Petroleum & Coal
ISSN 1337-7027

Available online at www.vurup.sk/pc
Petroleum & Coal 49 (1), 16-20, 2007

MAXIMIZING NAPHTHA AND DIESEL YIELDS OF AN INDUSTRIAL HYDROCRACKING UNIT WITH MINIMAL CHANGES

M.Bahmani, S.Sadighi, M.Mashayekhi, S.R.Seif Mohaddecy, D.Vakili

Catalytic Reaction Engineering Department, Catalyst Research Center, RIPI
RIPI Boulivard, Old Qom Road, Tehran, Iran, P.O.Box:18745-4163
e-mail:mbahmani@ripi.ir

Received February 12, 2007, accepted June 25, 2007

Abstract
A discrete model utilizing three parameters has been developed to simulate the yields of an industrial hydrocracking unit. Refinery test runs spanning over two years of operation were gathered and used to validate the model and check the simulation results. The simulator predicts the yields of LPG, light naphtha, heavy naphtha, kerosene, diesel and residue. The heavy naphtha and diesel yields were maximized by minimal changes in the operating conditions. Small changes in the catalyst loading and recycle ratio can significantly improve yields of these important cuts.

Key Words: Hydrocracking, Simulation, LPG, Naphtha, Kerosene, Diesel, Residue

1. Introduction

Hydrocracking units usually yield more middle distillates than naphtha. The H/C ratio of the feedstock is increased by 'hydrogen addition' instead of 'carbon injection'. This is achieved by hydrogenation of unsaturated feed stock and cracking products. The low aromatic content in the product results in a superior diesel quality, i.e., a high cetane index .By the appropriate choice of the Hydrocracking catalyst, severe deactivation by sulfur and nitrogen containing components can be avoided

Modeling of hydrocracking reactions has been approached by models of varying complexities such as discrete lumping [1], continuous lumping [2], structural oriented modeling [3] and single event modeling based on the carbenium ion chemistry [4]. Based on the applications to laboratory or industrial scale any of these methods can be used.

Stangeland [1] developed a discrete lumping approach utilizing only three parameters for the estimation of product yields of hydrocracking unit. Apart from its simplicity, the assumption of first order kinetics and the difficulty to assimilate nonlinear kinetics are the main disadvantages of this model.

In a recent review, Ancheyta [5] compares different modeling approaches and applied them to the hydrocracking data El-Kady [6].

2. Model development and validation

The simulations of an industrial reactor reported in this article were based on the model developed by Stangeland [1]. Due to its simplicity and requiring only three parameters for optimization, it can easily be adopted for simulation of industrial problems. In this approach, component i cracks into lighter components, the first term in equation (1), and it is formed from heavier components, second term in equations (1). The heaviest component is assigned F_1 .Cracking rates are assumed to follow first order kinetics.

$$\frac{dF_i(t)}{dt} = -k_i F_i(t) + \sum_{j=i+2}^{i-1} P_{ij} k_j F_j(t) \quad (1)$$

The variable P_{ij} represents the probability of formation of the lighter product i from the cracking of the heavier component j. These set of equations, one for each component, can be written as a single matrix differential equation

$$\frac{d}{dt} F(t) = -(I - P) K F(t) \quad (2)$$

Where F(t) is the vector containing the weight fractions of all components, I is the identity matrix , P is the lower triangular product distribution matrix and K is the diagonal matrix having the k_i's on the diagonal. If all cracking rate constants are distinct, a simple solution to equation (2) can be used as

F(t) = DE(t) (3)

Where the time independent $D_{i,j}$ is given by:

$$D_{ij} = \sum_{m=j}^{i-1} \frac{k_m P_{im}}{k_i - k_j} D_{mj} \qquad for \;\; i > j$$

$$D_{ij} = F_i(0) - \sum_{m=1}^{i-1} D_{im} \qquad for \;\; i = j$$

$$D_{ij} = 0 \qquad for \;\; i < j$$

The following expression proposed by Stangeland [1] has been used for the cracking rate constant:

$k(T) = k_0[T+A(T^3-T)]$ (4)

Where T= TBP/1200 and k_0=1

The yield of butanes is estimated from the following expression and this yield is set by parameter C:

$[C_4] = C \exp[-0.00693(TBP_{feed}-250)]$ (5)

The heavier products are distributed from 50°F up to a point 100°F below TBP_{feed}. This range is normalized by the following expression:

$$y = \frac{TBP_{prod} - 50}{(TBP_{feed} - 100) - 50} \quad (6)$$

The liquid product distribution function chosen for use here is:

$PC(y) = [y^2+B(y^3 - y^2)](1-[C_4])$ (7)

The actual yield of any $50\,^oF$ interval is obtained by subtracting the value of P(y) at the beginning of the interval from that at the end.

yield = $PC(y_i) - PC(y_{i-1})$ (8)

The VGO feed to the hydrocracking unit with a specific gravity of 0.912 has the following ASTM D1160 distribution

IBP (^{0} C)	5%	10%	30%	50%	70%	90%	95%	FBP
316	365	377	411	430	453	479	490	502

Figure (1) shows a typical TBP distribution of the feed and product streams. Extensive plant data and Levenburg-Marquardt optimization algorithm were used to obtain the parameters A, B and C. Figure (2) show a typical optimization result. The objective function used for the optimization was:

$$F = \sum_{i=1}^{n} (y_{i(EXP)} - y_{i(model)})^2 \qquad (9)$$

Figure (3) shows comparison of plant data and simulation results for over a two year period. Tables (1) through to (3) also show the comparison between simulations and plant data.

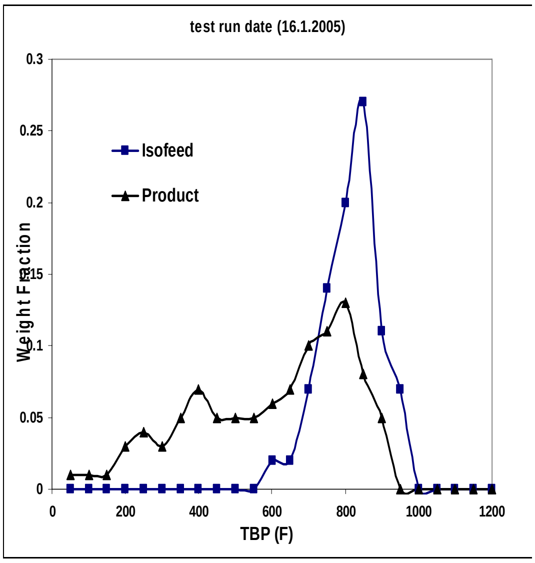

Figure 1.Isofeed and product TBP distributions

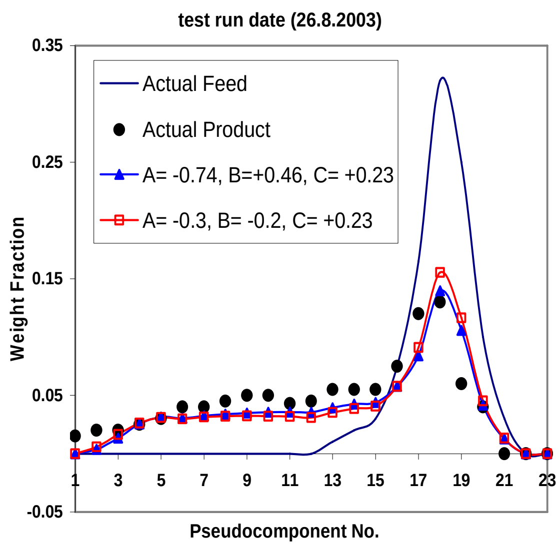

Figure 2. Effect of changing optimization parameters on simulation results

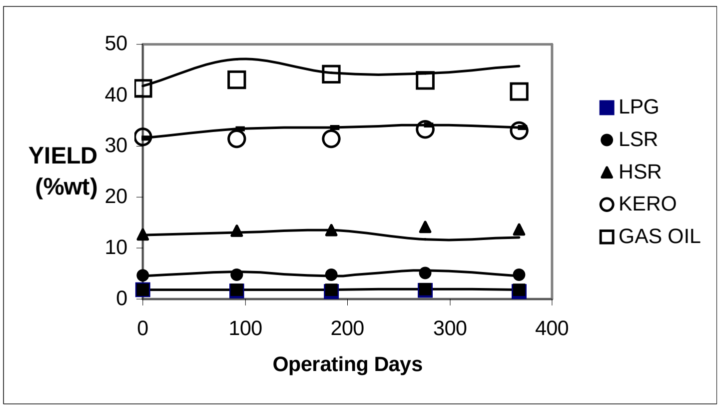

Figure 3. Comparison of plant data and simulation results for over a two years period

Table 1.Fresh feed rate = 164.6 m3/hr, recycle feed rate=109.8 m3/hr

	Actual	simulation	Error %
LPG	1.97	1.9	3.55
LN	5.85	5.65	3.42
HN	13.36	13.36	0.00
Kero	31.27	30.2	3.42
Diesel	44.86	42.86	4.46
Offtest	2.7	2.61	3.33

Table 2. 1 month later than data in Table (1), fresh feed rate = 164.4m3/hr, recycle feed rate=109.6 m3/hr

	Actual	simulation	Error %
LPG	2.17	1.94	10.60
LN	5.61	5.72	-1.96
HN	13.34	13.56	-1.65
Kero	32.92	30.51	7.32
Diesel	43.46	42.24	2.81
Offtest	2.51	2.42	3.59

Table 3. 2 month later than data in Table (1), fresh feed rate = 165m3/hr, recycle feed rate=110 m3/hr

	Actual	simulation	Error %
LPG	2.11	1.98	6.16
LN	5.82	5.84	-0.34
HN	13.43	13.83	-2.98
Kero	31.80	31.14	2.08
Diesel	42.58	41.31	2.98
Offtest	2.64	2.05	22.35

3. Maximizing naphtha and diesel yields

Catalyst vendors often provide an overall optimum operating reactor conditions to maximize product yields but usually a small fine tuning of operating conditions are still possible. In this section using the validated model the existing operating conditions of an industrial plant are optimized further to maximize yields of naphtha and diesel fractions. As the reaction conditions are fixed, a change in the recycle feed rate and catalyst loading are used to arrive at an optimum operating conditions.

Figures (4) to (6) show effect of changing recycle rate on the product yields. Increasing the recycle rate from the current value of 110 to 130 m^3/hr caused an increase in the diesel fraction yield and a decrease in Heavy naphtha yields. This means that the same catalyst loading more feed throughput is used and consequently heavier cuts such as diesel are produced more. LPG, light naphtha and kerosene yields are basically unaffected by the change in recycle feed rate.

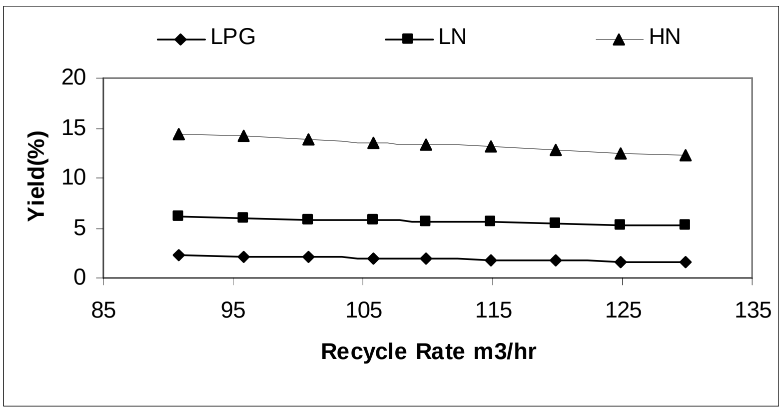

Figure 4. Effect of changes of the recycle rate on the yields of LPG, LN and HN

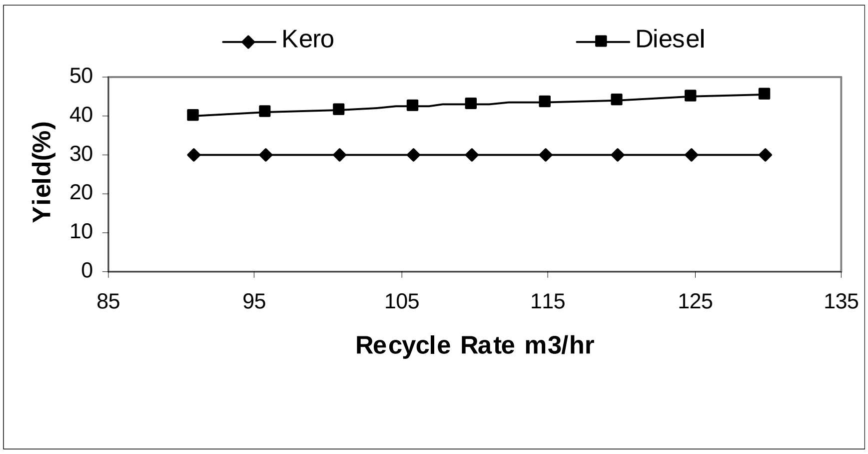

Figure 5. Effect of changes of the recycle rate on the yields of kerosene and diesel

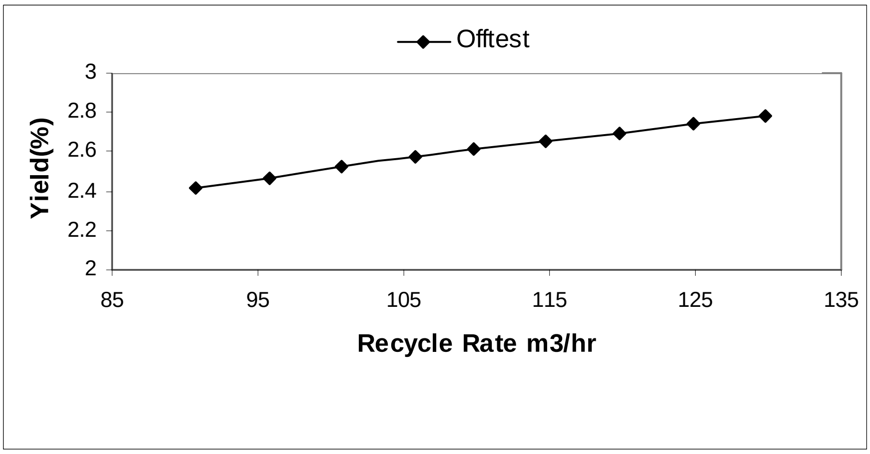

Figure 6. Effect of changes of the recycle rate on the yields of offtest

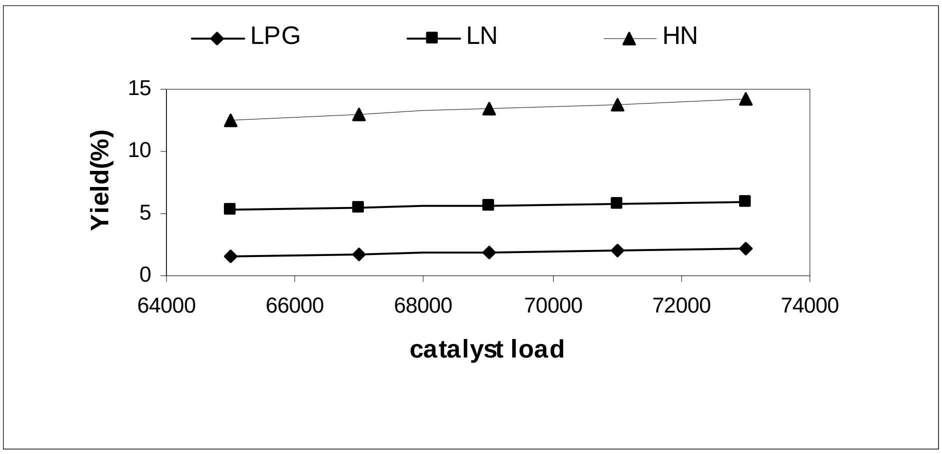

Figure 7. Effect of changes of the catalyst loading on the yields of LPG, LN and HN

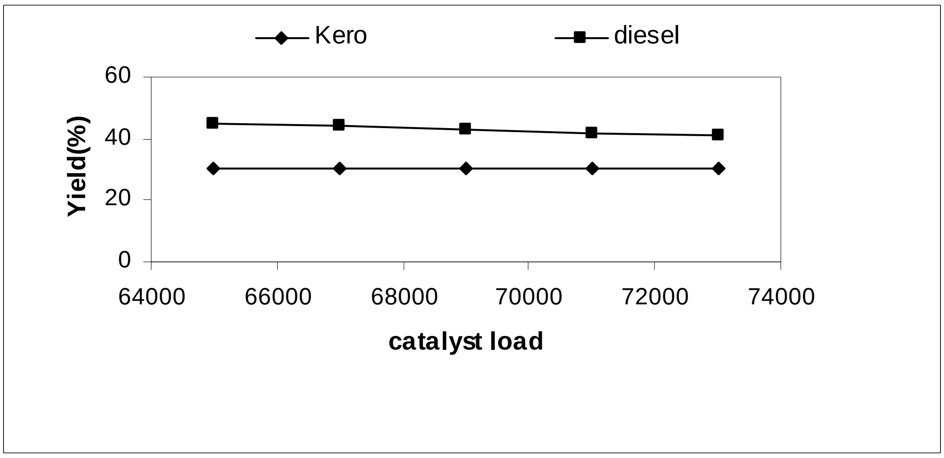

Figure 8. Effect of changes of the catalyst loading on the yields of kerosene and Diesel

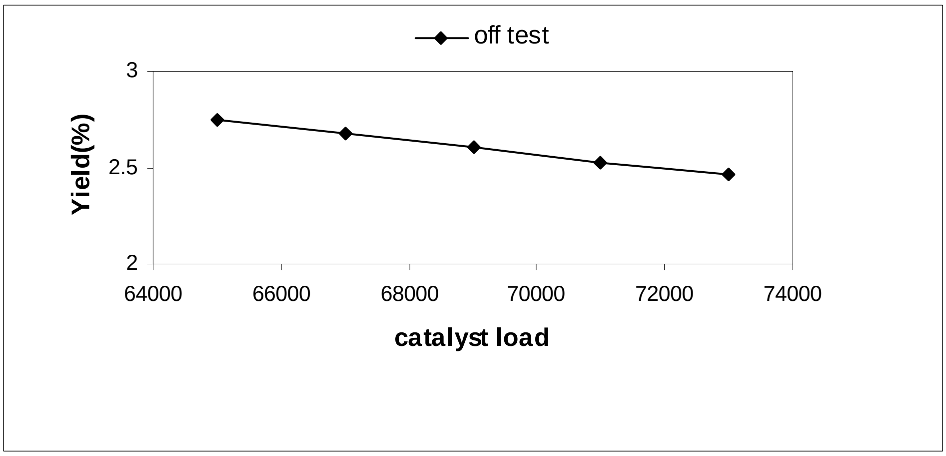

Figure 9. Effect of changes of the catalyst loading on the yields of offtest

Figures (7) to (9) show effect of increasing catalyst loading on the product yields. As more catalyst is available at a fixed throughput therefore more cracking is expected and it can be seen that from the existing loading of 69000 kg to 73000 kg heavy naphtha yield is increased whilst diesel production decreases.

4. References

[1] Stangeland, B.E., “Kinetic model for prediction of hydrocracker yields”, Ind. Eng. Chem. Proc. Des. Develop., 1974, 13(1), 72

[2] Laxminarasimahn, C.S., Verma, R.P., Ramachandaran, P.A., “Continuous lumping model for simulation of hydrocracking”, AIChEJ, Sept.1996, 43, No.9, 2645-2653

[4] J.Thybaut, G.B.Marin; "Production of Low Aromatic Fuels; Kinetics and Industrial Application of Hydrocracking";PhD Thesis; Ghent University;2002-2003

[5] Ancheyta, J., Sanchez, S., Rodriuez, M.A., “Kinetic modeling of hydrocracking of heavy oil fractions: A review”, Catalysis Today, 2005, 109, 76-92

[6] F.Y El-Kady;" Hydrocracking of Vacuum Distillate Fraction over Bifunctional Molybdenum-Nickel/Silica-Alumina Catalyst”; Indian Journal of Technology; vol.17, May 1979;pp 176-183