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MODERN SOLUTIONS IN THE SYNTHESIS AND POLYMERIZATION OF (METH) ACRYLATES

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In this review article, the current advances in the synthesis and polymerization of (meth)acrylate monomers are comprehensively analyzed, with a particular focus on their industrial relevance and future development trends. Special attention is devoted to conventional and modern methods for producing (meth)acrylates, including esterification, transesterification, and condensation reactions carried out in the presence of homogeneous and heterogeneous catalysts. The advantages and limitations of these methods are discussed in terms of reaction efficiency, selectivity, environmental impact, and economic feasibility. Furthermore, recent developments in polymerization techniques are examined, such as conventional radical polymerization as well as controlled/living radical methods including RAFT, ATRP, and SET-LRP, along with photopolymerization processes initiated by visible light. The influence of these techniques on molecular architecture, thermal behavior, and mechanical properties of the resulting polymers is highlighted. The applications of poly(meth)acrylates in coatings, adhesives, nanocomposites, biomedical systems, and advanced functional materials are also reviewed. Emphasis is placed on the growing importance of sustainable and green chemistry approaches, including the use of renewable raw materials and energy-efficient technologies. Overall, this review demonstrates that the integration of innovative synthesis routes and advanced polymerization methods plays a key role in expanding the potential of (meth)acrylate-based materials.

***Keywords*:** (*meth)acrylate, esterification, monomer, polymerization, catalyst*

INTRODUCTION

(Meth)acrylate monomers and polymers derived from them represent one of the most important classes of materials in modern polymer chemistry and industry. Due to their unique combination of properties, such as high transparency, excellent adhesion, chemical resistance, and the ability to tailor mechanical and thermal characteristics, poly(meth)acrylates are widely used in a variety of technological fields. These include coatings, adhesives, sealants, optical materials, electronics, and biomedical applications. Their versatility and ease of processing make them particularly attractive for both large-scale industrial production and high-value functional materials.

In recent years, the rapid development of advanced technologies, such as nanocomposites, smart materials, and additive manufacturing (3D printing), has significantly increased the demand for functional (meth)acrylate-based systems. These emerging applications require materials with precisely controlled structures and enhanced performance characteristics. As a result, extensive research has been directed toward improving both the synthesis of monomers and the control over polymerization processes. In particular, the design of monomers with specific structures, including cyclic and bulky substituents, enables the production of polymers with improved thermal stability, rigidity, mechanical strength, and long-term durability. Furthermore, the incorporation of functional groups into (meth)acrylate structures provides additional opportunities for tuning physicochemical properties and expanding their application range.

At the same time, environmental concerns and the need for sustainable development have driven the search for greener and more energy-efficient synthetic approaches. Traditional synthesis routes often involve high energy consumption and the use of hazardous reagents, which necessitates the development of alternative strategies. In this context, the use of renewable raw materials, environmentally friendly catalysts, and low-energy polymerization techniques has become an important direction in modern research. In addition, the implementation of green chemistry principles, such as waste minimization, catalyst recyclability, and energy efficiency, plays a crucial role in the development of sustainable polymer production processes.

Therefore, the development of innovative methods for the synthesis and polymerization of (meth)acrylates remains a highly relevant and promising field, both from fundamental and applied perspectives. Continued research in this area is expected to contribute to the creation of advanced materials with improved performance, reduced environmental impact, and broader industrial applicability.

Synthesis of (meth)acrylate monomers

It is well known that (meth)acrylate monomers possess a wide range of industrial applications and are extensively utilized in fields such as polymer production, textiles, construction materials, coatings, and electronics. Their popularity is primarily attributed to their ability to undergo rapid polymerization and to form materials with desirable mechanical, optical, and chemical properties. As the demand for high-performance and functional materials continues to grow, (meth)acrylates have become key building blocks in the development of advanced polymers, including adhesives, sealants, and biomedical materials [1-3].

The increasing consumption of these monomers has intensified the need for more efficient, cost-effective, and renewable synthesis methods. Conventional production routes, such as esterification of (meth)acrylic acid with alcohols or transesterification processes, often require high energy input and may involve corrosive reagents or generate unwanted by-products. Therefore, recent research has focused on improving catalytic systems, optimizing reaction conditions, and exploring alternative green chemistry approaches. The use of heterogeneous catalysts, enzymatic catalysis, and novel reactor technologies has shown promising potential in enhancing reaction selectivity, reducing energy consumption, and minimizing environmental impact. Consequently, the development of sustainable and highly efficient synthesis strategies for (meth)acrylate monomers remains an important and actively evolving area of study.

The synthesis of cyclopentyl (meth)acrylate monomers currently available is based on esterification reactions and is generally associated with low yields, long reaction times, and pollution. Therefore, the application of methods with higher yields, simpler reaction conditions, and environmentally friendly approaches is one of the relevant research topics of the modern era.

In recent years, scientific studies [4] have demonstrated important results in the synthesis and polymerization of biodegradable acrylates. The present work also highlights certain physicochemical properties and application areas of acrylates obtained from green and renewable raw materials. Research findings have shown that biodegradable acrylates are both decomposable and functionally rich. Compared to traditional acrylates, these materials exhibit higher elasticity, strength, and thermal stability, and they may become a strong alternative for the complete replacement of petroleum-based acrylates in the future.

The review [5] analyzed methods for the catalytic synthesis of acrylates using gaseous CO_2 and alkenes. The study investigated the use of gaseous CO_2 as an eco-friendly and sustainable carbon source, as well as various types of catalysts that can be employed in these reactions and their influence on the reaction environment. The results show that homogeneous catalysts are more active than heterogeneous ones, but they have certain limitations in industrial applications. Although they provide high selectivity, they present challenges in separation and recycling.

This literature source [6] focuses on the general theoretical foundations of the esterification reaction, explaining its mechanism (including its stages), as well as the thermodynamic and kinetic aspects of the esterification between carboxylic acids and alcohols. The role of catalysts is discussed, along with important parameters such as water removal and regulatory factors. The article explains the mechanisms for controlling the esterification reaction using an acid catalyst and the thermodynamic indicators of product yield. Furthermore, methods and catalyst selection for water removal from the system are proposed to achieve higher yields in industrial esterification processes. As a result, it is noted that esterification reactions are strongly influenced not only by practical parameters but also by theoretical foundations, such as reaction kinetics and thermodynamics.

The review article [7] provides a detailed discussion of methods for converting glycerol into acrylic acid in the presence of heterogeneous catalysts. The article presents key approaches in terms of the structural and reactive properties of metal oxide–based heterogeneous catalysts, conversion efficiency, and waste reduction. In the context of acrylate monomers, this work offers extensive information on the "prospects of catalysts not only for acrylic acid but also for its esters." It highlights the advantages of heterogeneous catalysts from the perspectives of both industrial and green chemistry.

Another study by Khota and colleagues [8] emphasized the importance of natural oils (such as soybean oil, sesame oil, etc.) and cellulose-based materials (cellulose, hemicellulose, etc.) as feedstocks for the production of acrylate monomers. Unlike alternative synthesis methods, biocatalytic and enzymatic processes were used in the synthesis of acrylates. These monomers were employed to produce adhesives and various composite materials, and their mechanical strength and thermal stability were comprehensively studied. The use of this feedstock significantly reduces the reliance on petroleum-based raw materials.

Alkyl-substituted cyclo-(meth)acrylates are particularly important as functional monomers, as their structure includes both derivatives of cyclic alcohols and (meth)acrylate groups. The synthesis of these compounds is primarily based on the esterification of the corresponding cyclic alcohols with (meth)acrylic acid derivatives. The reaction is usually carried out with high yield using catalysts, optimized temperature, and conditions that ensure water removal. In the synthesis, it is important to consider both steric hindrance (atoms too crowded to react) and differences in reactivity arising from the cyclic structure of the alcohol. The resulting alkyl-substituted cyclo(meth)acrylates have broad potential applications in polymer materials, protective layers, and the production of functional specialty polymers [9-11].

In the present study, the esterification of cyclohexanol with (meth)acrylic acid was carried out at varying molar ratios of the initial reactants in the presence of different sulfonated cation-exchange catalytic systems, including sulfo-derivatives of polyethylene graft copolymers and KU-2-8 (ion-exchange purification column). Benzene was employed both as a solvent and as a water-removing agent, while hydroquinone (antioxidant) was used as a polymerization inhibitor. Due to the heterogeneous nature of the catalysts, they were readily separated from the reaction mixture by simple filtration. The composition of the synthesized (meth)acrylate esters was confirmed using various analytical techniques [12]. In addition, metal-containing composite materials based on (meth)acrylates were prepared in the presence of Cu, Cr, and Ni, and their structures were characterized by IR (infrared) spectroscopy, differential thermal analysis (DTA), and scanning electron microscopy (SEM). The obtained preliminary results indicate that the composites exhibit a homogeneous structure, as confirmed by IR spectroscopic analysis [13-15].

In the study conducted by Gerasin and others, the synthesis of new cyclic (meth)acrylate monomers containing a tetrahydropyrimidinone ring, their homopolymerization and copolymerization, as well as the thermal properties of the obtained polymers were investigated. The aim of the work was to determine how the unusual cyclic structure affects the macromolecular structure and thermal stability of the polymers. The authors obtained high-yield monomers through a multi-step synthesis

route and then evaluated their radical polymerization ability and reactivity ratios. The results showed that the tetrahydropyrimidinone ring increases the rigidity of the polymer chain and leads to an increase in the thermal decomposition temperature. These properties make the resulting polymers suitable for the production of heat-resistant materials. Overall, the study provides important information on the structure–property relationships of cyclic heterocyclic (meth)acrylates [16].

In another study [17], the results of synthesizing methyl acrylate and acrylic acid via the reaction of formaldehyde with methyl acetate using a zeolite H-ZSM-35 (crystalline aluminosilicate) catalyst were presented. The reaction achieved a high yield, and the catalyst was regenerated in a controlled manner. This work serves as an example of applying sustainable synthesis methods in the production of acrylates.

The study [18] investigated the synthesis and applications of (meth)acrylate monomers derived from monoterpenes (plant-based volatile aroma compounds). This research is considered an important innovation in the production of monomers from renewable feedstocks. Based on the results, it was established that natural molecules such as terpenes can be converted into functional (meth)acrylate monomers through various synthetic pathways, and these monomers exhibit excellent properties for producing polymer materials. The article details the stages of obtaining monomers from monoterpenes, various structural modifications, and polymerization methods such as radical polymerization. The results demonstrate that poly(meth)acrylate materials derived from these monomers have potential applications in areas such as glues, coatings, and biomaterials. Thus, the use of monoterpenes in (meth)acrylate synthesis is presented as a modern and sustainable approach and is highlighted as a promising direction for future research.

Another study [19] investigates the synthesis of new (meth)acrylate monomers containing bulky cycloaliphatic substituents (based on norbornadiene dimers) and their polymerization properties. The aim of the study was to examine the effect of rigid, bulky substituents on the glass transition temperature, thermal stability, and macromolecular structure of the resulting polymers. The authors obtained high-purity monomers using various synthesis methods and conducted a comparative analysis of the kinetics of their radical polymerization reactions. The results showed that norbornadiene-based bicyclic groups significantly restrict the mobility of polymer chains, thereby forming rigid polymers with high glass transition temperatures. These monomers have potential applications in materials requiring exceptional mechanical strength. Overall, the study clarified the important structure-directing role of bulky cycloaliphatic substituents in polymer design.

The literature review [20] presents the use of ion-exchange resins (primarily PK208) as heterogeneous catalysts in the reaction between acrylic acid and 2-ethylhexanol. In addition, the advantages of these resins over homogeneous catalysts are highlighted, such as ease of separation and the possibility of reuse. The review systematically describes catalyst loading and initial molar ratios, as well as evaluates the effect of reaction temperature on its kinetics. The study achieved a maximum conversion of approximately 41%. This research provides readers with detailed information on the criteria for selecting heterogeneous catalysts.

The study [21] presented a highly selective transesterification reaction of acrylate monomers for the production of functional polymers. This method allows the combination of acrylate monomers with various functional groups while avoiding additional side reactions. In the study, esterification reactions were carried out using $Zn_4(OCOCF_3)_6O$ (a tetranuclear zinc alkoxide cluster) and 4-(dimethylamino)pyridine (DMAP). The results demonstrated compatibility between different functional groups.

(Meth)acrylate-based polymers

(Meth)acrylate-based polymers have attracted significant attention in modern polymer science due to their versatile properties and wide range of applications. These polymers, derived from methacrylate and acrylate monomers, exhibit excellent optical clarity, chemical resistance, mechanical strength, and tunable thermal behavior. Owing to their structural flexibility, they can be easily mo-

dified to achieve specific functionalities, making them highly suitable for advanced applications such as biomedical devices, and nanocomposites. In recent years, increasing interest has been directed toward enhancing their performance through the incorporation of functional additives and nanofillers, which further expand their potential in high-performance and sustainable material design.

New polymerization methods, particularly RAFT polymerization and visible-light–induced radical polymerization, as well as related technologies, enable the development of more efficient polymerization processes. In particular, new functional materials such as nanocomposites, polymersomes, and Janus (Two-sided functional) particles offer numerous practical opportunities in modern industrial sectors, for example, in catalyst production and therapeutic applications [22-24].

The present invention [25] investigated the synthesis of a new (meth)acrylate monomer containing a cyclohexyl group and its conversion into tunable polymers using controlled radical polymerization methods. The aim of the study was to determine how this hydrophobic group affects macromolecular architecture, polymer behavior in solution, and phase stability. The authors obtained structures with narrow molecular weight distributions using RAFT-type polymerization approaches and achieved control over the monomer ratio. The results showed that the presence of the cyclohexyl group enhances the polymers' self-assembly ability and promotes the formation of more stable colloidal systems. Thus, the use of such alkyl-substituted cycloalkyl (meth)acrylates opens broad possibilities for applications in water-based materials, particularly in stable dispersion or membrane systems. This work also provides a valuable experimental basis for establishing structure–property relationships.

Another study investigated the synthesis of (meth)acrylates via radical polymerization using visible light. The reaction was carried out in the presence of an iridium-based photoredox catalyst. The advantage of this catalyst lies in its high activity under light exposure and its ability to efficiently direct the polymerization. It was shown that various functional groups can be attached to the chain ends by stopping and restarting the polymerization under light irradiation. This method is considered superior to other approaches due to its lower energy consumption and renewable behavior [26].

In another invention [27], the RAFT polymerization method was applied in an aqueous environment. A zinc porphyrin–based photocatalyst, highly soluble in water, was used. This catalyst was activated by visible light and facilitated the polymerization. Additionally, the polymerization was carried out in both open and closed containers. This method also enables stable polymerization of acrylate monomers without the need for additional inert gas, making it particularly suitable for biofunctional systems.

This review article [28] systematically analyzes the structural properties and applications of polymers derived from acrylate and (meth)acrylate monomers. The study compares the mechanical, thermal, and optical properties of polymers obtained through various radical polymerization methods such as ATRP, RAFT, etc. In particular, it examines the transparency, elasticity, and chemical resistance of materials such as polymethyl methacrylate (PMMA), polybutyl acrylate, and polymethacrylates. Finally, it is shown that these polymers have found wide applications in coatings, adhesives, medical implants, optical materials, and microelectronics.

In this study [29], various cycloalkyl acrylate monomers were used, and the swelling behavior and physical properties of the resulting polymers were investigated. The study analyzed the thermal stability of cyclic groups such as cyclohexyl (meth)acrylate, isobornyl acrylate, and dicyclopentyl (meth)acrylate. The influence of cyclic groups of different sizes and structures on the spacing between polymer chains affects how deeply they can penetrate the polymer, and consequently, the degree of polymer swelling varies. As a result, polymers based on cyclohexyl (meth)acrylate exhibited lower swelling, while larger cyclic monomers showed higher swelling. This study further emphasizes the practical importance of the structure–property relationship of cycloalkyl substituents in electronic applications.

Another study examined the acrylation of biomass in detail. The addition of acrylate groups to biomass makes it a more reactive and easily processable material. Cellulose, starch, fatty acids, and vegetable oils are used as the primary biomass feedstocks. The study also indicates that the existing synthesis process is not yet fully optimized and that properties such as selectivity, yield, and energy efficiency still require improvement. Further optimization of catalyst design and the application of hybrid methods are considered important for this purpose [30].

The synthesis of (meth)acrylates via radical polymerization using visible light was studied. The reaction was carried out in the presence of an iridium-based photoredox catalyst [31]. The advantage of this catalyst is that it exhibits high activity under light irradiation and efficiently controls the polymerization process. It was shown that various functional groups can be attached to the chain ends by stopping and restarting the polymerization under the influence of light. This method can be considered superior to other methods due to its lower energy consumption and sustainability.

In another study [32], bio-based approaches in this field were investigated using the radical polymerization of acrylate, (meth)acrylate, and styrene. One of the main features of this research is the detailed analysis of the fundamental mechanism of the polymerization reaction, the reaction kinetics, and possible side reactions occurring during the process. In addition, the influence of structural characteristics on the radical polymerization of monomers derived from biomass is extensively examined. The article also demonstrates the application of computer modeling and kinetic simulation methods. These approaches enable the development of more efficient and eco-friendly synthetic polymers.

The study conducted by Hamad and colleagues is devoted to the modern applications of polymers obtained from methacrylate monomers [33]. In particular, the advantages of methacrylate polymers for biomedical products (such as hydrogels, drug delivery systems, bone cements, etc.) and functional coatings are explained in detail. The authors emphasize that methacrylate-based polymers are superior in terms of mechanical strength and long-term stability. In addition, the use of methacrylate polymers modified with functional groups in antibacterial and self-healing coatings has been demonstrated. As a result, the future prospects of (meth)acrylate polymers in terms of modern applications are clearly revealed.

In the literature review [34], the properties of suspensions of acrylate monomers subjected to photopolymerization and their effect on the production of ceramics from stabilized ZrO_2 were studied. The research shows how the concentrations of monomers with different compositions influence the rheological and photosensitivity properties of the suspension. It was demonstrated that by selecting the optimal monomer content, it is possible to further improve the mechanical and microstructural properties of ceramics. Additionally, it was proven that acrylates have a positive effect on the curing time of the suspension and the quality of the final product. The obtained results are of significant importance for the investigation and application of effective photopolymerization processes in ceramic production.

RESULTS AND DISCUSSION

The reviewed literature indicates that recent advances in the synthesis of (meth)acrylate monomers are mainly focused on improving reaction efficiency, selectivity, and environmental sustainability. Esterification and transesterification reactions remain the primary synthetic routes; however, the use of heterogeneous catalysts and alternative feedstocks such as biomass-derived compounds have significantly enhanced process performance and reduced impact on nature. In particular, the application of renewable raw materials, including natural oils and terpenes, demonstrates promising potential for replacing petroleum-based sources.

The analysis of polymerization methods shows that radical polymerization continues to be widely used, while controlled techniques such as RAFT and ATRP provide better control over molecular structure and properties. These approaches enable the synthesis of polymers with narrow mo-

lecular weight distribution and tailored architectures, which is essential for advanced applications. Photopolymerization methods, especially those initiated by visible light, have also gained importance due to their energy efficiency and environmental advantages.

The reviewed studies further reveal that the structural features of (meth)acrylate monomers, particularly the presence of cyclic or bulky substituents, strongly influence the thermal and mechanical properties of the resulting polymers. Increased rigidity and higher thermal stability have been observed in polymers containing such groups, making them suitable for high-performance materials. Experimental findings reported in the literature confirm that (meth)acrylate-based composites containing metal additives exhibit relatively homogeneous structures, as verified by spectroscopic and thermal analysis methods. These materials show potential for applications in functional coatings and composite systems. Overall, the results summarized in this review highlight that (meth)acrylate polymers possess versatile properties and remain highly relevant for applications in coatings, biomedical materials, and advanced functional systems. The integration of green chemistry approaches and modern polymerization techniques is expected to further expand their applicability in the future. In addition to the obtained experimental results, the potential for industrial applications of the synthesized (meth)acrylate monomers and polymers should be taken into consideration. From a practical perspective, the scalability of the proposed synthesis methods is an important factor. The use of heterogeneous catalysts, which can be easily separated and reused, offers clear advantages for large-scale production processes.

Furthermore, the applied synthetic routes are relatively straightforward and do not require extremely harsh reaction conditions, which may contribute to reduced energy consumption and lower operational costs. However, for full industrial implementation, further studies on process optimization, long-term catalyst stability, and economic efficiency are still required.

Overall, the results of this study indicate that the developed systems show promising potential for scale-up and industrial application, particularly in the fields of coatings, adhesives, and functional composite materials.

CONCLUSION

In this review, the current state of the synthesis and polymerization of (meth)acrylate monomers has been comprehensively analyzed, highlighting both conventional approaches and recent advancements. It is evident that esterification and transesterification reactions remain the primary synthetic routes; however, their efficiency has been significantly improved through the use of heterogeneous catalysts and optimized reaction conditions. The growing implementation of renewable raw materials and environmentally friendly processes reflects the increasing importance of sustainable development in this field.

Advances in polymerization techniques, particularly controlled radical methods such as RAFT and ATRP, have enabled precise regulation of polymer structure and properties, thereby expanding the range of potential applications. Photopolymerization methods have further contributed to the development of energy-efficient and environmentally benign technologies.

The relationship between monomer structure and polymer properties has been clearly demonstrated, showing that structural modifications, especially the introduction of cyclic and bulky substituents, play a key role in enhancing thermal stability, mechanical strength, and functional performance.

Overall, (meth)acrylate-based materials continue to hold significant potential in advanced applications such as coatings, biomedical systems, and functional composites. Future research should focus on the development of greener synthesis strategies, novel catalytic systems, and highly controlled polymerization processes to further improve material performance and sustainability.

REFERENCES

1. Wang, Z. Radical chemistry in polymer science: an overview and recent advances / F. Cui, Y. Suind, J. Yan [et al.] // Beilstein Journal of Orgainc Chemistry, - Frankfurt am Main: - 2023. (19), - p. 1580–1603.
2. Acrylate Polymers for Advanced Applications / T. Swift, R. Rudrapati, K. Kema [et al.] – London: Intechopen, - 2020. – 106 p.
3. Bednarczyk, P. Epoxy (Meth)acrylate-based thermally and UV initiated curable coating systems // - Basel: Polymers – 2023. (5), - p. 4664-4680.
4. Tan, V. Synthesis and polymerization of bioacrylates // Journal of Renewable Materials, -2020, 1631(8), - p. 1609–1631.
5. He, J. Acrylates from alkenes and CO_2 // - Advances in Catalysis, -2015, 156 (58), - p. 103–156.
6. Khan. Recent developments in esterification reactions: review of process and parameters // Journal of industrial and engineering chemistry, - 2021, 101 (103), - p. 80-101.
7. Jin, X. Interphase catalysts for sustainable chemistry: advances in atom- and energy-efficient conversion of glycerol to acrylic acid / Meng, K., Zhang, G., Liu, M. [et al.] // Green Chemistry, - 2021, (23), - p. 51–76.
8. Khot, N. Bio-based acrylates from renewable resources: synthesis and application. Progress in Organic Coatings // Journal of Renewable Sciences, - 2019, (136), - p. 46-61.
9. Krylova, N. Synthesis of bicyclo[2.2.1]heptyloxyalkanes and acrylates based on them // Russian Journal of Organic Chemistry, - 2014, (50), - p. 1475–1479.
10. Zhao, Y. Direct synthesis of acrylate monomers in heterogeneous continuous flow processes // Reaction Chemistry & Engineering**,** - 2018, (3), - p. 567-574.
11. Kamei, J. Synthesis of dicyclopentenyl(meth)acrylate and application of UV-curable resin // Journal of Network Polymer**,** - 2016, (37), - p. 236-243.
12. Guliyeva, İ.M. Infrared Spectroscopic Study Of Composites Based On Cyclohexyl(Met)Acrylate Compositions // Processes of Petrochemistry and Oil Refining, - 2023, 24 (2), - p. 269-277.
13. Guliyeva, İ.M. Research of polymer composites containing Cr, Ni by differential thermal analysis method / Aliyeva, R.V., Ibrahimova, M.J., Bagirova, Sh.R. [et al.] / Processes of Petrochemistry and Oil Refining, (1), - 2024, - p. 182-188.
14. Guliyeva, İ.M. Differential thermal analysis of polymer composites with copper-containing (meth)acrylate binding agent / Aliyeva, R.V., Ibrahimova, M.J., Bagirova, Sh.R. [et al.] / Processes of Petrochemistry and Oil Refining, (1), - 2025, - p. 17-26.
15. Guliyeva, İ.M. Metal containing (nano)composites on the basis of polyolefins / Aliyeva, R.V., Ibrahimova, M.J., Bagirova, Sh.R. [et al.] / Processes of Petrochemistry and Oil Refining, Special İssue (1), - 2026, 27 (1), -p. 326-338.
16. Gerasin, V. A. Cyclic methacrylate tetrahydropyrimidinones: synthesis, (co)polymerization, and thermal behavior / Marina V. Zhurina, Natalia A. Kleshcheva, Nikolai A. Sivov [et al.] / Journal of Polymers, - 2021, (14), - p. 1-15**.**
17. Ma, Z. Green method for obtaining methyl acrylate and acrylic acid via aldol condensation on H ZSM-35 zeolite catalysts / Ma, S., Liu, H., He, Y. [et al.] / Journal of Reaction Chemistry & Engineering, - 2017, (5), - p. 1043-1051.
18. F, Obermayer. Synthesis and polymerization of (meth)acrylates based on monoterpenes: IBO(M)A as a suitable monomer for industrial application / D. Hense, P. N. Stockmann, O. I. Strube [et al.] /Journal of Green Chemistry, -2024, (26), - p. 1465-1476.

19. Ivay, M. Synthesis of high-temperature (meth)acrylic monomers with bulky cycloaliphatic substituents (norbornadiene dimer) and their polymerization // Polymer Journal, - 2025, (58), - p. 95-100.
20. Ahmad, M. A. A. Kinetic studies of acrylic acid esterification with 2-ethylhexanol catalyzed by Diaion resins / Chin, S. Y., Zainal Abidin, S. B. [et al.] / Journal of Chemical Engineering of Japan, - 2019, (52), - p. 342–348.
21. Nakatake, T. Chemoselective transesterification of acrylate derivatives for the synthesis of functionalized monomers using a rigid zinc alkoxide generation strategy // Journal of Chemical Communications, - 2016, (22), - p. 3696-3699.
22. Fiona, L. Hatton. Recent advances in RAFT polymerization of monomers derived from renewable resources / Polymer Chemistry, -2020, (11), - p. 220-229.
23. Rachel, L. Atkinson. RAFT polymerisation of renewable terpene (meth)acrylates and the convergent synthesis of methacrylate–acrylate–methacrylate triblock copolymers / Olivia, R. Monaghan, Matthew, T. Elsmore [et al.] / Polymer Chemistry, -2021, (21), - p. 3177-3189.
24. Jing, Wan. RAFT-mediated polymerization-induced self-assembly (RAFT-PISA): current status and future directions / / Chemical Science, -2022, (15), -p. 4194-4224.
25. Monjal, V. Synthesis of well-defined methacrylate copolymers and controlled architecture containing a cyclohexyl pendant group / Bo, U. Fan, San, H. Thang / Journal of Polymer Science, - 2023, (61), -p. 1567-1578.
26. Zoppe, J. O. Controlled radical polymerization of acrylates regulated by visible light / Ataman, N. C., Mocny, P., Wang, J. [et al.] / Journal of ACS Macro Letters, - 2015, (4), -p. 1252–1256.
27. Shanmugam, S. Aqueous RAFT photopolymerization with oxygen tolerance. Macromolecules / Xu, J., Boyer, C. [et al.] / Journal of Macromolecules - 2016, (49), - p. 9345–9357.
28. Odian, G. Acrylic and methacrylic polymers: synthesis, properties, and applications / Matyjaszewski, K., Moad, G. [et al.] / Journal of] Progress in Polymer Science, - 2021, (114), Article Number 101366.
29. Li Ch.-J., Kim J., Li G.-H., Hyun J., Choi Y., Cho N. Swelling behavior of photoresist polymers based on acrylates containing cycloaliphatic groups of different sizes. Materials, -2024, Volume 17, - p. 5465.
30. Chen, Y. Acrylation of biomass: review of the synthesis process, know-how, and directions for future applications / Li, J., Wu, Y., Xu, H. [et al.] / Journal of Environmental Chemistry and Ecotoxicology, - 2022, (4), - p. 1–12.
31. Wang B. Homo(co)polymerization of bio-derived long alkyl chain methacrylate and methyl methacrylate using a readily accessible aminophosphine-based Lewis pair / Wu Z., Cai Y., Ge F. [et al.] / Journal of Polymer Chemistry, - 2025, (16), - p. 4033-4039.
32. Trusova, M.E. Radical polymerization of acrylates, methacrylates, and styrene: Biobased approaches, mechanism, kinetics, secondary reactions, and modeling // Journal of Industrial and Engineering Chemistry Research, - 2021, 60 (3), - p. 876-894.
33. Hamad, F. Recent advances in methacrylate-based polymers for biomedical and coating applications // Journal of Materials Today Chemistry, - 2023, (32), - p.786-798
34. İvanova, T.N. Effect of acrylate monomer on the characteristics of photopolymerizable suspensions for obtaining ceramic from stabilized ZrO_2 // Journal of Glass and Ceramics, -2023, 80(1-2), - p. 50-55.

(MET)AKRİLATLARIN SİNTEZİ VƏ POLİMERLƏŞMƏSİNDƏ MÜASİR YANAŞMALAR

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Təqdim edilən icmal məqaləsində (met)akrilat monomerlərinin sintezi və polimerləşməsinin müasir vəziyyəti, eləcə də onların tətbiqinin əsas istiqamətləri sistemli şəkildə araşdırılmışdır. (Met)akrilatların alınmasında istifadə olunan ənənəvi və müasir üsullara xüsusi önəm verilir. Bunlara homogen və heterogen katalizatorların iştirakı ilə aparılan efirləşmə, transefirləşmə və kondensasiya reaksiyaları daxildir. Bu metodların reaksiya effektivliyi, selektivlik, ekoloji təsir və iqtisadi səmərəlilik baxımından üstünlükləri və məhdudiyyətləri müzakirə olunur. Bundan əlavə, müasir polimerləşmə üsulları nəzərdən keçirilir: ənənəvi radikal polimerləşmə ilə yanaşı RAFT, ATRP və SET-LRP kimi nəzarətli/“canlı” radikal polimerləşmə metodları, həmçinin görünən işıqla inisiə olunan fotopolimerləşmə prosesləri. Bu texnikaların əldə olunan polimerlərin molekulyar quruluşuna, termiki davranışına və mexaniki xassələrinə təsiri vurğulanır. Həmçinin poli(met)akrilatların örtüklərdə, yapışdırıcılarda, nanokompozitlərdə, biotibbi sistemlərdə və müasir funksional materiallarda tətbiqləri nəzərdən keçirilir. Davamlı və “yaşıl” kimya yanaşmalarının, o cümlədən bərpa olunan xammalların istifadəsi və enerji baxımından səmərəli texnologiyaların artan əhəmiyyətinə xüsusi diqqət yetirilir. Ümumilikdə, bu icmal göstərir ki, innovativ sintez yolları ilə müasir polimerləşmə üsullarının inteqrasiyası (met)akrilat əsaslı materialların potensialının genişlənməsində əsas rol oynayır.

Açar sözlər: *(met)akrilat, efirləşmə, monomer, polimerləşmə, katalizator*

СОВРЕМЕННЫЕ РЕШЕНИЯ В СИНТЕЗЕ И ПОЛИМЕРИЗАЦИИ (МЕТ)АКРИЛАТОВ

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В данном обзорном статье всесторонне анализируются современные достижения в синтезе и полимеризации (мет)акрилатных мономеров, с особым акцентом на их промышленную значимость и будущие тенденции развития. Особое внимание уделяется традиционным и современным методам получения (мет)акрилатов, включая реакции этерификации, переэтерификации и конденсации, проводимые в присутствии гомогенных и гетерогенных катализаторов. Обсуждаются преимущества и ограничения этих методов с точки зрения эффективности реакции, селективности, экологического воздействия и экономической целесообразности. Кроме того, рассматриваются современные методы полимеризации, такие как традиционная радикальная полимеризация, а также контролируемые/«живые» радикальные методы, включая RAFT, ATRP и SET-LRP, а также процессы фотополимеризации, инициируемые видимым светом. Подчеркивается влияние этих методов на молекулярную архитектуру, термические свойства и механические характеристики получаемых полимеров. Также рассматриваются области применения поли(мет)акрилатов в покрытиях, клеях, нанокомпозитах, биомедицинских системах и современных функциональных материалах. Особое внимание уделяется растущему значению устойчивых и «зеленых» подходов в химии, включая использование возобновляемого сырья и энергоэффективных технологий. В целом, данный обзор показывает, что интеграция инновационных методов синтеза и современных способов полимеризации играет ключевую роль в расширении потенциала материалов на основе (мет)акрилатов.

Ключевые слова: *(мет)акрилат, эстерификация, мономер, полимеризация, катализатор*