Scopus

Documents

Abidin, S.Z.[a b] , Osazuwa, O.U.[c] , Othman, N.H.[d] , Setiabudi, H.D.[a e] , Sulaiman, S.[f]

Recent progress on catalyst development in biomass tar steam reforming: toluene as a biomass tar model compound

(2023) *Biomass Conversion and Biorefinery*, . Cited 1 time.

DOI: 10.1007/s13399-023-03876-9

[a] Centre for Research in Advanced Fluid & Processes, Universiti Malaysia Pahang, Lebuh Persiaran Tun Khalil Yaakob, Pahang, Kuantan, 26300, Malaysia
[b] Faculty of Chemical Engineering, Industrial University of Ho Chi Minh City, 12 Nguyen Van Bao St, Go Vap, Ho Chi Minh City, Viet Nam
[c] Faculty of Engineering, Department of Chemical Engineering, University of Benin, PMB 1154, Edo State, Benin City, Nigeria
[d] School of Chemical Engineering, College of Engineering, Universiti Teknologi MARA, Selangor, Shah Alam, 40450, Malaysia
[e] Faculty of Chemical and Process Engineering Technology, Universiti Malaysia Pahang, Lebuh Persiaran Tun Khalil Yaakob, Pahang, Kuantan, 26300, Malaysia
[f] Faculty of Engineering, Department of Chemical Engineering and Sustainability, International Islamic University Malaysia (IIUM), Jalan Gombak, Kuala Lumpur, 53100, Malaysia

Abstract
Scientists are currently focusing on eco-friendly and non-polluting fuels, and the production of H2 from biomass has recently garnered attention. Valorization of biomass via catalytic gasification has been proposed as a potential solution to the environmental problems associated with CO2 emissions and global warming. Nonetheless, the process generates tar as a by-product, which poses numerous difficulties for the reaction process. Recently, steam reforming has become a promising method for tar conversion since steam potentially contributes more H2 to the reaction. However, the reaction is endothermic and hence requires the use of a catalyst. This leads to the global challenge which is designing an affordable anti-coking sintering resistance catalyst. This review reports on advances made in the development of catalytic biomass tar reforming, focusing mainly on toluene as the biomass tar model compound. Recent developments in the toluene catalytic steam reforming, reaction pathways, catalyst deactivation studies, and catalyst development were comprehensively reviewed. In addition, the functions of active sites, support, and promoter in the performance of toluene steam reforming were discussed concurrently. The review concluded with an insight into the prospects and challenges of biomass tar reforming technology, as well as a few recommendations for future catalyst development.

Author Keywords
Biomass; Gasification; Hydrogen; Steam reforming; Toluene

Index Keywords
Catalyst deactivation, Catalytic reforming, Gasification, Global warming, Hydrogen, Sintering, Steam, Steam reforming, Tar, Toluene; Biomass tar, Catalytic gasification, Eco-friendly, Environmental problems, Polluting fuels, Recent progress, Tar model compounds, Tar reforming, Valorisation,]+ catalyst; Biomass

References

- Xu, H., Shen, Z., Chen, G.
  Carbon-coated mesoporous silica-supported Ni nanocomposite catalyst for efficient hydrogen production via steam reforming of toluene
  (2020) *Fuel*, 275, pp. 1-8.

- Sayas, S., Vivó, N., Da Costa-Serra, J.F., Chica, A.
  Toluene steam reforming over nickel based catalysts
  (2021) *Int J Hydrogen Energy*, 46, pp. 17472-17480.

- Yahya, H.S.M., Abbas, T., Amin, N.A.S.
  Optimization of hydrogen production via toluene steam reforming over Ni–Co supported modified-activated carbon using ANN coupled GA and RSM
  (2021) *Int J Hydrogen Energy*, 46, pp. 24632-24651.

- *The Future of Hydrogen – Analysis - IEA*,

- El-Emam, R.S., Özcan, H.
  Comprehensive review on the techno-economics of sustainable large-scale clean hydrogen production
  (2019) *J Clean Prod*, 220, pp. 593-609.

- Cao, L., Yu, I.K.M., Xiong, X.
  Biorenewable hydrogen production through biomass gasification: a review and future prospects
  (2020) *Environ Res*, 186, p. 109547.

- Safarian, S., Unnþórsson, R., Richter, C.
  A review of biomass gasification modelling
  (2019) *Renew Sustain Energy Rev*, 110, pp. 378-391.

- Bracciale, M.P., De Caprariis, B., Bassano, C.
  Influence of the catalyst support on the steam reforming performance of toluene as tar model compound
  (2018) *Chem Eng Trans*, 65, pp. 241-246.

- Wang, Y., Jiang, L., Hu, S.
  Evolution of structure and activity of char-supported iron catalysts prepared for steam reforming of bio-oil
  (2017) *Fuel Process Technol*, 158, pp. 180-190.

- Ail, S.S., Dasappa, S.
  Biomass to liquid transportation fuel via Fischer Tropsch synthesis - technology review and current scenario
  (2016) *Renew Sustain Energy Rev*, 58, pp. 267-286.

- Fang, Y., Paul, M.C., Varjani, S.
  Concentrated solar thermochemical gasification of biomass: principles, applications, and development
  (2021) *Renew Sustain Energy Rev*, 150, p. 111484.

- Valizadeh, S., Hakimian, H., Farooq, A.
  Valorization of biomass through gasification for green hydrogen generation: a comprehensive review
  (2022) *Bioresour Technol*, 365, p. 128143.

- Zhang, Y., Xu, P., Liang, S.
  Exergy analysis of hydrogen production from steam gasification of biomass: a review
  (2019) *Int J Hydrogen Energy*, 44, pp. 14290-14302.

- Lee, D., Nam, H., Won Seo, M.
  Recent progress in the catalytic thermochemical conversion process of biomass for biofuels
  (2022) *Chem Eng J*, 447, p. 137501.

- Ashok, J., Dewangan, N., Das, S.
  Recent progress in the development of catalysts for steam reforming of biomass tar model reaction
  (2020) *Fuel Process Technol*, 199, p. 106252.

- Gao, X., Wang, Z., Ashok, J., Kawi, S.
  A comprehensive review of anti-coking, anti-poisoning and anti-sintering catalysts for biomass tar reforming reaction
  (2020) *Chem Eng Sci X*, 7, p. 100065.

- Buentello-Montoya, D.A., Zhang, X., Li, J.
  The use of gasification solid products as catalysts for tar reforming
  (2019) *Renew Sustain Energy Rev*, 107, pp. 399-412.

- Ahmad, A.A., Zawawi, N.A., Kasim, F.H.
  Assessing the gasification performance of biomass: a review on biomass gasification process conditions, optimization and economic evaluation
  (2016) *Renew Sustain Energy Rev*, 53, pp. 1333-1347.

- Abdoulmoumine, N., Adhikari, S., Kulkarni, A., Chattanathan, S.
  A review on biomass gasification syngas cleanup
  (2015) *Appl Energy*, 155, pp. 294-307.

- Yin, F., Tremain, P., Yu, J.
  An experimental investigation of the catalytic activity of natural calcium-rich minerals and a novel dual-supported CaO-Ca12Al14O33/Al2O3 catalyst for biotar steam reforming
  (2018) *Energy Fuels*, 32, pp. 4269-4277.

- Anis, S., Zainal, Z.A.
  Tar reduction in biomass producer gas via mechanical, catalytic and thermal methods: a review
  (2011) *Renew Sustain Energy Rev*, 15, pp. 2355-2377.

- Arregi, A., Amutio, M., Lopez, G.
  Evaluation of thermochemical routes for hydrogen production from biomass: a review
  (2018) *Energy Convers Manag*, 165, pp. 696-719.

- Ashok, J., Kawi, S.
  Steam reforming of biomass tar model compound at relatively low steam-to-carbon condition over CaO-doped nickel-iron alloy supported over iron-alumina catalysts
  (2015) *Appl Catal A Gen*, 490, pp. 24-35.

- Yang, X., Liu, X., Guo, T., Liu, C.
  Effects of Cu and Fe additives on low-temperature catalytic steam reforming of toluene over Ni/AC catalysts
  (2019) *Catal Surv from Asia*, 23, pp. 54-63.

- Chong, C.C., Cheng, Y.W., Ng, K.H.
  Bio-hydrogen production from steam reforming of liquid biomass wastes and biomass-derived oxygenates: a review
  (2022) *Fuel*, 311, p. 122623.

- Kopyscinski, J., Schildhauer, T.J., Biollaz, S.M.A.
  Production of synthetic natural gas (SNG) from coal and dry biomass – a technology review from 1950 to 2009
  (2010) *Fuel*, 89, pp. 1763-1783.

- Silveira, E.B., Rabelo-Neto, R.C., Noronha, F.B.
  Steam reforming of toluene, methane and mixtures over Ni/ZrO2 catalysts
  (2017) *Catal Today*, 289, pp. 289-301.

- Namioka, T., Okudaira, K., Yukumoto, M.
  Low-temperature trace light-tar reforming in biomass syngas by atmospheric hydrogenation and hydrogenolysis
  (2018) *Fuel Process Technol*, 181, pp. 304-310.

- Kuba, M., Havlik, F., Kirnbauer, F., Hofbauer, H.
  Influence of bed material coatings on the water-gas-shift reaction and steam

reforming of toluene as tar model compound of biomass gasification
(2016) *Biomass Bioenerg*, 89, pp. 40-49.

- Jurado, L., Papaefthimiou, V., Thomas, S., Roger, A.C.
Low temperature toluene and phenol abatement as tar model molecules over Ni-based catalysts: influence of the support and the synthesis method
(2021) *Appl Catal B Environ*, 297.
(,),.,:,., https://doi.org/10.1016/j.apcatb.2021.120479

- Qian, K., Kumar, A.
Catalytic reforming of toluene and naphthalene (model tar) by char supported nickel catalyst
(2017) *Fuel*, 187, pp. 128-136.

- Valderrama Rios, M.L., González, A.M., Lora, E.E.S., Almazán del Olmo, O.A.
Reduction of tar generated during biomass gasification: a review
(2018) *Biomass Bioenerg*, 108, pp. 345-370.

- Gao, N., Salisu, J., Quan, C., Williams, P.
Modified nickel-based catalysts for improved steam reforming of biomass tar: a critical review
(2021) *Renew Sustain Energy Rev*, 145, p. 111023.

- Qin, Y.H., Campen, A., Wiltowski, T.
The influence of different chemical compositions in biomass on gasification tar formation
(2015) *Biomass Bioenerg*, 83, pp. 77-84.

- Guan, G., Kaewpanha, M., Hao, X., Abudula, A.
Catalytic steam reforming of biomass tar: prospects and challenges
(2016) *Renew Sustain Energy Rev*, 58, pp. 450-461.

- Furusawa, T., Tsutsumi, A.
Comparison of Co/MgO and Ni/MgO catalysts for the steam reforming of naphthalene as a model compound of tar derived from biomass gasification
(2005) *Appl Catal A Gen*, 278, pp. 207-212.

- Noichi, H., Uddin, A., Sasaoka, E.
Steam reforming of naphthalene as model biomass tar over iron–aluminum and iron–zirconium oxide catalyst catalysts
(2010) *Fuel Process Technol*, 91, pp. 1609-1616.

- Gai, C., Dong, Y., Fan, P.
Kinetic study on thermal decomposition of toluene in a micro fluidized bed reactor
(2015) *Energy Convers Manag*, 106, pp. 721-727.

- Zhang, L., Xu, C.
Energy Convers Manag, 51, pp. 969-982.
Charles), Champagne P (2010) Overview of recent advances in thermo-chemical conversion of biomass

- Liu, L., Wang, Q., Ahmad, S.
Steam reforming of toluene as model biomass tar to H2-rich syngas in a DBD plasma-catalytic system
(2018) *J Energy Inst*, 91, pp. 927-939.

- Zhou, Y., Wang, Q., Tian, X.
Electron-enriched Pt induced by CoSe2 promoted bifunctional catalytic ability for low carbon alcohol fuel electro-reforming of hydrogen evolution
(2022) *J Energy Chem*, 75, pp. 46-54.

- Roslan, N.A., Abidin, S.Z., Osazuwa, O.U.
  H2-rich syngas from glycerol dry reforming over Ni-based catalysts supported on alumina from aluminum dross
  (2021) *Int J Hydrogen Energy*, 46, pp. 30959-30975.

- Sutton, D., Kelleher, B., Ross, J.R.H.
  Review of literature on catalysts for biomass gasification
  (2001) *Fuel Process Technol*, 73, pp. 155-173.

- Xu, Y., Liu, M., Wang, M.
  Methanol electroreforming coupled to green hydrogen production over bifunctional NiIr-based metal-organic framework nanosheet arrays
  (2022) *Appl Catal B Environ*, 300, p. 120753.

- Ren, J., Liu, Y.L.
  Promoting syngas production from steam reforming of toluene using a highly stable Ni/(Mg, Al)Ox catalyst
  (2022) *Appl Catal B Environ*, 300, p. 120743.

- Yu, H., Zhang, Z., Li, Z., Chen, D.
  Characteristics of tar formation during cellulose, hemicellulose and lignin gasification
  (2014) *Fuel*, 118, pp. 250-256.

- Wu, W., Fan, Q., Yi, B.
  Catalytic characteristics of a Ni-MgO/HZSM-5 catalyst for steam reforming of toluene
  (2020) *RSC Adv*, 10, pp. 20872-20881.

- Betchaku, M., Nakagawa, Y., Tamura, M., Tomishige, K.
  Reforming of toluene with simulated automobile exhaust gas over hydrotalcite-like-compound-derived Ni catalyst
  (2020) *Fuel Process Technol*, 209, p. 106545.

- Łamacz, A., Babiński, P., Łabojko, G.
  The impact of components of synthesis gas from coal gasification on conversion of model tar compounds over Ni/CeZrO2 catalyst
  (2019) *Fuel*, 236, pp. 984-992.

- Zhang, H., Zhu, F., Li, X.
  Steam reforming of toluene and naphthalene as tar surrogate in a gliding arc discharge reactor
  (2019) *J Hazard Mater*, 369, pp. 244-253.

- Bracciale, M.P., de Caprariis, B., De Filippis, P.
  New synthetic route for the production of mayenite support to enhance Ni resistance to coke deposition in the reforming of tar model compounds
  (2019) *Appl Catal A Gen*, 574, pp. 48-59.

- Sun, J., Wang, Q., Wang, W., Wang, K.
  Study on the synergism of steam reforming and photocatalysis for the degradation of toluene as a tar model compound under microwave-metal discharges
  (2018) *Energy*, 155, pp. 815-823.

- de Castro, T.P., Silveira, E.B., Rabelo-Neto, R.C.
  Study of the performance of Pt/Al2O3 and Pt/CeO2/Al2O3 catalysts for steam reforming of toluene, methane and mixtures
  (2018) *Catal Today*, 299, pp. 251-262.

- Baidya, T., Cattolica, R.J., Seiser, R.
  High performance Ni-Fe-Mg catalyst for tar removal in producer gas

(2018) *Appl Catal A Gen*, 558, pp. 131-139.

- Zou, X., Chen, T., Zhang, P.
High catalytic performance of Fe-Ni/palygorskite in the steam reforming of toluene for hydrogen production
(2018) *Appl Energy*, 226, pp. 827-837.

- de Caprariis, B., Bracciale, M.P., De Filippis, P.
Steam reforming of tar model compounds over ni supported on CeO2 and mayenite
(2017) *Can J Chem Eng*, 95, pp. 1745-1751.

- Quitete, C.P.B., Manfro, R.L., Souza, M.M.V.M.
Perovskite-based catalysts for tar removal by steam reforming: effect of the presence of hydrogen sulfide
(2017) *Int J Hydrogen Energy*, 42, pp. 9873-9880.

- Artetxe, M., Alvarez, J., Nahil, M.A.
Steam reforming of different biomass tar model compounds over Ni/Al2O3 catalysts
(2017) *Energy Convers Manag*, 136, pp. 119-126.

- Tan, R.S., Tuan Abdullah, T.A., Johari, A., Md Isa, K.
Catalytic steam reforming of tar for enhancing hydrogen production from biomass gasification: a review
(2020) *Front Energy*, 14, pp. 545-569.

- Koike, M., Li, D., Watanabe, H.
Comparative study on steam reforming of model aromatic compounds of biomass tar over Ni and Ni-Fe alloy nanoparticles
(2015) *Appl Catal A Gen*, 506, pp. 151-162.

- Gao, N., Wang, X., Li, A.
Hydrogen production from catalytic steam reforming of benzene as tar model compound of biomass gasification
(2016) *Fuel Process Technol*, 148, pp. 380-387.

- Zhang, Z., Qin, C., Ou, Z., Ran, J.
Resistance of Ni/perovskite catalysts to H2S in toluene steam reforming for H2 production
(2020) *Int J Hydrogen Energy*, 45, pp. 26800-26811.

- Adnan, M.A., Hidayat, A., Ajumobi, O.O.
Fluidizable Fe-Co/Ce-ZrO 2 catalysts for steam reforming of toluene as a tar surrogate in biomass gasification
(2018) *Energy Fuels*, 32, pp. 12833-12842.

- Oh, G., Park, S.Y., Seo, M.W.
Ni/Ru-Mn/Al2O3 catalysts for steam reforming of toluene as model biomass tar
(2016) *Renew Energy*, 86, pp. 841-847.

- Oemar, U., Ming Li, A., Hidajat, K., Kawi, S.
Mechanism and kinetic modeling for steam reforming of toluene on La0.8Sr0.2Ni0.8Fe0.2O3 catalyst
(2014) *AIChE J*, 60, pp. 4190-4198.

- Zhang, R., Wang, Y., Brown, R.C.
Steam reforming of tar compounds over Ni/olivine catalysts doped with CeO2
(2007) *Energy Convers Manag*, 48, pp. 68-77.

- Hu, D., Zeng, X., Wang, F.
Comparison of tar thermal cracking and catalytic reforming by char in a micro

fluidized bed reaction analyzer
(2021) *Fuel*, 290, p. 120038.

- Cao, J.P., Ren, J., Zhao, X.Y.
Effect of atmosphere on carbon deposition of Ni/Al2O3 and Ni-loaded on lignite char during reforming of toluene as a biomass tar model compound
(2018) *Fuel*, 217, pp. 515-521.

- Liu, X., Yang, X., Liu, C.
Low-temperature catalytic steam reforming of toluene over activated carbon supported nickel catalysts
(2016) *J Taiwan Inst Chem Eng*, 65, pp. 233-241.

- Snoeck, J.W., Froment, G.F., Fowles, M.
Steam/CO2 reforming of methane. Carbon formation and gasification on catalysts with various potassium contents
(2002) *Ind Eng Chem Res*, 41, pp. 3548-3556.

- Mendiara, T., Johansen, J.M., Utrilla, R.
Evaluation of different oxygen carriers for biomass tar reforming (I): carbon deposition in experiments with toluene
(2011) *Fuel*, 90, pp. 1049-1060.

- Simell, P.A., Hepola, J.O., Krause, A.O.I.
Effects of gasification gas components on tar and ammonia decomposition over hot gas cleanup catalysts
(1997) *Fuel*, 76, pp. 1117-1127.

- Bartholomew, C.H.
Carbon deposition in steam reforming and methanation
(1982) *Catal Rev*, 24, pp. 67-112.

- Trimm, D.L.
The formation and removal of coke from nickel catalyst
(1977) *Catal Rev*, 16, pp. 155-189.

- Kawi, S., Kathiraser, Y., Ni, J.
Progress in synthesis of highly active and stable nickel-based catalysts for carbon dioxide reforming of methane
(2015) *Chemsuschem*, 8, pp. 3556-3575.

- Quan, C., Wang, H., Gao, N.
Development of activated biochar supported Ni catalyst for enhancing toluene steam reforming
(2020) *Int J Energy Res*, 44, pp. 5749-5764.

- Xiao, X., Liu, J., Gao, A.
The performance of nickel-loaded lignite residue for steam reforming of toluene as the model compound of biomass gasification tar
(2018) *J Energy Inst*, 91, pp. 867-876.

- He, L., Hu, S., Jiang, L.
Opposite effects of self-growth amorphous carbon and carbon nanotubes on the reforming of toluene with Ni/A-Al2O3 for hydrogen production
(2017) *Int J Hydrogen Energy*, 42, pp. 14439-14448.

- Tan, R.S., Tuan Abdullah, T.A., Abdul Jalil, A., Md Isa, K.
Optimization of hydrogen production from steam reforming of biomass tar over Ni/dolomite/La2O3 catalysts
(2020) *J Energy Inst*, 93, pp. 1177-1186.

- Park, S.Y., Oh, G., Kim, K.
  Deactivation characteristics of Ni and Ru catalysts in tar steam reforming
  (2017) *Renew Energy*, 105, pp. 76-83.

- Takise, K., Imori, M., Mukai, D.
  Effect of catalyst structure on steam reforming of toluene over Ni/La0.7Sr0.3AlO3-δ catalyst
  (2015) *Appl Catal A Gen*, 489, pp. 155-161.

- Santamaria, L., Artetxe, M., Lopez, G.
  Effect of CeO2 and MgO promoters on the performance of a Ni/Al2O3 catalyst in the steam reforming of biomass pyrolysis volatiles
  (2020) *Fuel Process Technol*, 198.

- De Castro, T.P., Peguin, R.P.S., Neto, R.C.R.
  Steam reforming of toluene over Pt/Ce x Zr1-x O2/Al2O3 catalysts
  (2016) *Top Catal*, 59, pp. 292-302.

- Zhou, F., Pan, N., Chen, H.
  Hydrogen production through steam reforming of toluene over Ce, Zr or Fe promoted Ni-Mg-Al hydrotalcite-derived catalysts at low temperature
  (2019) *Energy Convers Manag*, 196, pp. 677-687.

- Chen, M., Li, X., Wang, Y.
  Hydrogen generation by steam reforming of tar model compounds using lanthanum modified Ni/sepiolite catalysts
  (2019) *Energy Convers Manag*,

- Qian, N., Zhang, L., Ma, W.
  Core-shell Al2O3-supported Ni for high-performance catalytic reforming of toluene as a model compound of tar
  (2014) *Arab J Sci Eng*, 39, pp. 6671-6678.

- Zhao, X., Xue, Y., Lu, Z.
  Encapsulating Ni/CeO2-ZrO2 with SiO2 layer to improve it catalytic activity for steam reforming of toluene
  (2017) *Catal Commun*, 101, pp. 138-141.

- Li, Z., Li, M., Ashok, J., Kawi, S.
  NiCo@NiCo phyllosilicate@CeO2 hollow core shell catalysts for steam reforming of toluene as biomass tar model compound
  (2019) *Energy Convers Manag*, 180, pp. 822-830.

- Sehested, J.
  Four challenges for nickel steam-reforming catalysts
  (2006) *Catal Today*, 111, pp. 103-110.
  (,),.,:., https://doi.org/10.1016/J.CATTOD.2005.10.002

- Mukai, D., Tochiya, S., Murai, Y.
  Role of support lattice oxygen on steam reforming of toluene for hydrogen production over Ni/La0.7Sr0.3AlO3-δ catalyst
  (2013) *Appl Catal A Gen*, 453, pp. 60-70.

- Takise, K., Manabe, S., Muraguchi, K.
  Anchoring effect and oxygen redox property of Co/La0.7Sr0.3AlO3-Δ perovskite catalyst on toluene steam reforming reaction
  (2017) *Appl Catal A Gen*, 538, pp. 181-189.

- Li, S., Gong, J.
  Strategies for improving the performance and stability of Ni-based catalysts for

reforming reactions
(2014) *Chem Soc Rev*, 43, pp. 7245-7256.

- Zhang, S., Johnson, D.D., Shelton, W.A., Xu, Y.
Hydrogen adsorption on ordered and disordered Pt-Ni alloys
(2020) *Top Catal*, 63, pp. 714-727.

- Claude, V., Mahy, J.G., Geens, J.
Synthesis of Ni/Γ-Al2O3[sbnd]SiO2 catalysts with different silicon precursors for the steam toluene reforming
(2019) *Microporous Mesoporous Mater*, 284, pp. 304-315.

- Adnan, M.A., Muraza, O., Razzak, S.A.
Iron oxide over silica-doped alumina catalyst for catalytic steam reforming of toluene as a surrogate tar biomass species
(2017) *Energy Fuels*, 31, pp. 7471-7481.

- Kertthong, T., Chen, Y.H., Schmid, M., Scheffknecht, G.
Influence of gas atmosphere and role of tar on catalytic reforming of methane and tar model compounds: special focus on syngas produced by sorption enhanced gasification
(2022) *Fuel*, 317, p. 123502.

- McFarlan, A., Maffei, N.
Assessing a commercial steam methane reforming catalyst for tar removal in biomass gasification
(2022) *Bioresour Technol Reports*, 17, p. 100968.

- Khajonvittayakul, C., Tongnan, V., Namo, N.
Tar steam reforming for synthesis gas production over Ni-based on ceria/zirconia and La0.3Sr0.7Co0.7Fe0.3O3 in a packed-bed reactor
(2021) *Chemosphere*, 277, p. 130280.

- Tang, W., Cao, J.P., Yang, F.L.
Highly active and stable HF acid modified HZSM-5 supported Ni catalysts for steam reforming of toluene and biomass pyrolysis tar
(2020) *Energy Convers Manag*, 212, p. 112799.

- Zhu, T., Chen, Z., Gong, H.
Seeded-growth preparation of high-performance Ni/MgAl2O4catalysts for tar steam reforming
(2020) *New J Chem*, 44, pp. 13692-13700.

- Iida, H., Deguchi, S., Torigai, M., Osawa, Y.
Steam reforming of toluene over Ru/SrCO3-Al2O3 catalyst under extremely low steam-to-carbon ratio conditions
(2020) *Fuel*, 272, p. 117703.

- Jiao, Y., Du, Y., Wang, J.
A investigation of multi-functional Ni/La-Al2O3-CeOx catalyst for bio-tar (simulated-toluene as model compound) conversion
(2020) *J Energy Inst*, 93, pp. 395-404.

- Gu, J., Wang, S., Lu, T.
Synthesis and evaluation of pyrolysis waste peat char supported catalyst for steam reforming of toluene
(2020) *Renew Energy*, 160, pp. 964-973.

- Ren, L., Yan, L.J., Bai, Y.H.
Effects of loading methods and oxidation degree of support on the tar reforming

activity of char-supported Ni catalyst using toluene as a model compound
(2020) *Fuel Process Technol*, 201, p. 106347.

- Zhu, H.L., Pastor-Pérez, L., Millan, M.
Catalytic steam reforming of toluene: understanding the influence of the main reaction parameters over a reference catalyst
(2020) *Energies*, 13, p. 813.
(,),.,:,., https://doi.org/10.3390/en13040813

- Du, Z.Y., Zhang, Z.H., Xu, C.
Lowerature steam reforming of toluene and biomass tar over biochar-supported Ni nanoparticles
(2019) *ACS Sustain Chem Eng*, 7, pp. 3111-3119.

- Ren, J., Cao, J.P., Yang, F.L.
Layered uniformly delocalized electronic structure of carbon supported Ni catalyst for catalytic reforming of toluene and biomass tar
(2019) *Energy Convers Manag*, 183, pp. 182-192.

- Shen, C., Zhou, W., Yu, H., Du, L.
Ni nanoparticles supported on carbon as efficient catalysts for steam reforming of toluene (model tar)
(2018) *Chinese J Chem Eng*, 26, pp. 322-329.

- He, L., Hu, S., Jiang, L.
Carbon nanotubes formation and its influence on steam reforming of toluene over Ni/Al2O3 catalysts: roles of catalyst supports
(2018) *Fuel Process Technol*, 176, pp. 7-14.

- Meng, J., Wang, X., Zhao, Z.
A highly carbon-resistant olivine thermally fused with metallic nickel catalyst for steam reforming of biomass tar model compound
(2017) *RSC Adv*, 7, pp. 39160-39171.

- Syed-Hassan, S.S.A., Fuadi, F.A.
Catalytic steam reforming of biomass tar model compound using nickel and cobalt catalysts supported on palm kernel shell char
(2016) *J Chem Eng Japan*, 49, pp. 29-34.

- Ahmed, T., Xiu, S., Wang, L., Shahbazi, A.
Investigation of Ni/Fe/Mg zeolite-supported catalysts in steam reforming of tar using simulated-toluene as model compound
(2018) *Fuel*, 211, pp. 566-571.

- He, L., Hu, S., Yin, X.
Promoting effects of Fe-Ni alloy on co-production of H2 and carbon nanotubes during steam reforming of biomass tar over Ni-Fe/α-Al2O3
(2020) *Fuel*, 276, p. 118116.

- Yahya, H.S.M., Amin, N.A.S.
Catalytic steam reforming of toluene for hydrogen production over nickel-cobalt supported activated carbon
(2019) *Int J Integr Eng*, 11, pp. 209-218.

- Wang, X.B., Yang, S.Q., Xu, C.
Effect of boron doping on the performance of Ni/biochar catalysts for steam reforming of toluene as a tar model compound
(2021) *J Anal Appl Pyrolysis*, 155, p. 105033.

- Tian, B., Dong, K., Guo, F.
Catalytic conversion of toluene as a biomass tar model compound using monolithic

biochar-based catalysts decorated with carbon nanotubes and graphic carbon covered Co-Ni alloy nanoparticles
(2022) *Fuel*, 324, p. 124585.

- Xu, H., Shen, Z., Zhang, S.
Arming wood carbon with carbon-coated mesoporous nickel-silica nanolayer as monolithic composite catalyst for steam reforming of toluene
(2021) *J Colloid Interface Sci*, 599, pp. 650-660.

- Zhou, S., Chen, Z., Gong, H.
Low-temperature catalytic steam reforming of toluene as a biomass tar model compound over three-dimensional ordered macroporous Ni-Pt/Ce1−xZrxO2 catalysts
(2020) *Appl Catal A Gen*, 607, p. 117859.

- Wang, S., Shan, R., Gu, J.
Pyrolysis municipal sludge char supported Fe/Ni catalysts for catalytic reforming of tar model compound
(2020) *Fuel*, 279, p. 118494.

- Lu, M., Xiong, Z., Fang, K.
Effect of promoters on steam reforming of toluene over a Ni-based catalyst supported on coal gangue ash
(2020) *ACS Omega*, 5, pp. 26335-26346.

- Oh, G., Park, S.Y., Seo, M.W.
Combined steam-dry reforming of toluene in syngas over CaNiRu/Al 2 O 3 catalysts
(2019) *Int J Green Energy*, 16, pp. 333-349.

- Hu, S., He, L., Wang, Y.
Effects of oxygen species from Fe addition on promoting steam reforming of toluene over Fe–Ni/Al2O3 catalysts
(2016) *Int J Hydrogen Energy*, 41, pp. 17967-17975.

- Heo, D.H., Lee, R., Hwang, J.H., Sohn, J.M.
The effect of addition of Ca, K and Mn over Ni-based catalyst on steam reforming of toluene as model tar compound
(2016) *Catal Today*, 265, pp. 95-102.

- Díez, D., Urueña, A., Antolín, G.
Investigation of Ni–Fe–Cu-layered double hydroxide catalysts in steam reforming of toluene as a model compound of biomass tar
(2021) *Processes*, 9, pp. 1-21.

- Jayaprakash, S., Dewangan, N., Jangam, A.
LDH-derived Ni–MgO–Al2O3 catalysts for hydrogen-rich syngas production via steam reforming of biomass tar model: effect of catalyst synthesis methods
(2021) *Int J Hydrogen Energy*, 46, pp. 18338-18352.

- Osazuwa, O.U., Setiabudi, H.D., Rasid, R.A., Cheng, C.K.
Syngas production via methane dry reforming: a novel application of SmCoO3 perovskite catalyst
(2017) *J Nat Gas Sci Eng*, 37, pp. 435-448.

- Ren, J., Liu, Y.L.
Boosting syngas production from corncob tar reforming over Ni/MgAl hydrotalcite-derived catalysts
(2022) *Fuel*, 307, p. 121779.

- Zhang, S., Hu, W., Xiang, X.
Ni-Fe-Ce hydrotalcite-derived structured reactor as catalyst for efficient steam

reforming of toluene
(2022) *Fuel Process Technol*, 226.

- Zhang, Y., Zou, X., Liu, H.
Comparative study of mineral with different structures supported Fe-Ni catalysts for steam reforming of toluene
(2022) *Fuel*, 315, p. 123253.

- Tian, B., Mao, S., Guo, F.
Monolithic biochar-supported cobalt-based catalysts with high-activity and superior-stability for biomass tar reforming
(2022) *Energy*, 242, p. 122970.

- Yahya, H.S.M., Amin, N.A.S.
Oxygen-rich ultramicroporous activated carbon for boosting H2 production via toluene steam reforming: effect of H2O2-modification and Ni/Co loading
(2022) *Fuel Process Technol*, 232, p. 107275.

- Mitran, G., Mieritz, D.G., Seo, D.K.
Steam reforming of toluene as model of tar compound over Mo catalysts derived from hydrotalcites
(2019) *J Saudi Chem Soc*, 23, pp. 916-924.

- Mitran, G., Mieritz, D.G., Seo, D.K.
Hydrotalcites with vanadium, effective catalysts for steam reforming of toluene
(2017) *Int J Hydrogen Energy*, 42, pp. 21732-21740.

- Abou Rached, J., El Hayek, C., Dahdah, E.
Ni based catalysts promoted with cerium used in the steam reforming of toluene for hydrogen production
(2017) *Int J Hydrogen Energy*, 42, pp. 12829-12840.

- Takise, K., Sato, A., Muraguchi, K.
Steam reforming of aromatic hydrocarbon at low temperature in electric field
(2019) *Appl Catal A Gen*, 573, pp. 56-63.

- Higo, T., Saito, H., Ogo, S.
Promotive effect of Ba addition on the catalytic performance of Ni/LaAlO3 catalysts for steam reforming of toluene
(2017) *Appl Catal A Gen*, 530, pp. 125-131.

- Takise, K., Higo, T., Mukai, D.
Highly active and stable Co/La0.7Sr0.3AlO3-δ catalyst for steam reforming of toluene
(2016) *Catal Today*, 265, pp. 111-117.

Correspondence Address
Abidin S.Z.; Centre for Research in Advanced Fluid & Processes, Pahang, Malaysia; email: sumaiya@ump.edu.my

Publisher: Springer Science and Business Media Deutschland GmbH

ISSN: 21906815
Language of Original Document: English
Abbreviated Source Title: Biomass Convers. Biorefinery
2-s2.0-85149249966
Document Type: Review
Publication Stage: Article in Press
Source: Scopus