A New Separator Helps FCC Adapt to a New Refinery-Petrochemical Role

Jay Ross
Axens North America
650 College Rd East, Suite 1200
Princeton, NJ 08540

Stephane Wambergue and **Jean-Paul Lepage**
Axens
89, bd Franklin Roosevelt - BP 50802
92500 Rueil-Malmaison, France

Abstract:

New and revamped refining complexes are meeting the new clean fuels and shifting product requirements challenge with the help of new process technologies. The flexible, low cost FCC refinery conversion unit is adapting to play a role as a clean petrochemicals producer to help close a widening gap between propylene supply and demand. Axens has developed and commercially demonstrated a new riser separation system to attain high product containment for maximum yield selectivity. Most importantly, the new device has proven to be insensitive to startup procedure or unit upset and exhibits high separation efficiency with very low catalyst carryover to the fractionator – both at steady state and during upsets.

Market Forces

Refiners the world over are experiencing severe pressure from market and regulatory pressures. On the regulatory side, stringent product specifications relating to sulfur content and composition are being implemented at the same time that emission limits on SOx, NOx, CO, CO2, and particulates are tightening. Overlaying these changes are the market forces that demand a change in the product mix, aside from quality.

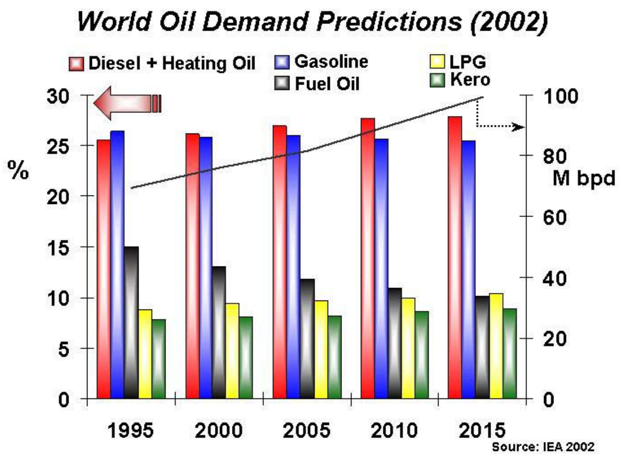

Figure 1 – World Oil Demand Predictions

While the worldwide consumption of fuels increases, the distribution of products is shifting towards the distillates fuels such as diesel and kerosene/jet. Heavy fuel oil demand continues to decline and the refinery margins for low conversion facilities are nearly zero and at times negative. Although VGO hydrocracking is a flexible process to produce high quality distillate products, it cannot help reduce vacuum resid and heavy fuel oil production. Residue FCC is the process of choice for economically upgrading atmospheric/vacuum residues to produce transportation fuels and destroy fuel oil. The distillate products are of moderate to poor quality, however, and require treatment in smaller distillate hydrotreating units.

The other major challenge is the widening gap between supply and demand for petrochemical olefins. Ethylene demand continues to be strong and there is a shift toward increasing production in ethane rich markets such as the Middle East. As a consequence, by-products such as propylene, butylenes and aromatics production will decline or grow at a much lower rate as these are produced only with steam cracker feeds heavier than ethane (propane or naphtha).

	Consumption (MT / year)			Average Annual Growth (%)	
	2000	2005	2010	2000-2005	2005-2010
Ethylene	91	108	130	4.1	4.0
Propylene	54	65	84	5.3	4.7
Butadiene	8	9	10	3.0	2.7

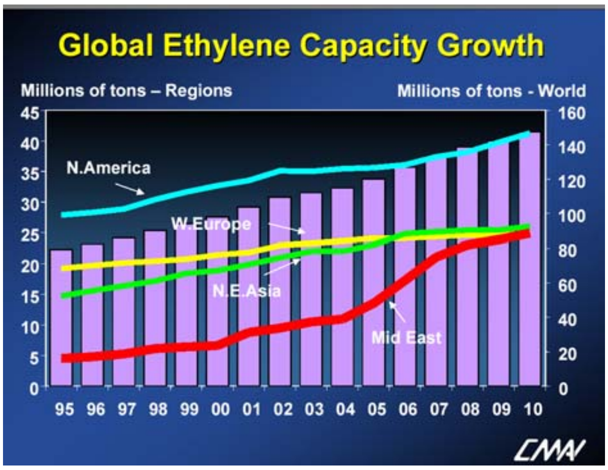

Figure 2 – World Olefins Demand Predictions

Steam crackers accounted for more than 70 % of the global propylene production in 1998 and this contribution should decline in the future as there is a shift to lighter feedstocks. As a consequence refinery based propylene production and recovery will become more and more important with a growth rate well in excess of propylene itself and on the order of 7%/yr.

	1998	2002	2010
Steam Crackers	71	66	60
Refineries (FCC)	27	32	35
Other	2	2	5

Figure 3 – Propylene Production Sources, %

In summary, the two main global demand trends are a reduction in fuel oil and an increase in propylene supply from the refinery sector. The FCC process has a pivotal role to play in addressing both of these requirements.

The FCC Process

A schematic of the Axens' resid FCC unit (the R2R process) is shown in Figure 4. Hot regenerated catalyst flows to the riser bottom. After a short re-acceleration zone to stabilize the catalyst flow, it is contacted with finely atomized feedstock. At the riser top, a riser termination device (RTD) rapidly disengages vapor products from the catalyst to reduce further thermal and catalytic cracking. The spent catalyst is degassed to remove most of the entrained hydrocarbons in a counter-current dense phase steam stripper with multiple steam injections. The stripped spent catalyst is then introduced on top of the first regenerator fluidized bed, where the hot flue gas provides ultimate stripping. The first regenerator acts as a mild pre-combustion zone to achieve 40 to 70% of the coke combustion. The partially regenerated catalyst with less than 0.5 wt% coke is then air lifted to the elevated second regenerator where complete regeneration is achieved, with slight air excess and at low steam concentrations in order to minimize catalyst deactivation.

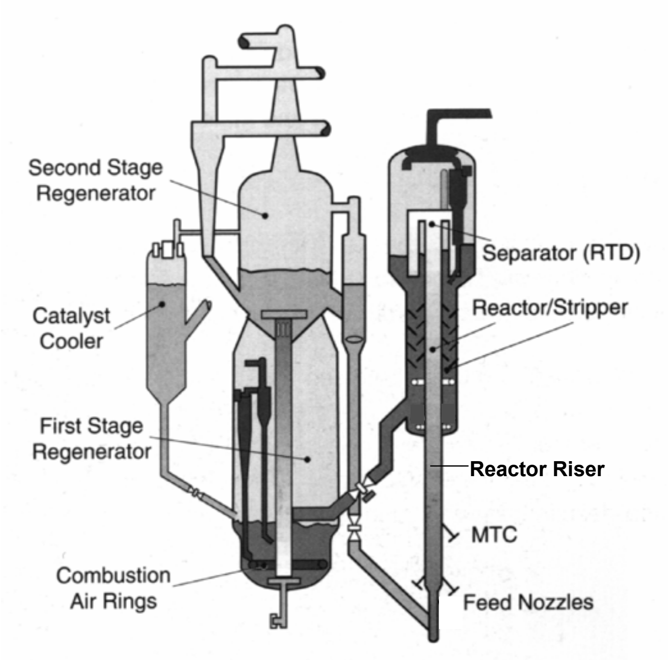

Figure 4: The R2R resid fluid catalytic cracking process

This proven configuration has been widely accepted in the industry for its versatility in processing VGO and residue feeds. With the addition of a dense phase catalyst cooler, the feed may be extended beyond 6-7 w% ConC to as high as 10 w% ConC or more.

When considering the market trends described above, the FCC process must adapt further:

- Increased residue conversion for reduced fuel oil
- Increased propylene production via:
  - Higher severity operation
  - Recycle to convert naphtha to olefins
  - ZSM-5 additive to reduce gasoline olefins and increase propylene production
  - Dedicated Petrochemical FCC (DCC)

In general the severity level of the FCC will need to increase. The application of higher reaction temperature and recycle schemes have been explored both in pilot and commercial units;

however the gain in petrochemical olefins often comes at a high cost in terms of gas production and other primary product degradation. The technology elements within the FCC must be adapted to improve operation and allow for higher severity without process compromises.

New improvements to catalyst stripping with structured packing, more reliable heat removal with catalyst coolers and low pressure operation for olefins selectivity are part of the solution. However at the heart of successful higher severity operation is the performance of the riser termination design. Earlier designs focused on rapid separation of the catalyst from the gas but closed systems often exhibited stability problems with high catalyst carryover to the fractionator. There was the added question of stagnant zones in the reactor filling with coke in resid operation. Through careful study of the process hydrodynamics, large-scale cold flow testing and CFD modeling, Axens has developed a new riser separation system to address the shortcomings of previous designs.

Riser Separation System (RSS) Enhancement

The yields produced in the highly selective reactor riser environment must be recovered and preserved in the rest of the reaction system. Improvements in the design of riser separation or termination systems focus on the rapid disengagement of catalyst from the cracked products in a highly contained system that directs the product vapors quickly to the fractionation system for thermal quench and recovery. The new Riser Separation System (RSS) design depicted in Figure 5 achieves these objectives in a robust design that can accommodate unit upsets without catalyst carryover to the fractionation system.

The RSS system comprises integrated separation and stripping compartments to achieve both rapid separation and efficient stripping. The separation compartments are shown on the left of Figure 5, and the right and left quadrants in the plan view at the extreme right. Catalyst is contained and directed down into the stripper bed to be stripped with steam within the large diplegs. The vapor turns within the separation compartment and exits through windows into the stripping compartment. The stripping compartment is not sealed in the bed and allows for stripping steam and other reactor gas to flow into the compartment and join the main riser gas as it exits through ducts connected to the cyclones. This combines the short contact time benefits of a closed system with the surge volume protection against catalyst carryover found in an open system.

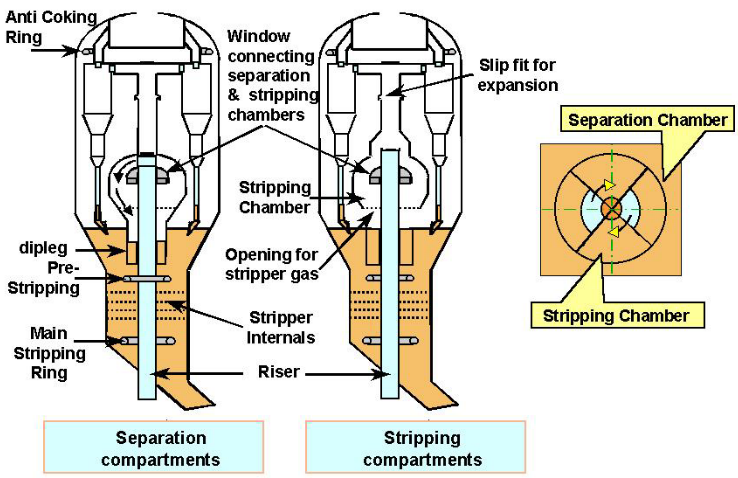

Figure 5: Riser Separation System (RSS) for High Containment

The compact RSS design improves both the separation system to reduce dry gas and the stripping system to reduce delta coke. The simple open design allows for easy inspection and access. In addition, the pressure drop is extremely low in order to limit dipleg immersion requirements to seal the positive pressure separator and so that the capacity of the unit will not be limited. The dipleg size and flux is optimized to minimize gas entrainment with the catalyst and even allow for stripping within the diplegs. The simple separator design is effective at high and low velocity such that collection efficiency is high under both conditions to limit catalyst carryover during startup and upset – a key requirement for a reliable separator.

The RSS system offers the best features of a highly contained rapid separation system with the safety and simplicity of operation found in open or simple separator systems. Ease of operation and maintenance are important factors for long service life and on-stream performance. When the unit severity is increased due to poor feed quality or to benefit from higher LPG production, the benefits of such a separation system become more and more important.

To evaluate the impact of the separation system, pilot plant tests were conducted with a post riser residence time of about 2 and 15 seconds to simulate a fast, closed separator and a simple ballistic separator. The feedstock was a heavy VGO (sg=0.94, ConC=2).

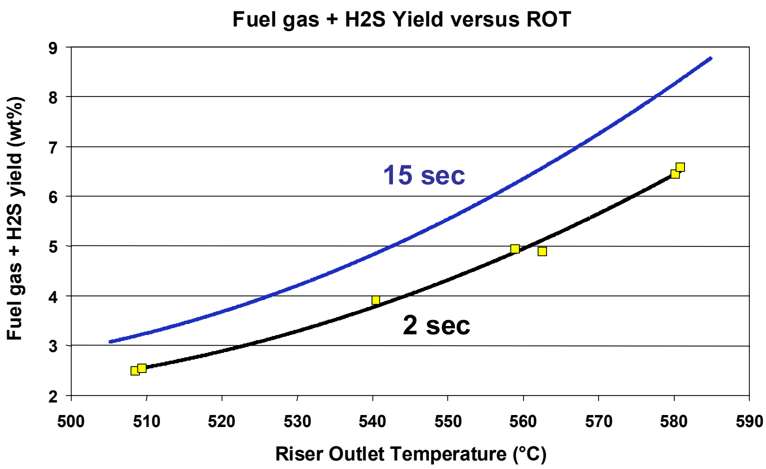

Figure 6: Dry gas yield as a function of Riser Outlet Temperature (ROT)

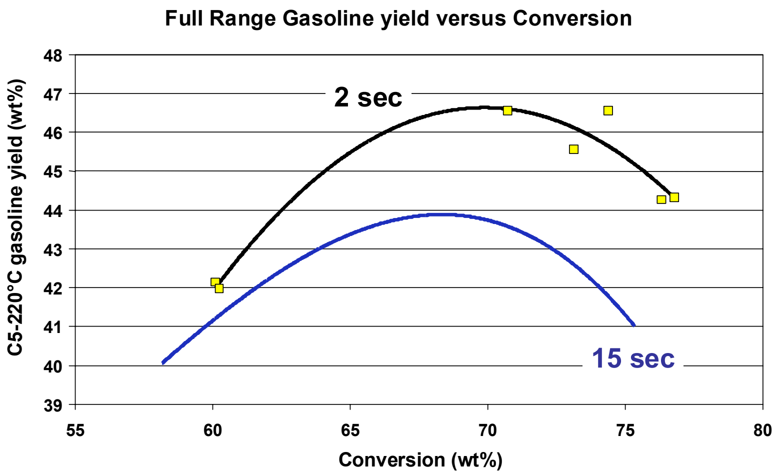

Figure 7: Gasoline yields as a function of conversion

At lower post-riser residence times, the hydrogen transfer reactions taking place in the disengager are also strongly limited. Hence, the olefinicity of the LPG fraction is increased at the same time by about 3 to 4 % to further increase propylene production. As the gasoline over-cracking is strongly reduced due to the reduction of both thermal and catalytic cracking reactions, there is not only a reduction in fuel gas yield, but the gasoline yield is also higher when using a rapid separator. The increase in gasoline yield varies between 1 and 3 wt% depending on the operating conditions, as shown on Figure 7.

As the conversion becomes more selective, the gas production is reduced thereby unloading the wet gas compressor. This allows for a more selective production of LPG via ZSM-5 addition to selectively crack gasoline olefins into C3/C4 olefins.

Commercial RSS Results

The latest R2R unit to startup is equipped with a new RSS separator. The resid feed is very challenging as the nitrogen level is quite high.

R2R RFCC Feed Quality	
API (SG)	17.5 (0.95)
S, wt%	0.8
ConC, wt%	5.5 - 6.9
Nitrogen, ppm	2000 – 4000
Ni+V, ppm	30

Table 1 – R2R Feed Quality

Although detailed yields are not yet available, the unit is highly instrumented to study the performance of the separator during startup and normal operation. A schematic of the reaction system is shown in Figure 8.

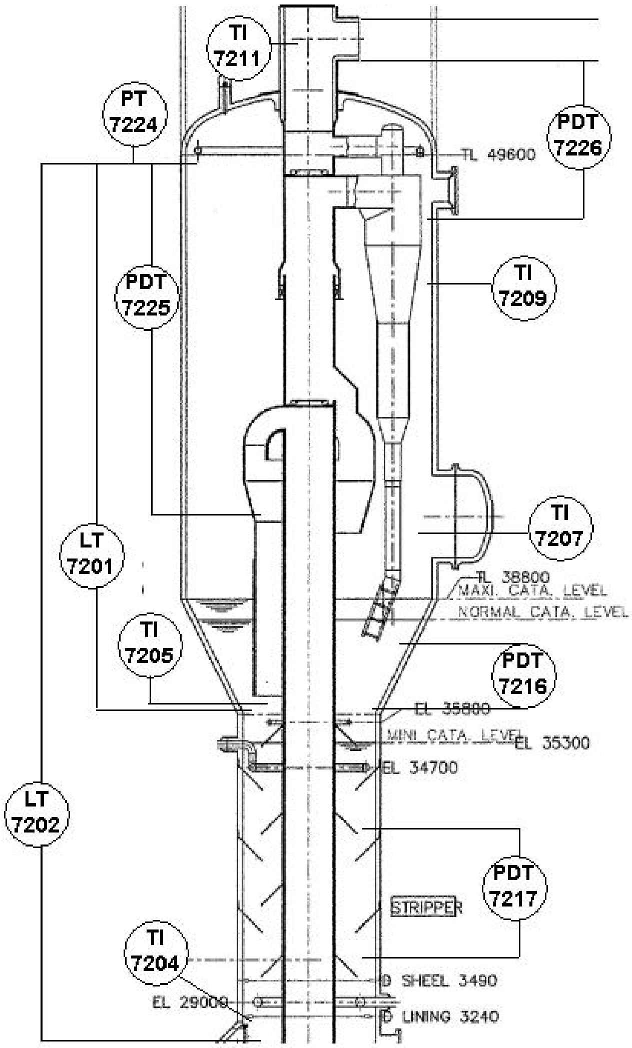

Figure 8: Commercial RSS Configuration

The unit was started up with the separator unsealed. As the level was increased to seal the separator, careful monitoring of the system demonstrated the effectiveness of the new separator.

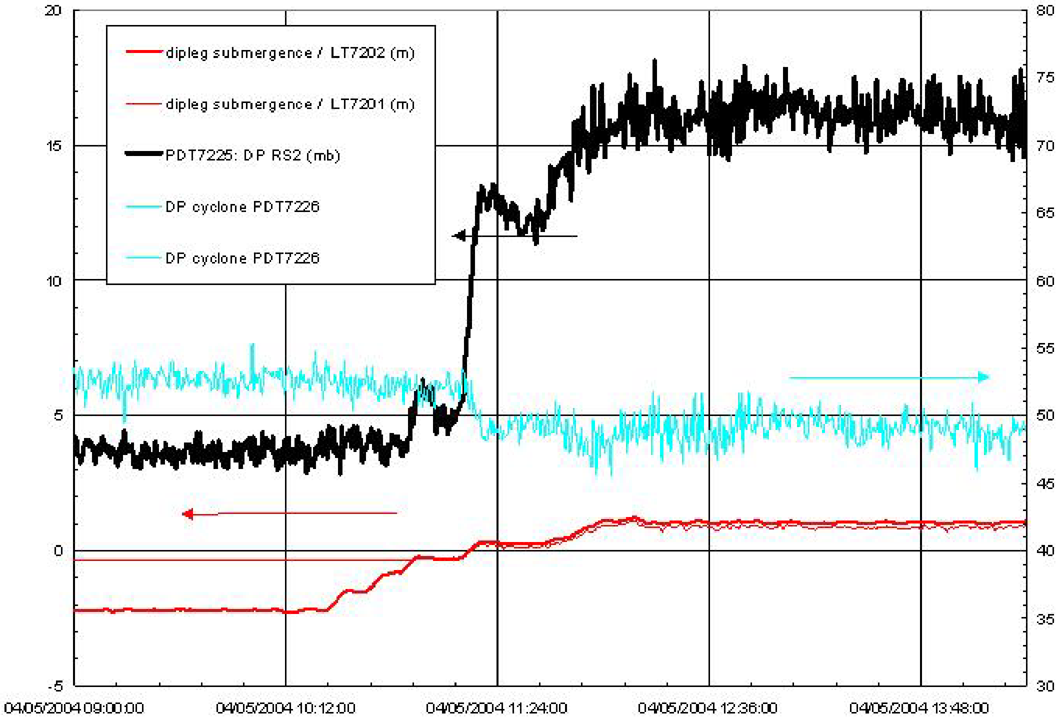

Figure 9: RSS Separator Pressure Drop Response to Sealing

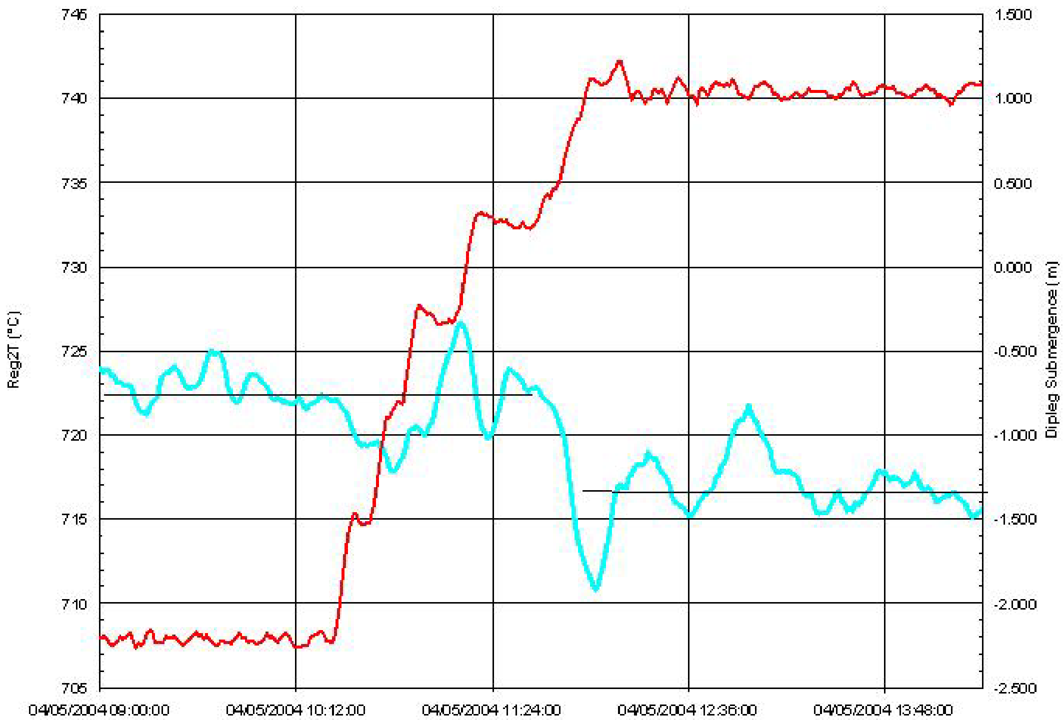

Figure10: Regenerator Response to Sealing the RSS Separator

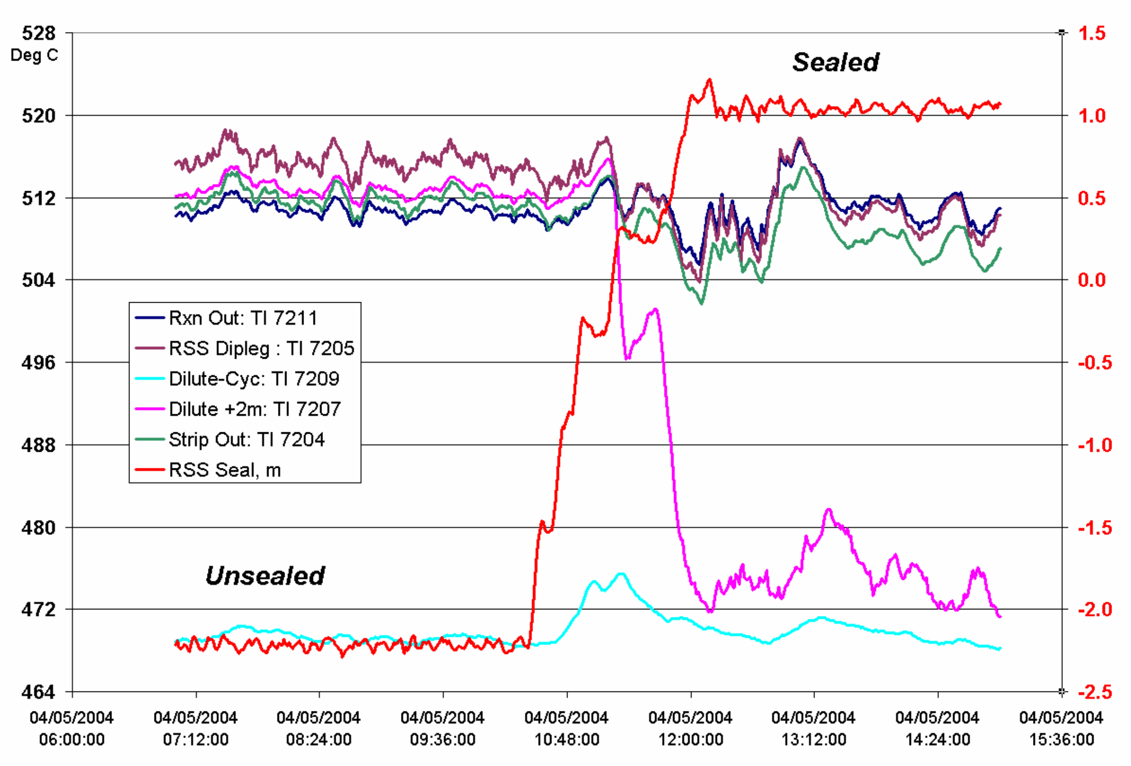

Figure11: Temperature Response to Sealing the RSS

Results to date are as expected. When the reactor level is increased to submerge the RSS dipleg, the gas underflow is reduced and the separator seals. In Figure 9 the separator pressure drop increases (PDT 7225) as the level increases – the level is tracked overall (LT 7202) and over a finer range (LT 7201). At the same time the regenerator temperature drops by 7 degC indicative of a reduction in delta coke, Figure 10. Dry gas measurements also show a 10% reduction in gas production.

At first glance the improvements seem rather modest compared to the pilot work and indeed compared to revamps from ballistic separators to the LD2 system (predecessor to the RSS design). Examination of the temperature profiles helps explain the results more fully –Figure 11. When the separator is unsealed the upper vessel temperature is 'cold' indicating little circulation of product gases (TI 7209 = Dilute-Cyc reading). During the sealing operation there is a brief blip as the gas flow is altered within the disengager vessel, but it returns to a low level. This means that the upper part of the vessel is inactive in both the sealed and unsealed mode of operation. The small underflow from the RSS when unsealed exits via the stripping chamber without extensive back-mixing into the disengager.

The temperature reading at the elevation of the stripping chamber inlet, TI 7207 located 2m above the catalyst bed level, is perhaps the most telling indicator of a positive seal. When unsealed, the temperature reading is close to the reactor riser outlet temperature. When sealed, however, the temperature falls to near that of the upper vessel – ie indicative of a stagnant inactive zone.

Careful sampling of the slurry system before, during and after the sealing of the RSS dipleg proved that the system is stable and highly efficient. BS&W samples (not just catalyst) recorded 1000 – 1500 ppm during the sealing test. When the sealed sample was ashed, the catalyst fines content was determined to be 560ppm.

Not long after the level test shown above, there was a utility trip causing a brief unit shutdown. To avoid delays in restart, the unit was started with the RSS diplegs sealed. The operators did not observe any difference in operation and there was no surge of catalyst carryover to the fractionator. In fact, the unit has proven to require no special startup design procedures with respect to stripper level or riser velocity.

Testing continues to further define the efficiency of the system, but to date all design expectations have been met.

Conclusion

A new compact riser separation system has been developed and commercialized to overcome the short-comings of existing designs. In addition to achieving rapid separation of products from catalyst to preserve very selective yields, the device has proven to be stable during startup and upset with on surges of catalyst carryover to the fractionator. A high containment Riser Separator System (RSS) device will allow refiners to operate at higher process severity to meet the future olefins production targets without the high gas production and wet gas compressor limiting options such as ultra-high severity or recycle cracking of naphtha. When combined with other design elements such as efficient feed injectors, ultra-low pressure operation, high efficiency structured packing stripping, and two stage catalyst regeneration, petrochemical production AND fuel oil destruction from heavy, hard to crack feedstocks can be a reality.