

Synthesis and catalytic properties of homogeneous and heterogeneous Pt(II) complexes in transfer hydrogenation reactions

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Citation: Aronova, A., Rafikova, K., Selenova, B., Adikanova, D., Iskakov, R., Shambilova, G. (2026). Synthesis and catalytic properties of homogeneous and heterogeneous Pt(II) complexes in transfer hydrogenation reactions. Bulletin of the L.N. Gumilyov ENU. Chemistry. Geography Series, 156(3), 11-22. <https://doi.org/10.32523/3107-278X-2026-156-3-11-22>

Academic Editor:
S.S. Dosmagambetova

Received: 07.07.2026

Revised: 10.09.2026

Accepted: 29.09.2026

Published: 30.09.2026



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Abstract. In this study, homogeneous and heterogeneous Pt(II) complexes based on phosphinite ligands containing ionic liquid fragments were synthesized and investigated as catalytic systems for transfer hydrogenation reactions. The homogeneous Pt(II) complex $[\text{PtCl}_2((\text{PPh}_2\text{O}_2\text{C}_7\text{H}_{14}\text{N}_2)_2)]\text{Cl}_2$ was synthesized and characterized by $^{31}\text{P}\{^1\text{H}\}$ NMR, ^1H NMR, ^{13}C NMR, IR spectroscopy, and elemental analysis. The obtained spectroscopic data confirmed the formation of a structurally well-defined square-planar Pt(II) complex.

To obtain a heterogeneous catalytic system, the Pt(II) complex was immobilized onto aminomethylated polystyrene. The polymer-supported catalyst was characterized by SEM and EDX analyses, which confirmed successful incorporation of Pt(II) species into the polymer matrix with a platinum loading of 0.25 wt.%.

The catalytic activities of both homogeneous and heterogeneous Pt(II) complexes were evaluated in the transfer hydrogenation of ketones using isopropanol as the hydrogen donor in the presence of KOH. The homogeneous Pt(II) catalyst exhibited excellent catalytic activity, achieving high conversion values within short reaction times. The heterogeneous catalyst also exhibited good catalytic performance together with practical advantages such as facile separation from the reaction medium and potential catalyst recyclability.

The obtained results demonstrate that Pt(II) complexes based on phosphinite ligands containing ionic liquid fragments represent promising catalytic systems for transfer hydrogenation reactions. The combination of high catalytic activity, structural stability, and heterogeneous catalyst recoverability makes these systems attractive for further applications in sustainable catalytic processes.

Keywords: Pt(II) complexes; phosphinite ligands; ionic liquid fragments; heterogeneous catalyst; transfer hydrogenation; ketones; polymer-supported catalyst.

1. Introduction

Hydrogenation is a core technology in chemical and petrochemical synthesis. For the petrochemical industry, many of the compounds found in crude oil are of little use since they contain multiple double bonds; they must be first converted to saturated compounds before use as commodities such as gasoline. In addition, countless other molecules are produced from petroleum; hydrogenation is most often the first step in their production. High rates and selectivities are attainable only by the coordination of structurally well-designed catalysts and suitable reaction conditions.

Transition-metal catalyzed processes for transfer hydrogenation of a wide variety of functional groups by different hydrogen donors are interesting alternatives to molecular hydrogenation (Johnson et al., 2021; Nekrasov et al., 2025; Rafikova et al., 2014a, 2014b; Xie & Török, 2022).

Ketones are the most common unsaturated substrates used in organic synthesis. Extensive efforts have been devoted to their reduction into secondary alcohols, especially via hydrogenation. The hydrogenation of ketones, which is one of the most exciting and powerful methods of synthesizing alcohols, has been receiving increased attention and has led to extraordinary success (Lee & Kim, 2018; Rafikova et al., 2013a, 2013b).

In particular, the catalytic transfer hydrogenation of ketones is one of the most attractive methods for synthesizing secondary alcohols, which form an important class of intermediates for fine chemicals and pharmaceuticals. The hydrogen transfer from 2-propanol to ketones is an elegant and economical method owing to its operational simplicity, since no hydrogen gas is required, enabling the avoidance of high-pressure equipment, as well as many favorable properties of the reductant; for example, it is stable, easy to handle, non-toxic, and inexpensive. Moreover, when 2-propanol is used as a hydrogen donor, the only side product is acetone, which is easily removed by distillation during workup (Aydemir et al., 2014; Rafikova et al., 2014a, 2014b, 2014c; Zazybin et al., 2014).

Catalytic hydrogenation reactions occupy a central position in the modern chemical industry and in fine organic synthesis. The reduction of carbon–carbon multiple bonds, as well as carbonyl, nitro, and other functional groups with hydrogen in the presence of metal-complex catalysts provides access to a wide range of valuable products, including pharmaceutical substances, agrochemicals, monomers, fine chemicals, and biologically active compounds (Claver, 2017; Meriç et al., 2014; Ningthoujam, 2022; Rafikova et al., 2014a, 2014b; Ragini & Jaya, 2019; Somwanshi et al., 2020).

Among the noble metals, platinum occupies a special position owing to its exceptional ability to activate molecular hydrogen under mild conditions, its high selectivity, and its tolerance to various functional groups. Platinum(II) complexes - in particular, derivatives of $K_2[PtCl_4]$ and phosphine complexes of the type $cis/trans-[Pt(PR_3)_2X_2]$ - are widely employed in both homogeneous and heterogeneous catalysis (Rafikova et al., 2014; Zazybin et al., 2014).

Homogeneous platinum catalysts provide a high degree of molecular uniformity of active sites, which accounts for their outstanding selectivity and the possibility of fine-tuning electronic and steric parameters by varying the ligand environment. However, the main drawbacks of homogeneous catalysis - the difficulty of separating the catalyst from the reaction products and the limited possibility of catalyst reuse - stimulate the development of heterogenized systems (Chen et al., 2022; Tungatarova & Zakumbayeva, 2020).

Heterogeneous catalysts based on platinum nanoparticles supported on oxide supports ($\gamma-Al_2O_3$, SiO_2 , TiO_2) or carbon materials combine high catalytic activity with technological simplicity of separation and regeneration. The nature of the support, the size of the nanoparticles, and the electronic state of the surface platinum atoms have a decisive influence on the activity and selectivity of such systems (Li & Chen, 2020; Masson et al., 2024; Rafikova et al., 2024).

Despite considerable progress in the study of platinum catalysts, systematic comparative investigations of homogeneous and heterogeneous Pt(II) complexes prepared by a unified methodology from common precursors remain relatively scarce. Establishing correlations of the "composition–structure–catalytic activity" type is of both fundamental and applied interest (Jia et al., 2022).

The aim of this work is to synthesize Pt(II) complexes based on phosphinite ligands and their polymer-supported analogues, and to study their catalytic activity in transfer hydrogenation reactions. Special attention is given to comparing homogeneous and heterogeneous systems and evaluating the effect of immobilization on catalytic performance.

2. Materials and Methods

2.1. Reagents and materials

Pt(cod)Cl₂ (dichloro(1,5-cyclooctadiene)platinum(II)), aminomethylated polystyrene, triethylamine (NEt₃), potassium hydroxide (KOH), dioxane, dichloromethane (CH₂Cl₂), chloroform, petroleum ether, ethanol, acetone, and isopropanol (iso-PrOH) were purchased from Sigma-Aldrich and used without further purification unless otherwise stated.

All reactions involving platinum complexes were carried out under an argon atmosphere using dry solvents. Degassed isopropanol was used as the hydrogen donor solvent in catalytic transfer hydrogenation reactions. Ketone substrates used in the catalytic studies were of analytical grade and employed without additional purification.

The synthesized homogeneous Pt(II) complex was characterized by ³¹P{¹H} NMR, ¹H NMR, ¹³C NMR, IR spectroscopy, and elemental analysis. The heterogeneous polymer-supported Pt(II) catalyst was characterized using SEM and EDX analyses.

2.2. Synthesis of [PtCl₂((PPh₂O₂C₇H₁₄N₂)₂)]Cl₂

Pt(cod)Cl₂ (0.047 g, 0.13 mmol) and phosphinite ligand [(Ph₂PO)-C₇H₁₄N₂Cl]Cl (0.10 g, 0.25 mmol) were dissolved in dry dichloromethane (CH₂Cl₂, 25 mL) under an argon atmosphere. The reaction mixture was stirred overnight at room temperature. After completion of the reaction, the solvent volume was reduced to approximately 1–2 mL under reduced pressure. Petroleum ether (20 mL) was added to precipitate the platinum(II) complex as a white solid. The obtained precipitate was collected by filtration, washed with petroleum ether, and dried under vacuum.

The yield was 0.12 g (88 %). The melting point of the obtained complex was found to be 197–209 °C.

The synthesized complex was characterized by ³¹P{¹H} NMR, ¹H NMR, ¹³C NMR, IR spectroscopy, and elemental analysis.

2.3. Synthesis of Pt (II) complexes based on polymer-anchored ionic liquids containing diphenyl groups

Aminomethylated polystyrene (0.022 g) was pre-swollen in dioxane (10 mL) for 1 h at room temperature. Then, a chloroform solution of the Pt(II) complex (0.011 g) was added. Triethylamine (NEt₃) was introduced as a base, and the reaction mixture was refluxed under continuous stirring.

After completion of the reaction, the mixture was cooled to room temperature. The obtained dark yellow solid was separated by filtration and washed successively with hot dioxane and hot ethanol to remove unreacted species and physically adsorbed compounds. The product was then dried in an air oven.

The synthesized polymer-anchored Pt(II) complex was characterized by SEM and EDX analyses. According to EDX results, the platinum content in the supported complex was determined to be 0.25 wt.%.

2.4. General Procedure for the transfer hydrogenation of ketones

The catalytic transfer hydrogenation reactions were carried out using homogeneous and heterogeneous Pt(II) catalysts. In a typical experiment, the corresponding Pt(II) catalyst (0.005 mmol), KOH (0.025 mmol), and ketone substrate (0.5 mmol) were mixed in degassed isopropanol (iso-PrOH, 5 mL). The reaction mixture was refluxed under continuous stirring until completion of the reaction.

After completion, an aliquot of the reaction mixture was withdrawn, diluted with acetone, and analyzed immediately by gas chromatography (GC). The conversion values were calculated based on the amount of residual unreacted ketone.

For the heterogeneous catalytic system, the polymer-supported Pt(II) catalyst was separated from the reaction mixture by filtration after completion of the reaction, washed with isopropanol, and dried for possible reuse.

3. Results and Discussion

3.1. Characterization of homogeneous Pt(II) complex

The Pt(II) complex $[\text{PtCl}_2((\text{PPh}_2\text{O}_2\text{C}_7\text{H}_{14}\text{N}_2)_2)]\text{Cl}_2$ was successfully synthesized via the coordination of $\text{Pt}(\text{cod})\text{Cl}_2$ with the corresponding phosphinite ligand in dry dichloromethane under an inert argon atmosphere. The reaction proceeded efficiently under mild conditions, affording the target complex as a white crystalline solid in high yield (88 %). The relatively narrow melting point range (197–209 °C) indicates the formation of a structurally well-defined and pure compound.

The coordination environment around the platinum center was elucidated by multinuclear NMR spectroscopy. The $^{31}\text{P}\{^1\text{H}\}$ NMR spectrum exhibits a single sharp resonance at $\delta = 77.12$ ppm, accompanied by a large platinum–phosphorus coupling constant ($J(\text{P-Pt}) = 4273.6$ Hz), which is characteristic of a direct coordination of phosphorus atoms to a Pt(II) center in a square-planar geometry. The presence of a single phosphorus signal suggests a symmetrical coordination. $^{31}\text{P}\{^1\text{H}\}$ NMR spectrum of the synthesized complex can be seen in Figure 2.

The ^1H NMR spectrum displays well-resolved signals corresponding to the ligand framework. The multiplet in the region of 7.13–7.78 ppm is assigned to aromatic protons of the diphenylphosphinite moieties, while the signals in the range of 3.80–4.94 ppm correspond to methylene groups (NCH_2 and CH_2Cl). The singlet at $\delta = 10.14$ ppm is attributed to the imidazolium-type proton, confirming the preservation of the ionic liquid fragment in the complex structure.

Further structural confirmation was obtained from the ^{13}C NMR spectrum, which shows characteristic resonances for aliphatic carbons (36.55–52.52 ppm), carbon atoms bonded to phosphorus (78.45 ppm, exhibiting P–C coupling), and aromatic carbons in the range of 122–140 ppm. The observed coupling patterns are consistent with the coordination of phosphinite ligands to the platinum center.

The IR spectrum provides additional evidence for the formation of the complex, with characteristic bands observed at 3053 cm^{-1} (aromatic C–H stretching), 1436 cm^{-1} (P–Ph vibrations), and 1045 cm^{-1} (P–O stretching), along with low-frequency bands at 303 and 283 cm^{-1} attributable to Pt–Cl stretching modes.

Elemental analysis data are in excellent agreement with the calculated values, confirming the proposed molecular composition and high purity of the synthesized complex. Taken together, the spectroscopic and analytical data confirm the successful synthesis of a well-defined Pt(II) complex featuring phosphinite ligands derived from ionic liquid fragments.

The obtained spectroscopic and analytical data clearly confirm the successful formation of a stable square-planar Pt(II) complex coordinated by phosphinite ligands containing ionic liquid fragments. The reaction formula for the synthesis of the homogeneous Pt(II) complex is shown in Figure 1.

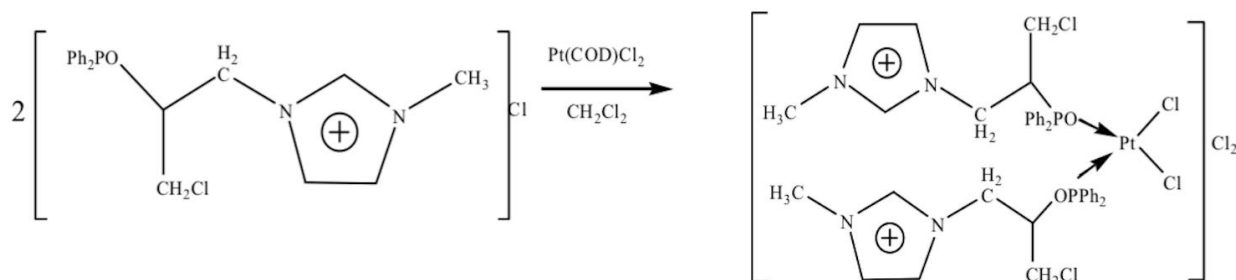


Figure 1. Formation of the homogeneous Pt(II) complex $[\text{PtCl}_2\{(\text{PPh}_2\text{O}_2\text{C}_7\text{H}_{14}\text{N}_2)_2\}]\text{Cl}_2$

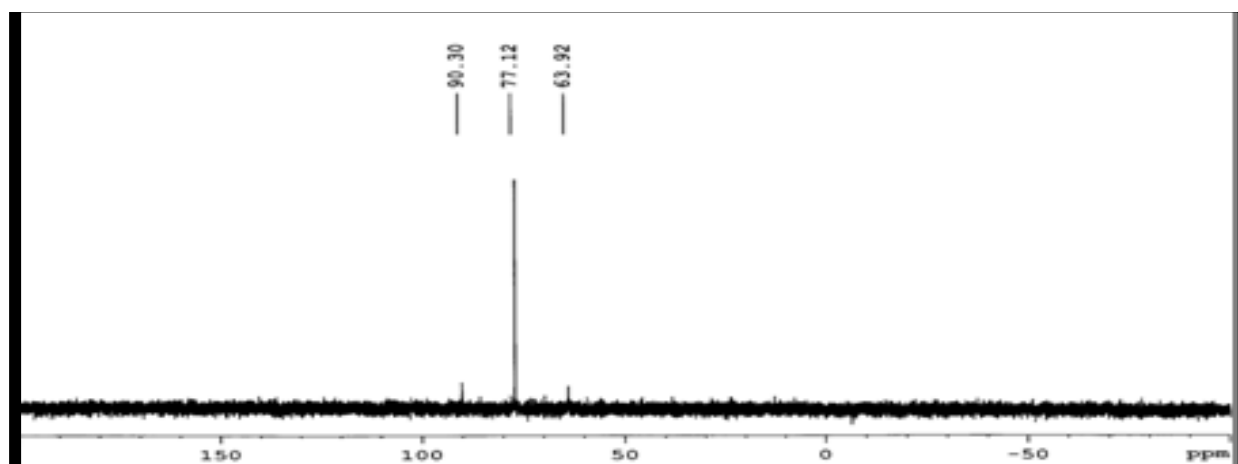


Figure 2. $^{31}\text{P}\{-^1\text{H}\}$ NMR spectrum of $[\text{PtCl}_2\{(\text{PPh}_2\text{O}_2\text{C}_7\text{H}_{14}\text{N}_2)_2\}]\text{Cl}_2$ complexes

3.2. Characterization of polymer-supported Pt(II) catalyst

The immobilization of the Pt(II) complex onto aminomethylated polystyrene was successfully achieved under reflux conditions in chloroform in the presence of triethylamine. The successful incorporation of platinum species into the polymer matrix was initially evidenced by the visible color change of the material from flesh-colored to dark yellow after immobilization. The obtained material remained stable during washing with hot dioxane and hot ethanol, indicating strong interaction between the Pt(II) complex and the polymer support.

The morphology of the polymer-supported catalyst was investigated by SEM analysis (Figure 3). The SEM image revealed that the material consists predominantly of spherical polymer particles with relatively uniform morphology and size distribution. The structural integrity of the polymer support remained preserved after immobilization of the Pt(II) complex, suggesting that the anchoring procedure did not lead to significant deformation or degradation of the support material.

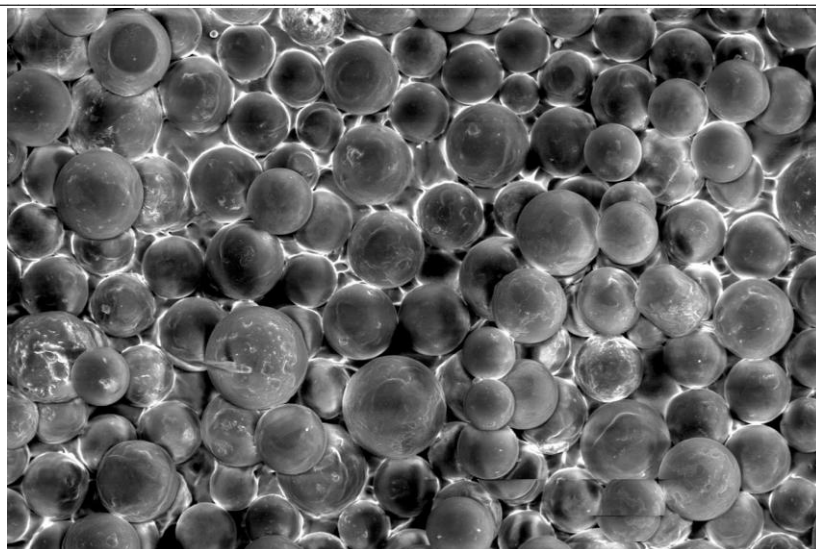


Figure 3. SEM image of the polymer-supported Pt(II) catalyst based on aminomethylated polystyrene

EDX analysis further confirmed the successful incorporation of platinum species into the polymer matrix (Figure 4). According to the EDX results, the platinum loading in the supported catalyst was determined to be 0.25 wt.%, demonstrating effective immobilization of the Pt(II) complex onto aminomethylated polystyrene.

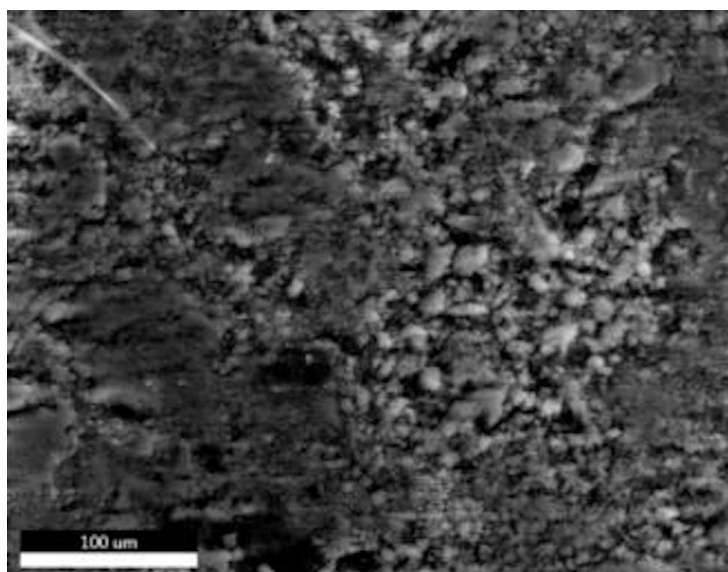


Figure 4. EDX mapping analysis of the polymer-supported Pt(II) catalyst

The obtained polymer-supported Pt(II) complex exhibited the characteristics of a heterogeneous catalytic system, allowing facile separation from the reaction medium by simple filtration. Compared with the corresponding homogeneous Pt(II) complex, the supported catalyst offers practical advantages such as easier recovery, improved handling, and potential catalyst recyclability.

Overall, the structural stability confirmed by SEM and EDX analyses, together with the successful incorporation of Pt(II) species, supports the potential of the polymer-supported platinum complex as a promising heterogeneous catalytic system for transfer hydrogenation reactions.

3.3. Catalytic activity of homogeneous and heterogeneous Pt(II) complexes in transfer hydrogenation of ketones

The catalytic activities of the synthesized homogeneous and heterogeneous Pt(II) complexes were investigated in the transfer hydrogenation of ketones using isopropanol as the hydrogen donor in the presence of KOH. The catalytic reactions were carried out under reflux conditions, and the obtained results are summarized in Table 1.

Both Pt(II) catalytic systems exhibited considerable activity in the reduction of ketones to the corresponding secondary alcohols. The results clearly showed that the catalytic performance strongly depended on the catalyst type and reaction conditions. Negligible conversion was observed in the absence of base, confirming that KOH plays an essential role in the hydrogen transfer process.

The homogeneous Pt(II) complex demonstrated higher catalytic activity compared with the polymer-supported heterogeneous catalyst. Under optimized conditions with a substrate/catalyst/base molar ratio of 100:1:5, the homogeneous catalyst afforded 98 % conversion within 15 min, corresponding to a TOF value of 392 h⁻¹ (Table 1, entry 1). In contrast, the heterogeneous Pt(II) catalyst required longer reaction times to achieve similar conversion values. Nevertheless, the supported catalyst exhibited good catalytic stability and allowed easy separation from the reaction medium by simple filtration.

Increasing the substrate/catalyst ratio from 100:1 to 500:1 and 1000:1 resulted in a gradual decrease in catalytic efficiency and an increase in reaction time for both catalytic systems. However, high conversions were still achieved under elevated substrate loading conditions, demonstrating the stability of the Pt(II) catalytic systems.

Overall, the homogeneous Pt(II) complex exhibited superior catalytic activity, whereas the heterogeneous polymer-supported Pt(II) catalyst offered practical advantages, including catalyst recovery, operational stability, and potential reusability.

Table 1. Transfer hydrogenation of ketones catalyzed by homogeneous and heterogeneous Pt(II) complexes in iso-PrOH/KOH system

Entry	Catalyst	S/C/NaOH	Time	Yield (%)	TOF (h ⁻¹)
1	Homogeneous Pt(II) complex	100:1:5	15 min	98	392
2	Homogeneous Pt(II) complex	500:1:5	45 min	99	132
3	Homogeneous Pt(II) complex	1000:1:5	1.5 h	97	65
4	Heterogeneous Pt(II) complex	100:1:5	45 min	98	365
5	Heterogeneous Pt(II) complex	500:1:5	1 h	98	126
6	Heterogeneous Pt(II) complex	1000:1:5	1.5 h	97	53

4. Conclusion

In this work, homogeneous and heterogeneous Pt(II) complexes based on phosphinite ligands containing ionic liquid fragments were successfully synthesized and characterized. The obtained spectroscopic and analytical data, including multinuclear NMR, IR spectroscopy, elemental analysis, SEM, and EDX analyses, confirmed the successful formation of structurally well-defined platinum complexes and the effective immobilization of Pt(II) species onto aminomethylated polystyrene.

The homogeneous Pt(II) complex exhibited high catalytic activity in the transfer hydrogenation of ketones using isopropanol as the hydrogen donor in the presence of KOH. Under optimized conditions, excellent conversion values were achieved within short reaction times, indicating efficient catalytic performance of the Pt(II) system.

The polymer-supported heterogeneous Pt(II) catalyst also exhibited considerable catalytic activity, although its activity was somewhat lower than that of the corresponding homogeneous catalyst. However, the heterogeneous system provided important practical advantages, including facile separation from the reaction medium, improved operational stability, and potential catalyst recyclability.

Comparative investigation of the homogeneous and heterogeneous catalytic systems showed that immobilization of the Pt(II) complex onto a polymer support preserves catalytic functionality while improving the handling properties of the catalyst. The obtained results suggest that the polymer matrix does not significantly hinder access to the catalytically active Pt(II) centers.

Overall, the synthesized Pt(II) complexes based on phosphinite ligands containing ionic liquid fragments represent promising catalytic systems for transfer hydrogenation reactions. The combination of high catalytic activity, structural stability, and the possibility of catalyst recovery makes these systems attractive for further development and potential application in sustainable catalytic processes.

5. Supplementary Materials: no supplementary material.

6. Author Contributions

Conceptualization - A.A., K.R.; methodology - A.A., B.S.; software - A.A., K.R.; validation - B.S., D.A.; formal analysis - B.S., R.I.; investigation - R.I.; resources - G.Sh., D.A.; data curation - A.A., K.R.; writing - original draft preparation - A.A.; writing - review and editing - A.A., R.K.; visualization - K.R.; supervision - K.R., B.S.; project administration - G.Sh.; funding acquisition - K.R., B.S. All authors have read and agreed to the published version of the manuscript.

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8. Funding: This research is funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. AP26102805). The part of the research concerning the development of polymer support is funded by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. BR28713197)

9. Acknowledgements: The authors thank the Caspian Center for Sustainable Innovation at Kh. Dosmukhamedov Atyrau University, which was developed under Grant No. BR28713197 by the

Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan, for the partial use of the Center's resources in preparing this article.

10. Conflicts of Interest: the authors declare no conflicts of interest.

11. References

1. Aydemir, M., Rafikova, K., Kystaubayeva, N., Paşa, S., Meriç, N., Ocak, Y., Zazybin, A., Temel, H., Gürbüz, N., & Özdemir, İ. (2014). Ionic liquid based Ru(II)–phosphinite compounds and their catalytic use in transfer hydrogenation: X-ray structure of an ionic compound 1-chloro-3-(3-methylimidazolidin-1-yl)propan-2-ol. *Polyhedron*, 81, 245–255. <https://doi.org/10.1016/j.poly.2014.05.079>
2. Chen, Y., Gao, R., & Liu, L. (2022). Platinum-based nanocatalysts for selective hydrogenation reactions: Recent progress and perspectives. *ACS Catalysis*, 12(18), 11376–11402.
3. Claver, C. (2017). Asymmetric hydrogenation and transfer hydrogenation of ketones. *Chemical Reviews*, 3, 567–574.
4. Fu, J., Xu, Q., Low, J., Jiang, C., & Yu, J. (2019). Ultrathin 2D/2D WO₃/g-C₃N₄ step-scheme H₂-production photocatalyst. *Applied Catalysis B: Environmental*, 243, 556–565. <https://doi.org/10.1016/j.apcatb.2018.11.011>
5. Jia, J., Zheng, L., Li, K., Zhang, Y., & Xie, H. (2022). Two-electron transfer mechanism from 3D/3D nickel selenide/MoS₂ heterostructure accelerates photocatalytic hydrogen evolution and tetracycline hydrochloride removal. *Chemical Engineering Journal*, 429, 132432. <https://doi.org/10.1016/j.cej.2021.132432>
6. Johnson, N. B., Lennon, I. C., & Moran, P. H. (2021). Rhodium catalysed transfer hydrogenation of ketones. *Thesis, University of Liverpool*, 21(1), 325–333.
7. Lee, J., & Kim, H. A. (2018). Recyclable nanoparticle-supported rhodium catalyst for hydrogenation of alkenes and ketones. *ACS Omega*, 47(1), 365–378.
8. Li, X., & Chen, W. (2020). Homogeneous and heterogeneous catalytic reduction of ketones. *Nature Communications*, 12, 237–243.
9. Masson, G., Ballico, M., Goi, B. E., Carvalho-Jr, V. P., & Baratta, W. (2024). Light-enhancing ketone transfer hydrogenation catalyzed by diphosphine phenanthroline ruthenium complexes. *Molecular Catalysis*, 564, 114337. <https://doi.org/10.1016/j.mcat.2024.114337>
10. Meriç, N., Aydemir, M., Işık, U., Ocak, Y. S., Rafikova, K., Paşa, S., Kayan, C., Durap, F., Zazybin, A., & Temel, H. (2014). Cross-coupling reactions in water using ionic liquid-based palladium(II)–phosphinite complexes as outstanding catalysts. *Applied Organometallic Chemistry*, 28, 818–825. <https://doi.org/10.1002/aoc.3205>
11. Nekrasov, R. I., Peganova, T. A., Strelkova, T. V., Gutsul, E. I., Filippov, O. A., Belkova, N. V., & Kalsin, A. M. (2025). Chloride-assisted transfer hydrogenation of ketones by half-sandwich rhodium iminophosphonamide complexes. *ChemCatChem*, 17(6), e202401692. <https://doi.org/10.1002/cctc.202401692>
12. Ningthoujam, R. (2022). Nanocatalyst in remediating environmental pollutants. *Chemical Physics Impact*, 4, 100064.
13. Rafikova, K., Kystaubayeva, N., Aydemir, M., Kayan, C., Ocak, Y. S., Temel, H., Zazybin, A., Gürbüz, N., & Özdemir, İ. (2014a). Transfer hydrogenation of ketones catalyzed by new rhodium and iridium complexes of aminophosphine containing cyclohexyl moiety and photosensing behaviors of rhodium and iridium based devices. *Journal of Organometallic Chemistry*, 758, 1–8. <https://doi.org/10.1016/j.jorganchem.2014.01.025>
14. Rafikova, K., Kystaubayeva, N., Aydemir, M., Meriç, N., Paşa, S., Zazybin, A., & Temel, H. (2014b). Use of ionic liquids based Ru(II)-phosphinite complexes in transfer hydrogenation (TH) reactions as catalyst. *5th National Catalysis Conference of Çukurova University*, 12(1), 231–240.

15. Rafikova, K., Kystaubayeva, N., Aydemir, M., Selim, Y., Kayan, C., Zazybin, A., Ok, F., Baysal, A., & Temel, H. (2014c). Rhodium-catalyzed transfer hydrogenation with aminophosphines and analysis of electrical characteristics of rhodium(I) complex/n-Si heterojunctions. *Applied Organometallic Chemistry*, 28, 396–404. <https://doi.org/10.1002/aoc.3140>
16. Rafikova, K., Meriç, N., Binbay, N. E., Okumuş, V., Sever, M. Ş., Belyankova, Y., & Aydemir, M. (2024). Biological assays, electrochemical behavior, and theoretical DFT calculations of Ru(II) complexes of chiral phosphinite based on β -amino alcohols: Transfer hydrogenation of ketones using a HCOOH/Et₃N mixture. *Journal of Molecular Structure*, 1303, 137556. <https://doi.org/10.1016/j.molstruc.2024.137556>
17. Rafikova, K. S., Meriç, M., Aydemir, M., Zazybin, A., & Temel, H. (2013a). Catalytic activity of polymer supported ionic liquid Pd(II) complex in Suzuki-Miyaura cross-coupling reactions. *Ulusal Kataliz Yaz Okulu*, 39(2), 543–552.
18. Rafikova, K. S., Meriç, M., Aydemir, M., Zazybin, A., & Temel, H. (2013b). Synthesis of polymer anchored ligand and Pd(II) complex with ionic liquid precursor. *Ulusal Kataliz Yaz Okulu*, 39(2), 468–479.
19. Rafikova, K. S., Zazybin, A. G., Aydemir, M., Meriç, N., Paşa, S., & Temel, H. (2014a). Catalytic activity of ionic liquid based platinum(II) complexes in Kharasch addition reaction. *Ionic Liquids: Gordon Research Conference*, 12(2), 134–143.
20. Rafikova, K. S., Zazybin, A. G., & Yu, V. K. (2014b). Metal containing ionic liquids as solvent and catalyst in alkylation reactions. *Chemical Journal of Kazakhstan*, 47, 194–203.
21. Rafikova, K. S., Zazybin, A. G., & Yu, V. K. (2014c). Synthesis of bidentate phosphorous-containing ligand based on imidazolium ionic liquid. *Academic Scientific Journal of Chemistry, Series of Chemistry and Technology*, 56, 51–54.
22. Rafikova, K. S., Zazybin, A. G., Temel, H., Aydemir, M., Meriç, N., Paşa, S., Yu, V. K., & Kystaubayeva, N. U. (2014). Kharasch addition reaction catalyzed by platinum(II) complexes based on ionic liquids. *Herald of KBTU, Chemico-Technological Sciences and Ecology*, 1, 41–48.
23. Ragini, D., & Jaya, P. (2019). Trends of green catalysis in synthetic chemistry. *International Journal of Pharmaceutical Sciences and Research*, 10, 5311–5317.
24. Somwanshi, S. B., Somvanshi, S. B., & Kharat, P. B. (2020). Nanocatalyst: a brief review on synthesis to applications. *Journal of Physics: Conference Series*, 43, 232–240.
25. Tungatarova, S. A., & Zakumbayeva, G. D. (2020). Catalytic properties of supported platinum catalysts in hydrogenation processes. *News of the National Academy of Sciences of the Republic of Kazakhstan, Series Chemistry and Technology*, 3, 45–56.
26. Xie, G., & Török, B. (2022). Rh-catalyzed environmentally benign selective hydrogenation of a broad variety of functional groups using Al-water as a hydrogen source. *Catalysts*, 12(12), 1578. <https://doi.org/10.3390/catal12121578>
27. Zazybin, A., Rafikova, K., Abilda, N., Yu, V., Begimova, G., Aydemir, M., Temel, H., & Sasaki, T. (2014). New homogeneous and heterogeneous catalytic systems containing metal-tagged ionic liquids in the C–C bond forming reactions. *The Seventh Tokyo Conference on Advanced Catalytic Science and Technology*, 33(1), 671–682.

Сутекті тасымалдау реакцияларындағы гомогенді және гетерогенді Pt(II) комплекстерінің синтезі мен каталитикалық қасиеттері

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Аңдатпа. Бұл жұмыста иондық сұйықтық фрагменттері бар фосфинитті лигандтар негізіндегі гомогенді және гетерогенді Pt(II) кешендері синтезделіп, сутекті тасымалдау

реакцияларындағы каталитикалық жүйелер ретінде зерттелді. Гомогенді Pt(II) кешені $[PtCl_2((PPh_2O_2C_7H_{14}N_2)_2)]Cl_2$ синтезделіп, $^{31}P\{^1H\}$, 1H , ^{13}C ЯМР спектроскопиясы, ИҚ-спектроскопия және элементтік талдау әдістерімен сипатталды. Алынған спектроскопиялық деректер құрылымы нақты анықталған квадратты-жазық Pt(II) кешенінің түзілгенін растады. Гетерогенді каталитикалық жүйені алу мақсатында Pt(II) кешені аминометилденген полистиролға имобилизацияланды. Полимерге бекітілген катализатор СЭМ және ЭДР талдау әдістерімен зерттелді. Нәтижелер Pt(II) түрлерінің полимер матрицасына сәтті енгізілгенін және платинаның мөлшері 0,25 масс.% екенін растады. Гомогенді және гетерогенді Pt(II) кешендерінің каталитикалық белсенділігі сутек доноры ретінде изопропанолды және негіз ретінде КОН қолдана отырып кетондарды сутекті тасымалдау арқылы гидрлеу реакцияларында бағаланды. Гомогенді Pt(II) катализаторы жоғары каталитикалық белсенділік көрсетіп, қысқа уақыт ішінде жоғары конверсия дәрежесіне қол жеткізді. Гетерогенді катализатор да жақсы каталитикалық қасиеттер көрсетіп, реакциялық ортадан оңай бөлінуі және катализаторды қайта пайдалану мүмкіндігі сияқты практикалық артықшылықтарға ие болды. Алынған нәтижелер иондық сұйықтық фрагменттері бар фосфинитті лигандтар негізіндегі Pt(II) кешендерінің сутекті тасымалдау реакциялары үшін перспективалы каталитикалық жүйелер болып табылатынын көрсетті. Жоғары каталитикалық белсенділік, құрылымдық тұрақтылық және гетерогенді катализаторды бөліп алып, қайта пайдалану мүмкіндігінің үйлесуі бұл жүйелерді тұрақты каталитикалық процестерде қолдану үшін тартымды етеді.

Түйін сөздер: Pt(II) кешендері; фосфинитті лигандтар; иондық сұйықтық фрагменттері; гетерогенді катализатор; сутекті тасымалдау реакциялары; кетондар; полимерге бекітілген катализатор.

Синтез и каталитические свойства гомогенных и гетерогенных Pt(II) комплексов в реакциях переноса водорода

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Аннотация. В данной работе синтезированы и исследованы в качестве каталитических систем для реакций переноса водорода гомогенные и гетерогенные комплексы Pt(II) на основе фосфинитных лигандов, содержащих фрагменты ионных жидкостей. Гомогенный комплекс Pt(II) $[PtCl_2((PPh_2O_2C_7H_{14}N_2)_2)]Cl_2$ был синтезирован и охарактеризован методами $^{31}P\{^1H\}$, 1H , ^{13}C ЯМР, ИК-спектроскопии и элементного анализа. Полученные спектроскопические данные подтвердили образование структурно определённого квадратно-плоского комплекса Pt(II). Для получения гетерогенной каталитической системы комплекс Pt(II) был имобилизован на аминометилированном полистироле. Полимер-имобилизованный катализатор был охарактеризован методами сканирующей электронной микроскопии (СЭМ) и энергодисперсионной рентгеновской спектроскопии (EDX). Результаты подтвердили успешное внедрение частиц Pt(II) в полимерную матрицу при содержании платины 0,25 мас.%. Каталитическая активность как гомогенных, так и гетерогенных комплексов Pt(II) была изучена в реакциях переноса водорода кетонов с использованием изопропанола в качестве донора водорода в присутствии КОН. Гомогенный катализатор Pt(II) продемонстрировал высокую каталитическую активность, обеспечивая глубокую конверсию за короткое время реакции. Гетерогенный катализатор также показал хорошие каталитические характеристики наряду с практическими преимуществами, такими как лёгкое отделение от реакционной среды и возможность повторного использования. Полученные результаты свидетельствуют о том, что комплексы Pt(II) на основе фосфинитных лигандов, содержащих фрагменты ионных

жидкостей, являются перспективными каталитическими системами для реакций переноса водорода. Сочетание высокой каталитической активности, структурной стабильности и возможности регенерации и повторного использования гетерогенного катализатора делает данные системы привлекательными для дальнейшего применения в устойчивых каталитических процессах.

Ключевые слова: комплексы Pt(II); фосфинитные лиганды; фрагменты ионных жидкостей; гетерогенный катализатор; реакции переноса водорода; кетоны; полимер-иммобилизованный катализатор.