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Study of Canadian FCC Feeds from Various Origins and Treatments. 1. Ranking of Feedstocks Based on Feed Quality and Product Distribution

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Accurate ranking of fluid catalytic cracking (FCC) feeds will help oil producers price their commodities. The value of an FCC feed depends on its properties, which, in turn, contribute toward producing high-value products with good qualities. Feed ranking based on general analyses is the simplest way to determine the best feeds but can be misleading for some. In this study, the authors propose a feed grading method with consideration of only concentrations of gasoline precursors, total nitrogen, and microcarbon residue (MCR), assuming that gasoline is the most desirable product. By assigning the merit and discount values of the three elements, the relative gasoline yield of a feed can be calculated and its apparent feed rank established. The method was tested on 10 feeds that were catalytically cracked in both a microactivity test (MAT) unit and a riser pilot plant. With some exceptions, the apparent feed ranks indicated an agreeable order with those based on individual high- and low-value MAT product yields at both constant test severity (catalyst/oil (C/O) ratio of 7) and conversion (65 wt %). The apparent feed ranks were also validated with the exact feed ranks determined by comparing the individual MAT yields at an achievable high conversion, using the maximum gasoline yields as a guide. The two feed ranks also showed good conformity, with respect to the sequence. Verification of apparent feed ranks against riser pilot plant yields in this study was difficult, because of limited test data for comparison. MAT yields of the 10 feeds compared better with riser pilot plant yields at the same conversion than with yields at the same C/O ratio. Among the six cracked products, dry gas gave the best comparison, in terms of absolute yields, whereas coke showed the worst results.

1. Introduction

The Canadian oil-sands resource is spread across 77 000 km², mostly in northern Alberta. The oil sands in Canada hold 1.7–2.5 trillion barrels of bitumen. Of this amount, ~300 billion barrels are considered recoverable, with currently known surface mining and in situ technologies. This scenario puts the oil-sands resource on par with Saudi Arabia's conventional oil reserves. In 1999, oil sands accounted for ~26% of the total Canadian crude oil production. Based on industry-wide expansion programs announced or underway, this amount could increase to 50% beyond 2005.¹

Syncrude Canada, Ltd., which is the greatest oil-sands bitumen upgrader in the world, operates a surface

mining plant in northern Alberta and produces a synthetic crude oil (SCO) called "Syncrude Sweet Blend", or "SSB". The extracted bitumen is currently upgraded in two fluid cokers and an ebullated-bed LC–Finer hydrocracker, followed by hydrotreatment of naphtha, light gas oil (LGO), and heavy gas oil (HGO). The hydrotreated products are combined as SSB and shipped to refineries by pipelines. Refiners use the naphtha, LGO, and HGO fractions in SSB as, respectively, catalytic reformer feed, diesel or jet fuel blending stock, and feed to the hydrocracker or fluid catalytic cracking (FCC) unit.

The disadvantages of using nonconventional bitumen-derived HGOs or vacuum gas oils (VGOs) as FCC feeds have been described in previous publications.^{2,3} Over the

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years, Syncrude has been engaged in research activities to improve the quality of HGO from SCO. In 1998, the company conducted a series of riser pilot plant tests that included 10 feeds. These feeds, were all derived from oil-sands bitumen, except one from conventional crude, and were related to Syncrude's existing⁴ or future potential processing schemes that involved a hydrocracker and a solvent deasphalter. Future Syncrude operations may produce various VGOs for downstream FCC use, and it is important to assess their performances in catalytic cracking. Prior to the riser experiments, microactivity (MAT) tests were performed to establish pilot-plant operating conditions. Riser results were reported fully by Yui et al.⁵ and partially by Ng et al. for brief comparisons of cracking yield^{2,6} and product quality⁷ between the riser reactor and the MAT unit. This paper supplements previous publications^{2,6} by providing detailed MAT results. The objective is to investigate and compare the catalytic cracking behavior of the 10 VGOs, thereby ranking them as FCC feeds. This work is complemented by a companion paper (Part 2)⁸ that focuses on specific observations in this study, the effects of progressive treatments of feeds on their yield and product quality improvements, and the comprehensive comparison of the product yields between the riser reactor and the MAT unit.

2. Experimental Section

2.1. Feedstocks. The 10 feeds supplied by the Syncrude Research Centre can be classified into the following categories:

(1) Feed from a conventional source: The Rainbow Zama VGO (RZ, 343–525 °C), obtained by distillation of Rainbow Zama crude, which is a typical Alberta light crude mix, was used as a reference in this study.

(2) Feed from a refinery hydrocracker: The hydrocracker bottoms (HCB, as received) was obtained from Petro-Canada's Edmonton refinery when it processed 100% SSB. HCB was included in the test program in consideration of the potential process development.

(3) Feeds from a bitumen source: (i) The untreated virgin VGO (VIR, 343–525 °C) was obtained from batch distillation of an entire bitumen to simulate a commercial product from Syncrude's newly installed vacuum tower. (ii) VIR was further hydrotreated in a fixed-bed catalyst testing unit (CTU) at Syncrude Research, using a typical commercial NiMo catalyst at 380 °C, 1276 psig, and an LHSV value of 1 h⁻¹. The resulting total liquid product (TLP) was distilled to produce the hydrotreated virgin VGO (HT-VIR, 343 °C+). (iii) The atmospheric topped bitumen from Syncrude's diluent recovery unit⁴ was deasphalted, using a mixture of *n*-butane and *i*-butane as the solvent, under typical conditions in a pilot plant. The deasphalted oil (DAO) from bitumen (DA-BIT, as received) was used directly for catalytic cracking. (iv) A mixture of deasphalted oils from bitumen under different extraction conditions was hydrotreated in a mini-ebullated bed pilot plant at Syncrude Research under typical LC–Finer operating conditions. The TLP was distilled to yield the hydrotreated deasphalted VGO from bitumen (HT-DA, 343 °C+).

(4) Feeds from Syncrude's LC–Finer hydrocracker: (i) The untreated LC–Finer VGO (LCF, 343–525 °C) was obtained by blending the LGO, HGO, and bottoms from the LC–Finer fractionator in a representative ratio, followed by a batch distillation. (ii) LCF was also hydrotreated under the same conditions as those for VIR. The resulting TLP was distilled to produce the hydrotreated LC–Finer VGO (HT-LCF, 343 °C+). (iii) The deasphalted oil from LC–Finer resid (DA-LCF, as received) was obtained by deasphalting the atmospheric resid from LC–Finer in the same manner as that for the topped bitumen.

(5) Feed from Syncrude's fluid coker: The blend of LGO and HGO from the coker fractionator was distilled in batch to IBP–343 °C and 343 °C+ fractions. The latter was hydrotreated under the same conditions as those for VIR. The TLP was distilled to yield the hydrotreated coker VGO (HT-C, 343 °C+). This VGO was used to simulate its counterpart in Syncrude's commercial plant.

All feeds were characterized using ASTM and other supplementary methods at the Syncrude Research Centre. Primary feed properties were reported previously.^{2,5–7} Feed analyses, with some addition and correction, are summarized in Table 1 for ease of discussion. Note that the distillation data were obtained by simulated distillation (simdist).

2.2. Catalyst. A refinery-generated equilibrium catalyst, Dimension 60, was used in this study. Table 2 gives some properties of this catalyst.

2.3. Catalytic Cracking of Feedstocks. The fixed-bed MAT unit used was an automated Zeton Automat IV, which is a modified version of ASTM D 3907, equipped with collection systems for gas and liquid products. For each feed, three runs were conducted at 510 °C and one and two runs were done at 500 and 520 °C, respectively. However, some runs were repeated later. Because the reaction temperature range was rather small (± 10 °C at 510 °C), it was assumed that the temperature effect on MAT yields was negligible and that one regression could be applied to the same set of data points obtained at three different temperatures. The omission of the temperature effect can be justified by the rather low sensitivity of the MAT yields to temperature in this study (Table 3). To obtain different conversions for each feed, the catalyst/oil (C/O) ratio was changed while keeping the catalyst contact time (t , given in seconds) constant, with varying weight hourly space velocity (WHSV, given in units of h⁻¹) or space time (τ , given in hours), where $\text{WHSV} = 1/\tau = 3600/(C/O \times t) = 3600/[C/(O/t)]$. In this study, $C = 4$ g and $t = 30$ s; therefore, the oil injection rate (O/t , given in units of g/s) was varied to obtain different amounts of oil (O , given in grams). Detailed description of the MAT reaction system and operation have been reported elsewhere.^{6,9} The FCC pilot plant data were obtained from a modified ARCO-type riser reactor, of which the operation and methodology have been described by Yui et al.⁵

3. Results and Discussion

3.1. Feedstock Properties. FCC feed quality is well-known to be the most important factor affecting catalytic cracking yields and product quality. Feed properties in Table 1 are discussed in several aspects.

3.1.1. Distillation Range. The distillation range can obviously affect the feedstock quality. As mentioned previously, HCB, DA-BIT, and DA-LCF were used as received. Thus, compared with other feeds, they contained relatively higher 343 °C– fractions (19.6 wt % for HCB and ~11 wt % for the two DAOs) and 525 °C+ fractions (38.1 and 25.0 wt % for DA-BIT and DA-LCF, respectively). HT-DA and HT-C were mostly 343 °C+ but relatively high in 525 °C+ (36.9 and 8.3 wt %, respectively).

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Table 1. Feedstock Properties^a

feed number	1	2	3	4	5	6	7	8	9	10
feed name	HCB	HT-VIR	RZ	HT-LCF	HT-C	HT-DA	VIR	LCF	DA-LCF	DA-BIT
density at 15 °C (g/mL)	0.8643	0.9252	0.8988	0.9284	0.9511	0.9430	0.9712	0.9562	0.9642	0.9776
hydrogen content (wt %)	13.7	12.3	12.8	12.1	11.5	11.8	11.1	11.2	11.2	11.1
H/C atomic ratio	1.892	1.669	1.764	1.638	1.562	1.619	1.549	1.532	1.536	1.556
total nitrogen content (wppm)	0	460	800	1090	2150	2450	1930	3370	4020	3050
basic nitrogen content (wppm)	<1	51	240	148	439	613	610	991	1212	815
total sulfur content (wppm)	<10	981	9170	880	4290	7040	32500	13500	15200	35400
MCR content (wt %)	0.04	0	0.08	0.02	0.50	2.61	0.33	0.24	3.40	5.37
nickel content (wppm)	-	-	0	-	-	4.1	0	0	4.5	11.6
vanadium content (wppm)	-	-	0	-	-	6.8	0.1	0	8.1	25.0
aromatic carbon content (%)	4.4	17.6	14.6	20.2	24.7	20.9	25.4	30.1	28.8	24.4
aniline point (°C)	99.8	74.2	89.4	71.8	63.6	81.0	50.8	58.0	65.8	62.8
refractive index at 20 °C	1.4747	1.5130	1.4967	1.5153	1.5323	1.5269	1.5397	1.5324	1.5370	1.5393
343 °C—by simdist (wt %)	19.6	7.4	2.0	5.5	4.5	1.5	6.0	7.7	11.0	10.8
524 °C+ by simdist (wt %)	1.4	1.3	2.5	1.2	8.3	36.9	2.0	1.4	25.0	38.1
hydrocarbon type, by MSD (wt %)										
saturates	90.1	46.8	61.0	45.7	34.4	35.4	28.7	35.5	29.1	23.0
paraffins	21.7	4.1	22.8	7.4	4.7	5.0	1.8	5.2	4.3	1.4
cycloparaffins	68.4	42.7	38.2	38.3	29.7	30.4	26.9	30.3	24.8	21.6
aromatics	9.3	52.3	36.1	52.3	61.8	57.5	65.6	58.4	59.1	61.8
mono-	6.9	29.1	16.6	27.6	29.5	29.5	22.5	20.6	26.3	24.7
di-	1.2	10.5	7.7	11.9	13.6	12.7	14.4	13.6	13.1	14.0
tri-	0.3	3.9	3.7	4.9	6.3	5.4	7.2	7.3	6.0	5.7
tetra- and greater	0.5	4.0	3.4	3.7	6.1	5.1	8.0	8.4	6.6	6.3
aromatic sulfur	0.3	2.8	3.7	2.6	4.2	3.4	10.7	6.8	5.4	9.1
2-ring compounds	0.2	0.9	1.5	0.7	0.7	1.2	5.0	2.3	1.9	4.5
3-ring compounds	0.1	1.7	1.8	1.7	3.0	2.0	4.6	3.9	3.1	3.9
4-ring compounds	0.0	0.2	0.4	0.2	0.5	0.2	1.1	0.6	0.4	0.7
unidentified	0.1	2.0	1.0	1.6	2.1	1.4	2.8	1.7	1.7	2.0
polar compounds	0.7	0.9	2.9	2.0	3.8	7.1	5.7	6.1	11.8	15.2
gasoline precursors ^b	97.0	75.9	77.6	73.3	63.9	64.9	51.2	56.1	55.4	47.7
LCO precursors ^c	1.5	12.3	10.1	13.5	15.8	14.9	21.7	17.9	16.6	20.5

^a Mostly taken from ref 5. ^b Saturates + monoaromatics. ^c Diaromatics + two-ring aromatic sulfur + $1/2 \times$ three-ring aromatic sulfur.

Table 2. Some Properties of Equilibrium Catalyst Dimension 60

property	value
X-ray diffraction	
unit-cell size	24.28 Å
zeolite content	13 wt %
nitrogen adsorption-desorption	
total surface area	150 m ² /g
zeolite surface area	100 m ² /g
matrix surface area	50 m ² /g
zeolite/matrix (Z/M)	2.00
micropore volume	0.05 mL/g
zeolite content	15.6 wt %
mercury porosimetry	
pore volume	0.22 mL/g
pore area	61 m ² /g
average pore diameter	109 Å
water absorption	
pore volume	0.31 mL/g
chemical analyses	
SiO ₂	55.7 wt %
Al ₂ O ₃	39.7 wt %
RE ₂ O ₃ (on catalyst)	1.21 wt %
RE ₂ O ₃ (on zeolite)	7.8 wt %
Na ₂ O	0.19 wt %
TiO ₂	1.62 wt %
Fe ₂ O ₃	0.67 wt %
nickel	291 wppm
vanadium	314 wppm
particle size distribution	
0–20 μm	1.7 wt %
20–40 μm	9.4 wt %
40–80 μm	37.0 wt %
80–120 μm	33.0 wt %
120–150 μm	10.5 wt %
>150 μm	8.4 wt %
average particle size	82.1 μm
MAT activity	72 wt %

respectively). The rest of the feeds were essentially in the 343–525 °C range.

Table 3. Sensitivity of MAT Yields to Temperature

	yield ^a at 520 °C and 5.5 C/O (wt %)	absolute difference, ^b relative to yield ^a at 520 °C and 5.5 C/O (%)
dry gas	2.56	15.9
LPG	13.5	9.5
gasoline	44.1	1.1
LCO	18.4	6.4
HCO	16.0	6.4
coke	5.53	5.1
conversion	65.7	2.2

^a For an average of 10 feeds. ^b Based on yields at 500 and 520 °C.

3.1.2. Density and Precursors Concentrations. Density or API gravity reflects the “lightness” of an oil and is considered to be a measure of feed quality. Low-density or high-API-gravity feeds usually contain less impurities, more convertible components or gasoline precursors (sometimes also called “conversion precursors”; these are defined as saturates + monoaromatics),¹⁰ and less light cycle oil (LCO, an unconverted product) precursors (defined as diaromatics + two-ring aromatic sulfur + $1/2 \times$ three-ring aromatic sulfur).¹⁰ Note that the precursors are based on the assumptions that (i) saturates and monoaromatics, upon catalytic cracking, would predominantly form gasoline and its derived products (also the converted products), including dry gas, liquefied petroleum gas (LPG), and some catalytic coke, and (ii) after removing the side chains of diaromatics, two-ring aromatic sulfur, and some three-ring aromatic sulfur, the retained core compounds would likely boil in the LCO range.

3.1.3. Impurity Levels. Feed impurities are destructive in the catalytic cracking process. Among them, nitrogen

(specifically basic nitrogen) and microcarbon residue (MCR) are poisons to catalysts. Although sulfur causes no harm in catalytic cracking, it deteriorates product quality and may induce operational problems. High metals (especially nickel and vanadium) in feeds deposit on the catalyst surface, resulting in negative impacts, which are not shown in limited MAT runs. Table 1 shows that the 10 feeds contained a wide range of impurities, the amounts of which were greater in heavier feeds and less in lighter feeds. The untreated feeds (RZ and VIR) and nonhydroprocessed feeds (DA-LCF and DA-BIT) were high in sulfur and nitrogen. By comparing the analyses of a hydrotreated feed against its predecessor's (i.e., HT-VIR's versus VIR's and HT-DA's versus DA-BIT's), one might conclude that hydrotreating substantially removed the impurities and improved the feed quality. Table 1 also indicates that basic nitrogen content was approximately one-third to one-fourth of the total nitrogen.

3.2. Feed Ranking Protocol. The value of an FCC feed depends on its processability to produce desirable products with good qualities. The definition of "desirable products" is controversial, because of the dependence of product value on geographical location. For example, in North America, gasoline is generally considered the most desired product, compared with gases and LCO, in FCC operation. However, in China and Thailand, commercial processes exist to maximize the yields of ethylene, propylene, and other light olefins for use in petrochemical industries.^{11,12} Similarly, in some countries where gasoline is not in high demand, the FCC unit, because of its low capital cost (one-fourth that of a hydrocracker), is used as a major producer of middle distillate. With proper design and operation, an FCC unit can produce 40–45 wt % LCO,¹³ which can be upgraded to No. 1 (diesel quality) and No. 2 fuel oils that generally have a lower initial boiling point (~182 °C). In Europe and the United States, many refiners seek seasonal means of increasing LCO yields to meet greater heating-oil demands in the winter. In this paper, we assume that gasoline is a premium product with the highest value, followed by LPG, LCO (medium-valued), heavy cycle oil (HCO, low-valued), dry gas, and coke (unwanted or least-valued). For simplicity, only yields, rather than product qualities, are emphasized.

It is simple to rank a feed based on its quality. Common sense dictates that a feed is good when it is low in density and impurities but high in saturates. However, uncertainties exist when feed properties vary toward opposite directions, resulting in both positive and negative impacts on cracking. It is thus necessary to establish a general formula for feed ranking. In this study, only three elements in feed analyses are considered: gasoline precursors, for positive contribution, and total nitrogen and MCR, for negative contribution to gasoline yield. Other analyses are excluded, because of the following reasons: (i) the long-term negative effects of nickel + vanadium cannot be shown in MAT runs;

and (ii) sulfur affects only the liquid product quality. Our in-house study provides estimates on the positive and negative impacts on gasoline yield by the three elements: (1) a 0.6 wt % contribution for every weight percentage of gasoline precursors, and (2) a 0.5 wt % penalty each for every 100 wppm total nitrogen and for every weight percent of MCR. The relative gasoline yield of a feed can be explicitly expressed as follows: relative gasoline yield (wt %) = (0.6 × gasoline precursors) (given in units of wt %) – (0.005 × total nitrogen) (given in units of wppm) – (0.5 × MCR) (given in units of wt %). The gasoline yields thus calculated for the 10 feeds were used to establish the apparent feed ranks, which were then compared with those based on (i) conversion, (2) individual product yields at a common severity and a common conversion, and (3) individual product yields at a practically high conversion.

3.3. Ranking Based on Feed Analyses. The 10 feeds from different origins and treatments were lumped into the following categories:

(1) Good-Quality Feeds (HCB, HT-VIR, RZ, and HT-LCF): These feeds were, in general, low in nitrogen (<1100 wppm), MCR (<0.1 wt %), sulfur (<0.1 wt %), except RZ, which had 0.92 wt %, because of its virgin nature), and nickel + vanadium (below detection limit). Their densities were <0.93 g/mL. With respect to chemical structure, they contained <53 wt % aromatics, >73 wt % gasoline precursors, and <14 wt % LCO precursors. On a relative scale, their gasoline yields were estimated at 58.2, 43.2, 42.5, and 38.5 wt %, respectively, based on the formula described previously.

(2) Medium-Quality Feeds (HT-C and HT-DA): These feeds had average levels of nitrogen (2300 ± 150 wppm). Between the two feeds, HT-C was lower in MCR (0.5 wt % versus 2.6 wt % for HT-DA), sulfur (0.43 wt % versus 0.70 wt % for HT-DA), and nickel + vanadium (undetectable versus 10.9 wppm for HT-DA). In comparison with good-quality feeds, HT-C and HT-DA had higher densities (0.94–0.95 g/mL), greater aromatics contents (58–62 wt %), and a larger amount of LCO precursors (~15 wt %) but much lower gasoline precursors (~64 wt %). Their relative gasoline yields were estimated at 27.3 and 25.4 wt %, respectively.

(3) Low-Quality Feeds (VIR, LCF, DA-LCF, and DA-BIT): These feeds were characterized by high contents of nitrogen (3000–4000 wppm, except VIR, which had 1930 wppm), sulfur (1.4–3.5 wt %), aromatics (58–66 wt %), polars (5.7–15.2 wt %), and LCO precursors (17–22 wt %), as well as high densities (0.95–0.98 g/mL), but low amounts of gasoline precursors (48–56 wt %). Among the four feeds in this category, the two deasphalted oils (DAOs) had much greater MCR values (3.4–5.4 versus ~0.3 wt % for the two non-DAOs) and nickel + vanadium contents (13–37 wppm versus ~0.1 wppm for the two non-DAOs). Their relative gasoline yields were estimated at 20.9, 16.7, 11.4, and 10.7 wt %, respectively.

In Table 1, the 10 feeds were ranked in descending order from feed 1 to feed 10, based on relative gasoline yields. The sequence of these ranks is as follows: HCB >> HT-VIR ≈ RZ > HT-LCF >> HT-C ≈ HT-DA > VIR > LCF > DA-LCF ≈ DA-BIT. Note that the relative positions of feeds with similar ranks (those connected by a double approximation sign, "≈") may be interchangeable, because of experimental error. Upon cata-

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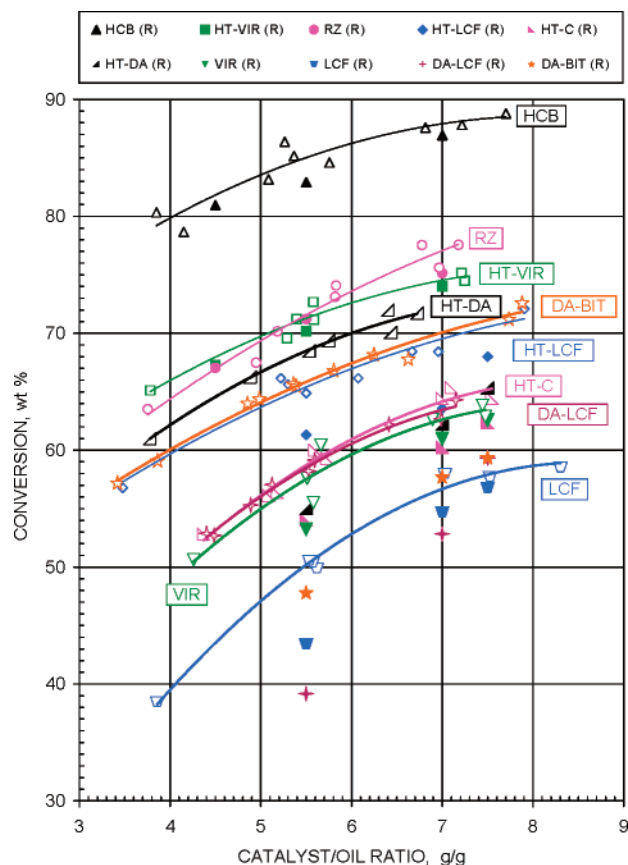


Figure 1. Relationship between conversion and the catalyst-to-oil (C/O) ratio for 10 feeds cracked in a riser pilot plant reactor (R, closed symbols) and a microactivity test (MAT) unit (open symbols).

lytic cracking at a constant severity or conversion, it was expected that the individual product yields, which were inter-related to some degree, would decrease (for high-value products, e.g., gasoline) or increase (for low-value products, e.g., dry gas and coke) following the order shown previously. In the following sections of this paper, this established sequence is compared with the MAT cracking results.

3.4. Validation of Apparent Feed Ranks with Conversion and Individual Yields. In this study, the MAT reaction temperature was assumed to be constant, and the catalyst weight and the catalyst contact time were all fixed for a given feed; therefore, the only variable was the catalyst-to-oil ratio (C/O), which affected the weight hourly space velocity through the relationship $WHSV = 3600/[(C/O)t]$. Cracking results are graphically presented in Figures 1–7, with each product yield plotted against both C/O ratio and conversion, for ease of interpretation. Conversion and yield data on common bases will be used to verify the validity of apparent feed ranks that have been established.

3.4.1. Conversion. Conversion is defined as the portion of the feed converted to 216 °C– products, including gas and coke. Figure 1 shows the relationships between conversion (from both MAT and riser data) and the C/O ratio for 10 feeds, with the trend lines established for MAT data only. At the same C/O ratio, the MAT unit gave slightly higher conversions for the seven non-DAO feeds but much higher conversions for the three DAO feeds, when compared with the corresponding conver-

sions obtained from the riser pilot plant. This phenomenon was explained in our earlier publication.⁶ Because of limited data, pilot-plant results were not used to evaluate the apparent feed ranks.

At constant C/O ratio (C/O = 7), the conversions of 10 feeds were in the following descending order: HCB \gg RZ > HT-VIR > HT-DA > DA-BIT \approx HT-LCF \gg HT-C \approx DA-LCF \approx VIR \gg LCF. This order was generally consistent with the apparent feed ranks for non-DAO feeds. For DAO feeds, high MCR and nitrogen contents caused deviation from the predicted order. The subsequent discussions on individual product yields will shed more light in this respect.

3.4.2. Dry Gas. The low-value dry gas is composed of H_2 , H_2S , and C_1 – C_2 hydrocarbons. Figure 2a shows the increase in dry gas yield with the increase in the C/O ratio. At a constant C/O ratio of 7, yields of dry gas for the 10 feeds varied in the following order: HCB < HT-LCF \approx HT-VIR < RZ \approx HT-C < LCF < HT-DA \approx DA-LCF < VIR \ll DA-BIT. This order did not quite agree with the apparent feed ranks. It demonstrated clearly that the dry gas yield was strongly influenced, other than the hydrocarbon composition, by the feed sulfur (0.70 wt % for HT-DA, 0.92 wt % for RZ, 1.4–1.5 wt % for LCF and DA-LCF, and 3.3–3.5 wt % for VIR and DA-BIT) and MCR (2.6 wt % for HT-DA, 3.4 wt % for DA-LCF, and 5.4 wt % for DA-BIT). In FCC, MCR might block the catalyst pores, promoting nonselective cracking to produce dry gas, whereas $\sim 40\%$ feed sulfur might contribute to dry gas as H_2S ¹⁴ (i.e., 1 wt % feed sulfur might produce 0.43 wt % H_2S). The feed sulfur and MCR could explain some of the unexpected observations on the aforementioned order, such as (i) RZ was inferior to HT-LCF, (ii) HT-DA also behaved worse than LCF, and (iii) VIR produced more dry gas than DA-LCF. The nitrogen poisoning effect on the catalyst probably could not be observed clearly in Figure 2a because (i) dry gas was mostly produced thermally rather than catalytically and (ii) other than the four good feeds, the rest were all high in nitrogen with only moderate variations in concentration (1900–4000 wppm). This masked the nitrogen effect to some degree. One should remember that a plot of yield versus the C/O ratio, such as Figure 2a, provides a comparison of product yields for different feeds at a chosen C/O ratio when the feeds are in contact with the same catalyst which exhibits different activities and selectivities to feeds, because of different degrees of deactivation during reaction.

The combination of Figures 1 and 2a gives the relationship between dry gas yield and conversion (Figure 2b). This plot provides a different comparison basis, which is more commonly adopted. The conversion of a feed is a key parameter closely monitored in a reaction study. The conversion, similar to the product yield, reflects the feedstock quality and is affected by the catalyst properties, reaction severity, and operating system used (e.g., reactor configuration, hydrodynamics, and test and analytical methods). For a given feed at a fixed severity, the yield–conversion relationship is interfered with less by the operating system, because

(14) Keyworth, D. A.; Reid, T. A.; Asim, M. Y.; Gilman, R. H. Presented at the 1992 National Petroleum Refiners Association (NPRA) Annual Meeting, New Orleans, LA, Paper No. AM-92-17.

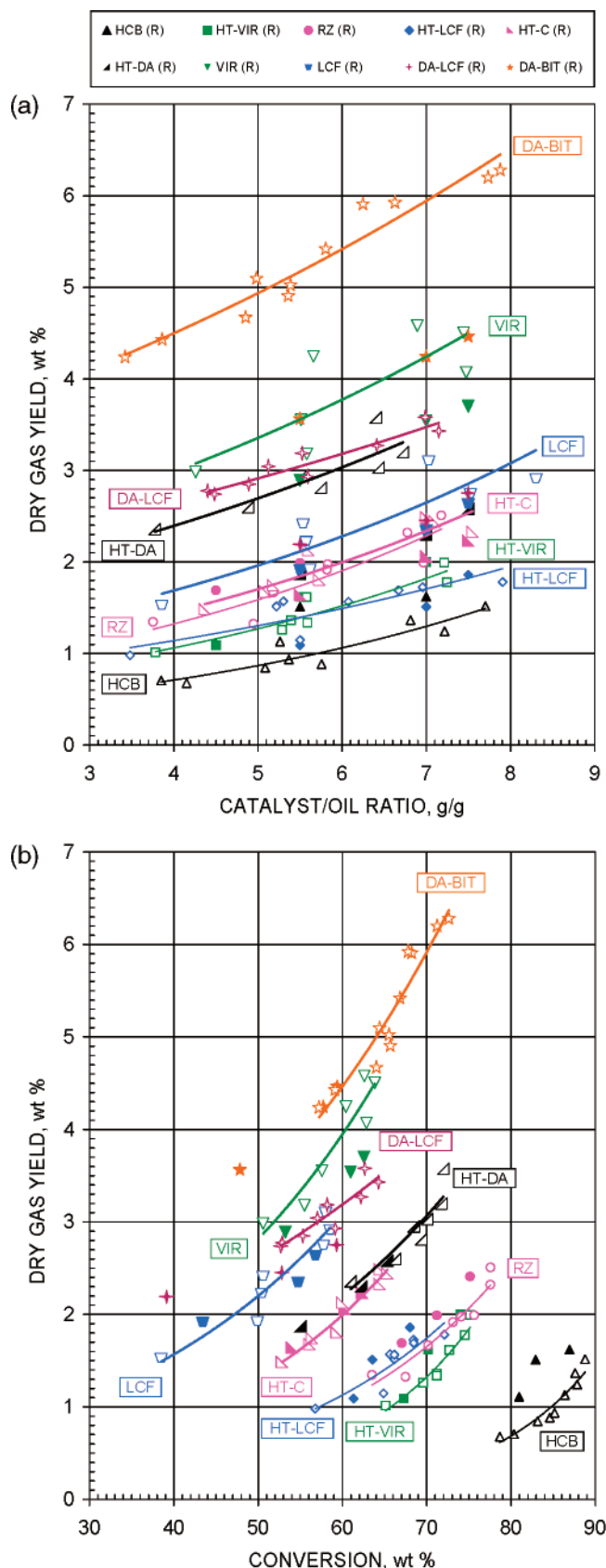


Figure 2. (a) Relationship between dry gas yield and C/O ratio for 10 feeds cracked in a riser pilot plant reactor (R, closed symbols) and a MAT unit (open symbols). (b) Relationship between dry gas yield and conversion for 10 feeds cracked in a riser pilot plant reactor (R, closed symbols) and a MAT unit (open symbols).

both the yield and conversion are affected to the same degree (the yield of a converted product is part of the conversion). The drawback of the yield–conversion plot is that one may not be able to compare all feeds at the same conversion, because of some limitations, resulting from feedstock characteristics, or the lack of sufficient experimental data, rendering the extrapolation of the trend line impossible or unreliable.

Figure 2b depicts the exponential increase in dry gas yield with conversion. At 65 wt % conversion (assuming that some trend lines can be extrapolated), the order of dry gas yields appeared as follows: HCB < HT-VIR < RZ ≈ HT-LCF < HT-C ≈ HT-DA < LCF ≈ DA-LCF < VIR < DA-BIT. This order was consistent with that determined by the feed quality, except for VIR, which had an extremely large amount of sulfur.

Figure 2a shows that, at the same C/O, the MAT unit gives a higher dry-gas yield than the riser reactor. This is probably attributed to the much longer contact time in MAT than in the riser reactor. It is known that long contact time favors the secondary cracking of gasoline to produce more gases, including dry gas. In contrast, Figure 2b gives a much better comparison in dry-gas yield between the MAT unit and the riser reactor. This was due to the differences in reaction systems, which showed more effect on yield–severity than on yield–conversion relationships, as explained previously. Generally, at the same C/O ratio, the MAT unit gave a greater dry-gas yield than the riser reactor did for the same feed, with greater differences in yield for feeds with higher MCR.

3.4.3. Liquefied Petroleum Gas. In FCC operation, LPG ($C_3 + C_4$ hydrocarbons) is considered a valuable product, because it consists of components that can be used as alkylation and petrochemical feedstocks. In this study, similar to the dry gas, LPG also increased as the C/O ratio increased (Figure 3a), but in a convex shape. This implies that as the C/O ratio increased, LPG gradually relaxed its rate of increase (resulting from its formation from the precursors, i.e., components in gasoline and the feed, less its decomposition to dry gas). At a given C/O ratio ($C/O = 7$), LPG yields decreased in the following order: HCB > RZ > HT-VIR > HT-DA > HT-LCF ≈ DA-BIT > HT-C ≈ VIR > DA-LCF ≈ LCF. This order generally agreed with the apparent feed ranks, except that DA-BIT outperformed HT-C and three other feeds, despite having the lowest gasoline precursors content, highest MCR content, and high nitrogen content. Careful examination of Table 1 revealed that DA-BIT, among the 10 feeds, had the highest content of polar compounds (15.2 wt %) that were not counted as gasoline precursors. This seems to suggest that some of the polar compounds in DAOs might be crackable. This also helps explain why HT-DA and DA-LCF, which also have greater polars contents, performed better than expected.

Figure 3b shows the increase in LPG, with the increase in conversion, but in a slightly concave shape. This indicates that, as conversion increased, LPG accelerated its net increase between its formation from the precursors and its decomposition to dry gas. Assuming that both trend lines of HCB and LCF could be extended for a comparison of LPG yields at a common conversion of 65 wt %, this produced the following order: HCB < HT-VIR < HT-DA ≈ DA-BIT ≈ DA-LCF

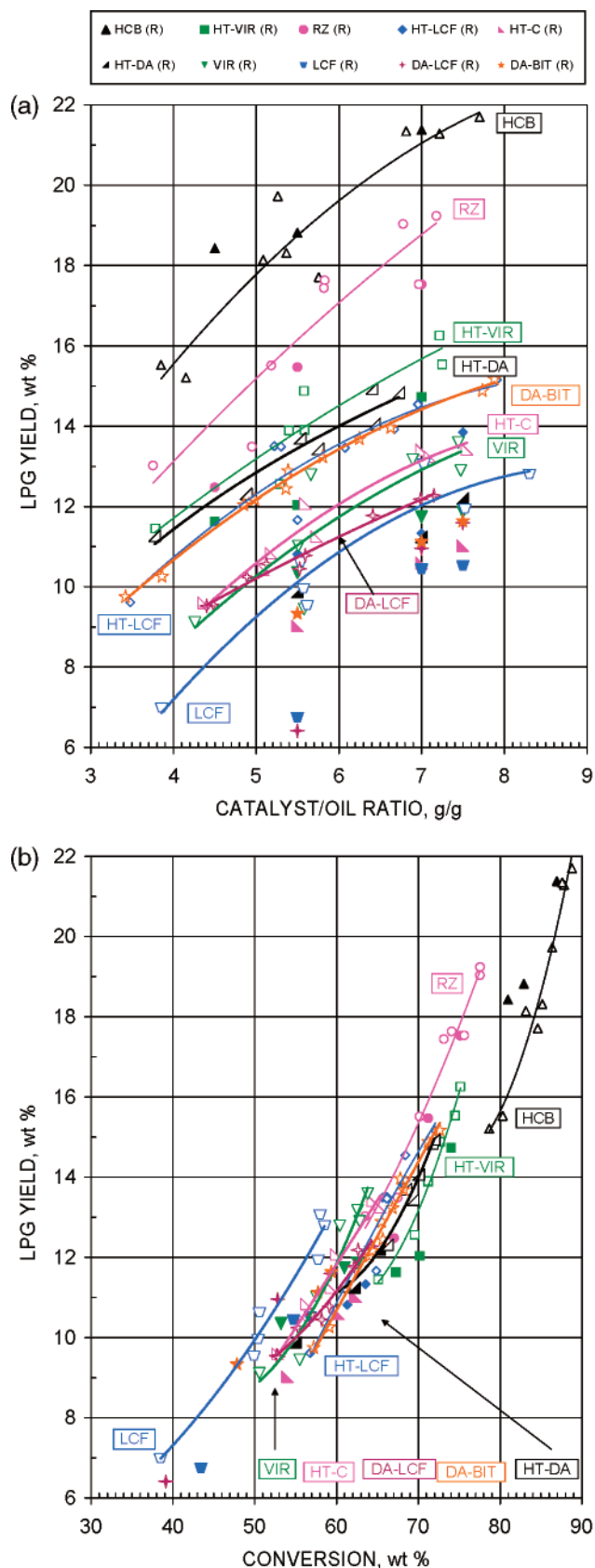


Figure 3. (a) Relationship between LPG yield and C/O ratio for 10 feeds cracked in a riser pilot plant reactor (R, closed symbols) and a MAT unit (open symbols). (b) Relationship between LPG yield and conversion for 10 feeds cracked in a riser pilot plant reactor (R, closed symbols) and a MAT unit (open symbols).

$\approx \text{HT-LCF} \approx \text{RZ} \approx \text{HT-C} < \text{VIR} < \text{LCF}$. This order did not follow the expected trend that was based on feed analyses. One could only conclude from Figure 3b that, with the exception of DA-BIT and HT-DA, the better the feed quality, the greater the LPG yield at high conversion.

Similar to the case of dry gas, the yield-conversion plot also gave a better comparison of the LPG yields between the MAT unit and the riser reactor than the yield-C/O ratio plot did. In Figure 3a, the riser reactor gave lower LPG yields than the MAT unit did, generally, at the same C/O ratio for the same feed. Again, the higher MCR in the feed, the greater the difference.

3.4.4. Gasoline. Gasoline (C_5 plus heavier hydrocarbons which boil at or below 216°C) is the major and the most desirable product in FCC operation. Thus, gasoline yield is an important indicator to judge the feed rank. Figure 4a illustrates that gasoline yield increased as the C/O ratio increased and tended to level off or decrease at high C/O ratios. At a constant C/O ratio of 7, the gasoline yields of the 10 feeds decreased in the following order: $\text{HCB} \gg \text{HT-VIR} > \text{RZ} > \text{HT-LCF} > \text{HT-DA} > \text{HT-C} > \text{VIR} > \text{DA-BIT} \approx \text{DA-LCF} \approx \text{LCF}$. This order agreed well with the apparent feed ranks, based on analyses, except that, similar to the case of LPG, DA-BIT and DA-LCF (both rich in polar compounds) were slightly higher in the order than LCF. The yield profile of DA-BIT was relatively flat, because of an unexpectedly high gasoline yield (probably related to the "easy-to-crack" polars) at low C/O ratios.

Overcracking was observed for some feeds in Figure 4b, which shows the general increase in gasoline yield (prior to overcracking) with conversion. Assuming that all yields could be compared at 65 wt % conversion, the approximate order of the yields was estimated as follows: $\text{HCB} > \text{HT-VIR} > \text{HT-LCF} \approx \text{RZ} > \text{HT-DA} \approx \text{HT-C} > \text{VIR} > \text{LCF} \approx \text{DA-LCF} \approx \text{DA-BIT}$. The order was even closer to the expected trend, based on feed analyses. The approximate maximum gasoline yield of a feed could be mathematically determined from Figure 4b, assuming that the yield was a parabolic function of conversion. The result is given in Table 4. The maximum gasoline yield was probably a better indicator to reflect the feed rank. Based on this table, and with reference to Figure 4b, the 10 feeds could be ranked as follows: $\text{HCB} \gg \text{HT-VIR} \approx \text{RZ} > \text{HT-LCF} > \text{HT-DA} \approx \text{HT-C} > \text{VIR} > \text{LCF} \approx \text{DA-LCF} \approx \text{DA-BIT}$. The aforementioned order is the closest to the pre-established ranking, based on feed analyses. However, the maximum gasoline yield is more difficult to determine.

In Figure 4a, MAT gasoline yields compared favorably with those from the riser reactor, except for the three DAOs, which showed much-higher MAT gasoline yields than those of the riser reactor at a C/O ratio of ~ 5.5 . In contrast, Figure 4b gave better comparison between the MAT data and the riser data, with the former showing lower gasoline yields, generally, at the same conversion. Note that the observed crossovers of yield curves between RZ and HT-LCF, and between HT-DA and HT-C, were due to RZ and HT-DA having much-higher conversions (because they contained more MCR and/or sulfur, relative to HT-LCF and HT-C, respectively) at the same C/O ratio (Figure 1).

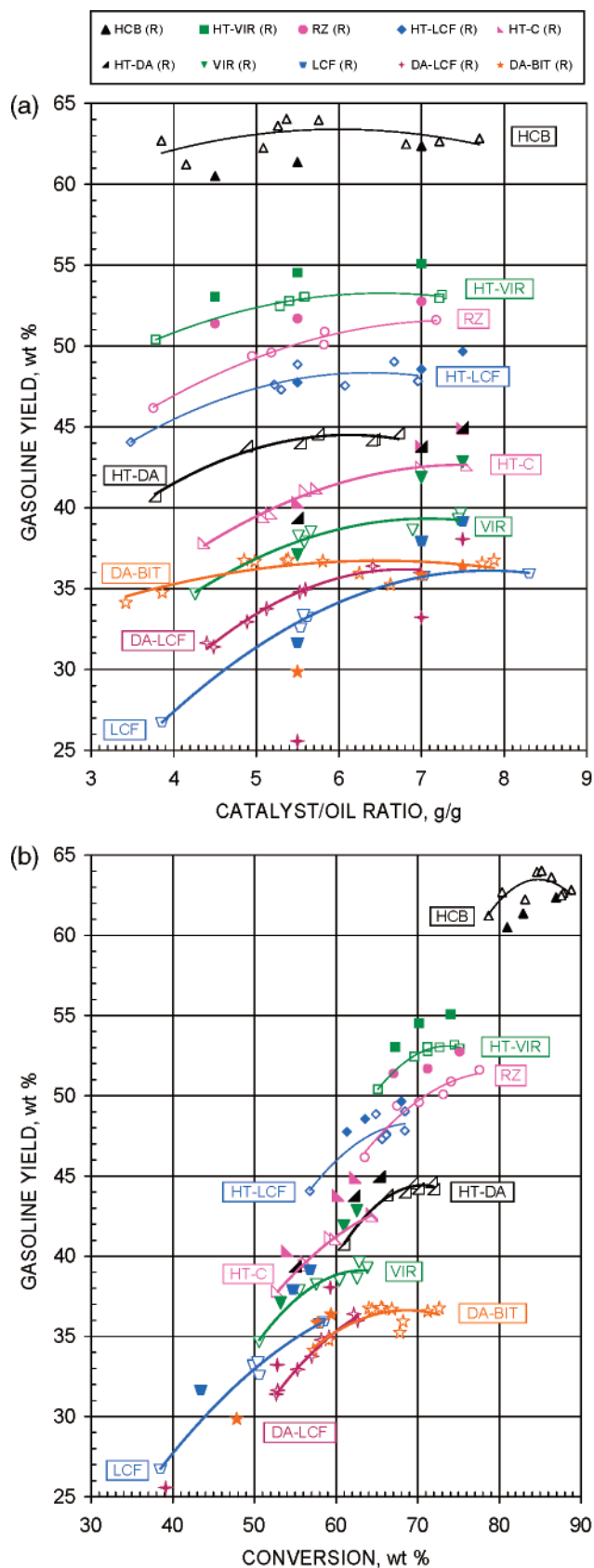


Figure 4. (a) Relationship between gasoline yield and C/O ratio for 10 feeds cracked in a riser pilot plant reactor (R, closed symbols) and a MAT unit (open symbols). (b) Relationship between gasoline yield and conversion for 10 feeds cracked in a riser pilot plant reactor (R, closed symbols) and a MAT unit (open symbols).

Table 4. Maximum Gasoline Yield

feed	maximum gasoline yield (wt %)
HCB	63.2
HT-VIR	53.3
RZ	51.5
HT-LCF	48.5
HT-C	43.6
HT-DA	44.5
VIR	39.1
LCF	37.8
DA-LCF	37.6
DA-BIT	36.6

3.4.5. Light Cycle Oil. Light cycle oil (LCO, with a boiling point of 216–343 °C) is classified as an unconverted product that is not highly desirable in North America, especially when derived from an aromatics-rich feed. The cetane number of LCO from FCC is generally low and its sulfur content is high. The lower the LCO yield, the poorer its quality, because of the enrichment of aromatics at higher conversion. Figure 5a shows the general decrease in LCO for most feeds (except for VIR and LCF), as the C/O ratio increases. At a high C/O ratio (C/O = 7), the LCO yields of the feeds varied in the following order: HCB < RZ < HT-DA < HT-VIR < DA-BIT ≈ HT-LCF < DA-LCF < HT-C < LCF < VIR. Generally, this was consistent with the established feed rank with a few exceptions, especially the two DAOs, which outperformed HT-C, LCF, and VIR. It is interesting to note the concave yield curves of HCB and HT-VIR as the C/O ratio increased from 4 to 7.

Figure 5b shows the familiar convex yield curves, which should increase at low conversion but decrease at high conversion. Assuming that both trend lines of HCB and LCF could be extended for comparison of LCO yields at a common conversion of 65 wt %, the following order was produced: RZ ≈ HCB < DA-LCF ≈ HT-DA ≈ HT-C ≈ HT-LCF ≈ DA-BIT ≈ LCF ≈ HT-VIR < VIR. This order did not quite follow the expected trend, based on feed analyses. One could only conclude from Figure 5b that, with the exception of the three DAOs, the better the feed quality, the lower the LCO yield at high conversion.

A yield–conversion plot (Figure 5b) gave a slightly better comparison of LCO yields between the MAT unit and the riser reactor than a yield–C/O ratio plot (Figure 5a). There seemed to be no definite relationship between the riser and MAT data for the same feed in Figure 5a. However, in Figure 5b, the riser reactor gave lower LCO yields than the MAT unit, generally, for the same feed.

3.4.6. Heavy Cycle Oil. Heavy cycle oil (HCO, with a boiling point of 343–525 °C) is an unwanted, unconverted product with comparatively high aromatics and sulfur. HCO is usually burned as heavy fuel oil, which currently has limited markets, because of the enforcement of environmental regulations. Thus, HCO yield should be reduced to a minimum. The convex yield curves in Figure 6a show the gradual decreases in HCO yield as the C/O ratio increases. At a constant C/O ratio of 7, the variation of HCO yield was as follows: HCB < HT-VIR < RZ < HT-DA ≈ DA-BIT ≈ HT-LCF < VIR ≈ HT-C < DA-LCF < LCF. This order generally agreed with the feed quality, if the DAO feeds are excluded; these DAO feeds performed better than expected, prob-

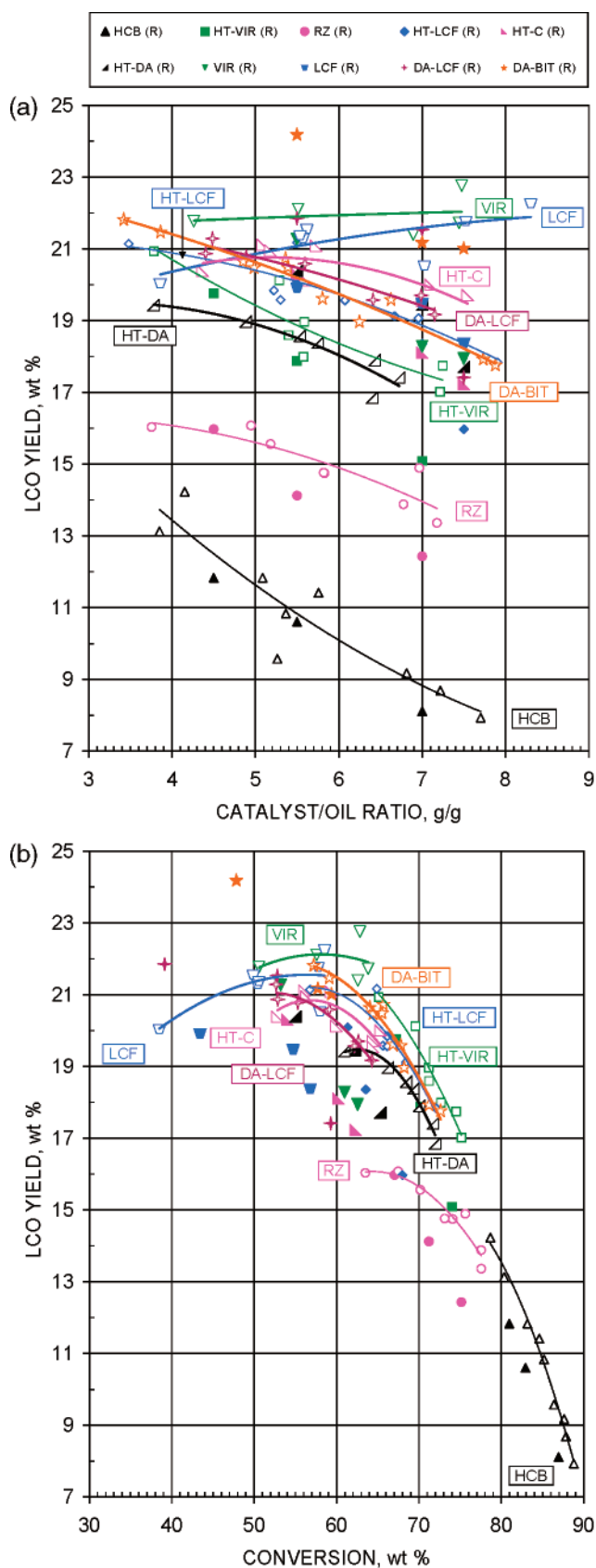


Figure 5. (a) Relationship between LCO yield and C/O ratio for 10 feeds cracked in a riser pilot plant reactor (R, closed symbols) and a MAT unit (open symbols). (b) Relationship between LCO yield and conversion for 10 feeds cracked in a riser pilot plant reactor (R, closed symbols) and a MAT unit (open symbols).

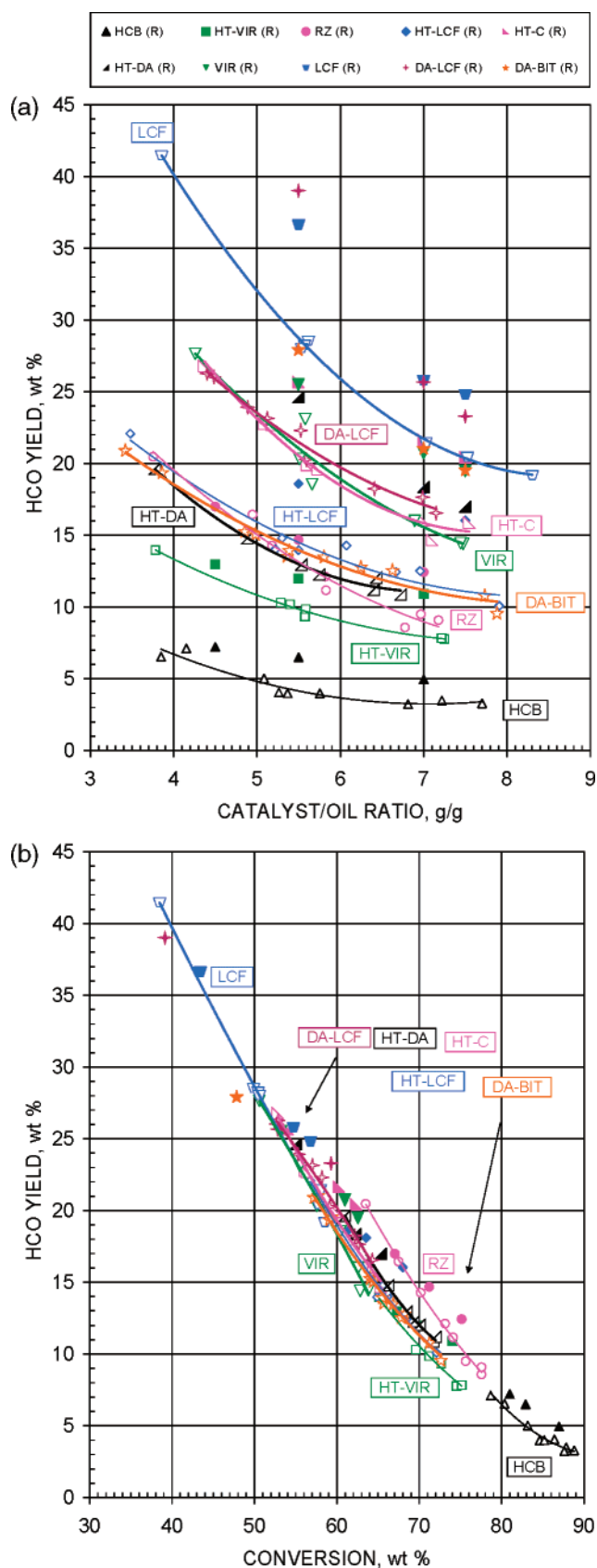


Figure 6. (a) Relationship between HCO yield and C/O ratio for 10 feeds cracked in a riser pilot plant reactor (R, closed symbols) and a MAT unit (open symbols). (b) Relationship between HCO yield and conversion for 10 feeds cracked in a riser pilot plant reactor (R, closed symbols) and a MAT unit (open symbols).

ably because of the conversion of heavy aromatics to coke. The bad performance of LCF might be related to a high nitrogen content, which poisoned the catalyst.

Figure 6b shows the monotonic decrease in HCO with conversion. Yield curves of feeds appear in a narrow band, except for those of RZ and HCB. The magnitude of HCO yield for all feeds at a given conversion should be in the reverse order to that of LCO, based on the simple relationship $\text{HCO} = 100 - \text{conversion} - \text{LCO}$. Thus, at a common conversion of 65 wt %, the order of HCO yields of the 10 feeds was as follows: $\text{RZ} \approx \text{HCB} \gg \text{DA-LCF} \approx \text{HT-DA} \approx \text{HT-C} \approx \text{HT-LCF} \approx \text{DA-BIT} \approx \text{LCF} \approx \text{HT-VIR} > \text{VIR}$. Again, this order did not quite follow the expected trend that was based on feed analyses. Similar to the LCO yields, the conclusion reached from Figure 6b is that, with the exception of the three DAOs, the better the feed quality, the lower the HCO yield at high conversion.

HCO yields from the riser compared reasonably well with their corresponding counterparts in Figure 6b but not in Figure 6a, which shows consistently higher riser yields than those of the MAT at a given C/O ratio for the same feed.

3.4.7. Coke. In FCC operation, coke is necessary to supply heat for feed preheating and cracking. However, too much coke can seriously poison the catalyst and overload the air blower during catalyst regeneration, causing excessively high temperature in the regenerator. Figure 7a shows the linear increase in coke yield as the C/O ratio increases. At a constant C/O ratio of 7, the coke yields varied in the following order: $\text{HCB} \ll \text{HT-VIR} \approx \text{HT-LCF} \approx \text{RZ} \ll \text{HT-C} \approx \text{LCF} \approx \text{VIR} \ll \text{HT-DA} \ll \text{DA-LCF} \ll \text{DA-BIT}$. This order generally agreed with the feed quality, except for HT-DA, because of its high MCR content (2.6 wt %). In Figure 7a, the straight lines representing each feed intersected the y -axis ($\text{C/O} = 0$), giving intercepts that should be close to their MCR values. Some feeds did not show this expected observation because of (i) varying reaction temperatures, which affected empirical constants in Voorhie's equation;¹⁵ (ii) insufficient data points in the low C/O ratio (< 4) region; (iii) possible experimental error, as described previously³ (i.e., some unrecovered heavy product (HCO) that remained at the "cold" spot near the exit of the reactor was picked up later as coke at a higher reactor temperature (600 °C) during catalyst in situ regeneration).

Figure 7b shows the exponential increases in coke yield with conversion. Assuming that trend lines could be extrapolated, the order of coke yields at 65 wt % conversion was as follows: $\text{HCB} \ll \text{HT-VIR} < \text{RZ} \approx \text{HT-LCF} \ll \text{HT-C} < \text{VIR} < \text{HT-DA} < \text{LCF} \ll \text{DA-BIT} \approx \text{DA-LCF}$. This order was also consistent with the feed quality, except for HT-DA, because of its high MCR content.

Figure 7b also had a better comparison of coke yields between the MAT unit and the riser than Figure 7a. In both cases, the MAT gave higher coke yields than the riser at a given C/O ratio or conversion, with greater differences evident in Figure 7a.

In FCC, delta coke (the amount of coke per unit weight of spent catalyst) is an important parameter to watch, because its magnitude affects the heat balance.

Delta coke is calculated from the coke yield divided by the C/O ratio. Figure 7c shows the general decline of delta coke, with the increase in conversion, for all feeds. This is understandable, because higher conversion required a higher C/O ratio or less feed per unit weight of catalyst. At 65 wt % conversion, the order of delta coke yields was as follows: $\text{HCB} \ll \text{HT-VIR} \approx \text{HT-LCF} < \text{RZ} \approx \text{LCF} < \text{HT-C} \approx \text{VIR} \ll \text{DA-LCF} \approx \text{HT-DA} \ll \text{DA-BIT}$. This order was only consistent with the ranking of the good-quality feeds, notably because of the influences of MCR and nitrogen contents on the other feeds. Again, the riser gave much-smaller delta coke yields than the MAT for each feed, especially the DAOs.

3.5. Comparison of Apparent Feed Ranks with Exact Feed Ranks. The aforementioned discussions showed the exceptions in ranking for some feeds where the product yields did not follow the sequence established by the apparent feed ranks. These might be attributed to the following: (i) the common comparison bases, i.e., a C/O ratio of 7 and a conversion of 65 wt %, were not adequately chosen for these feeds; and (ii) the apparent feed rank was designed for gasoline yield by taking the relevant feed properties into consideration. Properties with strong influences on other yields (e.g., H_2S on dry gas and MCR on coke) had been overlooked. Therefore, an attempt was made to compare yields of selected feeds (in lieu of all feeds) on a practical and flexible basis. Because gasoline was considered the most valuable product, the maximum gasoline yields in Table 4 were used as a guide to group feeds for comparison at a high conversion, which was realistic and achievable. If uncertainty in ranking still persisted after yield comparison, feed qualities would be further considered. The following illustrates how the exact feed ranks were established:

(1) HCB was indisputably the top feed, because of its much-higher maximum gasoline and LPG yields and its lowest undesirable product yields, compared with other feeds at a given high conversion.

(2) HT-VIR was ranked second, based on its maximum gasoline yield, which was 1.9 wt % higher than that of RZ. This was further supported by other yields at a conversion of 75 wt %: the yield for HT-VIR was 2.0 and 2.6 wt % higher than that of RZ in gasoline and LCO, respectively, and 0.2, 1.7, and 2.6 wt % lower than that in dry gas, LPG, and HCO, respectively. There was no difference between HT-VIR and RZ, in regard to coke yield. However, being a conventional crude VGO, RZ was more flexible to be cracked at conversions of > 75 wt % (Figure 1) to reduce the yield difference in HCO, which is a low-value product. Given this information, HT-VIR was just marginally better than RZ.

(3) RZ was the third-best feed, because its maximum gasoline yield was 3.0 wt % higher than that of HT-LCF. Yields at a conversion of 70 wt % also favored RZ, relative to HT-LCF: 1.4, 0.5, and 2.9 wt % higher in gasoline, LPG, and HCO, respectively, and 0.1, 2.9, and 0.8 wt % lower in dry gas, LCO, and coke, respectively. Again, it was more beneficial to crack RZ at conversions of > 70 wt % to reduce the production of LCO and HCO while increasing the yields of gasoline and LPG.

(4) HT-LCF was ranked the fourth-best feed, because of its maximum gasoline yield, which was 4.9 wt %

(15) Voorhies, A. *Ind. Eng. Chem.* **1945**, 37, 318–322.

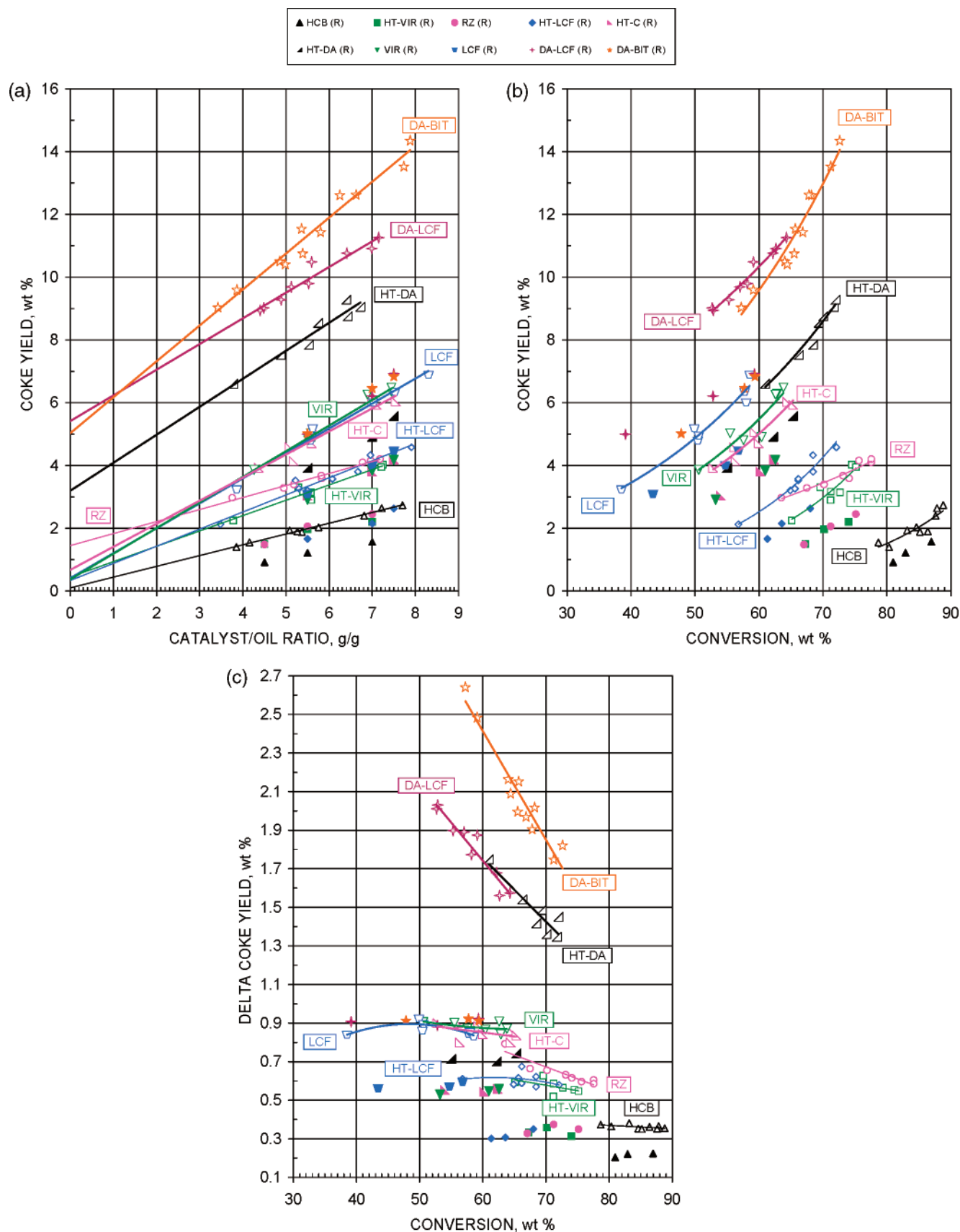


Figure 7. (a) Relationship between coke yield and C/O ratio for 10 feeds cracked in a riser pilot plant reactor (R, closed symbols) and a MAT unit (open symbols). (b) Relationship between coke yield and conversion for 10 feeds cracked in a riser pilot plant reactor (R, closed symbols) and a MAT unit (open symbols). (c) Relationship between delta coke yield and conversion for 10 feeds cracked in a riser pilot plant reactor (R, closed symbols) and a MAT unit (open symbols).

higher than that of HT-C, which is the next-best feed (to be discussed later). Additional yields at a conversion

of 65 wt % were also considered: 5.0 and 0.5 wt % higher in gasoline and LCO, respectively, and 1.0, 0.6,

0.5, and 2.7 wt % lower in dry gas, LPG, HCO, and coke, respectively.

(5) The ranking of HT-C and HT-DA could be controversial. Although the former had a maximum gasoline yield that was 0.9 wt % less than the latter, yields at a conversion of 65 wt % were slightly in favor of HT-C: 1.3 and 0.4 wt % higher in LPG and LCO, respectively, and 0.1, 0.4, 0.4, and 1.4 wt % lower in dry gas, gasoline, HCO, and coke, respectively. Note that HT-C could be readily cracked at higher conversions (>65 wt %) for further reduction of LCO and HCO (see Figures 5b and 6b), and increased in gasoline and LPG (see Figures 4b and 3b); however, this would also increase dry gas and coke yields significantly (see Figures 2b and 7b). After further consideration on feed qualities, that HT-DA has much higher sulfur, MCR, and nickel + vanadium contents than HT-C, it was more convincing to rank HT-C marginally higher.

(6) HT-DA was rated the No. 6 feed, because its maximum gasoline yield is 5.4 wt % higher than that of VIR. This difference is large enough to ignore some of the unfavorable yields at a conversion of 65 wt %: 4.1, 2.7, and 0.8 wt % higher in gasoline, HCO, and coke, respectively, and 2.1, 2.3, and 2.7 wt % lower in dry gas, LPG, and LCO, respectively.

(7) VIR was ranked No. 7, considering its maximum gasoline yield, which was 1.3 wt % higher than that of LCF, which is tentatively the next-best feed after VIR. The supporting evidence was based on yields at a conversion of 60 wt %: 2.5, 0.2, and 0.9 wt % higher in gasoline, LCO, and dry gas, respectively, and 1.5, 0.2, and 1.4 wt % lower in LPG, HCO, and coke, respectively.

(8) LCF was classified as the next-best feed after VIR, although its maximum gasoline yield was only 0.2 wt % higher than that of DA-LCF. The justification was largely based on yields at a conversion of 60 wt %: 1.0, 2.1, and 1.7 wt % higher in gasoline, LPG, and LCO, respectively, and 0.1, 1.7, and 3.5 wt % lower in dry gas, HCO, and coke, respectively.

(9) The ranking of DA-LCF and DA-BIT could also be controversial. Although the former was 1.0 wt % higher in maximum gasoline yield than the latter, yields at a conversion of 65 wt % were somewhat less supportive: 0.5, 0.1, 1.5, and 0.3 wt % higher in gasoline, LPG, HCO, and coke, respectively, and 1.6 and 1.5 wt % lower in dry gas and LCO, respectively. Note that DA-BIT could be readily cracked at higher conversions (>65 wt %). This would reduce LCO and HCO (Figures 5b and 6b) but would not increase gasoline (see Figure 4b). In addition, the yield of LPG would increase (see Figure 3b), in addition to significant increases in dry-gas and coke yields (see Figures 2b and 7b). In view of their feed qualities, in terms of total sulfur, MCR, and

nickel + vanadium content, it was justifiable to rank DA-LCF slightly higher than DA-BIT as the ninth-best feed.

(10) Consequently, the remaining DA-BIT was the worst feed; it had the lowest gasoline yield and the highest dry gas and coke yields at conversions of >65 wt %.

Based on the aforementioned summary, the sequence of the exact rankings of the 10 feeds could be symbolized as follows: HCB \gg HT-VIR \approx RZ $>$ HT-LCF $>$ HT-C \approx HT-DA $>$ VIR $>$ LCF $>$ DA-LCF \approx DA-BIT. This compares favorably with the sequence that is based on apparent feed ranks. Note that the exact feed ranks were strictly based on MAT yields that were obtained in this study. If the choice of process conditions or catalysts significantly altered the product distributions, the sequence of feed ranks would need to be re-examined.

4. Conclusions

Fluid catalytic cracking (FCC) feeds could be reasonably ranked based on their analyses, with an emphasis on the concentrations of gasoline precursors, total nitrogen, and microcarbon residue (MCR). The validity of the apparent feed ranks thus established could be verified by cracking experiments. In this study, the order of apparent feed ranks for 10 feeds compared best with those based on either the maximum gasoline yields or gasoline yields at a conversion of 65 wt %. Minor discrepancies existed if the comparison was against the sequence that was established by dry gas or coke yields at a conversion of 65 wt %, because some feeds were rich in sulfur or MCR. For final validation, the apparent feed ranks were compared with the exact feed ranks that were based on individual product yields at a common realistically high conversion that was achievable. The results indicate a good conformity in sequence between the two sets of feed ranks. Microactivity test (MAT) yields of the 10 feeds compared better with riser pilot plant reactor yields at the same conversion than at the same C/O ratio. Among the six cracked products, dry gas gave the best comparison, in terms of absolute yields, whereas coke showed the worst.

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