Volver

Shell Global Solutions

ARE YOU SITTING ON UNTAPPED POTENTIAL? HOW LATEST-GENERATION REACTOR INTERNALS CAN BE USED TO ENHANCE PROFITABILITY

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1. ABSTRACT

Reactor issues such as thermal maldistribution and high pressure drop are indicators that a refinery may be failing to capture the maximum value from a hydroprocessing unit.

Fortunately, a low-cost revamp involving the installation of the latest-generation reactor internals can usually address such issues. These include high-dispersion trays, which help to prevent thermal maldistribution by achieving near-perfect wetting and ultra-uniform utilisation of the catalyst, anti-fouling trays designed to reduce pressure drop buildup, quench internals for uniform process and quench mixing at the interbeds, catalyst support grids, ultra-low bottom baskets and speciality devices to accommodate the elevations that may be required for bed optimisation.

When installing the latest-generation reactor internals, there are often opportunities to capture additional value. For instance, depending on the axial temperature gradient, it could be possible to combine beds to increase catalyst uptake. And, when the quenches, bottom baskets and filter trays are designed to occupy minimal reactor volume, they can enable more catalyst to be loaded into the reactor. This can be used to help extend the catalyst cycle life, lower the weighted average bed temperature (WABT), increase the throughput or process heavier, less-expensive feedstock, which results in a higher margin. In some cases, the unit yields can be redefined for better economics.

In addition, some latest-generation reactor internals are designed for fast removal and installation, which can help to increase days on stream and can be worth significant revenue. There also are safety advantages, such as far less confined space residence time, because cutting and welding are not required and manways are large to enable fast entry and exit. In some cases, no inert entry is required to get access to the bed.

This paper will discuss many of the most common issues encountered in a hydroprocessing reactor and, through the inclusion of case studies, explain how the latest-generation reactor internals can help to resolve them.

2. INTRODUCTION

2.1. Could latest-generation reactor internals unlock additional value for you?

Reactor issues such as thermal maldistribution and high pressure drop are indicators that a refinery or petrochemical plant may be failing to capture the maximum value from a hydroprocessing unit or other fixed-bed catalytic reactor. Fortunately, a low-cost revamp involving the installation of latest-generation reactor internals can often help to address such issues.

If you have a need to…

- meet tighter product specifications
- process more difficult feeds
- increase capacity
- enhance profitability
- improve safety
- extend cycle length
- reduce turnaround times

Or if you have experienced any of the following in your reactor…

- high pressure drop
- bed fouling
- thermal maldistribution
- short cycle length
- high WABT
- reliability issues

…then installing latest-generation reactor internals could help to unlock additional value.

2.2 Value estimates: what new reactor internals could be worth to you as an operator

Despite the important role that reactor internals play, many refineries continue to use conventional or bubble-cap distribution trays in their hydrocrackers. In doing so, they may be failing to capture the maximum value from their units. Some of the potential benefits of installing state-of-the-art reactor internals are quantified below.

a. Increased cycle life

Latest-generation reactor internals may enable fewer interim shutdowns between major turnarounds. Based on an upgrade margin of \$20/t in a typical diesel hydrotreater, the potential value for a 100-t/h unit that has a total shutdown time of 14 days is, therefore, \$670,000.

b. Processing higher-margin feeds

Increased catalyst utilisation enables increased feed severity while achieving the same cycle length. Assuming that the light cycle oil upgrade margin is \$50/t more than the gas oil upgrade margin, the potential value of increasing the proportion of light cycle oil by just 5% in a 100-t/h unit is some \$2.2 million per year.

c. Improved product quality

Installing latest-generation reactor internals can help to improve most product properties, including cetane, density, cold flow and viscosity index, through increased effective catalyst utilisation.

d. Better hydrocracker product yields

Latest-generation reactor internals may enable a higher selectivity catalyst to be installed to produce higher volumes of valuable middle distillates. Based on a $100/t naphtha–diesel spread, the potential value for a 200-t/h unit is about $3.5 million per year.

e. Shorter turnaround times

Latest-generation reactor internals that are designed for easy access and fast removal and installation could save two days per turnaround. Based on an upgrade margin of $20/t in a typical diesel hydrotreater, the potential value for a 100-t/h unit is, therefore, $96,000 per turnaround.

f. Enhanced safety

There are major safety benefits when reactor internals do not require cutting and welding as power tools, welding equipment and hot-work permits are not required. In addition, some licensors maximise the size of the manways to enable fast entry and exit, and relatively easy removal of personnel in the case of an emergency.

3. DEVELOPMENT

3.1 Preventing common reactor issues

3.1.1 Preventing bed fouling

A consequence of the trend toward processing increasingly difficult feeds is that there may be an increased tendency for fouling. Conventional backwash filters and fouling abatement measures can often fall short of resolving the challenges presented by heavier feeds.

The impact of fouling on a hydroprocessing unit's performance can be costly. When contaminants build up on the surface of the catalyst, a layer of fouling particles can form, which leads to a sharp increase in the reactor's pressure drop that limits the unit throughput (feed pump and compressors bottleneck). Moreover, this can also cause residual build-up to loosen and flow through the reactor, thereby further decreasing performance.

Well-designed filter trays and scale-catching trays can help to reduce bed fouling. They may offer additional filtering capacity by trapping contaminants and sediments, and have the benefit of enabling a higher catalyst loading capacity by minimising the height of the top-bed grading layers. In addition, some are designed for feeds that contain high amounts of impurities.

Limiting fouling can also help to minimise turnaround times, which is a major concern for any refiner. Less fouling has the benefit of a shorter catalyst unloading time, as catalyst beds that are not heavily fouled are easier to unload.

Proof point: As shown in Figure 1, when a North American refinery revamped the guard reactor of a hydroprocessing unit by installing a Shell filter tray, the pressure drop fell substantially, despite the increase in iron sedimentation.

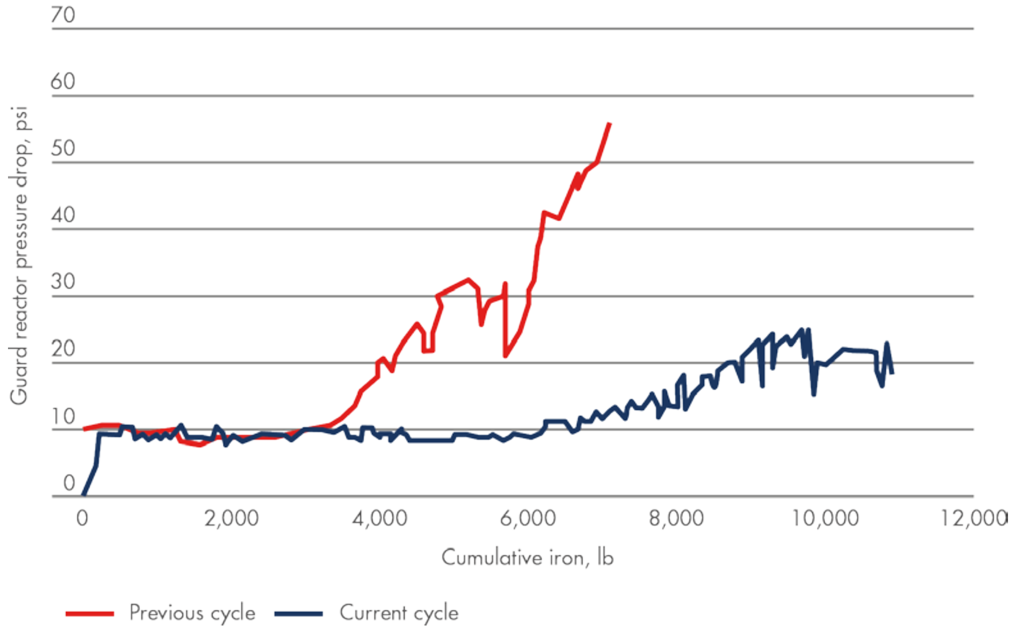

Figure 1: When a Shell filter tray was fitted to the guard reactor, the pressure drop fell substantially.

3.1.2 Increasing catalyst utilisation and cycle length

Have you ever experienced thermal maldistribution or a reduced cycle length in your reactor? These issues can severely affect profitability. The cause is likely to be suboptimal distribution.

Conventional distribution trays, even advanced bubble-cap designs, are notorious for low uniformity of vapour–liquid distribution and undesirable radial temperature maldistribution.

Modern trays feature customised nozzles that use the gas flow momentum to disperse the liquid as a mist. Unlike conventional downcomers or bubble caps, the nozzles uniformly wet the entire catalyst surface and make very efficient use of the upper layers of the catalyst bed (Figure 2).

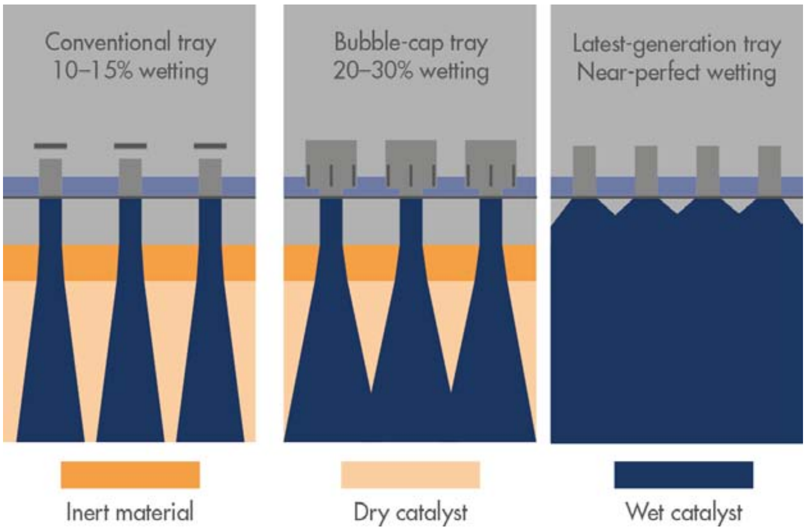

Figure 2: Some modern trays are designed to optimise catalyst utilisation by achieving enhanced vapour–liquid and thermal distribution. These trays can be extremely efficient; some enable nearly 100% of the catalyst inventory to be utilised and offer high feed rate flexibility.

By using the latest-generation trays, some refiners have doubled their cycle lengths. These increased cycle lengths are made possible by a lower WABT, the lower inlet temperatures required to produce high-specification products and improved thermal distribution.

Proof point: Operations at a hydrocracking unit were being hampered by liquid–vapour maldistribution in Bed 1. This resulted in major thermal maldistribution that was transferred to Bed 2 owing to the poor performance of a conventional interbed internal. As shown in Figure 3, when the original bubble-cap distribution tray at the top of Bed 1 was replaced with a Shell high-dispersion (HD) tray, the radial thermal maldistribution in both beds was virtually eliminated. The average radial temperature difference at the bottom of Bed 1 dropped from 10.6 to 1.6°C and from 8.0 to 2.4°C at the bottom of Bed 2.

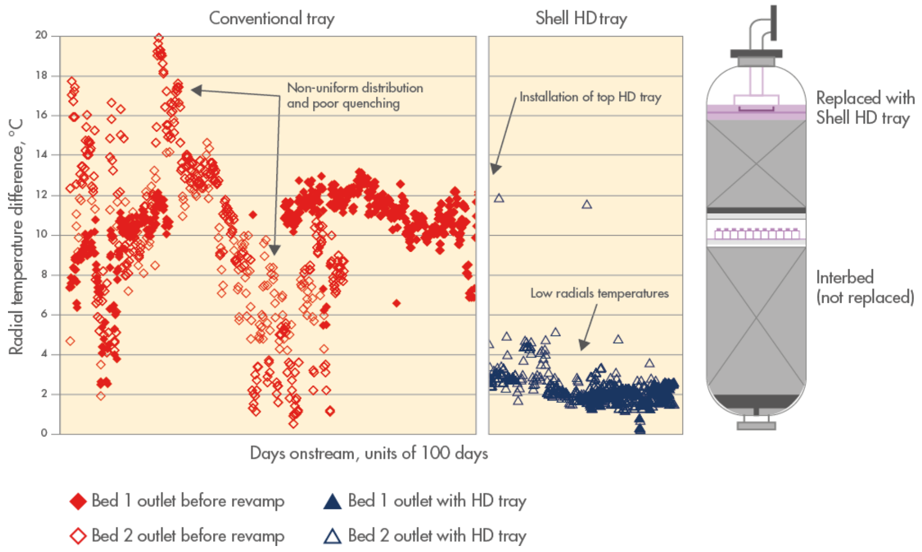

Figure 3: The radial temperature differences at the bed outlet before and after retrofitting a Shell HD tray above the top bed.

3.1.3 Achieving uniform quench mixing

Uniform heat distribution throughout the reactor is imperative for optimum catalyst utilisation and some of the latest-generation quenches can provide discrete mixing of the gas and liquid phases with a consistent performance independent of the quench load. In addition, some feature an ultra-flat design that supports another key objective: maximising the reactor volume that is available for catalyst loading.

Because more catalyst can be loaded into the reactor, refiners can benefit in several ways. For instance, they can increase cycle lengths, throughput and conversion rate. Alternatively, they can use the extra catalyst to achieve tighter product quality specifications for sulphur, boiling point, density, cetane and cold flow properties.

Proof point: When a refiner installed Shell ultra-flat quench (UFQ) interbed internals, the radial temperature maldistribution was substantially reduced, as shown in Figure 4.

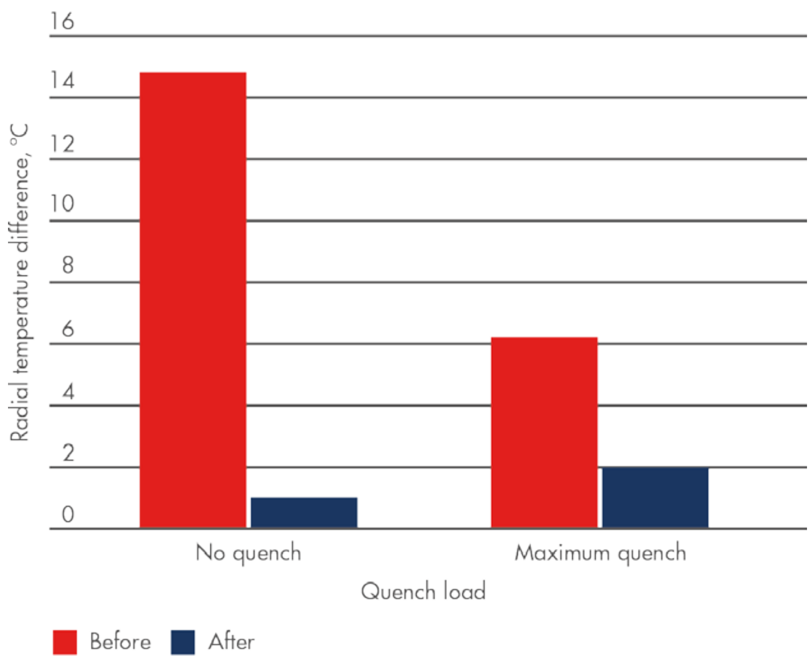

Figure 4: Radial temperature maldistribution before and after retrofitting with Shell UFQ interbed internals. These provide high quench efficiency and drastically reduce radial temperature maldistribution, regardless of the quench flow rate.

3.2 Increasing catalyst volume and utilisation

When replacing conventional reactor internals with next-generation hardware, refiners could benefit from (a) an increase in the volume of catalyst that can be loaded into the reactor and (b) improved utilisation (close to 100% can be achieved) of the catalyst.

Enabling more catalyst to be loaded into the reactor, and using almost 100% of the loaded catalyst, provides refiners with options to generate more margin. The increase in catalyst utilisation can be used to either extend the catalyst cycle life or process heavier, less-expensive feeds, both of which can result in higher margins.

3.2.1 Increasing catalyst volume

Every hydroprocessing reactor vessel must give up a certain percentage of the available reactor volume to reactor internals at the expense of the catalyst load. However, the proper selection and design of the reactor internals can help to maximise the mixing of the reactants (gases and liquids) and enable efficient use of the catalyst.

The poor selection and design of reactor internals can lead to significant underutilisation of both reactor volume and loaded catalyst. Because reactor internals may occupy reactor volume that could otherwise be filled with catalyst, there are continuing efforts to minimise the size of the internals or, where possible, to remove the need for them.

Some questions to ask of your reactor internals:

- Are the filter trays installed in the empty space of the upper dome? If not, up to 1 m of grading material used for fouling abatement could be replaced by catalyst.
- Do the internal skirts enable the top trays to be relocated higher in the reactor? If not, the catalyst could be loaded closer to the tangent line.
- Do the trays use distributive grading material? If so, the volume of catalyst that can be loaded may be suboptimal.
- Is the bed-to-bed distance less than 1.4 m? If not, the reactor volume utilisation for catalyst loading may be able to be increased.
- Do the catalyst support grids extend upward into the catalyst bed? If not, there may be opportunities to reduce the interbed spacing.

3.2.2 Increasing catalyst utilisation

Poor feed distribution can cause hot or dry spots in the catalyst bed due to poor catalyst utilisation, which leads to part of the catalyst inventory being overutilised while the remainder is underutilised. Liquid maldistribution and catalyst underutilisation can have severe negative impacts on the overall unit performance.

For instance, the WABT may have to be increased to achieve the desired product qualities. In a hydrodesulphurisation unit, the focus may be on reducing sulphur content, improving cold flow properties or reducing density. Reducing sulphur content would likely also be key in a hydrocracker, along with reducing nitrogen and metals content, and increasing selectivity towards middle distillates.

Alternatively, the catalyst deactivation rate may increase because of higher severity operation with a reduced effective catalyst volume. Radial thermal maldistribution may increase, which could result in: the premature enforcement of the reactor's thermal limits, a shorter cycle length, increased catalyst consumption or increased unit downtime.

Maximum catalyst utilisation can only be achieved if the gas and liquid reactants are uniformly volumetrically and thermally distributed before they are introduced into the top of each catalyst bed.

The latest-generation reactor internals can help maximise catalyst utilisation because:

- trays that incorporate proprietary nozzles can provide enhanced vapour–liquid and thermal distribution. Using conventional bubble caps and sieve trays as feed distributors typically achieves only 85% effective utilisation of the catalyst.
- quench internals are available that provide near-perfect mixing of process liquid and gas, and quench medium between the beds, while using minimum reactor volume.

3.3. Ease of installation, maintenance advantages, reduced shutdown time and enhanced staff safety

There may be opportunities for significant reductions in shutdown times because the latest reactor internals are designed to eliminate the need for cutting and welding, and to make catalyst loading and unloading easier and faster.

Latest-generation reactor internals are designed to reduce the time required for confined space entry to at least a quarter of the time generally taken when compared with older hardware. This is because they are quicker to open, clean, inspect and close. In some cases, the confined space entry requirements of a unit have been greatly reduced, especially where a multiple bed reactor unit has been redesigned into a single-bed reactor.

In addition, latest-generation reactor internals are designed to have the largest possible manways to enable people to move very quickly through the trays and quenches, which is particularly important in the case of a serious incident. For example, the larger manways facilitate faster recovery of an unconscious person from the reactor.

Moreover, some licensors are designing them to reduce the need for hot work in the reactors by enabling them to be installed without welding and opened and closed using just a hammer.

3.4 Case studies

These case studies show how operators have achieved their business objectives through the installation of state-of-the-art reactor internals.

3.4.1 How Petrobras leveraged latest-generation reactor internals to produce clean fuels and increase capacity

Petrobras, Brazil's state-owned oil company, needed to adapt its units to make 10-ppm sulphur diesel. It was also vital for the refiner to increase its refining capacity. The organisation's response included a plan to revamp an existing, moderate-pressure diesel hydrotreater at its Paulínia refinery for ultra-low-sulphur-diesel service. The unit, which has two reactors in series, was originally designed to produce 500-ppm sulphur diesel at a feed rate of 5,000 m^3/d. Petrobras' objectives were to revamp the unit to produce 10-ppm sulphur diesel and to increase its capacity.

Technologists from the refinery and Petrobras's technology arm joined forces with catalyst and process experts from Shell Global Solutions and Criterion to investigate solutions. The team found a way to achieve the objectives, which was a drop-in solution that involved Shell reactor internals in combination with a new state-of-the-art Criterion catalyst. In less than six months, the reactor internals were designed and manufactured.

This enabled the refinery to increase the loaded catalyst volume by 19% without increasing the total reactor volume, which helped to increase the unit's capacity to 6,000 m^3/d. Not having to change the reactor was a significant capital saving. Another benefit was that the time to achieve the increased capacity and margin by revamping was much less than it would have been to build a new unit, being less than two years from the time of the first evaluation. All the modifications were also completed in the normal turnaround period of just over a month.

3.4.2 How latest-generation reactor internals helped to debottleneck a Total hydrocracker

After two hydrocracker cycles that were challenged by pressure drop, reliability issues and short cycle lengths, the technologists at the Total refinery in Normandy, France, asked Shell Global Solutions and Criterion to help resolve these issues.

The unit was not a Shell design but it was imperative that Total addressed the root cause of its problems, as it also needed to increase the hydrocracker capacity to produce more valuable middle distillates.

The single-reactor hydrocracker originally featured six catalyst beds. The first four were to pretreat the feed to remove nitrogen, sulphur and aromatics, and the last two beds hydrocracked the intermediate product into ultra-low-sulphur diesel, kerosene and naphtha.

Working closely with Total, Shell Global Solutions and Criterion identified reasons why the unit was not achieving its targeted cycle length: one of these was a high radial temperature spread over the pretreatment catalyst beds. This is common when conventional distribution trays are used. The combination of higher radial temperatures and the higher deactivation rate caused by the lower feed quality resulted in an unpredictable and hard to manage cycle length.

Installing Shell reactor internals helped to resolve these issues. In addition, beds 2 and 3 were combined. Because one set of interbed internals could be omitted, much more catalyst could be loaded into the reactor.

3.4.3 How Preem used latest-generation reactor internals to prevent thermal maldistribution

Preem operates a single-stage, two-reactor, 142-bar, 53,000-bbl/d hydrocracker at its 220,000-bbl/d Preemraff Lysekil facility in Sweden. Studies showed, however, that only about 85% of the two reactors' catalyst volume was being utilised owing to maldistribution.

Thermal maldistribution in the pretreatment and cracking reactors is a common issue that can cause performance-limiting hot spots and dry areas. In an effort to boost the utilisation of the catalysts, Preem's technologists called on catalyst vendors to propose their best catalyst option and reactor internals to help solve this problem.

The proposed solutions were then tested competitively, back to back, at an independent pilot-plant testing laboratory. After successful testing, Preem implemented a solution involving Shell reactor internals and Criterion catalyst.

The new internals increased the amount of catalyst that could be loaded into the reactor by 10% and, because of the improved dispersion, nearly 100% of the catalyst is now used. In addition, their quick-to-open-and-close design also means that the time spent on any future maintenance of the new reactor internals will be cut down for more onstream days for the hydrocracker.

4. CONCLUSIONS: ARE YOU SITTING ON UNTAPPED POTENTIAL?

If you answer "yes" to any of these questions…

- ***Has your reactor shown signs of fouling, high pressure drop or thermal maldistribution?***
- ***Has it been a challenge to achieve any particular product specifications, such as density, cetane or cloud point?***
- ***Is reactor internals maintenance a critical path activity during turnarounds?***
- ***Would it be beneficial to increase the severity of your feeds?***
- ***Have you had any difficulties in achieving your desired cycle length?***
- ***Are you under pressure to increase product yields?***

…then the latest-generation reactor internals could provide an opportunity to unlock additional value from your operations.

5. BIOGRAPHY: PANKAJ DESAI, LICENSING SALES MANAGER

Education

- BTech Chemical Engineering, Indian Institute of Technology, Kanpur, 1974
- MS Chemical Engineering, University of Houston, USA, 1976
- PhD Chemical Engineering, University of Houston, USA, 1979

Professional summary

Pankaj has extensive experience in licensing various process technologies, catalysts, reactor internals, proprietary hardware such as cyclones and particulate emissions controls, and software such as process technology models. He has also achieved three patents.

Current role

July 2007–present: Licensing Sales Manager – Americas, Shell Global Solutions (US) Inc., based at Shell Technology Center, Houston. Pankaj serves as lead business development licensing sales manager and commercialisation leader for Shell technologies such as hydroprocessing, catalytic cracking, distillation, thermal conversion and gas treating. In this role, he liaises with Shell technology leaders and focal points, and third-party oil industry executives, refinery managers, process managers and capital project directorates.

Previous roles

February 1980–June 2007: At Akzo Nobel Catalysts/Albemarle Catalysts, Pankaj held various positions in research and development, marketing, sales, technical services, business development and licensing.

Publications

Pankaj has more than 30 papers and publications in various trade journals, including *Oil & Gas Journal*, *Hydrocarbon Processing*, *Fuels Reformulation*, *Petroleum Technology Quarterly*, AFPM and AIChE.