CONVERSION OF LIGHT CYCLE OIL TO BENZENE AND ALKYLATED MONOAROMATICS OVER VARIOUS MONOMETALLIC AND BIMETALLIC OXIDE CATALYSTS IN THE PRESENCE OF HYDROGEN DONOR

AKSHATA RAMTEKE

DEPARTMENT OF CHEMICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI
JANUARY 2025

Conversion of light cycle oil to benzene and alkylated mono-aromatics over various monometallic and bimetallic oxide catalysts in the presence of hydrogen donor

by

Akshata Ramteke

Department of Chemical Engineering

Submitted

In fulfillment of the requirements of the degree of

Doctor of Philosophy

to the

Indian Institute of Technology Delhi

January 2025

Dedicated to my Parents

Savita Ramteke and Vijay Ramteke

Without whom this Ph.D. journey would have been incomplete

Certificate

This is to certify that the thesis entitled "**Conversion of light cycle oil to benzene and alkylated mono-aromatics over various monometallic and bimetallic oxide catalysts in the presence of hydrogen donor"** being submitted by **Ms. Akshata Ramteke** to the Indian Institute of Technology Delhi for the award of the degree of **Doctor of Philosophy** is a record of *bonafide* research work carried out by her. **Ms. Akshata Ramteke** has worked under our guidance and supervision and has fulfilled the requirements for the submission of this thesis, which to our knowledge has reached the requisite standard. The research report and results presented in this thesis are original and have not been submitted, in part or full, to any other University or Institute for the award of any other degree or diploma.

Dr. K. K. Pant
Professor,
Department of Chemical Engineering
Indian Institute of Technology Delhi
New Delhi-110016

Dr. Divesh Bhatia
Professor,
Department of Chemical Engineering
Indian Institute of Technology Delhi
New Delhi-110016

Acknowledgments

Every project combines the knowledge and experience of both students and experts, with proper guidance being essential. I express my profound gratitude to **Prof. Divesh Bhatia** and **Prof. K.K. Pant** from the Department of Chemical Engineering at IIT Delhi, whose mentorship made this project possible. Their invaluable guidance, encouragement, and constructive criticism over the past six years have been instrumental in my research. Despite their busy schedules, they reviewed my work and provided crucial feedback, greatly enhancing its quality. Working under their esteemed guidance has been an unforgettable experience, and their kindness and support are deeply appreciated. I am also thankful to the Head of the Department of Chemical Engineering Indian Institute of Technology Delhi and all the faculty members of the department for their support and valuable suggestions. I wish to convey my gratitude to members of my research committee Prof. M. Ali Haider, Prof. S. Upadhyayula, and Prof. Nidhi Jain for their valuable suggestions and critical review of my work. I am thankful to all the staff members in the departmental characterization laboratory and Central Research Facility (CRF), their eagerness to help will always be appreciated and remembered.

I express my special thanks to my senior lab members Dr. Sonal Asthana, Dr. Rohit Kumar, Dr. Sourabh Mishra, Dr. Uma Dwivedi, Dr. Ejaz Ahmed, Dr. Sonit Balyan, Dr. Kaushal Parmar, Dr. Prashant Jadhao, Dr. Ashish Bohre, Dr Kunwar Pal, Dr. Arindam Modak, Dr. Akshay Mankar, Dr. Rajan Singh, Dr Ramdayal Panda, Dr. Komal Tripathi, and Dr. Sagar Dhanuskar, for their valuable suggestions to make the research work more cordial. I would like to thank my colleagues in the lab Dr. Shreya Singh, Dr. Amrita Preetam, Dr. Snigdha Mishra, Dr. Vaibhav Pandey, Dr. Vallari Chourasia, Dr. S.C Tiwari, Mr. Pranit Samanta, Mr. Venkanna, Mr. Shashank Shekhar Pandey, Ms. Iqra, Dr. Deepti Mishra, Ms. Komal Sharma, Mr. Avijit Das, Dr. Marut Jain, Dr. Sadaf, Ms. Shally Gupta, Mr Abhishek Shaoo, Ms. Nidhi Kushwaha, Mr. Abdul, Ms. Neetu, Ms. Aisha Noor, Mr. Kaushik Kundu, Ms. Marvi Kaushik,

Dr. Pranav kherdekar, Ms. Chaitra Borkar, Mr. Ilyas Yusuf Mir, and Mr. Vishal Yogi for the peasant lab environment and for helping me with doubts throughout my studies. I am thankful to all my friends of IIT Delhi Mr. Manoj Kumar Beriya, and Mr. Ranjan Singh. I would like to thank Dr. Omvir Singh and my M. Tech senior Dr. Payal Bhautik for fruitful technical discussion during my Ph.D. I would like to extend my thanks to Mr. Vishesh Kumar, Mr. Krishna Kumar, Mr. Suchit Kumar, Mr. Ashish, and Mr. Vijay Pal for their constant help in every possible way to carry forward my research and performing experiments.

I have no words to express the motivation and inspiration given by my parents Mr. Vijay Ramteke and Mrs. Savita Ramteke, whose courage through their life has been a spiritual inspiration to me and holds no bounds. Their encouraging words and deeds through these tough and emotional times will always remain in my heart and soul. I am thankful to my sister (Poonam) and brother (Aman Ramteke) for their constant moral support and motivation during my studies. I cannot thank enough my whole family for having faith and trust in all my dreams and allowing me to pursue my goals without any bindings. I am also grateful to my bestfriend Dr. Nikhil Dhimole for his encouragement, support, and care throughout my research work. I am deeply grateful to my beloved pets Summu and Duggu, whose love and companionship bring immense joy to my life. A special thanks to Jimmy, the cherished dog from the IIT Delhi campus, who holds a special place in my heart. They have been my source of happiness and balance throughout this journey. I also want to express my sincere thanks to all those who had directly or indirectly helped me at various stages of this work thereby making it a total success. At last, thanks to the almighty God for his blessing and for giving me patience, strength, and peace throughout the journey of life.

Akshata Ramteke

Abstract

The per capita consumption of polymers is projected to increase, while the demand for conventional fuels like gasoline and diesel is expected to decrease. This shift has prompted a focus on converting crude to chemicals. Light cycle oil (LCO), with high amounts of sulfur and aromatics, has a low cetane number, making it unsuitable for diesel blends. Converting LCO to benzene, toluene, and xylene (BTX) can meet the rising chemical demand and utilize low-quality LCO feedstock. However, LCO conversion under FCC conditions is typically low, necessitating modifications to catalysts and processes for higher BTX yields. Even though various studies have been performed on bifunctional monometallic and bimetallic oxide catalysts at high pressure, their application at atmospheric pressure has not yet been studied. In this study, the selective conversion of diaromatics and triaromatics in LCO into monoaromatics using bifunctional catalysts is studied under FCC conditions. The hydrogen donor source utilized was n-hexadecane (n-HD) at atmospheric pressure instead of H_2. Thermodynamic analysis and cracking experiments indicate that the optimal temperature for maximizing BTX yield is 550 °C. n-HD is found to be an effective hydrogen donor when co-fed with LCO, resulting in enhanced BTX yield and reduced coke formation, with a 30 wt. % concentration shown to optimize feed conversion. Catalytic cracking experiments highlight Beta zeolite's superior activity compared to other zeolites (Y, ZSM-5, and Mordenite), and the trends are correlated to the acidity and structural characteristics such as pore volume, pore diameter, crystallite size, and surface area. Additionally, DFT calculations show that amongst various zeolites, Beta zeolite exhibits the lowest activation barrier for 1-methylnaphthalene cracking. The distinct reactivity levels of triaromatic, diaromatic, and condensed polyaromatic compounds are highlighted, with triaromatic compounds exhibiting the highest reactivity. These results are explained by the degree of unsaturation and bond angle analysis. Both monometallic (Ni, W, Co, Mo) and bimetallic (NiW, CoMo) oxide catalysts supported on

various zeolites (Mordenite, ZSM-5, Beta, Y, and Mix) were investigated. Bimetallic oxide catalysts exhibited superior performance, displaying higher total monoaromatic hydrocarbon (MAH) yield, BTX yield, and feed conversion compared to monometallic oxide catalysts. This improvement was attributed to the formation of bimetallic oxide species along with their strong interactions with the support, as evidenced by XPS, H_2-TPR, and UV-DRS analyses. Bimetallic oxide catalysts also demonstrated higher moderate acidity, an optimal balance of Brønsted and Lewis acid sites, and a higher hydrogen transfer index, explaining their higher BTX yield and lower coke formation. Experiments with n-HD as the sole reactant indicated that LCO primarily contributed to MAH formation, with n-HD serving as the hydrogen source. DFT simulations aligned with experimental findings, showing that bimetallic oxide catalyst had the lowest activation barrier for 1MN cracking in the presence of n-HD. The selective cracking of triaromatic compounds to diaromatics was rapid, with the conversion of diaromatics governing total MAH yield and the cracking of monoaromatic-2-ring compounds governing BTX production. An inverse correlation between the selectivity for 2-ring monoaromatics and BTX shows the formation of 2-ring monoaromatics as intermediates. Based on detailed product characterization, reaction pathways for the conversion of diaromatic and triaromatic are proposed. Additionally, a Co/Mo ratio above 0.5 leads to the formation of a dense $CoMoO_4$ phase, adversely affecting catalytic activity, while the optimal Co/Mo ratio of 0.5 maximizes BTX yields and minimizes coke production. Similar reactivity among alkylated naphthalene compounds suggested grouping them in developing a lumped kinetic model. A 12-lump kinetic model was developed based on the experimental data to elucidate the kinetic characteristics of LCO cracking on the CoMo/Beta catalyst, serving as a foundational tool for optimizing catalytic processes in refinery operations.

Keywords: Light cycle oil (LCO); BTX; Bifunctional catalysts; Hydrogen donor; Bimetallic catalysts; Structure-activity relation; FCC; Cracking

सार

पॉलिमर के प्रति व्यक्ति की खपत में वृद्धि की अपेक्षा है, जबकि पारंपरिक ईंधनों जैसे कि गैसोलीन और डीज़ल की मांग में कमी आने की संभावना है। इस बदलाव ने कच्चे तेल को रसायनों में परिवर्तित करने पर ध्यान केंद्रित करने के लिए प्रेरित किया है। लाइट सायकल तेल, जिसमें उच्च मात्रा में अरोमैटिक्स और सल्फर होता है, की सेटेन संख्या कम होती है, जिससे यह डीज़ल मिश्रण के लिए अनुपयुक्त हो जाता है। लाइट सायकल तेल को बेंजीन, टोल्युइन और ज़ाइलिन (बीटीएक्स) में परिवर्तित करना बढ़ती रासायनिक मांग को पूरा कर सकता है और निम्न गुणवत्ता वाले लाइट सायकल तेल फीडस्टॉक का उपयोग कर सकता है। हालांकि, एफसीसी स्थितियों के तहत लाइट सायकल तेल का रूपांतरण आमतौर पर कम होता है, जिससे बीटीएक्स की उपज बढ़ाने के लिए उत्प्रेरकों और प्रक्रियाओं में संशोधन की आवश्यकता होती है। जबकि विभिन्न अध्ययनों में उच्च दबाव पर बायफंक्शनल मोनोमेटलिक और बायमेटलिक ऑक्साइड उत्प्रेरकों का उपयोग किया गया है, उनकी वायुमंडलीय दबाव पर उपयोग का अभी तक अध्ययन नहीं किया गया है। इस अध्ययन में, एफसीसी स्थितियों के तहत बायफंक्शनल उत्प्रेरकों का उपयोग करके लाइट सायकल तेल में डायरोमैटिक्स और ट्राईरोमैटिक्स को मोनोरोमैटिक्स में परिवर्तित करने का अध्ययन किया गया है। हाइड्रोजन डोनर स्रोत के रूप में H_2 के बजाय न-हेक्साडेकेन का उपयोग किया गया। थर्मोडायनामिक विश्लेषण और क्रैकिंग प्रयोगों से पता चलता है कि बीटीएक्स की अधिकतम उपज के लिए सर्वोत्तम तापमान 550 °C है। लाइट सायकल तेल के साथ सह-फीड के रूप में न-हेक्साडेकेन को उपयोग करने से बीटीएक्स की उपज में सुधार और कोक निर्माण में कमी होती है, जिसमें 30 wt. % की

सांद्रता फीड रूपांतरण के लिए अनुकूल होती है। कैटेलिटिक क्रैकिंग प्रयोगों से पता चला है कि बीटा ज़ियोलाइट का प्रदर्शन अन्य ज़ियोलाइट्स (वाई, जेडएसएम-5, और मोर्डेनाइट) की तुलना में बेहतर है, और प्रवृत्तियों को अम्लता और संरचनात्मक विशेषताओं (जैसे क्रिस्टलाइट का आकार, छिद्र का आयतन, छिद्र का व्यास, और सतह क्षेत्र) से जोड़ा गया है। इसके अलावा, डीएफटी गणनाएँ दिखाती हैं कि विभिन्न ज़ियोलाइट्स के बीच, बीटा ज़ियोलाइट का 1-मिथीलीनाफ्थालीन क्रैकिंग के लिए सबसे कम सक्रियता बाधा है। ट्रायरोमैटिक, डायरोमैटिक, और संकुचित पॉलीअरोमैटिक यौगिकों की भिन्न प्रतिक्रियाशीलता को उजागर किया गया है, जिसमें ट्रायरोमैटिक यौगिकों की उच्चतम प्रतिक्रियाशीलता होती है। ये परिणाम असंतृप्तता और बंध कोण विश्लेषण के माध्यम से समझाए गए हैं। मोनोमेटलिक (को, मो, नी, डब्ल्यू) और बायमेटलिक (कोमो, नी-डब्ल्यू, नीमो) ऑक्साइड उत्प्रेरकों का विभिन्न ज़ियोलाइट्स (मोर्डेनाइट, जेडएसएम-5, बीटा, वाई, और मिक्स) पर अध्ययन किया गया। बायमेटलिक ऑक्साइड उत्प्रेरकों ने उत्कृष्ट प्रदर्शन दिखाया, जिसमें मोनोमेटलिक ऑक्साइड उत्प्रेरकों की तुलना में उच्च कुल मोनोरोमैटिक हाइड्रोकार्बन (एमएएच) उपज, बीटीएक्स उपज, और फीड रूपांतरण पाया गया। इस सुधार को बायमेटलिक ऑक्साइड प्रजातियों के निर्माण और उनके समर्थन के साथ मजबूत अंतःक्रियाओं के लिए जिम्मेदार ठहराया गया है, जैसा कि H_2-TPR, XPS, और UV-DRS विश्लेषणों से स्पष्ट हुआ है। बायमेटलिक ऑक्साइड उत्प्रेरकों ने उच्च मध्यम अम्लता, ब्रॉन्स्टेड और लुईस अम्ल साइट्स का अनुकूल संतुलन, और उच्च हाइड्रोजन ट्रांसफर इंडेक्स प्रदर्शित किया, जो उनकी उच्च बीटीएक्स उपज और कम कोक उत्पादन को स्पष्ट करता है। न-हेक्साडेकेन को एकमात्र अभिकर्ता के रूप में उपयोग करने पर, लाइट

सायकल तेल मुख्य रूप से मोनोरोमैटिक्स के निर्माण में योगदान करता है, जिसमें न-हेक्साडेकेन हाइड्रोजन स्रोत के रूप में कार्य करता है। डीएफटी सिमुलेशंस ने प्रयोगात्मक निष्कर्षों के साथ संरेखित किया, दिखाते हुए कि बायमेटलिक ऑक्साइड उत्प्रेरकों का न-हेक्साडेकेन की उपस्थिति में 1-एमएन क्रैकिंग के लिए सबसे कम सक्रियता बाधा है। ट्रायरोमैटिक यौगिकों का डायरोमैटिक में चयनात्मक क्रैकिंग तेजी से होती है, जिसमें डायरोमैटिक्स का रूपांतरण कुल मोनोरोमैटिक उत्पादन को नियंत्रित करता है और 2-रिंग मोनोरोमैटिक यौगिकों का क्रैकिंग बीटीएक्स उत्पादन को प्रभावित करता है। 2-रिंग मोनोरोमैटिक्स के लिए चयनिता और बीटीएक्स के बीच एक विपरीत संबंध दर्शाता है, जिसमें 2-रिंग मोनोरोमैटिक्स मध्यवर्ती के रूप में कार्य करता है। उत्पाद वितरण के विश्लेषण ने डायरोमैटिक और ट्रायरोमैटिक क्रैकिंग के लिए एक तंत्र का प्रस्तावित किया। इसके अलावा, को/मो का अनुपात 0.5 से अधिक होने पर घन कोमोओ$_4$ चरण का निर्माण होता है, जो कैटेलिटिक गतिविधि को नकारात्मक रूप से प्रभावित करता है, जबकि 0.5 का आदर्श को/मो अनुपात बीटीएक्स उपज को अधिकतम करता है और कोक उत्पादन को न्यूनतम करता है। अल्काइलित नाफ्थालीन यौगिकों के बीच समान प्रतिक्रियाशीलता ने सुझाव दिया कि उन्हें एक समूह में विकसित किया जाए ताकि एक लंपड काइनेटिक मॉडल विकसित किया जा सके। प्रयोगात्मक डेटा के आधार पर 12-लंप काइनेटिक मॉडल विकसित किया गया है, जो कोमो/बीटा उत्प्रेरक पर लाइट सायकल तेल क्रैकिंग की काइनेटिक विशेषताओं को स्पष्ट करता है, जो रिफाइनरी संचालन में उत्प्रेरक प्रक्रियाओं के अनुकूलन के लिए एक मौलिक उपकरण के रूप में कार्य करता है।

Declaration by author

This thesis is composed of my original work and contains no material previously published or written by another person except where due reference has been made in the text. I have clearly stated the contribution of others to jointly authored works that I have included in my thesis.

I have clearly stated the contribution of others to my thesis as a whole, including statistical assistance, survey design, data analysis, significant technical procedures, professional editorial advice, financial support, and any other original research work used or reported in my thesis.

The content of my thesis is the result of work I have carried out since the commencement of my higher degree by research candidature and does not include a substantial part of work that has been submitted to qualify for the award of any other degree or diploma in any university or other tertiary institution. I have clearly stated which parts of my thesis, if any, have been submitted to qualify for another award.

I acknowledge that an electronic copy of my thesis must be lodged with the University Library and, subject to the policy and procedures of the Indian Institute of Technology Delhi, the thesis be made available for research and study following the Copyright Act 1968 unless a period of embargo has been approved by the Dean of the Graduate School.

I acknowledge that the copyright of all material contained in my thesis resides with the copyright holder(s) of that material. Where appropriate I have obtained copyright permission from the copyright holder to reproduce material in this thesis and have sought permission from co-authors for any jointly authored works included in the thesis.

Publications included in this thesis

[1] Ramteke, A. V., Kaushik, M., Bhatia, D., & Pant, K. K. (2024). Effect of temperature, hydrogen donor, and zeolites on light cycle oil cracking: Thermodynamic, experimental, and DFT analyses. Sustainable Energy & Fuels, 8(16), 3740-3752. (Incorporated within Chapter 4).

[2] Ramteke, A. V., Bhatia, D., & Pant, K. K. (2024). Selective cracking of light cycle oil to monoaromatics over non-noble bifunctional zeolite-supported Ni and NiW catalysts. Fuel, 358, 130085. (Incorporated within Chapter 5).

[3] Ramteke, A. V., Bhatia, D., & Pant, K. K. (2023). Conversion of light cycle oil to benzene and alkylated monoaromatics over monometallic and bimetallic CoMo catalysts in the presence of hydrogen donor. Fuel, 342, 127737. (Incorporated within Chapter 6).

[4] Ramteke, A. V., Mishra, D., Mishra, S., Pant, K. K., & Bhatia, D. (2023). Conversion of fly-ash into pristine ZSM-5 and its application for methane dehydroaromatization reaction. Journal of Industrial and Engineering Chemistry. (Incorporated a few parts within Chapter 4).

Submitted manuscripts included in this thesis

I have no other manuscripts from the thesis submitted and under review at the time of submission.

To be submitted manuscripts containing thesis work

[6] Ramteke, A. V., Kaushik, M., Bhatia, D., & Pant, K. K. Cracking of light cycle oil into BTX over bifunctional CoMo catalysts supported on Beta zeolite: Structure-activity relationship, optimizing Co and Mo ratio, DFT and kinetic study (Under preparation)

[7] Ramteke, A. V., Bhatia, D., & Pant, K. K. Conversion of Light Cycle Oil to BTX using various bifunctional catalysts supported on fly-ash derived zeolites (Under preparation)

Contributions by others to the thesis

In the above-listed publications, my contribution to the authored works is specified by the order of author names. For papers included in this thesis, where I appeared as a first author, I was accountable for material synthesis, testing, experiments design and implementation, data analysis, drafting of the manuscript, and preparation of figures and tables. In paper 4, Ms. Marvi Kaushik provided me the theoretical insights by conducting DFT studies. For other sections of the papers, the corresponding authors Prof. K. K. Pant, and Prof. Divesh Bhatia guided conception and manuscript drafting. Prof. K. K. Pant was responsible for securing research funds that supported experimental consumables and measuring instruments.

Other publications during candidature

[1] Singh, O[#]., Ramteke, A. V[#]., Joshi, B., Vempatapu, B. P., Pant, K. K., Ray, A., & Sarkar, B. (2023). Sustainable Bioaromatics from Sapium Oil over Encaged AlPO4 Zeolite Material: A Feasibility Study. ACS Sustainable Chemistry & Engineering, 11(48), 17061-17074.

[2] Sagar Dhanuskar, **Akshata Vijay Ramteke**, Yashi Agrawal, Ejaz Ahmad, Arindam Modak, K. K. Pant, Catalytic cracking and deoxygenation of cottonseed oil to produce light olefins over lanthanum impregnated zeolite. Biomass and Bioenergy (under review).

[2] Sagar Dhanuskar[#], **Akshata Vijay Ramteke**[#], Arindam Modak, K. K. Pant, Catalytic cracking and deoxygenation of cottonseed oil to produce light olefins over metal impregnated coal fly-ash derived ZSM-5. Journal of Environmental Chemical Engineering (under review).

Statement of parts of the thesis submitted to qualify for the award of another degree.

No works submitted towards another degree have been included in this thesis.

Research involving human or animal subjects.

No animal or human subjects were involved in this research.

Nomenclature

A_C	Area of the catalyst bed, m^2
A_T	total acidity (mmol/g)
C_R	relative crystallinity (%)
d_c	average crystallite size (nm)
D_{po}	average pore diameter (Å)
E_a	activation barrier (kJ/mol)
E_i	activation energy for the formation of species 'i' (kJ/mol)
F	objective function
k_{i_o}	pre-exponential factor for the formation of lump 'i' (1/sec)
k_i	kinetic constant for the formation of lump 'i' (m/sec)
M	mass of catalyst (g)
$\dot{m}$	mass flow rate of the feed (g/sec)
m_1	mass transfer coefficients
S_i	selectivity of the product 'i' (%)
r_i	rate of reaction
S_{micro}	micropore area ($m^2\ g^{-1}$)
V_{cat}	volume of the catalyst in m^3
V_{meso}	mesopore volume ($cm^3\ g^{-1}$)
V_{micro}	micropore volume ($cm^3\ g^{-1}$)
V_{total}	total volume ($cm^3\ g^{-1}$)
WHSV	weight hourly space velocity (h^{-1})
w_j^{feed}	mass of component j at the reactor inlet (g)
$w_j^{product}$	mass of component j at the reactor outlet (g)
w_{LCO}^{feed}	mass of the LCO cut in the feed (g)
$w_{LCO}^{product}$	mass of the LCO cut in the product (g)
W_T^{feed}	total mass of the feed at the reactor inlet (g)
$X_{e,ind}$	individual equilibrium conversion (%)
$X_{e,ov}$	overall equilibrium conversion (%)
X_j	conversion of component j (%)
X_{LCO}	LCO conversion (%)
$Y_{e,BTX}$	equilibrium yield of BTX (%)
Y_i	yield of the product 'i' (%)
Y_{iS}	yield of lump 'i' at the surface (%)
φ	deactivation function
ΔH_{rxn}	heat of reaction (kJ/mol)

Abbreviations

1MN	1-methylnaphthalene
2MA	2-methylanthracene
2MN	2-methylnaphthalene
3MA	3-methylanthracene
3MN	3-methylnaphthalene
4MA	4-methylanthracene
4MN	4-methylnaphthalene
9MA	9-methylanthracene
Anth	anthracene
B	benzene
BaA	benz[a]anthracene
BAS	brønsted acid sites
B.E.	binding energy
BTX	benzene, toluene, and xylene
BTEX	benzene, toluene, ethyl benzene, and xylene
B3LYP	becke 3 parameter hybrid functional
CLO	clarified oil
COM	commercial
COTC	crude oil to chemicals
Di-AR	diaromatics
DFT	density functional theory
EB	ethyl benzene
FBP	final boiling point
FCC	fluidized catalytic cracking
FID	flame ionization detector
GC−DHA	gas chromatography with detailed hydrocarbon analysis
GGA	generalized gradient approximation
HCK	hydrocracking
HCN	heavy cracked naphtha
HCO	heavy cycle oil
HDT	hydrotreatment
HTI	Hydrogen transfer index
HSD	high-speed diesel
HCK	hydrocracking
IBP	initial boiling point
LAS	lewis acid sites
LCN	light cracked naphtha

LCO	light cycle oil
MAH	monoaromatic hydrocarbons
MAT	micro activity testing
MEP	minimum energy path
MPhA	methylphenanthrene
n-HD	n-hexadecane
NEB	nudged Elastic Band method
PAHs	polyaromatic hydrocarbons
PBE	Perdew–Burke–Ernzerhof exchange correlation
PhA	phenanthrene
PFO	pyrolysis fuel oil
SAR	silica to alumina ratio
SimDist	simulated distillation
T	toluene
TBP	true boiling point
TCD	thermal conductivity detector
TS	transition state
VASP	Vienna ab initio simulation package
VGO	vacuum gas oil
X	Xylene

Table of Contents

List of Figures

List of Tables