Catalytic Reformers in Latin America benefit from new generation of welded plate exchanger

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ABSTRACT

Oil refineries have been using welded plate heat exchangers since the 90's with the intent of improving refinery profitability. Achieving this profitability has been validated by major licensors because of the welded plat heat exchanger's high efficiency capabilities in heat transfer, resulting in considerable energy savings, a decrease in emissions and greater yields of high-value streams.

The largest welded plate heat exchanger in existence is the Packinox, which is widely used in the energy intensive process of catalytic reforming. There are approximately 20 Packinox welded plate heat exchangers currently operating in refineries located in Latin America and the Caribbean. While there are successful cases of continuous operation for many years, on average, its lifetime tends to be less than that of equipment in similar operating conditions in refineries in North America, Europe and Asia.

This paper compares the lifetime of Packinox exchangers in Latin America to those of refineries in other regions of the world. It also shares some of the best operating practices and turnaround lessons learned about those refineries with the best operating Packinox exchangers.

Additionally, this paper presents the most recent welded bundle design named Hypercut— designed to ensure the operational reliability of the Packinox welded plate heat exchanger in catalytic reforming units during critical stages such as shutdowns and startups. The goal is to keep the unit operating at its maximum capacity so the local fuel supply can meet the demand at times when the price of natural gas has been at its highest point during the last five years.

The Hypercut plate bundle can be successfully retrofitted in existing units. Recent feedback from two operating units is presented.

Introduction

The first Packinox exchanger to start up at a catalytic reforming unit was in June 1985. In the Latin America, the first Packinox to go operational was at a Continuous Catalytic Reformer (CCR) in a refinery in Mexico in December of 1993. The reduced fuel consumption at the fired heater has been documented in previous papers,[1] but when refiners saw this happen live, many operators were surprised because of the fuel firing reduction rate at the fired heaters. Within the next 10 years, almost every major refinery in the Latin America had transitioned to using a Packinox exchanger at their Semi Regenerative (SR) or their CCR type catalytic reformer. Soon, the operating challenges started for this new type of exchanger.

As defined by Gulati (2009) [2], "Reliability is a broad term that focuses on the ability of an asset (product) to perform its intended function. It is concerned with predicting and preventing failures to ensure assets will perform to their required or design functions."

In many refineries the catalytic reformer supplies a significant percentage of all hydrogen used in other hydrotreating and hydrocracking processes; therefore, it is vital to make sure all its components operate properly and among them, the Packinox exchanger

The Packinox is a welded-type plate heat exchanger which means there are no gaskets between the corrugated plates (figure 1). The plates are welded to each other on the extremes, forming channels for the feed side and the cold side. All these channels form a bundle which is inserted inside a pressure vessel—also known as shell. The gap, or distance between plates, can vary between 3 to 8 mm. This small gap, together with the corrugations, provides very high turbulence which enhances the heat transfer coefficient; however, it requires the fluids to be very clean to avoid plugging of the channels and to minimize fouling.

Figure 1. Packinox cutaway showing welded bundle inside a pressure vessel,

Packinox Inspection and maintenance

The Packinox heat exchanger requires very limited inspection over its lifespan. It should be inspected every five years following the major turnaround schedule for CCR units (industry average of every 5 years). The inspection protocol is mostly visual inspection of internals and liquid penetrant testing of critical welds as shown in table 1.

Description	**Time**
Top expansion bellows (visual inspection). Dye penetrant test in case of doubts.	Every 5 years
Bottom expansion bellows (visual inspection). Dye penetrant test in case of doubts.	Every 5 years
Spray bar(s) (visual inspection)	Every 5 years
Bundle supports & guidance system (visual inspection)	Every 5 years
Welded walls (visual or camera inspection). Dye penetrant test in case of doubts.	Every 5 years
Visual or camera (borescope) inspection of effluent inlet & outlet	Depends on local regulations
Internal inspection of the vessel walls & welds (after removing insulation)	Depends on local regulations

Table 1. Packinox inspection guidelines

In theory, there is little maintenance required on a Packinox exchanger when operated under normal conditions. The liquid naphtha should have few to zero contaminants which should be captured well in advance by the liquid feed strainers. These strainers should have been installed in parallel with one being redundant so the operating one can be cleaned periodically. At the spray bar opening, there is a conical strainer which, in units with two spray bars, can be backflushed by means of recycle gas provided that a pipes and valves setup for the backflush has been provisioned.

In real life, it has been noticed that overlooking simple steps during the startup has caused challenges in its operation and long-term reliability resembling a domino effect. The following is a list of frequently observed steps which are frequently overlooked and resulting consequences:

1. Liquid feed lines not flushed properly have plugged the spray bars.
2. Effluent lines not flushed properly have plugged the effluent header.
3. Not having more than two people who witnessed the proper insertion of the spray bars has resulted in units started without spray bars, resulting in bad thermal performance.
4. The lack of a spray bar backflushing arrangement has caused a premature shutdown of the unit because of feed rate limitations.

Maintenance times can be estimated, in advance, if the refinery personnel can analyze the operating data and relate changes in performance to specific events that could have caused the changes. Table 2 shows the average times and complexities of different tasks.

Task	**Maintenance time**	**Complexity**
Chemical Cleaning	6-10 days depending on number of washes	Simple
Solvent cleaning	2-3 additional days from chemical cleaning	Simple
Leak test	1 day	Simple
Welded wall repair	1-2 days	Medium. Can be done by local welder
Effluent header cleanup	1-2 days	Medium.
Header channels repair	1-3 days depending on damaged channels	Advanced. Requires specialized welder
Steam – Air Decoking	5-8 days after setup	Advanced. Requires specialized Supervisor
Bundle Replacement	3 to 5 weeks	Advanced. Requires specialized Supervisor

Table 2. Typical Packinox Maintenance times, after the exchanger has been made available to the maintenance group.

Any event which could limit the uniform flow of either combined feed (naphtha + recycle gas) or reformate effluent has the potential to create thermal stresses on the plate bundle. Alfa Laval thermal and hydraulic engineers have studied this phenomenon and have performed multiple studies to quantify thermal stress as shown in figure 2. If not addressed properly, the non-homogeneous flow within channels could result in cracks at the plates or headers. In most cases, the Packinox can still operate with some leaks; however, this will decrease the reformate yield and, in the long term, could render the bundle useless due to multiple unrepairable leaks.

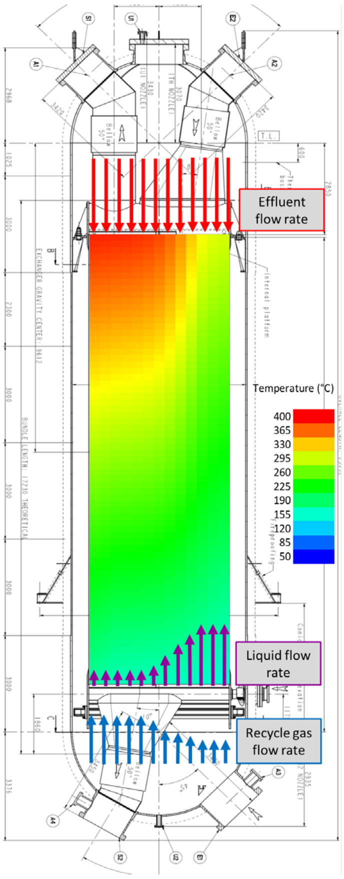

Figure 2. Thermal and mechanical stress study of improper liquid lift due to spray bar plugging

Fouling

Fouling, as opposed to a sudden plugging, is an event that occurs over a period of time; it is unavoidable and accounts for billions of dollars in annual losses[3]. The following are the most recurrent following observed in combined feed exchangers of all types in catalytic reformers:

Feed Side

Liquid feed filtration is fundamental to avoid plugging or fouling in the feed side channels. Whenever a new Packinox is installed, an installation review should be performed by a person with previous Packinox experience. That person must thoroughly follow the manufacturer's installation manual. It is imperative to install the recommended filter type; otherwise, the filtration element could collapse, and all the small particles will plug the spray bars.

Significant plugging of the feed side channels can occur as the result of gum formation from liquid feed coming from an intermediate storage tank exposed to oxygen i.e., without nitrogen blanketing or other operational issues at the naphtha hydrotreating unit.
Figure 3 show gums formation at the bottom of the feed side channel where the spray bar injects the liquid feed into the feed side channels.

Figure 3. Gum formation plugging feed side channels. This is the area where the spray bars inject liquid into the channels

Effluent side

An excursion of nitrogen in the naphtha liquid feed will create ammonium salts which tend to deposit on the effluent channels once they reach their sublimation temperature. This is something that builds up gradually and can be easily cleaned by offline water washes.

Poly Nuclear Aromatics (PNA's): PNA's can precipitate on the effluent channels creating sticky spots which can catch iron corrosion products and even catalyst fines creating a solid amalgam which requires special cleaning methods.

Effluent side solids carryover could happen if the last reactor screen collapses for any given reason. This has been observed more frequently on older Semi Regen units; however, it can also happen on CCR's. The catalyst fines can flow through the effluent channels; the support material tends to accumulate at the top of the effluent inlet channels header and can be removed by vacuum after cutting an access window of the headers.

Cleaning methods

Chemical Cleaning

Given its welded plate bundle construction, the Packinox can only be chemically cleaned by a fill and drain procedure which could be slightly improved by adding recirculation of the cleaning solution. The chemistry of the cleaning solution depends on the type of foulant present. The most observed foulants are ammonium salts, iron oxides and heavy hydrocarbons. The effectiveness of this procedure depends on four variables: time, action, chemicals, and temperature summarized by the acronym TACT.

For any Packinox, whether in catalytic reforming or distillate hydrotreating applications, there are two rules that must always be followed during chemical cleaning. First, the shell & feed side needs to be at a higher pressure than on the effluent side; therefore, the shell side must be filled first. For the opposite procedure, draining, the order is reversed—drain the effluent side first. The second rule is to ensure the bundle is passivated before opening to the atmosphere. Stainless steel is sensitive to Chloride stress corrosion cracking; therefore, it is important to neutralize any acid media present in the bundle.

Steam-Air Decoking
Besides the chemical cleaning, the most significant development in Packinox cleaning techniques has been the Steam-Air Decoking[4] of the bundle which removes hardened gums and hydrocarbons. The development of this cleaning method started in 2001 with the collaboration of a process licensor. The R&D phase lasted over one year culminating in several successful demonstration at a pilot plant.

This cleaning method is based on the controlled combustion of hardened hydrocarbons (coke) over a period of hours or even days. Nitrogen is first introduced in recirculation up to 160 °C to prevent corrosion followed by medium pressure steam gradually heated by means of a fired heater up to temperature of 400 °C. At this stage, air is slowly introduced so the hardened hydrocarbons starts to combust in the presence of the oxygen from the air. CO_2 and O_2 concentrations are monitored at the steam exhaust nozzle. As of today, this cleaning method has been successfully performed at least twelve times on different Packinox exchangers. So far, it has not been performed in any Latin American refinery, although it has been proposed for two of them where hardened gums are present on the feed side.

Comparison between Packinox exchangers operating in US and Canadian refineries and other geographical locations

For the purpose of benchmarking the reliability of the Packinox exchangers, the operation of ten Packinox exchangers in Latin America, including two with the longest running time (17 years each one), were compared to ten other Packinox exchangers divided among North America, Europe and Asia each of them including the oldest one in operation for its region. The list, without location names, is show in table 3. The following facts were observed:

1. Europe and Asia were early adopters of the Packinox technology whereas the Americas region followed later as it can be seen in the “Years of Packinox usage column” or the height of the bars in the graphs.

2. The average lifespan of a Packinox bundle in Latin America is 13.3 years. The lifespan is calculated by counting the time in years at which the initial bundle had to be replaced.

3. When a Packinox needs to be replaced, there is a choice of replacing only the bundle or the complete exchanger. A bundle has a shorter fabrication time than a complete exchanger; however, a replacement at site is a complex task and the vessels’ age and post weld heat treatments limitations might prevent this option. This is a task that must be carefully planned to avoid delays.

4. The Latin American Packinox lifespan is lower than the one for North American refineries by eight years. The oldest Packinox exchangers currently operating in Latin America are significantly younger than the oldest ones from North America, Europe or Asia.

5. In one Latin American refinery (LA9), the replacement Packinox was able to last 20 years which is a result of the refinery implementing solutions to extend the exchanger’s reliability such as spray bar backflush, stainless steel liquid feed lines and changes on the Packinox bundle design implemented on its third generation.

6. The number of interventions from Packinox Service supervisors at refinery sites has no direct relation to the lifespan of the Packinox exchanger.

7. In all regions, we found that the cleaning of the Packinox is an activity which the refinery subcontracts to local maintenance subcontractors.

Refinery Reference	Years using Packinox exchangers	Catalytic Reformer Type	Design HAT	Service assistances
LA 1	17	SR	45 °C	4
LA 2	17	CCR	41 °C	0
LA 3	19	SR	15 °C	4
LA 4	22	CCR	55 °C	5
LA 5	23	CCR	37 °C	8
LA 6	23	CCR	35 °C	5
LA 7	25	CCR	31 °C	3
LA 8	27	SR	35 °C	4
LA 9	27	CCR	38 °C	4
LA 9	28	CCR	44 °C	8
Averages	**22.8**			**4.5**
NA 1	17	CCR	32 °C	3
NA 2	19	CCR	44 °C	2
NA 3	27	CCR	31 °C	3
NA 4	28	SR	37 °C	3
Averages	**22.75**			**2.75**
Europe 1	23	CCR	44 °C	1
Europe 2	28	SR	35 °C	3
Europe 3	33	CCR	30 °C	8
Averages	**28**			**4.0**
Asia 1	29	CCR	44 °C	3
Asia 2	30	SR	30 °C	3
Asia 3	30	CCR	42 °C	6
Averages	**29.7**			**4.0**

Table 3. Comparison of operation of different Packinox. LA means Latin America. NA means North America.

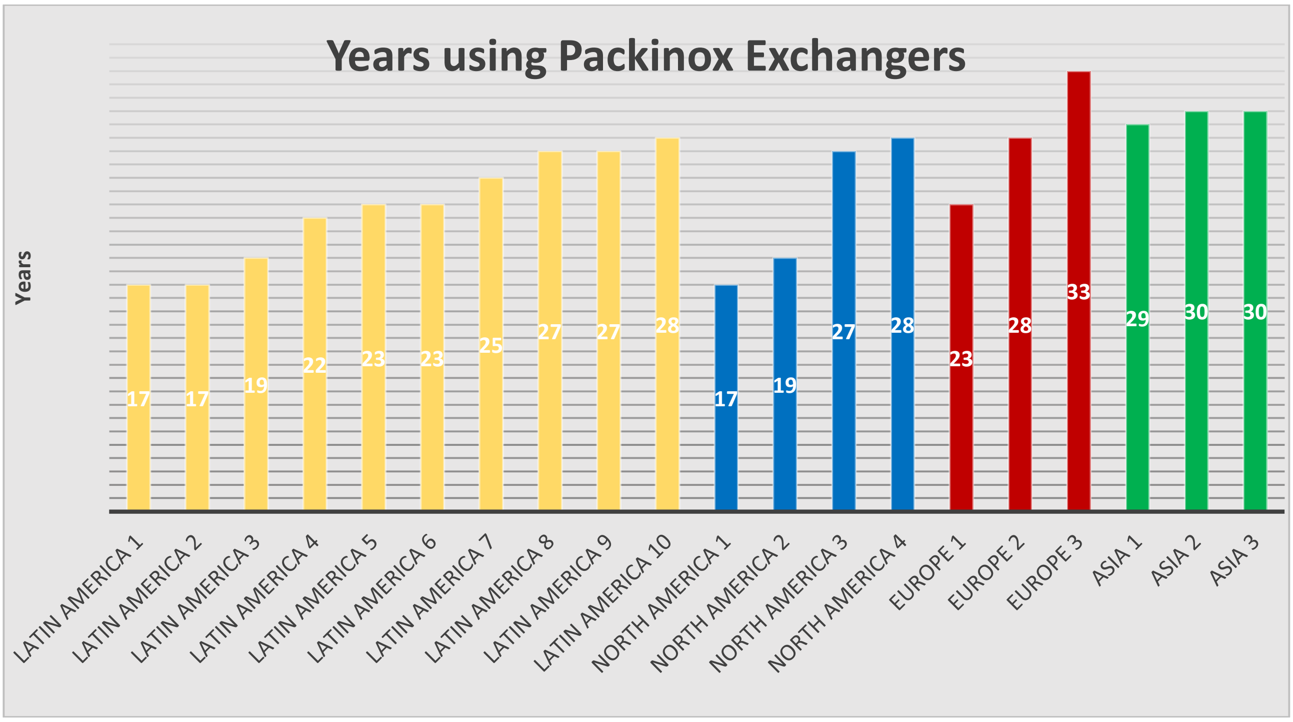

Figure 4. Years operating with Packinox exchangers.

Packinox Reliability

Since its early beginning in 1985, more than 450 Packinox exchangers have started up worldwide. The current Packinox bundle is in its 4th generation since 2018. The evolution timeline highlighting the major changes is show in Figure 5. The Alfa Laval Packinox R&D department is constantly proposing changes on the bundle design through:

1. Analyzing data from the mechanical and hydraulics departments who, in turn, analyze operating data from existing units,
2. Listening to specific feedback from licensors and customers,
3. The use of world-renowned Computational Flow Design Software
4. Simulations of transient operating conditions,
5. Feedback from our bundle fabrication site.

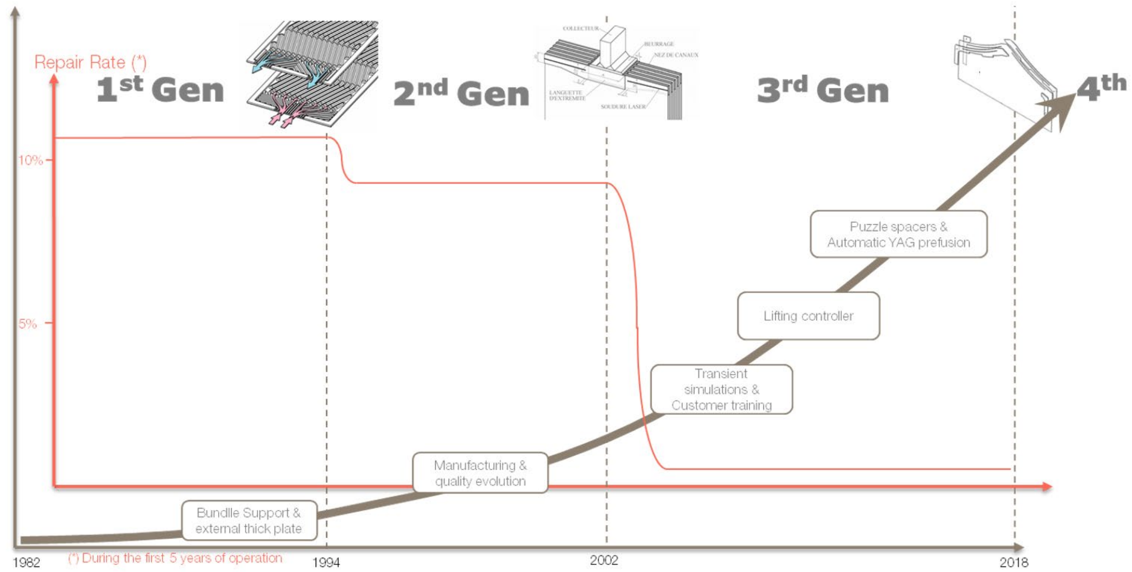

Figure 5. Evolution of Packinox bundle improvements.

The result of bundle improvements over the years has been a significant decrease on the repair rate over the years as show in Figure 6.

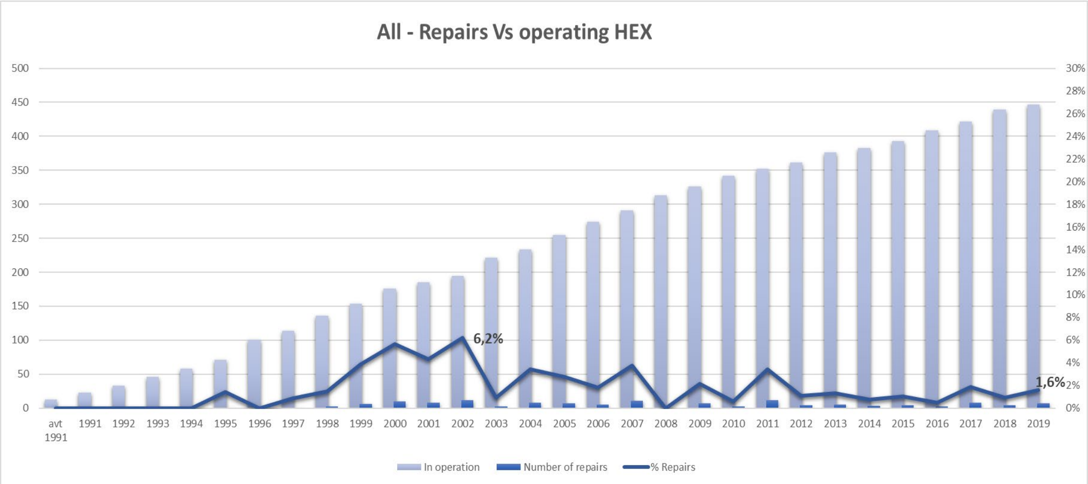

Figure 6. Packinox repair rate evolution

Fourth Generation of Packinox heat transfer bundle

The fourth generation of Packinox bundle is known as "Hypercut" because of the new hyperbolic-curve shape of its headers. The design and test phase lasted for three year and finally, in 2018, the first unit was fabricated with these new headers. Figures 7 & 8 show the new headers and a comparison with the previous one.

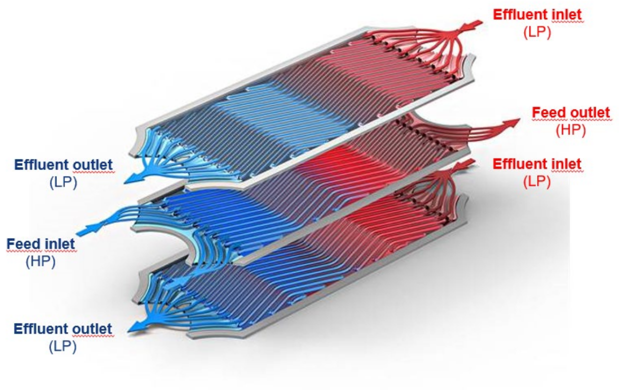

Figure 7. Hypercut plates

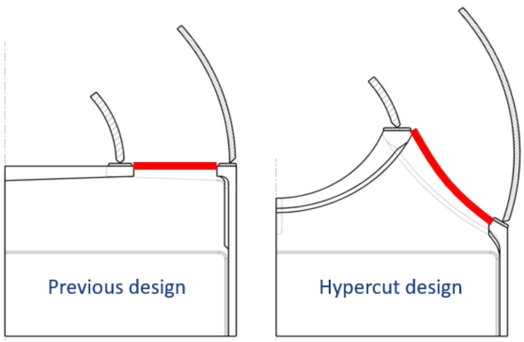

Figure 8. Header cutaway

The new shape of the headers allows for a 50% reduction on the distribution area pressure drop, validated by CFD simulations. A lower pressure drop on the distribution area allows for more pressure drop to be allocated on the active heat transfer area and better liquid lifting all of which benefit the operation of the Packinox exchanger in the catalytic reforming process.

Another benefit of the Hypercut shape header is a better distribution of forces in the zone where the header meets the plate bundle. This is an important zone due to the transition from a relatively thick header plate (average of 20 mm) to the thin plates (average 1 mm). The Hypercut shape achieves a 30% increase of tensile strength which brings extra robustness during start up, shutdowns and transient operations.

Since 2018, all new Packinox exchangers incorporate these headers; for existing units needing replacement bundles, it is possible to retrofit a bundle with Hypercut hot side headers (upper) and traditional (lower) headers on existing shells without any modification. Retrofitting a bundle with Hypercut upper and lower headers into a previous generation shell would require a modification on the spray bar location.

Hypercut design experience

As of January 2022, there have been twenty Hypercut Packinox bundles delivered to different customers worldwide and at least six of them are already in operation. Validation of the design condition with the live operating data has been positive so far. Two cases are presented:

Hypercut case 1.

This Packinox exchanger is operating in a CCR reformer in a refinery which recently had to replace a 14-year-old Packinox due to mis operations during chemical cleaning which resulted in severe corrosion. The new Packinox started up back in July 2021. The thermal performance is per specification and the hydraulic performance, shown in figure 9 has been better than expected.

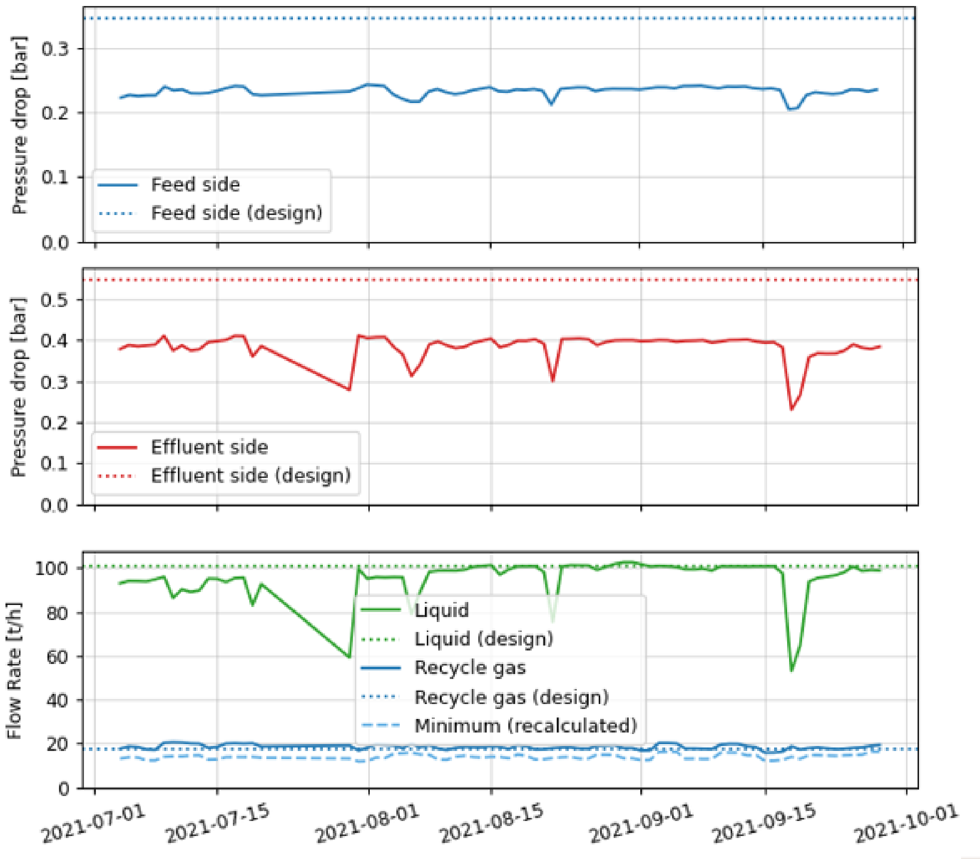

Figure 9. Fourth generation "Hypercut" bundle recent performance.

Hypercut case 2.

This Packinox exchanger is operating in a CCR reformer in a refinery located in Latin America (LA10) where a replacement bundle was delivered in Q1 2021 and later installed in November 2021. So far, the performances have been better than expected. This particular installation is an example of retrofitting the new bundle design in an existing vessel.

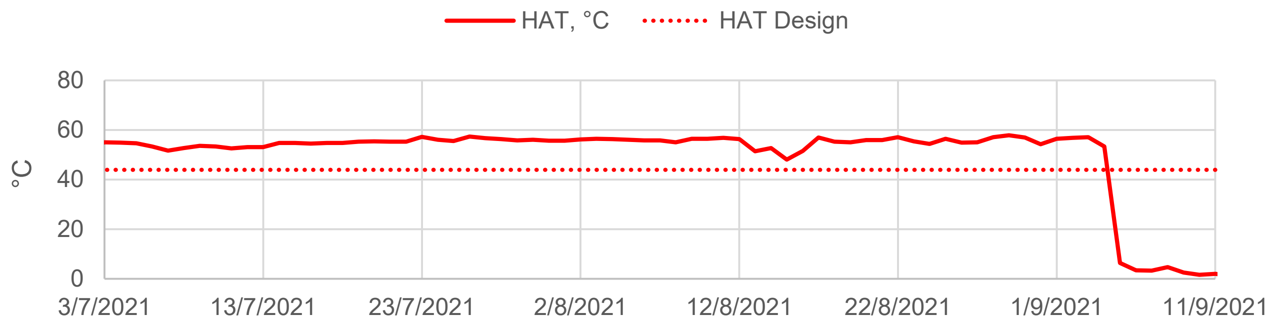

Figure 10. Hot Approach Temperature (HAT) Before bundle replacement LA10. Observed values are above design value.

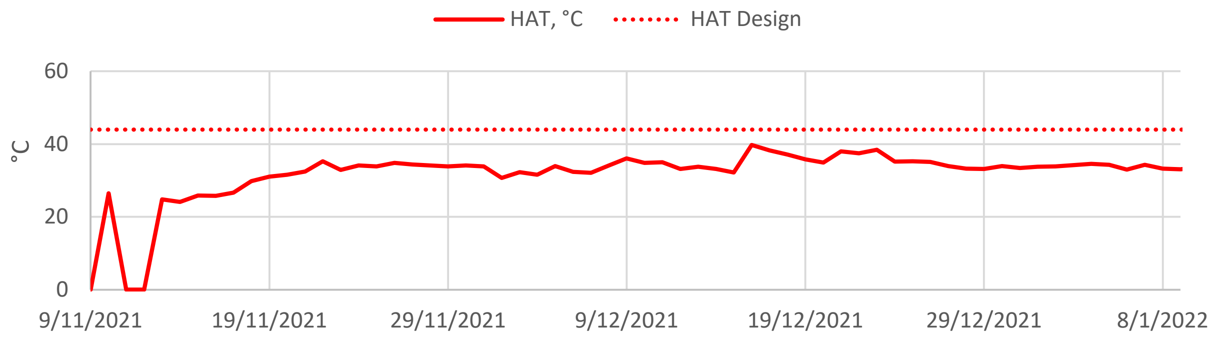

Figure 11. Hot Approach Temperature (HAT) After bundle replacement. LA10. Observed values are below design value.

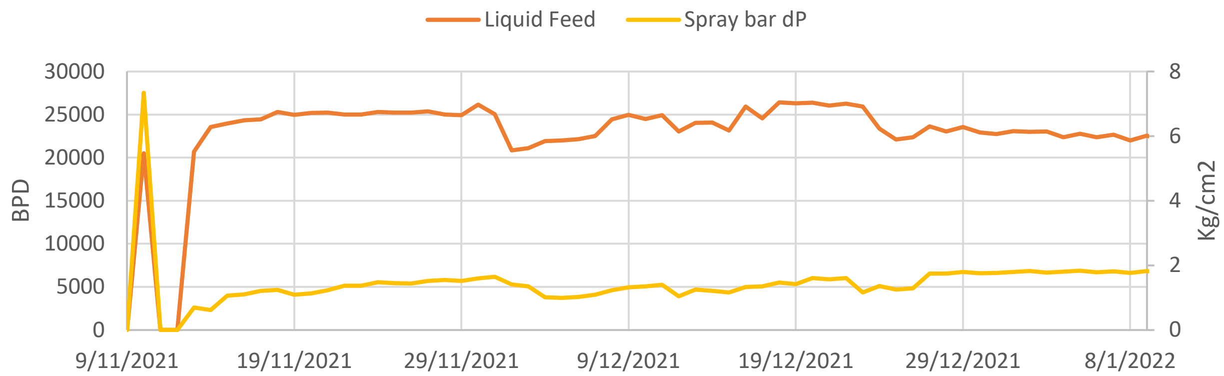

Figure 12. During startup the cleaning of the liquid feed lines was overlooked and resulted in spray bar plugging which required a shutdown to clean and restart.

Conclusions

The Packinox is a very simple equipment which, when operated properly, requires minimum periodic maintenance. The most important tool to predict and prevent failures is the monitoring of its operation parameters such as hot approach temperature (HAT) and pressure drops.

Completing a check list before initial or routine startup is a critical step in assuring the long-term operation of the Packinox exchanger.

Knowledge transfer programs within the refineries are fundamental to ensure any new Catalytic Reforming process engineer has all information available to make proper decisions and to assess when to request the presence of a Packinox specialized supervisor at site.

The Hypercut new generation of the Packinox bundle offers many advantages to new and existing installations. The combination of proper treatment of liquid feed and the increased robustness of the bundle will significantly improve the lifespan of Packinox exchangers in Latin America and the Caribbean.

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