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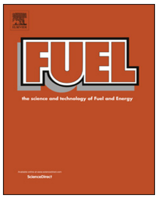

Full Length Article

Pilot plant study on continuous propane deresining of atmospheric crude cylinder stock

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ABSTRACT

With the market transition from API Group I to Group II and Group III lubricating base stocks and decline in the Group I supply, highly valuable grades of Group I solvent-refined bright stocks are gaining more attention today. Continuous improvement in the bright stock production is crucial for refineries to accelerate the gain from the volatile Group I base oil market. To develop a pathway for improving the production of bright stock in the refinery, the continuous propane deresining pilot plant study was conducted on the atmospheric crude cylinder stock for propane deresined cylinder stock production. The propane deresined oil is referred to as D-stock, which is the feedstock for MEK dewaxing downstream for bright stock production in the refinery. Different propane solvent to oil (vol./vol.) conditions were studied at Intertek PARC's continuous solvent deasphalting unit with varying column top and bottom temperatures at a fixed column pressure. A significant improvement in the D-Stock yield was observed without compromising the D-Stock viscosity specification. The Intertek PARC deresining tower with staggered half-moon baffle internals enhanced separation of the D-stock from the resin component. The real-time operational data and analytical measurements were presented for propane dosages. The detailed characterization of Intertek PARC D-stock and resin was studied at 10.5/1 and 8/1 solvent to oil ratios.

1. Introduction

Upgrading the bottom of the barrel using carbon rejection technologies have been adopted by refineries in attempt to get more liquid fuels, waxes and base oils from the heavier portion of atmospheric and vacuum crude bottom [1,2]. The need for heavy-end processing is critical for refineries, as worldwide crude oil slate is trending to the lower gravity crudes, sulfur specifications becoming more stringent, concentration of sulfur, heavy metals, and other contaminants have been increasing. The demand for No.6 fuel oil is also declining and the cost of light crude relative to heavy crude is increasing [3,4]. In addition, the trends in the United States have become more complicated due to the glut of light, sweet, tight oil from shale. There are various physical separations and chemical reaction pathways that have been employed to process heavier ends such as vacuum distillation, solvent deasphalting, lube oil processing, visbreaking, catalytic cracking, coking, hydrocracking and gasification [5,6]. Among these technologies, solvent deasphalting is considered the most efficient primary route for residue upgrading due to low capital cost and the flexibility to process a wide range of feedstocks to a low carbon-residue deasphalted oil as well as an option to produce resin product [7,8].

Solvent deasphalting (SDA) is a robust, economical refinery process that uses an aliphatic solvent to separate the typically more valuable deasphalted oils (DAO) from the more polar and aromatic resin/asphalt components of the atmospheric and vacuum residue [8]. The earliest commercial application of SDA used C3/propane as the solvent to extract high-quality lubricating oil bright stock from vacuum residue. Bright stocks are widely used in applications where the lubricant is exposed to high temperatures or under heavy loads such as industrial gear oils. The process gradually extended to be used as feedstock to the fluid catalytic crackers, hydrocrackers, hydrodesulphurization units as well as the production of specialty asphalts using various light hydrocarbon solvents [9]. Propane and butane have been generally used in the SDA process for high quality DAO while heavier deasphalting solvent (C5, C6 or a mixture) are utilized to generate higher DAO yield [10].

Extraction of DAO with solvent deasphalting process has been studied under various conditions for maximum utilization of the heavier residue [11,12]. Elshout et al. [13] evaluated the solvent deasphalting for residuum demetallization and decarbonization to remove catalyst deactivators such as Ni, V, and asphaltenes which poisons catalyst in the downstream units. The solvent recovery is one of crucial steps in the

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DAO extraction for the development of SDA process with low operating cost [14]. In the supercritical extraction process, the maximum amount of solvent charged to the extraction tower is separated, recovered and recycled back to the tower and thus reduces the energy cost [15]. Residuum Oil Supercritical Extraction (ROSE®) process is the most energy efficient solvent-extraction option for recovering higher value products from resids. The extraction process efficiency is the main extraction column design variable impacting both the capital and operating cost of SDA [16]. There are different types of solvent extraction columns available based on operating principle, cost, and application. Lab-scale researchers have used mixer-settlers or centrifugal settlers as their solvent extraction column for SDA evaluation. Pilot plants and commercial scale SDA technologies have implemented either structured packings with proprietary column internals in multi-stage counter-current extractor or multistage rotating disc contactor (RDC) to achieve high product quality and yield. However, there is limited or no experimental pilot plant data found using continuous propane solvent system using deasphalting/deresining extraction tower with staggered half-moon baffle internals evenly spaced throughout the column. These column internals are designed to enhance better separation of the DAO from the residue with better capability of handling the fouling issues (high fouling resistance) in the tower.

In this research, two different solvent/oil conditions (10.5/1 and 8/1) were studied at Intertek PARC's continuous solvent deasphalting/deresining P73 Unit with varying column top and bottom temperatures at a fixed pressure of 550 psig and a feed flow rate of 1 gallon/hour for equilibrium separation of deresined cylinder stock (D-Stock). The cylinder stock is the bottom residue product from atmospheric distillation tower while D-stock is the deresined product separated from cylinder stock. The feedstock (cylinder stock) used in this study is primarily derived from Pennsylvania grade crude oil and therefore does not contain an appreciable level of asphaltenes. Therefore, the residual product is actually a resin component that has paraffinic constituents in addition to polar and aromatic constituents. The objective of this study is to improve the production and quality of D-stock without compromising the defined viscosity limits (viscosity @ 100 °C, cSt: min 28.5, max 30). The minimum viscosity requirements are defined such that when the D-stock is dewaxed in an MEK Unit downstream, that the dewaxed oil (Bright Stock) meets the viscosity limits of a 150 SUS @ 210 °F base oil.

2. Experimental

2.1. Reagents

The on-spec cylinder stock (atmospheric crude tower residue) drum sample was provided by American Refining Group (ARG). The composite viscosity of cylinder stock sample for the Intertek PARC trial was measured as 46.87 cSt @ 100 °C and a KF moisture at 130 ppm. The asphaltenes in the cylinder stock sample was determined (By modified ASTM D893) to be 0.1%. The propane solvent used for the experimentation was obtained from Butler Gas Products Company, Pittsburgh, PA. The laboratory chemicals and solvents for analytical testing were mostly procured from Sigma-Aldrich. American Refining Group at Bradford, PA processes mostly Pennsylvania Grade crude oil, which is thermally stable paraffinic crude oil. In the ARG refining process, the atmospheric crude unit provides feedstock to the ROSE® unit which is the atmospheric tower bottoms known as cylinder stock. The finished products made at the ROSE® are D-Stock (top product) and light resins and heavy resins (bottom products). The light resin from ARG still contains 50% D-stock in it.

2.2. Pilot plant setup

The pilot plant experiments were performed at Intertek PARC continuous solvent deasphalting P73 unit. Fig. 1 shows the process schematic for continuous solvent deasphalting unit. The structure includes a solvent extraction tower, oil feed tank, recycle propane tank, deresined oil and resin product receivers, oil feed pump, predilution and stripping propane pump, feed and product preheaters, propane condenser, solvent preheater, DAO and asphalt strippers, pressure, level, and interface controllers. In this system, the cylinder stock, prediluted with propane (1:1), enters the top of the extractor while the bulk of the propane solvent enters the bottom of the extractor separate from the feed. The process consists of contacting the feedstock/cylinder stock with a propane solvent in a counter-current extractor at temperatures and pressures to precipitate the resin fractions (bottom product) and selectively dissolve DAO (top product).

Unit P73 is a counter-current solvent deasphalting/deresining pilot plant that consists of a 9.155 m (30 ft.) tall 304SS extractor column containing 160 alternating half-moon baffles spaced 5 cm (2 in) apart. The unit can co-process C3, C4, or C5 solvents (or blends thereof) and includes integrated resin/asphalt and DAO and flash chambers to allow for the solvent to be recovered and recycled. The charge rate (prior to propane dilution) varies from 1.9 L/h (0.5 Gal/h) to 5.7 L/h (1.5 Gal/h). The feed plus solvent rate can be processed up to maximum of 53.2 L/h (14 Gal/h). The extraction tower can operate up to 650 psig (45 bar) and 260 °C (500F). It has three optional feed injection ports to the extraction tower to allow for adjusting the feedstock/solvent contact surface area. The products are typically drained every two hours into five gallon pails for material balance purposes. It takes approximately 12 h to bring the unit up to baseline conditions and generally takes a few more hours for each change of condition based on the magnitude of the change. The product yields are calculated based on % mass as the charge drum is placed on a scale and the deresined oil and resin products are all weighed.

3. Results and discussion

The baseline process condition (ARG optimal operating conditions for typical D-stock) executed at Intertek PARC P73 unit for de-resining pilot plant trial were as follows: propane to oil (pre-dilution) 1:1(vol./vol.); propane to oil solution (tower) 10.5:1 (vol./vol.) including pre-dilution, tower pressure 550 psig, tower top temperature 150 °F (66 °C), tower bottom temperature 130 °F (55 °C), tower temperature spread ΔT 20 °F (11 °C), feed charge rate 1 gallon/hour. The tower temperature spread (ΔT) and feed flow rate were kept constant throughout the experimentation. The fluctuation in tower temperature spread was observed possibly due to bottom temperature indicator location (Inserted just above the asphalt/resin boot section). In this pilot plant study, the temperatures were recorded in 'degree Fahrenheit/° F' and volumes in 'Gallons' as this scale system is commonly used in US refineries.

3.1. Operational data for 10.5/1 (solvent/oil)

The operating conditions, D-stock yield and analytical testing results on 10.5/1 solvent to oil ratio are presented in Table 1. At the beginning of the experimentation when the unit stabilized, the D-stock yield and viscosity were recorded as 83 wt% and 30.18 cSt @ 100 °C respectively. The column top temperature was 151 °F and bottom 133 °F. ASTM color and conradson carbon residue (CCR) was measured as 7.9 and 1.29% respectively. As the viscosity of the product was higher than set specification for D-stock (Min 28.5, Max 30), the column temperature was raised by 7 °F across the tower profile (159–139 °F) to drop the viscosity on D-stock. It was noted that the D-stock yield and viscosity was dropped to 81 wt% and 28.15 cSt respectively. Material balance appeared unsteady sometimes due to the resin nature being light/liquid. ARG Resin is paraffinic type and does not behave like a normal asphalt. The column temperatures were lowered down (153–135 °F) to achieve the targeted viscosity range. The unit was then stabilized with 82% of yield and viscosity of 28.83 cSt. ASTM color and CCR was measured as 7.2 and 0.99% respectively for the D-stock. The carbon residue