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FULL LENGTH ARTICLE

Economic evaluation and sensitivity analysis of some fuel oil upgrading processes

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Abstract Seven upgrading schemes, identified as high distillate production schemes have been proposed for upgrading of 3.50×10^6 t/y atmospheric residues. The seven schemes were evaluated using the discounting cash flow method. Economic parameters such as internal rate of return, **IRR**, payback period, **PBP** and net present value, **NPV** have been calculated for each option.

All studied schemes proved profitable with **IRR** ranging between **25.2** and **33.7**% with option 7 having the highest NPV, IRR and payback period. Sensitivity analyses were performed on this option. The parameters investigated are: sales price (Revenue); production rate (feed weight); feed cost; utilities cost; direct and indirect costs; tax% and discount rate%. Their impact on NPV and %IRR has been evaluated. Tornado diagrams were constructed to illustrate the effect of variation of different cost parameters on NPV and IRR. The single most effective input variable is Revenue on both NPV and IRR. With two-factor sensitivity analysis, the two most important input variables for NPV and IRR are revenue and utilities.

Spider charts for option 7 have been created to show how the model's outputs depend on the percentage changes for each of the model's input variables.

1. Introduction

World interest in upgrading fuel oil has been revived [1] this is being stimulated by;

- The rate of decline in size of the fuel oil market. In Europe, environmental regulations are restricting fuel oil utilization, leaving only bunker markets.
- The growing demand for transportation fuels, especially middle distillates. In Europe, for example, the deficit for road diesel is forecast to be around 45 million Tons by 2020. Also the USA is becoming more diesel-orientated because of the higher miles per gallon obtained and resulting reduction in CO_2 emissions.
- Tightening fuel specifications and facility emission controls.
- Improving refining margins.
- Growing confidence in residue upgrading technologies, based on commercial performance, technology development and capital cost reduction.

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- The opportunity to produce the required, high quality transportation fuels by residue upgrading rather than additional crude processing.

Egypt has the largest refining sector on the African continent with nine refineries and a combined crude oil processing capacity of 975,000 bbl/d.

The country currently has a large surplus of heavy fuel oil and a deficit of lighter products. As a result, Egypt has an unfavorable import–export balance, with expensive, lighter products being imported and heavy fuel oil being exported and sold to marine bunkers. Existing plans foresee expanding of upgrading refining capacity to produce more light products and distillates and cut heavy fuel–oil surplus.

The international price differential between distillate products and high sulfur fuel oil, coupled with the subsidizing cost to maintain the local market prices at a reasonable level, offers a good driving force to think of bottom of the barrel processing [2].

Crude atmospheric distillation residue AR (Fuel oil BP 320 °C+) and vacuum distillation residue VR (BP 550 °C+) are what we mean by ‘‘bottom of the barrel'' or simply residual fractions.

Residue is the highest molecular weight and the lowest hydrogen content fraction of the crude oil. It is generally requested to obtain lighter and environmentally acceptable high value products from heavier, low value feed. Achieving these process goals requires that the residue molecules undergo a number of thermal and some catalytic reactions. Therefore, the objective of upgrading processes can be defined as:

- Convert high molecular weight residual components to distillates. This conversion requires the breakage of C–C bond and C–S bonds in the residue fraction.
- Improve the H/C ratio, moving from 1.5 in the feed to 1.8 mol/mole as suitable for transportation fuels.
- Remove the heteroatom down to environmentally acceptable levels. The main heteroatoms of interest are sulfur and nitrogen.

The heading ‘‘upgrading of residual fuel oil'' has been tackled in many text books examples are Gray [3] and Gary and Handwork [4] and in the literature e.g. [5]. Significant advances have been made in these technologies over the last three decades [1,2,6].

Residue upgrading processes may be generally grouped into two general categories [3]: carbon rejection and hydrogen addition depending on the technique used to increase the hydrogen to carbon ratio. Solvent deasphalting, visbreaking, thermal cracking, coking and catalytic cracking are carbon rejection processes, while catalytic hydro-demetallization, hydrodesulphurization and hydrocracking, are typical hydrogen addition processes.

There are two families of VGO conversion processes that vary according to the production goals; gasoline, or middle distillates. When gasoline production is the main driver, a combination of VGO hydrotreating and FCC produces high yields of low sulfur gasoline. If, however, middle distillates production is the target, VGO hydrocracking is the most attractive option where the products have excellent characteristics. It is worth mentioning that if petro- chemical feedstock is the target then the newly developed deep fluid catalytic cracking can be used at very attractive economic indicators [7].

Several VR conversion processes are available that cope with different feedstock characteristics and process objectives. Fixed bed residue hydrotreating is suitable for feeds having low to medium metal contents and when moderate conversion levels are required. The unconverted residue is used as low sulfur fuel oil or as a feed to RCC or DC units.

Delayed coking or Flexi coking can be applied to any type of VR feedstock to produce the full spectrum of distillates while eliminating completely fuel oil. The main concern would be marketing of the produced coke.

When very high conversion is the objective, new slurry-phase residue hydrocracking processes can be of interest e.g. Eni slurry technology; **EST** [8]. These processes still lack industrial application.

Depending on **AR** characteristics, mainly metal and sulfur content, residue catalytic cracking, **RCC**, can be applied directly or after hydrodemetallizaton/hydrodesulphurization of the residue feedstock. The product would be rich in gasoline.

When feeds have high metal content, the use of guard hydrodemetallization reactors of the type On-stream Catalyst Replacement, **OCR**, [9] or Permutable Reactor System, **PRS** [10]. provide effective solutions to free the residue feedstock from metals prior to further processing. Alternatively, solvent deasphalting of **VR** using light hydrocarbons separates asphaltenes carrying metals from deasphalted oil which can be further processed. If high conversion is requested residue hydrocracking using one- or two-stage ebullated bed reactors can be used, [1].

The present paper is an update to the work presented by the authors in 2008 [11]. The reference work studied in detail the available technology alternatives to upgrade locally produced fuel oil to more valuable and lighter distillates, so as to fill the existing gap in the middle distillates. The final choice of the best alternative(s) was governed by techno-economic profitability analysis. In this communication, economic analysis of the seven previously studied cases is repeated after updating equipment, utility and crude oil and products' prices. More over sensitivity analysis was performed to study the most influential factors that affect the net present value and the internal rate of return.

2. Cases studied for upgrading of atmospheric residue produced in Egyptian refineries

Seven upgrading schemes (Fig. 1), identified as high diesel production schemes [12] have been evaluated for a proposed plant capacity of 3.5 million t/y of the atmospheric residue produced in the Egyptian refineries. The Schemes evaluated are:

1. Atmospheric Residue hydrodemetallization/hydrodesulphurization + Residue Fluid Catalytic Cracking + Naphtha Hydrotreating, **ARDM/ARDS + RFCC + HDT**.
2. Vacuum distillation + Delayed Coker + High Pressure Hydrocraker + Hydrotreatment of Naphtha and Gasoil, **VDU + DC + HP-HCK + HDT**.