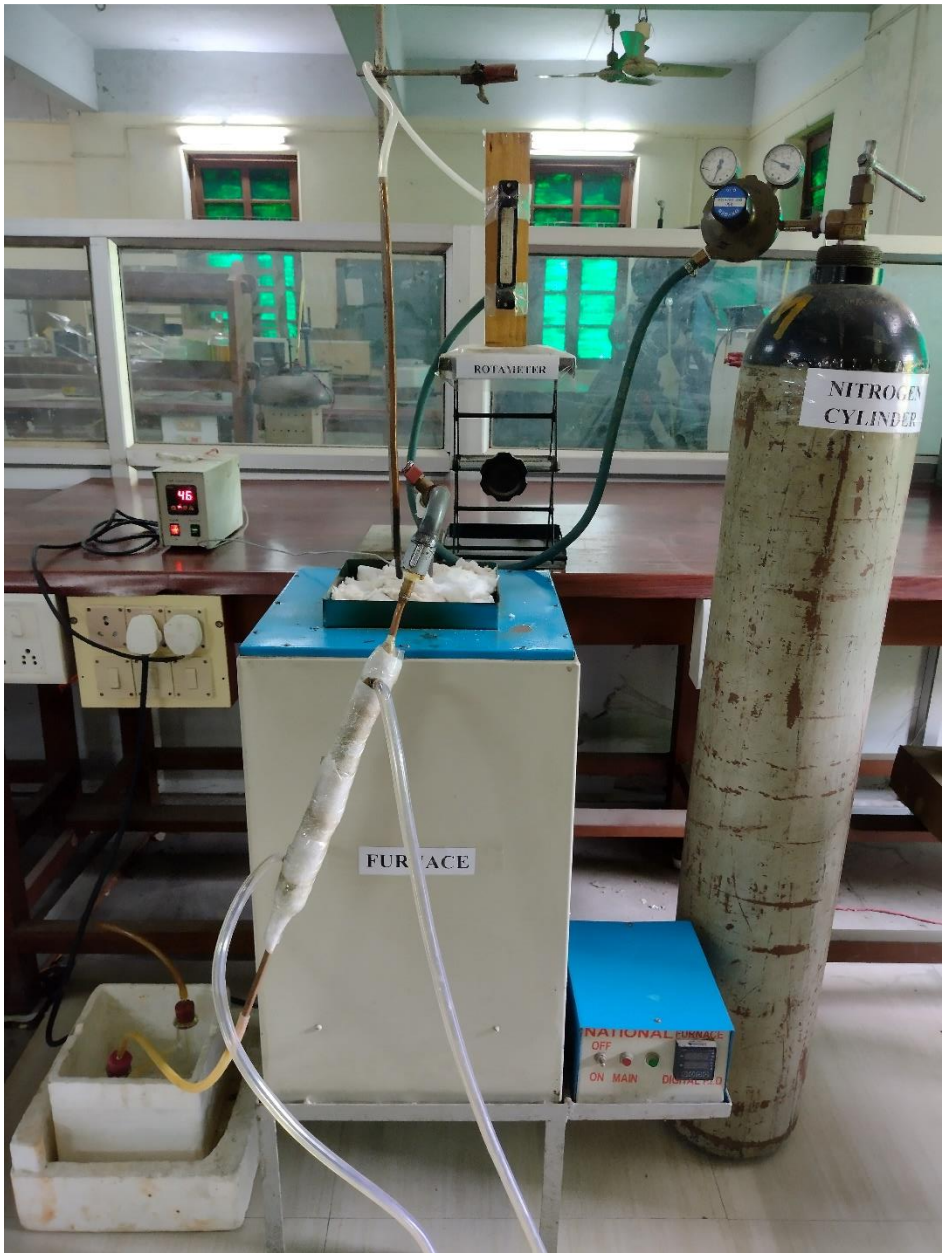
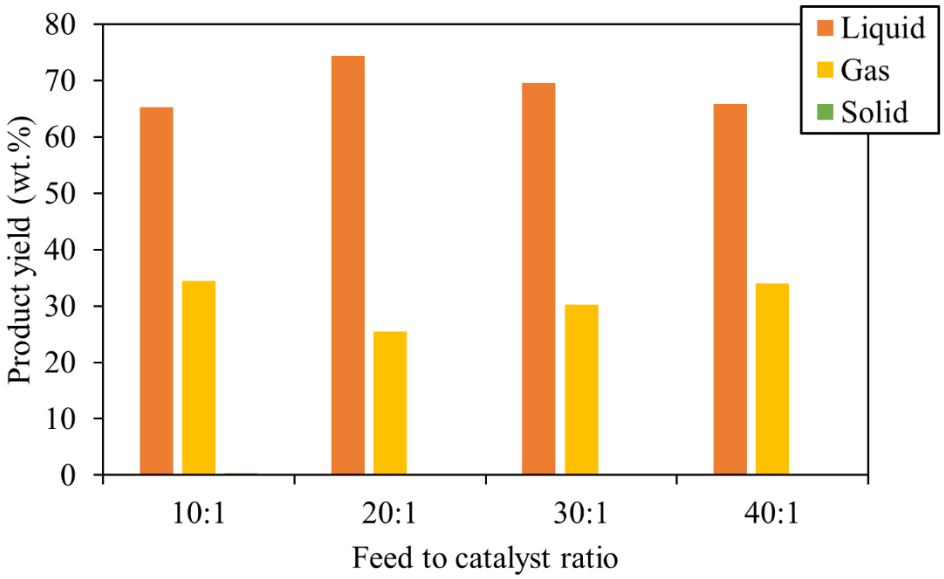
APPENDIX A1

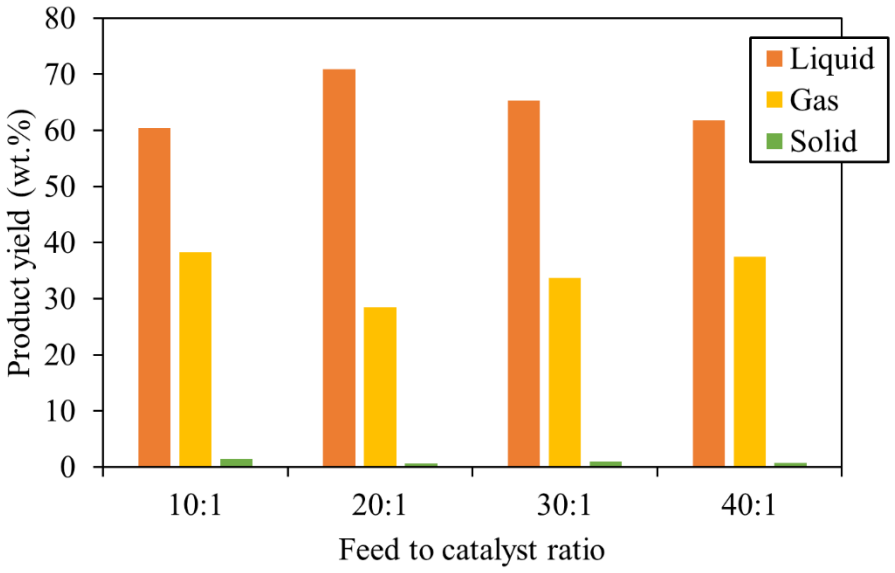


Appendix A1 Photographic view of experimental setup.

APPENDIX A2

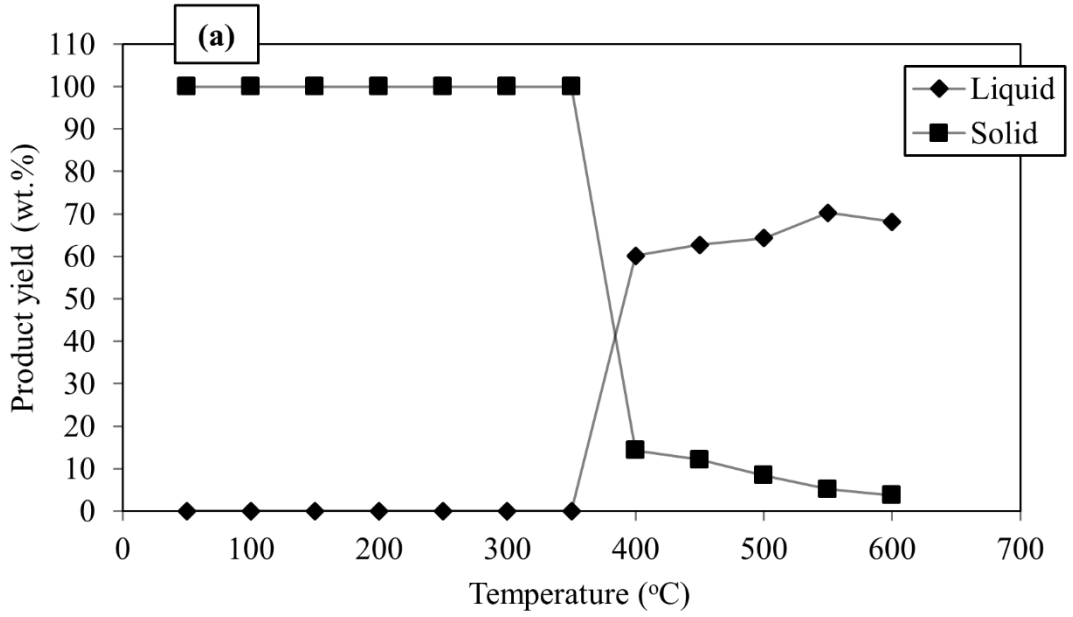


Appendix A2.1a Effect of feed to catalyst ratio on product yield for vapour phase catalytic process/B-type at 600 ºC and 15 ºC/min using ZSM-5 ammonium powder catalyst.

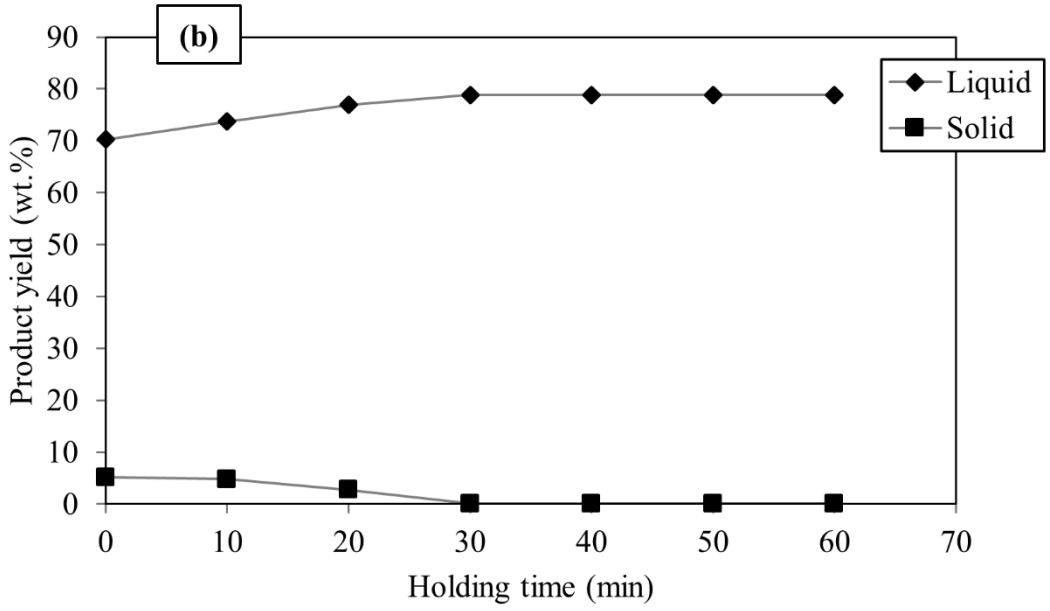


Appendix A2.1b Effect of feed to catalyst ratio on product yield for multiphase phase catalytic process/AB-type at 600 ºC and 15 ºC/min using ZSM-5 ammonium powder catalyst.

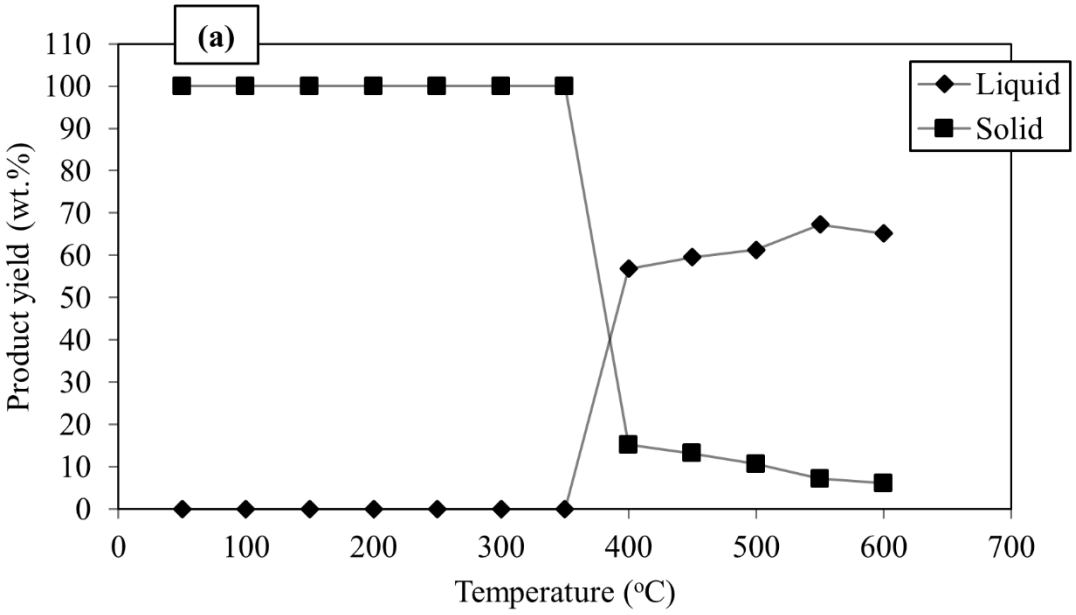
APPENDIX A3



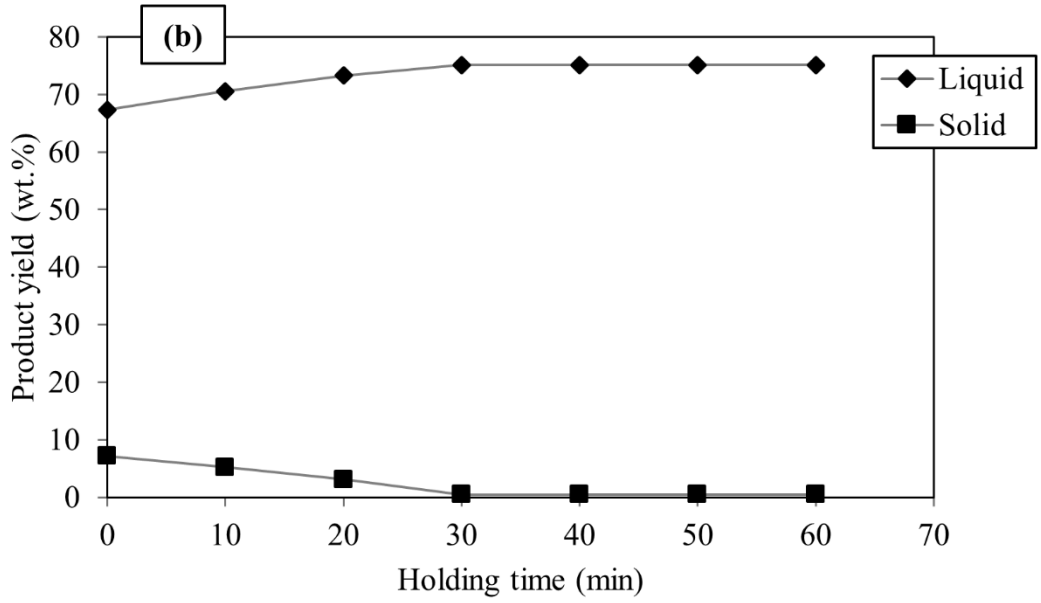
Appendix A3.1a Effect of temperature on liquid and solid yield for vapour phase catalytic/B-type pyrolysis at 15 °C/min heating rate and zero hold time using ZSM-5 ammonium powder catalyst.



Appendix A3.1b Effect of holding time on liquid and solid yield for vapour phase catalytic/B-type pyrolysis at 15 °C/min and 550 °C using ZSM-5 ammonium powder catalyst.

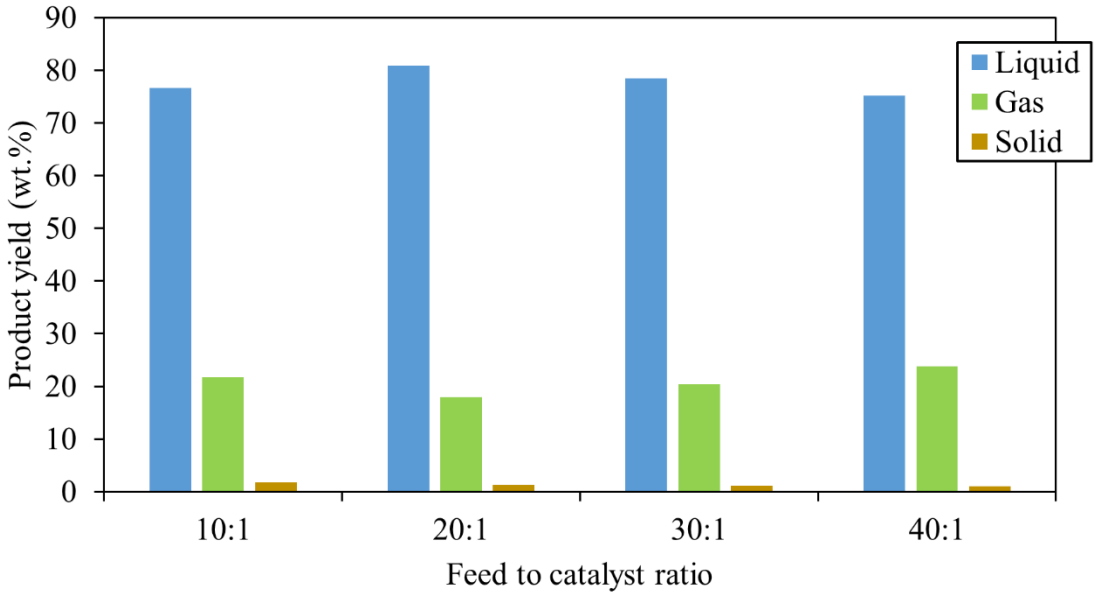


Appendix A3.2a Effect of temperature on liquid and solid yield for multiphase catalytic/AB-type pyrolysis at 15 °C/min heating rate and zero hold time using ZSM-5 ammonium powder catalyst.

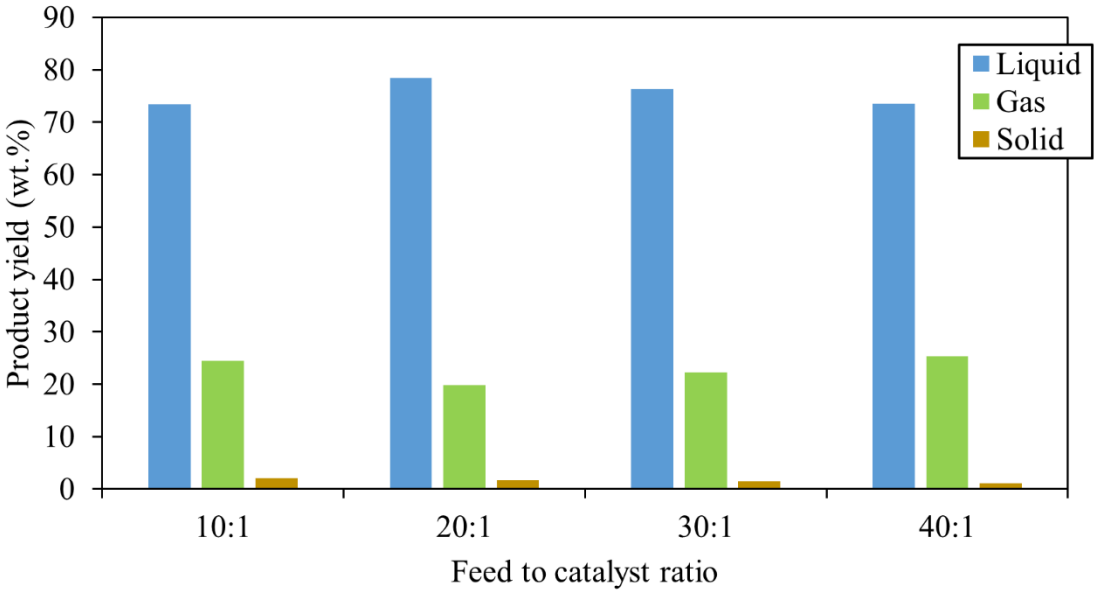


Appendix A3.2b Effect of holding time on liquid and solid yield for multiphase catalytic/AB-type pyrolysis at 15 °C/min and 550 °C using ZSM-5 ammonium powder catalyst.

APPENDIX A4



Appendix A4.1a Effect of feed to catalyst ratio on product yield for vapour phase catalytic process/B-type at 600 ^{o}C and 15 ^{o}C/min using Nickel on silica-alumina catalyst.



Appendix A4.2b Effect of feed to catalyst ratio on product yield for multiphase phase catalytic process/AB-type at 600 ^{o}C and 15 ^{o}C/min using Nickel on silica-alumina catalyst.

APPENDIX A5

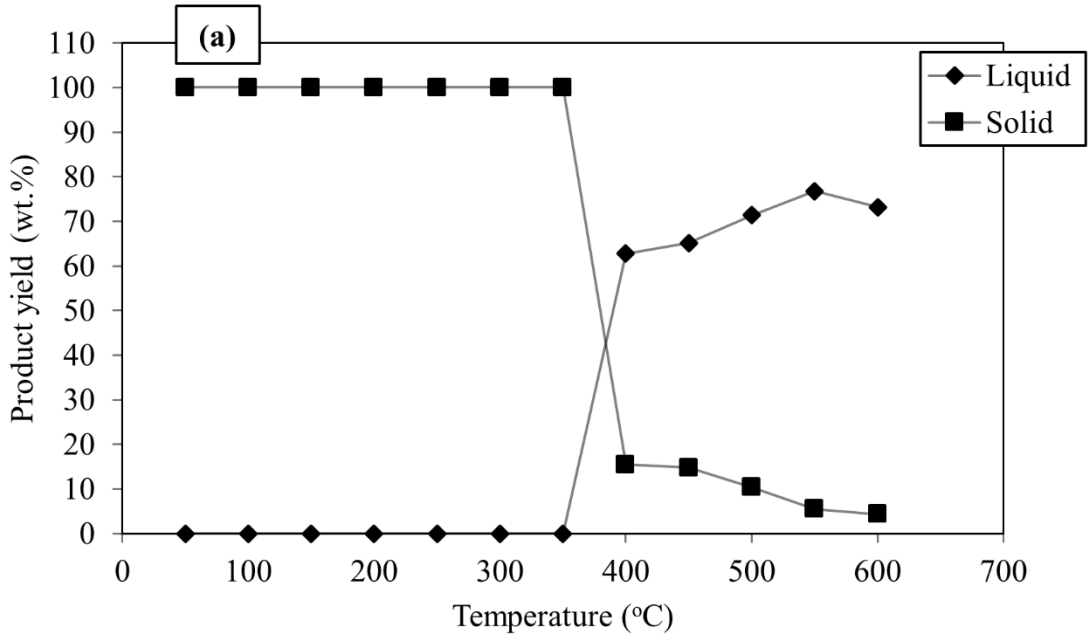


Figure A5.1a Effect of temperature on liquid and solid yield for vapour phase catalytic/B-type pyrolysis at 15 °C/min heating rate and zero hold time using Nickel on silica-alumina catalyst

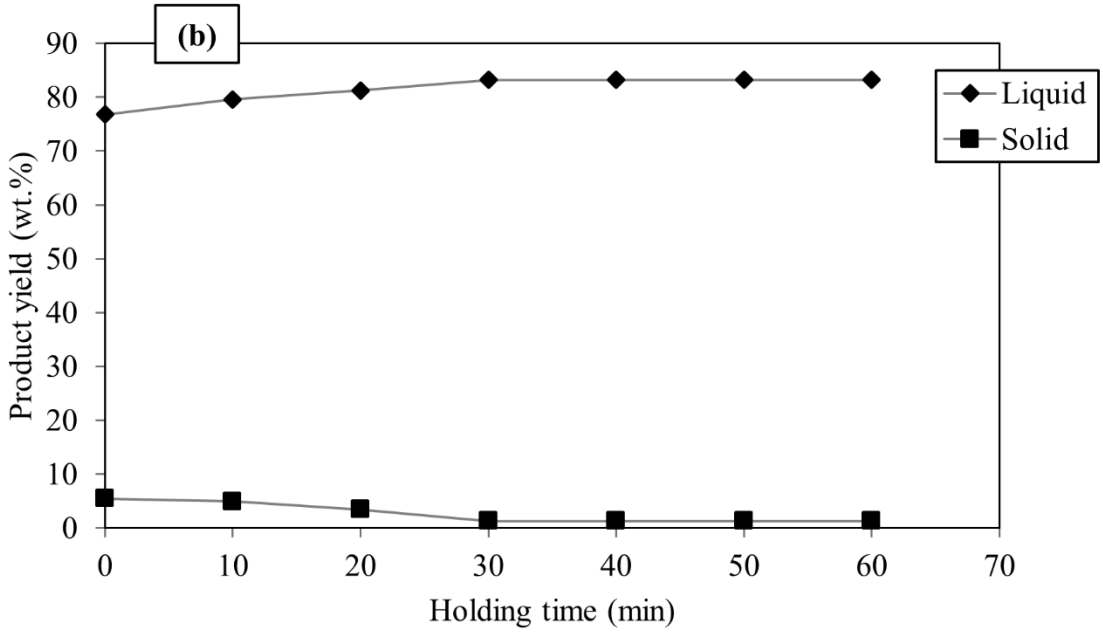


Figure A5.1b Effect of holding time on liquid and solid yield for vapour phase catalytic/B-type pyrolysis at 15 °C/min and 550 °C using Nickel on silica-alumina catalyst.

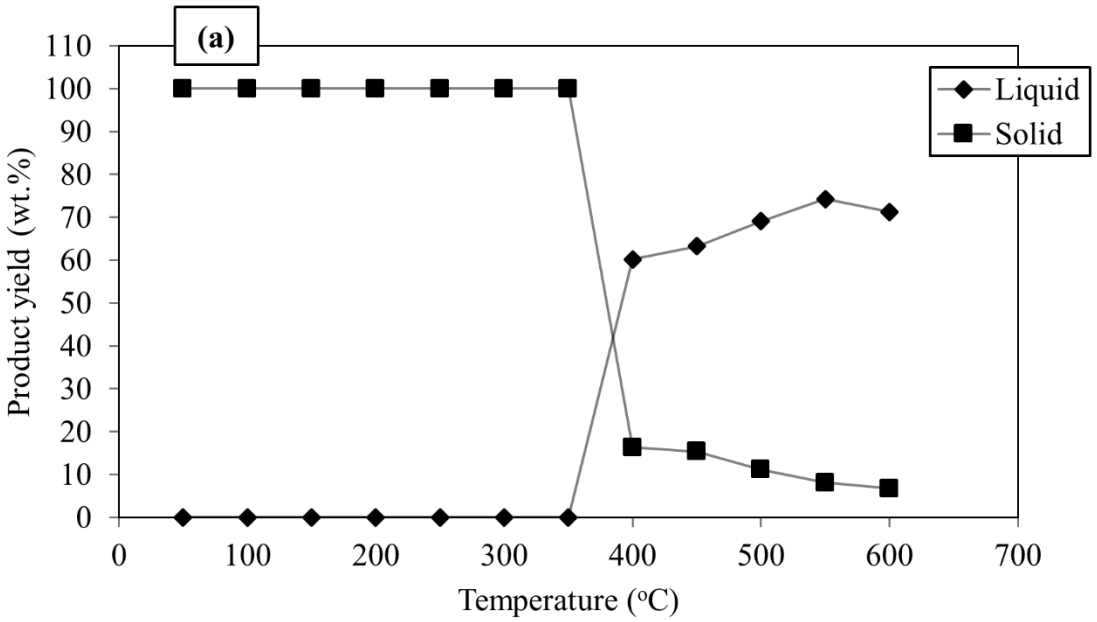


Figure A5.2a Effect of temperature on liquid and solid yield for multiphase catalytic/AB-type pyrolysis at 15 °C/min heating rate and zero hold time using Nickel on silica-alumina catalyst

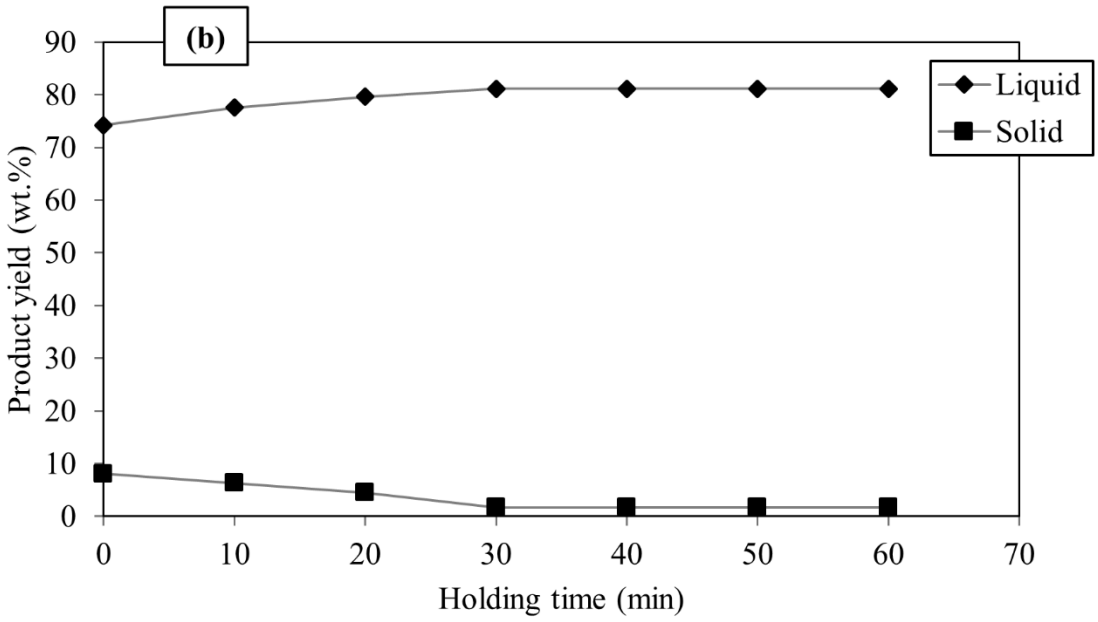
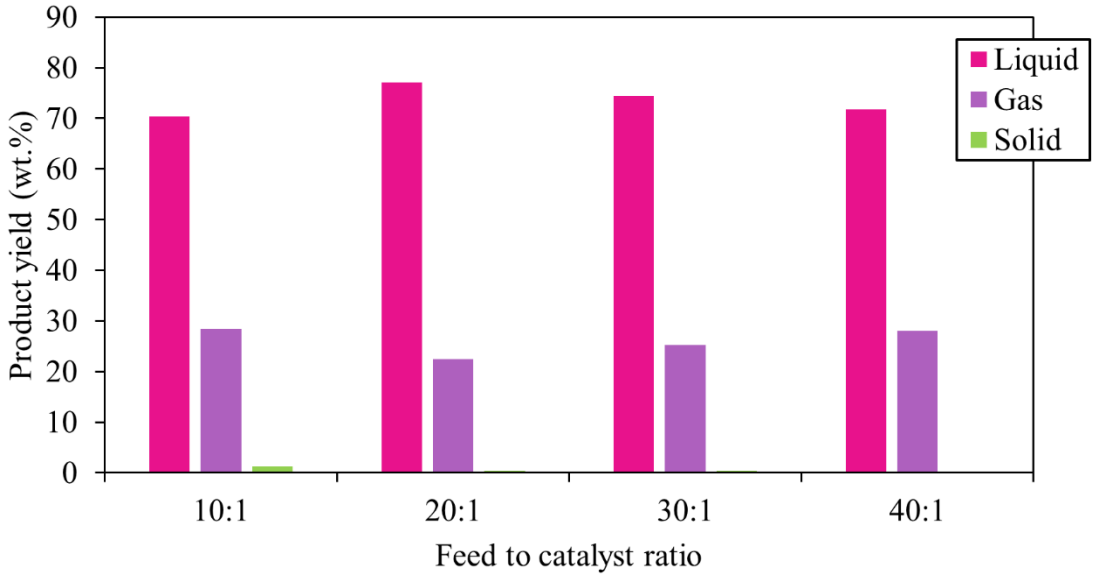
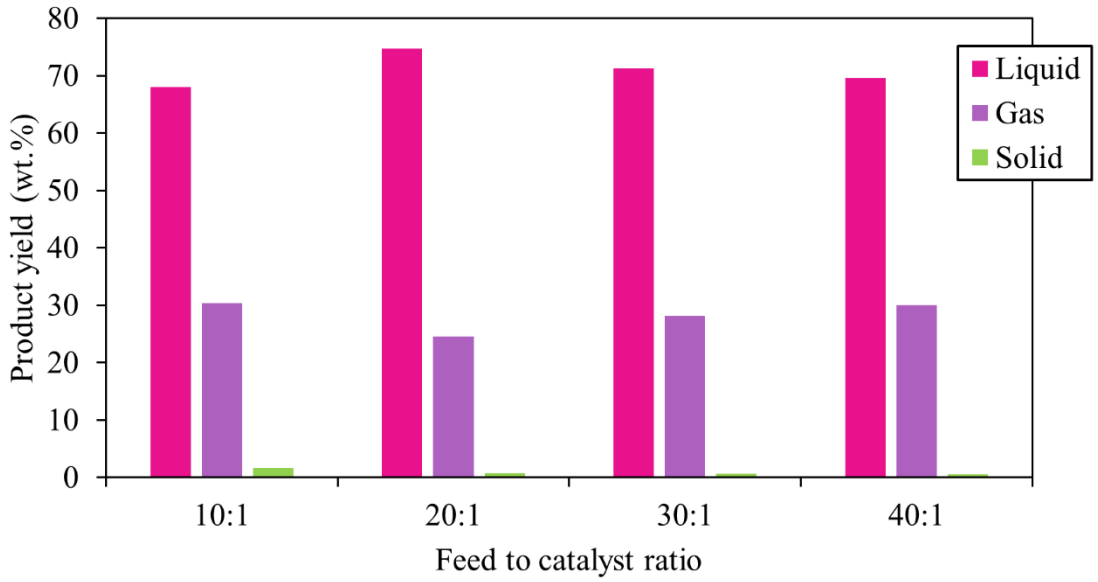


Figure A5.2b Effect of holding time on liquid and solid yield for multiphase catalytic/AB-type pyrolysis at 15 °C/min and 550 °C using Nickel on silica-alumina catalyst

APPENDIX A6



Appendix A6.1a Effect of feed to catalyst ratio on product yield for vapour phase catalytic process/B-type at 600 ^{o}C and 15 ^{o}C/min using red clay catalyst RC-800.



Appendix A6.2b Effect of feed to catalyst ratio on product yield for multiphase phase catalytic process/AB-type at 600 ^{o}C and 15 ^{o}C/min using red clay catalyst RC-800.

APPENDIX A7

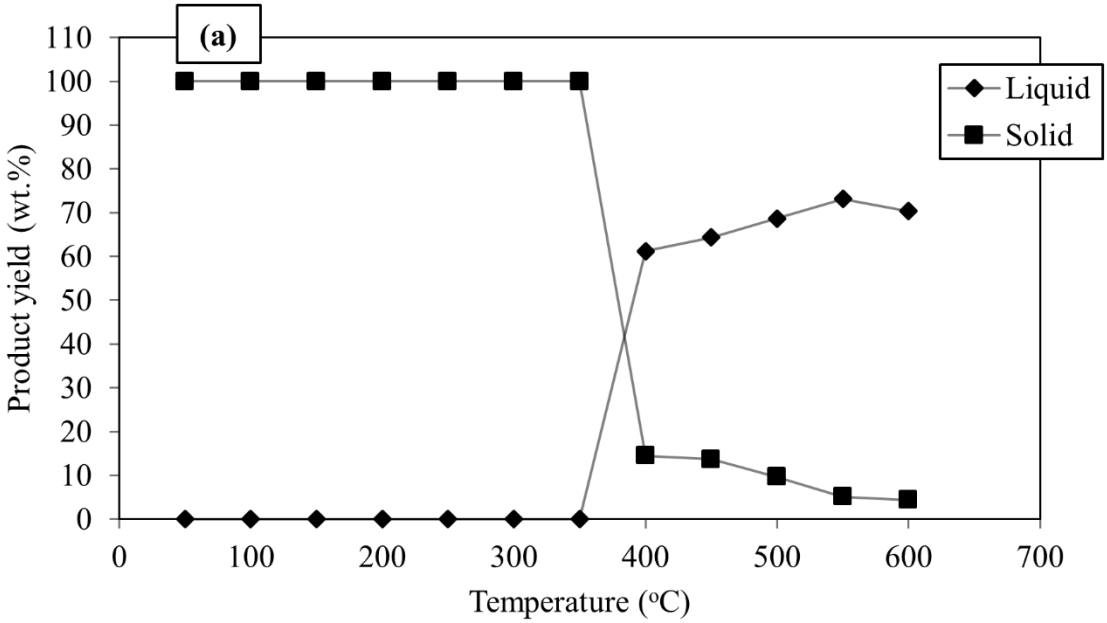


Figure A7.1a Effect of temperature on liquid and solid yield for vapour phase catalytic/B-type pyrolysis at 15 °C/min heating rate and zero hold time using red clay catalyst RC-800.

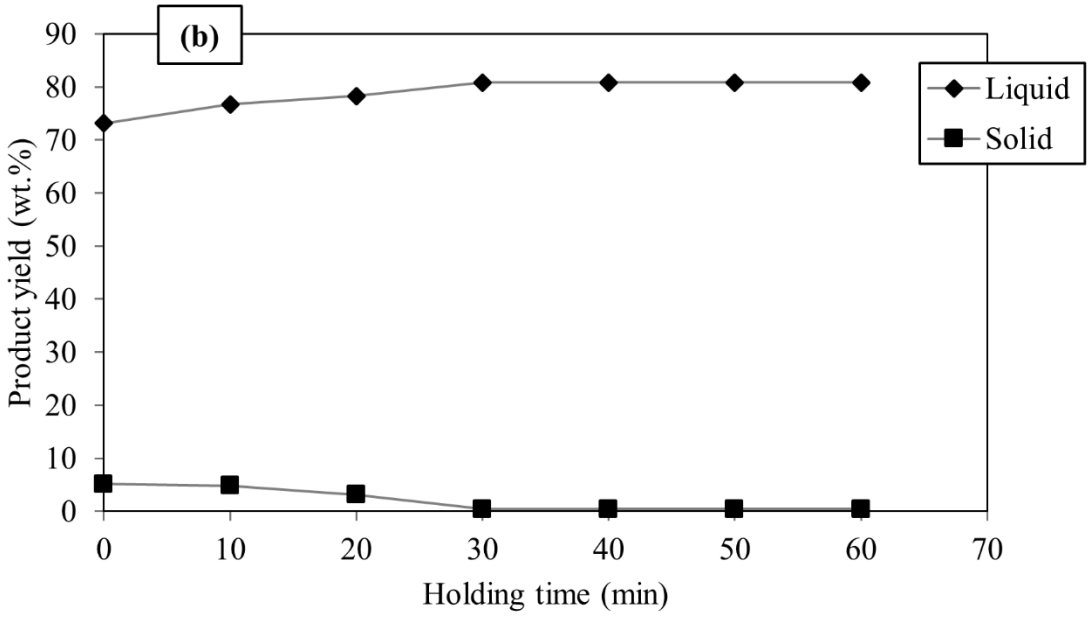


Figure A7.1b Effect of holding time on liquid and solid yield for vapour phase catalytic/B-type pyrolysis at 15 °C/min and 550 °C using best red clay catalyst RC-800.

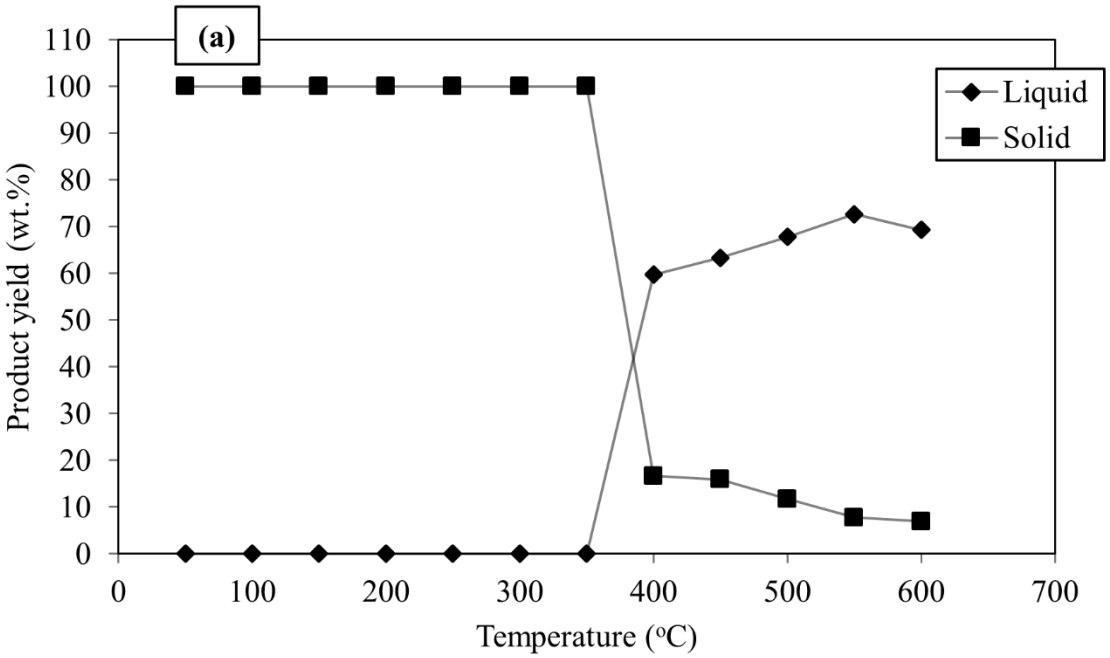


Figure A7.2a Effect of temperature on liquid and solid yield for multiphase catalytic/AB-type pyrolysis at 15 °C/min heating rate and zero hold time using red clay catalyst RC-800.

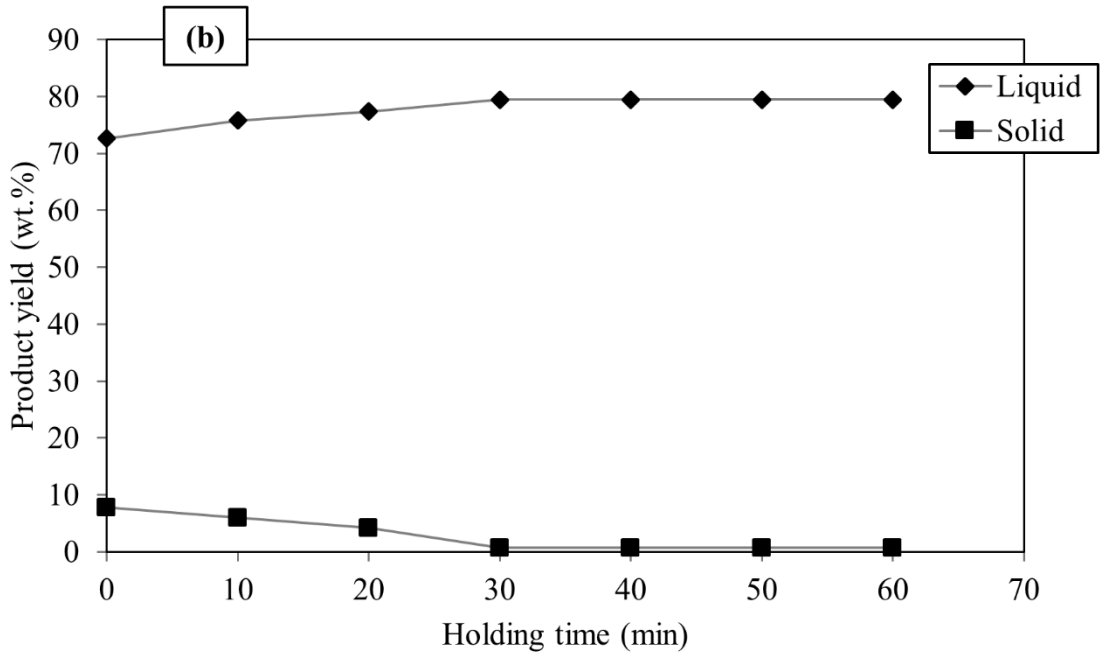
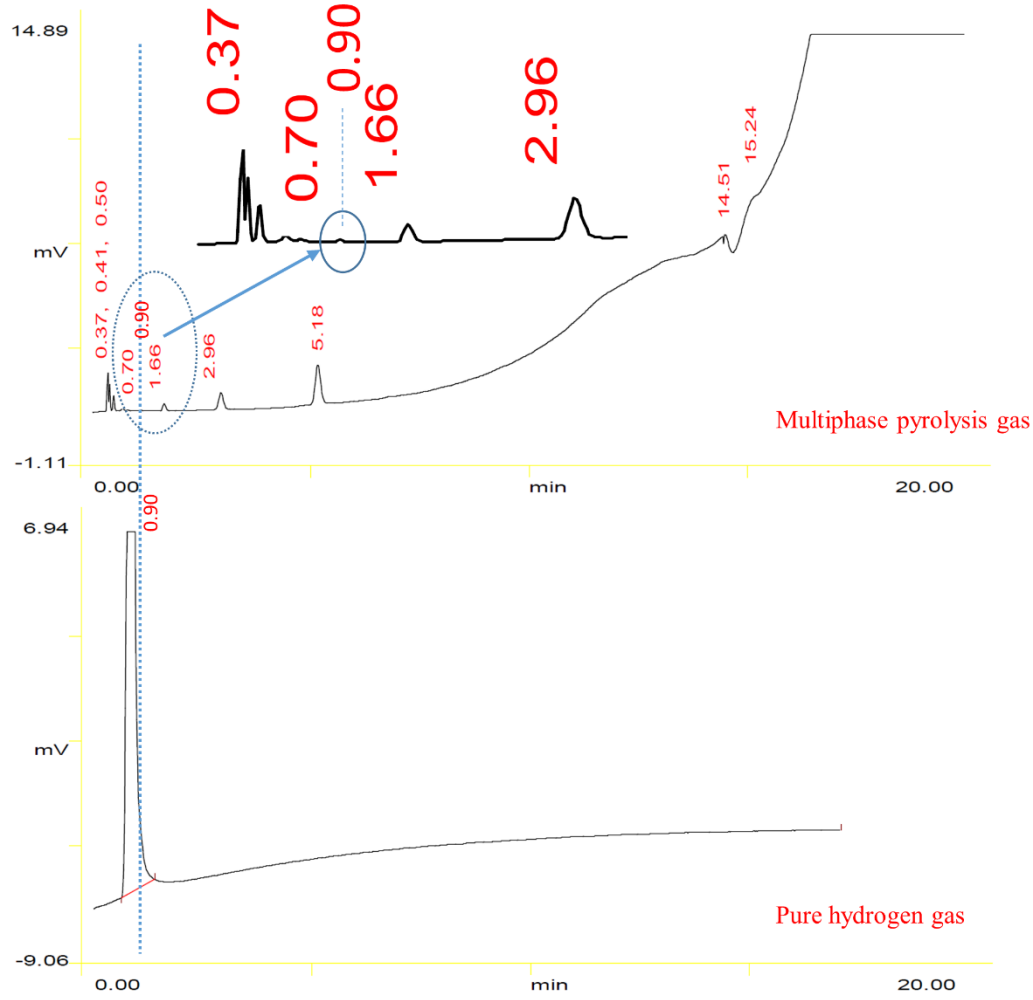


Figure A7.2b Effect of holding time on liquid and solid yield for multiphase catalytic/AB-type pyrolysis at 15 °C/min and 550 °C using best red clay catalyst RC-800.

APPENDIX A8



Appendix A8.1 Comparison of GC characteristics of multiphase pyrolysis gas and pure hydrogen gas

CERTIFICATE

It is certified that the work contained in the thesis titled "**Studies on Production of Valuable Aromatics Benzene, Toluene and Ethylbenzene Using Multiphase Catalytic Pyrolysis of Waste Expanded Polystyrene"** by **"Anjali Verma"** has been carried out under my/our supervision and that this work has not been submitted elsewhere for a degree.

It is further certified that the student has fulfilled all the requirements of Comprehensive Examination, Candidacy and SOTA for the award of Ph.D. Degree.

30/09/2022

Prof. Hiralal Pramanik

(Supervisor)

Department of Chemical
Engineering & Technology
Indian Institute of Technology
(Banaras Hindu University)
Varanasi-221005, India

प्राचार्य/Professor
रासायनिक अभियांत्रिकी एवं प्रौद्योगिकी विभाग
Deptt. of Chemical Engg. & Tech.
भारतीय प्रौद्योगिकी संस्थान
Indian Institute of Technology
काशी हिन्दू विश्वविद्यालय
Banaras Hindu University
वाराणसी/Varanasi-221005

30/09/2022

Dr. Sweta

(Co-supervisor)

Department of Chemical
Engineering & Technology
Indian Institute of Technology
(Banaras Hindu University)
Varanasi-221005, India

सहायक प्राचार्य
Assistant Professor
रासायनिक अभियांत्रिकी एवं प्रौद्योगिकी विभाग
Deptt. of Chemical Engg. & Tech.
भारतीय प्रौद्योगिकी संस्थान
Indian Institute of Technology
काशी हिन्दू विश्वविद्यालय
Banaras Hindu University
वाराणसी/Varanasi-221005

DECLARATION BY THE CANDIDATE

I, **"Anjali Verma"**, certify that the work embodied in this thesis is my own bona fide work and carried out by me under the supervision of **Prof. Hiralal Pramanik** and co-supervision of **Dr. Sweta** from "July 2017 to October 2022" at the "Department of Chemical Engineering & Technology", Indian Institute of Technology (BHU), Varanasi. The matter embodied in this thesis has not been submitted for the award of any other degree/diploma. I declare that I have faithfully acknowledged and given credits to the research workers wherever their works have been cited in my work in this thesis. I further declare that I have not willfully copied any other's work, paragraphs, text, data, results, etc., reported in journals, books, magazines, reports dissertations, theses, etc., or available at websites and have not included them in this thesis and have not cited as my own work.

Date: 30/09/2022

Place: Varanasi

Anjali Verma 30/09/2022

(Anjali Verma)

CERTIFICATE BY THE SUPERVISOR

It is certified that the above statement made by the student is correct to the best of my/our knowledge.

30/09/2022

Prof. Hiralal Pramanik

(Supervisor)

Department of Chemical
Engineering & Technology
Indian Institute of Technology
(Banaras Hindu University)
Varanasi-221005, India

प्राचार्य/Professor
रासायनिक अभियांत्रिकी एवं प्रौद्योगिकी विभाग
Deptt. of Chemical Engg. & Tech.
भारतीय प्रौद्योगिकी संस्थान
Indian Institute of Technology
काशी हिन्दू विश्वविद्यालय
Banaras Hindu University
वाराणसी/Varanasi-221005

30/09/2022

Dr. Sweta

(Co-supervisor)

Department of Chemical
Engineering & Technology
Indian Institute of Technology
(Banaras Hindu University)
Varanasi-221005, India

सहायक प्राचार्य
Assistant Professor
रासायनिक अभियांत्रिकी एवं प्रौद्योगिकी विभाग
Deptt. of Chemical Engg. & Tech.
भारतीय प्रौद्योगिकी संस्थान
Indian Institute of Technology
काशी हिन्दू विश्वविद्यालय
Banaras Hindu University
Varanasi-221005

30/9/22

Head

(Prof. V. L. Yadav)

Department of Chemical Engineering & Technology
Indian Institute of Technology (Banaras Hindu University)
Varanasi-221005

विभागाध्यक्ष/Head
रासायनिक अभियांत्रिकी एवं प्रौद्योगिकी विभाग
Deptt. of Chemical Engg. & Tech.
भारतीय प्रौद्योगिकी संस्थान/Indian Institute of Technology
काशी हिन्दू विश्वविद्यालय/Banaras Hindu University
वाराणसी/Varanasi-221005

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Parents &

Family Members

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Finally, I wish to extend warm thanks to all those who could not find a separate name but have helped directly or indirectly.

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Date: 30/09/2022

Anjali Verma
30/09/2022

Place: Varanasi

(Anjali Verma)

REFERENCES

Abbas-Abadi MS, Ebrahimi A, Liyaghati-Delshad M. The pyrolysis of high density polyethylene and polystyrene wastes as environmental problem using used FCC and Ga/used FCC catalysts and different heating rates to produce the valuable products. Current Analytical Chemistry 2018; 1: 33-44.

Aboul-Enein AA, Awadallah AE. Production of nanostructure carbon materials via non-oxidative thermal degradation of real polypropylene waste plastic using La2O3 supported Ni and Ni–Cu catalysts. Polymer Degradation and Stability. 2019; 167: 157-69.

Aboulkas A, Makayssi T, Bilali L, Nadifiyine M, Benchanaa M. Co-pyrolysis of oil shale and plastics: Influence of pyrolysis parameters on the product yields. Fuel processing technology. 2012;96:209-13.

Achilias DS, Kanellopoulou I, Megalokonomos P, Antonakou E, Lappas AA. Chemical recycling of polystyrene by pyrolysis: potential use of the liquid product for the reproduction of polymer. Macromolecular Materials and Engineering. 2007; 292(8): 923-34.

Adnan, Shah J, Jan MR. Effect of polyethylene terephthalate on the catalytic pyrolysis of polystyrene: Investigation of the liquid products. Journal of the Taiwan Institute of Chemical Engineers. 2015; 51: 96-102.

Adnan, Shah J, Jan MR. Thermo-catalytic pyrolysis of polystyrene in the presence of zinc bulk catalysts. Journal of the Taiwan Institute of Chemical Engineers. 2014; 45(5): 2494-500.

Adrados A, De Marco I, Caballero BM, López A, Laresgoiti MF, Torres A. Pyrolysis of plastic packaging waste: A comparison of plastic residuals from material recovery facilities with simulated plastic waste. Waste Management. 2012 May 1;32(5):826-32.

Ahmad I, Khan MI, Ishaq M, Khan H, Gul K, Ahmad W. Catalytic efficiency of some novel nanostructured heterogeneous solid catalysts in pyrolysis of HDPE. Polymer degradation and stability. 2013; 98(12): 2512-9.

Ahmad I, Khan MI, Khan H, Ishaq M, Khan R, Gul K, Ahmad W. Pyrolysis of HDPE into fuel like products: Evaluating catalytic performance of plain and metal oxides impregnated waste brick kiln dust. Journal of Analytical and Applied Pyrolysis. 2017; 124: 195-203.

Ahmad N, Ahmad N, Maafa IM, Ahmed U, Akhter P, Shehzad N, Hussain M. Thermal conversion of polystyrene plastic waste to liquid fuel via ethanolysis. Fuel. 2020; 279: 118498.

Alauddin MB, Choudhury IA, El Baradie MA, Hashmi MS. Plastics and their machining: a review. Journal of Materials Processing Technology. 1995; 54(1-4): 40-6.

Alhassan Y, Kumar N, Bugaje IM. Catalytic upgrading of waste tire pyrolysis oil via supercritical esterification with deep eutectic solvents (green solvents and catalysts). Journal of the Energy Institute. 2016;89(4):683-93.

Aljabri NM, Lai Z, Hadjichristidis N, Huang KW. Renewable aromatics from the degradation of polystyrene under mild conditions. Journal of Saudi Chemical Society. 2017; 21(8): 983-9.

Almeida D, Marques MD. Thermal and catalytic pyrolysis of plastic waste. Polímeros. 2016; 26: 44-51.

Al-Salem SM, Lettieri P, Baeyens J. Recycling and recovery routes of plastic solid waste (PSW): A review. Waste management. 2009; 29(10): 2625-43.

Aminu I, Nahil MA, Williams PT. Hydrogen from waste plastics by two-stage pyrolysis/low-temperature plasma catalytic processing. Energy & Fuels. 2020; 34(9): 11679-89.

Amjad UE, Ishaq M, Rehman HU, Ahmad N, Sherin L, Hussain M, Mustafa M. Diesel and gasoline like fuel production with minimum styrene content from catalytic pyrolysis of polystyrene. Environmental Progress & Sustainable Energy. 2021; 40(2): e13493.

Andoni A, Xhaxhiu K, Taraj KR, Çomo A. An adsorption method for characterization of surface area and pore size of solid surfaces. Asian Journal of Chemistry. 2014;26(20):6833-8.

Anene AF, Fredriksen SB, Sætre KA, Tokheim LA. Experimental study of thermal and catalytic pyrolysis of plastic waste components. Sustainability. 2018;10(11):3979.

Artetxe M, Lopez G, Amutio M, Barbarias I, Arregi A, Aguado R, Bilbao J, Olazar M. Styrene recovery from polystyrene by flash pyrolysis in a conical spouted bed reactor. Waste management. 2015; 45: 126-33.

Babajo SA, Enaburekhan JS, Rufa'i IA. Design, Fabrication and Performance Study of co-pyrolysis system for production of liquid fuel from jatropha cake with polystyrene waste. Journal of Applied Sciences and Environmental Management. 2021; 25(3): 407-14.

Bartoli M, Rosi L, Frediani M, Undri A, Frediani P. Depolymerization of polystyrene at reduced pressure through a microwave assisted pyrolysis. Journal of analytical and applied pyrolysis. 2015;113:281-7.

Benedetti M, Cafiero L, De Angelis D, Dell'Era A, Pasquali M, Stendardo S, Tuffi R, Ciprioti SV. Pyrolysis of WEEE plastics using catalysts produced from fly ash of coal gasification. Frontiers of Environmental Science & Engineering. 2017; 11(5): 1-1.

Bezerra MA, Santelli RE, Oliveira EP, Villar LS, Escaleira LA. Response surface methodology (RSM) as a tool for optimization in analytical chemistry. Talanta. 2008; 76(5): 965-77.

Budsaereechai S, Hunt AJ, Ngernyen Y. Catalytic pyrolysis of plastic waste for the production of liquid fuels for engines. RSC advances. 2019; 9(10): 5844-57.

Busca G. Silica-alumina catalytic materials: A critical review. Catalysis Today. 2020;357:621-9.

Caldas LF, de Paula CE, Brum DM, Cassella RJ. Application of a four-variables Doehlert design for the multivariate optimization of copper determination in petroleum-derived insulating oils by GFAAS employing the dilute-and-shot approach. Fuel. 2013; 105: 503-11.

Campbell SM, Bibby DM, Coddington JM, Howe RF, Meinhold RH. Dealumination of HZSM-5 zeolites: I. Calcination and hydrothermal treatment. Journal of Catalysis. 1996;161(1):338-49.

Capleton AC, Levy LS. An overview of occupational benzene exposures and occupational exposure limits in Europe and North America. Chemico-biological interactions. 2005; 153: 43-53.

Cardona SC, Corma A. Tertiary recycling of polypropylene by catalytic cracking in a semibatch stirred reactor: use of spent equilibrium FCC commercial catalyst. Applied Catalysis B: Environmental. 2000; 25(2-3): 151-62.

Cases JM, Grillet Y, François M, Michot L, Villiéras F, Yvon J. Evolution of the porous structure and surface area of palygorskite under vacuum thermal treatment. Clays and Clay Minerals. 1991;39(2):191-201.

Castillo R, Fernández R, Antoni M, Scrivener K, Alujas A, Martirena JF. Activation of low grade clays at high temperatures. Revista Ingeniería de Construcción. 2010;25:329-52.

Chargui F, Hamidouche M, Belhouchet H, Jorand Y, Doufnoune R, Fantozzi G. Mullite fabrication from natural kaolin and aluminium slag. boletín de la sociedad española de cerámica y vidrio. 2018;57(4):169-77.

Charusiri W, Numcharoenpinij N. Characterization of the optimal catalytic pyrolysis conditions for bio-oil production from brown salwood (Acacia mangium Willd) residues. Biomass and Bioenergy. 2017; 106: 127-36.

Chauhan RS, Gopinath S, Razdan P, Delattre C, Nirmala GS, Natarajan R. Thermal decomposition of expanded polystyrene in a pebble bed reactor to get higher liquid fraction yield at low temperatures. Waste Management. 2008; 28(11): 2140-5.

Chaukura N, Gwenzi W, Bunhu T, Ruziwa DT, Pumure I. Potential uses and value-added products derived from waste polystyrene in developing countries: A review. Resources, Conservation and Recycling. 2016; 107: 157-65.

Chen HL, Nath TK, Chong S, Foo V, Gibbins C, Lechner AM. The plastic waste problem in Malaysia: management, recycling and disposal of local and global plastic waste. SN Applied Sciences. 2021; 3(4): 1-5.

Chen PY. Table of key lines in X-ray powder diffraction patterns of minerals in clays and associated rocks. Indiana Geological & Water Survey; 1977.

Chen T, Yu J, Ma C, Bikane K, Sun L. Catalytic performance and debromination of Fe–Ni bimetallic MCM-41 catalyst for the two-stage pyrolysis of waste computer casing plastic. Chemosphere. 2020; 248: 125964.

Cho KH, Cho DR, Kim KH, Park DW. Catalytic degradation of polystyrene using albite and montmorillonite. Korean Journal of Chemical Engineering. 2007; 24(2): 223-5.

Cho KH, Jang BS, Kim KH, Park DW. Degradation of polystyrene using natural clay catalysts. Studies in surface science and catalysis. 2006: 433-6.

Coates J. Interpretation of infrared spectra, a practical approach. Encyclopedia of Analytical Chemistry: Applications,Theory and Instrumentation. Chichester, UK: John Wiley & Sons; 2006. doi:10.1002/9780470027318.a5606

da Costa Gardolinski JE. *Interlayer Grafting and Delamination of Kaolinite* (Doctoral dissertation, Faculty of Mathematics and Natural Sciences of the Christian-Albrechts-University).

de Luna MD, Sablas MM, Hung CM, Chen CW, Garcia-Segura S, Dong CD. Modeling and optimization of imidacloprid degradation by catalytic percarbonate oxidation using artificial neural network and Box-Behnken experimental design. Chemosphere. 2020; 251: 126254.

Dewangga PB, Purnomo CW. Pyrolysis of polystyrene plastic waste using bentonite catalyst. InIOP Conference Series: Earth and Environmental Science 2019 Dec 1 (Vol. 399, No. 1, p. 012110). IOP Publishing.

Dhall S, Mehta BR, Tyagi AK, Sood K. A review on environmental gas sensors: Materials and technologies. Sensors International. 2021; 2: 100116.

Donald JM, Hooper K, Hopenhayn-Rich C. Reproductive and developmental toxicity of toluene: a review. Environmental health perspectives. 1991; 94: 237-44.

Dwivedi P, Mishra PK, Mondal MK, Srivastava N. Non-biodegradable polymeric waste pyrolysis for energy recovery. Heliyon. 2019; 5(8): e02198.

Elaiopoulos K, Perraki T, Grigoropoulou E. Monitoring the effect of hydrothermal treatments on the structure of a natural zeolite through a combined XRD, FTIR, XRF, SEM and N2-porosimetry analysis. Microporous and Mesoporous Materials. 2010; 134(1-3): 29-43.

Escalera E, Antti ML, Odén M. Thermal treatment and phase formation in kaolinite and illite based clays from tropical regions of Bolivia. InIOP Conference Series: Materials Science and Engineering 2012 Feb 20 (Vol. 31, No. 1, p. 012017). IOP Publishing.

Fadillah G, Fatimah I, Sahroni I, Musawwa MM, Mahlia TM, Muraza O. Recent progress in low-cost catalysts for pyrolysis of plastic waste to fuels. Catalysts. 2021; 11(7): 837.

Flogeac K, Guillon E, Aplincourt M, Marceau E, Stievano L, Beaunier P, Frapart YM. Characterization of soil particles by X-ray diffraction (XRD), X-ray photoelectron spectroscopy (XPS), electron paramagnetic resonance (EPR) and transmission electron microscopy (TEM). Agronomy for sustainable development. 2005;25(3):345-53.

Fu J. Flash points measurements and prediction of biofuels and biofuel blends with aromatic fluids. Fuel. 2019; 241: 892-900.

Fuentes C, Lerner JC, Vázquez P, Sambeth J. Analysis of the emission of PAH in the thermal and catalytic pyrolysis of polystyrene. Catalysis Today. 2021; 372: 175-82.

Gandidi IM, Susila MD, Rustamaji H. Effect of natural zeolite and kaolin as a catalyst in the isothermal-catalytic cracking of real municipal solid waste (MSW) for bio-oil production. In IOP Conference Series: Earth and Environmental Science 2018 (Vol. 160, No. 1, p. 012018).

García RA, Serrano DP, Otero D. Catalytic cracking of HDPE over hybrid zeolitic–mesoporous materials. Journal of Analytical and Applied Pyrolysis. 2005; 74(1-2): 379-86.

Gaurh P, Pramanik H. A novel approach of solid waste management via aromatization using multiphase catalytic pyrolysis of waste polyethylene. Waste Management. 2018a; 71:86-96.

Gaurh P, Pramanik H. Performance and reusability assessment of ZSM-5 for the production of lighter aromatics via pyrolysis of waste polystyrene. Indian Journal of Chemical Technology 2020; 27: 375-386.

Gaurh P, Pramanik H. Production and characterization of pyrolysis oil using waste polyethylene in a semi batch reactor. Indian Journal of Chemical Technology. 2019;25(4):336-44.

Gaurh P, Pramanik H. Production of benzene/toluene/ethyl benzene/xylene (BTEX) via multiphase catalytic pyrolysis of hazardous waste polyethylene using low cost fly ash synthesized natural catalyst. Waste management. 2018b; 77: 114-30.

Gil-Jasso ND, Segura-González MA, Soriano-Giles G, Neri-Hipolito J, López N, Mas-Hernández E, Barrera-Díaz CE, Varela-Guerrero V, Ballesteros-Rivas MF. Dissolution and recovery of waste expanded polystyrene using alternative essential oils. Fuel. 2019; 239: 611-6.

Gilmour SG. Response surface designs for experiments in bioprocessing. Biometrics. 2006; 62(2): 323-31.

Gralik G, Chinelattot AL, Chinelatto AS. Effect of different sources of alumina on the microstructure and mechanical properties of the triaxial porcelain. Cerâmica. 2014;60:471-81.

Grigore ME. Methods of recycling, properties and applications of recycled thermoplastic polymers. Recycling. 2017; 2(4): 24.

Gupta GK, Mondal MK. Bio-energy generation from sagwan sawdust via pyrolysis: product distributions, characterizations and optimization using response surface methodology. Energy. 2019; 170:423-37.

Hall WJ, Williams PT. Removal of organobromine compounds from the pyrolysis oils of flame retarded plastics using zeolite catalysts. Journal of analytical and applied pyrolysis. 2008; 81(2): 139-47.

Huang J, Veksha A, Chan WP, Giannis A, Lisak G. Chemical recycling of plastic waste for sustainable material management: A prospective review on catalysts and processes. Renewable and Sustainable Energy Reviews. 2022; 154: 111866.

Imani Moqadam S, Mirdrikvand M, Roozbehani B, Kharaghani A, Shishehsaz MR. Polystyrene pyrolysis using silica-alumina catalyst in fluidized bed reactor. Clean Technologies and Environmental Policy. 2015; 17(7): 1847-60.

Inayat A, Fasolini A, Basile F, Fridrichova D, Lestinsky P. Chemical recycling of waste polystyrene by thermo-catalytic pyrolysis: A description for different feedstocks, catalysts and operation modes. Polymer Degradation and Stability. 2022:109981.

Jan MR, Shah J, Gulab H. Catalytic degradation of waste high-density polyethylene into fuel products using BaCO3 as a catalyst. Fuel processing technology. 2010; 91(11): 1428-37.

Jiang F, Li Y, Zhao L, Cang D. Novel ceramics prepared from inferior clay rich in CaO and Fe2O3: Properties, crystalline phases evolution and densification process. Applied Clay Science. 2017;143:199-204.

Jin S, Cui K, Guan H, Yang M, Liu L, Lan C. Preparation of mesoporous MCM-41 from natural sepiolite and its catalytic activity of cracking waste polystyrene plastics. Applied Clay Science. 2012; 56: 1-6.

Jing X, Dong J, Huang H, Deng Y, Wen H, Xu Z, Ceylan S. Interaction between feed stocks, absorbers and catalysts in the microwave pyrolysis process of waste plastics. Journal of Cleaner Production. 2021; 291: 125857.

Jung JS, Pyo S, Park Y, Lee S, Kim YM, Yoo KS, Park YK. Effect of desilication of HZSM-5 on the catalytic pyrolysis of polystyrene. Materials Letters. 2021; 300: 130107.

Kalogeras IM, Vassilikou-Dova AB. Electrical properties of zeolitic catalysts. InDefect and diffusion forum 1998 (Vol. 164, pp. 1-36). Trans Tech Publications Ltd.

Karimifard S, Moghaddam MR. Application of response surface methodology in physicochemical removal of dyes from wastewater: a critical review. Science of the Total Environment. 2018; 640: 772-97.

Karisathan Sundararajan N, Ramachandran Bhagavathi A. Experimental investigation on thermocatalytic pyrolysis of HDPE plastic waste and the effects of its liquid yield over the performance, emission, and combustion characteristics of CI engine. Energy & Fuels. 2016;30(7):5379-90.

Kasar P, Sharma DK, Ahmaruzzaman M. Thermal and catalytic decomposition of waste plastics and its co-processing with petroleum residue through pyrolysis process. Journal of Cleaner Production. 2020; 265: 121639.

Kazemi M, Kabir SF, Fini EH. State of the art in recycling waste thermoplastics and thermosets and their applications in construction. Resources, Conservation and Recycling. 2021; 174: 105776.

Khalil U, Vongsvivut J, Shahabuddin M, Samudrala SP, Srivatsa SC, Bhattacharya S. A study on the performance of coke resistive cerium modified zeolite Y catalyst for the pyrolysis of scrap tyres in a two-stage fixed bed reactor. Waste Management. 2020; 102: 139-48.

Kim SS, Kim S. Pyrolysis characteristics of polystyrene and polypropylene in a stirred batch reactor. Chemical Engineering Journal. 2004; 98(1-2): 53-60.

Kim YS, Hwang GC, Bae SY, Yi SC, Moon SK, Kumazawa H. Pyrolysis of polystyrene in a batch-type stirred vessel. Korean Journal of Chemical Engineering. 1999; 16(2): 161-5.

Kumar R, Jilte R, Nikam KC, Ahmadi MH. Status of carbon capture and storage in India's coal fired power plants: A critical review. Environmental Technology & Innovation. 2019; 13: 94-103.

Kunwar B, Cheng HN, Chandrashekaran SR, Sharma BK. Plastics to fuel: a review. Renewable and Sustainable Energy Reviews. 2016;54:421-8.

Kyaw KT, Hmwe CS. Effect of various catalysts on fuel oil pyrolysis process of mixed plastic wastes. International Journal of Advances in Engineering & Technology. 2015; 8(5): 794.

Lam SS, Russell AD, Lee CL, Chase HA. Microwave-heated pyrolysis of waste automotive engine oil: Influence of operation parameters on the yield, composition, and fuel properties of pyrolysis oil. Fuel. 2012;92(1):327-39.

Lanzafame P, Barbera K, Papanikolaou G, Perathoner S, Centi G, Migliori M, Catizzone E, Giordano G. Comparison of H+ and NH4+ forms of zeolites as acid catalysts for HMF etherification. Catalysis Today. 2018; 304: 97-102.

Lebreton L, Andrady A. Future scenarios of global plastic waste generation and disposal. Palgrave Communications. 2019; 5(1): 1-1.

Lee A, Liew MS. Tertiary recycling of plastics waste: an analysis of feedstock, chemical and biological degradation methods. Journal of Material Cycles and Waste Management. 2021; 23(1): 32-43.

Lee KH, Noh NS, Shin DH, Seo Y. Comparison of plastic types for catalytic degradation of waste plastics into liquid product with spent FCC catalyst. Polymer Degradation and Stability. 2002; 78(3): 539-44.

Lee KH, Shin DH. Characteristics of liquid product from the pyrolysis of waste plastic mixture at low and high temperatures: Influence of lapse time of reaction. Waste Management. 2007; 27(2): 168-76.

Lee KH. Composition of aromatic products in the catalytic degradation of the mixture of waste polystyrene and high-density polyethylene using spent FCC catalyst. Polymer degradation and stability. 2008; 93(7): 1284-9.

Lee SY, Yoon JH, Kim JR, Park DW. Catalytic degradation of polystyrene over natural clinoptilolite zeolite. Polymer Degradation and Stability. 2001; 74(2): 297-305.

Li K, Lee SW, Yuan G, Lei J, Lin S, Weerachanchai P, Yang Y, Wang JY. Investigation into the catalytic activity of microporous and mesoporous catalysts in the pyrolysis of waste polyethylene and polypropylene mixture. Energies. 2016; 9(6): 431.

Li K, Lei J, Yuan G, Weerachanchai P, Wang JY, Zhao J, Yang Y. Fe-, Ti-, Zr-and Al-pillared clays for efficient catalytic pyrolysis of mixed plastics. Chemical Engineering Journal. 2017; 317: 800-9.

Li S, Sun S, Qi F, Dou X. Enhanced hydrolytic removal of tylosin in wastewater using polymer-based solid acid catalysts converted from polystyrene. Journal of Environmental Sciences. 2023; 126: 287-96.

Liang Z, Ni J. Improving the ammonium ion uptake onto natural zeolite by using an integrated modification process. Journal of Hazardous Materials. 2009;166(1):52-60.

Listiani A, Sembiring E, Rahman H. Evaluation of expanded polystyrene (EPS) plastic waste utilization as an asphalt substitution material in asphalt concrete wearing course. In5th Environmental Technology and Management Conference (ETMC) 2015; 2015.

Liu Y, Qian J, Wang J. Pyrolysis of polystyrene waste in a fluidized-bed reactor to obtain styrene monomer and gasoline fraction. Fuel Processing Technology. 2000; 63(1): 45-55.

López A, De Marco I, Caballero BM, Adrados A, Laresgoiti MF. Deactivation and regeneration of ZSM-5 zeolite in catalytic pyrolysis of plastic wastes. Waste management. 2011a; 31(8): 1852-8.

López A, De Marco I, Caballero BM, Laresgoiti MF, Adrados A, Aranzabal A. Catalytic pyrolysis of plastic wastes with two different types of catalysts: ZSM-5 zeolite and Red Mud. Applied Catalysis B: Environmental. 2011b; 104(3-4): 211-9.

Luo W, Hu Q, Fan ZY, Wan J, He Q, Huang SX, Zhou N, Song M, Zhang JC, Zhou Z. The effect of different particle sizes and HCl-modified kaolin on catalytic pyrolysis characteristics of reworked polypropylene plastics. Energy. 2020; 213: 119080.

Ma C, Yu J, Wang B, Song Z, Xiang J, Hu S, Su S, Sun L. Catalytic pyrolysis of flame retarded high impact polystyrene over various solid acid catalysts. Fuel Processing Technology. 2017a; 155: 32-41.

Ma C, Yu J, Wang B, Song Z, Xiang J, Hu S, Su S, Sun L. Chemical recycling of brominated flame retarded plastics from e-waste for clean fuels production: a review. Renewable and Sustainable Energy Reviews. 2016; 61: 433-50.

Ma C, Yu J, Yan Q, Song Z, Wang K, Wang B, Sun L. Pyrolysis-catalytic upgrading of brominated high impact polystyrene over Fe and Ni modified catalysts: Influence of HZSM-5 and MCM-41 catalysts. Polymer Degradation and Stability. 2017b; 146: 1-2.

Maafa IM. Pyrolysis of polystyrene waste: A review. Polymers. 2021; 13(2): 225.

Mahmudul HM, Hagos FY, Mamat R, Adam AA, Ishak WF, Alenezi R. Production, characterization and performance of biodiesel as an alternative fuel in diesel engines–A review. Renewable and Sustainable Energy Reviews. 2017;72:497-509.

Marcilla A, Gómez A, Menargues S, Ruiz R. Pyrolysis of polymers in the presence of a commercial clay. Polymer degradation and stability. 2005; 88(3): 456-60.

Marczewski M, Kamińska E, Marczewska H, Godek M, Rokicki G, Sokołowski J. Catalytic decomposition of polystyrene. The role of acid and basic active centers. Applied Catalysis B: Environmental. 2013;129:236-46.

Martín-Lara MA, Piñar A, Ligero A, Blázquez G, Calero M. Characterization and use of char produced from pyrolysis of post-consumer mixed plastic waste. Water. 2021; 13(9): 1188.

Mehta NS, Sahu PK, Tripathi P, Pyare R, Majhi MR. Influence of alumina and silica addition on the physico-mechanical and dielectric behavior of ceramic porcelain insulator at high sintering temperature. boletín de la sociedad española de cerámica y vidrio. 2018;57(4):151-9.

Messaoud IB, Hamdi N, Srasra E. The suitability of thermally activated red illite/kaolinitic clay as raw material for geopolymer binders. J Mater Env. Sci. 2018;9:946-54.

Mgbemere H, Ekpe I, Lawal G. Zeolite synthesis, characterization and application areas: a review. International Research Journal of Environmental sciences.2017; 6(100): 45-59.

Miandad R, Barakat MA, Aburiazaiza AS, Rehan M, Ismail IM, Nizami AS. Effect of plastic waste types on pyrolysis liquid oil. International biodeterioration & biodegradation. 2017;119:239-52.

Miandad R, Barakat MA, Aburiazaiza AS, Rehan M, Nizami AS. Catalytic pyrolysis of plastic waste: A review. Process Safety and Environmental Protection. 2016; 102: 822-38.

Miandad R, Barakat MA, Aburiazaiza AS, Rehan M, Nizami AS. Catalytic pyrolysis of plastic waste: A review. Process Safety and Environmental Protection. 2016; 102: 822-38.

Miandad R, Barakat MA, Rehan M, Aburiazaiza AS, Ismail IM, Nizami AS. Plastic waste to liquid oil through catalytic pyrolysis using natural and synthetic zeolite catalysts. Waste Management. 2017; 69: 66-78.

Miandad R, Rehan M, Barakat MA, Aburiazaiza AS, Khan H, Ismail IM, Dhavamani J, Gardy J, Hassanpour A, Nizami AS. Catalytic pyrolysis of plastic waste: moving toward pyrolysis based biorefineries. Frontiers in energy research. 2019; 7: 27.

Miller RR, Newhook R, Poole A. Styrene production, use, and human exposure. Critical Reviews in Toxicology. 1994; 24(sup1): S1-0.

Miskolczi N, Bartha L, Deák G, Jóver B, Kallo D. Thermal and thermo-catalytic degradation of high-density polyethylene waste. Journal of Analytical and Applied Pyrolysis. 2004; 72(2): 235-42.

Miskolczi N, Juzsakova T, Sója J. Preparation and application of metal loaded ZSM-5 and y-zeolite catalysts for thermo-catalytic pyrolysis of real end of life vehicle plastics waste. Journal of the Energy Institute. 2019; 92(1): 118-27.

Mittal M, Kumar A. Carbon nanotube (CNT) gas sensors for emissions from fossil fuel burning. Sensors and Actuators B: Chemical. 2014; 203: 349-62.

Mo Y, Zhao L, Wang Z, Chen CL, Tan GY, Wang JY. Enhanced styrene recovery from waste polystyrene pyrolysis using response surface methodology coupled with Box–Behnken design. Waste management. 2014; 34(4): 763-9.

Mohapatra SS, Rath MK, Singh RK, Murugan S. Performance and emission analysis of co-pyrolytic oil obtained from sugarcane bagasse and polystyrene in a CI engine. Fuel. 2021; 298: 120813.

Mortezaeikia V, Tavakoli O. Catalytic Microwave Assisted Pyrolysis of Abs-Br Using Fe/Sic: Accelerating Approach to Recycle Value Added Aromatics. Sic: Accelerating Approach to Recycle Value Added Aromatics.

Mukasa-Tebandeke IZ, Schumann A, Nyakairu GW, Lugolobi F. Evaluating the Changes in Surface Properties of Acid-Leached Iliri Clay. Academic Journal of Chemistry. 2016;1(3):76-92.

Mukasa-Tebandeke IZ, Ssebuwufu PJ, Nyanzi SA, Schumann A, Nyakairu GW, Ntale M, Lugolobi F. The elemental, mineralogical, IR, DTA and XRD analyses characterized clays and clay minerals of Central and Eastern Uganda. Advances in Materials Physics and Chemistry, 2015, 5, 67-86

Mukhraiya V, Yadav RK, Raikawar B. Production of Fuel Through Waste Plastic and Polythene and Used In Four Stroke Petrol Engine as A Fuel. International Journal of Mechanical Engineering and Technology. 2015;6:12.

Munir D, Usman MR. Catalytic hydropyrolysis of a model municipal waste plastic mixture over composite USY/SBA-16 catalysts. Journal of Analytical and Applied Pyrolysis. 2018; 135: 44-53.

Murugan S, Ramaswamy MC, Nagarajan G. Performance, emission and combustion studies of a DI diesel engine using Distilled Tyre pyrolysis oil-diesel blends. Fuel Processing Technology. 2008;89(2):152-9.

Nagendrappa G. Organic synthesis using clay and clay-supported catalysts. Applied Clay Science. 2010; 53(2): 106-38.

Nagendrappa G. Organic synthesis using clay catalysts. Resonance. 2002; 7(1): 64-77.

Nisar J, Ali G, Shah A, Ashiq MN, Farooqi ZH, Sharif A, Ahmed E, Iqbal M, Sherazi ST, Shah MR. Pyrolysis of polystyrene waste for recovery of combustible hydrocarbons using copper oxide as catalyst. Waste Management & Research. 2020; 38(11): 1269-77.

Nisar J, Ali G, Shah A, Iqbal M, Khan RA, Anwar F, Ullah R, Akhter MS. Fuel production from waste polystyrene via pyrolysis: Kinetics and products distribution. Waste management. 2019;88:236-47.

Ojha DK, Vinu R. Resource recovery via catalytic fast pyrolysis of polystyrene using zeolites. Journal of analytical and applied pyrolysis. 2015; 113: 349-59.

Olalo JA. Pyrolytic Oil Yield from Waste Plastic in Quezon City, Philippines: Optimization Using Response Surface Methodology. International Journal of Renewable Energy Development. 2022; 11(1): 325-332.

Onu P, Vasile C, Ciocılteu S, Iojoiu E, Darie H. Thermal and catalytic decomposition of polyethylene and polypropylene. Journal of Analytical and Applied Pyrolysis. 1999; 49(1-2): 145-53.

Onwudili JA, Insura N, Williams PT. Composition of products from the pyrolysis of polyethylene and polystyrene in a closed batch reactor: Effects of temperature and residence time. Journal of Analytical and Applied Pyrolysis. 2009; 86(2): 293-303.

Pan R, Martins MF, Debenest G. Optimization of oil production through ex-situ catalytic pyrolysis of waste polyethylene with activated carbon. Energy. 2022; 248: 123514.

Panda AK, Alotaibi A, Kozhevnikov IV, Shiju NR. Pyrolysis of plastics to liquid fuel using sulphated zirconium hydroxide catalyst. Waste and Biomass Valorization. 2020; 11(11): 6337-45.

Panda AK, Singh RK, Mishra DK. Thermolysis of waste plastics to liquid fuel: A suitable method for plastic waste management and manufacture of value added products—A world prospective. Renewable and Sustainable Energy Reviews. 2010;14(1):233-48.

Panda AK, Singh RK. Catalytic performances of kaoline and silica alumina in the thermal degradation of polypropylene. Journal of Fuel Chemistry and Technology. 201; 39(3): 198-202.

Panda AK. Thermo-catalytic degradation of different plastics to drop in liquid fuel using calcium bentonite catalyst. International Journal of Industrial Chemistry. 2018; 9(2): 167-76.

Panjiara D, Pramanik H. Optimization of process parameters using response surface methodology (RSM) for power generation via electrooxidation of glycerol in T-Shaped air breathing microfluidic fuel cell (MFC). International Journal of Hydrogen Energy. 2020; 45(58): 33968-79.

Papari S, Bamdad H, Berruti F. Pyrolytic conversion of plastic waste to value-added products and fuels: A review. Materials. 2021;14(10):2586.

Parasuram B, Karthikeyan S, Sundram S. Catalytic pyrolysis of polystyrene waste using bentonite as a catalyst. J. Environ. Nanotechnol. 2013; 2: 97-100.

Park JJ, Park K, Kim JS, Maken S, Song H, Shin H, Park JW, Choi MJ. Characterization of styrene recovery from the pyrolysis of waste expandable polystyrene. Energy & fuels. 2003;17(6):1576-82.

Park KB, Jeong YS, Guzelciftci B, Kim JS. Two-stage pyrolysis of polystyrene: Pyrolysis oil as a source of fuels or benzene, toluene, ethylbenzene, and xylenes. Applied Energy. 2020; 259: 114240.

Patil V, Adhikari S, Cross P. Co-pyrolysis of lignin and plastics using red clay as catalyst in a micro-pyrolyzer. Bioresource technology. 2018;270:311-9.

Paucar-Sánchez MF, Calero M, Blázquez G, Muñoz-Batista MJ, Martín-Lara MA. Characterization of liquid fraction obtained from pyrolysis of post-consumer mixed plastic waste: A comparing between measured and calculated parameters. Process Safety and Environmental Protection. 2022; 159: 1053-63.

Peng Y, Wang Y, Ke L, Dai L, Wu Q, Cobb K, Zeng Y, Zou R, Liu Y, Ruan R. A review on catalytic pyrolysis of plastic wastes to high-value products. Energy Conversion and Management. 2022; 254: 115243.

Perra D, Drenchev N, Chakarova K, Cutrufello MG, Hadjiivanov K. Remarkable acid strength of ammonium ions in zeolites: FTIR study of low-temperature CO adsorption on NH 4 FER. RSC Advances. 2014; 4(99): 56183-7.

Pinto F, Paradela F, Gulyurtlu I, Ramos AM. Prediction of liquid yields from the pyrolysis of waste mixtures using response surface methodology. Fuel processing technology. 2013; 116: 271-83.

Qureshi MS, Oasmaa A, Pihkola H, Deviatkin I, Tenhunen A, Mannila J, Minkkinen H, Pohjakallio M, Laine-Ylijoki J. Pyrolysis of plastic waste: Opportunities and challenges. Journal of Analytical and Applied Pyrolysis. 2020; 152: 104804.

Rahman MM, Muttakin M, Pal A, Shafiullah AZ, Saha BB. A statistical approach to determine optimal models for IUPAC-classified adsorption isotherms. Energies. 2019; 12(23): 4565.

Ramachandra TV. Emissions from India's transport sector: statewise synthesis. Atmospheric Environment. 2009; 43(34): 5510-7.

Ramanan V, Siddaiah B, Raji K, Ramamurthy P. Green synthesis of multifunctionalized, nitrogen-doped, highly fluorescent carbon dots from waste expanded polystyrene and its application in the fluorimetric detection of Au3+ ions in aqueous media. ACS Sustainable Chemistry & Engineering. 2018; 6(2): 1627-38.

Ramanan V, Siddaiah B, Raji K, Ramamurthy P. Green synthesis of multifunctionalized, nitrogen-doped, highly fluorescent carbon dots from waste expanded polystyrene and its application in the fluorimetric detection of Au3+ ions in aqueous media. ACS Sustainable Chemistry & Engineering. 2018; 6(2): 1627-38.

Reddy MS, Venkataraman C. Inventory of aerosol and sulphur dioxide emissions from India: I-Fossil fuel combustion. Atmospheric Environment. 2002; 36(4): 677-97.

Rehan M, Miandad R, Barakat MA, Ismail IM, Almeelbi T, Gardy J, Hassanpour A, Khan MZ, Demirbas A, Nizami AS. Effect of zeolite catalysts on pyrolysis liquid oil. International Biodeterioration & Biodegradation. 2017; 119: 162-75.

Renzini MS, Sedran U, Pierella LB. H-ZSM-11 and Zn-ZSM-11 zeolites and their applications in the catalytic transformation of LDPE. Journal of Analytical and Applied Pyrolysis. 2009; 86(1): 215-20.

Rezvanipour M, Alikhani HF, Pazouki M. Catalytic pyrolysis of general purpose polystyrene using red mud as a catalyst. Iranian Journal Chemical Engineering. 2014; 11(4): 10-20.

Riswanto FD, Rohman A, Pramono S, Martono S. Application of response surface methodology as mathematical and statistical tools in natural product research. Journal of Applied Pharmaceutical Science. 2019; 9(10): 125-33.

Romeiro GA, Salgado EC, Silva RV, Figueiredo MK, Pinto PA, Damasceno RN. A study of pyrolysis oil from soluble coffee ground using low temperature conversion (LTC) process. Journal of analytical and applied pyrolysis. 2012; 93: 47-51.

Sadi JA. Designing experiments: 3 level full factorial design and variation of processing parameters methods for polymer colors. Advances in Science, Technology and Engineering Systems Journal. 2018; 3(5): 109-15.

Salman B, Nomanbhay S, Salema AA. Microwave-synthesised hydrothermal co-pyrolysis of oil palm empty fruit bunch with plastic wastes from Nigeria. Biofuels. 2022; 13(1): 31-47.

Samudro H, Samudro G, Mangkoedihardjo S. Prevention of indoor air pollution through design and construction certification: A review of the sick building syndrome conditions. Journal of Air Pollution and Health. 2022; 7(1): 81-94.

Sanahuja-Parejo O, Veses A, Navarro MV, López JM, Murillo R, Callén MS, García T. Drop-in biofuels from the co-pyrolysis of grape seeds and polystyrene. Chemical Engineering Journal. 2019; 377: 120246.

Santos BP, Almeida D, Maria de Fatima VM, Henriques CA. Petrochemical feedstock from pyrolysis of waste polyethylene and polypropylene using different catalysts. Fuel. 2018; 215: 515-21.

Santos PS, Santos HS, Toledo SP. Standard transition aluminas. Electron microscopy studies. Materials Research. 2000;3:104-14.

Selvaganapathy T, Muthuvelayudham R, Jayakumar M. Process parameter optimization study on thermolytic polystyrene liquid fuel using response surface methodology (RSM). Materials Today: Proceedings. 2020; 26: 2729-39.

Seo YH, Lee KH, Shin DH. Investigation of catalytic degradation of high-density polyethylene by hydrocarbon group type analysis. Journal of Analytical and Applied Pyrolysis. 2003; 70(2): 383-98.

Shah J, Jan MR, Mabood F, Jabeen F. Catalytic pyrolysis of LDPE leads to valuable resource recovery and reduction of waste problems. Energy Conversion and Management. 2010; 51(12): 2791-801.

Shah J, Jan MR. Conversion of waste polystyrene through catalytic degradation into valuable products. Korean Journal of Chemical Engineering. 2014; 31(8): 1389-98.

Shakirullah M, Ahmad W, Ahmad I, Ishaq M. Oxidative desulphurization study of gasoline and kerosene: role of some organic and inorganic oxidants. Fuel processing technology. 2010;91(11):1736-41.

Sharuddin SD, Abnisa F, Daud WM, Aroua MK. A review on pyrolysis of plastic wastes. Energy conversion and management. 2016; 115: 308-26.

Shim EH, Kim J, Cho KS, Ryu HW. Biofiltration and inhibitory interactions of gaseous benzene, toluene, xylene, and methyl tert-butyl ether. Environmental science & technology. 2006;40(9):3089-94.

Singh RK, Ruj B, Sadhukhan AK, Gupta P. Impact of fast and slow pyrolysis on the degradation of mixed plastic waste: Product yield analysis and their characterization. Journal of the Energy Institute. 2019; 92(6): 1647-57.

Singh S, Chakraborty JP, Mondal MK. Optimization of process parameters for torrefaction of Acacia nilotica using response surface methodology and characteristics of torrefied biomass as upgraded fuel. Energy. 2019; 186: 115865.

Socci J, Osatiashtiani A, Kyriakou G, Bridgwater T. The catalytic cracking of sterically challenging plastic feedstocks over high acid density Al-SBA-15 catalysts. Applied Catalysis A: General. 2019; 570:218-27.

Soliman A, Farag HA, Nassef E, Amer A, ElTaweel Y. Pyrolysis of low-density polyethylene waste plastics using mixtures of catalysts. Journal of Material Cycles and Waste Management. 2020; 22(5): 1399-406.

Sonawane YB, Shindikar MR, Khaladkar MY. High calorific value fuel from household plastic waste by catalytic pyrolysis. Nature Environment and Pollution Technology. 2017 Sep 1;16(3):879.

Song YK, Hong SH, Eo S, Han GM, Shim WJ. Rapid production of micro-and nanoplastics by fragmentation of expanded polystyrene exposed to sunlight. Environmental Science & Technology. 2020; 54(18): 11191-200.

Soni VK, Singh G, Vijayan BK, Chopra A, Kapur GS, Ramakumar SS. Thermochemical recycling of waste plastics by pyrolysis: a review. Energy & Fuels. 2021; 35(16): 12763-808.

Su J, Fang C, Yang M, You C, Lin Q, Zhou X, Li H. Catalytic pyrolysis of waste packaging polyethylene using AlCl3-NaCl eutectic salt as catalyst. Journal of Analytical and Applied Pyrolysis. 2019; 139: 274-81.

Sun K, Huang Q, Chi Y, Yan J. Effect of $ZnCl_2$-activated biochar on catalytic pyrolysis of mixed waste plastics for producing aromatic-enriched oil. Waste Management. 2018; 81: 128-37.

Suriapparao DV, Boruah B, Raja D, Vinu R. Microwave assisted co-pyrolysis of biomasses with polypropylene and polystyrene for high quality bio-oil production. Fuel Processing Technology. 2018; 175: 64-75.

Syamsiro M, Cheng S, Hu W, Saptoadi H, Pratama NN, Trisunaryanti W, Yoshikawa K. Liquid and Gaseous Fuels from Waste Plastics by Sequential Pyrolysis and Catalytic Reforming Processes over Indonesian Natural Zeolite Catalysts. Waste Technology. 2014; 2(2): 44-51.

Tae JW, Jang BS, Kim JR, Kim I, Park DW. Catalytic degradation of polystyrene using acid-treated halloysite clays. Solid State Ionics. 2004; 172 (1-4): 129-33.

Ahmad Tajjamal A, Ul-Hamid A, Faisal A, Zaidi SA, Sherin L, Mir A, Mustafa M, Ahmad N, Hussain M, Park YK. Catalytic cracking of polystyrene pyrolysis oil: Effect of Nb2O5 and NiO/Nb2O5 catalyst on the liquid product composition. Waste Management. 2022; 141: 240-50.

Tao P, Ma XB, Chen DZ, Wang H. Pyrolysis of waste plastics: effect of heating rate on product yields and oil properties. In Advanced Materials Research 2013 (Vol. 666, pp. 1-10). Trans Tech Publications Ltd.

Thahir R, Irwan M, Alwathan A, Ramli R. Effect of temperature on the pyrolysis of plastic waste using zeolite ZSM-5 using a refinery distillation bubble cap plate column. Results in Engineering. 2021; 11: 100231.

Thommes M, Kaneko K, Neimark AV, Olivier JP, Rodriguez-Reinoso F, Rouquerol J, Sing KS. Physisorption of gases, with special reference to the evaluation of surface area and pore size distribution (IUPAC Technical Report). Pure and applied chemistry. 2015; 87(9-10): 1051-69.

Tulashie SK, Boadu EK, Dapaah S. Plastic waste to fuel via pyrolysis: A key way to solving the severe plastic waste problem in Ghana. Thermal Science and Engineering Progress. 2019; 11: 417-24.

Uddin MK. A review on the adsorption of heavy metals by clay minerals, with special focus on the past decade. Chemical Engineering Journal. 2017; 308:438-62.

Ukei H, Hirose T, Horikawa S, Takai Y, Taka M, Azuma N, Ueno A. Catalytic degradation of polystyrene into styrene and a design of recyclable polystyrene with dispersed catalysts. Catalysis today. 2000; 62(1): 67-75.

Usmani Z, Kumar V, Varjani S, Gupta P, Rani R, Chandra A. Municipal solid waste to clean energy system: a contribution toward sustainable development. In current developments in biotechnology and bioengineering 2020 (pp. 217-231). Elsevier.

Uttaravalli AN, Dinda S, Gidla BR, Kasturi G, Kasala P, Penta G. Studies on development of adhesive material from post-consumer (waste) expanded polystyrene: a two-edged sword approach. Process Safety and Environmental Protection. 2021; 145: 312-20.

Uttaravalli AN, Dinda S, Gidla BR. Scientific and engineering aspects of potential applications of post-consumer (waste) expanded polystyrene: a review. Process Safety and Environmental Protection. 2020; 137: 140-8.

van der Westhuizen S, Collard FX, Görgens J. Pyrolysis of waste polystyrene into transportation fuel: Effect of contamination on oil yield and production at pilot scale. Journal of Analytical and Applied Pyrolysis. 2022; 161: 105407.

Verma A, Sharma S, Pramanik H. Pyrolysis of waste expanded polystyrene and reduction of styrene via in-situ multiphase pyrolysis of product oil for the production of fuel range hydrocarbons. Waste Management. 2021; 120: 330-9.

Verma A, Sharma S, Pramanik H. Synthesis and efficient use of low-cost natural red clay catalyst for the production of upgraded fuel oil using pyrolysis of waste expanded polystyrene and in situ vapour phase hydrogenation. International Journal of Energy Research. 2022; 1-22.

Wang J, Emmerich L, Wu J, Vana P, Zhang K. Hydroplastic polymers as eco-friendly hydrosetting plastics. Nature Sustainability. 2021; 4(10): 877-83.

Wang J, Jiang J, Sun Y, Wang X, Li M, Pang S, Ruan R, Ragauskas AJ, Ok YS, Tsang DC. Catalytic degradation of waste rubbers and plastics over zeolites to produce aromatic hydrocarbons. Journal of Cleaner Production. 2021; 309: 127469.

Wang J, Jiang J, Sun Y, Zhong Z, Wang X, Xia H, Liu G, Pang S, Wang K, Li M, Xu J. Recycling benzene and ethylbenzene from in-situ catalytic fast pyrolysis of plastic wastes. Energy Conversion and Management. 2019; 200: 112088.

Wang JL, Wang LL. Catalytic pyrolysis of municipal plastic waste to fuel with nickel-loaded silica-alumina catalysts. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects. 2011; 33(21): 1940-8.

Wang K, Ou L, Brown T, Brown RC. Beyond ethanol: a techno-economic analysis of an integrated corn biorefinery for the production of hydrocarbon fuels and chemicals. Biofuels, Bioproducts and Biorefining. 2014;9(2):190-200.

Wang Z, Fingas M, Yang C, Christensen JH. Crude oil and refined product fingerprinting: Principles. InEnvironmental forensics 1964 Jan 1 (pp. 339-407). Academic Press.

Wathakit K, Sukjit E, Kaewbuddee C, Maithomklang S, Klinkaew N, Liplap P, Arjharn W, Srisertpol J. Characterization and impact of waste plastic oil in a variable compression ratio diesel engine. Energies. 2021;14(8):2230.

Williams PT, Bagri R. Hydrocarbon gases and oils from the recycling of polystyrene waste by catalytic pyrolysis. International Journal of Energy Research. 2004; 28(1): 31-44.

Williams PT, Horne PA, Taylor DT. Polycyclic aromatic hydrocarbons in polystyrene derived pyrolysis oil. Journal of analytical and applied pyrolysis. 1993; 25: 325-34.

Witek-Krowiak A, Chojnacka K, Podstawczyk D, Dawiec A, Pokomeda K. Application of response surface methodology and artificial neural network methods in modelling and optimization of biosorption process. Bioresource technology. 2014; 160:150-60.

Xie C, Liu F, Yu S, Xie F, Li L, Zhang S, Yang J. Study on catalytic pyrolysis of polystyrene over base modified silicon mesoporous molecular sieve. Catalysis Communications. 2008 ; 9(6): 1132-6.

Xue Y, Johnston P, Bai X. Effect of catalyst contact mode and gas atmosphere during catalytic pyrolysis of waste plastics. Energy Conversion and Management. 2017; 142: 441-51.

Yang Y, Brammer JG, Samanya J, Hossain AK, Hornung A. Investigation into the performance and emissions of a stationary diesel engine fuelled by sewage sludge intermediate pyrolysis oil and biodiesel blends. Energy. 2013;62:269-76.

Yao D, Li H, Dai Y, Wang CH. Impact of temperature on the activity of Fe-Ni catalysts for pyrolysis and decomposition processing of plastic waste. Chemical Engineering Journal. 2021; 408: 127268.

Yolmeh M, Jafari SM. Applications of response surface methodology in the food industry processes. Food and Bioprocess Technology. 2017; 10(3): 413-33.

Yu C, Ke Y, Deng Q, Lu S, Ji J, Hu X, Zhao Y. Synthesis and characterization of polystyrene-montmorillonite nanocomposite particles using an anionic-surfactant-modified clay and their friction performance. Applied Sciences. 2018;8(6):964.

Zaitan H, Bianchi D, Achak O, Chafik T. A comparative study of the adsorption and desorption of o-xylene onto bentonite clay and alumina. Journal of hazardous materials. 2008;153(1-2):852-9.

Zayoud A, Thi HD, Kusenberg M, Eschenbacher A, Kresovic U, Alderweireldt N, Djokic M, Van Geem KM. Pyrolysis of end-of-life polystyrene in a pilot-scale reactor: Maximizing styrene production. Waste Management. 2022; 139: 85-95.

Zhang Y, Duan D, Lei H, Villota E, Ruan R. Jet fuel production from waste plastics via catalytic pyrolysis with activated carbons. Applied Energy. 2019; 251: 113337.

Zhang Z, Hirose T, Nishio S, Morioka Y, Azuma N, Ueno A, Ohkita H, Okada M. Chemical recycling of waste polystyrene into styrene over solid acids and bases. Industrial & engineering chemistry research. 1995;34(12):4514-9.

Zhao B, Wang H, Yao Z, Alfarraj S, Alharbi SA, Krishnan R, Chi NT, Brindhadevi K. Processing and utilization of the solid plastic waste oil as the sustainable substitute for fossil fuel for the CI engine from microwave assisted pyrolysis process. Fuel. 2022; 327: 125191.

Zheng Y, Yanful EK, Bassi AS. A review of plastic waste biodegradation. Critical reviews in biotechnology. 2005; 25(4): 243-50.

Zhibo Z, Nishio S, Morioka Y, Ueno A, Ohkita H, Tochihara Y, Mizushima T, Kakuta N. Thermal and chemical recycle of waste polymers. Catalysis Today. 1996; 29(1-4): 303-8.

Zhou CH. An overview on strategies towards clay-based designer catalysts for green and sustainable catalysis. Applied Clay Science. 2011; 53(2): 87-96.

Zhou N, Dai L, Lv Y, Li H, Deng W, Guo F, Chen P, Lei H, Ruan R. Catalytic pyrolysis of plastic wastes in a continuous microwave assisted pyrolysis system for fuel production. Chemical Engineering Journal. 2021; 418: 129412.

Ziad M, Khan S, Miandad R, Ali G, Hashmi MZ, Ahmed Z. Assessment of plastic waste generation and its feasibility for establishment of plastic waste refinery. Arabian Journal of Geosciences. 2021; 14(19): 1-9.

Publications from the Work

International Journals:

Verma A, Sharma S, Pramanik H., "Pyrolysis of waste expanded polystyrene and reduction of styrene via in-situ multiphase pyrolysis of product oil for the production of fuel range hydrocarbons", **Waste Management**. 2021; 120: 330-339.

Verma A, Sharma S, Pramanik H., "Synthesis and efficient use of low-cost natural red clay catalyst for the production of upgraded fuel oil using pyrolysis of waste expanded polystyrene and in situ vapour phase hydrogenation", **International Journal of Energy Research**. 2022; 46: 15463-15484.

Verma A, Sharma S, Pramanik H., "Rapid identification of optimized process parameters via RSM and experimental validation for the production of valuable aromatic hydrocarbons using multiphase catalytic pyrolysis of mixed waste plastics and in-situ hydrogenation/aromatization" **Arabian Journal for Science and Engineering**. 2023; 1-16.

Verma A, Pramanik H. Production of gasoline octane booster aromatics benzene, toluene and ethylbenzene from multiphase catalytic pyrolysis of mixed waste expanded polystyrene and high density polyethylene. **Progress in Rubber, Plastics and Recycling Technology**. 2023; 0(0): 14777606231174919.

Verma A, Pramanik H., "Multiphase pyrolysis of waste expanded polystyrene and in-situ hydrogenation of pyrolysis oil on silica-alumina supported nickel catalyst for the production of fuel range paraffinic and aromatic hydrocarbons", **Indian Journal of Chemical Technology**. 2023; 30: 461-475.

Verma A, Pramanik H., "Multiphase catalytic pyrolysis of waste expanded polystyrene via solid base catalyst calcium carbonate", **Indian Journal of Chemical Technology; (Under Review)**.

Verma A, Pramanik H., "Synthesis of modified river clay catalyst for valuable BTE production via catalytic pyrolysis of hazardous plastic waste", **Chemistry Select; (Under Review)**.

Conferences:

Verma, A., Sweta Sharma, Pramanik, H., "Pyrolysis of waste polystyrene in semi batch reactor for the recovery of valuable aromatics" 71th Annual session of IIChE, Chemcon 2018, Jalandhar, 27th -30th Dec, 2018.

Anjali Verma, Sweta Sharma, Hiralal Pramanik "Production of gasoline range hydrocarbon from the mixture of waste expanded polystyrene and waste high-density polyethylene using multiphase catalytic pyrolysis" International Conference on

Advances in Sustainable Research for Energy and Environmental Management (ASREEM-2021), SVNIT Surat, August 6th to 8th, 2021.

Verma A, Pramanik H., "Reusability study of catalyst for the production of valuable aromatics benzene, toluene and ethylbenzene via multiphase catalytic pyrolysis of waste expanded polystyrene" ICRSC 2022, Kottayam, Kerala, September 9th to 11th 2022.

Verma A, Pramanik H., "Multiphase catalytic pyrolysis of waste expanded polystyrene via solid base catalyst calcium carbonate" Chemcon 2022, Kanpur, 27th -30th Dec, 2022.