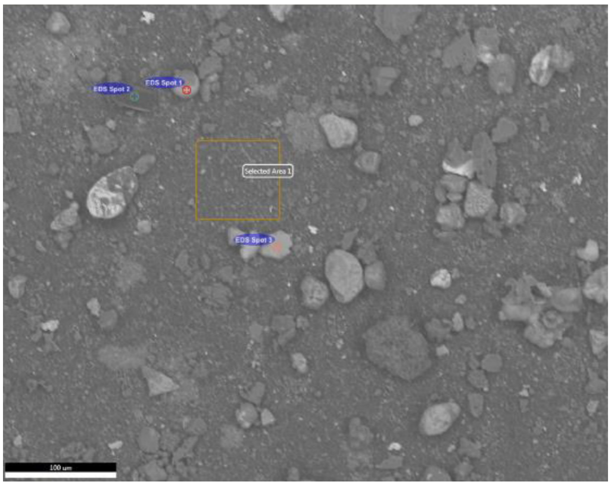

Figure 4. Scanning electron micrograph of a contaminant entering the brazed aluminium cryogenic exchanger section of an LNG plant.

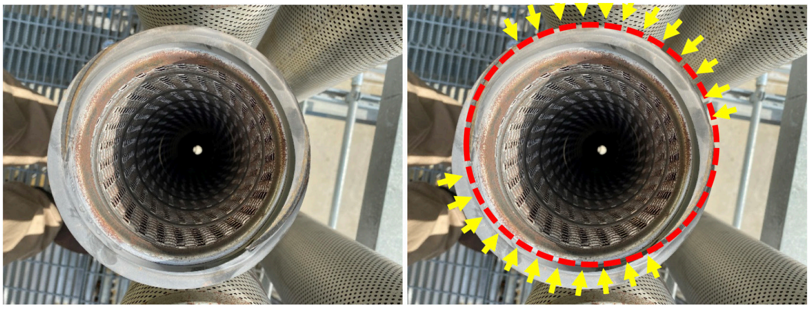

Figure 5. Sealing surface of the dust filters. Left: the groove of the 'knife edge' sealing surface. Right: the regions where the elastomer does not seal.

Figure 6. Sour water feed prior to the TORSEP system (left) and after (right).

Consider, for example, a typical 5 million tpy LNG train (equivalent to 700 000 000 ft^3). The production margin on natural gas conversion to LNG is greater than US\$0.015/ft^3.

(a) 1% loss in recovery costs 0.01 x 700 000 000 ft^3 x US\$0.015/ft^3 = US\$105 000/d.

(b) A single day outage costs 700 000 000 ft^3 x US\$0.015/ft^3 = US\$10 500 000 of lost revenue per event.

Similarly, consider a 200 000 000 ft^3 cryogenic recovery facility that produces 30 000 bpd of NGL. The NGL recovery margin is approximately US\$40/bbl.

(a) 1% loss in recovery costs 0.01 x 30 000 bpd x US\$40/bbl x 365 d/yr = US\$4 380 000/yr.

(b) A single day outage costs 30 000 bbl x US\$40 = US\$1 200 000 of lost revenue per event.

Example two: hydrocarbon contamination of sulfur plant feed

Globally, air quality considerations have impelled the installation of sulfur recovery units (SRUs) within hydrocarbon processing facilities where sulfur compounds are present. These SRUs are most commonly Claus units where sulfur compounds are oxidised in an air-deficient environment to produce elemental sulfur, and the tail gas is reduced back to H_2S to be recovered and recycled in order to minimise sulfur emissions. The feed to the sulfur plant is commonly from the acid gas removal unit (AGRU) and the sour water stripper (SWS) unit. If hydrocarbons are present in either of these streams, they can end up in the sulfur plant feed on either a continuous or episodic basis. Figure 3 illustrates a generic scheme.

Note the 2:1 ratio of H_2S and sulfur dioxide (SO_2) that is required to form sulfur as part of the Claus reaction. This ratio is managed by means of a H_2S/SO_2 analyser that controls the air demand to the SRU. If hydrocarbons are entrained into the SRU, they consume considerably more oxygen (8 – 30 times more) than the same molar quantity of H_2S depending on the length of the hydrocarbon chain in question:

$$H_2S + 0.5O_2 = S + H_2O \qquad (1)$$
$$C_3H_8 + 5O_2 = 3CO_2 + 4H_2O \qquad (2)$$
$$C_9H_20 + 14O_2 = 9CO_2 + 10H_2O \qquad (3)$$

The oxygen consumed by combusting hydrocarbons will starve H_2S conversion to SO_2 and affect the air demand analyser, resulting in intermittent excursions of SO_2 into the tail gas treating unit (TGTU). SO_2 breakthrough to the TGTU will cause corrosion and column instability in addition to affecting environmental emissions. Further to this, oxygen consumption by hydrocarbons reduces the amount of oxygen available to combust H_2S, and if the refinery or gas plant is environmentally regulated, the reduction in capacity to treat H_2S has a direct impact on refinery crude capacity. For example, a typical 250 000 bpd refinery treating a 3 – 4% sulfur crude will have a 1000 tpd sulfur plant. The production margin of a sour refinery is approximately US$10/bbl of oil processed.

- 1% loss in crude capacity = 0.01 x 250 000 bbl/d x US$10/bbl x 365 d/yr = US$9 125 000 /yr.
- A single day outage costs = 250 000 bbl x US$10/bbl = US$2 500 000 lost profit per event.

Identifying a path forward

Refineries, midstream cryogenic recovery gas plants, and LNG plants are the three largest hydrocarbon processors in the energy segment, outside of coal. As fossil fuel processors, these are the companies that will be immediately and directly affected by the energy transition. They are highly integrated and highly susceptible to contamination-related process upsets. In many cases, the plant already has a separator in place, but it is just not performing at the level that is needed. As a result, contamination makes its way downstream. If the separator in question can be upgraded to mitigate the contamination, will it improve operating excellence? Obviously, there is a need to characterise the contaminant, verify compatibility with the process, validate the capability, and estimate cost. In virtually all cases, a tremendous impact on operating excellence ensues without significant capital expense, or with exceptionally high return (< one year ROI) capital expense.

Case study: LNG production facility – protection of cryogenic heat exchanger

As discussed, cryogenic heat exchangers are very sensitive to fouling. The cost of lost efficiency or downtime is significant. Faced with fouling, a large LNG facility was interested in evaluating its feed dust filters to the cryogenic heat exchangers. A photomicrograph of the contamination captured from the product is illustrated in Figure 4.

The presence of large contaminant particles indicated inadequate performance of the dust filters onsite. An evaluation of those elements indicated poor sealing (as seen in Figure 5), and the use of inefficient media technology. An upgrade to the conventional separator was developed to improve the sealing and media efficiency, and enhance operating ergonomics.

Case study: sour water stripper

A refiner experienced hydrocarbon contamination of its sour water unit. The foulant was affecting the feed-bottoms exchanger and required frequent cleaning. In addition, the lost heat transfer was affecting the energy efficiency of the stripper column. Finally, a fraction of the hydrocarbon contaminant was in a boiling range that would build up within the column. As such, the risk of episodic hydrocarbon carryover to the sulfur plant was endemic. The feed was routed through a high-efficiency particle separator and high-efficiency emulsion separator which were part of a Transcend TORSEP^{TM} demonstration system, prior to contacting the heat exchangers. The impact on the heat exchanger was immediate. Figure 6 shows pictures of the inlet sour water and the TORSEP effluent. The pressure drop of the exchanger immediately plateaued and even decreased. The exchanger has not required cleaning in over three years. The downstream sulfur plant reported no hydrocarbon excursions following the installation of the system. The refiner was so impressed that it bought the demonstration system.

Conclusion

The disruption caused by the energy transition is imminent. The winners will be the operationally excellent and resilient. Implementing operating excellence and operating resilience is a high return investment, and often requires no new capital expenditure as existing equipment can be upgraded. The key to operating resilience is understanding where risk tolerance is to be implemented. Among the easiest to identify are contamination control related resilience.

References

1. THUNDYIL, M., SEEGER, D., and HAHN, C., 'Beyond band-aids', *Hydrocarbon Engineering*, (March 2021), pp. 75 – 80.
2. THUNDYIL, M., SEEGER, D., and HAHN, C., 'Operating excellence without capital expense', *Hydrocarbon Engineering*, (November 2021), pp. 57 – 61.