

REFORMING SOLUTIONS FOR IMPROVED PROFITS IN AN UP-DOWN WORLD

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SUMMARY

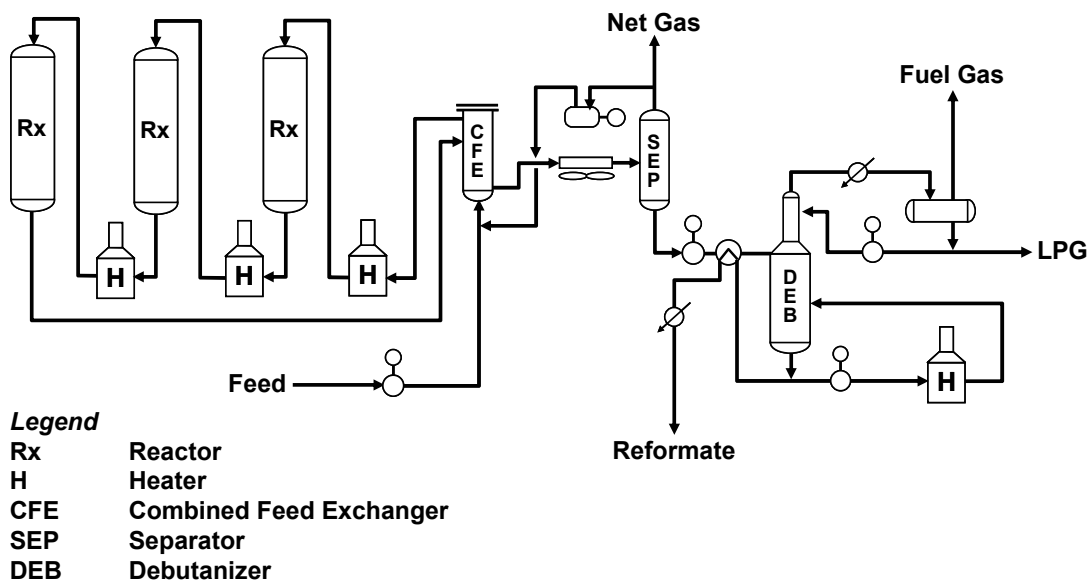
Catalytic reforming continues to play an important role in meeting the world's demands for high octane gasoline, petrochemicals and hydrogen. Due to shifting market demands and aging equipment, many of today's reforming units are operating under a much different set of conditions than for what they were originally designed. This paper will examine some of the major issues facing today's reforming unit operators and propose solutions to help improve unit profitability and reliability. Three broad categories will be explored: process/equipment solutions, catalyst solutions and services solutions.

BACKGROUND

Since its inception in the 1940's, catalytic reforming has played an important role in helping refiners convert heavy naphtha feedstock into high octane reformate for gasoline blending and high purity hydrogen for use in hydrotreating and hydrocracking applications. The first reforming units designed (UOP Fixed-Bed Platforming™ Process units) were operated in a semi-regenerative fashion, and periodically needed to be taken off-line to regenerate the monometallic platinum-containing reforming catalyst. In order to maximize cycle lengths, the first fixed-bed reforming units operated at relatively high pressures (up to 500 lb/in²g) since reforming catalyst stability increases with increasing pressure. In reforming, however, catalyst selectivity to desired products increases with decreasing pressure. So low pressures are desirable in order to maximize catalyst selectivity. Through the 1950's and 1960's, advancements were made to increase the stability of reforming catalysts by adding stability-enhancing rhenium to the catalyst. This allowed for operation at lower pressures (generally 200 to 300 lb/in²g), which improved the selectivity to desired products considerably. The new bi-metallic reforming catalysts also allowed for higher severity operations while maintaining acceptable cycle lengths¹. To date, UOP has licensed more than 600 Fixed-Bed Platforming Process Units worldwide and continues

to develop new catalyst and equipment innovations for the Fixed-Bed Platforming Process. A block flow diagram of a typical UOP Fixed-Bed Platforming Process unit is shown in Figure 1.

Figure 1
Typical UOP Fixed-Bed Platforming Process Unit

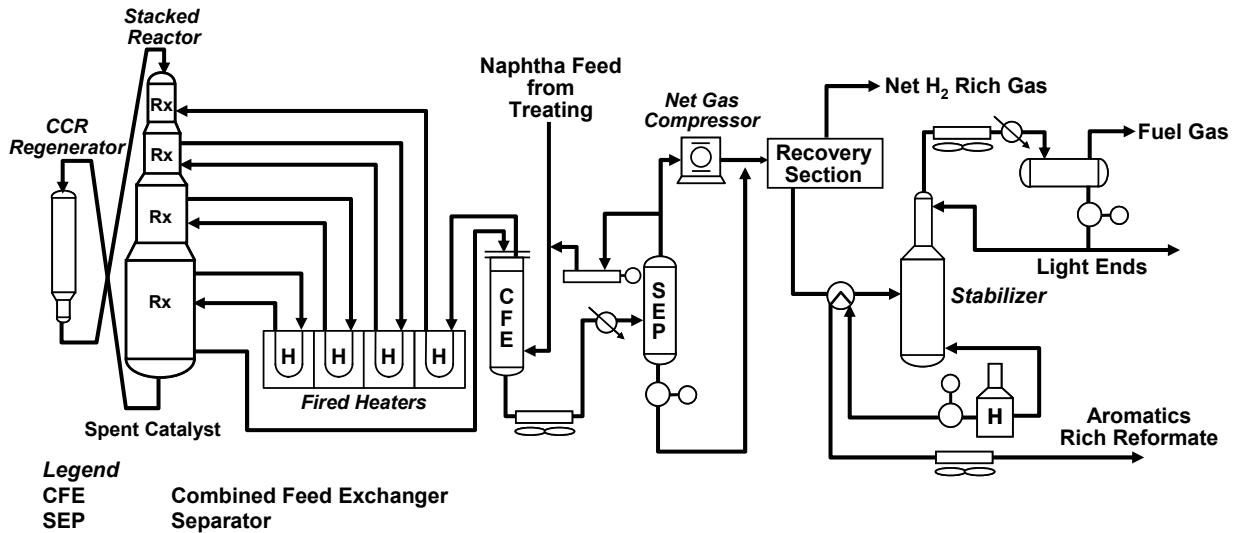


Despite further catalyst innovations to improve catalyst stability, by the mid-1960's fixed-bed reforming units could not keep up with the increasing demand for octane barrels of reformate. Other technology licensors developed the cyclic reforming process, where individual reactors can be swung off-line, regenerated and returned to service without the need to shut down the entire unit. UOP responded by developing a new reforming process with continuous catalytic regeneration, the CCR Platforming Process. The first UOP CCR Platforming Process unit was started up in 1971, ushering in a new era for catalytic reforming. In CCR reforming, catalyst flows through the reactors in series instead of remaining static in fixed beds of individual reactors. Spent catalyst is continuously removed from the last reactor, transferred to the regeneration section, regenerated in a controlled environment and transferred back to the first reactor. Since the catalyst is regenerated much more frequently in CCR reforming than in fixed-bed reforming, much higher severity operation is possible. In addition to making high octane reformate for gasoline blending, many CCR reforming units are used to create feedstocks for aromatics complexes, since the reformate product contains a high concentration of C₆ - C₁₀ range aromatics.

Modern CCR Platforming units operate with pressures as low as 35 lb/in²g, which allows for a high selectivity to desired products (C₅+ reformate and hydrogen) and a minimal production of undesired products (methane, ethane and LPG)¹. Since the first CCR Platforming unit was

started up in 1971, UOP has developed and continues to develop many significant innovations to the process configuration and individual pieces of equipment to allow for more profitable and reliable operations. CCR reforming catalysts still contain platinum, which is required to catalyze important reforming reactions. The level of platinum required on the catalyst has been considerably reduced over time as feedstock contaminant levels and regeneration quality have improved. Rhenium is not used since CCR reforming catalysts do not need to be as stable as fixed-bed reforming catalysts. However CCR reforming catalysts do use other metals, most notably tin, to enhance catalyst selectivity. While most CCR reforming catalysts are bi-metallic (containing platinum and tin), other proprietary promoter metals are also used in some catalysts, with their objective being catalyst selectivity enhancement. UOP offers a wide range of CCR Platforming catalysts for use in UOP-designed CCR Platforming Process units or CCR reforming units designed by other licensors. UOP also offers many services that can assist reforming unit operators improve unit profitability and reliability. More than 300 CCR reforming units have been licensed throughout the world², with more than 250 of those being UOP CCR Platforming Process units. A block flow diagram of a typical UOP CCR Platforming Process unit is shown in Figure 2.

Figure 2
Typical UOP CCR Platforming Process Unit



Recent shifts in the demand for reformate (used for both gasoline blending and petrochemicals production) and hydrogen have caused many reforming unit operators to have to adjust their operations considerably from their initial designs. This has caused many reforming units to be operated in a less efficient manner. Many reforming units that were designed decades ago are also more prone to reliability issues. These and other issues facing today's reforming unit operators will be examined in the next section.

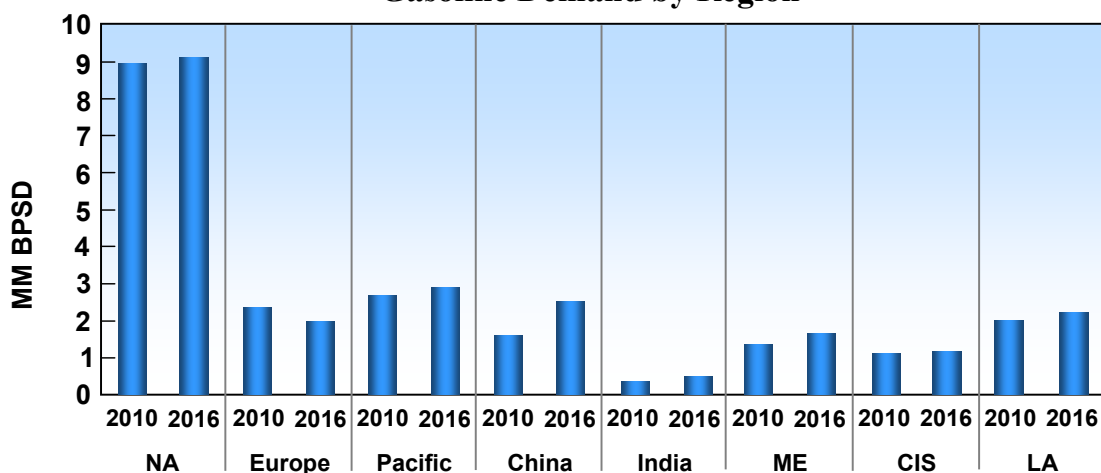
ISSUES FACING TODAY’S REFORMING UNITS: MARKET OVERVIEW

GASOLINE PRODUCT DEMAND AND UTILIZATIONS

Reformate is an aromatics rich, high octane intermediate that is produced in catalytic reforming units from heavy naphtha feedstock. Its two primary applications include use as a high octane blending component in gasoline and as an aromatics rich petrochemical feedstock. In this section, we will review the reformate “market” to better understand the market situation and issues facing today’s reforming units. The reformate market is really a subset of the gasoline and aromatics markets, which, are in turn, subsets of the refining and petrochemicals markets. This section focuses on reformate produced for the gasoline market.

Current worldwide gasoline consumption exceeds 22 million barrels per stream day (BPSD). Growth is expected to be moderate, with a projected compounded annual growth rate (CAGR) of 1.30% from 2010 to 2016, based upon data from the Purvin & Gertz Global Petroleum Market Outlook (GPMO)³. Almost half of the gasoline produced today is being consumed in North America. Other regions such as Europe, Asia Pacific, China, Middle East, and Latin America are consuming 1 – 3 million BPSD each,. Product demand for these various regions is depicted in Figure 3³ and Table 1³. Gasoline demand in North America is relatively flat and declining in Europe, while the major growth is occurring in emerging regions such as China (7.7%), India (6.8%), and the Middle East (3.3%). These trends also track regional demand for refined product as shown in Table 1.

**Figure 3 and Table 1
Gasoline Demand by Region**



	%	Mb	%	Mb	%	Mb	%	Mb	%	Mb	%	Mb	%	Mb	%	Mb
Ref Prod	1.1%	1.0	0.2%	0.1	0/8%	0.6	6.0%	2.8	3.4%	0.5	3.0%	1.1	1.5%	0.3	1.3%	0.5
Gasoline	0.3%	0.1	-2.7%	-0.4	1.2%	0.2	7.7%	0.9	6.8%	0.2	3.3%	0.3	0.8%	0.1	1.7%	0.2

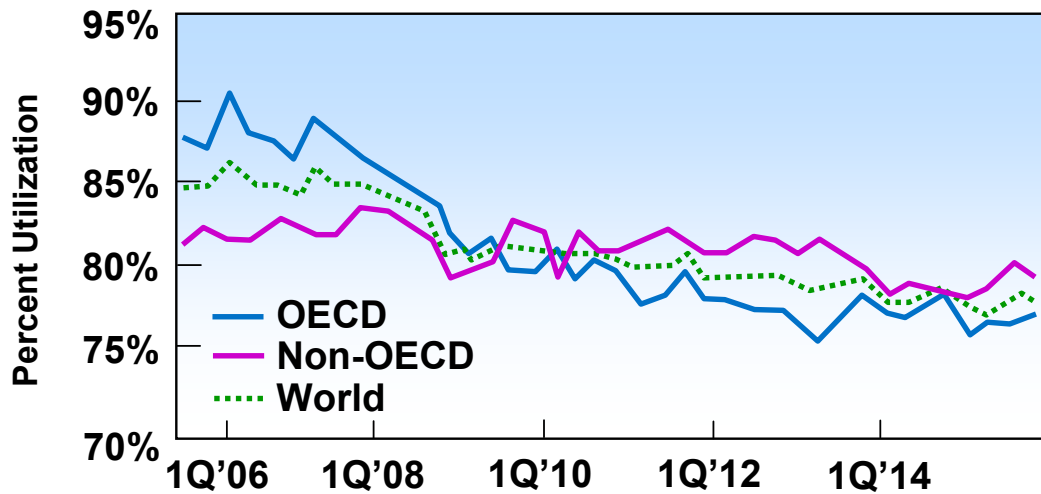
Source: Purvin & Gertz 2010 GPMO

In China, gasoline demand is projected to grow from 1.6 to 2.5 million BPSD between 2010 and 2016. To satisfy this increase in demand, China would have to add approximately 5 modern-day capacity CCR reforming units annually over the next 5 years. Based upon capacity projections and average unit sizes, the rest of the world would also need to add approximately 5 similar CCR reforming units annually over the next 5 years.

In contrast, Europe is expected to see a 2.7% reduction in gasoline demand over the same time frame, requiring a combination of refinery-wide or process unit shutdowns and lower utilization rates. For the reforming units remaining in operation in many of the developed regions, utilization rates and overall severity are generally down. Demand and utilization in the US is expected to remain relatively flat over this period.

Refinery capacity utilization is projected to fall below 80% on average in the world with little sign of recovery unless the world economic recovery is stronger and more rapid than currently anticipated, as shown in Figure 4⁴. With utilization rates falling from almost 90% to below 80% in the developed economies, it is clear that the situation is challenging to the refining sector. Developed economies consist of 20 countries including Canada, Japan, United States, United Kingdom, etc., all of whom are members of the Organization for Economic Cooperation and Development (OECD). Non-OECD refers to the emerging countries and regions as a collective and includes India, China, South East Asia, South America, etc.

**Figure 4
Refinery Utilization Rates**



Source: International Energy Agency (IEA) Medium Term Oil & Gas Markets 2010

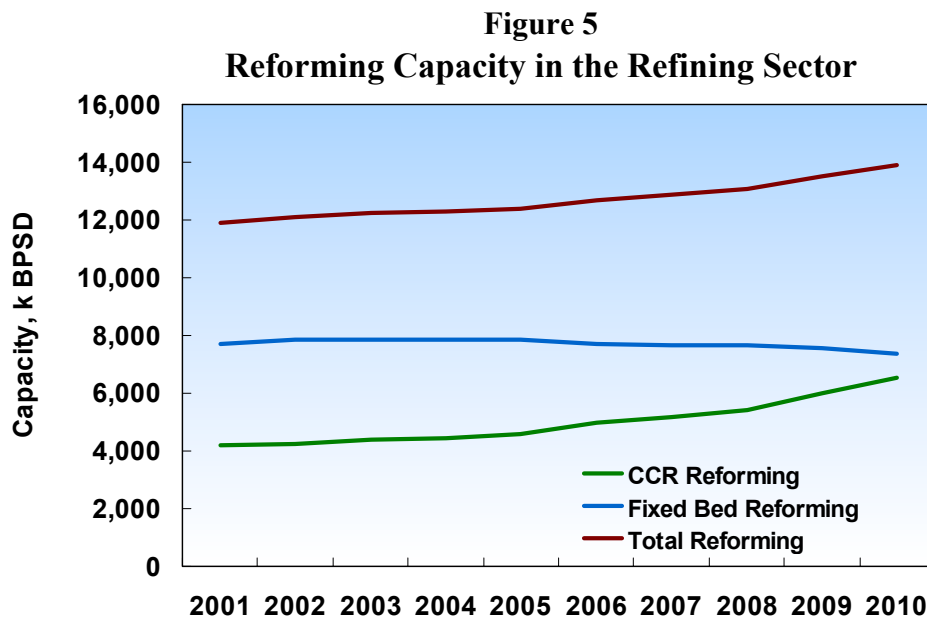
It is clear that refinery throughput growth is projected to increase in non-OECD regions, while it is expected to simultaneously decline in the OECD regions. There is clearly a dichotomy in the world with respect to economic growth and fuels consumption.

Increased gasoline demand in emerging regions is being fuelled by large populations, growing middle classes, increased manufacturing and exports, and strong economies. Conversely, some of the driving forces for the flat to declining gasoline demand in the developed regions include:

- Increased use of ethanol as a gasoline blending component, particularly in the USA and Brazil
- Shift from gasoline to diesel powered transportation fuels, particularly in Europe
- Improved automotive fuel economies driven by governmental regulations
- Available imports
- Changing demographics (aging populations, less drivers), such as in Japan

REFORMING UNIT CAPACITY AND GROWTH

Recent data from the PIRA Energy Group – World Refinery Database⁵ shows that the total reforming capacity in the refining sector is presently 13.9 million BPSD, comprising both CCR and fixed-bed reforming technologies. It should be noted that this data contains information primarily on the refining sector, so reforming units operating in petrochemical facilities are for the most part excluded. Based upon UOP data, approximately one third of the reforming applications are for aromatics production and two thirds are for motor fuels production.



Source: PIRA Energy Group – World Refinery Database, Q4 2010 Capacity Data

In 2010, CCR reforming process technology (UOP and other) makes up 47% of the total reforming capacity, but has experienced steady growth as seen in Figure 5⁵. In fact, total CCR reforming capacity is projected to exceed fixed-bed reforming capacity within the next few

years. The CAGR for CCR reforming capacity additions has been 4.5% over the past 10 years, whereas fixed-bed reforming capacity has undergone an overall reduction, with a -0.4% CAGR. The decline in fixed-bed reforming can be attributed to aging assets being replaced with higher efficiency, larger capacity CCR reforming units.

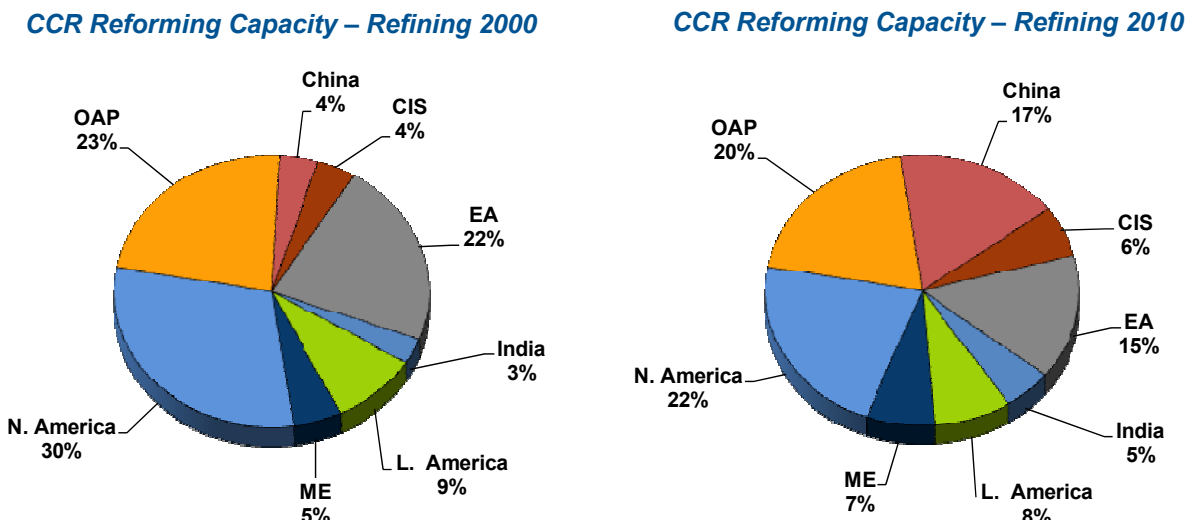
During the last 10 years, a significant amount of CCR reforming capacity growth has occurred in developing regions such as China, India, and the Middle East as shown in Table 2 and Figures 6 and 7. Developed economies such as North America and Europe have experienced very moderate growth of approximately 1%.

Table 2
CCR Reforming Capacity Growth Rates by Region, Refining, 2001 – 2010

<i>Region</i>	<i>CAGR</i>
China	19.4%
CIS (Commonwealth of Independent States- former USSR)	9.4%
EA (Europe and Africa)	0.7%
India	10.7%
L. America (Latin America)	3.3%
ME (Middle East)	7.4%
N. America (North America)	1.4%
OAP (Other Asia Pacific)	3.2%
World Total	4.5%

Source: PIRA Energy Group – World Refinery Database, Q4 2010 Capacity Data

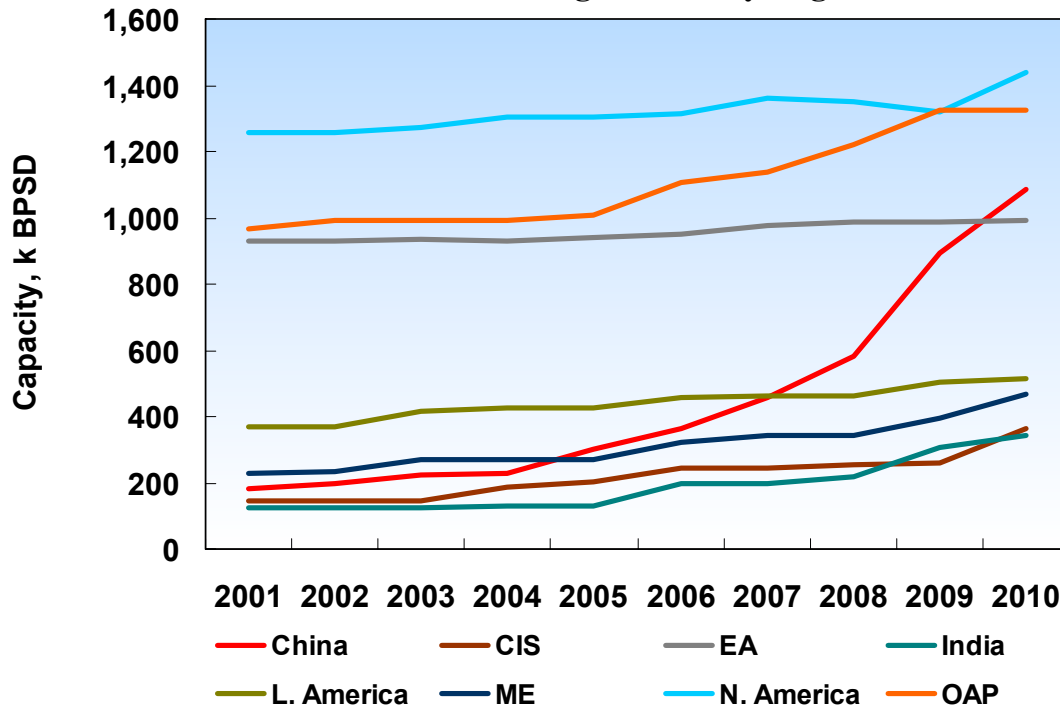
Figure 6
Regional Reforming Capacity 2000 vs. 2010



Data source: PIRA Energy Group – World Refinery Database, Q4 2010 Capacity Data

With a CAGR of 19.4% over the past decade, China’s CCR reforming capacity in the refining sector has now exceeded that of Europe, and is rapidly approaching other Asia Pacific and North American regions as illustrated in Figure 7. Although not illustrated here, a substantial portion of China’s growth can be attributed to increased demand for aromatics to produce polyesters via para-xylene. UOP currently estimates that CCR reforming capacity for aromatics applications is approaching 60% in China.

**Figure 7
CCR Reforming Growth by Region**



Source: PIRA Energy Group – World Refinery Database, Q4 2010 Capacity Data

THE REFORMING LANDSCAPE

Based on the preceding discussion, the reforming “market” is very dynamic, influenced by region, unit type, and application. The overall reforming landscape is quite multifaceted, considering:

- It is a mix of older fixed-bed reforming and newer, more efficient CCR reforming technologies
- Capacity growth is occurring in CCR reforming, whereas fixed-bed reforming capacity is shrinking
- Capacity is being added primarily in developing regions
- Developed regions are also adding CCR reforming capacity, replacing less efficient fixed-bed reforming technology

- Fixed-bed reforming comprises both cyclic and semi-regenerative type operations
- Dedicated units (and refineries) are employed for motor fuels and aromatics production
- Depending on local market needs, some units will operate in a flex-mode and produce lower octane motor fuel grades as well as higher octane aromatics rich streams
- Motor fuel unit objectives include maximum C₅+ liquid production and/or maximum hydrogen production, with the latter being required to satisfy a refineries hydrogen needs such as hydrotreating and hydrocracking
- Units must be operated in a manner to satisfy more stringent fuel specifications
- Energy efficiency and safety should also be considered in design and operation
- All reforming technologies are important to a given plant's production, with overall profitability a key goal

REFORMING UNIT OPERATOR ISSUES

As previously mentioned, there exists a global dichotomy where reforming units in the developed regions are generally subject to lower severity operations and the higher growth rate emerging regions are more focused on higher severity operations. However, this is a generalization and not universally true. The issues facing reforming unit operators across the globe are manifold, including:

- Pushing throughput and severity to maximize production
- Operating at lower severity: lower RON reformate, lower throughput, lower coke on spent catalyst
- Flexible operations (changing throughput and/or severity demands)
- Producing hydrogen needed for other critical units
- Overcoming design and equipment limitations
- Managing aging assets and catalysts
- Operating with limited budgets
- Minimizing downtime
- Maintaining knowledge to maximize productivity and reliability

While it is convenient to attempt to categorize reforming units and users, operators will have to continue to operate at the highest efficiency to meet their facilities' objectives and maximize profitability. Keys to success include reforming unit design, operations, and reliability, which is the major emphasis of this paper.

OPTIONS FOR IMPROVING REFORMING UNIT PROFITABILITY

Due to shifting demands for reformat and hydrogen products, changes in feed stocks and product specification changes, many reforming units are currently being operated with feed quantities, feed qualities and unit severities that are significantly different from their original design points. This can lead to inefficient operation and decrease profitability. This section will focus on several solutions that reforming unit operators can utilize to improve their profitability.

PROCESS / EQUIPMENT SOLUTIONS

Reforming unit designs should allow for some flexibility to operate with different feed quantities or qualities, different operating condition or different production targets. However if the unit is operated far away from where it was designed in any of these areas, inefficiencies can result. This section will focus on solutions that should be contemplated when reforming units are being operated in a much different manner than for which they were designed.

1. Unit Reconfiguration and Rationalization

As mentioned, many reforming units today are running with feeds and operating conditions that are significantly different than the original design. In many cases units are running at severities that are much lower than design, balancing the need for maximum hydrogen production with gasoline blending constraints. The evolutionary movement of reforming units to lower severity in developed regions has created a number of opportunities to improve the profitability of both fixed-bed and CCR reforming units today. A well-executed unit revamp can unlock significant unit improvements and lead to increased profitability, as described below.

- a. Unit Optimization – For both fixed-bed and CCR reforming units, if the current operating severity or feed rate is below the original design, there may be significant opportunity to reconfigure the unit to more beneficial operating conditions. Operating reforming units at the lowest possible pressure results in the highest possible yields of reformat and hydrogen. For fixed-bed and CCR reforming units that are running either below their design feed rate or octane, relatively simple revamps may be possible to reduce operating pressure and thereby increase product yields. The main considerations in this sort of revamp are hydraulic capability of the recycle compressor, evaluation of flow distribution in the reactors and fired heaters and rerating of the heat exchangers in the reactor section. In addition, the catalyst regeneration rate (CCR reforming units) or the minimum allowable cycle length (fixed-bed reforming units) should also be scrutinized. In addition to mechanical modifications, considering a replacement

of catalyst is also very important, since new catalysts can in many cases significantly reduce the mechanical modifications required for a revamp.

- b. Process More Difficult Feeds – For CCR reforming units running at reduced severity, there is typically excess regeneration capacity. One way to take advantage of this opportunity is through processing more difficult feed stocks such as coker naphtha. Depending on the particular conditions of the unit, it may be possible process coker naphtha without any modifications. But if additional regeneration capacity is required, UOP's CCR regeneration systems are generally easily adapted to higher catalyst circulation and coke burning rates.

- c. Capacity Increase – Virtually any reforming unit can be revamped to increase capacity. While many refiners do not need increased reforming capacity, for those who have two or more reforming units operating a capacity increase in one of the units may allow an older, less efficient unit to be shutdown. This strategy is particularly useful if a CCR reforming unit can be expanded to eliminate fixed-bed reforming unit capacity, such that higher overall reformate and hydrogen yields are achieved by moving feed from a fixed-bed reforming unit to a CCR reforming unit. UOP CCR Platforming unit revamps have been completed for feed rate increases of up to 91%. With proper design and planning, even a large capacity increase can be accomplished within the time frame of a normal turnaround.

- d. Convert to CCR Reforming – While the best yields are achieved in new CCR reforming units using the latest design features, significant improvements in reformate and hydrogen yields (along with continuous production) can be achieved by converting an existing fixed-bed reforming unit to CCR operation. The complexity of this type of revamp depends on a number of factors including the age of the fixed-bed reforming unit and the ultimate processing goals. But for a relatively modern fixed-bed reforming unit, the conversion to a UOP CCR Platforming Process unit could be as straight forward as adding new stacked reactors, one fired heater cell and a regeneration section. Often a new combined feed exchanger and additional net gas compression are also included in this revamp. As with the case of a capacity increase, a well planned and executed unit conversion can be completed during a relatively short turnaround.

2. Improve Energy Efficiency

Maximizing energy efficiency within reforming units is an important factor in maintaining profitability. While much of the energy consumed in the process is required

to supply the heat of reaction and thus leaves as energy stored in the reformat product, there are opportunities to improve energy efficiency in operating units.

- a. Process Optimization – Within a CCR reforming unit there are a number of constraints and competing process variables. Operating pressure can be reduced to maximize yields, but this pressure reduction will increase the severity of operation and required catalyst regeneration rate, and may limit reactor section hydraulic capacity. Similarly, hydrogen recycle rate can be reduced, which will result in recycle compressor energy savings but will also cause increased catalyst regeneration demands. If the various parameters are properly balanced, an optimal operating condition can be realized, but the optimum will change as feeds, feed rate and processing objectives change. Real-time optimization solutions are available from UOP for UOP CCR Platforming units which can evaluate all of the relevant factors and provide optimal unit performance on a continuous basis.
- b. Replace Combined Feed Exchanger – Modern CCR reforming units typically incorporate a welded plate-type combined feed exchanger such as a Packinox exchanger from Alfa Laval. This type of exchanger is characterized by its low pressure drop and tight approach temperatures, both of which contribute directly to reduced energy consumption. These exchangers can be used in either CCR or fixed-bed reforming units and provide significant benefits over both multi-pass horizontal and single pass vertical exchangers. They are also extremely scalable and space efficient. Only a single exchanger is needed for nearly any size reforming unit so the need for parallel exchanger trains can be eliminated. Addition of a Packinox combined feed exchanger can easily be accomplished in a standard turnaround.

CATALYST SOLUTIONS

Evaluating current catalyst performance to determine when a changeout is warranted is a critical component to maintaining profitable operations in reforming units. Once a changeout is justified, determining which catalyst features are able to provide the most profitable operations becomes important. This section will consider these elements.

1. Catalyst Changeout Criteria

The first step in evaluating how catalysts can improve the profitability of a reforming unit is to determine when a catalyst changeout will be required. In UOP CCR Platforming units, it is possible to change the catalyst "on-the-fly" (without needing to shut down the reactor section to unload catalyst), so a changeout can be performed at virtually any time.

It is sometimes desirable to change the catalyst during a scheduled turnaround, however, since this will allow for a thorough inspection and cleaning of the reactor internals. In fixed-bed reforming units, catalyst changeouts are conducted during catalyst regeneration, although the regeneration can be abbreviated if all of the catalyst is being changed out.

Each reforming unit operator will have a different economic situation to evaluate when contemplating a catalyst changeout, however there are several factors that all operators should consider:

- a. Higher Performance Catalyst Available - In some cases a changeout can be justified even if the existing catalyst is still in good condition. If the increased performance (increased yields, ability to process more feed or to run to a higher severity) results in an acceptable economic payout period, then catalyst replacement can be considered at any time. Most operators typically wait until the existing catalyst performance has declined due to some factor, as described below, before changing the catalyst, however.

- b. Low Catalyst Surface Area - Chloride is injected into the reforming unit at prescribed rates to reach a target level of chloride on the catalyst. Controlling the chloride level on the catalyst is very important, since chloride catalyzes important reforming reactions. Too much chloride on the catalyst can lead to excessive cracking, which reduces the yields of desired products. Reforming catalysts use gamma phase alumina as their base. The gamma alumina in fresh reforming catalyst has a high surface area (in some cases, upwards of 200 m²/g), which allows the catalyst to retain chloride well. Each time the catalyst is regenerated, a small amount of surface area is lost. Since chloride retention on the catalyst is proportional to surface area, taking care to regenerate the catalyst efficiently can help to minimize the surface area loss and maintain good chloride retention of the catalyst. The higher the catalyst surface area, the easier it also is to disperse the metals on the catalyst during the regeneration procedure. It is essential to have good metals dispersion on the catalyst to allow the metals to effectively catalyze reforming reactions. As the surface area on the catalyst slowly declines over time, it becomes increasingly difficult to keep chloride on the catalyst at the appropriate level and to keep the metals on the catalyst well dispersed. At some point in time, catalyst performance may be affected, and a catalyst changeout may become warranted. Some customers have been able to operate for extended periods with low surface area levels (near 120 m²/g), however most customers do change their catalyst before the surface area drops this low. Some of UOP's customers have established guidelines to

automatically change a reforming catalyst when the catalyst surface area drops to a certain level.

- c. Alumina Phase Damage - As mentioned above, reforming catalyst uses gamma phase alumina as its base. Gamma alumina has a high surface area, which allows for good chloride retention and metals dispersion on the catalyst. During catalyst regeneration, excessive heat can be generated if coked catalyst is allowed to come into contact with a regeneration gas stream containing high levels of oxygen. The heat generated during the rapid combustion of coke can thermally damage the catalyst base, irreversibly converting the gamma alumina to undesirable phases such as theta or alpha. High levels (greater than 5 to 10%) of theta or alpha alumina in the catalyst will rapidly reduce the catalyst surface area, causing a drop in catalyst performance. These undesirable phases of alumina also cause the catalyst to become weakened and in turn can lead to excessive amounts of fines make in the unit. High fines make can lead to screen plugging and mechanical damage, which can result in further poor performance. Some of UOP's customers have guidelines established for changing out catalyst when the amount of phase damage on the catalyst reaches certain levels.

- d. Metals Poisoning - Certain metal contaminants present in the feed to the reforming unit may irreversibly accumulate on the reforming catalyst and adversely affect its performance over time. Most metal contaminants should be trapped by the catalyst in the upstream naphtha hydrotreating unit (NHT). NHT catalyst can become saturated with metals, however, which causes the contaminants to be sent to the downstream reforming unit. Most metal poisons, notably arsenic, lead and silicon, affect the metal functionality of the reforming catalyst. Other contaminants such as fluoride affect the acid functionality of the reforming catalyst. Corrosion products from within the reforming unit such as iron will also accumulate on the catalyst, which can affect the pore structure of the alumina base and inhibit reforming reactions from occurring properly. Various metals levels can build gradually over time on the reforming catalyst, or very quickly if the upstream NHT catalyst allows metals breakthrough to the reforming unit. Metals contamination can become so severe that significant performance debits are seen, sometimes requiring catalyst changeouts. A best practice is to have the catalyst supplier periodically monitor the reforming catalyst's condition to track metals contamination over time. This can alert an operator to a gradual or sudden increase of certain metals so corrective action can be taken, hopefully before catalyst replacement becomes necessary. The catalyst analytical service program offered by UOP for users of its Platforming catalysts (for both CCR and Fixed-Bed Platforming catalysts) does routinely test for metals contamination.

- e. Convenience - In some cases, catalyst is changed out in conjunction with a planned turnaround. If CCR reforming unit reactors are unloaded for reactor internals inspection, it can be risky to reload the existing catalyst. This is because a highly-coked type of catalyst known as "heel" catalyst is unloaded along with normal catalyst. Care must be taken to segregate heel catalyst from normal catalyst and not allow it to be reloaded into the reactors after the inspection is completed. This is because it is very difficult to successfully burn the coke from heel catalyst without damaging catalyst or equipment in the regeneration section. So some CCR reforming unit operators avoid this risk by reloading new catalyst into the reactors after a reactor inspection, especially if the existing catalyst does show signs of performance decline.

These are the primary factors that can precipitate a reforming unit catalyst changeout. UOP plays an active role in assisting our customers in evaluating catalyst performance by performing analytical testing on the catalyst and examining the operating performance of the catalyst to help determine when a changeout is warranted.

2. Improved Catalyst Selectivity

In reforming, catalyst selectivity is a relative measure of the amount of desired products (C₅+ reformate and hydrogen) made with a constant feed quantity and quality and a constant conversion level (reformate octane or aromatics content). A catalyst with high selectivity will produce a greater yield of desired products than a catalyst with low selectivity. Maximizing catalyst selectivity is critical for reforming operators, since high selectivity will lead to high yields of high-value desired products and low yields of low-value undesired products (methane, ethane and LPG).

Catalyst selectivity can be improved somewhat by reducing the chloride content of the reforming catalyst. This is because acid-catalyzed cracking reactions, which cause reduced selectivity, are minimized with low catalyst chloride levels. However there are limitations as to how far the catalyst chloride level can be dropped. Reforming unit operators who desire maximum yields of desired products should consider choosing a high selectivity catalyst for their next changeout.

Operators who are running at low severity and/or low throughput should target maximizing the selectivity of their reforming catalyst in order to maximize the profitability of the reforming unit. Even small changes in selectivity can have a large impact on the profitability of a reforming unit. It is not uncommon for the economic payout for switching to a new catalyst to be less than one year. Reforming unit operators should track their catalyst selectivity over time (generally by comparing the actual yields

to predicted yields for a given feed and severity) in order to ensure that catalyst selectivity remains as high as possible.

In fixed-bed reforming, modern catalysts may use a promoter metal in addition to the standard platinum and rhenium in order to maximize catalyst selectivity. UOP's two newest Fixed-Bed Platforming catalysts, R-98 and R-500, employ proprietary promoters to boost selectivity and maximize profitability. R-98 was introduced in 2005 and is currently loaded in more than 25 fixed-bed reforming units throughout the world. R-500 was introduced in 2010, and has been commercialized by one fixed-bed reforming unit operator in the USA. In certain instances, non-promoted catalysts such as UOP's R-86 can provide high selectivity as well. To date, R-86 has been loaded into more than 100 fixed-bed reforming units throughout the world since its introduction in 2001. UOP's R-56 catalyst, which has been loaded in more than 150 units since its inception in 1992, is still used today for customers who desire a particularly robust catalyst that can perform well despite a relatively high concentration of feed contaminants. UOP can perform yield estimates to evaluate how our catalysts will perform under certain conditions in order to help our customers decide which catalyst choice is right for them. Table 3 shows a summary of the various Fixed-Bed Platforming catalysts offered by UOP.

Table 3
UOP Fixed-Bed Platforming Catalysts

<i>Name</i>	<i>Year Introduced</i>	<i>Relative Density</i>	<i>Promoter?</i>	<i>Comment?</i>
R-56	1992	High	No	Robust, high contaminant tolerance
R-86	2001	Low	No	Extensive experience, Low base fill cost
R-98	2005	Low	Yes	High selectivity, low metals fill cost
R-500	2010	High	Yes	High activity, stability, selectivity

In CCR reforming, promoter metals other than the traditional platinum and tin may also be used on the catalyst in order to boost selectivity. In certain cases (generally when the feed has a low paraffin content or the desired severity is low), the promoter(s) do not boost the catalyst selectivity by a large amount, so traditional non-promoted catalysts can be used. UOP has done extensive research on the usage of promoters other than platinum and tin in CCR reforming catalysis. While some promoters can be beneficial to maximize catalyst selectivity, the use of such promoters must be balanced against other factors such as the ability to maintain acceptable catalyst activity over the life of the catalyst.

UOP's newest CCR Platforming catalysts, R-254 and R-284, do contain a proprietary promoter to increase catalyst selectivity. These new catalysts build upon the successful

performance of UOP's R-274 catalyst, which uses the same proven promoter as these new catalysts. R-274 has been loaded in more than 15 units worldwide to provide superior selectivity. R-254, which modifies the relative metals levels of platinum, tin and the proprietary promoter relative to R-274, has been commercialized in early 2011 in a UOP CCR Platforming unit in the USA. The adjustment in metals content for R-254 allows for the superior selectivity seen in R-274 with a significant improvement in catalytic activity. This allows R-254 to be considered for a wider variety of applications than was possible for R-274. High density R-284 is also available to deliver the absolute highest selectivity of any UOP CCR Platforming catalyst while maintaining high catalyst activity. UOP's non-promoted CCR Platforming catalysts such as R-264 and R-234 can also deliver good catalyst selectivity with even higher levels of catalyst activity. Table 4 below shows a comparison of the various CCR Platforming catalysts offered by UOP.

Table 4
UOP CCR Platforming Catalysts

<i>Name</i>	<i>Year Introduced</i>	<i>Relative Density</i>	<i>Promoter?</i>	<i>Comments</i>
R-234	2000	Low	No	Extensive experience, low fill cost
R-254	2010	Low	Yes	High selectivity, good activity
R-262	2007	High	No	High contaminant tolerance
R-264	2004	High	No	Highest activity, High selectivity
R-274	2002	Low	Yes	High selectivity
R-284	2010	High	Yes	Highest selectivity

3. Improved Catalyst Activity

In reforming, catalyst activity is a relative measure of the reactor temperature required to reach a certain conversion level (reformate octane or aromatics content). With constant feed quantity and quality, a catalyst with higher activity can reach the desired conversion level at lower reactor temperatures than a catalyst with lower activity at constant operating conditions. Catalyst activity becomes very important in high severity operations, since the reforming unit heaters are limited in the amount of heat they can produce and there are metallurgical temperature limits in the reactor circuit. If the desired production rate is also being pushed, high activity catalyst also becomes very important since an increased feed rate requires more temperature to reach a constant conversion level.

Catalyst activity can be improved slightly for an existing catalyst by increasing the amount of chloride on the catalyst, since higher chloride levels on the catalyst raise the catalyst activity. However high catalyst chloride levels also decrease the selectivity to desired products. So there is a limit as to how much the chloride can be raised on a catalyst to improve activity. Reforming unit operators who are activity limited and who desire to be able to process more feed to a constant conversion level or the same feed to a higher conversion level should consider a change to a higher activity catalyst. If there is an ability to process more feed or increase the severity of a reforming unit, operators should take advantage of this since both scenarios would cause an increase in the total number of octane barrels of reformat produced.

In fixed-bed reforming, UOP introduced R-500 Fixed-Bed Platforming catalyst in 2010. R-500 has a very high catalyst activity, with more than 10 °F better activity than any of UOP's other Fixed-Bed Platforming catalysts. Better catalyst activity translates to lower start-of-run (SOR) reactor temperatures for each cycle of a fixed-bed reforming unit. Reduced SOR temperature requirements can help to reduce fuel firing or to extend cycle lengths for those customers whose cycle lengths are dictated by reaching maximum reactor temperatures or fired heater limitations. A US refiner who loaded R-500 in late 2010 reports that the activity of R-500 is ~ 15 °F better at SOR than the previous competitor's catalyst that had been loaded in the unit for approximately one year.

Catalyst activity is also an important factor to consider when evaluating CCR reforming catalysts. Units running at high throughput and/or high severity can be near mechanical design temperature limitations or heater limitations (fuel firing limitations, heater tube wall or bridgewall limitations, etc.). In those situations, using a high activity catalyst is of paramount importance so that throughput and severity targets can be maintained. When a high activity catalyst is desired, UOP normally recommends its R-264 high density or R-234 low density catalyst since these catalysts offer good selectivity at the highest possible activity.

SERVICES SOLUTIONS

Advanced process equipment and catalysts have great ability to improve profitability, but without the people and confidence to operate the reforming unit to its potential each day, the full benefit of this state-of-the-art technology will not be realized. Or even worse, expensive catalyst and equipment can be damaged by inexperienced personnel

This is where services will make a difference. Services are the way you give your operations team the confidence to push the bar ever higher. Whether it is receiving the latest training to improve knowledge, skills and behaviors, having the correct tools to perform quick and accurate

data analysis or understanding exactly where the bottlenecks are in the unit and the economic impact of these bottlenecks, confident operations personnel will ensure that reforming unit operations are on target.

Below are three examples where UOP can specifically provide services to improve profitability - optimization services, Operations Monitoring tools and training. There are others such as advanced process control, online analyzers and data management tools that are also critical. Improving inspection and optimizing turnaround will also improve profitability, however these are covered in the Options For Improving Reforming Unit Reliability section below.

1. Optimization Services

While not every refinery has all of the same process units, the naphtha complex can include hydrotreating, reforming, isomerization, benzene saturation, and any associated separation units. The complex interaction between each of these process units makes it increasingly difficult and increasingly important to consider the naphtha processing units as a complex, rather than individually. The output of one unit influences the operation of the next. Cut-point choices and separation efficiency can affect multiple processes. The ability of the refiner to integrate accurate process technology models with representative separation models, product blending models, and current demand and pricing data, is crucial to optimizing the overall complex operations. The tools and skills needed to conduct this type of study may not be available in every refinery, or within every refining corporation.

Significant money is generally left on the table when it comes to naphtha block operations and configuration, particularly when it comes to the reforming unit. To ensure that the maximum value is being captured from the processing of the refinery naphtha, a study should evaluate:

- Feed changes – including cut point changes in naphtha streams; processing purchased streams; use of hydrocracked, coker or FCC naphtha; or changing routing of naphtha between units.
- Equipment – The debottlenecking of existing equipment or addition of other processing equipment can improve operations and yields
- Catalyst changes – As objectives and catalyst technology improves or existing catalyst performance declines it is important to understand the possible benefits of using newer products.
- Conditions – Changes in fractionation efficiency or catalytic unit conditions should be evaluated.

- Different Product Mix – The ability of the naphtha block to adjust to changing gasoline specifications needs to be understood well.

To achieve this range of evaluation, an effective naphtha study needs to have the following characteristics:

- Component-based modeling of C₁₂ and lighter materials
- Fairly rigorous modeling of separation and equipment
- Strong reaction modeling that use compositional data and can show feed composition effects as well as operating conditions and catalyst change effects
- Effective modeling of gasoline blending – this is needed to show the effects on the final product production and properties so that the overall economics of any change can be measured with a minimum of pricing of intermediate streams

A detailed evaluation of the naphtha complex can evaluate opportunities to improve competitiveness and efficiency of current assets. Managing feedstock more efficiently, reducing bottlenecks and increasing feed rates will increase the capacity to make desired products. Examining ways to manage energy, hydrogen and CO₂ emissions, improve operations flexibility, looking into the use more effective catalysts and reconfiguring processes should be considered.

UOP's technology-integrated profitability studies combine the entire knowledge of UOP from engineering, research and technical service with state-of-the-art modeling tools to ensure that maximized profitability of the naphtha complex can be obtained. By using key economic assessment tools, UOP is able to quickly identify where opportunities lie to ensure the studies are focused and valuable.

2. Operations Monitoring Tools

On a day-to-day basis it is critical to transform data into actionable information. Improved data analysis will enable engineers to make better operating decisions. The collection and management of operations data can be cumbersome and tedious. Today process engineers can spend more time gathering, organizing and processing data than they do determining how to best optimize operations. Advanced operations monitoring tools take on the data manipulation task and perform advanced calculations to help make better operating decisions and offer significant productivity gains. Linking this with direct access to the technology licensor allows for instant data evaluation in case of plant upset or reduced performance. The technology specialists are also able to include key performance metrics based on technology expertise to ensure that the correct variables are optimized.

The UOP OpAware™ operations monitoring tool has been designed to specifically address the data evaluation challenge. It involves secure remote data acquisition which is then reconciled and mass balanced using UOP proprietary calculations. The results are compiled in standard outputs and reports and can be compared against key performance metrics. Daily data updates and online access ensures that all staff can be evaluating the same data at the same time. Simultaneous sharing with UOP maximizes the support possible.

3. Training

Training is the key to giving your operations team the confidence to push the bar ever higher for your reforming unit. It is the combination of sound technology and a competent workforce that make highly profitable reforming units possible. Currently we are going through a period of transition as a new generation of engineers and operators enter the refining industry. In countries with mature economies and slow growth rates, this transition is largely due to a wave of retiring expertise. In countries with developing economies and high growth rates, the transition is due to a rapid addition of new process plants and the corresponding shortage of expertise. In both cases, there is a looming shortage of skills that are typically gained over many years of experience; skills that are crucial for avoiding operational errors that can negatively affect plant performance.

In addition to the worldwide shortage of skilled refining personnel, process units and automation are becoming more complex and the existing training methodology requires a long lead time to build the skills required. Traditional training methods have focused on classroom training as well as informal “hands-on” and “on-the-job” training. This hands-on training has the advantage of learning one-on-one from experts by accompanying them on day-to-day activities. However it takes significant time to train on all of the possible scenarios, especially when many occur infrequently. The quality of training also depends on the expertise and mentoring skills of the expert. The challenge is to expose the operators and engineers to scenarios and upset conditions rapidly and frequently so they can act instinctively.

There are three key parts to competency development that play equally large roles in developing a skilled operations staff. These elements are knowledge, skill and behaviors. Knowledge serves as the foundation on which skills and behaviors are built. **Knowledge development** refers to the acquisition of facts about the plant and its operation. Examples of facts include process chemistry, process variable control schemes, cause and effect diagrams, operator responsibilities, and operating goals under normal and abnormal situations. **Skill development** refers to mastering the ability to respond in an automated

manner to plant conditions. **Behavior development** is more intangible, but refers to the motivation, role expectations and values instilled in the person.

UOP has developed a portfolio of training tools and courses to help refiners develop knowledge, skills and behavior, as illustrated in Table 5 below. All of these tools are available for Platforming units. While they are available as standalone tools, it is the combination of these tools, at the right time in the technology transfer horizon, that allows for the successful merging of knowledge, skills and behaviors. For more background information refer to AM-11-68 (“Operations Skills for the 21st Century”)⁶.

Table 5
UOP Training Portfolio

	<i>Knowledge</i>	<i>Skills</i>	<i>Behaviors</i>
Classroom Training	X	X	X
Web Based Training	X		
UOP Training Simulators		X	
Honeywell Process Solutions Custom Simulators		X	
Expert Systems Troubleshooting Tool	X	X	X

Classroom Training

Classroom training combines knowledge, skills and behavior development, using traditional lectures, Q&A, cases studies and process simulation. Topics include process fundamentals for technology courses and advanced operations and troubleshooting. Courses are developed and presented by technical experts utilizing adult learning methodologies at either one of UOP’s Training Centers or at a customer’s site.

Web Based Training

Web based training has proven a cost effective flexible training tool that allows a large group of staff to gain the process technology basics at their own pace and without time away from the office. It is key for operators, engineers as well as management to have the basic technology knowledge. By incorporating interactive, high quality graphics & animations, as well as quizzes and learning assessments, retention is improved compared to simply reading a book, or listening to a lecture. Web based training is self-paced, and can be used for stand alone technology training, as pre-work for instructor led training, or refresher training.

Training Simulators

The use of training simulators enhances the effectiveness of a training program by giving participants an opportunity to apply knowledge and practice skills learned in the classroom. The “hands-on” experience provided by training simulators gives the participants an added level of confidence, security and knowledge to function competently during the actual pre-commissioning, start-up, steady state operation, emergencies and long-term operation of the process units. As a result of using the training simulator, operator skill levels can be dramatically improved. These improvements can be sustained when the training simulators are utilized as a core component of the customer’s in-house learning management system. Training simulators are available as a generic model of a process unit or can be customized to accurately reflect the customer’s unit configuration.

Built using the Honeywell UniSim[®] simulation platform, UOP Training Simulators are based on typical designs of UOP process technology. Unlike other training simulators, UOP embeds proprietary reactor models, operating philosophy and engineering expertise directly into the training simulator software. The simulators include realistic exercises that reproduce real-life emergency operations and allow the operator to experience in a matter of weeks what would typically take years to experience and master. An added feature of the UOP Training Simulators is the ability to score the responses of the operations personnel to upset conditions. The UOP proprietary expertise can also be utilized to build Honeywell Process Solutions custom operator training simulators for a fully customized solution.

Expert Systems Troubleshooting Tool

The UOP Expert Systems are computer based tools to troubleshoot operating issues. They were developed by UOP technical experts with years of operating knowledge and are based on decision tree diagnostics. These self-paced tools can be used as training tools as well as troubleshooting tools in case of upset conditions. Significant background and reference materials are included so that users can gain a deeper understanding of the subject matter. The system provides rapid troubleshooting of operating problems, increased self-reliance and confidence of the user and helps prevent future operating problems. UOP has developed expert systems to assist troubleshooting CCR Platforming and several other technologies.

OPTIONS FOR IMPROVING REFORMING UNIT RELIABILITY

While many reforming units, especially CCR reforming units, have been commissioned in the past two decades, there are a very large number of fixed-bed and CCR reforming units operating today that have been in service for several decades. Reliability has become an increasingly

important issue for reforming units as operators strive to keep units on stream for longer periods and gain a competitive edge. Reforming unit operators should begin thinking about reliability as soon as a new unit is commissioned to help ensure long equipment life and stable production of reformate and hydrogen. This section will focus on several solutions that reforming unit operators can utilize to improve their reforming unit reliability.

PROCESS / EQUIPMENT SOLUTIONS

Since many reforming units are now several decades old, many pieces of equipment in these units are reaching or have surpassed their useful lives. Several process or equipment solutions are available from UOP are available to help improve the reliability, as described below.

1. Improved Regeneration Capability

While regeneration conditions are largely controlled in CCR reforming, regeneration procedures for fixed-bed reforming units can vary widely. While all regeneration procedures share common elements, it is very common for the procedures to have evolved over years as unit configurations and throughputs have changed. Sub-optimal regeneration procedures can have a number of negative impacts on subsequent operation. Operators can consult general operating manuals, process licensors or catalyst suppliers for information on the recommended, most up-to-date regeneration procedures, but often the quality and speed of catalyst regenerations is limited by the regeneration equipment in the unit. Engaging a regeneration improvement study with the technology licensor, such as UOP, can identify modest configuration and equipment modifications that can result in significant improvements. Typical areas for improvement are in regeneration gas circulation, air injection and caustic injection and control.

In CCR reforming, the regeneration process is set by the unit configuration. While it is important to maintain individual zones at the appropriate conditions, the consistency of regeneration is typically much better than in fixed-bed reforming units. One common issue for many CCR reforming unit operators today is the need to operate the unit at low coke levels for long periods of time. This low coke operation is typically the result of units operating at feed rates or octane levels significantly below design rates. Depending on the style of the regeneration section, there are a number of relatively simple equipment modifications that can be made to UOP CCR Platforming units to allow for long-term operation at spent catalyst carbon levels of 2% or lower.

2. Incorporate New Design Features

While fixed-bed and CCR reforming units have been used for decades, the designs are constantly evolving, incorporating both design and equipment improvements and adding

new features. Incorporation of selected updated features can have a measureable positive impact on unit operations.

For CCR reforming, a number of improved design features may be available:

- a. Updated reactor internals – Improved designs for inlet distributors (scallops) and center pipes are available with increased strength and integrity
- b. Transient condition managers – For UOP CCR Platforming units, logic systems are available which can minimize mechanical stresses which can occur in the reactor system during transient operations such as unplanned shutdowns. Systems are available which can prevent mechanical damage in both the reactors (Cool Down Mode) and Packinox welded plate exchangers (Low Flow / Low Firing Mode). The control function for these systems can be integrated into existing control systems.
- c. Catalyst Transfer System Improvements – Over the course of the development of the CCR Platforming process, many new equipment options have become available. Some upgrades that could be considered include the following:
 - i. Improved Valves – for CCR reforming units with valves in the catalyst transfer lines, there has been steady improvement in valve technology. Valves are available today which offer improved durability and lower fines production than earlier generation designs
 - ii. Catalyst lift lines – For UOP CCR Platforming Process units, the most current design for catalyst lift lines minimizes the generation of catalyst fines by incorporation of an impactless elbow at the top of the vertical lift section. The impactless elbow redirects catalyst flow from the vertical riser to the reactor without the use of an elbow in the catalyst transfer line. Incorporation of the impactless elbow can be combined with addition of Dur-O-Lok[®] couplings in the lift lines. These couplings minimize catalyst fines generation by providing very smooth internal surfaces at lift line pipe connections.

3. Update Systems

- a. Control Systems - For CCR reforming units, the regeneration control system is a critical component of reliable operation. Like all electronic systems, these units will eventually become outdated and become difficult to maintain as individual system components become obsolete and are no longer easily available. Updated systems, such as the UOP Catalyst Regeneration Control System (CRCS), are based on the latest software and hardware platforms. Replacement of an outdated system with a

new CRCS can directly improve the reliability of regeneration operations. Additionally, the new systems today have a host of new features including enhanced trouble shooting capabilities that help maximize operational reliability beyond simply hardware maintenance.

- b. Chlorsorb™ Process - A second system in UOP CCR Platforming units that can require frequent maintenance is the vent gas wash system. While these systems are designed for trouble free operation, they require regular attention, and it is not uncommon for corrosion and plugging problems to develop over time. There are two basic options for dealing with systems that require replacement. The original system could be replaced with a new caustic wash system or a Chlorsorb Process. New caustic wash systems are designed to be highly corrosion resistant and easier to operate. These systems can be available as package systems. The UOP Chlorsorb Process represents an alternative to caustic treating which does not use caustic or generate a waste stream of any sort. In the Chlorsorb Process, the reforming catalyst is used to adsorb chloride from the Regeneration Tower vent gas. This chloride is then returned to the Burn Zone section of the Regeneration Tower. In this way the process recycles the chloride and reduces the amount of organic chloride that must be injected into the regenerator section. The Chlorsorb Process can be integrated into all types of regenerators in UOP CCR Platforming units.

CATALYST SOLUTIONS

Proper care of the existing catalyst or a changeout to a new catalyst can also help improve reforming unit reliability, as discussed below.

1. Sound Regeneration Practices

One of the most important factors in maintaining the overall reliability of reforming catalyst for both CCR and fixed-bed applications is to practice sound regeneration techniques. Catalyst damage can easily occur during catalyst regeneration due to the high temperatures that can occur during the carbon burn phase of the regeneration, and catalyst life can be dramatically shortened if the damage becomes excessive. Other steps during the regeneration process, such as oxy-chlorination and reduction, also play a vital role in determining the overall performance of the catalyst in the reforming unit. Optimizing each regeneration step can help to ensure the reforming catalyst will reliably perform for many regeneration cycles. UOP Platforming unit operators can consult their General Operating Manuals or contact UOP for more details on effective catalyst regeneration procedures.

2. Improved catalyst stability

In reforming, catalyst stability is defined as the tendency of a catalyst to form coke under a certain set of operating conditions. Catalysts with high stability make less overall coke at constant conditions than catalysts with low stability. Catalyst coke make is also proportional to catalyst surface area, so catalysts with higher surface areas will make more coke than catalysts with lower surface areas. This is an important factor to remember when changing catalysts, since the catalyst surface area is significantly higher for fresh catalyst after a catalyst reload.

In CCR reforming, high catalyst stability is generally desired to minimize the coke made on the catalyst in the reactor section. While some CCR reforming units today struggle with making enough coke to maintain constant regeneration operations, it is still widely recognized that CCR reforming catalysts should have a high level of stability. This is so units can easily catch up from occasional down time in the regenerator section without sacrificing severity of operation in the reactor section. It is normally understood that issues with making enough coke on the catalyst in the reactor section should be dealt with by modifying process conditions in the reactor section. Methods to increase the catalyst coke make include decreasing the unit pressure, reducing the hydrogen-to-hydrocarbon ratio or running feed to the unit with an increased ASTM D86 end point. As discussed above, modifications can be made to the regeneration section to allow for more or less coke burning in the regeneration section as required. All modern UOP CCR Platforming catalysts have excellent catalyst stability to enhance the flexibility of operations in CCR Platforming units.

In fixed-bed reforming, high catalyst stability is generally desired in order to maximize the achievable cycle length (the period of time in between catalyst regenerations) at a constant set of operating conditions. UOP's R-500 Fixed-Bed Platforming catalyst offers ~ 25% better catalyst stability than other commercially available UOP Fixed-Bed Platforming catalysts. This means that units can run to cycle lengths that are at least 25% longer than existing cycles at constant conditions. If the cycle length is kept at historical levels, then higher severity operation (increased feed rate, decreased feed quality, increased product severity, reduced reactor pressure, etc.) can be achieved while keeping the cycle length constant. If the cycle length and all operating conditions are kept constant, the yield decline seen over the course of the fixed cycle is decreased, which increases the average yields seen over the course of the cycle. This combination of potential advantages makes R-500 a very flexible catalyst that can address many needs for just about any fixed-bed reforming unit operator. Other UOP Fixed-Bed Platforming catalysts such as R-56, R-86 and R-98 also offer high catalyst stability and allow for flexible operations in fixed-bed reforming units.

3. Reduced fines make

In CCR reforming, catalyst circulates in a closed loop from the reactor section to the regeneration section and back. As the catalyst circulates, some finite amount of attrition occurs. Catalyst attrition is undesirable for several reasons. First, catalyst attrition produces catalyst dust and other fines that may plug up reactor or regenerator internals. This pluggage can lead to high pressure drop in the reactors or difficulties effectively burning the coke off the catalyst in the regeneration section. Catalyst attrition also causes a loss in the circulating inventory of catalyst, so make-up requirements increase with increased attrition.

In a CCR reforming unit, increases in catalyst attrition over time can be caused by changes in the mechanical equipment in the circulating catalyst's path or by changes to the strength of the catalyst itself. The strength of the catalyst can be compromised if the catalyst is subject to abnormally high temperatures where the alumina phase of the catalyst base changes from its normal gamma state to undesirable states such as theta or alpha. Catalyst attrition should be monitored over time so changes to the attrition rate can be quickly detected and corrective action can be taken.

All UOP CCR Platforming catalysts exhibit excellent strength characteristics to minimize catalyst attrition. UOP's high density catalysts such as R-262, R-264 and R-284 offer superior attrition resistance, and should be considered for reloads where minimizing catalyst attrition is of high importance.

4. Higher platinum containing catalysts

Reforming catalysts perform best when feed contaminants, such as sulfur, are kept below prescribed values (normally 0.5 wppm of the feed). Further, reforming catalysts also perform best when the metals on the catalyst are well dispersed during catalyst regeneration. For units that have issues with maintaining low feed sulfur content or for units that have a difficult time consistently dispersing metals on the catalyst during regeneration, UOP has developed catalysts with higher-than-normal platinum content. The extra platinum on these catalysts allows for sufficient platinum to be available to catalyze reactions even if some of the platinum is unavailable due to poor dispersion. These catalysts with higher platinum contents also have an optimized platinum-to-tin ratio in order to ensure good catalyst performance with minimal side effects, such as high coke make.

For these situations, UOP's primary CCR Platforming catalyst of choice is R-262, which contains a 20% higher platinum loading than in R-264. R-262 is recommended for some older generation CCR Platforming units and is typically also recommended when UOP

catalyst is used in CCR reforming units designed by others. R-262 is also being used by several customers with relatively high sulfur levels in the feed to their reforming units.

For fixed-bed reforming, high density catalysts such as UOP's R-56 and R-500 contain a higher amount of platinum per unit volume than UOP's lower density catalysts. These catalysts are therefore recommended to customers who have difficulties successfully regenerating their catalyst or have issues with maintaining feed contaminants at prescribed levels.

SERVICES SOLUTIONS

The services solutions mentioned above are significant contributors to the profitability of reforming units, but they can also have significant impact on unit reliability. The Optimization Services can identify weaknesses in the unit, The Operations Monitoring tools allow for incidents to quickly be analyzed and resolved to avoid more serious situations, while increased training will reduce the number of upset conditions and improve operational responses to incidents.

With historically tight margins not expected to improve for extended periods, the availability of process units and equipment is critical in achieving performance targets. While most availability events are not catastrophic, increased clarity as to the costs and causes of these events is key to prioritizing and implementing corrective actions that will result in sustainable improvements in reliability and availability. There are many things that can be done on a day-to-day basis to improve the reliability of reforming units, but these are a few of the many areas where UOP's in-depth technical knowledge plays a vital part.

1. Inspection

The key objective of inspection is to maximize process unit reliability, availability, profitability and safety. A robust inspection process is the cornerstone of an effective reliability and maintenance program. Finding potential problems and correcting them before failures occur can result in significantly reduced downtime and longer equipment lift. Organizations that consistently execute quality inspection programs can maximize process unit reliability, availability, profitability and safety.

The key differentiation of UOP's inspection services is that it is backed by UOP's technical experts within the engineering, research and technical service organizations to ensure that the latest learnings and designs are incorporated into any recommendations. Who better to inspect and troubleshoot key process units than the company who developed, designed and continually supports them? With over 230 CCR Platforming Process units in operation, UOP is uniquely suited to provide in-depth inspection with the

knowledge that any recommendations will be state-of-the-art. UOP's expertise can be utilized to support turnaround inspections, fabrication shop inspections, inspection planning and even inspection training to ensure reforming units remain reliable.

2. Turnaround Support

Turnarounds can be costly events due to lost production. However they can present an opportunity to implement upgrades that will improve operations. The key is to be prepared. During every turnaround there are lessons learned, unexpected problems found and new questions that need to be addressed to ensure that the next turnaround is more successful and captures more value. It is essential to be prepared and it often takes the support of specialists to be able to truly analyze issues and identify state-of-the-art solutions.

Evaluating the current performance and root causes of unplanned shutdowns is critical to ensure that problems are addressed rather than just hurriedly patched up during a turnaround. As technology is constantly evolving, equipment designs are being updated which can mean less unplanned shutdowns, increased safety and reliability, better performance and easier turnarounds.

UOP can offer insight into where these opportunities exist and help develop the best plan for implementation. The emphasis is to provide a solution strategically focused on repairs and upgrades that will lead to safer, more reliable operations with improved performance. By combining the expertise of inspection, engineering and technical services, UOP's valuable recommendations for the upcoming turnaround can be provided.

CONCLUSION

While growth in gasoline demand has been recently more moderate, reformate remains an important component for use as a high octane blending component in gasoline and as an aromatics rich petrochemical feedstock. In addition to production of liquids, reforming is very important for hydrogen production to feed other process units. Global CCR reforming capacity additions have been approximately 4.5%, with higher growth rates in emerging regions such as China and India, and flat-to-declining growth in developed regions such as USA and Europe. Installed capacity for fixed-bed reforming is on the decline via unit retirement. Virtually every reforming unit operator faces multiple challenges in today's climate related to technology, operations, and profitability.

There are many solutions to manage the up-down world of reforming today. Capabilities and enablers a refiner should consider when selecting a technology provider to partner with to identify the optimal economic solution for addressing future processing needs include:

- Full understanding of the constraints within the reforming unit, both process and catalyst
- Comprehensive knowledge of unit functionality, operating conditions and the variables that affect unit performance
- Knowledge, experience and ability to apply a broad portfolio of catalyst choices to attain the desired processing and financial objectives
- Experience developing revamp solutions and process equipment to enable a rapid response to attain maximum unit performance

Over the past 70 years, UOP has built upon its depth of reforming knowledge to offer refiners a competent and reliable partner for reforming unit optimization for both new and existing reforming assets.

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