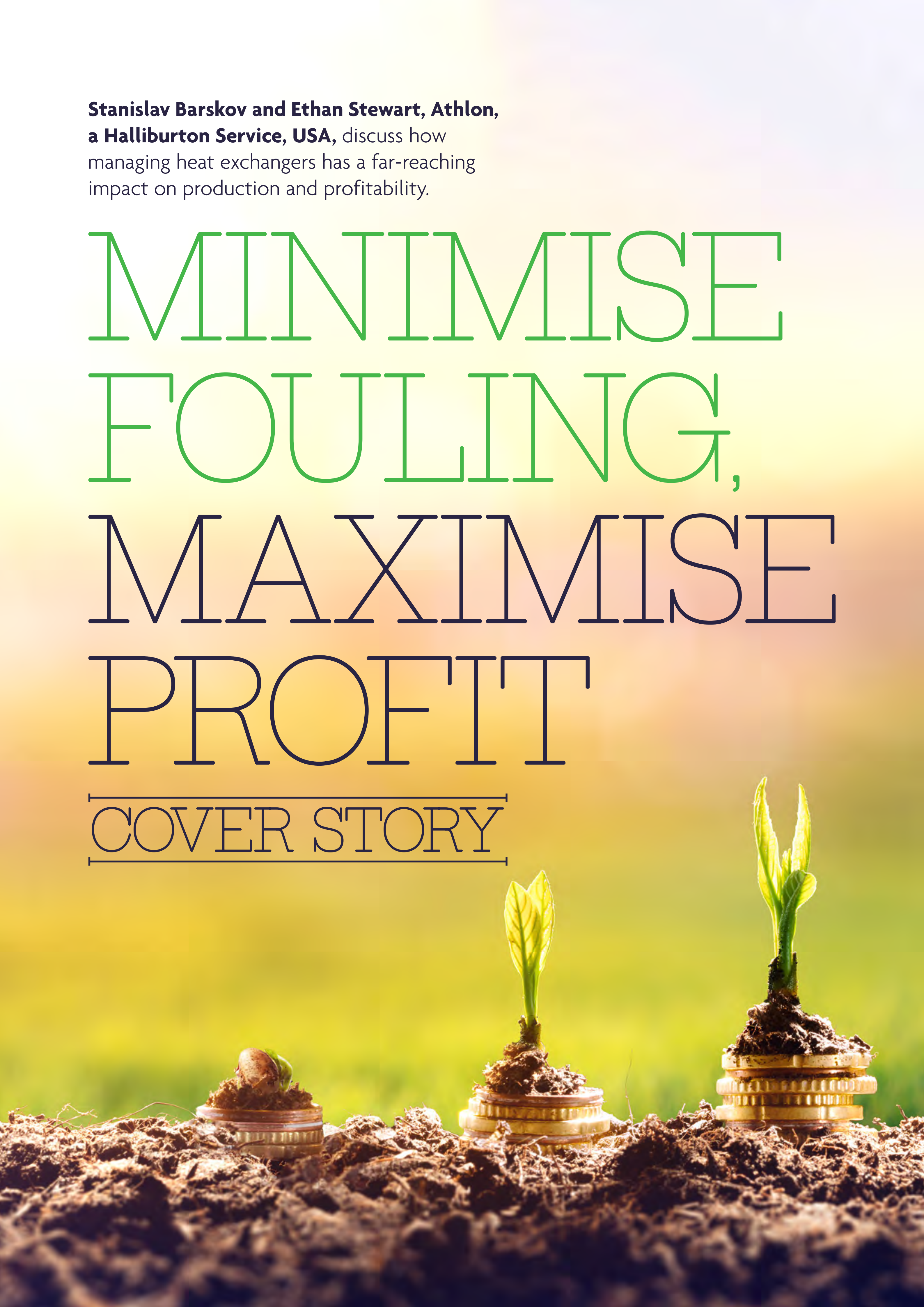
Stanislav Barskov and Ethan Stewart, Athlon, a Halliburton Service, USA, discuss how managing heat exchangers has a far-reaching impact on production and profitability.

MINIMISE FOULING, MAXIMISE PROFIT

COVER STORY



Heat exchanger fouling has been an issue since heat exchangers were first introduced to industry in the early 1900s. Since then, significant research has been performed to minimise heat exchanger fouling. In the 20th century, more than 200 patents relevant to heat exchanger fouling were awarded. Nonetheless, fouling of heat exchangers remains one of the major unresolved industrial problems today. Prevention and mitigation of heat exchanger fouling is still an ongoing process.

The economic impact of exchanger fouling is significant in most industries today. The total annual estimated fouling related losses for major industrialised nations exceeds US$4.4 billion. This can account for more than 0.25% of a nation's gross domestic product (GDP). The top fouling-related costs are:

- CAPEX: cost for excess surface area to compensate for heavily fouled surfaces.
- Energy costs: higher power and fuel required to overcome the lost heat transfer from fouled surfaces.

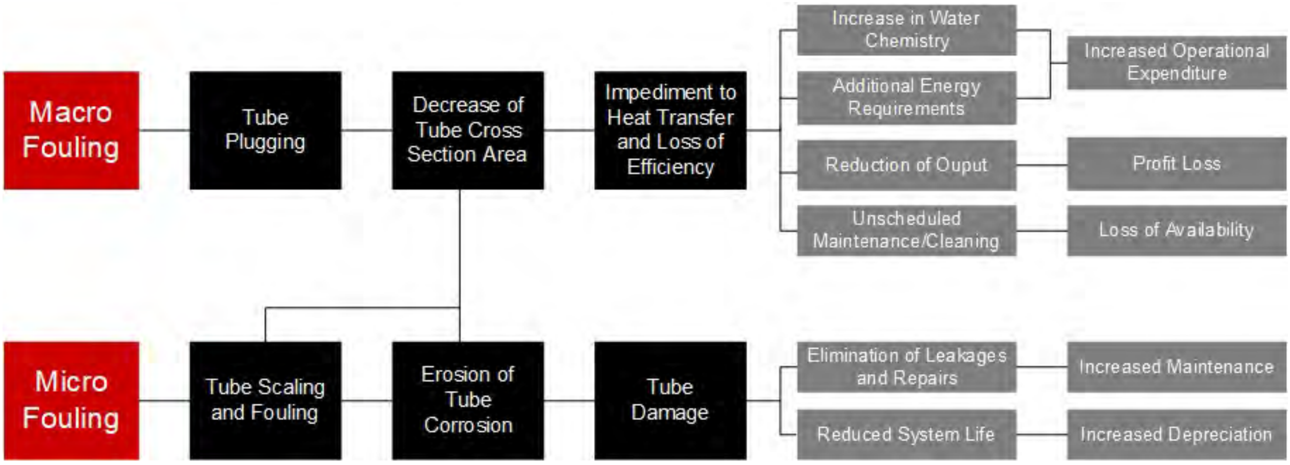


Figure 1. Micro fouling vs macro fouling.

- Maintenance costs: mechanical and chemical cost for removal of deposits, and other anti-fouling methods.
- Cost of production loss: planned or unplanned plant shutdowns, and process volume reductions due to fouling in heat exchangers.
- Safety: added risk from production anomalies caused by fouled heat exchangers.

With the global heat exchanger market expected to top US$20 billion by 2022 at an annual growth rate of 9%, efficient fouling prevention and remediation methods must be made available to safeguard industrial operations.

Not all fouling is created equal

Exchanger fouling can be generally categorised into two major types: macro- and microfouling. Distinguishing between these fouling types can help engineers to better understand the cause/effect of fouling on their unit in order to develop and implement best practices to mitigate future fouling.

Macrofouling is defined as materials that cover and obstruct heat exchanger tubes and tube sheets. Common foulants are cooling tower fill, wood pieces, ear plugs, plastic, etc. that partially or completely block the heat exchanger tubes and tube sheet surfaces and reduce water circulation through the bundle.

Microfouling is fouling associated with mineral scaling on the heat transfer surfaces, particulate fouling, biofouling and deposition of corrosion products.

Both types of fouling ultimately lead to profit loss through restriction of a refinery's output capacity and increased overall cost of operation. Figure 1 details the 'domino effect' that takes place once foulants contaminate a cooling water system.

Critical exchangers

Although it is good practice to keep all heat exchangers operating at their optimum design capacity, not all heat exchangers in the plant are equally important or receive the same consideration. A large refinery can have more than 1000 heat exchangers and complex piping layout, and it is very unlikely that all the heat exchangers will be operating at their maximum capability. Most of the refinery process streams are not simple, single component streams and their physical properties already start off as assumptions. At best, heat exchanger performance is an estimation. Nevertheless, it is important to focus on monitoring the temperature and flow rates of the critical heat exchangers.

Large-scale refineries produce a variety of different products, including diesel, gasoline, LPG, aviation fuel and lubricants. A refinery's operations can be generally categorised into four types of processing units:

- Straight run units:
  - Atmospheric distillation.
  - Vacuum distillation.
- Sulfur removal units:
  - Naphtha hydro-desulfurisation unit (NHDS).
  - Selective hydrogenation unit (SHU).
  - Diesel hydro-desulfurisation unit (DHDS).
- Upgrading units:
  - Reforming.
  - Alkylation.
- Cracking units:
  - Fluid catalytic cracking unit (FCCU).
  - Coker.

Every unit will have a set of critical cooling water exchangers whose performance will inevitably affect plant-wide economics. For example:

- Insufficient cooling on the overhead (OH) system will increase off gas from the OH accumulator, increase overhead pressure, and force operations to reduce crude unit throughput.
- Poor cooling of the compressor inter-stage exchanger will overload the wet gas compressor and limit the charge rate through the FCCU.
- Inadequate cooling of process streams to tankage can limit unit throughput if temperatures exceed established health, safety, and environmental guidelines.

These are just a few examples of critical exchangers that should be kept in pristine condition to maintain the desired hydrocarbon processing output and reduce overall operational cost. Effective performance of these exchangers will be dependent on the quantity (flowrate) and quality (temperature, cleanliness) of the cooling water supply and simple preventative maintenance in these units can improve production reliability and save plants millions of dollars.

Cooling water quality and quantity

Just as humans perspire to cool their bodies through evaporative cooling, process cooling systems rely on cooling towers to dissipate heat from process cooling water. Heat dissipation is accomplished by countercurrent contact of large volumes of air with water in a cooling tower as water falls over into the basin. Cooling tower efficiency is measured by its ability to dissipate heat from the water before it reaches the basin where it is recirculated back through the heat exchanger to absorb additional heat.

Since hot summer days place extreme demand on cooling systems, cooling towers and heat exchangers need to be in good physical shape, properly serviced and maintained to avoid significant cost implications associated with the loss of process efficiency, loss in production volume or damage to downstream equipment.

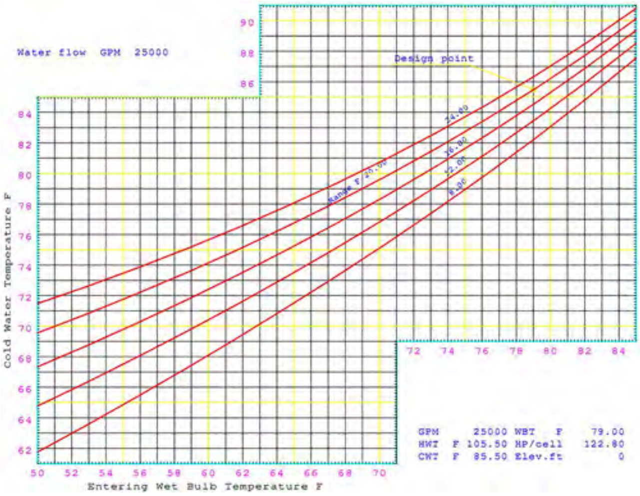


Figure 2. Cooling tower performance curve.

Cooling towers are gigantic air scrubbers that can capture airborne debris floating nearby. Accumulation of this debris will eventually clog spray nozzles and fill; however, the real problem stems from these foulants circulating to heat exchangers where plugged tubes cause lost efficiency and overheating. Since chemical treatment cannot remove debris, it is the plant's responsibility to execute routine cooling system maintenance. Properly executed, routinely scheduled maintenance will keep cooling systems clean and operating efficiently to maximise plant production rates.

OEM vs actual performance

Cooling tower efficiency begins with establishing an operational baseline. When examining the cooling tower performance, it is best to consult the original equipment manufacturer (OEM) performance curves that specifies OEM-guaranteed cold water supply temperature (y-axis) under a specific set of variables – namely the recirculation rate (bottom right corner), wet bulb temperature (x-axis), and range (isotherms; see Figure 2).

Because there is a maximum amount of heat a cooling tower can remove from the circulating water, the larger the recirculation rate, the lower the supply temperature (holding all other variables constant). One can determine the projected supply temperature for an actual recirculation rate and wet bulb temperature by selecting an isotherm that most closely approximates the actual tower temperature range. If the supply temperature measured in the field is warmer than the graph predicts, the tower has lost efficiency.

There are numerous causes of tower inefficiency – fouled fill, plugged distribution nozzles, incorrect fan blade pitch, and improper water distribution, which will be discussed later. If the supply temperature is lower than the graph predicts, check for calculation or measurement errors. Routine cooling tower inspections should be conducted to determine the contributing factors to the reduced cooling efficiency. Finally, it is critical to compare design circulation pump performance to actual pump performance. It is not uncommon for pumps to lose efficiency due to impeller wear, resizing or trapped debris in the impeller veins.

Figure 3. Cooling tower fill collapse (left), broken screens and debris (right).

Cooling tower inspections

Louvers and fill

When performing cooling tower inspections, it is critical to assess every structural component of the tower that can influence cooling efficiency. Cooling tower louvers and fill are essential components of the cooling system and affect a tower's ability to dissipate heat. The function of cooling tower louvers is to provide a barrier to sunlight to prevent algae growth, water splash-out, and debris influx while improving the airflow. Pieces of the deteriorating louvers falling into the basin will generate macrofouling of heat exchangers. Broken and missing fill and splash bars will reduce the water-air contact, plug up heat exchanger tubes resulting in higher supply temperature, loss of process efficiency and hydrocarbon production. Figure 3 shows a neglected cooling tower desperately needing structural repairs.

Distribution decks

Crossflow cooling towers are equipped with hot decks. Process return water flows from the crossflow cooling tower distribution system across the hot water deck and is distributed into the cooling tower fill. Uniform water distribution on the decks is critical to the efficient operation of the tower. Decaying wood decks, corroded structural elements, clogged spray nozzles and water level imbalance across deck sections will reduce cooling tower performance.

The screens and basin

Cooling towers should be equipped with sump screens specifically to trap debris from the cooling tower basin to protect downstream heat exchangers from macro-fouling. The structural condition and mesh size of the screens is critical for minimising debris ingress. Because most of the industrial heat exchangers are designed with 0.75 in. tube inside dia. (ID), primary screen mesh should be 0.5 in. and secondary 0.25 in. to trap all the debris. Screens should be routinely pulled and cleaned to prevent flow restriction.

Open cooling tower basins that are not cleaned routinely are an ideal breeding ground for bacteria and algae. The basin layout is also critical to prevent contaminated water carryover during high rain events. Basins that are not equipped with a sidewall tend to catch all the debris (e.g., Styrofoam cups, plastic bags, etc.) from nearby roads and get contaminated very easily. Figure 4 is an example of how debris such as plastic wrappers completely block the exchanger tubes resulting in reduced water flow, scaling and increased potential for under deposit corrosion.

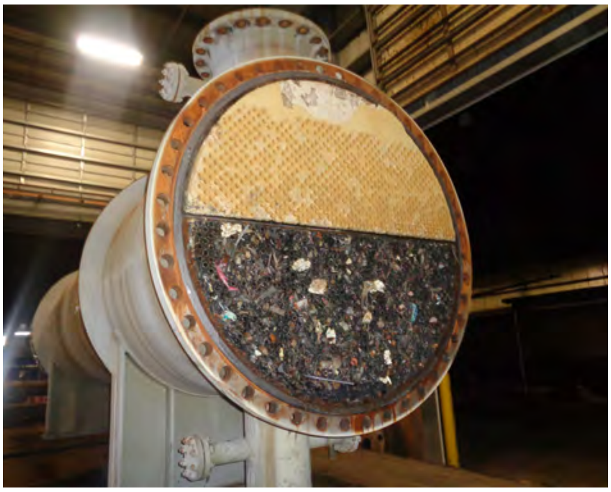


Figure 4. Debris driven fouling of a critical exchanger.

Lessons learned from case studies

Optimising cooling water performance can seem complex for those less familiar with common industry operating best practices. Below are a few useful examples that entry level engineers can use for optimising cooling water efficiency to provide increased production yields

Exchanger design issues – catalytic reforming unit steam gland condenser

- Supply/return piping installed backwards.
- Backwash line is rendered ineffective for debris removal.
- 0.5 in. tube ID rather than a standard 0.75 in., increased potential for fouling.

Improper backwash piping – stream coolers

- Old unit with kerosene and aviation jet product coolers.
- Exchangers under designed since the expansion, increased rates resulting in 150% heat duty.
- Upstream fin fans too few and unreliable.
- Backwash piping retrofitted because of leaking valves – inability to remove debris.

'Water guzzler' upstream – exchanger addition line-up

- Following unit expansion, exchangers were added downstream of a 'water guzzler' exchanger.
- Inadequate water pressure caused insufficient flow in the downstream exchangers.

Process configuration – prioritising exchangers

- An intermittent service light slop cooler was installed downstream of critical overhead condensers, utilising a bypass line to control the water flow through this exchanger.
- Back pressure created by the bypass valve cause imbalance in the water flow through the critically important upstream debutaniser condensers.
- Flow through the debutaniser overhead condensers was reduced due to the inability to precisely control the position of the bypass valve downstream.

Conclusion

Exchanger fouling continues to be one of the foremost operational and economic challenges experienced by the downstream oil and gas industry today. Effectively determining and addressing the fouling mechanisms is often the gateway to achieving optimal performance and maximising economic value of unit heat exchangers. Detailed exchanger surveys are an invaluable tool for unveiling previously unforeseen design shortcomings and operational deviance. As downstream refineries continue to expand operations and increase throughput, continuous re-evaluations are recommended to prevent negative impact on exchanger performance.