NPRA AM 95-19

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ECONOMIC AND ENVIRONMENTAL ADVANTAGES OF WELDED PLATE FEED EFFLUENT HEAT EXCHANGERS IN REFINING.

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Presented at the

1995 NPRA
ANNUAL MEETING
March 19-21, 1995
San Francisco, California

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SUMMARY

Welded plate heat exchangers have become a common technology in the refining industry. They are now recognized as the standard technology for feed preheating in catalytic reforming. From that platform, their use has recently spread upstream (hydrotreating-HDT, hydrodesulfurization-HDS) and downstream (aromatics plants, in particular). They have proven their high reliability over the past decade, cumulating over one hundred years of satisfactory service.

On new projects, process licensors are now taking full advantage of the outstanding thermal capabilities of welded plate feed effluent heat exchangers, and fired heaters and product coolers are sized for smaller duties. Refiners benefit in many ways: economically, by a reduction in total capital cost requirements and by lower operating costs; in the field, through the advantage of unique safety features; and environmentally, through a reduction in total emission.

The most outstanding value of welded plate feed effluent heat exchangers is often found in the retrofit of older, existing reformers and hydrotreaters. It is not uncommon to see a unit's pressure lowered by 100 psi and / or its throughput increased by 30% or more principally by the installation of a high efficiency, low pressure drop PACKINOX in replacement of an outdated feed preheat train.

Two case stories are presented in the paper as examples of new and retrofit applications.

EVOLUTION OF HEAT TRANSFER TECHNOLOGY

Nothing happens overnight, and PACKINOX is no exception to the rule. The development of the welded plate feed effluent heat exchanger is part of a general evolution of the technology of heat transfer in response to changing process technologies, economic realities and environmental pressures.

Going back a few decades, the development of the large train of horizontal shell and tubes was an appropriate reflection of the times: Energy was not valued very highly, therefore there was no need for an efficient preheat train; Also, many processes were operating at high pressure, which the horizontal shell & tubes could handle quite well; Pressure drop was not a major concern.

With the arrival of higher priced energy in the 1970's, the push started towards thermal efficiency, a push which is now motivated by the need to reduced operating cost and boost refining margins.

Concurrently, process engineers have made very significant progress in reducing the operating pressure of catalytic reformers, etc... On these lower pressure units, pressure drop became less and less desirable.

The appearance of the vertical shell & tubes, also known as "Texas Tower" outside of Texas, in the 1970's marked a significant step toward higher energy efficiency and lower pressure drops.

The next significant step has been the development of the welded plate feed effluent heat exchanger in the mid 1980's, at a time when evolutionary trends in process and catalyst technologies pushed towards very low recycle gas rates and very low operating pressure/ pressure drops.

Today, PACKINOX heat exchangers, with their bundles of long, corrugated plates and their liquid feed injectors, represent the state of the art for low pressure, low pressure drop, high efficiency feed effluent heat exchangers.

INDUSTRY RECOGNITION

PACKINOX exchangers enjoy a definite recognition on the market place:

- They are the standard equipment in catalytic reforming worldwide, with 43 PACKINOX exchangers in operation, plus 23 at various stages of fabrication or installation.
- Their use has recently spread upstream (7 references in HDS and HDT) and downstream (7 references, mostly in aromatics plants).
- For grass root projects, they are typically fully integrated in the base package of a process licensor. Heat / materials balance is optimized with the process capabilities of the plate design.

- PACKINOX exchangers have cumulatively recorded more than 130 years of service, with the oldest unit having eight years of continuous service.
- The overall on-line availability of PACKINOX exchangers is very good by industry standards.
- No user has ever reported a leak of product to the atmosphere. This "No-fault" record is somewhat to be expected, as PACKINOX exchangers by design include a form of double containment. Since both the feed and the effluent flow through the bundle, the pressure vessel is in effect a second containment wall. The fact that the pressure vessel does not include a body flange is also good insurance against the threat of leakage to the atmosphere.
- A clean safety record: No accident in the field has ever been reported that could be attributable to a PACKINOX exchanger.
- Performance on-line consistently meets or exceeds challenging design specifications, with the effect that more and more refiners are raising their expectations on performance.

MECHANICAL DESIGN:

It would be helpful for the comprehension of this paragraph that the reader also refer to the cutout view of a PACKINOX presented on ***Figure 1 page 14***.

Concept:

The driving force behind the development of welded plate heat exchangers was the desire to come up with a new type of exchanger that would combine the performance capabilities of plate type exchangers and the mechanical capabilities of shell & tube designs.

Prior to that development, it was not possible to install a traditional high efficiency plate exchanger in hydrogen service at 750°F (let alone 1000°F). Similarly, high thermal efficiency in hydrogen service at medium to high temperature and/or at high pressure was simply not an available option.

The new type of exchanger that resulted from this development can be seen as "Shell & Plates".

General arrangement

The PACKINOX heat exchanger is a very large welded plate exchanger comprised essentially of a heat transfer bundle and of a pressure vessel.

All the heat transfer takes place inside the bundle which operates in counter current flow. The bundle is made of thin stainless steel, corrugated sheets formed by underwater explosion, stacked and welded together. There are no gaskets in the bundle.

The bundle is set inside the pressure vessel which is pressurized with the recycled gas, the fluid under the highest pressure. There is no fluid circulation inside the pressure vessel, which is used solely to withstand the operating pressure and to protect the bundle. The pressure vessel uses a fully welded construction for the safest possible operation. It is generally code stamped.

Bellows compensate for the thermal differential expansion between the stainless steel bundle and the low alloy pressure vessel. The bellows are located inside the pressure vessel, between the bundle inlet / outlet pipes and the vessel nozzles.

The exchanger is set vertically and operates in counterflow. Hot effluent from the last reactor enters the heat exchanger at the top and flows downward as it is being cooled. Cold feed enters the heat exchanger at the bottom and rises as it is being heated. The cold feed is made up of two streams, the recycle gas and the liquid feed. The recycle gas is fed directly into the bottom of the vessel, then flows into the bottom of the bundle through a specially designed inlet. The liquid feed is injected directly into the bundle through spray bars to ensure its proper distribution in the bundle. Liquid feed and recycle gas are therefore combined just as they enter the heat transfer bundle.

The design is such that all required maintenance (***refer to page 8***) is performed on site, on the foundation, and a primary access manhole is provided near the top of the pressure vessel. This manhole is large enough for insertion of replacement parts for hot-end expansion bellows, if ever necessary. A secondary access in the bottom of the exchanger is provided, either through the recycle gas connection or through a second manhole.

ECONOMIC ADVANTAGES OF PACKINOX ON GRASS ROOTS PROJECTS

Lower capital cost

The opportunities to reduce capital cost requirements on a grass roots project with a PACKINOX are quite significant.

- A PACKINOX feed effluent heat exchanger is a ***single shell design***, even for very large feed rates (50,000 bpd or over).
  Its heat transfer bundle can be made of a cross section and a length sufficient to handle the largest flow rates at the prescribed pressure drop, while at the same time delivering a very challenging heat recovery.
  The capacity to manufacture very long plate counterflow bundles is such that there has never been a need to install multiple PACKINOX exchangers in series, even for cases of very high thermal efficiency.

By comparison, a vertical shell & tubes solution will require multiple shells in parallel to handle even relatively low flowrates.
In addition, the efficiency of large vertical shell & tubes is limited by practical tube length.

Figure 2, page 15 gives a prospective view on relative sizes of shell & tubes and PACKINOX.

- When a process licensor optimizes the heat and materials balance of the process loop, the ***charge heater and product cooler are usually sized for a smaller heat duty*** because the plate type feed effluent exchanger is sized to deliver more of the heating / cooling duty.

  Limits of efficiency of large welded plate feed effluents can be very high, and an economic analysis is usually performed to determine which heat balance gives the best overall project pay-back.

- Finally, and as a consequence of the smaller size equipments required, ***installation costs are lower***. The savings can be quite appreciable, especially when :

  - duplication of high temperature piping can be avoided (single versus multiple shell design)
  - equipment has to travel a long distance before reaching jobsite
  - poor soil or earthquake design requires significant structural support

Higher operating margins.

Higher operating margins attributable to a PACKINOX on a grass roots project can be put in three main categories:

- Lower operating costs, principally due to fuel cost savings at the fired charge heater.

- High reliability and on-line availability at full performance.

- High flexibility of operation.

  - Refiners appreciate particularly the capability to push throughput beyond nameplate capacity without any concern of reaching vibration limits (PACKINOX bundles will not vibrate under any operating condition, as the plates of the bundle are continuously braced)

- The *liquid feed injection system* allows to run at a very wide range of H2/HC ratios (wider than any other feed effluent design) and of turndown rates without penalizing process performance.
The injection system has proven over the years to be a key contributing factor to the high flexibility of operation and predictability of performance of PACKINOX exchangers.
Because it allows proper distribution of the liquid feed between all the channels of the heat transfer bundle, the injection system ensures a proper vertical entrainment of the two phase feed. The proper entrainment in turn ensures the predictability of performance and greatly reduces the risks of fouling in the heat transfer bundle.

ECONOMIC ADVANTAGES OF PACKINOX IN REVAMPING PROJECTS

The economic advantages of welded plate heat exchangers in revamping projects vary greatly from project to project and are a function of existing site and market conditions. Any of the following advantages may be applicable, by itself or in combination.

- Replacing an older preheat train by a high efficiency, low pressure drop plate exchanger in many cases will allow to ***process more barrels*** at a ***lower pressure*** without modifying existing heaters and compressor.

  In some rare cases, as exemplified by the Belgian Refining case history (see below), the total replacement of the preheat train is not necessary. Instead, the PACKINOX can be put in series with part of the existing train.

  The throughput capacity increase is generally between 10% and 35%.

  In high pressure catalytic reforming, the operating pressure is often decreased by 100 psi or more, which has a positive impact on liquid yields and on net hydrogen production.

  Economic justification of the revamping is usually straightforward when both higher throughput and lower pressure are expected.
  Such a situation would occur if a Refiner wanted to ***consolidate two older reformers into a single unit***, for instance.

- Revamping of an older unit to PACKINOX service will always yield ***large energy savings***, principally at the fired heater, with secondary savings at the product cooler and at the compressor.

  A very typical example would be a 300 psi catalytic reformer, 25000 bpd nameplate capacity, with current feed preheat temperature entering the charge heater at about 760°F to 800°F.
  The additional heat duty that a PACKINOX would offer on this type of unit could be as high as 30 MM Btu/h (9 MW), which would represent about $750,000 (USD) per year.

Compressor horse power savings may come from a reduced H2/HC ratio and/or lower pressure drop in the PACKINOX.

- When revamping, PACKINOX is also a ***plot space saver***, as its single, vertical shell design typically requires only a 12 ft x 12 ft (3.5m x 3.5m) square of plot space.

  In some cases, where Refiners have over the years used most of their available plot space, the PACKINOX is even seen as a means of freeing some space on the ground. That extra space could be significant, particularly when the PACKINOX replaces a large bank of horizontal shells (8 to 16 shells). (Please refer to ***Figure 3, page 16***)

SAFETY + THE ENVIRONMENT

Please refer again to ***Figure 1, page 14.***

It is quite certain today that the most ardent supporters of the technology of welded plate feed effluent heat exchangers are found in the refineries. Part of that support comes from their appreciation of the reassuring safety features inherent to the design. And some of the environmental benefits of PACKINOX are direct consequences of its safe design.

- ***Fewer flanges overall, and no "body flange"***: A single shell PACKINOX will have four main process piping flanges, one or two manhole covers, and a few secondary flanges (liquid feed injection nozzles, vent, drain, etc...).
  Otherwise, the shell is of fully welded construction and does not have the body flanges typical of shell and tubes (S&T). Due to its internal arrangement, a welded plate feed effluent exchanger does not need a body flange, and the decision was made long ago in concert with refinery operators not to add one. This is universally perceived as a ***significant improvement against fire and environmental hazards from hydrogen leaks.***
  Note also that the need to monitor fugitive emissions from a flange disappears when that flange disappears. A PACKINOX replacing a train of shell and tubes will typically eliminate several dozen flanges...

  It is appropriate here to mention that no PACKINOX user has ever reported a leak of product to the atmosphere.

- ***"Cold" shell***: In addition to having very few bolted flanges, the shell is also "cold". Most of the shell wall is in direct physical contact with recycle gas coming directly from the compressor. Although radiation from the bundle will heat the shell wall, the latter's temperature will be substantially colder than the shell wall of the equivalent S&T with effluent on the shell side. Since the shells of PACKINOX exchangers have historically been designed for the same temperature gradients as those of the equivalent S&T, they in effect include an extremely high safety factor in their design.

- **All maintenance done from inside the pressure vessel, on site**. Of course, a fully welded pressure vessel prevents routine pulling of the bundle.

  From an operability point of view, this is totally acceptable because all maintenance required can be performed directly on site and inside the pressure vessel.

  From an environmental compliance point of view, this is desirable because there is no oily bundle to manipulate.

  And from an economic point of view, this is also quite positive since maintenance will generally be performed at a lower cost. This is at a time when the cost of heat exchanger maintenance is rapidly escalating, particularly in North America since new environmental regulations have come into effect in 1991.

  - Cleaning : The main methods of cleaning are chemical wash (principally for salt deposits) and steam jet flushing (when hydrocarbon fouling is present, including polymerized gums in hydrotreating service). Vacuum suction has also been used to remove solids accumulated in header boxes. Note that cleaning of a plate bundle is a lot less frequent than for a S & T in same service, because fouling rates are about three times lower.

  - Bundle inspection and testing, bundle weld repairs, channel plugging: All will be performed inside the shell. Accessibility inside the shell is a function of its diameter.
    There is generally sufficient internal clearance between the shell wall and the bundle to allow an operator to perform a visual or dye penetrant test of the bundle welds. On the lower pressure units, the tendency is to oversize the vessel diameter for enhanced accessibility.

  - Bellows replacement: Will also be performed onsite, inside the pressure vessel. The manhole(s) are made large enough to allow insertion of replacement bellows.

- ***Smaller charge heater duty for lower atmospheric emission.*** This is quite straightforward. Reducing a charge heater's process heater duty by 10 to 30 MM Btu/h will bring a noticeable reduction in SOx / NOx emission from that heater's flue. Of course, the reduction amount will depend on the type of heater and burner, and on the quality of the fuel burned.

CASE STORY (1): BELGIAN REFINING CORPORATION (600 psi Naphtha HDT)

The project:

Belgian Refining Corporation (BRC) wanted to ***increase the processing capacity of this 40 bar (600 psi) naphtha Hydrotreater by 35%*** (from 20,000 bpd to 27,000 bpd), with as few modifications to the existing equipment as possible.

Existing equipments:

This HDT unit had first been put in service in 1968.
The existing equipment, including charge heater, compressor and feed effluent heat exchangers, was in suitable mechanical condition. BRC wanted to reuse them as much as possible in the new configuration to reduce the capital cost of the project.

Two important parameters came into play:

Heater limitation: It was determined early on that the fired heater thermal capacity would be the main bottleneck to overcome in order to increase throughput.
Compressor availability: Supplemental compressor capacity was readily available and the existing equipment could handle the increased flow.

Revamping study with conventional Shell & Tubes:

A study and cost estimate were performed on a revamping that would have involved only S&T in the feed preheat train.

BRC considered adding five horizontal shells to the existing train of five shells. The ten shells would have had a total pressure drop of 9.1 bars (132 psi), which was still acceptable for the existing compressor. The total heat transfer duty of the preheat train would have been 18.5 MW (63 MM Btu/h). This preheat duty would still not have been sufficient to accommodate the limitations of the existing heater, and a new heater would have been required, or substantial heater revamping at a high cost.

The expected total cost of this revamping option was $1,950,000, of which 60% was for the heater.

Revamping study with PACKINOX

We then considered the use of a plate technology to enhance the heat recovery in the preheat train, with the aim of eliminating the need for a new heater.

BRC and PACKINOX teamed up to review the different possibilities to integrate a welded plate feed effluent exchanger in the existing scheme. Several options were available, going from a complete replacement of the preheat train with a plate exchanger, to a more judicious mixing of old and new exchangers.

We finally determined that the best payout (PFD, ***Figure 4, page 17***) occurred when we added one PACKINOX in series to five existing shell & tubes. The new preheat train had a total pressure drop of only 5.6 bars (81 psi), which was quite acceptable. Best of all, the preheat duty was now 24.5 MW (83.6 MM Btu/h), and the existing fired heater was more than sufficient. Part of the gain came from conversion of the effluent heated stabilizer reboiler to steam heating.

The expected total cost of this revamping option was $1,400,000, which was less than the S&T solution.

Revamping with the plate technology offered the most economic combination:

- A lower capital cost ($550,000);
- The lowest operating cost (expected $250,000 fuel savings at fired heater)

Careful consideration was given to possible fouling and corrosion in the plate exchanger. Because no problem had ever been experienced at the hot S&T's, it was decided to place the plate exchanger in series at the hot end. As insurance, swing elbows were incorporated to permit bypassing of the PACKINOX. Onstream water wash facilities were also provided.

PACKINOX has since gained commercial experience where the plate bundle sees both the hot end and the cold end in hydrotreating. In retrospect, perhaps we could have installed the PACKINOX at the cold end and therefore saved a bit on its cost.

Results after one year of service:

The revamped unit went on line in October 1993, and the results so far are completely satisfactory:

- The PACKINOX consistently achieves better performance than specified (***Figure 5, page 18***)
  The Hot End Approach (Temperature difference, Effluent In - Feed Out) varies between 25°C and 30°C (45°F and 54°F), for a design of 45°C (81°F). Admittedly, PACKINOX applied a safety factor in its design, because this was a first in hydrotreating.
  Looking at the pressure drop curves, you will also see that they are quite satisfactory and slightly better than design.

- The actual fuel gas saved at the charge heater (compared to the S&T solution envisioned) are even better than expected : $308,000 .
  The corresponding reduction in SO2 emission in the flue gas is sizable : 0.33 ton / day.

- The excellent thermal performance of the PACKINOX gave rise to two potential problems. The heater is so under loaded that half of the burners have had to be spaded off. Secondly, a possible danger arises of a thermal runaway if the reactor exotherm were to exceed the approach. We have therefore had to install additional alarms and shut-down / depresurizing trip functions.

- The PACKINOX has required no maintenance so far, and judging from its stable thermal performance, there is no evidence of any fouling in the heat transfer bundle. A complete inspection of the unit will occur next month at turnaround time.

CASE STORY (2): CHEVRON USA, EL SEGUNDO, CA. (40,000 BPD CCR PLATFORMING UNIT BY UOP)

The project:

As a part of phase one of its Reformulated Gasoline Program (RFG) at the El Segundo, California Refinery, Chevron USA decided to consolidate three older, semi regenerative catalytic reformers (25,000 bpd; 15,000 bpd; 10,000 bpd) into a ***low pressure CCR Platforming Unit (40,000 bpd) licensed by UOP.***

One of the two smaller reformers was scrapped because of its general condition, and the other one was converted into an isomerization unit. The largest reformer was extensively revamped into a CCR Platforming Unit.

Several factors contributed to the justification of this sizable capital project. In particular, the refinery needed additional hydrogen production for RFG, and it also wanted to improve the reliability of its hydrogen supply. Revamping the older catalytic reformer into a low pressure CCR Platforming Unit satisfied the needs for increased, steady hydrogen production. Chevron USA also expected increased operating margins on the CCR Platforming Unit because of lower operating cost, lower maintenance cost, and lower regeneration cost.

Required modifications:

Modifications to the 25,000 bpd cyclic unit were extensive, because a number of limitations on the existing equipment (unsuitable mechanical condition, duty too low, pressure drop too high, etc...) were incompatible with the requirements of the low pressure CCR service.

Chevron USA installed:

- Four new reactors;
- New feed effluent heat exchanger;
- New net gas compressor;
- New continuous catalyst regenerator.

The fired heaters were also retubed.

The feed-effluent heat exchanger:

It would have been impossible to reuse the existing bank of eight shell and tubes on the 40,000 bpd, low pressure CCR Unit, because its pressure drop would have been extremely high. In addition, several of the shells required maintenance, the colder ones in particular due to corrosion.

The project team performed an ***extensive review of both PACKINOX and vertical shell & tubes*** before deciding which technology was best for its new feed effluent heat exchanger.

Chevron USA selected PACKINOX, for a number of reasons:

- First and foremost, a detailed cost study showed that PACKINOX would ***save roughly one million dollars in capital cost*** on an installed cost basis. The primary reason for this large capital cost advantage is that PACKINOX was able to handle the 40,000 bpd in a single and relatively small shell, whereas two larger vertical shell and tubes in parallel would have been required with associated support structure.
  Figure 2, page 15, clearly shows the inherent size / cost advantage of PACKINOX.

- With its single shell design, PACKINOX was also able to guarantee a higher duty (310.6 MM Btu/h) than the shell and tubes . Net fuel cost savings were therefore expected at the charge heater.

- Experience on a reformer at the Port Arthur Refinery had shown that it is difficult to balance the flow between two vertical shell and tubes in parallel, even with flow control valves, because of the "liquid lag" phenomenon. PACKINOX eliminated this concern entirely because it offered a single shell design.

- PACKINOX's shell and plate design was deemed superior from an operator's point of view. With the proper process instrumentation in place, the unique design of PACKINOX with the recycle hydrogen pressurizing the shell gives ample advance warning should internal failures start to develop. The chances of an unplanned, catastrophic shut down of the Platforming Unit are lower with PACKINOX than with shell & tubes.

- Chevron USA had consulted and visited several other refineries operating a PACKINOX, and the feed back had been very positive. In addition, the detailed information collected from those visits became helpful to the project team in planning their own PACKINOX.

Results after one year of service:

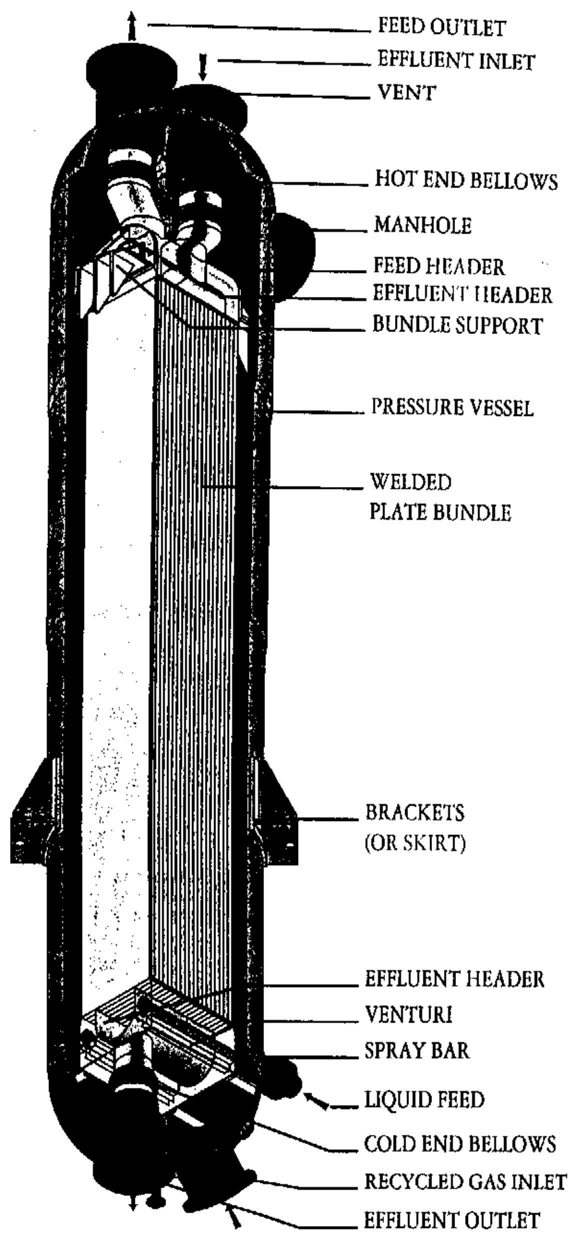
The CCR Platforming Unit has been on line since March 1994 and the results so far are quite good:

- The PACKINOX was started up without any difficulties
- Its thermal and pressure drop performances are slightly better than design and are stable
- We have no evidence of any fouling
- The PACKINOX has been running trouble free since its start up

CONCLUSION

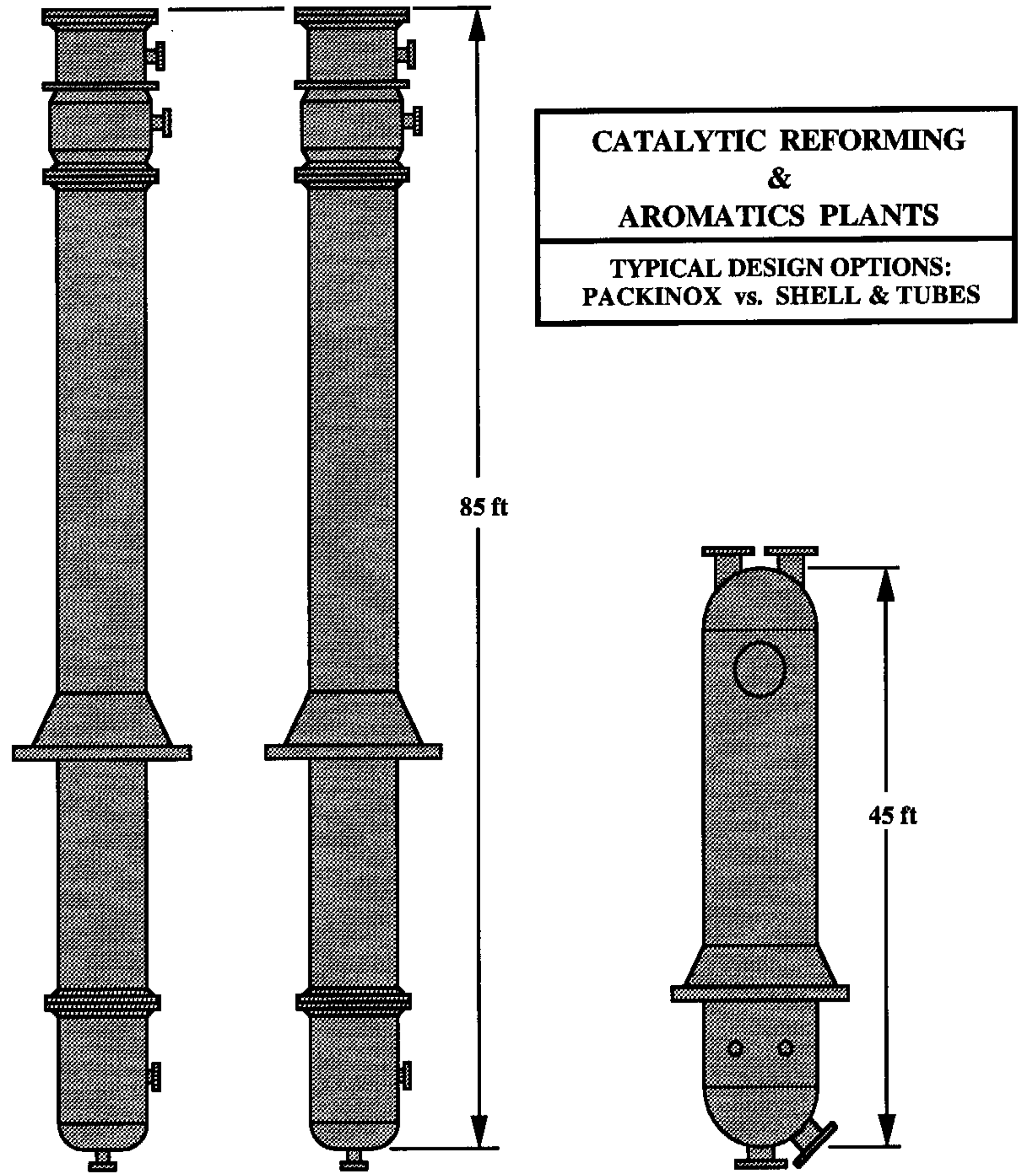
Perhaps the only thing the reader needs to remember from this entire paper is that PACKINOX plate & shell feed effluent heat exchangers are a ***proven, successful technology*** in the refining world :

- They are often a good tool to reduce project capital cost and unit operating cost for better economics overall
- They are inherently safe to operate and have a good reliability track record
- Plant operators like them for their steady performance under varied operating conditions.



TYPICAL GENERAL ARRANGEMENT

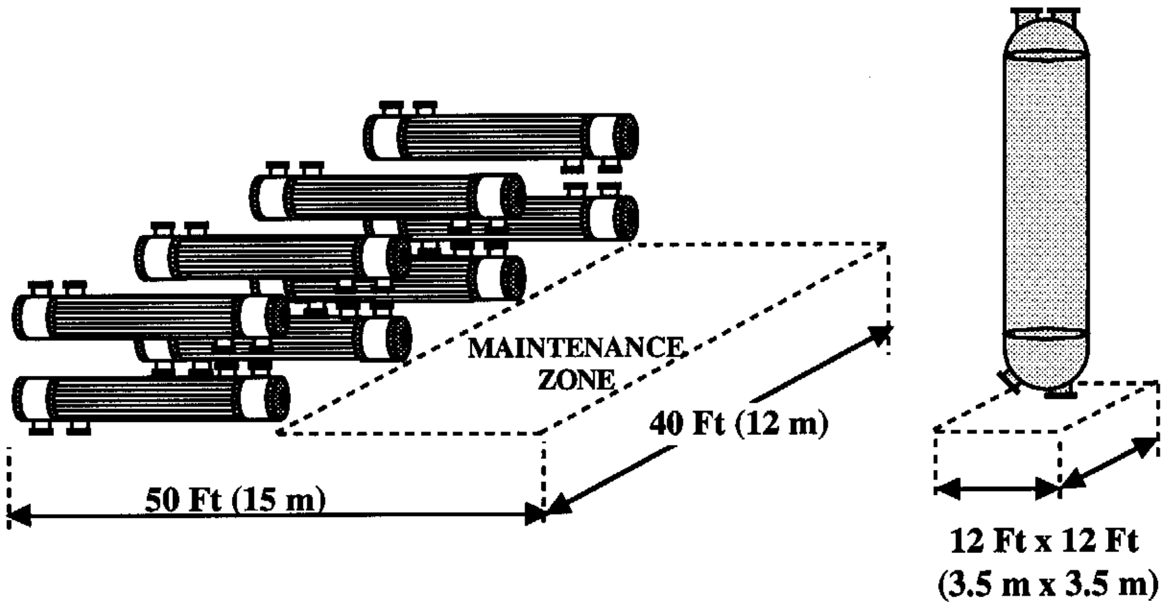
Figure 1



TWO SHELL & TUBES IN PARALLEL
Dry weight = **500,000 lb**

ONE PACKINOX
Dry weight = **200,000 lb**

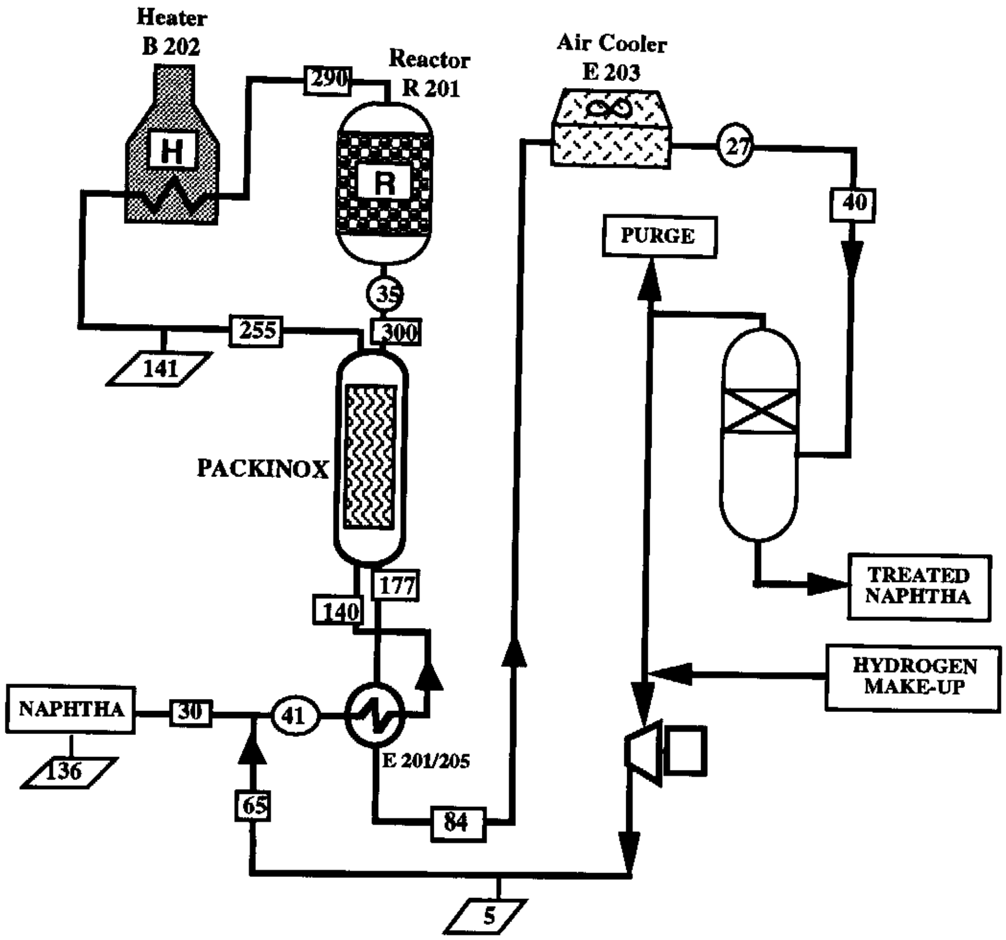
Figure 2



CONVENTIONAL TRAIN OF SHELL & TUBES **PACKINOX**

<u>PLOT SPACE SAVINGS</u>

Figure 3

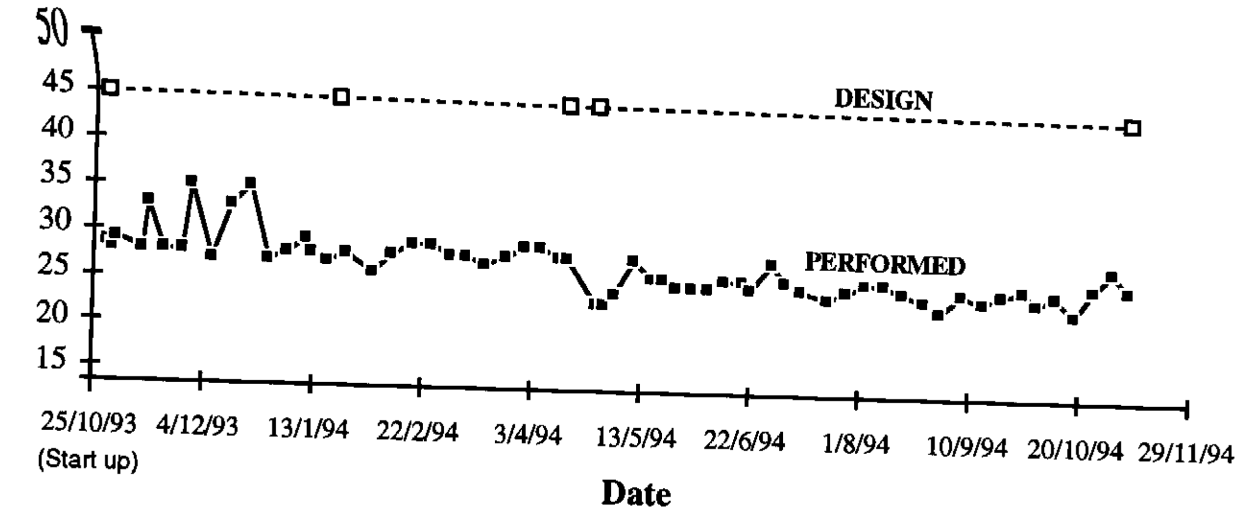


LEGEND: ▱ Mass flow (t/h)
□ Temperature(°C)
○ Pressure (bar)

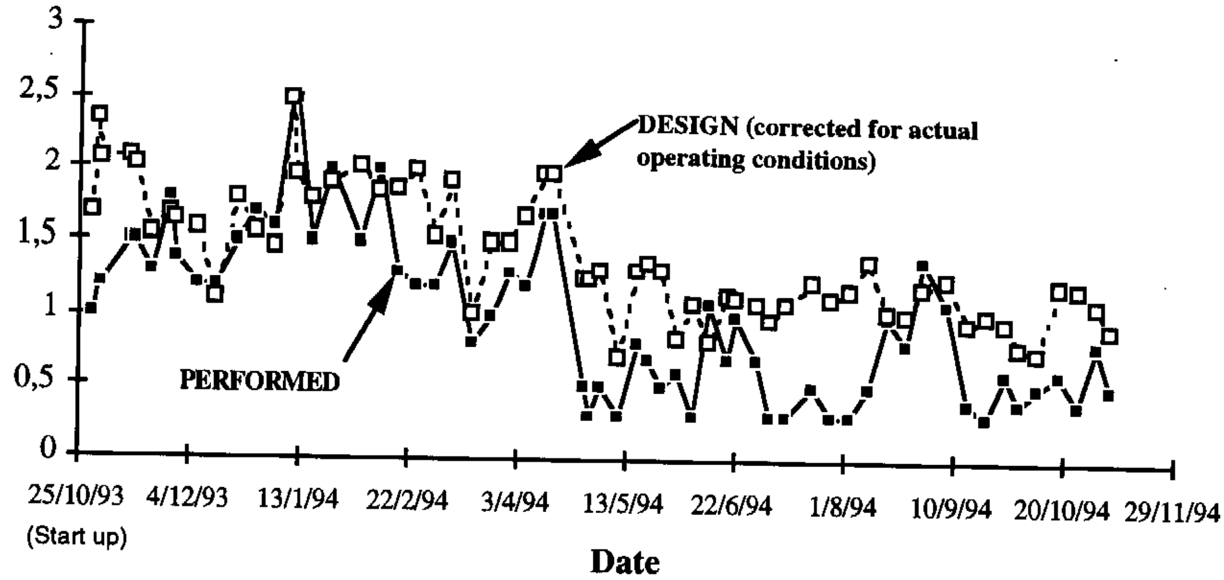
SIMPLIFIED PROCESS FLOW DIAGRAM

CASE STORY (1): BELGIAN REFINING CORPORATION
(600 psi Naphtha HDT)

Figure 4



HOT END APPROACH , °C
(Reactor Effluent In Temp. - Combined Feed Out Temp.)



TOTAL PRESSURE DROP, bar
(Feed side + Effluent side)

CASE STORY (1): BELGIAN REFINING CORPORATION
(600 psi Naphtha HDT)

Figure 5