Maximizing the FCC's Potential for RFG Production

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INTRODUCTION

The Fluidized Catalytic Cracking (FCC) unit has traditionally been the dominant conversion process in U.S. refineries. It has served as a major source of high octane naphtha for blending into the gasoline pool. With the passage of the Clean Air Act, U.S. refiners are reformulating their gasoline blends utilizing increasing volumes of "clean burning" alkylate and ethers. Both of these premium products use light olefins including propylene as feedstocks. Environmental trends in other major world markets will force much of the world FCC operating capacity to follow the same path.

Concurrently, the petrochemical demand for light olefins, in particular propylene, has outpaced conventional supply routes (ie., steam crackers). Propylene production from steam cracking is highly dependent on the overall economics for ethylene production. Given the current and anticipated demand for propylene relative to ethylene and the fact that the Steam Cracker can not offer the necessary flexibility to modify yields, it is likely that refinery sourced propylene will grow in importance. Obviously, a need for an economical light olefin generating process is required to meet the demand of these light olefins. New catalytic cracking technologies, such as Deep Catalytic Cracking(DCC), appear to be very promising for this application.

DCC is a new commercially proven fluidized catalytic cracking process for selectively cracking a wide variety of feedstocks to light olefins. The technology was originally developed by the Research Institute of Petroleum Processing (RIPP) and Sinopec both located in the Peoples Republic of China. Stone & Webster is the exclusive licensor of this technology outside of China. Currently three units are operating in China and another three are under construction. One of the units under construction is part of a Stone & Webster grassroots DCC complex in Thailand for Thai Petrochemical Industry Co. Ltd.

Although DCC can readily be integrated into either a refinery or petrochemical facility, the intent of this paper is to quantify its impact on the gasoline pool and overall profitability of a U.S. Gulf Coast refinery dedicated to making reformulated gasoline (RFG).

PROCESS DESCRIPTION

DCC is a fluidized catalytic process for selectively cracking a wide variety of feedstocks to light olefins. Propylene yields over 20 wt% are achievable with paraffinic VGO feeds. A traditional reactor/regenerator unit design is employed using a catalyst with physical properties similar to traditional FCC catalyst. The DCC unit may be operated in one of two operational modes: Maximum Propylene (TYPE I) or Maximum Iso-Olefins (TYPE II). Each operational mode utilizes an unique catalyst as well as reaction conditions. DCC Maximum Propylene (Type I) uses both riser and bed cracking at severe reactor conditions while Type II utilizes only riser cracking like a modern FCC unit at milder conditions.

The overall flow scheme of DCC is very similar to that of a conventional FCC. However, innovations in the areas of catalyst development, process variable selection, and severtiy enables the DCC to produce significantly more olefins than FCC. A detailed process description has been published previously[1] and is not included in this paper.

DCC PRODUCT YIELDS

DCC reaction products are light olefins, high octane gasoline, light cycle oil, dry gas and coke. Typical Type I and II DCC yields are shown in the Table 1. Yields for FCC in a maximum olefin operating mode with a low rare earth , high mesopore activity, and high ZSM-5 catalyst are shown for comparison.

Table I

DCC vs. FCC Yield Comparison, wt%

Products	DCC Type I	DCC Type II	FCC
Dry Gas	10.9	5.6	3.2
LPG	41.0	34.2	31.8
Naphtha	26.6	39.2	34.6
LCO/HCO	12.7	15.9	25.2
Coke	8.8	4.6	5.2
Total	100.0	100.0	100.0
Ethylene	6.1	2.3	0.9
Propylene	20.5	14.3	11.4
Butylene	14.3	14.6	11.2
in which $IC_4^=$	5.4	6.1	4.2
Amylene	--	9.8	8.5
in which $IC_5^=$	--	6.5	4.3

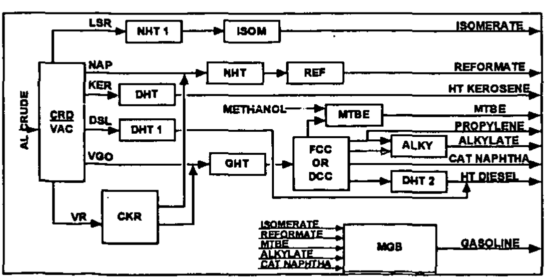
Although large amounts of dry gas are produced in the DCC Type I operation it is rich in ethylene and may be desirable for petrochemical enduse. Propylene is abundant in the DCC LPG stream and considerably higher than FCC. The DCC LPG is also rich in butylenes making it an ideal MTBE and/or alkylation feedstock. Of particular interest is the selectivity of both Type I and II towards $IC_4^=$. The ratio of isobutylene to total butylene is much higher for DCC than FCC(38-42 vs. 17-33 wt%). The same result is true for the isoamylene to total amylene ratio. Obviously , this can have a significant impact on downstream MTBE and TAME production capabilities. The high olefin yields are achieved by selectively overcracking naphtha.

Because of the high conversion, all of the DCC C_5+ liquid products are highly aromatic. Consequently the octane values of the naphtha are quite high: 84.7 MON and 99.3 RON . The BTX content of the naphtha is over 25 wt % making it suitable for extraction. The naphtha will need to be selectively hydrotreated to improve its stability due to the di-olefin content. This is easily accomplished without octane loss.

The LCO will need further upgrading before it can be included in the diesel pool or it can be used as an excellent cutter stock due to its low viscosity and pour point. The HCO and small amounts of slurry oil can go directly to fuel oil blending or be used as hydrocracker feedstock.

CASE STUDY BASIS

In order to illustrate the overall economic impact of adding either DCC Type I or II versus an FCC in a U.S. Gulf Coast refinery dedicated to the production of reformulated gasoline three possible processing options were examined. Each case was analyzed with regard to the disposition of propylene (ie., alkylation or petrochemical sales). An overall onstream factor of 94 % was used for the 100,000 BPD refinery. The production rate was optimized based on producing prime fuels and fuel grade coke from an Arabian Light Crude source. Wright-Killen's 'Refine" model was used to evaluate the different processing scenarios. A simplified overall Block Flow Diagram is shown above.



Purchased feedstocks included butanes, methanol and MTBE. The primary products were:

- LPG(C_3/ C_4's)
- Reformulated Gasoline
- Jet/ Low Sulfur Diesel
- Fuel Grade Coke
- Sulfur

The feedstock and product prices are reported in Table 5 which can be found at the end of the paper. These prices represent typical current U.S. Gulf Coast Basis. Product specifications used to constrain the model are reported in Table 6. Key gasoline blending parameters were set so that the resulting reformulated gasoline pool would :

- Not exceed 1 LV% Benzene
- Contain 2 Wt% Oxygen, and
- Meet EPA mandated reductions in emissions

A simple economic evaluation was performed utilizing the following assumptions:

Delta Capital Cost:	Estimated for U.S. Gulf Coast
Project Life:	20 years from completion
Depreciation:	10 years straight line
Salvage Value:	20% of original investment
Tax Rate:	35% starting in year 1
Inflation Rate:	0 %
Feedstock Prices:	Constant based on current U.S. Gulf Coast prices
Product Prices:	Constant based on current U.S. Gulf Coast prices
Delta Utility Cost:	Constant current average prices
Operating Capital:	0
Investment Timing:	All in year 0

The price of propylene was varied from +/- 30% of the base cost to determine the sensitivity to propylene cost.

RESULTS

The following tables summarize the gasoline pool quality, operating severities, revenues,and overall economics for each case. As previously mentioned the price of propylene was varied to determine its impact for the cases where propylene is routed to sales and is shown in Figure 1 later in the paper.

The impact of switching propylene from petrochemical sales to alkylation and ultimately to the gasoline pool is readily apparent in each case. as shown in Table 2. The DCC operation magnifies this effect over the FCC operation. DCC Type I produces the largest amount of propylene and the least amount of gasoline. The isobutane requirment for the cases where the propylene goes to alkylation is quite substantial for the DCC options. In addition, the increased isobutylene yield with both DCC Type I & II significantly reduces the purchased

Table 2
Feedstocks and Products

Feedstocks, BPD	Base Case FCC		Case 1 DCC I		Case 2 DCC II	
C3= Disposition	**Alky**	**Sales**	**Alky**	**Sales**	**Alky**	**Sales**
Crude	100,000 BPD		100,000 BPD		100,000 BPD	
Isobutane	4684	1174	14433	1705	11831	2162
Methanol	342	342	914	914	1042	1042
Purchased MTBE	6105	5533	5041	2972	4755	3184
Products, BPD						
Propylene		2722		9860		7491
LPG (C3 & C4)	4345	4345	5603	5603	6190	6190
Gasoline (RFG)	63716	58240	70462	50625	70940	55869
Low Sulfur Diesel	24712	24712	21615	21615	21220	21220
Jet Fuel	14621	14621	14621	14621	14621	14621
Coke (Ton /day)	820	820	817	817	815	815
Sulfur (Lton/day)	203	203	203	203	203	203
Refinery Fuel (FOEB)	1985	1985	4846	4846	2532	2532

MTBE requirement.. The LPG make also increases significantly with both types of DCC operation. The middle distillate production is relatively constant for each case.

The operating severities for each unit are shown in Table 3. The reformer severity was kept constant for all cases at 97 RON. Although a future case might be warranted where the severity is lowered. The reformer feed was prefractionated to an IBP of 190°F to minimize the benezene precursors. The DCC has a much higher C5+ liquid conversion than the FCC. The gasoline pool was constrained to meet Federal Phase 1 RFG specifications and if possible CARB specifications. The purchase of MTBE was limited to a maximum of 2.0 wt% for all cases. The Rvp requirement of 7.1 applies only in the summer months and can be quite difficult to meet. Although pulling all of the normal butane from the pool may seem like the obvious first step it is often not desirable as addition of this blendstock permits the refiner an easy control of his pool Rvp. Alkylating the propylene versus selling it satisfies the more stringent summer Rvp requirement in all cases. The alkylate dilutes the overall pool with its low Rvp. The dilution effect of the alkylate is also evidenced by the reduction in aromatics, olefin and sulfur content of the pool as compared to the cases where the propylene is sold.

Table 3
Operating Severities

Qualities	Base Case FCC		Case 1 DCC I		Case 2 DCC II	
C3= Disposition	Alky	Sales	Alky	Sales	Alky	Sales
FCC/DCC Conversion, vol%	75.8	75.8	85.3	85.3	86.8	86.8
Reformate, RON	97	97	97	97	97	97
Captive MTBE, BPD	1004	1004	2679	2679	3056	3056
Purchased MTBE, BPD	6105	5533	5041	2972	4755	3184

Table 4
Gasoline Pool Quality

Qualities	Base Case FCC		Case 1 DCC I		Case 2 DCC 2	
C3= Disposition	Alky	Sales	Alky	Sales	Alky	Sales
RON	95.7	95.7	96.7	97.4	96.3	96.6
MON	86.9	86.4	89.0	87.8	88.5	87.5
FON	91.3	91.1	92.9	92.6	92.4	92.1
RVP	7.1	7.2	6.8	7.2	6.8	7.2
Olefin, vol%	7.9	8.7	6.6	9.2	7.4	9.3
Aromatics, vol%	24.2	26.5	21.9	30.6	22.5	28.6
Benzene, vol%	0.86	0.95	0.63	0.87	0.69	0.88
Oxygen, wt%	2.0	2.0	2.0	2.0	2.0	2.0
Sulfur, ppmw	32	35	34	46	46	57

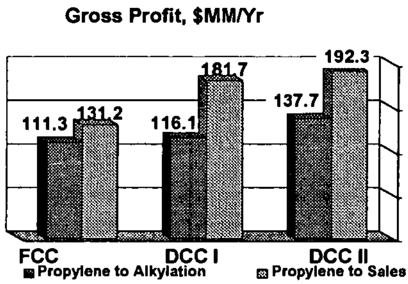
(Shaded) Does not meet one of the following Federal Phase 1 specifications : 7.1 RVP max 9.1 vol% olefins or 27 vol% aromatics.

Although the aromatic, olefin and Rvp Phase 1 RFG specifications are not met in Cases 1 and 2 where the propylene is sold the reformer severity can be lowered bringing these specifications easily into compliance. For example, when the reformer severity is lowered to 89 and 92 for Cases 1 & 2 respectively the pool specifications are met. The FON drops to 89.5 and 90.0 for Case 1 and Case 2 at these severities.

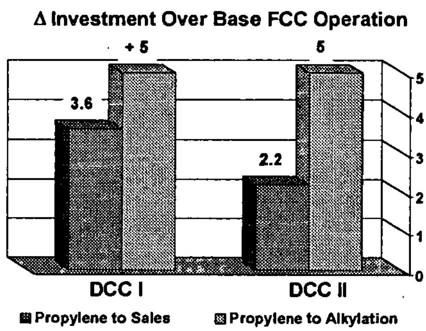
The T50 and T90 specifications were not evaluated for this study as the 'Refine" model does not accurately account for changes in product distillations. Typically, the T90 specification is one of the most difficult and costly specifications to meet. Complying with this specification will also have a great impact on reducing the T50. FCC gasoline and reformate typically do not meet the T90 specification and will require further fractionation or processing. This evaluation is outside the scope of this study basis.

ECONOMIC ANALYSIS

The gross profit for each case is shown in the following bar chart. For the cases where propylene is routed to alkylation, both DCC type I and II generate more gross profit than the FCC case. DCC type II is the most favorable option. The gross profit for the cases where propylene is routed to petrochemical sales shows that both DCC Type I and II are more profitable than the base FCC operation. Of the DCC operations, DCC type II again generates the greatest gross profit.



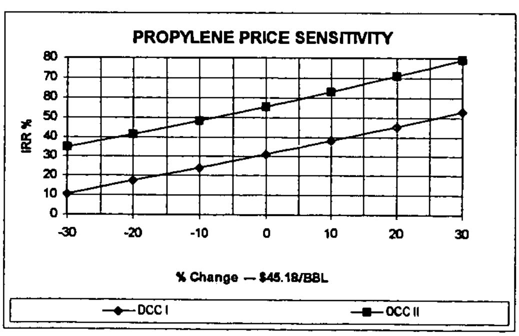
The Internal Rate of Return (IRR), Payout and Net Present Value figures were calculated for the cases where propylene was routed to alkylation or to sales for each type of operation. The analysis showed that for the cases where propylene was routed to alkylation the DCC Type II operation was the most profitable with an IRR of 20.3%. The cases where propylene was routed to petrochemical sales showed that the installation of an DCC unit in place of a conventional FCC was very profitable. The incremental IRR for DCC Type I was 31.1% and 55.6% for DCC Type II. The payout was 2.2 years after tax for DCC Type II and 3.6 years for DCC Type II.



PROPYLENE SENSITIVITY

The price of propylene was varied from +/- 30% of the base price and its impact on the IRR is shown in Figure 1. Even at a propylene price 30% lower than the base value the IRR for DCC Type II is still attractive. The sensitivity to the propylene value is more pronounced for DCC Type I. Although it still appears favorable at propylene values up to 10 % less than the base value.

Figure 1



REVAMP ECONOMICS

Work recently completed in Stone & Websters' Milton Keynes office indicates that a revamp of an existing FCC to an equivalent DCC type I operation (most extreme revamp) can be quite attractive. The majority of the revamp costs were found to be in the regenerator and flue gas system to handle the additional coke burning capacity. Polymer grade propylene was produced for petrochemical sales. A very attractive pretax payback of 1.5 years was found

CONCLUSION

As the price of propylene remains high there will be continued interest in refinery sourced propylene for petrochemical sales. Based on average prices during the last two years, a new DCC plant for production of propylene provides an attractive return on investment. The sensitivity of the project economics to fluctuations in propylene prices is relatively low.

The integration of DCC technology into a refinery offers an atractive opportunity to produce large quantities of light olefins by the conversion of heavy vacuum gas oils. Thus, providing the refiner with the flexibility to produce either polymer grade propylene or premium gasoline blending components (ie. ethers and alkylate).

Acknowledgement

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Table 5
Feedstock and Product Pricing*

Feedstocks	$/BBL
Arabian Light	18.47
Isobutane	17.64
Methanol	18.90
MTBE	42.84
Products	
Sulfur (LT)	75.00
Propane	14.35
N-Butane	16.80
Petroleum Coke	25.00
Fuel Gas (FOEB)	9.30
Low Sulfur Diesel	20.89
Kerosine/Jet Fuel	23.12
RFG Gasoline Blend	30.86
Propylene to Sales	45.18

US Gulf Coast Pricing Basis
Sources: The Oil Daily, 28 June 95 & Octane Week, 29 May 95

Table 6
Product Specifications

Propylene	Polymer Grade	
Reformulated Gasoline*	CARB Phase 2 March 1996	Phase 1 Federal Jan 1 1995
• RVP (max)***	7.0	8.0^(N) / 7.1^(S) **
• FON (min)	91.0	91.0
• Olefins (vol%, max)	6.0	9.2
• Aromatics (vol%, max)	25.0	27.0
• Benzene (vol%, max)	1.0	1.0
• Oxygen (wt%, min)	2.0	2.0
• Sulfur (ppm,wt%)	40	339
Diesel		
• Sulfur (wt%, max)	0.05	
• Aromatics (vol%, max)		
• Cetane No. (min)	40.0	
Jet Fuel		
• Sulfur (wt%, max)	0.3	
• Aromatics (vol%, max)	24.0	

* T50 and T90 specs beyond scope of this evaluation
** (N) Northern States, (S) Southern States
*** Summer Season only