Refinery Profitability Drives FCC Revamps

by

L. A. Lacijan
Manager
FCC Technical Services
UOP LLC

and

M. W. Schnaith
Business Development Manager
FCC & Alkylation
UOP LLC

Abstract

Each refinery has unique economics that depend on crude selection, processing and equipment capabilities, and local market product values. As the economic drivers for the refinery evolve over time, opportunities to improve profitability will appear. In the FCC unit, these opportunities usually include such items as increased capacity, processing lower-cost heavier feeds, changing product yields, and improving unit reliability.

Any FCC revamp poses unique challenges. Due to the wide variety of unit styles, the increasing age of many units, and the typical desire to extend capacity well beyond original design values, the FCC revamp must deal with complexities that transcend normal new unit process design issues. To ensure success, it is important to work with companies that have the technological innovation, experience and service commitment to meet the challenges.

This paper describes three different refinery FCC projects, their constraints, the routes that were taken to revamp the FCC units to improve the profitability of each refinery, and the results of the revamp. In one case, the FCC was modified to produce more petrochemical feedstock because of the local demand and value. In the other cases, higher feed rates of resid were desired to increase crude flexibility, and higher overall feed rates were targeted. UOP was able to study each case and provide the FCC technology to achieve the individual processing objectives consistent with each refiner's overall goals.

Introduction

The last new FCC unit put into operation in North America was an 8000 BPD RFCC unit in Shreveport, LA in 1997. Prior to that, a new 90,000 BPD FCC unit in St. Croix was put into operation in 1993. Both of these units were new conversion capacity rather than replacing older units. There have been several major revamps where either existing older FCC units were completely replaced or thermal cracking conversion capacity was replaced by catalytic cracking capacity. Because of the slow demand growth in refined fuel products over the last decade and the continued projection for slow growth as shown in Table 1, the need for increased conversion capacity has been satisfied with revamps rather than new FCC units.

Table 1

Region (Average annual growth rates, %)	*2003 - 2006* GDP (Short Term)	*2000 - 2030* GDP (Long Term)	Population
N. America	3.0	2.1	0.8
Europe	2.1	2.0	0.1
OECD Pacific	1.2	2.0	0.1
Transition Economies	4.3	3.1	-0.3
China	7.8	4.8	0.5
S. E. Asia	4.5	3.6	1.0
India	5.7	4.6	1.3
S. America	2.4	3.0	1.1
M. East	4.1	2.6	2.3
Africa	3.5	3.6	2.1

Source: IEA

The market place has not been stagnant, however, and the value of the various conversion products has changed over time. Refiners are challenged with keeping their FCC units working for them. Figure 1 shows the trend in refining margins over the last decade. The shrinking margins are particularly difficult because of the pressure to utilize available capital for “necessary” spending on clean fuels and environmental projects that have been legislated. It is more important than ever to optimize the operation of existing refinery assets.

Due to the nature of FCC units and the continuing evolution of the technology, it is possible to expand capacity well beyond original design. Most refiners take advantage of this trend in the lifecycle of their FCC unit and continue to revamp older units for greater capacity and product flexibility. But this path carries with it complex challenges, due to existing equipment limitations and constraints that cannot be easily overcome. Many times FCC revamps do not meet their full potential, have only marginal success, or fail to deliver on the promised benefits.

Critical Success Factors

The success of any FCC revamp will depend on many factors. First on the list is obtaining a quality engineering and technology design for the project. Included with this is a realistic projection of the expected benefits. Predicting process performance in a revamp is more difficult than starting with a clean sheet of paper. Equipment limitations and trade-offs must be properly understood and evaluated to produce a trustworthy revamp design. Attention to detail is of paramount importance, as many times lack of success can be traced to unforeseen issues. While there are many companies who can provide engineering services for FCC revamps, there are few that bring the specialized knowledge and expertise to ensure success.

When technology upgrades are part of the revamp, as is frequently the case, not only is the quality of the technology important, in terms of commercial experience and performance, but the ability to apply improved technology in a revamp setting is critical. Many times limitations will create compromises to normal design criteria that can restrict the ability of the technology to deliver. Being able to create innovative solutions to overcome constraints is a skill that can mean the difference between a highly successful revamp project and one that achieves only marginal benefits.

Project execution is another factor that can have a tremendous impact on the overall economics of the revamp. Finding the best way to implement the revamp is critical to making it a viable project in the first place. Combining the elements of equipment procurement, demolition and construction planning, staging and erection, and overall turnaround planning, all within a limited timetable can be an imposing task. Overall project management has become an increasingly important function for revamps that is frequently outsourced to specialized companies.

The final factor that ensures ultimate success for any FCC revamp is ongoing technical service. It is not enough to have a quality technology design and project execution plan. Once the revamp is commissioned the critical tasks of evaluating and optimizing the performance begin. “Expect the unexpected” is perhaps a useful motto to observe during this time. Depending on how dramatic the changes to the unit, the operations staff may have to relearn how to achieve the best performance. Proper technical support during this period can be critical to refiners capturing the full economic benefit of their revamp.

UOP executes 15 to 20 FCC revamp projects in any given year. We have the necessary technology, innovative application and engineering skills, attention to detail and ongoing technical service to ensure that your FCC revamp will succeed. The following examples serve to illustrate these critical success factors and show how refiners have improved their profitability by revamping the FCC unit to achieve new goals.

FCC Revamp Examples

Three cases are presented here of successful revamps to older FCC units. Each confronted unique challenges and utilized commercially well-proven technology, but applied that technology in quite innovative ways.

Case 1

A refinery located in Memphis, TN, with a capacity of 130,000 BPD found itself constrained by the capacity and conversion capability of the existing FCC unit[1]. The unit was originally a UOP high efficiency design with a capacity of 29,300 BPD and started up in 1980. This unit was revamped several times previously to increase its capacity to 62,000 BPD. During this time, upgrades and improvements to other units in the refinery occurred that complemented the FCC growth. A crude unit revamp in 1999 resulted in better recovery of Jet Fuel and Distillate, and heavier feed to the FCC.

The plans for the refinery included a crude unit expansion, a new CCR Platforming™ unit, and FCC and Alky unit revamps for capacity increases. Because the unit had been revamped so far beyond its original capacity, it faced some severe challenges. Reactor catalyst containment was poor with catalyst losses at about 5 tons per day. Catalyst section cyclone velocities were high and reliability was poor causing unplanned shutdowns.

The refiner set 69,000 BPD as the new feed rate goal with a heavier feedstock having 2 to 4 degrees API lower gravity and an increased Conradson Carbon residue of 2.0 wt%. UOP performed a revamp feasibility study to analyze the best technical options and weigh their benefits versus cost and implementation. The targets caused the operating conditions in the existing unit to be beyond the capacity of most of the catalyst section, and resulted in the need to replace vessels with larger upgrades. Ultimately UOP was able to retain the existing structure by an innovative solution for catalyst containment in the regenerator. The VSS™, previously used exclusively in the reactor, was proposed for the regenerator. This allowed the cyclone system to be single stage and essentially halved the required number of cyclones. To accommodate the heavier feed and maintain conversion and product selectivity, new Optimix™ feed distributors and a VSS reactor riser disengager were employed.

The existing combustor section was too small for the new coke yield, so a larger vessel was proposed. The main fractionator and gas concentration section also required modifications for the new conditions.

The feasibility study and economic analysis showed the following goals could be achieved:

- Increase capacity to 69,000 BPD with a future capability of 75,000 BPD
- Reduce reactor catalyst losses from 5 tons per day to 1.5 tons per day
- Charge a heavier feed to the unit, up to 2.2 wt% Conradson Carbon with an API gravity of 24.4
- Reduce cyclone velocities
- Increase coke burning capacity
- Expand main column and gas concentration sections
- Meet scheduled turnaround start date and duration of turnaround

With this focus, a team from the refiner, UOP, and International Alliance Group (IAG) was assembled to implement the revamp. IAG is a company that provides a specialized approach of overall management and implementation for FCC revamps. UOP provided the basic engineering and technology package and IAG provided the project management and execution. The sub-contractors were managed by the IAG project team so that all aspects of the revamp and turnaround execution were coordinated in concert. A complete scope of work was developed and a capital budget of $35 MM established. A $10 MM maintenance budget for the turnaround was also set at this time. To control the cost and timing of the revamp, the scope was "frozen" prior to the start of the project implementation. The new reactor and regenerator configuration selected by the team is shown in Figure 2.

A detailed pre-turnaround and turnaround construction schedule was developed based on six 10-hour days for pre-turnaround work and two 12-hours shifts working seven days a week for the turnaround. The shortest possible turnaround time was required to mesh with overall refinery limitations. New equipment was staged adjacent to the operating unit on a temporary structure and pre-inspected to help minimize turnaround time.

The unit was shutdown on October 17 and the revamp progressed as scheduled. The old reactor, combustor, riser, and catalyst standpipes were removed and the new equipment installed in the existing structure. The main column and gas concentration section work was carried out simultaneously.

The plan was for a 21 to 25 day outage to perform all the work. The actual work schedule resulted in a 25 day outage. The unit was placed back in operation on November 11, and was processing 68,000 BPD (total feed available) within two days of commissioning. Subsequently, the unit has also achieved the 75,000 BPD target.

As a result of the careful planning and attention to detail, all project objectives for the revamp were met. The combined capital and maintenance budget of $45 MM was not exceeded, the turnaround started on time, and was completed after 25 days.

Case 2

A Gulf coast refinery found that the conversion capability of the existing FCC unit was limiting refinery economics[2]. Changing feed quality, combined with feed rate increases beyond the original design, were limiting the performance of the unit. Further changes in feed quality were proposed to increase the heavy syncrude percentage processed by the refinery.

The FCC unit, a stacked Kellogg Orthoflow F originally designed for 30,600 BPD, was already constrained by the air blower, wet gas compressor driver, regenerator superficial velocity, catalyst circulation rate, and high flue gas temperatures. A team consisting of refinery personnel, UOP, IAG, and Andrews Consulting was assembled to evaluate the following refinery objectives:

- Increase production of more valuable liquid products
- Address catalyst circulation limits
- Maintain same level of coke yield
- Provide flexibility for future changes in feed quality

The team focused its effort in addressing the yield selectivity improvement that would be required to process a heavier feed while maintaining coke yield constant, and on the mechanical constraint of limited catalyst circulation. Both of these existing items were addressed by bringing new technology upgrades to the unit design. The team recommended replacing the existing riser "J bend" and plug valve with a "wye" section including catalyst acceleration, new feed distributors, and an increased riser residence time to address the conversion, reliability, and profitability issues. To address the catalyst circulation limitations, a new supplemental reactor stripper was proposed to augment the existing stripper. The original design incorporated an internal stripper and spent catalyst standpipe and was impossible to modify without extensive demolition and construction inside the vessel. A new external side stripper was proposed to allow implementation of the revamp to a higher catalyst circulation rate and avoid the time consuming internal vessel work.

An economic analysis was performed based on installed cost estimates from IAG and yield estimates from UOP. The total installed cost estimate for the new regenerated catalyst standpipe, wye section, feed distributors and upper riser was $5.9 MM. The unit profitability estimate based on the heavier feed and new yields was $4.2 MM per year for a simple payback of less than 15 months.

The total installed cost estimate for the new external spent catalyst stripper was $1.4 MM, and the profitability estimate based on its benefits was an increase of $1.4 MM per year for a one year simple payback. Based on these economics, the refiner proceeded to the implementation phase of the project. Figure 3 shows the changes to the catalyst section.

Preliminary engineering was started in March 2000 and long lead delivery items were requisitioned in May. Detailed Engineering was started in June, with all equipment required for the project being procured. Pre-turnaround activities not requiring unit shutdown were begun in January 2001, and the actual turnaround started on March 7. The turnaround duration was planned for 31 days with two 10-hour shifts per day six days per week. The seventh day was reserved for critical path activities and x-ray inspection work.

The turnaround revamp activities were completed within the planned 31 day window, but re-start of the unit was delayed by greater than expected maintenance work in other areas of the unit and an unexpected problem with the main air blower. When the unit was started, the new equipment allowed greater control of the catalyst circulation rate and a nearly "flare-less" startup was accomplished with products on specification six hours after feed in. The improved control of the catalyst circulation with the wye section and slide valve replacing the "J-bend" and plug valve resulted in a reactor temperature control of less than 1 °F variation compared to +/- 3 °F previously. This provides a more consistent yield pattern and allows operation to be continuously closer to maximum.

The post revamp operation had an improved conversion and reduced coke yield per expectations. Table 2 shows the base case compared to the revamped operation.

Table 2

	Base Case	Post-Revamp
Feed Rate, BPD	48,000	47,450
Feed API	24.4	24.6
UOP K	11.75	11.69
Feed Con Carbon, wt%	0.3	0.2
Feed Steam, wt%	2.1	1.3
Cat/Oil	6.1	6.1
Yields, wt%		
C2 minus	2.9	2.8
C3s	5.5	6.3
C4s	9.6	9.9
Gasoline, 430°F TBP EP	46.0	48.8
LCO, 650°F TBP EP	17.8	18.3
MC Botts	14.7	9.7
Coke	4.4	4.2
Conversion	67.5	72.0

All of the revamp goals were met:

- Increased yield of higher value liquid products
- Improved operating flexibility
- Improved catalyst circulation control
- Obtained flexibility to process more aromatic feedstocks

Part of the success of the revamp was due to a focused team accountable for the goals and execution of the project. The team stayed with the project for its duration ensuring the objectives were well defined and implementation was carried out as planned.

Case 3

A European FCC unit originally designed for 10,250 BPD of fresh feed and started up in 1963 had been revamped several times to increase capacity and to incorporate various technology improvements[3]. In 1998, the refiner decided to revamp the unit to increase capacity slightly, but more important, to increase the unit's conversion and double the propylene (C_3=) yield. There is a nearby petrochemical facility and capturing the C_3= value had become a significant way to improve refinery profitability.

The revamp design basis was set at 26,815 BPD with a minimum C_3= yield target of 8.2 wt-% of feed. To achieve this target, the design incorporated the Optimix feed distributors, the VSS riser disengager, and new reactor stripper internals. The revamp case also included the use of a ZSM-5 additive to increase the LPG olefin yields at the expense of gasoline yield. The configuration of the reactor revamp is shown in Figure 4. The new VSS riser disengager was installed in the existing reactor shell to help minimize costs. A new gas plant was also designed by UOP to accommodate the increased LPG product. The revamp was implemented and the unit started operation in August 2000.

The feed rate for the post-revamp test run was 27,700 BPD with a C_3= yield of 8.5 wt-% of feed, both above design values. Figure 5 shows the trend of FCC products post-revamp as operating conditions and ZSM-5 additive were adjusted in the unit. Although the capacity and yield targets were met, all aspects of the unit operation were not satisfactory. Catalyst containment in the reactor was not achieving its target as shown by catalyst present in the main column slurry product.

The catalyst losses were not sufficient to cause an immediate shutdown, but were high enough to warrant an investigation and find a solution. From an initial target of 0.5 tons per day, the actual losses of 3 to 5 tons per day indicated that something was wrong. An experienced team of UOP FCC specialists and refinery personnel was assembled to work the problem. Ultimately, the problem was resolved and catalyst losses from the reactor were reduced to well below the initial target. The complete story of the successful troubleshooting effort utilizing Six Sigma methodology and modern diagnostic tools has been told elsewhere[3] and serves to underline the importance of a strong ongoing technical service function from the technology provider. The significance of this particular story is that even with yield performance exceeding expectations, any revamp project is not complete until every aspect of operation meets the satisfaction of the refiner.

Conclusions

All three of the FCC revamp examples show that innovative technology can be added to existing units to remove operating constraints and unlock the potential value of the FCC unit. Successful revamp projects are well focused, have clear process and economic goals, have a planning cycle sufficiently in advance of the revamp to address all details, and incorporate execution plans that live by the old adage: “Plan the work and work the plan.” Through attention to the critical success factors of technology design, project execution and technical service, refiner’s can capture the impressive profitability improvement of the FCC revamp.

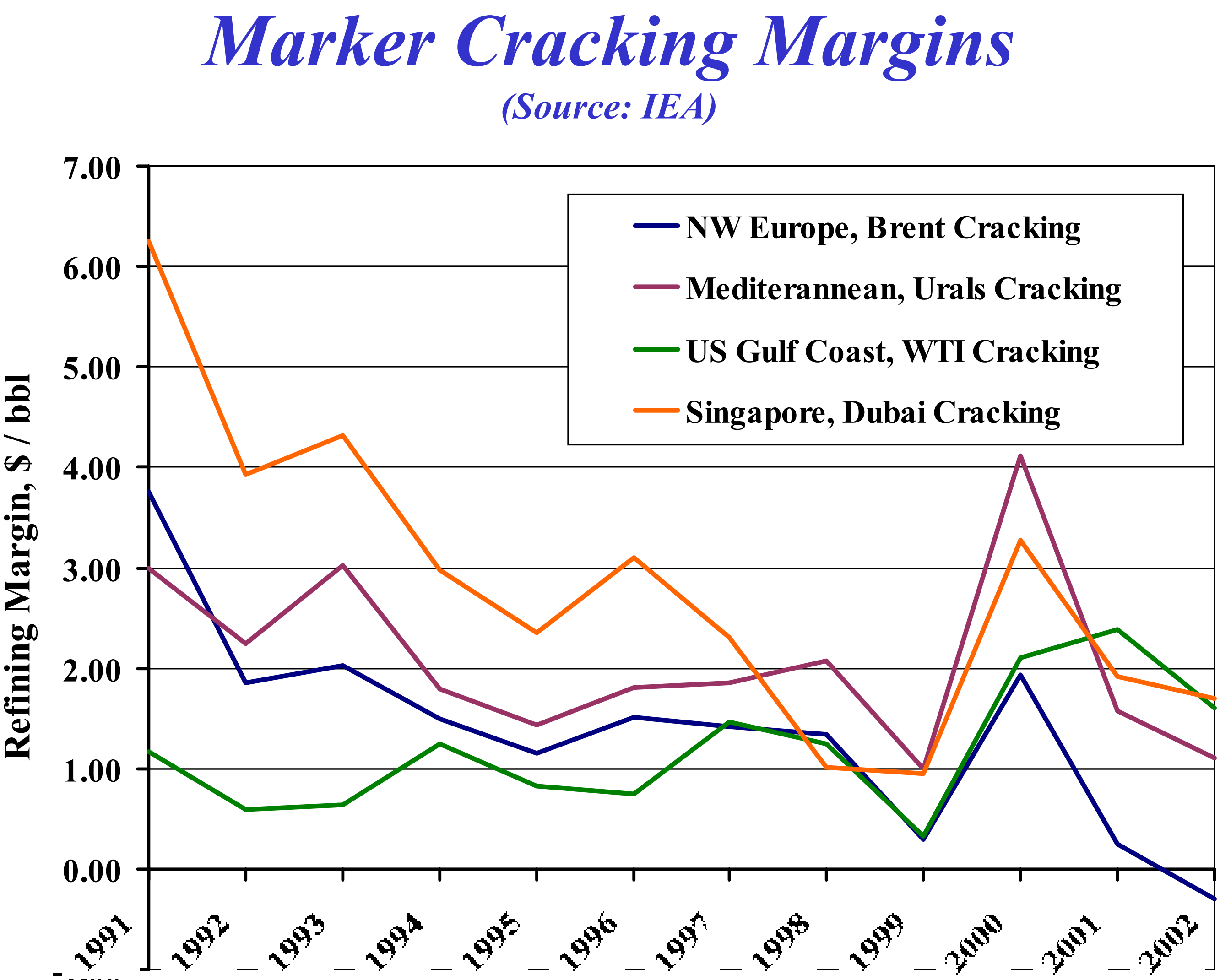
References

1. W. Miller, J. Warmann, A. Copeland, T. Stewart, “Effective FCC Revamp Management Leads to Substantial Benefits”, NPRA Annual meeting, March, 2000, AM-00-24

2. J. D. McKinney, P. Andrews. W. D. Henning, B. Dodds, “Changes To Maintain FCCU Conversion”. NPRA Annual Meetng, March 2002, AM-02-44

3. L. A. Lacijan, S. Niewiedzial, H. Rhemann, “Modern Design and Troubleshooting Tools Create a Successful Revamp”, NPRA Annual Meeting March 2002, AM-02-54

Figure 1



Marker Cracking Margins
(Source: IEA)
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Refining Margin, $ / bbl
NW Europe, Brent Cracking
Mediterannean, Urals Cracking
US Gulf Coast, WTI Cracking
Singapore, Dubai Cracking
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Figure 2

New Reactor/Regenerator Section

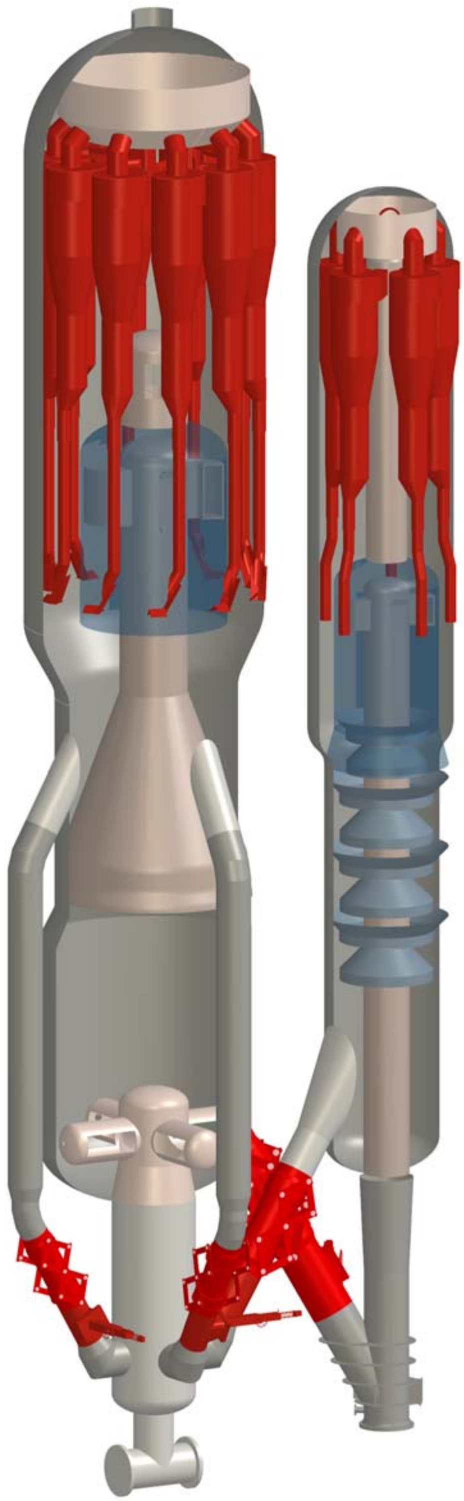


Figure 3

Reactor/Regenerator Sectional Elevation

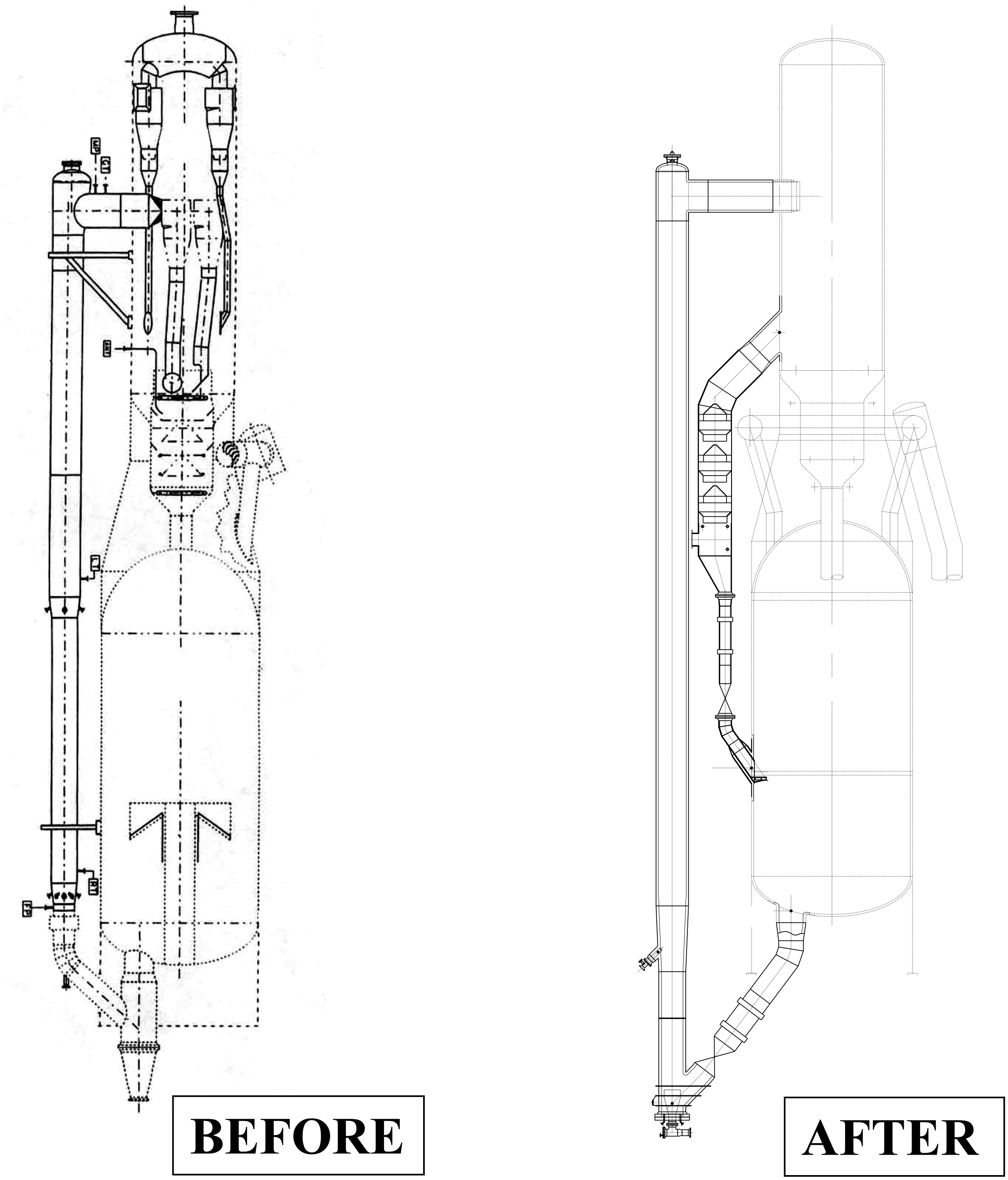


Figure 4

VSS Riser Disengager for Stacked UOP FCC Unit

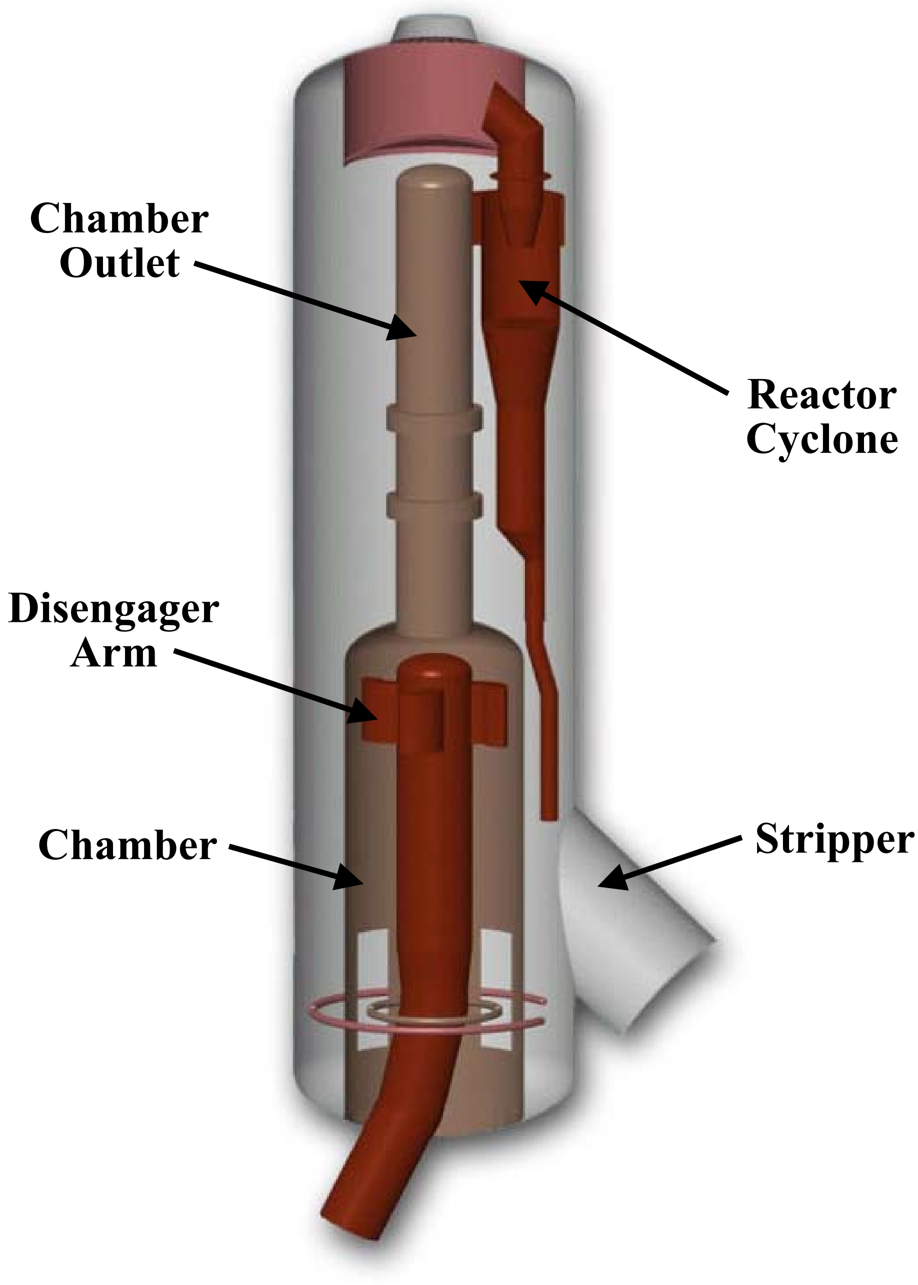
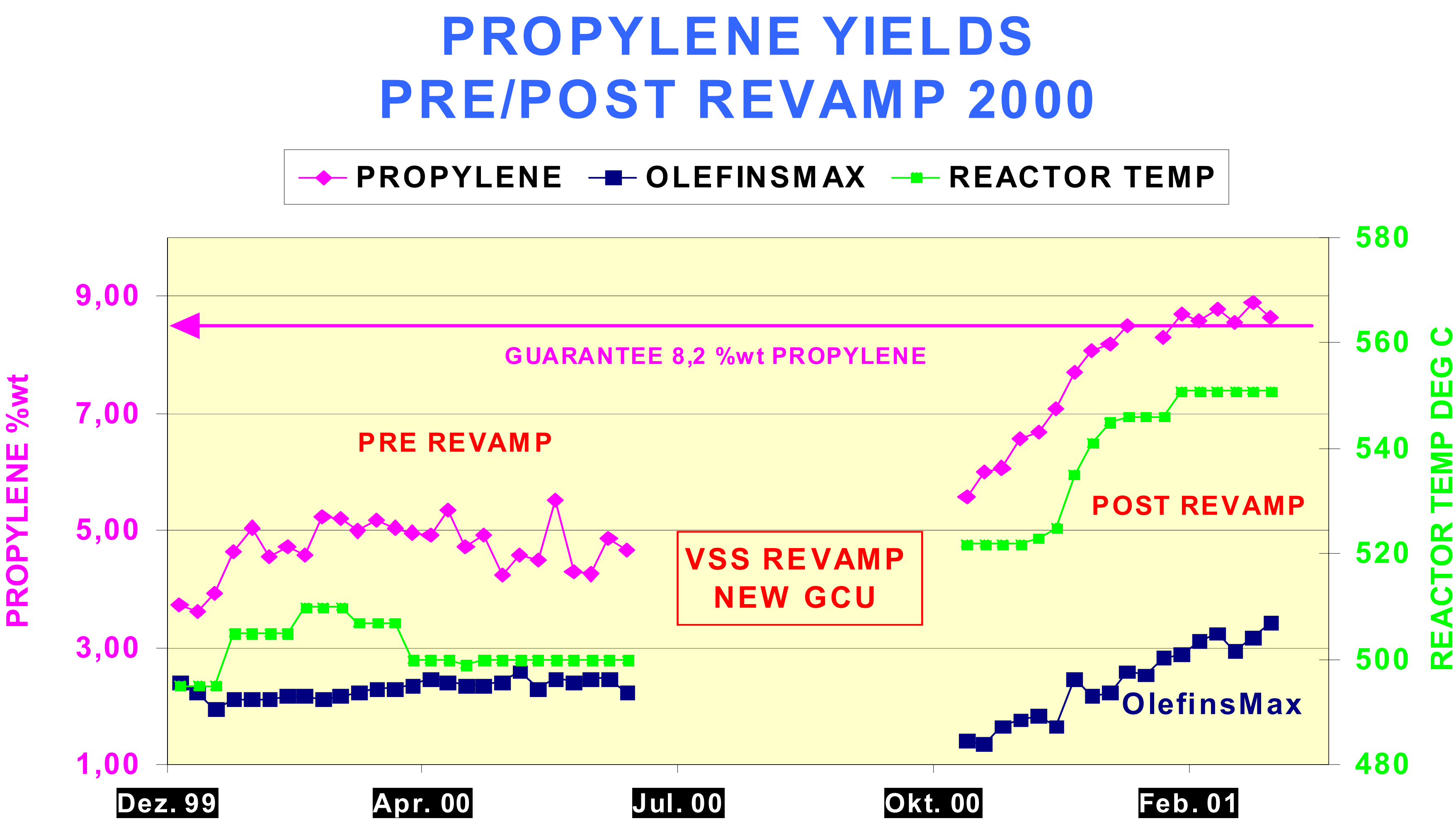


Figure 5


PROPYLENE YIELDS
PRE/POST REVAMP 2000
PROPYLENE
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REACTOR TEMP
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REACTOR TEMP DEG C
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GUARANTEE 8,2 %wt PROPYLENE
PRE REVAMP
POST REVAMP
VSS REVAMP
NEW GCU
OlefinsMax
Dez. 99
Apr. 00
Jul. 00
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Feb. 01