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REVIEW ARTICLE

Recent Developments in Catalysts for Methanol-to-Olefins Reactions: Challenges and Opportunities

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ABSTRACT

Methanol-to-olefins (MTO) remains a strategic conversion in the petrochemical conversion chain based on natural gas or biomass feedstock to generate fresh or light olefins, in particular ethylene and propylene, which are applicable to polymerizations and chemical manufacture. This paper aims to give a current literature synthesis of the MTO process, containing advances in catalysts, the mechanism of reactions, and process improvements. The critical evaluation of the various challenges associated with the MTO process, such as catalyst deactivation, selectivity, and formation of byproducts, is discussed in detail. The review also discusses advancements in catalyst design with particular emphasis on new-generation zeolite-based catalysts, hybrid catalysts, and metal-organic frameworks, which have proved to give improved catalytic activity, selectivity, and stability. Furthermore, the possibility of using renewable feedstocks for MTO, notably bio-methanol, is analyzed as a strategy that can improve the sustainability characteristics of the technology. The paper also focuses on issues related to the environment, including CO_2 emissions and energy consumption, which can be solved using more efficient and environmentally friendly MTO technologies. Finally, the prospects for further improvement of the MTO process, concerning catalyst lifetime, the intensification of the process, and the description of how the MTO process is integrated with other responses.

Key words: Catalyst deactivation, catalysts, light olefins, methanol-to-olefins, silicoaluminophosphates-34, Zeolite Socony Mobil-5

INTRODUCTION

One of the most important areas of C1 conversion technology is the opportunities concerning the change of methanol-to-olefins (MTO), manufacturing industrial added-value compounds such as ethylene and propylene derived from non-oil sources such as natural gas and coal.[1] This procedure establishes a link between the modern petrochemical sector and the chemical industries that rely on natural gas or coal as feedstocks. Thus, this area is considered to be important for research and application. The need for MTO has led to great progress since the first attempt in 1977 by Mobil Corporation, especially in knowledge of the reaction mechanisms, catalysts, and process control.[2]

In the MTO process, catalysts act as an important component of the process, with the most promising one being composed of acidic silicoaluminophosphates (SAPOs) and zeolites. The current commercial catalyst, SAPO-34, performs well in the synthesis of light olefins because of its distinctive pore system and chabazite structure. However, owing to superior thermal stability and stronger acidity, other zeolites such as Zeolite Socony Mobil-5 (ZSM-5) and SSZ-13 have been considered for enhancing the MTO operation. However, the following demerits still prevail: The MTO process is affected because the production of coke and undesirable byproducts causes the catalyst to quickly deactivate.[1]

However, the MTO process has roots in Mobil's methanol-to-petrol (MTG) technology. It consists of a plurality of synthesized low framework figures discerning zeolite compounds and Si/Al proportion. For the technique to be used commercially, side product production must be minimized.[3] Further catalyst and operating condition development is required for this, in addition to quantitative mechanistic and kinetic

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studies. Froment *et al*. gave a broad rundown of the MTO procedure. Numerous zeolites have been employed as catalysts, although coking has a negative impact on them. Compared to other catalysts such as ZSM-5 and other related zeolites, the para-methylfonation deactivation is relatively less effective. Substantial efforts have been made to modify these catalysts with a view to enhancing the selectivity toward the desired light olefins.

Advancements in the use of stronger and more selective catalysts, as well as the HPM and hydrocarbon pool (HCP) model, have provided the MTO process with new opportunities for increased efficiency and decreased resource consumption. The research has undertaken steps to change the structure of the catalysts used and also the operating conditions, and has integrated advanced characterization techniques to address these challenges.[4]

The current study is justified by the increasing production and consumption of light olefins worldwide, which are used as raw materials in the production of chemicals and polymers. These olefins can likewise be produced from methanol via the MTO process, though other techniques are currently used. Nevertheless, it has drawbacks such limited selectivity, byproduct production, and catalyst deactivation. By improving catalyst performance and reaction efficiency, recent developments in catalyst design seek to address these issues. However, optimization of such structures remains a problem. The current activities investigate the advanced technologies of MTO catalysts in recent years, particularly with reference to challenges defeating and opportunities capturing regarding the enhanced efficiency, stability, and selectivity related to MTO catalysts for the better and more effective production of olefins. This is the contribution of the paper as summarized below:

- This is achieved through a detailed discussion of MTO reaction mechanisms and identification of essential steps of the reaction, such as C–C bond formation, HCP intermediates, and the processes of catalyst deactivation.
- By comparing the trends in the summation of ZSM-5 and SAPO-34 catalysts' performance and structures, all-encompassing recent growth, which increases selectivity, decreases the coking problem, and extends catalyst lifetime.
- Moreover, the study proves the importance of MTO processes in the industrial world, especially focusing on the adopted technologies such as D-MTO and S-MTO for manufacturing olefins from renewable feedstock.
- The study narrows down the following challenges: catalyst deactivation, selectivity, and scalability, and provides a deeper view of potential solutions that can bridge the gap between efficiency, cost, and sustainability.
- By focusing on the utilization of non-petroleum feedstocks and environmentally friendly synthesis approaches for catalysts, the study contributes to the creation of more sustainable and environmentally friendly chemical processes.

Specifically, The paper is organized as follows: In Section II, information on the MTO reactions is explained briefly, in Section III, recent developments in reaction mechanisms are described, in Section IV, the opportunities and challenges of catalyst advancements are highlighted, in Section V, literature studies are discussed, and in Section VI, the conclusion is summarized with important findings and recommendations for the future.

FUNDAMENTALS OF MTO REACTIONS

MTO is a commercially feasible method for producing small-chained hydrocarbons like ethylene and propylene from hydrocarbon sources, including coal, natural gas, and biomass. In this process, solid acid catalysts are employed, including microporous aluminosilicates and SAPO molecular sieves. Mostly in China, MTO facilities make substantial use of the commercially available catalyst SAPO-34, which has a small-pore chabazite (CHA) framework structure.

Under ideal reaction conditions, SAPO-34 can obtain a selectivity of 85–90% for ethylene and propylene. This great selectivity is caused by the geometry of the CHA framework, which is made up of eight-membered ring (8-MR) pores (3.8 Å × 3.8 Å) connecting the huge cavities (8.35 Å × 8.35 Å × 8.23 Å). The balanced acidity of SAPO-34, which takes into account both the density and strength of its acid sites, is another factor contributing to this performance.[5] Only small linear molecules are able to diffuse through these pores, whereas larger branched or aromatic intermediates are unable to escape from the cages within which they are contained.[6]

The MTO reaction is autocatalytic, as a small number of products catalyze additional reactions of methanol to lead to a stable and efficient reaction cycle. Over the past 50 years, there has been discussion on the nature of the mechanism by which a C-C bond is formed from the C1 reactant. The carbene, oxonium ylide, carbon cation, and free radical mechanisms earlier proposed were later found to be thermodynamically unfavorable in terms of energy.[7] On a new catalyst, the slow rates of the first step of methanol conversion imply that only a route with a high energy of activation may create C–C bonds. Despite a wealth of research in this area, the specifics of the first creation of C–C bonds are currently being actively studied.[1]

MTO Process

A cutting-edge chemical process called "methanol-to-olefins" efficiently converts methanol into ethylene and propylene, two light olefins, the basic feedstock for the petrochemical industry. Novel synthesis technique, which was actually an outgrowth of the MTG process, which was discovered by Mobil Oil Corporation, the MTO process is a crucial invention that came out of the control interruption of methanol to hydrocarbon reactions. The following points and Figure 1 are mentioned below:

Discovery and Development

The discovery of the reaction between methanol and hydrocarbons, or more specifically, the MTG process, was of the order of serendipity but was occasioned by Mobil Oil Corporation. The following are some special benefits of the MTG process:

- Hydrocarbons are synthesized within a somewhat limited range of carbon compositions; only small amounts of methane and no hydrocarbon possessing more than C_{11} atoms are made.
- ZSM-5-based catalysts age relatively slowly, and it is revealed that a high methanol conversion can be achieved simultaneously with high selectivity of the aromatics boiling in the range of gasoline pool and isoparaffins with higher octane numbers.

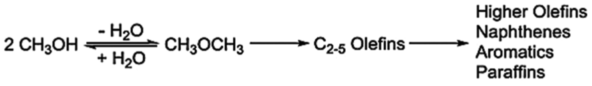

Figure 1: A general reaction scheme for the methanol-to-gasoline process

The methylation of isobutylene, contrary to the initial reaction hypothesis, did not proceed as expected. However, when the ZSM-5 catalyst was used, a second group of researchers discovered that the methanol conversion was significant and thorough at Mobil's Central Research Laboratories. An equation that may be used to express the overall reaction stoichiometry for this process is as follows Equation (1):

$$CH_3\,OH \rightarrow [CH_2] + H_2O \qquad (1)$$

With 44% of the result being water and 56% being hydrocarbons, the conversion of methanol is almost finished. An olefin hydrocarbon's average oligomeric branch, $[CH_2]$, matches the reaction model shown in Figure 1, for the process of turning MTG. The hydrocarbons from methanol conversion can be stopped by carefully regulating variables such as temperature and space velocity, which will cause the product to move toward light olefins rather than petrol. This change led to the appearance of the most efficient in terms of yields of the MTO process.

MTO Process–Commercial Technologies

The main technology most implemented together with the MTO process, which is D-MTO/-MTO-II, is creosoting; these are methanol-to-propylene (MTP) by Lurgi, MTO by UOP/Norsk Hydro, S-MTO, and D-MTO/-MTO II.

In China, many local companies and groups expanded the "S-MTO" and "D-MTO/D-MTO-II" technologies. For instance, Sinopec provided funding to the Dalian Institute of Chemical Physics (DICP) researchers for the first development of D-MTO technology.[6,8] Another important participant in MTO technology and licensing is Sinopec, which also introduced the S-MTO technology. With 64% of the units and 70% of the capacity, at this moment, the Chinese market is dominated by D-MTO/D-MTO-II technology, which has the largest overall market share of any general electric technology in that country. Figure 2 shows a general outlook of the MTO.

MTO Reaction Mechanism

When the initial C–C bond that will transform into ethene or propene is formed, the MTO process's induction stage begins. It is evident that the initial HCP species of polyMBs and MCPdiene intermediates emerge during the transition period. During the stable stage, the HCP mechanism continually produces light olefins. Finally, the deactivation stage is when coke species are created and accumulate. Figure 3 demonstrates the various MTO process phases' response processes.

There are four steps in the MTO process, In the induction stage, methoxymethyl and formaldehyde are used in formation of C–C bonds; throughout the transition stage, methylcyclopentadiene and methylbenzene are used to form HCP intermediates; stage of steady production of light olefins through dual-cycle mechanisms (alkene and aromatic cycles); and deactivation stage, marked by coke species accumulation on catalyst surfaces, leading to catalyst deactivation.

An acid first dehydrates methanol to DME; the ether is then mixed with water to reach an equilibrium composition. This is the first stage in the MTO synthesis. Further reactions of this combination result in the production of butenes, propylene, and ethylene, which are light olefins. These light olefins can then undergo a number of alkylation, aromatization, and/or polycondensation processes to yield higher olefins, alkanes, and aromatics mentioned in Figure 4. It is widely known that methanol attacks a protonated surface methoxyl group that forms during the first stage of the process known as MTO. There is considerable debate over the second step, which entails the initial formation of a C–C bond. There have been more than 20 processes put forth, including free radical, carbene, carbocationic, and oxonium ylide pathways.

RECENT DEVELOPMENTS IN MTO CATALYSTS

Catalyst development is a central aspect of MTO technology, consistently attracting significant interest from both academic and industrial communities. The fundamental chemistry of MTO reactions can be better understood by delving further into the catalytic performance and structure–activity

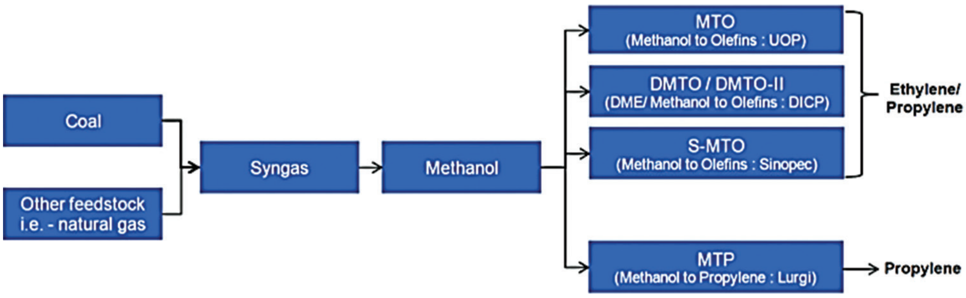

Figure 2: Overview of the methanol-to-olefins process

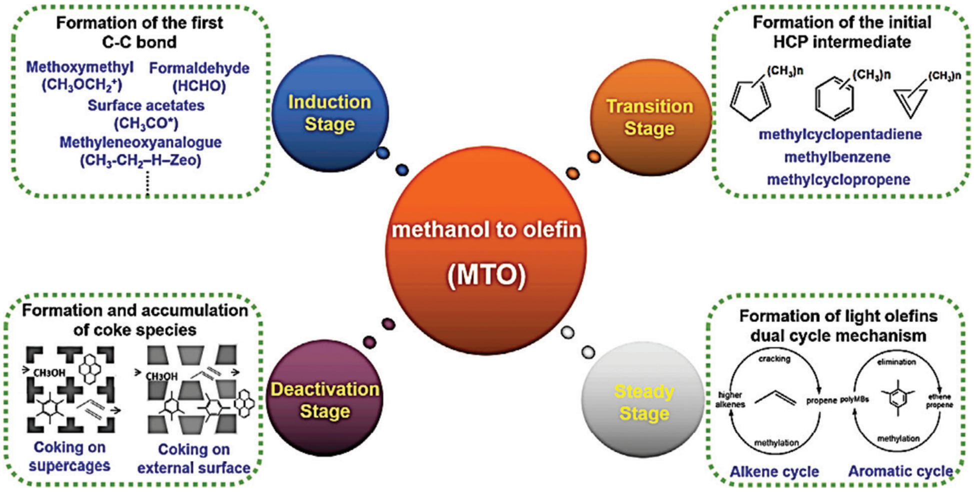

Figure 3: Reaction mechanism of different stages of the methanol-to-olefins process

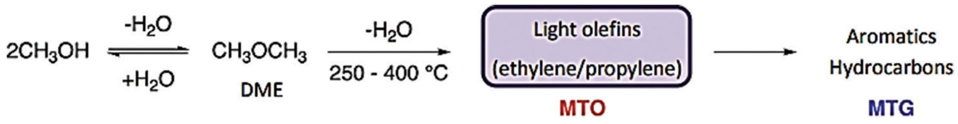

Figure 4: Principal steps occurring in the conversion of methanol-to-olefins

connection of certain catalysts. This knowledge ultimately helps establish principles for controlling selectivity and effectively manipulating product distribution.[9] Among the most, ZSM-5 and SAPO-34, two significant commercial catalysts, have remained at the forefront of catalyst research for decades, continuing to receive sustained attention due to their crucial role in MTO processes.

Enhancing selectivity, stability, and resistance to deactivation have been the main goals of recent developments in MTO catalysts. This section explores key developments in zeolite-based catalysts, metal-organic frameworks (MOFs), and hybrid catalysts. The following are the recent developments:

ZSM-5 Zeolite

Acidic zeolites can catalyze the production of hydrocarbons from methanol because of their high activity and great sensitivity to catalysts. Despite being a tiny and straightforward molecule, methanol undergoes a complicated transition into several compounds. A solid acid catalyst, such as a zeolite, is usually needed for the MTO process. Zeolites, a subclass of molecular sieves, are distinguished by their high acidity and remarkable surface area, both of which are essential for promoting the MTO reaction.

In the initial phases of the MTG and MTO process development, ZSM-5 was essential. ZSM-5 is still the most catalytically active zeolite in the MTG process, and practically all MTO methods that are based on fixed-bed reactors use it as a catalyst. As shown in Figure 5, which depicts the basic ZSM-5 structure, a sinusoidal 10-MR channel of 5.35.6 Å is crossed either with a straight 10-MR channel of 5.15.5 Å to produce a huge gap of approximately 8.9 Å in diameter surrounding the channel junction.

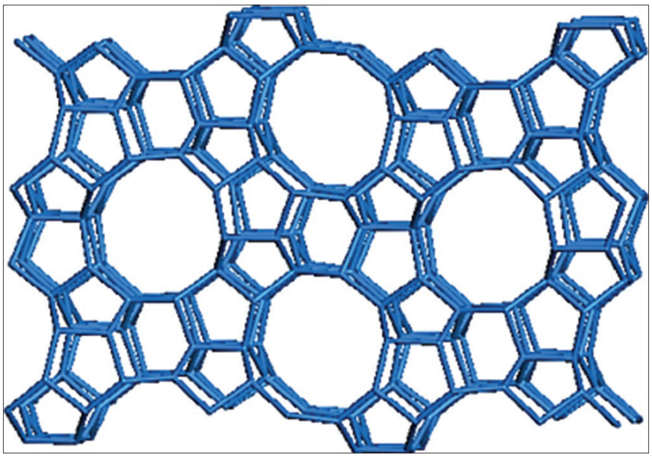

Figure 5: Illustration of MFI structure

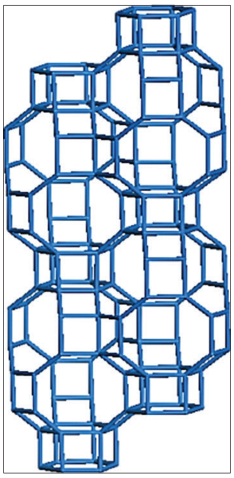

Figure 6: Illustration of chabazite structure

SAPO-34 Catalyst

A lot of research effort has been channeled toward manufacturing molecular sieves for SAPO, namely SAPO-34, which contains an 8-MR 3.8 × 3.8 Å that connects its 10 × 6.7 × 6.7 Å window. It is distinguished by the CHA framework topology, and its structure is shown in Figure 6. Its strong selectivity for light olefins, great hydrothermal stability, and mild acidity strength are the reasons for this. The Chinese Academy of Sciences' DICP initially documented SAPO-34's MTO catalytic activity process in 1990.

This groundbreaking discovery is unquestionably seen as a crucial advancement in MTO technology, which in turn greatly motivates researchers to concentrate more on improving SAPO-34's synthesis process and identifying the MTO mechanism for this exceptional catalyst.

Advancements in SAPO-34 Catalysts for MTO Reactions

The adsorption selectivity of the SAPO molecular sieve SAPO-34 has made it one of the most effective catalysts in the MTO process for producing light olefins such as ethylene and propylene. Through shape selectivity, this 8-membered ring (8-MR) pore structure enables selective diffusion, thereby suppressing the formation of larger hydrocarbon byproducts. Recent research has focused on overcoming challenges such as rapid deactivation from coke deposition.[10] Advances such as optimizing silicon content to control acidity and developing nanosized or mesoporous SAPO-34 have significantly improved catalyst performance. These innovations necessitate diffusion improvement, minimization of coke loose accumulation, and the enhancement of the catalyst lifespan. Furthermore, new strategies such as the formation of fluoride-free synthesis are still being studied for enhancing the environmental and economic performances, making SAPO-34 the best material to drive the MTO process toward more industrial applicability.[2]

CHALLENGES AND OPPORTUNITIES IN MTO CATALYSIS

The MTO process is an accurate technology for olefin production, but the process encounters some difficulties that affect its ability to be efficient, flexible, and sustainable.[11] The several challenges are given below:

Catalyst Deactivation

Coating of active sites by carbonaceous materials is the main problem in MTO catalysis, and this is regarded as catalyst deactivation. This accumulation coats active sites and pore structures where catalytically active species reside, reducing catalytic performance and selectivity with time. It has been found that coke deposition altered the catalyst's mass transfer and decreased accessibility to the active sites, which led to a decline in performance.

Catalyst deactivation due to coke production is a significant issue that impacts catalyst stability in MTO processes. The word "COKE" refers to the carbonaceous materials that accumulate on the catalyst's surface throughout a reaction, blocking the reaction's active sites and resulting in poor performance.

Selectivity Control

Sustaining a high level of selectivity of the manufactured product is one of the most viable requirements for the economic viability of MTO processes. Particularizing the catalysts for promoting specific olefin production, including ethylene or propylene, requires insights into the reaction mechanisms and other factors affecting selectivity.[12] The enhancement of the characteristics of SAPO-34 catalysts has shifted toward the enhancement of selectivity for particular desired olefins in recent developments.

Scalability and Cost-Effectiveness of Advanced Catalysts

One research gap that has remained relatively difficult to satisfy has been in developing advanced catalysts that are, at the same time, scalable and cheap. It is noted that previously synthesized materials such as MgAPO-18 have shown high activity and stability; however, issues with practical application include the question of scale-up and economic viability. Such catalysts may result from complex syntheses and the use of expensive materials, so the use of the catalysts could be limited in industrial applications.[13]

Environmental and Sustainability Concerns

Environmentally friendly and sustainability issues inevitably play an important role in MTO catalysis. Deposition of coke not only kills the catalysts but also results in the formation of solid materials, which are wastes to be disposed of properly.[14] Furthermore, the requirement for stringent control of the reaction conditions to enhance the effectiveness of the catalytic system is frequently followed by augmented power consumption and, as a consequence, negative impacts on the environment.

Opportunities in MTO Catalysis

This section briefly discusses the possibilities developing in MTO catalysis concerning stability, progress, and regeneration:

Enhancing catalyst stability

Preventing coking and thermal runoff, or enhancing the catalysts' resistance to these effects, would lead to better long-term performance of these catalysts in industries.

Tailoring acidity for selectivity

The primary objective of this research is to increase light olefins' selectivity, especially while generating the minimum byproducts. The catalyst's acidity can be changed, or it can be synthesized by utilizing novel ways.

Nanostructured and mesoporous catalysts

To increase the diffusion of molecules and thus avoid high diffusion resistances and quicker deactivation of the catalysts, the nanosized and mesoporous versions of SAPO-34 were examined.[15]

Fluoride-free synthesis methods

To overcome environmental and cost challenges, new synthesis procedures that use the least amount of fluoride with the efficiency of catalyst performance should be employed.

Integration with renewable feedstocks

Increasing the MTO processes' consumption of renewable methanol and similar green feedstocks in response to the increasing global pressure on making chemical industries more environmentally friendly.

Advanced reactor design

The researcher suggests that better-designed reactors for MTO should be developed in a bid to enhance the efficiency of the entire process and thus minimize the cost of operations.[16]

Catalyst regeneration techniques

Enhancing the regeneration processes for the reactivation of the catalyst after it has become less effective, in an effort to reduce the frequency of catalyst replacement, and hence enhancing sustainability.

Hybrid catalytic systems

Further research on using other materials or additional catalysts in conjunction with SAPO-34 to increase performance, decrease coat formation, and increase selectivity of products.

Process intensification

Exploring innovative approaches of process enhancement, including reaction conditions enhancement and multi-functional catalysts that can enhance the general MTO process efficiency by minimizing power utilization.

Automation and digitalization

Incorporating automation, machine learning, and artificial intelligence in MTO process optimization to predict catalyst behavior, improve reaction conditions, and enhance process control for greater industrial viability.

LITERATURE REVIEW

This section offers an overview of the research on the MTO process, with a focus on developments in catalyst technology, reaction processes, and industrial applications. For a brief overview, Table 1 presents a summary of the examined papers.

Standl and Hinrichsen analyze a large number of deterministic kinetic models that have been elaborated for publications since 2000. Following a brief discussion of basic models in chemistry and thermodynamics are contrasted according to catalysts, reaction setups, and operational parameters. Although the most commonly used catalyst for these procedures is ZSM-5, alternative catalysts, including ZSM-23, SAPO-34, and SAPO-18, are also covered in this article. Finally, some general and reaction-specific suggestions for further research on complicated reaction network modeling are provided.[17]

Hadi and Farzi studied the processes of MTP and MTO intensively using various reaction theories and mechanisms for MTP and MTO, apart from reaction kinetics, including complex elementary step reaction mechanisms and lumped kinetic models. The most precise and trustworthy response mechanisms were presented based on the results and the authors' opinions. The best catalysts used for MTO/MTP processes were then compared in a methodical manner. A thorough overview was given of several modified catalysts that had been suitably constructed to increase catalytic activity, light olefin selectivity, and catalytic lifetime.[18]

Table 1: Presents the summary of the literature review based on catalytic processes and MTO reactions

References	Study on	Key findings	Challenges	Limitations	Future work
Standl and Hinrichsen (2018)[17]	Deterministic kinetic models for MTO	Reviewed and compared different kinetic models for MTO, including lumped and microkinetic approaches. Discussed catalysts such as ZSM-5, SAPO-34, SAPO-18, and ZSM-23.	Lack of comprehensive data on complex reaction networks and catalyst behaviour.	Limited scope of catalysts reviewed.	Future work on improving modeling for complex reaction networks.
Hadi and Farzi[18]	Reaction mechanisms and catalysts for MTO/MTP	Comprehensive review of reaction mechanisms (lumped kinetic models, detailed elementary steps) and catalysts. Discussed modified catalysts to enhance activity and selectivity.	Difficulty in determining the most reliable reaction mechanism for MTO/MTP.	Limited focus on specific catalyst modifications.	Future work on optimizing catalysts for longer lifetime and higher selectivity.
Wang *et al*.[19]	MTO process optimization using Process Systems Engineering	Established a data-driven framework using RVM for optimal MTO plant operations. Analyzed industrial data to predict yield distribution and conditions.	Lack of contributions to optimal operation from a Process Systems Engineering perspective.	Limited application of RVM to MTO optimization in practice.	Future work will be on expanding the RVM application for industrial MTO plant optimization.
Yarulina *et al*.[20]	Catalyst deactivation and olefin selectivity in MTO	Studied the impact of physicochemical characteristics on olefin selectivity and catalyst deactivation. High selectivity for light olefins was demonstrated by ZSM-58 and Sigma-1 zeolites.	Difficulty in controlling catalyst deactivation and maintaining high selectivity.	Limited to two zeolites with DDR topology.	Future work on synthesizing zeolites with tunable properties for better performance.
Xie *et al*.[13]	CO_2 to light olefins via MTO reaction	Studied CO_2, CO, and H_2 transformation into light olefins using isomorphically substituted zeotype catalysts (MAPO-18s). Found that co-feeding H_2 improved catalyst activity.	Hydrogenation of olefins when co-feeding H_2 and methanol affects the olefin/paraffin ratio.	Limited to a specific set of co-feed gases and catalyst types.	Future work will focus on optimizing co-feeding conditions and catalyst performance.

MTO: Methanol-to-olefins, SAPO: Silicoaluminophosphates, MTP: Methanol-to-propylene, RVM: Relevance vector machine, DDR: Deca-dodecasil 3 rhombohedral, ZSM-5: Zeolite Socony Mobil-5

Wang *et al*. discuss the potential to use the MTO process to produce olefins from non-petroleum feedstocks such as natural gas, coal, and biomass. There are already over 20 commercial MTO plants operating. There are currently few contributions on how to operate industrial MTO facilities as efficiently as possible from the standpoint of process systems engineering. To maximize the numerous industrial data sets, a relevance vector machine (RVM) model is proposed for classifying the inputs and selecting the appropriate conditions required for the efficient functioning of the industrial MTO process. RVM links the operating circumstances with the major product's yield distribution projection.[19]

Yarulina *et al*. used two deca-dodecasil 3 rhombohedral-type zeolites, Sigma-1 and ZSM-58, to illustrate how the catalyst's physicochemical parameters affect catalytic deactivation, total olefin selectivity, and the ethylene/propylene ratio while ignoring changes in the catalyst's physicochemical properties during the MTO process. Both catalysts show high selectivity for light olefins and <1% selectivity for ethane and traces of propane. They also prevent the production of hydrocarbons bigger than C4. A range of Sigma-1 zeolites with regulated crystal size and Bronsted acidity was created using the seeded growth technique.[20]

Xie *et al*. proposed a study, the second step in producing light olefins with CO_2, CO, and H_2 is called the MTO process. In the framework of the AEI topology, they provide many zeotype catalysts that have been isostructural substituted (MAPO-18s, where M is Si, Mg, Co, or Zn). They demonstrate that the M(II)-substituted MAPO-18s convert MTO more effectively by evaluating the catalysts at 350°C and 20 bar using reactive feeds of $CH_3OH/CO/CO_2/H_2$. When the $H_2/CO/CO_2/N_2$ mixtures were co-fed with methanol, the reaction revealed a significant, as-yet-unknown, influence of CO in inhibiting the hydrogenation of olefins over the BAS.[13]

CONCLUSION AND FUTURE WORK

A vital technique for creating necessary petrochemicals from substitute feedstocks, reducing reliance on crude oil, can be achieved sustainably using the MTO process. The process's efficiency and selectivity have increased over time due to notable developments in catalyst design, especially with zeolites such as ZSM-5 and SAPO-34. However, challenges such as catalyst deactivation, limited selectivity, and byproduct formation still persist. As of late, the availability of superior and specific catalysts, as well as the increase in knowledge of reaction pathways, has effectively presented opportunities to improve the sustainability and industrial applicability of the MTO process. More work would be required to overcome these difficulties and enhance the process even more for other industries to adopt and use. Directions for further research in the MTO process include finding a way to produce catalysts that are resistant to deactivation and more selective in order to produce light olefins, as well as methods for minimizing the formation of unwanted byproducts. Opportunities to resolve these issues may be provided by new generations of catalysts, including hybrid catalysts and MOFs. Furthermore, important progress in increasing knowledge concerning the reaction mechanisms, especially for enhancements, the first phase of C–C bond formation, will be essential. Future work should also endeavor to understand the applicability of MTO technologies, examine the renewable feedstock compatibility in the MTO process, and determine the relevance of MTO technology's major impacts on the large-scale-up of the MTO process.

REFERENCES

1. Tian P, Wei Y, Ye M, Liu Z. Methanol-to-olefins (MTO): From fundamentals to commercialization. ACS Catal 2015;5:1922-38.
2. Chandu HS. A survey of memory controller architectures: Design trends and performance trade-offs. Int J Res Anal Rev 2022;9:930-6.
3. Goyal A. Enhancing engineering project efficiency through cross-functional collaboration and IoT integration. Int J Res Anal Rev 2021;8:396-402.
4. Dusselier M, Deimund MA, Schmidt JE, Davis ME. Methanol-to-olefins catalysis with hydrothermally treated zeolite SSZ-39. ACS Catal 2015;5:6078-85.
5. Patel R, Patel PB. A review on mechanical system reliability & maintenance strategies for maximizing equipment lifespan. ESP J Eng Technol Adv 2022;2:173-9.
6. Ji Y, Deimund MA, Bhawe Y, Davis ME. Organic-free synthesis of CHA-type zeolite catalysts for the methanol-to-olefins reaction. ACS Catal 2015;5:4456-65.
7. Patel R. Offshore oil operations: Innovations in maintenance, safety, and asset integrity management. Int J Sci Res Comput Sci Eng Inf Technol 2022;8:388.
8. Zhou J, Gao M, Zhang J, Liu W, Zhang T, Li H, *et al*. Directed transforming of coke to active intermediates in methanol-to-olefins catalyst to boost light olefins selectivity. Nat Commun 2021;12:17.
9. Thakaran V. A comparative study of piping stress analysis methods with different tools, techniques, and best practices. Int J Adv Res Sci Commun Technol 2022;2:675-84.
10. Thakran V. A review of 3D printing methods for pharmaceutical manufacturing: Technologies and applications. Int J Sci Res Arch 2021;4:250-61.
11. Zuo Y, Zhang Y, Ren Q, Xu Y, Luo Y, Shu X. A strategy combining the catalytic cracking of C6-C8 olefins and methanol to olefins (MTO) reaction through SAPO-34 pre-coking. Catal Commun 2022;168:106461.
12. Suyambu MR, Vishwakarma PK. An efficient machine learning based solutions for renewable energy system. Int J Res Anal Rev 2022;9:951-8.
13. Xie J, Firth DS, Cordero-Lanzac T, Airi A, Negri C, Øien-Ødegaard S, *et al*. MAPO-18 catalysts for the methanol to olefins process: Influence of catalyst acidity in a high-pressure syngas (CO and H_2) environment. ACS Catal 2022;12:1520-31.
14. Kumar VV, Liou FW, Balakrishnan SN, Kumar V. Economical impact of RFID implementation in remanufacturing: A chaos-based interactive artificial bee colony approach. J. Intell Manuf 2015;26:815-30.
15. Kumar VV, Yadav SR, Liou FW, Balakrishnan SN. A digital interface for the part designers and the fixture designers for a reconfigurable assembly system. Math Probl Eng 2013;2013:943702.
16. Zhong J, Han J, Wei Y, Liu Z. Catalysts and shape selective catalysis in the methanol-to-olefin (MTO) reaction. J Catal 2021;396:23-31.
17. Standl S, Hinrichsen O. Kinetic modeling of catalytic olefin cracking and methanol-to-olefins (MTO) over zeolites: A review. Catalysts 2018;8:26.
18. Hadi N, Farzi A. A review on reaction mechanisms and catalysts of methanol to olefins process. Chem Eng Commun 2022;209:1664-1710.
19. Wang Z, Wang L, Yuan Z, Chen B. Data-driven optimal operation of the industrial methanol to olefin process based on relevance vector machine. Chinese J Chem Eng 2021;34:106-15.
20. Yarulina I, Goetze J, Gücüyener C, Van Thiel L, Dikhtiarenko A, Ruiz-Martinez J, *et al*. Methanol-to-olefins process over zeolite catalysts with DDR topology: Effect of composition and structural defects on catalytic performance. Catal Sci Technol 2016;6:2663-78.