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**Eliminate Fuel Oil Production with Slurry Hydrocracking**

Uniflex™ Process

5th December 2017 | Bottom of the Barrel Workshop | NIORDC, Tehran

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Slurry Hydrocracking

Crude Oil → CDU

CDU:
- SR Kerosene
- SR Light Gasoil

SR Kerosene → DHT Unit
- H2

DHT Unit:
- Jet
- Diesel

SR Light Gasoil → Naphtha Hydrotreating Unit
- H2

Naphtha Hydrotreating Unit:
- UNI Naphtha

UNI Naphtha → NHT Splitter
- H2
- LPG

NHT Splitter:
- Reformate

NHT Splitter → CCR Unit
- Isomerate

CCR Unit:
- Refractate

CCR Unit → Isom Unit
- Isomate

Isom Unit:
- Wet Gas + LPG to Sat Gas Plant

Isomate → HCU Unit
- H2

HCU Unit:
- HCU Kerosene
- HCU Diesel

HCU Kerosene → HCU Kerosene Unit

HCU Diesel → HCU Diesel Unit

HCU Diesel Unit:
- Wet Gas + LPG to Sat Gas Plant

HCU Diesel Unit → SHC Unit
- SHC VGO
- UCO

SHC Unit:
- SHC Diesel

SHC Diesel → SHC Diesel Unit

SHC Diesel Unit:
- Pitch

Vac Res → SDA Unit
- SDA Pitch

SDA Pitch → SDA Pitch Unit

SDA Unit:
- SDA VGO

SDA VGO → SDA Unit

H2 → Hydrogen Plant

Natural Gas → Hydrogen Plant

Hydrogen Plant:
- H2

H2 → LPG Sales

LPG Sales:
- Gasoline Sales

Gasoline Sales:
- Kerosene Sales

Kerosene Sales:
- Diesel Sales

Diesel Sales:
- Bitumen Sales

At Res → VDU

VDU:
- VGO
- Vac Res

V GO → SDA Unit
- SDA Pitch

Vac Res → SDA Unit
- SDA Pitch
Agenda

- High Sulphur Fuel Oil Market Changes
- Uniflex Process
- Commercial Experience in Slurry Hydrocracking
High Sulphur Fuel Oil Global Demand Changes from 2020

- Greatly reduced HSFO use for bunkering as a result of new regulations
- Surplus residue expected after residue conversion and power generation usage
- Will have significant impact on products & crude differentials in 2020
- HSFO expected to be priced at severe discount compared with 2016 (~40% lower)
Refinery Options to Upgrade High Sulphur Fuel Oil

Conversion Options

• Slurry HC process such as Uniflex process
  – Good payback

• Ebullated bed process
  – Limited conversion
  – High capex
  – Lower payback

• Delayed coking process
  – Similar capex
  – Lower payback

Treating Options

• Desulphurise HS fuel oil with process such as RCD Unionfining™ process
  – Limited product value uplift

• Desulphurise DAO
  – Lowest capex, but still makes some HSFO

Uniflex process gives highest NPV based on our analysis
Slurry Hydrocracking – Uniflex Process

- Uniflex process is UOP’s slurry hydrocracking technology
- Uniflex offering is close to that achieved in commercial unit that operated for 15 years (CANMET). High onstream factor demonstrated

- Performance:
  - Up to 95% conversion of residue
  - High yield of Euro V middle distillates
  - Low yield of VGO that can often be accommodated in existing refinery conversion units

- Process includes an integrated hydrotreater to reduce capex and produce high quality products directly from the unit
- Pressure similar to hydrocracking – similar capex
- Onsite catalyst preparation
- Effective measures taken to prevent coking and fouling in the unit
- 6 units licensed
Uniflex Unit with Integrated Hydrotreater

- Integrated hydrotreater minimizes number of equipment items leading to lower capital cost
- External diesel streams could be hydrotreated to Euro 5
Uniflex Performance with Integrated Hydrotreater

- **95% conversion**: Higher conversion comparable to other residue conversion processes
- **Euro V Diesel**: High yield of diesel compared to other slurry processes
- **Minimum VGO**: Can be accommodated in existing conversion units
- **Naphtha**: < 1 wppm S and N
- **Pitch**: Cement Plant, Gasification Unit, Boiler/Kiln, or solidified into pellets
Uniflex commercial experience in the Petro-Canada CANMET unit

- 5000 bpsd unit operated for 15 years at Petro-Canada’s Montreal Refinery
- Demonstrated excellent reliability
- Processed many residue feeds
- Also demonstrated processing of VGO, Visbroken VR, FCC Slurry Oil
- Developed design, control and analytical techniques to optimize reactor performance and reliability
CANMET Development Timeline

• 1980s
  - Construction of the Petro-Canada Montreal 5,000 bpsd demonstration unit
  - The plant was started up in October of 1985, and testing was carried out to verify the reactor design parameters, the accuracy of the yield prediction model and the suitability of the materials of construction.
  - Having met the demonstration objectives, the unit was shut down in late 1989.

• 1990s to 2003
  - An increase in the light / heavy crude differential provided the incentive to restart the plant as a refinery unit in 1992
  - Successfully process a wide range of refinery residues from conventional crudes as well as residues from refinery conversion units
  - FCCU slurry, visbreaker vacuum tower bottoms, deasphalter bottoms residue, and poor quality gas oils from cokers and visbreakers are all upgradeable in the CANMET process.
  - Improvements in operability based on new reactor control strategy
  - Reliability was over 98% during last 5 years of operations
Petro-Canada Montreal CANMET Unit – Aerial View
Petro-Canada Montreal CANMET Unit – Aerial View
Petro-Canada Montreal CANMET Unit – Reactor Section
Typical Feeds Processed in Commercial Operation of CANMET Unit

<table>
<thead>
<tr>
<th></th>
<th>Cold Lake VTB</th>
<th>Isth-Mayan VTB</th>
<th>Bent Horn VTB</th>
<th>Iranian Light VB VR</th>
<th>Mene Mota VB VR</th>
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<tr>
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<td>33.5</td>
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<td>34.8</td>
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- Visbroken vacuum residue from Iranian crudes successfully processed in commercial operation
- Pilot plant testing in early 1990s demonstrated conversion of over 90%wt on residue from Iranian crude
CANMET Slurry Hydrocracking – Proven Commercial Experience

• Processed a wide range of feedstocks and operating conditions
  - Achieved once-through pitch conversion of 93.5% with Cold Lake VTB feed
  - Achieved over 95% conversion on Visbroken Vacuum Residue
  - Operated successfully in most difficult operating ranges

• Developed excellent design correlations, allowing accurate scale-up

• Inherent safety and reliability proven during many refinery upsets

• Very high reliability over last 5 year period
  - Over 98% adjusted availability
UOP Heavy Oil Development Centre

- Integrated pilot plant facilities dedicated to heavy oils development
  - High Capacity Feed Preparation/Fractionation:
    - Multi-column fractionation unit
  - Uniflex pilot plant:
    - High capacity operation with multiple reactors capable of staged operation
  - Flexible Heavy Oil Hydroprocessing pilot plant:
    - Heavy Oil Technologies fully integrated with UOP Unicracking™ and RCD and Distillate Unionfining™ pilot plants
    - Capable of high pressure (345 barg) operation with reactor configurable in all Hydrocracking and Hydrotreating modes
  - Continuous operation with online analysis operating on commercial feeds
  - **Used as basis for guarantee representations**
Uniflex Process – Continuous Improvement

- New catalyst innovations
- Process enhancements
- High conversion to valued products
- Process design for sustained operability and reliability
- Economically efficient catalyst systems, and manufacturing capability
- Economically advantaged use for all products
Uniflex Developments

• UOP continues to invest in development of the Uniflex process

• New catalyst system
  - Prepared onsite from raw materials available on the open market
  - Low injection rate required

• Process enhancements to increase conversion and yields
  - Staged conversion
  - External reactor recirculation
  - Recycle of heavy product streams
  - Solids removal from pitch

• First unit incorporating new features expected to start up in 2019
Uniflex Benefits

**Enables 95+ Wt-% conversion (525°C+ material)**

**Low catalyst addition rate**
- On-site catalyst preparation

**Usable pitch**
- Low solids content, low sulfur level
- Fungible product (e.g., fuel, low sulfur petcoke, asphalt production)

**Euro V diesel product**
- Integrated hydrotreating lowers overall capital cost