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# Slurry-phase hydrocracking—possible solution to refining margins

## Opportunity crudes require more hydrogen addition to upgrade orphan product streams into higher-value 'clean' products

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Refinery margins are complex topic; margins are subject to substantial uncertainties and are impacted by global fluctuations in regional feed and product pricing structures. A conscientious analysis of historical data will indicate that for every one good year, on average, refiners are subject to seven years of depressed margins. New globalization trends, which include a changing transport-fuel supply/demand balance, geographic shift in consumption, soaring crude-oil prices, depressed natural-gas prices and impending regulations, all pose interesting challenges to the very survival of many small- and medium-sized refineries.

**Definitions of profitability.** A simple analysis of refinery economics will reveal that margins are largely impacted by three basic factors; crude cost, type of products produced and disposition of low-value, stranded streams. While the first two factors are simple to understand, the relationship between the refiner's ability to handle these orphaned streams and margins is more complex.

**Crude price.** The cost of crude is the *single most important factor* in setting refinery margins. This is the primary reason for the recent surge in refinery upgrades targeted at processing "opportunity crudes." While the definition of opportunity crudes is nimble and can vary from refinery to refinery, for the purpose of this article, it makes sense to simply define these crudes as the cheapest possible crude basket available to any given refinery on any given day. This basket may consist of heavy or extra heavy crudes, bitumen-derived crudes, high-acid/high-metals naphthenic crudes or high metals-containing, paraffinic, heavy inland crudes.

Most refiners are limited in their ability to handle this wide range of opportunity crudes; more often than not, they are constrained by the residues derived from these crudes. In recent years, the surge in interest over resid upgraders was catalyzed by the growing light-heavy differentials. This, in turn, forced refiners to evaluate their bottoms processing technologies, as margins dictated a higher percentage of heavy oils in their crude diet. Although the large light-heavy differentials have since diminished, this phenomenon is likely to be temporary. The renewed interest in monetizing heavy-oil reserves and the influx of substantial heavy crude volumes to the marketplace suggests that in the long run, refinery margins are likely to return, in large part influenced by the restoration of the light-heavy differentials. Central to this theory is that light-oil fields are on the decline and almost all new crudes entering the market place are substantially heavier than the current crude basket. This is evident by the decreasing API as shown in Fig. 1, of the composite worldwide crude blend and increasing volumes of extra-heavy crudes such as Canadian and Latin American bitumens.

As the world's supply of crude oil becomes heavier and contains higher sulfur levels, the challenge to the refiners will be compounded by the need to meet the growing demand for light, high-quality, ultra-low-sulfur transportation fuels. This leads to the next major determining factor that sets refinery margins, i.e., quality of products.

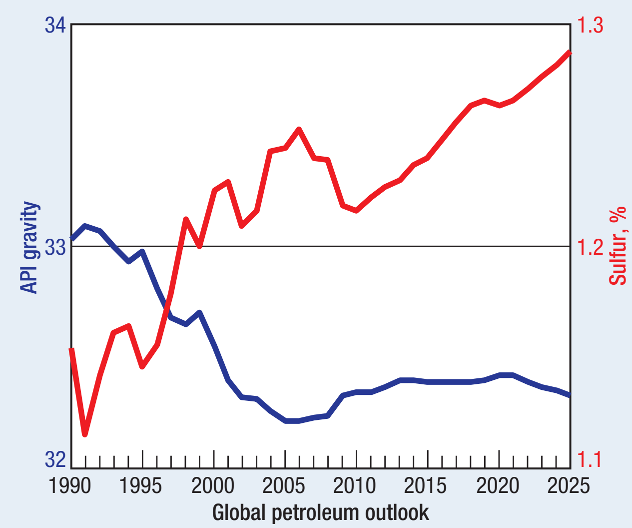


**FIG. 1** Crude API trends, 1990–2025.

**Product quality.** Global trends show a growing diesel demand and stable-to-declining gasoline demand (Fig 2). As the world emerges from the global recession and as the growth margin in 40% of the world's population continues at a rapid pace, this trend can only be expected to amplify. With the majority of existing refinery configurations slanted towards gasoline production, the price differential between diesel and gasoline will widen over the long haul, validating the market tilt towards dieselization. In addition, regulatory demands will only accelerate the shift towards lower density, higher-cetane index, ultra-low-sulfur diesel production, as the regional outlets for lower quality transport fuels diminish.

This combination of lower cost "opportunity crudes" and the need to produce high-quality distillate-selective products is an important consideration for refiners, when making long-term, high-dollar investment decisions.

**Choices.** The least understood variable in determining refinery margins is the disposition of stranded streams. Refineries are littered with low-value streams that are blended off, often downgrading higher-value products for the sole purpose of finding positive outlets for less saleable streams. While the ability to upgrade these streams is a major factor that sets refinery complexity, the solutions for these streams often rests in understanding its potential applications and value within and outside the refining industry.

The single largest stranded stream for most refineries is the vacuum residue (VR). The bulk of the operating refineries around the world have little or no residuum processing capability and produce large volumes of high-sulfur fuel oil and bunker fuel. A small volume is used to produce road asphalt. The future of VR is, therefore, intrinsically tied to the future of these three outlets.

The large growth market for residues may appear to be the bunker fuel market predominantly influenced by globalization trends and consequential incremental trade and shipping traffic. However, the use of VR as the major blending component in bunker fuel will come under serious scrutiny as new maritime regulations come in to effect starting in 2015 (Fig. 3). This will significantly inhibit VR demands, and the eventual solution may come from either the shipping or the refining industry.

While one of the solutions under debate involves using onboard flue gas scrubbers, this issue is more complex. There are several reasons to underscore the reluctance of the shipping industry to take on the burden of these operating facilities. Regulatory trends are almost always unidirectional, and the shipping industry can only expect the sulfur oxide ($SO_x$) regulations to extend to nitrogen oxide ($NO_x$), particulates, volatiles and other controls, not to mention the added capital investment, operating cost, monitoring and reporting requirements. Conversely, the refining industry is unlikely to invest in expensive VR hydroprocessing with the sole purpose of producing specification bunker fuels.

**Regulation directs actions.** The global trends show a sharp decline in high-sulfur fuel oil demand (Fig. 4), driven mainly by environmental regulations. While the sharp decline in fuel oil prices seen through the mid part of this decade has been temporarily arrested by the installation of many cokers, a reversal can be expected as regulatory pressures extend to the rest of the world. As is evident from the crack margins, producing large volumes of fuel oil will result in negative refinery economics and cannot be sustained.

Road asphalt is a relatively small market (Fig. 5), and environmental pressures are also likely to force refiners to produce specification-grade bitumens without resorting to air blowing. While this may lead to investment in alternate technologies such as solvent de-asphalting, the overall impact on the volume of stranded VR or its pricing, will be minimal.

All of these factors lead to one obvious conclusion. Going forward, high refining margins will depend upon the ability to capitalize on opportunity crudes, while consistently producing high-quality distillate-selective products from refinery residues. Selecting the appropriate residue upgrading technology, therefore, is a critical part of this puzzle that will define the future of refining and refinery margins.

**Selecting residue upgrading technologies.** To better understand the technology options, one must recognize that VR, in essence, is defined by what is not VR. The quality and quantity of VR is a function of crude selection and the lowest boiling impurity contained within the resid fraction that shows up as the limiting factor in the vacuum gasoil (VGO) fraction that is fed to a catalytic

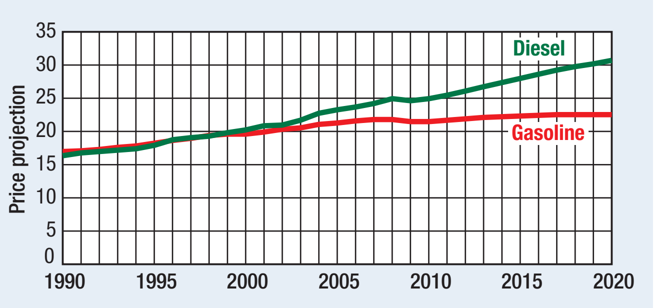


**FIG. 2** Demand for gasoline and diesel, 1990–2010.

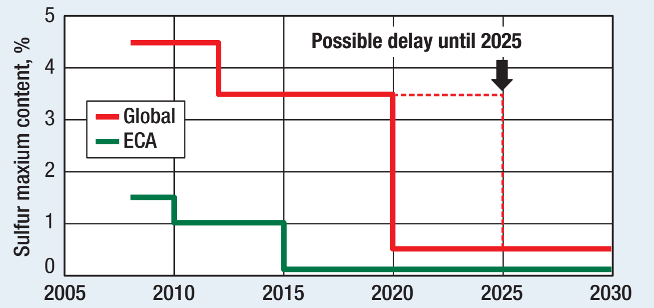


**FIG. 3** Expected timeline for IMO regulation enactment.

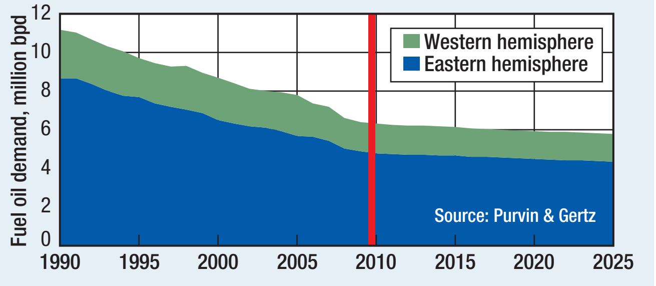


**FIG. 4** Declining oil demand trend, 1990–2015.

hydrotreater, hydrocracker or fluid catalytic cracking (FCC) process. The choice of resid conversion technology must be set by project economics, preferred reaction chemistry and mechanism of conversion aimed at reliably achieving the overall processing objectives.

We present seven questions that one would expect refiners to ponder as they investigate the appropriateness of available technology options. The direct relevance of these questions is premised on projected market trends and is intended to address the desire to achieve and sustain high refinery margins:

1. Has the technology been demonstrated in one or more large scale units?
2. Can the technology handle residues irrespective of the feed quality?
3. Can the technology achieve near complete conversion on a once-through basis?
4. Can the technology produce finished diesel-selective products?
5. Does the technology database demonstrate the ability to handle a whole range of crudes?
6. Can the technology do all of this with high reliability?
7. Can the technology achieve all of this at an attractive net present value (NPV)?

Aided by low crude oil prices and high natural gas prices, the delayed coker has, thus far, been the technology of choice for resid upgrading. When tested against the "seven questions" above, and weighed against the prevalent market conditions of the past, the conclusions are obvious.

However, going forward, with projected high crude oil prices, low natural gas prices and diminishing outlets for low-grade petroleum coke, the need for hydrogen addition is now here. In the rest of this article, we will examine the landscape of the available resid upgrading hydrogen addition technologies against this backdrop. As shown in Fig. 6, the technology choice for resid hydroprocessing is inherently determined by the metals and Conradson Carbon Residue (CCR) content in the residuum.

**Fixed-bed resid hydrocrackers.** Fixed-bed technologies have been used to hydrotreat residues containing low concentrations of metals and CCR. In most cases, the operation of these units is severely inhibited by the rapid deactivation of the catalyst system. The resultant combination of high operating pressure, low conversion, poor quality products and low catalyst cycle length make the process capital intensive with limited overall benefits.

To improve the economics of fixed-bed resid hydrocrackers, the unit must be protected from feed impurities. A feed cleanup unit such as a solvent deasphalter (SDA) may be installed upstream of the hydrocracker to reject the heaviest CCR and metals containing fraction as a pitch stream.

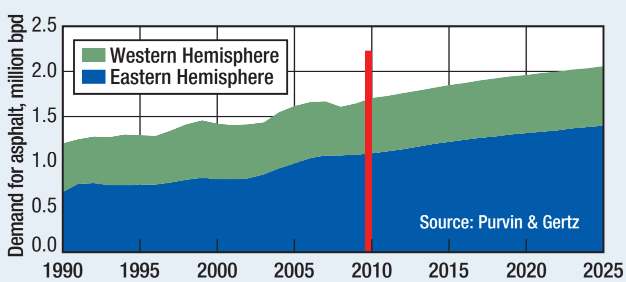


**FIG. 5** Demand for asphalt for road and roofing applications, 1990–2025.

The SDA works on the principles of solubility driven separation and is capable of lifting light deasphalted oil (DAO) from resid feeds. For most crudes, especially the lower value opportunity crudes, the overall lift will be low, limited by the CCR and metal specifications set by the DAO hydrotreating catalyst.

As a result of the low DAO yield, the reject asphaltenic stream will be large and can range from 50 wt%–80 wt% of the VR. For refiners who lack an economic outlet for this pitch stream, the value derived from the incremental distillate production through hydroconversion of the DAO is negated by transportation and handling costs associated with moving the pitch from the facility. Thus, DAO derived from the vast majority of solvent deasphalters operating in fuel services is directed to an FCC unit.

Fixed-bed resid hydroconversion processes will achieve minimal overall resid conversion, will produce a large volume of fuel oil, and are inherently limited by changing feed qualities. This incompatibility is evidenced by high operating pressures, large capital investments, low catalyst cycle length and a maintenance-intensive operating history. The quality of the products will not meet Euro V specifications, and the overall investment will not be commensurate with the derived benefits. When tested against the "seven questions to ponder," it is obvious that fixed-bed resid hydrocracking technology based schemes would need to be critically examined by the refiner on almost every issue.

**Ebullated-bed hydrocrackers.** Another option that has been considered and practiced by refiners for resid conversion is the ebullated bed technology. In this case, the same deactivation phenomenon seen in fixed-bed technologies is inherent with the one exception: the issue of low catalyst cycle length may be resolved through continuous addition and removal of catalysts.

Every resid handling process is subject to asphaltene precipitation as the saturates and aromatics contained in the feed that hold the asphaltenes in solution are removed or converted. This phenomenon is essentially driven by asphaltene-solubility chemistry, and the achievable conversion is a function of the saturates, aromatics, resins and asphaltene content in the residue, which in effect defines crude compatibility. In most cases, these units operate at a nominal 55% to 75% conversion, and in an era of "opportunity crudes", this inherent limitation must be recognized.

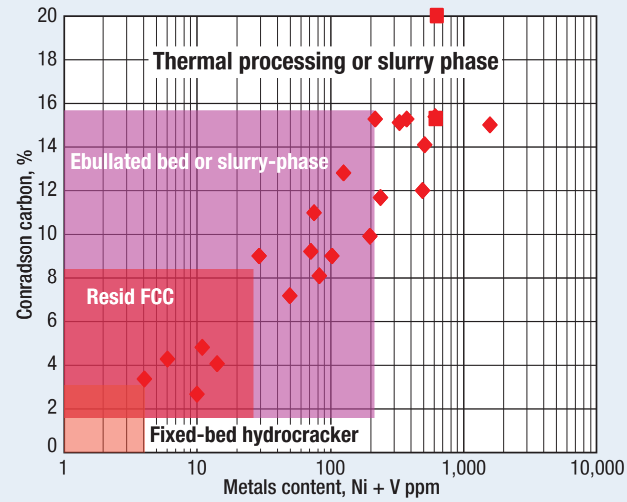


**FIG. 6** Resid upgrading technology options as directed by CCR %.

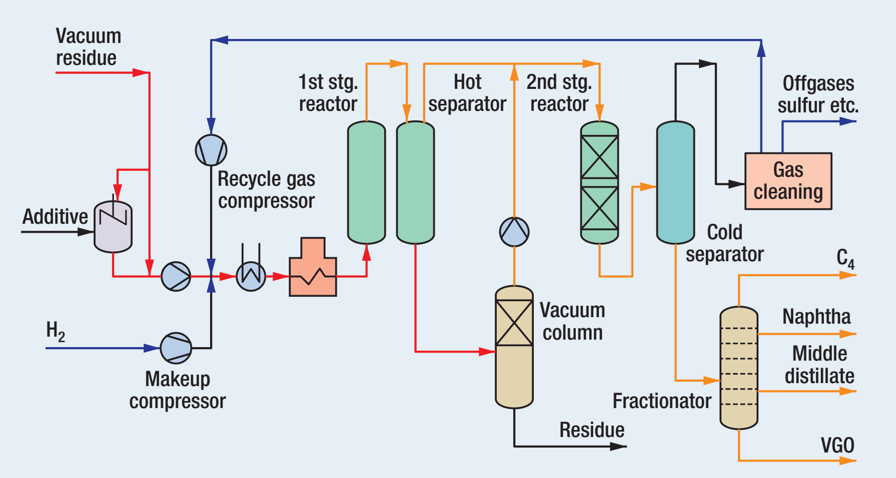


**FIG. 7** Typical resid hydrocracker flowsheet.

While refinery economics dictate the need to operate at or near the asphaltene-precipitation boundary limits, the operation of these units can be fairly complex as the refiner balances the need to operate at maximum conversion while minimizing reliability issues associated with asphaltene-induced fouling.

With this narrow operating window, any changes in feed quality can contribute to higher maintenance costs and low onstream factors. To achieve a relatively small overall improvement in resid conversion, and to improve reliability, operators often limit once-through conversion, recycle polynuclear aromatics (PNAs) and add other external aromatic-rich streams to help solubilize the asphaltenes, which, in turn makes the process more capital intensive and will result in higher operating costs. Although these processes are catalytic and use metal-containing catalysts, the conversion chemistry is a blend of catalytic cracking and deactivation-induced thermal cracking. Along with the addition of aromatic external feeds, the chemistry will result in lower naphtha, diesel and gasoil qualities requiring the streams to be re-hydroprocessed to meet Euro V product quality specifications.

This need to add two catalytic steps makes the process capital intensive, thus challenging the economics of this option. With declining fuel-oil prices, and tightening fuel-oil quality regulations, the large volume of unconverted fuel oil will leave the refiner with much of the same issues to deal with in the post investment scenario, although in a smaller scale. When tested against the "seven questions to ponder," the choice of crudes, achievable conversion, product qualities, reliability and investment threshold gain significance.

**Slurry-phase hydrocrackers.** With high crude price and low natural gas prices on the horizon, slurry-phase hydrocracking (Fig. 7) is emerging as the preferred approach for upgrading residue streams via hydrogen addition. The principles of slurry-phase hydrocracking essentially overcome the limitations of fixed-bed and ebullated-bed technologies and provide for substantially higher conversion of the residuum.

The primary conversion of residues can be achieved through either catalytic or noncatalytic routes. Investigations for using catalysts or noncatalytic additive systems for primary conversion of the residues can be traced back to the early 1900s and span the entire century, with several hundred patents that have been awarded in support of these activities. Over the past few years, substantial effort has been expended by technology providers exploring nanocatalysts to enable the primary conversion of residues at marginally lower operating pressures. While catalyst-based systems are technically viable, the use of a relatively expensive catalyst system, catalyst deactivation, low quality of derived products and the need for catalyst recovery, all contribute to the economic considerations which in the authors' view, is likely to make this option less attractive.

**Key performance criteria.** We will focus on the non-catalytic slurry-phase hydrocracking in the context of hydrogen addition and examine the appropriateness of the technology to the current market conditions. **HP**

**Extended version avaiable online at HydrocarbonProcessing.com.**

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