OPTIMUM HYDROGEN UTILIZATION KEY TO REFINERY PROFITABILITY

by

Jerome K. DeHey
Senior Staff Consultant

KBC Advanced Technologies Inc.
Parsippany, New Jersey

Abstract

In the not-so-distant past hydrogen was viewed as a fuel-value byproduct of catalytic reforming. Hydrogen production from the reforming unit was set by pool octane requirements and was subject to high season-to-season variability. On the other hand, hydrogen demand was always much less than production and relatively invariable.

This is not the case in the complex, highly integrated, refinery of today. The need to produce higher quality products from poorer quality crudes has led to an increased use of hydrotreating. With the addition of these new hydrogen consumers, hydrogen demands now generally exceed production. In these cases optimization of hydrogen utilization is key to the overall profitability of the refinery.

To fully optimize hydrogen utilization, additional capabilities must generally be added to existing planning and optimization tools. These tools must not only determine hydrogen and hydrocarbon routings, but individual unit operating severities which maximize profitability while maintaining the refinery hydrogen balance. Incremental benefits in excess of $ 0.15/BBL can be achieved by optimizing hydrogen utilization.

Introduction

The key to any refinery profit improvement program is to not only optimize the current operations within the prevailing constraints, but to weigh the costs of relieving those constraints against the benefits to be gained. In many cases, the costs of relieving a constraint may require little or no capital investment. Even with only modest gains, minimal investment initiatives can have very attractive payouts. In the current economic climate where the costs of capital are high, these type of initiative must be aggressively sought out and implemented.

Many of the initiatives directed at optimizing hydrogen utilization within the refinery are minimal investment initiatives. The purpose of this paper is to outline a procedure for optimizing utilization, and identifying minimal investment initiatives in this area for improving overall profitability.

Background

The importance of hydrogen addition to intermediate refinery streams has grown significantly in recent years[1][2][3]. Hydrotreating capacity is growing faster than any other refining process. The interest in hydrotreating, and hydrogen addition processes in general, has been stimulated by two factors.

Firstly, new, stricter, environmental regulations on transportation fuels require higher quality refinery products[4]. In most cases, hydrotreating is the most cost-effective process for achieving the required product quality improvements.

Secondly, the price spread between light and heavy crudes continues to grow as light crude reserves are replaced by new heavy crude discoveries. Refiners are taking advantage of these spreads by slowly replacing the light crudes in their slates with cheaper, heavier, more sour, opportunity crudes (See Figures 1 and 2). These heavier crudes are more deficient in hydrogen. Therefore, to produce the same yields of transportation fuels, either more carbon must be rejected, or more hydrogen must be added. In actuality, even with the addition of incremental carbon rejection process capacity, some additional hydrogen addition process capacity will be required.

Growing Hydrogen Demand Requires Additional Hydrogen Supply Options

With the growth of hydrogen addition processing capacity, the need for additional hydrogen supply options has increased. In the simple, skimming refinery of the past, the quantity and quality of hydrogen produced in the catalytic reforming process exceeded the minimal hydrotreating demand required for transportation fuel production. Modest gains in catalytic reforming technology have indirectly yielded more hydrogen for hydrotreating. Unfortunately, these modest gains have been easily outpaced by the growing demand for hydrogen. With rare exception, hydrogen demands in a modern, complex refinery far exceed the hydrogen production from the catalytic reforming unit.

To balance hydrogen demands, a number of hydrogen production options are available. The most popular has generally been steam reforming[6]. However, a number of alternate technologies for hydrogen production[7] such as partial oxidation are gaining in popularity. In the US gulf coast hydrogen is even available by pipeline.

Regardless of the source of incremental hydrogen, its cost will almost certainly exceed its fuel value. Even the cost of producing incremental hydrogen from catalytic reforming can exceed its fuel value if the catalytic reforming unit feedrate and/or severity must be raised above the levels needed to meet downstream blending requirements within prevailing marketing constraints.

Ability to Adjust Hydrogen Supply and Demands Offers Opportunity For Optimization

The hydrogen demands within a refinery are dynamic. Demands can vary by shifting crude slates, intermediate stream re-routing, unit shutdowns and operating condition adjustments on hydrogen addition units as well as upstream processing units. With the ability to vary the incremental hydrogen supply and demands, comes the opportunity to optimize the overall profitability of the refinery. Depending upon the incremental costs of hydrogen, and the flexibility to vary demand, potential benefits in excess of $ 0.15/BBL can be realized.

Sophisticated Tools Required to Estimate Costs/Benefits

To adequately estimate the costs and benefits of the array of options available for adjusting the hydrogen supply and demands, sophisticated predictive tools are required(8). These tools must be able to track the effects of processing changes from the point of the change, through downstream processing and product blending. These tools must factor in changes in the refinery fuel, hydrogen, steam and energy balances simultaneously to insure that all the options are feasible within the refinery infrastructure constraints.

KBC's PETROFINE^{SM} refinery flowsheeting program is one such tool developed to meet the most rigorous demands of refinery simulation and optimization. PETROFINE^{SM} carries the effects of processing changes onto downstream units by maintaining a matrix of information on all intermediate streams. This matrix contains as many as 25 physical and chemical properties on each of 75 pure and pseudo components. Additional properties are estimated by proprietary correlations using the 25 properties stored on each intermediate stream.

PETROFINE^{SM} has been used to simulate some of the most complex refineries in the world. The individual process models are rigorous and non-linear. PETROFINE^{SM} can be used directly to evaluate the effect of single or multiple process moves. Alternately, PETROFINE^{SM} can be used to generate vectors to represent various processing options of interest in an existing LP model of the refinery.

Step One: Optimize Base Operations

Before evaluating initiatives for optimal utilization of hydrogen, one must optimize the current operation. As with any non-linear optimization, initiatives which show net incentives from a non-optimized base, will not necessary show net incentives, or the same levels of net incentive, off of an optimized base operation. Also, in the evaluation stage as incentives are ranked and considered for implementation, benefits need to be re-evaluated for various combinations of initiatives. This information will determine which initiatives interact in a positive way, and which incentives interact in a detrimental way.

Minimize Product Quality Giveaway

One item that could be investigated in this step would be product quality giveaway. Frequently, units are operated well above the severity required to meet final product pool specifications. This practice can be as a result of miscommunication, infrequent monitoring, inadequate predictive tools or excessive conservatism. The amount of hydrogen "wasted" due to overtreating can be quite significant. For example, the incremental severity required to hydrotreat a diesel product to 250 wppm, versus a specification of 500 wppm, would consume 100 SCF/BBL more hydrogen. In addition, this higher severity level would hydrocrack valuable products into less valuable gas, accelerate catalyst deactivation and lower recycle gas purity.

Eliminate Purging of High Purity Hydrogen

Another item that must could be investigated in this step would be purging of high purity hydrogen to the fuel system, or worse the flare. High purity hydrogen could be purged to the fuel system though a number of routes.

- To control pressure on hydrogen header or producing unit. To eliminate this, make-up rates at the various hydrogen consumers should be increased until the purge valve is essentially closed. This will increase the high pressure purges in the consuming units, but the high pressure purges will be lower in purity. As a result of increasing the make-up to the consuming units, the treat gas purity in each of these units will generally be increased. Increased treat gas purity will allow severity to be reduced and lengthen catalyst runs.

- To control pressure on reformer feed surge drum. Due to a leaking pressure control between the surge drum and the fuel system, a significant quantity of hydrogen can be lost directly to fuel, or the flare. Testing is required to determine if there is a problem. If there is, then the valve should be replace as soon as possible, obviously.

Step Two: Rank Initiatives By Net Hydrogen Value

We assume that a complex refinery has enough current hydrogen demand, plus estimated additional demand for initiatives being considered (with positive net benefits for hydrogen valued as fuel) to exceed the minimum hydrogen production rate. In addition, we assume that hydrogen production can be reduce at at least one source and increased at at least one source. Given these assumptions, the refinery will always be in hydrogen balance and no hydrogen will need to be purged directly to fuel, or flare.

Since we have assumed that there will always be a mechanism for increasing or reducing hydrogen production, and thereby balancing hydrogen at all times, all initiatives which compete for additional hydrogen must be ranked according to the net value of the incremental hydrogen consumed. To do the ranking we start by estimating the gross benefits of each initiative per incremental barrel of feed to the downstream hydrotreating unit. The gross benefits can include operating costs, but generally will not have additional catalyst costs factored in at this stage. For these estimates, incremental hydrogen will be based on its fuel value. As discussed earlier, a simulation program such as PETROFINE℠ must be used for these estimates because effects on downstream units, blending, fuel balance, etc. must be accounted for in these estimates.

Once gross benefits have been estimated, the effect of each initiative on catalyst costs must be factored into the estimates. This can be done by estimating the effect of the incremental feed to the hydrotreating unit on the catalyst runlength relative to the base feed to each unit. Next the incremental catalyst costs for one additional barrel of the base feed to each hydrotreating unit must estimated. All these estimates can be done using tools external to the simulator, or calculated and added into the estimates by the simulator. In all cases, the simulator must be capable of estimating the qualities of incremental feeds to each hydrotreating unit, for each initiative.

Finally, the value of incremental hydrogen for each initiative is estimated by subtracting incremental catalyst and operating costs from the gross benefit estimates. Then this net benefit per barrel of increment feed to the effected downstream hydrotreating unit is divided by the incremental hydrogen consumption per barrel of incremental feed. The result is the value of incremental hydrogen consumed, or not consumed, by this initiative.

If more than one downstream hydrotreating unit is affected, one of the units is chosen as the base. Net benefits, operating costs, catalyst costs and incremental hydrogen consumption estimates are based on one barrel of incremental feed to that base hydrotreating unit.

Step 3: Rank Hydrogen Producers

In the same manner that initiatives which consume incremental hydrogen are ranked, initiatives that produce incremental hydrogen can be ranked per SCF of incremental hydrogen produced. Again, incremental operating and catalyst costs must be factored into the estimates.

Final Step: Determine Initiatives to Implement

After the values and costs of incremental hydrogen have been estimated. Initiatives can begin to be implemented in order of the incremental value of the hydrogen, for the initiatives consuming incremental hydrogen, and incremental cost of hydrogen, for the initiatives which produce incremental hydrogen. The hydrogen balance must be maintained at all times by implementing a hydrogen producing initiative to balance the hydrogen consumed by the hydrogen consuming initiative.

If there were no interactions between the initiatives, then initiatives would be implemented as long as the incremental cost of producing hydrogen was lower than the benefits from the initiative which increase hydrogen consumption. If interactions exist, the analyses in steps 3 and 4 must be repeated after each hydrogen consuming initiative, and corresponding hydrogen producing initiative to balance the hydrogen, is implemented.

Example of Initiatives Effecting Cat Feed Hydrotreater

Table 1 contains an example of several initiatives which effect the cat feed hydrotreating unit (CFHT) in a hypothetical refinery. This refinery processes both a sour crude and a sweet crude in blocks. It contains a coker, FCCU, catalytic reforming unit and distillate hydrotreating unit, in addition to a cat feed hydrotreating unit. In this example, incremental hydrogen was being purged to fuel. Therefore, in this case the incremental cost of hydrogen was its fuel value.

The gross benefit estimates listed in column A of Table 1 were calculated using a PETROFINE^{SM} simulation of the refinery. PETROFINE^{SM} was also used to estimate the qualities of the incremental feeds to the CFHT unit. This information was then used in a series of spreadsheet programs to calculate the incremental hydrogen consumptions and relative catalyst deactivation rates used in the incremental catalyst cost estimates.

References

1. Krenzke, L. D., Kennedy, J. E., Baron K., Skripek, M., “Hydrotreating Technology Improvements For Low-Emissions Fuels”, AM-96-67, 1996 NPRA Annual Meeting, March 17-19, 1996.

2. Stanger, C. W., Fletcher, R., Johnson, C., Reid, T., “New Process Technology Already Existing in Your Refinery: Hydroprocessing-FCC Synergy”, AM-96-66, 1996 NPRA Annual Meeting, March 17-19, 1996.

3. Rhodes, A. K., “Distillation Capacity Exceeds 76 Million B/D, Hydrotreating Surges”, OGJ, December 23, 1996, 41-48.

4. Krambuhl, C. J., “Gasoline & Diesel Fuel - Where We Are and Where We’re Going”, AM-96-20, 1996 NPRA Annual Meeting, March 17-19, 1996.

5. Speight, J. G., Chemistry and Technology of Petroleum, 2nd Edition, Marcel Dekker, New York, 1991.

6. Abrardo, J. M., Patel, N. M., Davis, R. A., Sekhri, S., Bredehoft, R. L., “Steam Reforming-- A Flexible Solution to Refiners’ Hydrogen Requirements”, AM-93-23, 1993 NPRA Annual Meeting, March 21-23, 1993.

7. Plummer, M. A., “The HYSULF^{SM} Process A Valuable Hydrogen Resource From Hydrogen Sulfide”, AM-95-21, 1995 NPRA Annual Meeting, March 19-21, 1995.

8. Kleinschrodt, F., Edwards, L. A., White, D. C., Haydel, J. J., “Refinery Process Optimization: Maturing Technology Creates New Business Opportunities”, AM-95-12, 1995 NPRA Annual Meeting, March 19-21, 1995.

FIGURE 1

Crude API - Historical Data

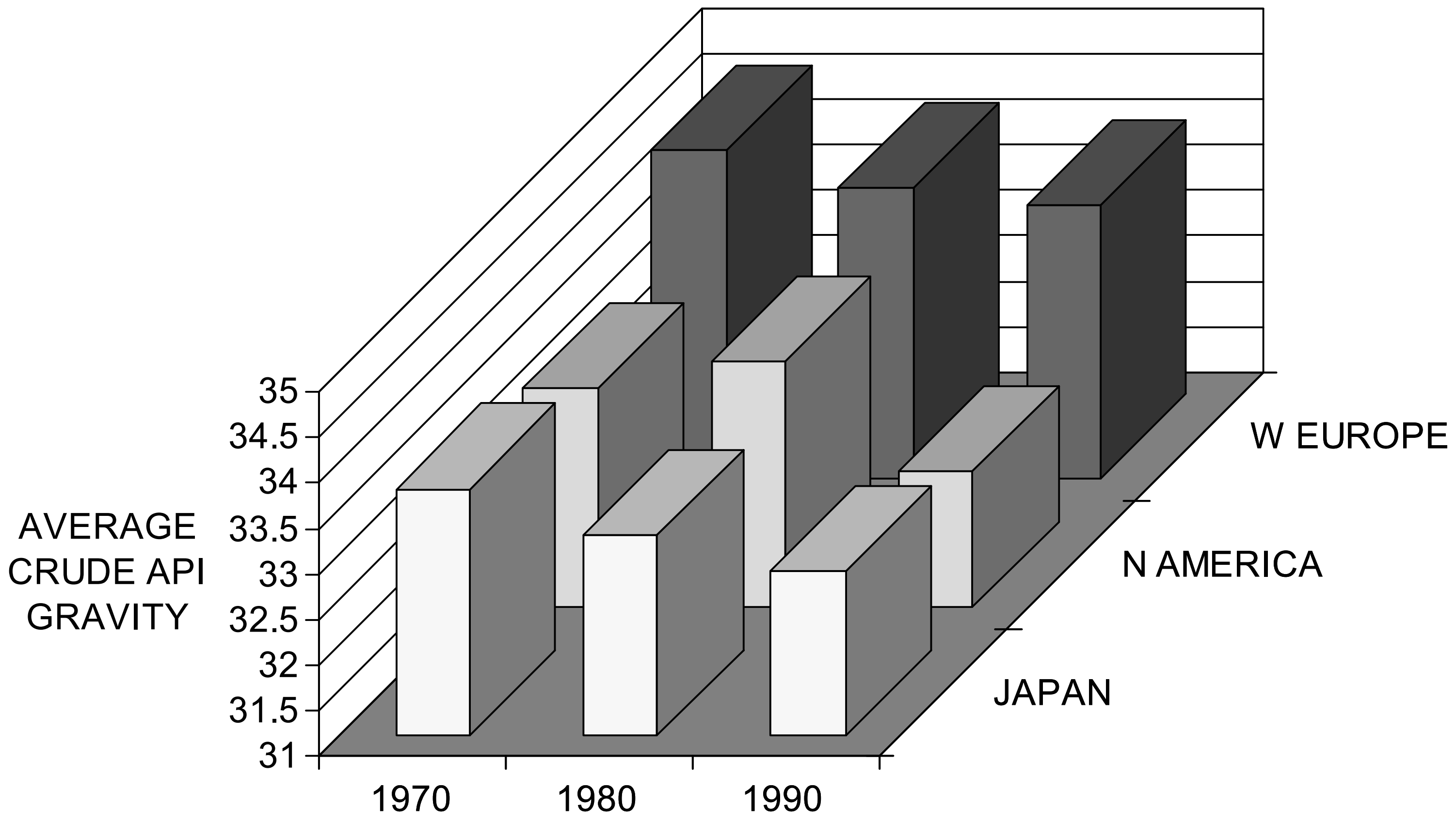

FIGURE 2

Crude Sulfur - Historical Data

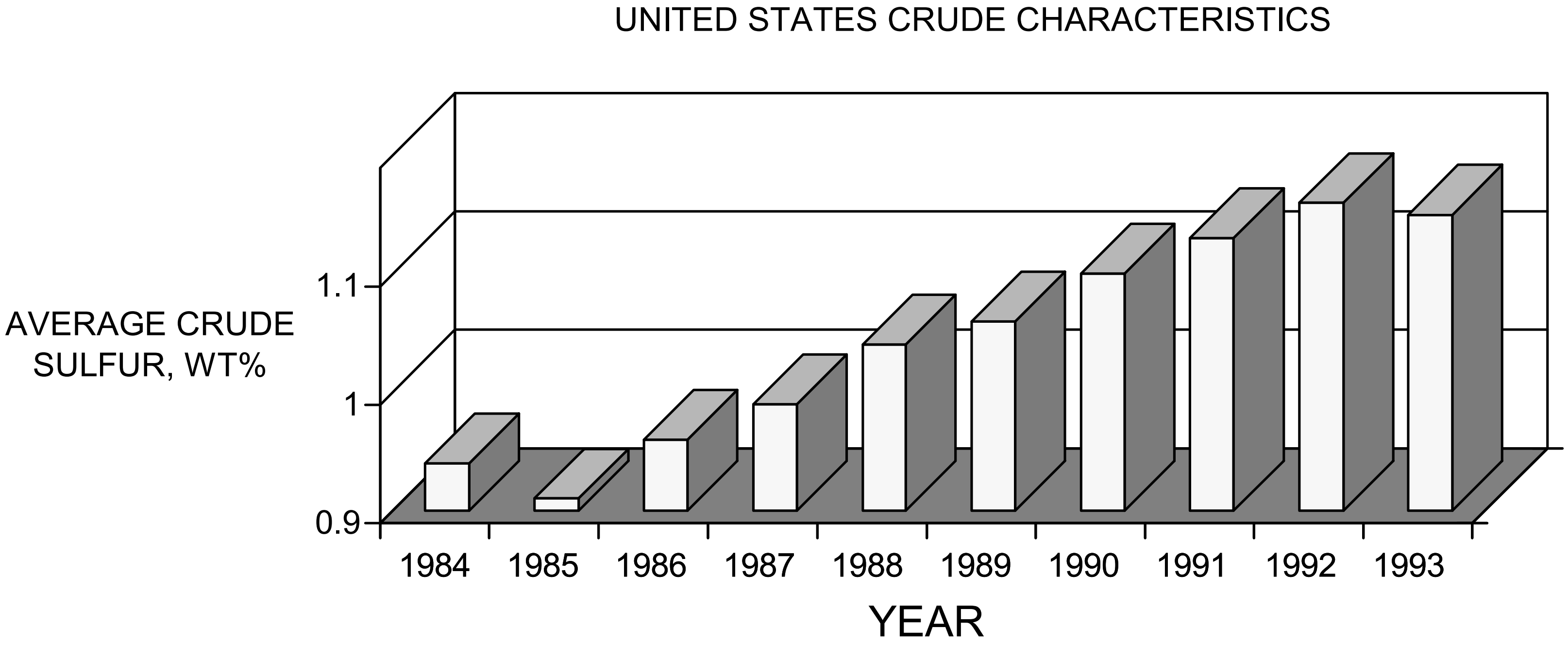

TABLE 1

Data For Example Problem

Initiative	A Gross Margin, $/B	B Operating Costs, $/B	C Relative Deactivation Factor, B-Base/B	D = C X 0.10 Catalyst Costs, $/B	E = A - B - D Hydrogen-Free Margin, $/B	F Hydrogen Consumption, SCF/B	E/F Marginal Hydrogen Value, $/KSCF
1. Reduce Coker CFR (Raise Recycle Cutpoint)	7.34	0.20	2.68	0.27	6.87	483	**14.23**
2. Increase Vacumn Cutpoint	3.17	0.20	10.51	1.05	1.92	418	**4.59**
3. Increase CFHT Severity 30°F	1.31	0.00	2.0	0.10	1.21	173	**6.99**
4. Hydrotreat Sweet HVGO	0.38	0.20	1.01	0.10	0.08	123	**0.65**

Notes:

B = Barrels to CFHT

B-Base = Barrels to CFHT in base