JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

HYDROGEN REQUIREMENT ESTIMATION IN INDIAN PETROLEUM REFINERIES UNDER BS-VI FUEL NORMS: AN ANALYTICAL ASSESSMENT

[1]Pradyut Kumar Dhar

Research Engineer

Abstract: The enforcement of Bharat Stage VI (BS-VI) fuel specifications in India has imposed ultra-low sulfur limits and stringent fuel quality requirements, leading to a substantial increase in hydrogen consumption in petroleum refineries. Hydrogen is a critical and high-cost utility, predominantly consumed in hydrotreating and hydrocracking processes for impurity removal and product quality enhancement. This study presents an analytical methodology to estimate hydrogen requirements in Indian petroleum refineries under BS-VI norms, based on sulfur mass balance, reaction stoichiometry, and industrial process losses. A national-level case study for the year 2020 is presented, along with an assessment of the relative contribution of sulfur removal and aromatic saturation to total hydrogen demand. Results indicate that removal of approximately 2,910 ktpa of sulfur requires nearly 550 ktpa of hydrogen, while aromatic saturation consumes an even larger fraction in deep hydrotreating operations. The analysis highlights that refinery hydrogen demand accounted for nearly 40% of India's total hydrogen consumption in 2020 and is projected to increase significantly toward 2050. The study underscores the importance of catalyst selectivity, process severity optimization, and hydrogen network integration for sustainable refinery operations.

1. Introduction

Petroleum refineries play a crucial role in supplying transportation and industrial fuels while complying with increasingly stringent environmental regulations. In India, the introduction of Bharat Stage VI (BS-VI) fuel standards has limited sulfur content in gasoline and diesel fuels to below 10 ppm. Achieving such ultra-low sulfur levels requires severe hydroprocessing operations, thereby significantly increasing hydrogen consumption.

Hydrogen is extensively used in refineries for hydrodesulfurization, hydrodenitrogenation, hydrodearomatization, and hydrocracking reactions. In addition to impurity removal, hydrogen is essential for improving fuel quality parameters such as cetane number, smoke point, and stability. Reduction of aromatic content, particularly in diesel fuels, improves ignition quality but requires substantial hydrogen input due to aromatic ring saturation reactions.

Hydrogen is generated within refineries through steam methane reforming (SMR), steam naphtha reforming (SNR), and as a by-product of continuous catalytic reforming (CCR) units. Given its high production cost, typically in the range of INR 150–200 per kg, hydrogen availability has become a critical constraint influencing refinery throughput, operating severity, and product slate optimization.

Although several studies have addressed refinery hydrogen management and network optimization, limited literature is available that quantitatively estimates national-level hydrogen demand for Indian refineries under BS-VI norms using transparent stoichiometric and process-based assumptions. The present study addresses this gap by providing an analytical framework for hydrogen demand estimation and highlighting the dominant contributors to hydrogen consumption.

The objectives of this study are:
(i) to develop a methodology for estimating hydrogen demand in petroleum refineries based on sulfur balance and reaction stoichiometry,
(ii) to quantify hydrogen requirements for Indian refineries under BS-VI fuel specifications, and
(iii) to analyze the relative impact of sulfur removal and aromatic saturation on overall hydrogen consumption.

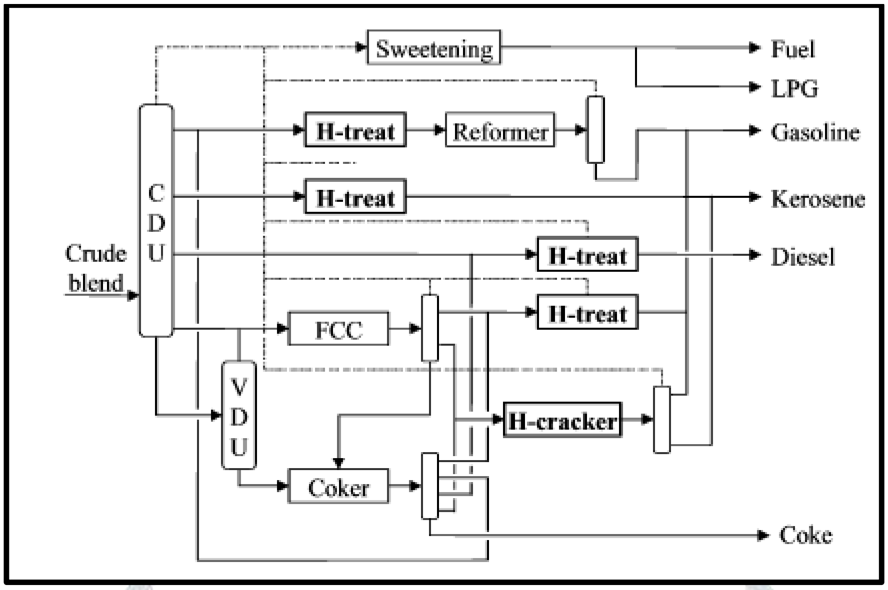

Figure 1: Process flow diagram of a refinery highlighting the hydrogen-consuming processes (1)

2. Methodology for Hydrogen Demand Estimation

In petroleum, hydrogen gas is majorly getting consumed in Hydrotreating and Hydrocracking process of different hydrocarbons like naphtha, diesel, vacuum gas oil etc. Hydroporcessing process (hydrotreating and hydrocracking) involves following reactions. All these reactions happen in presence of hydrogen.

- Elimination of sulfur by hydrodesulfurization ($RSH + H_2 \rightarrow RH + H_2S$)
- Elimination of nitrogen by hydrodenitrogenation ($C_4H_4NH + 4H_2 \rightarrow C_4H_{10} + NH_3$)
- Elimination of oxygen by hydrodeoxygenation ($C_6H_5OH + H_2 \rightarrow C_6H_6 + H_2O$)
- Elimination of halogens by hydrodehalogenation ($RCl + H_2 \rightarrow RH + HCl$)
- Elimination of metals by hydrodemetalization [The organometallic compounds (containing Pb, Cu, Ni, Si, and V) are cracked and the metals are trapped on the catalyst.]
- Saturation of olefins, di-olefins, and aromatics ($C_5H_{10} + H_2 \rightarrow C_5H_{12}$)
- Hydrocracking of hydrocarbons ($R - CH_2 - CH_2 - R' + H_2 \rightarrow R - CH_3 + R' - CH_3$)

Based on the extent of impurities presence in feed stocks (such as sulfur, nitrogen, olefins, metals, aromatics), overall hydrogen consumptions are being estimated. Normally, it is considered that for one mole of sulfur removal 3 moles of hydrogen is required, for one mole of aromatic removal 3 moles of hydrogen is required. So the overall amount of hydrogen required is determined by:

- Chemical Hydrogen Consumption - The hydrogen consumed during the hydrotreating reactions
- Solution Losses - The hydrogen that is removed from the reactor circuit dissolved in the liquid hydrocarbon leaving the high pressure separator
- Mechanical Losses - The hydrogen lost through the makeup and recycle gas compressors packing vents and seals. This value may be roughly estimated at 3-5% of the combined chemical consumption plus solution losses
- Venting Losses - The hydrogen lost in the purge stream from the high pressure separator to maintain recycle gas purity

Table 1 represents indicative hydrogen consumptions data for different refining processes

Table 1 : Hydrogen consumptions in refining processes (2)

Process	%wt on feed	%wt on crude
HT Str. Run Naphtha	0.05	0.01
HT FCC/TC Naphtha	1	0.05-1
HT Kerosene	0.1	0.01-0.02
HDS LS Gasoil to 0.05%	0.15	0.04
HDS HS Gasoil to 0.05%	0.35	0.05
HDS FCC/TC Gasoline	1	0.1
Cycle oils hydrogenation	3	0.3
Hydrocracking VGO	2-3	0.5-0.8
Deep residue conversion	2-3.5	1-2

Figure 2 shows a typical refinery hydrogen utilization network. Here hydrogen from hydro plant and CCR unit has been used for hydrocracking (HCU) unit, diesel hydrotreating (DHT) unit, naphtha hydrotreating (NHT) unit, kerosene hydrotreating (KHT) unit, hydrodearomatization (HDA) unit, cracked naphtha hydrotreating (CNHT) unit.

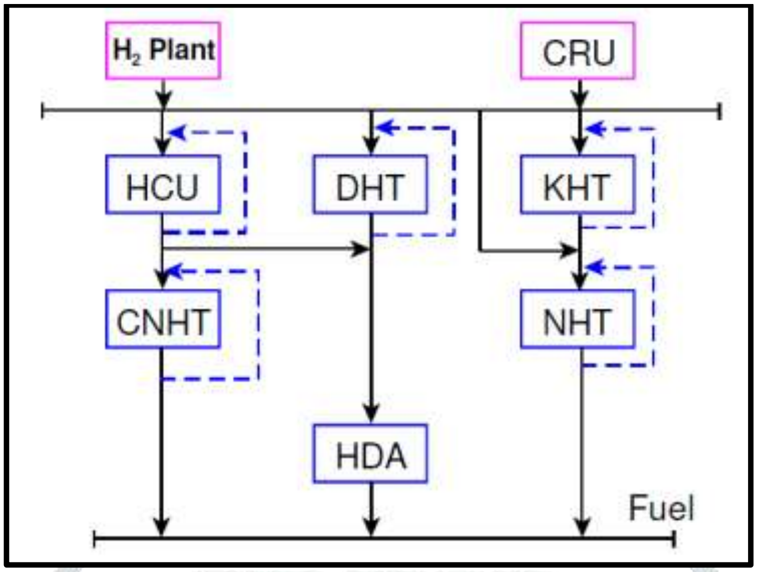

Figure 2: Hydrogen utilization network (3)

3.0 Results : Hydrogen Demand Estimation for Indian Refineries

In this section estimation of hydrogen consumptions has been discussed. To estimate the total amount of hydrogen required for a petroleum refinery, following steps has been taken:

I. Estimate the allowable sulphur content in the refinery products
II. Estimate the quantity of sulphur present in the crude oil
III. Subtract the allowable sulphur from the sulphur present in crude oil to estimate how much sulphur needs to be removed
IV. Calculate the amount of hydrogen required for removal of this amount of sulphur
V. Estimate the amount of hydrogen produced as by product from continuous catalytic reforming process
VI. Subtsract Hydrogen produced from continuous catalytic reforming process overall hydrogen demand
VII. The result of these steps leads to the final hydrogen demand.

Now for Indian crude basket which is majorly a ratio of 25:75 of European crude and Middle East crude, the average Sulphur content is around 1.275 wt%. This, including the domestic oil production (~17% of total crude required), which has a lower sulphur content (less than 0.5%), yields an total average sulphur content of 1.15% (4). In 2020, based on total crude processed in India , the total amount of sulphur present in the feedstock is approximately 3,500 ktpa (3) . The allowable sulphur is around 590 ktpa. So nearly 2,910 ktpa of sulphur needs to be removed via desulphurisation process. As indicated, that for one mole of sulfur removal, 3 moles of hydrogen is required.

Total Sulfur: 2910 ktpa = 2910000 kg = (2910000/32) kmol = 90,937.5 kmol

Hydrogen required = (90,937.5 * 3) kmol= 272,812.5 kmol = (272,812.5 * 2.016) kg= 549,990 kg = 550 ktpa

So overall hydrogen requirement is 550 ktpa for removal of 2910 ktpa Sulphur. In this way , it estimated that in 2020, total refinery demand for hydrogen is 2.6 Mt, or around 40% of total hydrogen demand in India (4).

Accordingly assessment for hydrogen demand for Indian refineries has been done and shared in Figure 3.

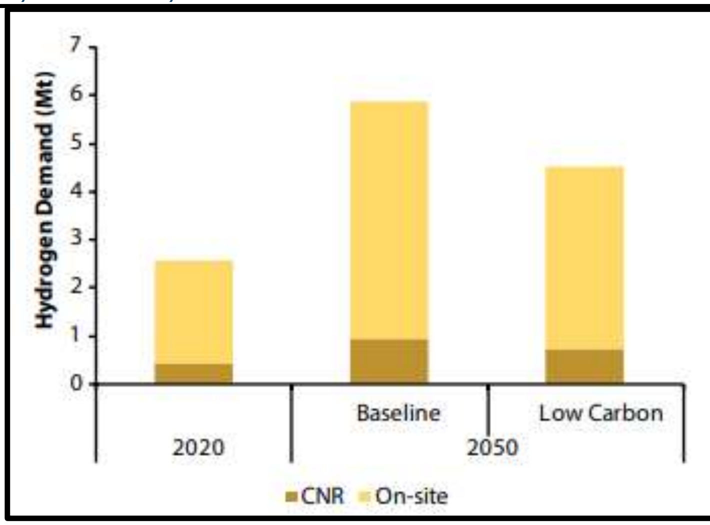

Figure 3: Hydrogen demand in refineries, 2020 and 2050 (4)

4.0 Discussion

Hydrogen requirement in petroleum refineries is not only for removal of sulfur compound but also for removal of other impurities (example: nitrogen) and improvement of product qualities (example: cetane number). Following table 2 summarizes an in depth hydrogen consumption calculations for a diesel hydrotreating process.

Table 2: Calculation of hydrogen consumptions for a typical diesel hydrodesulphurization process

Properties / Descriptions	**Feed Diesel**	**Product Diesel**	**Hydrogen consumed (wt%)**
Sulfur (ppm)	14000	8	0.244
Nitrogen (ppm)	133	0.36	0.003
Bromine No	0.93	0.02	0.012
Aromatics	21.8	12.8	0.500
Total Chemical Hydrogen Consumed			0.759
Total hydrogen consumptions (including 10 % in total of solution loss, mechanical loss and venting loss)			0.835

So it is understood from the above table that nearly 2 times of hydrogen is getting consumed for aromatics saturation processes compared to sulfur removal processes. As hydroprpocessing processes are catalytic process, so it is important to develop catalysts (low aromatic saturation, favorable for direct desulphurizations etc) and optimize the processes (low pressure, low temperature) which selectively removes sulfur, nitrogen, and other impurities and saturates less amounts of aromatics.

Hydrogen consumption in refineries is strongly influenced by aromatic saturation reactions, particularly in diesel hydrotreating units. Aromatic hydrogenation improves cetane number but represents the largest hydrogen sink. Catalyst selectivity toward direct desulfurization and optimized operating conditions can significantly reduce hydrogen demand.

5.0 CONCLUSION

This study provides a national-level analytical assessment of hydrogen requirements in Indian petroleum refineries under BS-VI norms. Hydrogen demand is governed not only by crude sulfur content but also by aromatic saturation requirements and process severity. Hydrogen is a critical utility in petroleum refineries, primarily consumed in hydrotreating and hydrocracking processes for sulfur, nitrogen, and aromatic removal. Case-based assessment shows that removal of approximately 2,910 ktpa of sulfur requires nearly 550 ktpa of hydrogen. Detailed analysis of diesel hydrotreating reveals that aromatic saturation accounts for a larger share of hydrogen consumption than sulfur removal.

Therefore, refinery hydrogen demand depends not only on crude sulfur content but also on catalyst performance, reaction selectivity, and process operating conditions. Projections indicate that hydrogen demand in Indian refineries could reach approximately 6 Mt by 2050, underscoring the importance of hydrogen optimization strategies and advanced catalytic technologies.

6.0 REFERENCES

1) Alves, J.J., Towler, G.P., "Analysis of Refinery Hydrogen Distribution Systems", Ind.Eng.Chem.Res.,2002,vol.41,5759-5769.
2) Aitani, A.M., "Process to Enhance Refinery- Hydrogen Production", Petroleum and Gas Technology Devision, The Research Institute, Kin
3) Singh, B. B., Bi-linear Data Reconciliation and Rigorous Optimisation of Refinery Hydrogen Networks with Hydrogen Plant. Process Integration Research Consortium, Manchester, 2006
4) Will Hall, Thomas Spencer, G Renjith, Shruti Dayal, The Potential Role of Hydrogen in India, The Energy and Resources Institute