UPGRADING AND REFINING OF NATURAL BITUMEN AND HEAVY OIL

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Summary

Tar sand (also known as oil sand and bituminous sand) is a sand deposit that is impregnated with dense, viscous petroleum-like material called bitumen. Tar sand deposits are widely distributed throughout the world and the various deposits have been described as belonging to two types: (a) stratigraphic traps; and (b) structural traps although gradations between the types of deposit invariably occur.

The only commercial operations for the recovery and upgrading of bitumen occur in northeast Alberta, Canada, near to the town of Ft. McMurray where bitumen from the Athabasca deposit is converted to a synthetic crude oil. Therefore most of the data available for inspection of bitumen and determination of behavior originate from studies of these Canadian deposits. The work on bitumen from other sources is fragmented and spasmodic. The exception is the bitumen from deposits in Utah, United States where on-going programs have been I place at the University of Utah for more than three decades.

Bitumen is relatively hydrogen-deficient when compared to heavy oil and conventional crude oil therefore requires that there be substantial hydrogen addition during refining. Heavy oil and conventional crude oil can be commercially upgraded and refined by a variety of processes. Bitumen is currently commercially upgraded by a combination of carbon rejection (coking) and product hydro treating.

Coking, the process of choice for residua (i.e., the non-volatile portions of conventional crude oil and heavy oil), is also the process of choice for bitumen conversion. Bitumen is currently converted commercially by delayed coking and by fluid coking. In each case the bitumen is converted to distillate oils, coke, and light gases. The coker distillate is a partially upgraded material and is a suitable feed for Hydrodesulfurization to produce a low-sulfur synthetic crude oil.

1. Introduction

The essential step required of refineries in the upgrading of heavy oil and bitumen is the conversion of these low-value feedstocks to high-value products such as liquid fuels.

Upgrading heavy oil and bitumen began with the introduction of Desulfurization processes that were designed to reduce the sulfur content of residua as well as some heavy crude oils and products from there. In the early days, the goal was Desulfurization but, in later years, the processes were adapted to a 10% to 30% by weight partial conversion operation, as intended to achieve Desulfurization and obtain low-boiling fractions simultaneously, by increasing severity in operating conditions. Refinery evolution has seen the introduction of a variety of heavy feedstock residuum cracking processes based on thermal cracking, catalytic cracking, and hydro conversion. Those processes are different from one another in cracking method, cracked product patterns and product properties, and will be employed in refineries according to their respective features.

Heavy oil has fewer components distilling at atmospheric pressure and under vacuum than conventional petroleum. Nevertheless, some heavy oils still pass trough the distillation stage of a refinery before further processing is undertaken. This is a question of economics and the ultimate goal of the refinery in terms of product slate. After distillation the residuum from the heavy oil might pass to a cracking unit such as visbreaking or coking to produce saleable products. Catalytic cracking of the residuum or the whole heavy oil is also an option but is very dependent on the constituents of the feedstock and their interaction with the catalyst.

In general terms, the quality of tar sand bitumen is low compared to that of conventional crude oil and heavy oil. The high carbon residue of heavy oil and bitumen dictate that considerable amounts of coke will be produced during thermal refining (see Table 1.) Upgrading and refining bitumen requires a different approach to that used for upgrading heavy oil. In addition, the distance that the bitumen must be shipped to the refinery and in what form as well as product quality must all be taken into account when designing a bitumen refinery.

API gravity of feedstock	Carbon residue, % by weight	Coke yield	
		Delayed coking	Fluid coking
2	30	45	35
6	20	36	23
10	15	28	17
16	10	18	12
26	5	9	3

Table 1. Predicted coke yields from various feedstocks

The low proportion of volatile constituents (i.e., those constituents boiling below 200 ^oC, below 390 ^oF) in bitumen precludes refining by distillation and it is recognized that refining by thermal means is necessary to produce liquid fuel streams. A number of factors have influenced the development of facilities that are capable of converting bitumen to a synthetic crude oil. A visbreaking product would be a hydrocarbon liquid that was still high in sulfur and nitrogen with some degree of unsaturation. This latter property enhances gum formation with the accompanying risk of pipeline fouling and similar disposition problems in storage facilities and fuel oil burners. A high sulfur content in finished products is environmentally unacceptable. In addition, high levels of nitrogen cause problems in the downstream processes, such as in catalytic cracking where nitrogen levels in excess of 3000 parts per million will cause rapid catalyst deactivation; metals (nickel and vanadium) cause similar problems.

However, higher boiling constituents (i.e., those boiling in the range 200 ^{o}C to 400 ^{o}C (390 ^{o}F to 750 ^{o}F) can be isolated by distillation but, in general terms, more than 40% by weight of tar sand bitumen boils above 540 ^{o}C (1000 ^{o}F). Thus, a product of acceptable quality could be obtained by distillation to an appropriate cut point but the majority of the bitumen would remain behind to be refined by whichever means would be appropriate, remembering, of course, the need to balance fuel requirements and coke production. It is therefore essential that any bitumen-upgrading program convert the non-volatile residuum to a lower-boiling, low-viscosity, low molecular weight, product that also has a high hydrogen/carbon ratio.

Bitumen is hydrogen-deficient that is upgraded by carbon removal (coking) or hydrogen addition (hydro cracking). There are two methods by which the conversion of bitumen can be achieved: (1) by direct heating of mined tar sand; and (2) by thermal decomposition of separated bitumen. The latter is the method used commercially but the former deserves mention here since there is the potential for commercialization.

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Biographical Sketch

James G. Speight has a Ph.D. in Organic Chemistry from the University of Manchester, England, and works for CDW Inc. as an Author/Lecturer/Technical and Business Advisor. Previously, he was Chief Executive Officer at the Western Research Institute (1990–1998). Dr. Speight has thirty years of experience in areas associated with the properties and processing of conventional and synthetic fuels. He has participated in, as well as led, significant research in defining the use of chemistry of heavy oil and coal. He has well over three hundred publications, reports, and presentations detailing these research activities. Dr. Speight is currently editor of the journal Petroleum Science and Technology (formerly Fuel Science and Technology International), editor of the journal Energy Sources, and co-editor of the journal Reviews in Process Chemistry and Engineering. He is recognized as a world leader in the areas of fuels characterization and development. Dr. Speight is also Adjunct Professor of Chemistry and Adjunct Professor of Chemical Engineering at the University of Wyoming as well as Adjunct Professor of Chemical and Fuels Engineering at the University of Utah. Dr. Speight is the author/editor/compiler of nineteen books and bibliographies related to fossil fuel processing and environmental issues. As a result of his work, he was awarded the Diploma of Honor, National Petroleum Engineering Society, For Outstanding Contributions to the Petroleum Industry in 1995 and the Gold Medal of Russian Academy of Sciences (Natural) for Outstanding Work in the Area of Petroleum Science in 1996. He has also received the Specialist Invitation Program Speakers Award from NEDO (New Energy Development Organization, Government of Japan) in 1987 and again in 1996. Dr. Speight also received the degree of Doctor of Sciences from the Scientific Research Geological Exploration Institute (VNIGRI), St. Petersburg, Russia For Exceptional Work in Petroleum Science in 1997.