Л.Н. Гумилев атындағы Еуразия ұлттық университетінің ХАБАРШЫСЫ.
ISSN: 2616-6771. eISSN: 2617-9962

ХИМИЯ СЕРИЯСЫ / CHEMISTRY SERIES/ СЕРИЯ ХИМИЯ

IRSTI 31.21.19
Article

https://doi.org/10.32523/2616-6771-2024-146-1-32-42

Green chemistry principles in the organic teaching laboratory: an environmentally benign synthesis of banana oil and aspirin

M.D. Arkharbekova, Ye.O. Tashenov*

NJSC «L.N. Gumilyov Eurasian National University», Astana, Kazakhstan

*(E-mail: arkharbekovamoldir02@gmail.com, *tashenovyerbolat@gmail.com)*

Abstract. This study explores how undergraduate organic chemistry courses may incorporate green chemistry concepts. It gives a summary of the findings and explains the rationale for integrating ecologically friendly practices into education. The article aims to demonstrate the possible benefits of incorporating green chemistry topics at the fundamental level of organic chemistry instruction by examining teaching strategies and providing case studies. Emphasis is placed on the transformative impact of integration on student learning and the broader environmental landscape that promotes a more sustainable and environmentally friendly approach to chemistry education. The article includes examples of laboratory exercises, featuring the application of green chemistry concepts in the synthesis of banana oil and acetylsalicylic acid. Through these experimental works, students' theoretical knowledge of stereochemistry, reaction processes, and the synthesis and analysis of organic molecules are strengthened. In particular, the aspirin and isoamyl acetate synthesis helps explain the processes of the esterification and acetylation reactions. Additionally, by demonstrating essential techniques like extraction, reflux, and recrystallization, these types of experiments help undergraduate students become more proficient in the lab.

Keywords: Organic chemistry, Green chemistry, Green synthesis, Laboratory application, Isoamyl acetate, Acetylsalicylic acid.

Received: 22.02.2024 Accepted: 10.03.2024 Available online: 30.03.2024

Introduction

In the dynamic landscape of modern chemistry, where sustainability and environmental responsibility are increasingly prioritized, the integration of green chemistry principles into laboratory practices has become paramount. Organic chemistry, as a cornerstone of chemical education, stands at the forefront of this revolution. This article explores the innovative realm of "Organic Chemistry Lab Exercises Created by Using Green Chemistry Concepts," delving into the profound implications of infusing sustainable practices into the very fabric of hands-on chemical experimentation.

Traditionally, undergraduate organic chemistry laboratories conjure images of complex syntheses, intricate reactions, and a trail of chemical byproducts. However, the imperative to align chemical education with environmental stewardship has ushered in a new era. Green chemistry, defined by its commitment to designing processes that minimize the use of hazardous substances and reduce environmental impact, has reshaped the way we approach the teaching and learning of organic chemistry [1]. The Scheme illustration (Figure 1) outlines the significance and driving factors behind the integration of green chemistry concepts into organic chemistry lab courses. It visually represents the rationale and benefits of incorporating ecologically friendly practices into chemical education.

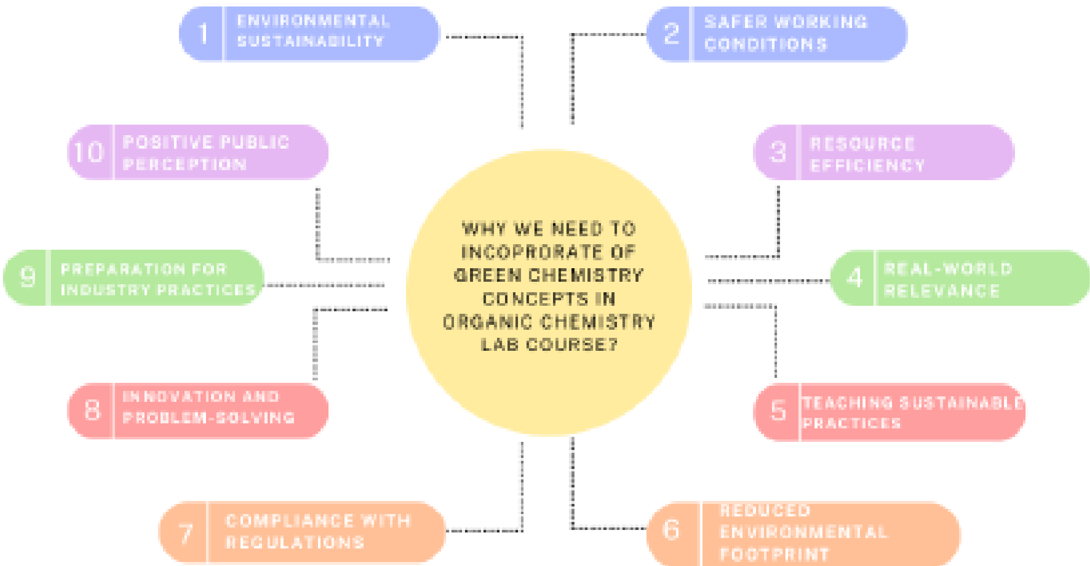

Figure 1 The significance and reasons for integrating green chemistry concepts into organic chemistry lab courses

A brief description of the meaning and driving factors behind the integration of green chemistry concepts into organic chemistry laboratory courses are provided bellow:

1. Green chemistry lab exercises minimize the use of hazardous chemicals and reduce the generation of waste [2]. This promotes environmentally sustainable practices and helps minimize the impact of laboratory activities on ecosystems.

2. By using greener alternatives and reducing the reliance on toxic substances, organic chemistry labs become safer environments for both students and instructors. This contributes to a healthier and more secure workplace [3].

3. Green chemistry emphasizes the efficient use of resources. Lab exercises designed with green chemistry concepts often involve fewer steps, reducing the overall consumption of reagents and energy [4]. This efficient use of resources aligns with sustainable practices.

4. Green chemistry lab exercises often mimic or use principles applied in industrial processes that prioritize sustainability. This approach provides students with a more realistic understanding of how chemistry is practiced in the professional field [5].

5. Integrating green chemistry into lab exercises allows educators to instill the importance of sustainability and responsible chemical practices in the next generation of chemists [6]. Students gain an understanding of their role in minimizing the environmental impact of chemical processes.

6. Green chemistry lab exercises typically generate less waste and require fewer steps involving harmful chemicals. This reduction in waste production contributes to a decreased environmental footprint associated with laboratory activities [7].

7. Green chemistry lab exercises align with and often exceed regulatory standards for environmental protection and safety [8]. Adhering to these standards ensures that educational institutions are compliant with legal and ethical guidelines.

8. Green chemistry encourages innovative thinking and problem-solving. Designing lab exercises with green principles challenges students to find alternative, environmentally friendly methods, fostering creativity and critical thinking skills [9].

9. As industries increasingly adopt green chemistry principles, students exposed to these concepts in lab exercises are better prepared for future careers [10]. Understanding and practicing green chemistry can give students a competitive edge in the job market.

10. Embracing green chemistry in educational settings enhances the public perception of the chemical sciences. Demonstrating a commitment to sustainability and responsible practices helps build trust and support from the community [11].

Recognizing this shift, many undergraduate chemistry programs have integrated green and sustainable chemistry concepts into the organic chemistry laboratory curriculum [12]. Moreover, a variety of green chemistry laboratory manuals are readily available [13-14]. These initiatives aim not only to enhance laboratory safety but also to reduce the volume and toxicity of waste [15-16]. Additionally, they have been found to engage and inspire students [17], fostering a greater appreciation for ethics in science [18].

By integrating green and sustainable chemistry into the organic chemistry laboratory curriculum through research- or project-based pedagogies, numerous benefits can be realized. These include the promotion of scientific learning, cognitive and critical thinking skills, and problem-solving abilities. Such integration also contributes to deeper, cumulative learning experiences and has the potential to improve retention rates, graduation rates, and post-graduation achievements of future chemists. Thus, incorporating the concepts of green chemistry into undergraduate organic chemistry lab courses not only aligns with the ethos of environmental responsibility but also enhances the overall quality and effectiveness of chemical education.

The aim of the article is to provide examples of lab activities that use green chemistry ideas to make banana oil and acetylsalicylic acid (commonly known as aspirin). These experiments help students understand stereochemistry, how reactions happen, and how to make and study organic molecules better. Making aspirin and banana oil in the lab helps students learn about esterification and acetylation, important chemical reactions. Plus, they learn important lab skills like extraction, reflux, and recrystallization, which makes them better at working in the lab. In the next part of our article we navigate through the multifaceted significance of infusing green chemistry principles into organic chemistry 2 lab exercises for first-year undergraduate students.

Research methods

Green Synthesis of Banana Oil (Isoamyl Acetate):

Objective: Synthesize banana-scented ester using green chemistry principles.

Description of reaction: The green synthesis of banana oil, or isoamyl acetate involves an esterification reaction between acetic acid (often from vinegar) and isoamyl alcohol (derived from banana essence) (Figure 2), producing isoamyl acetate and water as a result. This reaction is catalytic, as a catalyst we use a sulfuric acid.

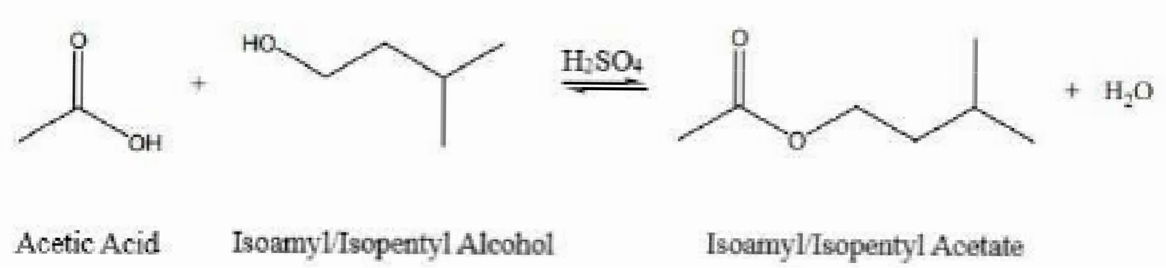

Figure 2 Green synthesis reaction of isoamyl acetate

This reaction is catalytic, as a catalyst we use a sulfuric acid. List of required reagents and equipment for this reaction are provided in Table 1.

Table 1

List of required reagents and equipment for green synthesis of banana oil

Materials
1. Isoamyl alcohol
2. Acetic acid
3. Sulfuric acid
4. Water
5. Sodium carbonate solution
6. Separatory funnel or funnel with stopcock
7. Condenser for distillation

Figure 3 provides a visual representation of the procedure for conducting the green synthesis experiment of isoamyl acetate. Students are required to adhere to the step-by-step instructions outlined in the detailed procedure:

1. In a small flask, mix 10 mL of isoamyl alcohol with 5 mL of acetic acid.
2. Add a few drops of sulfuric acid as a catalyst.
3. Swirl the mixture and set up a water bath to heat it gently (do not boil).
4. Allow the reaction to proceed for about 30 minutes.
5. After the reaction, cool the mixture and transfer it to a separatory funnel.
6. Add an equal volume of water to the funnel and shake gently to form two layers.
7. Drain the lower aqueous layer and keep the organic layer.
8. Neutralize the remaining acid in the organic layer by washing it with a sodium carbonate solution.
9. Collect the organic layer and perform a simple distillation to isolate isoamyl acetate.
10. Smell the pure product to experience the banana scent.

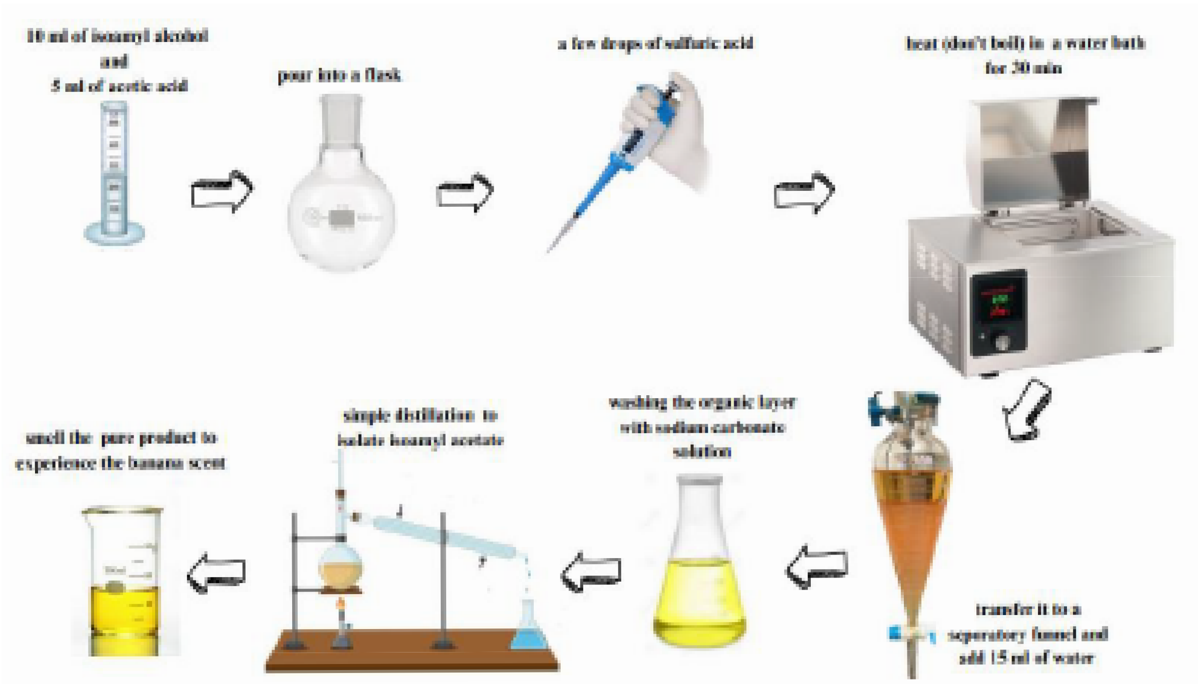

Figure 3 Schematic illustration of green synthesis of isoamyl acetate

Green Synthesis of Aspirin:

Objective: Synthesize aspirin using environmentally friendly reagents and methods.

Description of reaction: The green synthesis of aspirin involves an esterification reaction between salicylic acid and acetic anhydride. (Figure 4) In this reaction, salicylic acid reacts with acetic anhydride to produce acetylsalicylic acid (aspirin) and acetic acid as a byproduct. This reaction is catalytic, as a catalyst we use a phosphoric acid.

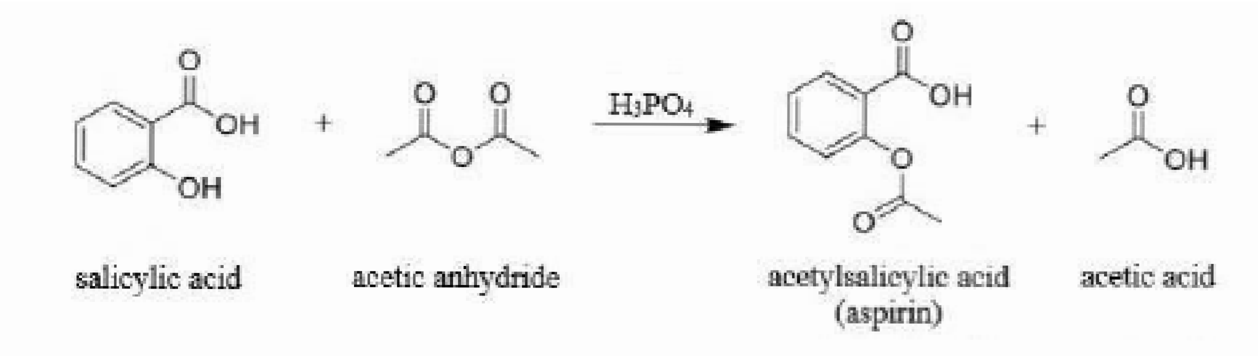

Figure 4 Green synthesis reaction of acetylsalicylic acid

This reaction is catalytic, as a catalyst we use phosphoric acid. List of required reagents and equipment for this reaction are provided in Table 2.

Table 2

List of required reagents and equipment for green synthesis of aspirin

Materials
1. Isoamyl alcohol
2. Acetic acid
3. Sulfuric acid
4. Water
5. Sodium carbonate solution
6. Separatory funnel or funnel with stopcock
7. Condenser for distillation

Figure 5 provides a visual representation of the procedure for conducting the green synthesis experiment of aspirin. Students are required to adhere to the step-by-step instructions outlined in the detailed procedure:

1. In a small flask, mix 2 grams of salicylic acid with 5 mL of acetic anhydride.
2. Add a few drops of phosphoric acid as a catalyst.
3. Stir the mixture and set up an ice bath to cool it.
4. Allow the reaction to proceed for about 15-20 minutes.
5. After the reaction, add the mixture to a cold water bath.
6. Add sodium bicarbonate solution to neutralize the excess acetic anhydride.
7. Collect the solid aspirin product by filtration.
8. Wash the aspirin with cold water and allow it to dry.

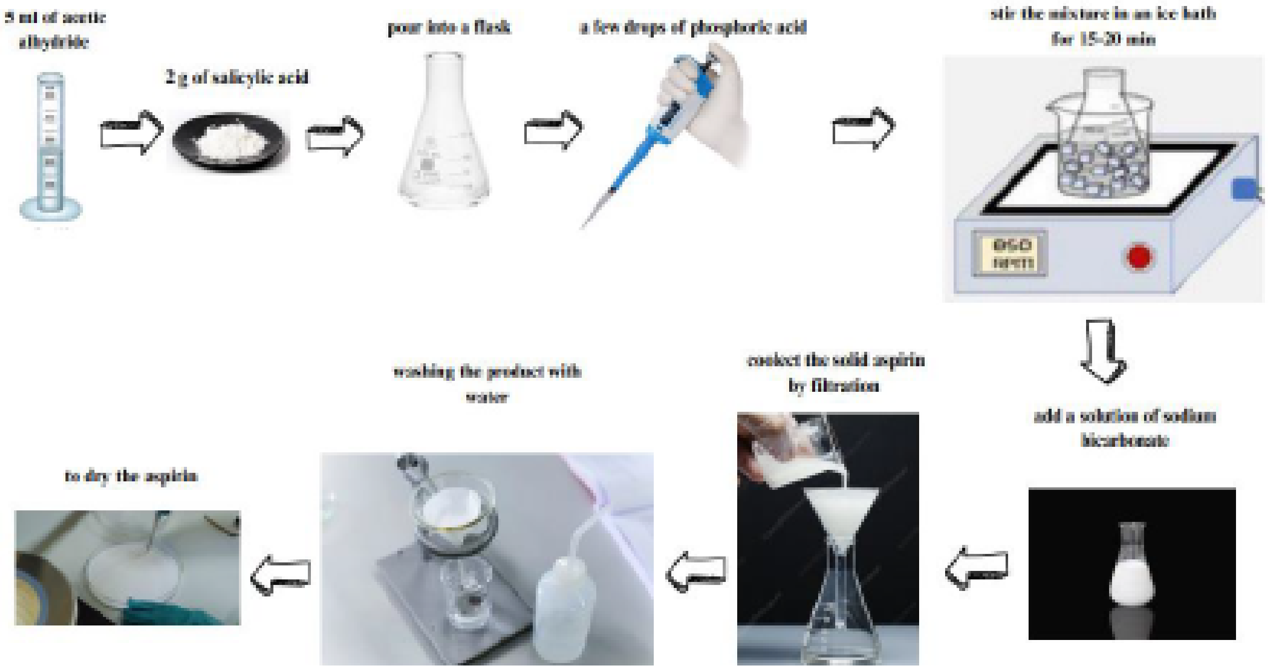

Figure 5 Schematic illustration of green synthesis of aspirin

Results and discussion

Green Synthesis of Banana Oil: The synthesis of banana oil involves the esterification of isoamyl alcohol and acetic acid, resulting in the formation of isoamyl acetate, which imparts the characteristic aroma of bananas. This process aligns with green chemistry principles by utilizing a green catalyst, sulfuric acid, and employing water as a solvent. Sulfuric acid is chosen for its efficacy as a catalyst while minimizing environmental impact. The incorporation of water as a solvent reduces the reliance on traditional organic solvents known for their hazardous properties, further promoting sustainability in the laboratory setting.

Moreover, the use of a separatory funnel during the extraction process enhances the green aspect of the experiment by minimizing waste generation. This technique allows for the efficient separation of the desired product from impurities, thereby reducing the need for additional purification steps and minimizing chemical waste.

The final product, isoamyl acetate, serves as an environmentally friendly flavoring agent commonly used in food and beverage industries. Its production through green synthesis methods not only demonstrates the feasibility of sustainable chemical processes but also highlights the potential for environmentally friendly alternatives in industrial applications.

Green Synthesis of Aspirin: The green synthesis of aspirin, a widely used pharmaceutical compound, exemplifies the application of green chemistry principles in drug synthesis. In this process, acetic anhydride is employed as the esterification agent, and phosphoric acid serves as the catalyst. These choices are made to minimize environmental impact while maintaining high yields and reaction efficiency.

Furthermore, the use of water for hydrolysis and sodium bicarbonate for neutralization contributes to the overall greenness of the synthesis process. Water is a benign solvent that avoids the use of hazardous organic solvents, while sodium bicarbonate offers a safe and effective means of neutralizing excess acid without generating harmful byproducts.

The solid aspirin product obtained from the synthesis is a common over-the-counter medication, underscoring the practical relevance of green chemistry approaches in pharmaceutical manufacturing. By adopting green synthesis strategies, such as those demonstrated in the synthesis of aspirin, the pharmaceutical industry can reduce its environmental footprint while meeting the global demand for safe and effective medications.

In summary, the green synthesis of banana oil and aspirin showcases the application of green chemistry concepts in organic chemistry lab courses, offering students practical experience in sustainable chemical synthesis. These experiments not only demonstrate the feasibility of green methodologies but also underscore the importance of incorporating environmentally friendly practices into chemical education and industrial processes.

Conclusion

Incorporating green chemistry concepts into organic chemistry lab exercises not only contributes to environmental sustainability, but also enhances safety, resource efficiency, and the overall educational experience for students. It aligns with current trends in the chemical industry and prepares students for careers that prioritize environmentally friendly practices. Undergraduate students study green chemistry concepts to understand and promote sustainable practices in chemistry. It emphasizes environmentally friendly processes, minimizing the use of hazardous substances and reducing the impact of chemical research and production on the environment. This knowledge equips students to contribute to more sustainable and responsible scientific practices in their future careers.

References

1. Deligeorgiev T., Gadjev N., Vasilev A., Kaloyanova St., Vaquero J.J., Alvarez-Builla J. Green chemistry in organic synthesis//Mini-Reviews in Organic Chemistry, 7(1), 44-53 (2010), DOI: https://doi.org/10.2174/1570193X11007010044

2. Martínez J., Cortés J.F., Miranda R. Green chemistry metrics: a review//Processes, 10(2), 1274 (2022), DOI: https://doi.org/10.3390/pr10071274

3. Abdussalam-Mohammed W., Ali A.Q., Errayes A.O. Green Chemistry: Principles, Applications, and Disadvantages//Chemical Metadology, 4(4), 408-423 (2020), DOI: https://doi.org/10.33945/SAMI/CHEMM.2020.4.4

4. Lenoir D., Schramm K.-W., Lalah J. O. Green Chemistry: Some important forerunners and current issues//Sustainable Chemistry and Pharmacy, 18(3), 108-117 (2020), DOI: https://doi.org/10.1016/j.scp.2020.100313

5. Anastas P., Eghbali N. Green chemistry: principles and practice//Chemical Society Reviews, 39(1), 301–312 (2010), DOI: https://doi.org/10.1039/B918763B

6. Dunn P.J., Wells A.S., Williams M.T. Green chemistry in the pharmaceutical industry. (Weinheim, 2010, 370 p.).

7. Sheldon R.A. Green chemistry and resource efficiency: towards a green economy//Green Chemistry, 18(11), 3180–3183 (2016), DOI: https://doi.org/10.1039/C6GC90040B

8. Roger A.S. Fundamentals of green chemistry: efficiency in reaction design//Chemical Society Reviews, 41(4), 1437-1451 (2012), DOI: https://doi.org/10.1039/C1CS15219J

9. Tobiszewski M., Marć M., Gałuszka A., Namieśnik, J. Green chemistry metrics with special reference to green analytical chemistry//Molecules, 20(6), 10928–10946 (2015), DOI: https://doi.org/10.3390/molecules200610928

10. Mestres R. Green chemistry - views and strategies//Environmental Scince and Pollution Research, 12(6), 128–132 (2005), DOI: https://doi.org/10.1065/espr2005.04.253

11. Wanisa A.M., Amna Q.A., Asma O. E. Green chemistry: principles, applications, and disadvantages//Chemical Methodologies, 4(4), 408-423 (2020), DOI: https://doi.org/10.33945/SAMI/CHEMM.2020.4.4

12. Aubrecht K.B., Bourgeois M., Brush E.J., MacKellar J., Wissinger J.E. Integrating green chemistry in the curriculum: building student skills in systems thinking, safety, and sustainability//Journal of Chemical Education, 96(12), 2872-2880 (2019), DOI: http://dx.doi.org/10.1021/acs.jchemed.9b00354

13. Ribeiro M. Gabriela T.C, Dominique A. Costa, and Adélio A.S.C. Machado. “Green Star”: a holistic Green Chemistry metric for evaluation of teaching laboratory experiments//Green Chemistry Letters and Reviews, 3(2), 149-159 (2010), DOI: https://doi.org/10.1080/17518251003623376

14. Armstrong, L.B., Rivas M.C., Zhou Z., Irie L.M., Kerstiens G.A., Robak M.T., Douskey M.C., Baranger A.M. Developing a green chemistry focused general chemistry laboratory curriculum: What do students understand and value about green chemistry?//Journal of Chemical Education, 96(11), 2410-2419 (2019), DOI: https://doi.org/10.1021/acs.jchemed.9b00277

15. Graham K.J., Jones T.N., Schaller C.P., McIntee E.J. Implementing a student-designed green chemistry laboratory project in organic chemistry. Journal of Chemical Education, 91(11), 1895-1900 (2014), DOI: https://doi.org/10.1021/ed5000394

16. Reed S.M., Hutchison J.E. Green chemistry in the organic teaching laboratory: an environmentally benign synthesis of adipic acid//Journal of Chemical Education, 77(12), 1627–1629 (2000), DOI: https://doi/abs/10.1021/ed077p1627

17. McKenzie L.C., Huffman L.M., Hutchison J.E., Rogers C.E., Goodwin T.E., Spessard G.O. Greener solutions for the organic chemistry teaching lab: exploring the advantages of alternative reaction media. Journal of Chemical Education, 86(5), 488–493 (2009), DOI: https://doi.org/10.4236/ce.2016.72029

18. Armstrong L.B., Rivas M.C., Douskey M.C., Baranger A.M. Teaching students the complexity of green chemistry and assessing growth in attitudes and understanding//Current Opinion in Green and Sustainable Chemistry, 13(2). -P.61–67. (2018), DOI: https://doi.org/10.1016/j.cogsc.2018.04.003

М.Д. Архарбекова, Е.О. Ташенов*
КеАҚ «Л.Н. Гумилев атындағы Еуразия ұлттық университеті», Астана, Қазақстан

Органикалық химия зертханасындағы жасыл химияның принциптері: банан майы мен аспириннің экологиялық таза синтезі

Аңдатпа. Зерттеу бакалавриат органикалық химия курстары жасыл химия тұжырымдамаларын қалай қамтитынын талдайды. Мақалада зерттеу нәтижелерінің қысқаша мазмұны берілген және тұрақты тәжірибелерді білім беру жүйесіне енгізудің негіздемесі түсіндіріледі. Мақаланың мақсаты – оқыту стратегияларын зерттеу және кейстерді ұсыну арқылы органикалық химияны оқытудың іргелі деңгейіне жасыл химия тақырыптарын енгізудің мүмкін болатын артықшылықтарын көрсету. Бұл интеграцияда студенттердің оқуына және қоршаған ортаның түрлендіруші әсерін қабылдауына назар аударылады. Сол сияқты химия пәнін оқытуға неғұрлым тұрақты және экологиялық тұрғыдан айқын көзқарастың орнығуына ықпал етеді. Мақалада банан майы мен ацетилсалицил қышқылының синтезінде жасыл химия ұғымдарын қолдануды көрсететін зертханалық жаттығулардан мысалдар келтірілген. Осы эксперименттік жұмыстардың нәтижесінде студенттердің стереохимия, реакция процестері, органикалық молекулалардың синтезі мен анализі туралы теориялық білімдері нығаяды. Аспирин мен изоамилацетаттың синтезі этерификация және ацетилдену реакцияларының процестерін түсіндіруге көмектеседі. Сонымен қатар, экстракция, дистилляция және қайта кристалдану сияқты негізгі әдістерді көрсету арқылы эксперименттердің бұл түрлері бакалавриат білім алушыларына зертханалық жағдайда неғұрлым білікті болуға көмектеседі.

Түйін сөздер: органикалық химия, жасыл химия, жасыл синтез, зертханалық қолдану, изоамилацетат, ацетилсалицил қышқылы.

М.Д. Архарбекова, Е.О. Ташенов*
НАО «Евразийский национальный университет имени Л.Н. Гумилева», Астана, Казахстан

Принципы зеленой химии в учебной лаборатории органической химии: экологически безопасный синтез бананового масла и аспирина

Аннотация. В этом исследовании рассматривается, как курсы органической химии для студентов бакалавриата могут включать концепции зеленой химии. В нем дается краткое изложение результатов и объясняется обоснование интеграции экологически безопасных практик в образование. Цель статьи – продемонстрировать возможные преимущества включения тем зеленой химии на фундаментальный уровень преподавания органической химии путем изучения стратегий преподавания и предоставления тематических исследований. Особое внимание уделяется преобразующему влиянию интеграции на обучение студентов и более широкий экологический ландшафт, который способствует более устойчивому и экологически чистому подходу к химическому образованию. В статье приведены примеры лабораторных занятий, демонстрирующие применение концепций зеленой химии при синтезе бананового масла и ацетилсалициловой кислоты. Благодаря этим экспериментальным работам укрепляются теоретические знания учащихся по стереохимии, реакционным процессам, синтезу и анализу органических молекул. В частности, синтез аспирина и изоамилацетата помогает объяснить процессы реакций этерификации и ацетилирования. Кроме того, демонстрируя основные методы, такие, как экстракция, отгонка и перекристаллизация, эксперименты такого типа помогают студентам бакалавриата стать более опытными в лабораторных условиях.

Ключевые слова: органическая химия, зеленая химия, зеленый синтез, лабораторное применение, изоамилацетат, ацетилсалициловая кислота.

Information about authors:

Tashenov Yerbolat Ordabekovich – corresponding author, Doctor Ph.D, Senior Lecturer of the Department of Chemistry, L.N. Gumilyov Eurasian National University, K. Munaitpasov str., 13, 010008, Astana, Kazakhstan.

Arkharbekova Moldir Dauletkyzy – 1st year Master student of «Teacher training in Chemistry» speciality, L.N. Gumilyov Eurasian National University, K. Munaitpasov str., 13, 010008, Astana, Kazakhstan.

Ташенов Ерболат Ордабекович – хат-хабар үшін автор, PhD, Л.Н. Гумилев атындағы Еуразия ұлттық университеті химия кафедрасының аға оқытушысы, Қ. Мұнайтпасов көш., 13, 010008, Астана, Қазақстан

Архарбекова Мөлдір Даулетқызы – Л.Н. Гумилев атындағы Еуразия ұлттық университеті «Химия педагогтерін даярлау» мамандығының 1 курс магистранты, Қ. Мұнайтпасов көш., 13, 010008, Астана, Қазақстан