Catalysis Today 220–222 (2014) 248–273

Contents lists available at ScienceDirect

Catalysis Today

journal homepage: www.elsevier.com/locate/cattod

Current situation of emerging technologies for upgrading of heavy oils

Luis C. Castañeda*, José A.D. Muñoz, Jorge Ancheyta

Instituto Mexicano del Petróleo, Eje Central Lázaro Cárdenas 152, Col. San Bartolo Atepehuacan, México D.F. 07730, Mexico

ARTICLE INFO

Article history:
Received 17 January 2013
Received in revised form 22 April 2013
Accepted 27 May 2013
Available online 4 July 2013

Keywords:
Heavy oil
Upgrading
Emerging technologies

ABSTRACT

With the increased production of heavy and extra-heavy crude oils, and the need to add them into the regular diet to refineries, there has been much interest for developing new technologies for upgrading those heavy materials. Traditional commercially available carbon rejection and hydrogen addition routes are still applicable for this purpose, however they have shown some limitations when the oil is heavier, which directly impact in the economy of the technology. Various emerging technologies have been reported in the literature, mainly in patents, which have been developed and tested at different scale and with a wide variety of heavy petroleum. The most important emerging technologies for upgrading of heavy crude oils are reviewed and discussed. Particular emphasis is put in a comparison with the available information. It is recognized that all the technologies have great opportunity to be applied commercially depending on the support that they receive by the petroleum companies.

1. Introduction

A number of technologies have been developed over the years for heavy crude and residue oil upgrading, which include processes that are based on carbon rejection, hydrogen addition and combination of both routes [1,2], most of them with proven commercial experience. Fig. 1 summarizes the distribution of these technologies and their processing capacity. Carbon rejection processes represent 56.6% of the total worldwide processing capacity mainly due to its relative low investment.

There are also other technologies at different level of development or close to commercialization or even already used, that have been abandoned as uncompetitive during the years of cheap crude oil.

The changing prices of crude oils as well as the increasing production of heavy and extra-heavy crude oils have motivated more research and development aiming at upgrading of such heavy materials. The new approaches are named emerging technologies. This group of technologies is reviewed in this work and their advantages, disadvantages and current situation are highlighted.

2. Typical technologies for upgrading of heavy oils

Standard technologies developed for heavy crude and residue oil upgrading include processes that are based on carbon rejection, hydrogen addition and combination of these two routes.

2.1. Carbon rejection

Carbon rejection is one of the first types of conversion processes applied in the oil industry, and has been used since 1913 for different fuels and heavy hydrocarbons heated under pressure. This group of technologies includes processes such as visbreaking, thermal cracking, and coking. Foster Wheeler and Universal Oil Products made an agreement to combine their technical experiences, developing over 50 visco-reduction plants. Shell and ABB-Lummus have developed and commercialized a drum type application namely Reaction Chamber (Soaker), with over 80 projects based on this process [3,4]. Fluid coking and Flexicoking are developments of Exxon Mobil Research & Engineering (EMRE). The combined capacity of Fluid coking and Flexicoking amounts 241,000 and 426,000 bbl/day, respectively. Delayed Coking a mature technology is offered by Foster Wheeler SYDEC (Selective Yield Delayed Coking) with over 25 revamps designed in the last 10 years, and over 20 new units designed in the last 5 years [5].

2.2. Hydrogen addition

Traditional upgraders reduce carbon-to-hydrogen ratio by adding hydrogen obtained from natural gas. Hydrogen addition technologies are classified depending on the type of reactor used, e.g. fixed-bed, moving-bed, ebullated-bed and slurry-bed processes.

Axens technology utilizing its Hyvahl process (Permutable Reactor System), has reached an important commercialization level. Chevron Lummus Global (CLG) licenses On-stream Catalyst Replacement technology (OCR) for processing high-metal feeds and the revamp alternative, an Upflow reactor (UFR). Shell developed

* Corresponding author. Tel.: +52 55 9175 6619; fax: +52 55 9175 8429.
E-mail addresses: luiscarlos.castaneda@gmail.com, lcastane@imp.mx (L.C. Castañeda), jamunoz@imp.mx (J.A.D. Muñoz), jancheyt@imp.mx (J. Ancheyta).

0920-5861/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.cattod.2013.05.016

Nomenclature

AB	Athabasca bitumen
ADC	Accelerated decontamination
AERI	Alberta Energy Research Institute
AMEC	AMEC Group Ltd.
BA	BA Energy Inc.
CAT	CAT process
CCR	Conradson carbon
CCU	Catalytic Crude Upgrading
CDP	Commercial Demo Plant
CE3	Canadian Environmental Equipment and Engineering
CIMAV	Centro de Investigación en Materiales Avanzados
CLB	Cold Lake Bottoms
CLG	Chevron Lummus Global
CP	Cracking Process
CPBB	Chinese Paraffinic Bottoms Blend
CPJ	Conversion Pierre Jorgensen
DAO	Deasphalted oil
DBT	Dibenzothiophene
DBTO	Dibenzothiophene sulfone
DC	Delayed Coking
DRV	Distillate Recovery Unit
EMRE	Exxon Mobil Research & Engineering
EST	Eni Slurry Technology
FCC	Fluid Catalytic Cracking
FGDSU	Flue Gas Desulphurization Unit
GCC	Gulf Cooperation Council
GHG	Green House Gases
GHU	Genoil Hydroconversion Upgrader
HCAT	Hydrocracking technology
HCU	Heavy Crude Upgrader
HDC	Hydrocracking
HDCCR	Conradson Carbon Residue Reduction
HDM	Hydrodemetallization
HDN	Hydrodenitrogenation
HDS	Hydrodesulfurization
HDT	Hydrotreating
HGO	Prototype heavy oil upgrader
HOG	Heavy oil upgrader
HOUP	Heavy Oil Upgrade Project
HP	High pressure
HRH	Heavy Residue Hydroconversion
HTGI	Headwaters Technology Innovations Group
HTL	Heavy to light
HVGO	Heavy vacuum gas oil
HYCON	Hydroconversion process
HYT	Haiyitong Inc.
IBA	Ion Beam Applications
IFP	Institut Français du Pétrole
IGCC	Integrated Gasification Combined Cycle
IMP	Instituto Mexicano del Petróleo
LP	Low pressure
LVGO	Light Vacumm Gas Oil
MIB	Maya–Isthmus blend
NCUT	National Center for Upgrading Technology
NRC	National Research Council
NRL	National Refinery Limited
OCR	On-Stream Catalyst Replacement
P	Pressure
PDVSA	Petroleos de Venezuela Sociedad Anonima
PEMEX	Petroleos Mexicanos
PONA	Paraffin, Olefin, Naphthenic, Aromatic
PSA	Pressure Swing Adsorption
RFCC	Residue Fluid Catalytic Cracking
RIPI	Research Institute of Petroleum Industry
RTP	Rapid Thermal Processing
RVP	Reid Vapor Pressure
RVTI	Company Rival Technologies Inc.
SAGD	steam assisted gravity drainage
SCO	Synthetic crude oil
SDA	Solvent deasphalting
SYDEC	Selective Yield Delayed Coking
T	Temperature
TaBoRR	Tank Bottoms Recovery and Remediation
TDG-1	Terre de Grace
TRU	TRU process
UAOD	Ultrasound assisted oxidative desulfurization
UFR	Upflow reactor
UOP	Universal Oil Products
USP	Ultra selective pyrolysis
USPTO	United States Patent and Trademark Office
VCG	Value Creation Technology
VCI	Value Creation INC
VGO	Vacuum gas oil
VR	Vacuum residue
VTB	Vacuum tower bottoms
WHB	Waste heat boiler
WRI	Western Research Institute
WRITE	Western Research Institute Thermal Enhancement
ΔP	Pressure drop

the HYCON process (Bunker Reactor System) which uses conventional fixed-bed reactors and a system for continuous catalyst replacement [6,7].

In the ebullating-bed processes, the H-Oil process of Axens/IFP and the LC-Fining process of Chevron Lummus Global, similar in concept but different in some mechanical details, offer a final product containing around 25% of non-converted residual [8,9].

The slurry phase reactor processes employ disposable catalysts whose development aimed at decreasing the cost of the catalyst inventory, i.e., cost of the fresh hydroprocessing catalysts and that of the spent catalysts. A number of processes employing a disposable catalyst are in a developmental stage and others are in a near commercial stage [10].

2.3. Combined technologies

The main advantages of the integrated process schemes are in terms of product yields, quality of products, elimination of low-value by-products, and reduction of impurities. Various integrations of upgrading processes are reported in the literature, which include deasphalting, gasification, delayed coking, RFCC, ebullating-bed reactor, slurry phase reactor and fixed-bed hydrotreating [11].

3. Emerging technologies

Since the light crude reservoirs are getting scarce and because the current processes in refineries are not totally adequate to process heavy and extra-heavy crude oils a new group of technologies has emerged as a promising solution of the problem. These technologies are focused on the upgrading of the properties of those crudes, i.e. increase of API gravity and reduction of viscosity and impurities content such as sulfur, nitrogen and metals, either to transportation purposes or to feed to refineries.